Journal of Geek Studies

Vol. 9(2): 2022.

ISSN 2359-3024

Journal of Geek Studies

The Journal of Geek Studies is a non-peer-reviewed, open-access, non-profit, online biannual publication devoted to the popularization of science.

Journal of Geek Studies
http://jgeekstudies.wordpress.com/
http://jgeekstudies.org /

ISSN: 2359-3024 (online).
Vol. 1 (2014) – present.
São Paulo, SP, Brazil.

1. Science; 2. Technology; 3. Geek Culture.

Cover art: *Vampire*, by Edvard Munch (1895). Public domain.

Journal of Geek Studies

jgeekstudies.org

Killer plants and fungi in horror cinema

Luciano L. Rasia
División Paleontología Vertebrados, Museo de La Plata, La Plata, Argentina.
Email: lucianorasia@hotmail.com

As recently addressed (Rasia, 2020), animals have been the focus of horror films since the very beginning of the genre, with more than 400 films about killer animals to date. That is not the case for other two "Kingdoms" of life – Plantae and Fungi – despite many plants and fungi representing a danger to humans due to their poisonous nature. Nevertheless, some plants (e.g., carnivorous plants) and fungi (e.g., zombie-insect fungus) have inspired a handful of horror movies because of their bizarre manner to kill animals (although not humans).

In this work I analyze horror films about killer plants and fungi, attempting a classification of them.

METHODOLOGY

I revised all the horror movies about plants and fungi that I could find in movie databases and compared them to extant plants and fungi. A total of 27 films were considered, excluding those in which plants and fungi are not the central figure of danger, or at least do not have a significant participation. All the movies can be found in the following list: https://letterboxd.com/ghelhal/list/killer-plants-fungus/.

This study discusses plot details (also known as spoilers) of many films. So, if the reader intends to watch any of the mentioned films, please consider doing so before reading this article.

In this work I introduce the term "deep-sploitation" to refer to deep ocean-themed films of the late 1980s and early 90s, like *The Abyss* (1989), directed by James Cameron, and *DeepStar Six* (1989), directed by Sean S. Cunningham (known from *Friday the 13th*, 1980).

The movies were classified in two major groups: (1) inspired by real plants or fungi, and (2) not inspired by real plants or fungi.

MOVIES INSPIRED BY REAL PLANTS/ FUNGI

Carnivorous plants

Carnivorous plants live in nitrogen-poor soils and therefore, need to gain nutrients by trapping animals, mainly arthropods. These plants have modified parts of their body that act as traps (e.g., Lloyd, 1942; Ellison & Gotelli, 2001).

Films in which these types of plants can be clearly identified are *The Little Shop of Horrors* (1960), and its musical remake *Little Shop of Horrors* (1986), where a giant plant called Audrey eats people using a modified flower as a "mouth" (Fig. 1).

In adaptations of John Wyndam's novel The *Day of the Triffids* (1951), which comprises a movie (1962) and two TV series (1981, 2009), giant plants with the ability to walk and communicate among themselves suddenly start to kill and eat people using a modified flower as a poisonous whip.

Figure 1. Top: Venus flytrap (*Dionaea muscipula*) trapping a fly; source: Wikimedia Commons (B. Moisset, 2007). Bottom left: poster of *Little Shop of Horrors* (1986); source: IMDB. Bottom right: the singing carnivorous plant Audrey, from *Little Shop of Horrors* (1986); screen capture from the movie.

Other killer plants

There are some plants that have the capability to kill indirectly, entangling the body of animals, with the possible advantage that brings having extra nutrients from the decomposing carcass. These plants are bromeliads like *Puya chilensis* (Wikipedia, 2022), and many brambles of the genus *Rubus* (e.g., Way Out West, 2015; BBC, 2021; Fig. 2).

Films that get some inspiration from these killer brambles, though adding more active and conscious movement, are a segment of *Dr. Terror House of Horrors* (1965) and *The Ruins* (2008; Fig. 2), about vines that can trap and kill people. In addition, the film *The Crawlers* (a.k.a. *Contamination .7*; 1991) has radioactive tree roots in the forest that attack the people of a small town.

Figure 2. Left: sheep trapped in a bramble; source: BBC (2021). Right: poster of *The Ruins* (2008); source: IMDB.

Zombie-insect fungi

Entomopathogenic or insect-pathogenic fungi, also known as zombie-insect fungi, are fungi that act as parasites of insects, changing their behavior and killing them (e.g., Samson et al., 1988).

Many films have been deeply inspired by these type of fungi. The oldest one is *Matango* (1963), directed by Inoshiro Honda (known mainly for *Gojira*, 1954), about an island with strange fungus-people that are actually humans infected with the spores of a local fungus (Fig. 3).

In *The Girl with All the Gifts* (2016), based on the homonymous novel and with a similar plot to the videogame *The Last of Us* (Sony Computer Entertainment, 2013), A fungus turns people into ravaging zombies. The infected finally form giant sporangia (i.e., spore-producing structures) to infect other people.

In the film *The Superdeep* (2020), a massive fungus living thousands of meters below the surface infects humans that ventured down a drill hole near the Arctic. The infected people aggregate to form a creature to capture other humans.

There are two recent films, *Gaia* (2021) and *In the Earth* (2021), where a giant fungus-like organism living in the jungle/forest parasitizes humans, either using some of the infected to obtain new prey (in the former) or compelling them to sacrifice other humans (in the latter).

In addition, in the film *Splinter* (2008) some kind of fungus infects animals (including humans), killing them and taking control of their dead bodies.

Hallucinogenic mushrooms

In the film *Shrooms* (2007), the hallucinogenic effects of mushrooms have terrible consequences for humans.

Killer spores

The spores of the black mold (*Stachybotrys chartarum*) can cause severe respiratory diseases in humans (e.g., Mooney, 2004).

In the film *The Spore* (2021) a mutated fungus infects and kill everybody that get in contact with its spores.

Figure 3. Top: zombie-insect fungus (*Cordyceps* sp.) growing on a wasp; source Wikimedia Commons (E.G. Vallery, 2005). Bottom left: Japanese poster of *Matango* (1963); source: Wikimedia Commons. Bottom right: human in initial stage of fungal infection from *Matango* (1963); source: IMDB.

MOVIES NOT INSPIRED BY REAL PLANTS/FUNGI

Supernatural plants and fungi

There are some films where the plants have some degree of consciousness and it is generally related to supernatural or magical forces.

In the Killer Tomato "saga", which comprises four movies (*Attack of the Killer Tomatoes!*, 1978; *Return of the Killer Tomatoes!*, 1988; *Killer Tomatoes Strike Back!*, 1991; *Killer Tomatoes Eat France!*, 1992), a group of giant conscious tomatoes attacks people. Similarly, in the low-budget film *Fungicide* (2002), giant conscious blood-thirsty mushrooms attack people.

The film *The Guardian* (1990), directed by the horror master William Friedkin (from *The Exorcist*, 1973), shows a tree that represents the embodiment of an ancient deity feeding on human babies.

Little Otik (a.k.a. *Otesánek*, 2000), directed by the Czech stop-motion master Jan Švankmajer, tells the story of a couple that raises a tree root as their own child, which turns into a murderous tree-monster (Fig. 4).

In the classic deepsploitation film *The Rift* (1990), directed by the Spanish Juan Piquer Simón (from *Mil Gritos Tiene la Noche*, 1982, and *Slugs*, 1988), a submarine is sent to the deep ocean to rescue the wreck of another submarine. There, they find all sort of mutated creatures, including mutated algae that can grow astonishingly fast, killing humans.

Plants revenge against humanity

This is an original movie plot that counts with two films released in the same year: *Treevenge* (2008) about Christmas trees that went into a killing spree; and T*he Happening* (2008) directed by M. Night Shymalan, were plants reacts to humans when they are a threat, killing them with some kind of toxic pheromone.

Plants take control of humanity

In the stylish film *Little Joe* (2019), a genetically engineered flower, designed to bring happiness, threatens to take control of humanity (Fig. 4).

Figure 4. Left: movie poster of *Otesánek* (2000; Source: IMDB.com); rigth: movie poster of *Little Joe* (2019; Source: Filmaffinity.com).

CONCLUSIONS

Despite the potential for original and interesting plots for horror movies, plants and fungi have a markedly lower number of features (less than 30) than animals (more than 400; see Rasia, 2020). However, in recent years the number of films about fungi and their spores have increased notably (five films in the last three years alone), which possibly forecasts a brighter future for plants and fungi in horror films.

REFERENCES

BBC [Anonymous]. (2021) Available from: https://www.bbc.com/news/uk-england-cambridgeshire-59756501 (Date of access: 23/Mar/2022).

Ellison, A.M. & Gotelli, N.J. (2001) Evolutionary ecology of carnivorous plants. Trends in Ecology & Evolution 16: 623–628.

Lloyd, F.E. (1942) The Carnivorous Plants. Chronica Botanica Company, Waltham.

Money, N.P. (2004) Carpet Monsters and Killer Spores: A Natural History of Toxic Mold. Oxford, Oxford University Press.

Rasia, L.L. (2020) Killer animals in films: reality vs fiction. Journal of Geek Studies 7(1): 23–27.

Samson, R.; Evans, H.C.; Latgé, J.-P. (1988) Atlas of Entomopathogenic Fungi. Berlin, Springer.

Way Out West. (2015) World's biggest carnivorous plant catches whole sheep! Available from: https://www.youtube.com/watch?v=RuzLXxbGc4c (Date of access: 23/Mar/2022).

Wikipedia. (2022) *Puya chilensis*. Available from: https://en.wikipedia.org/wiki/Puya_chilensis (Date of access: 23/Mar/2022).

About the author

Dr. **Luciano Rasia** is a paleontologist working on the evolutionary history of a group of rodents. His interest for horror and sci-fi literature and films, macabre art, and hard music usually finds its way to the scientific part of his life.

Journal of Geek Studies

jgeekstudies.org

Entomophagy and future foodstuff: a saga of sinister locusts in *The Swarm*

Muzafar Riyaz

Division of Taxonomy & Biodiversity, Entomology Research Institute, Loyola College, Chennai, Tamil Nadu, India. Email: bhatmuzaffar471@gmail.com

The Swarm (*La Nuée*) is a 2020 French horror film later released by Netflix worldwide on 06 August 2021 (except in France, China and Spain). The film was directed by Just Philippot; the story takes place in a rural area of southern France, where a single mother, Virginie, has been living with her two children, Laura and Gaston. Before the death of her husband Nico, they were raising goats to make ends meet, but to support her children and save her property from foreclosure, she decided to raise locusts, the species is *Locusta migratoria* (Linnaeus, 1758), as a protein supplement and pet feed. Virginie, however, fails to produce a good harvest and the pay is poor. What's more, her daughter Laura has a fight with a boy at school for mocking her family in videos that he was posting online.

The anguish and distress lead Virginie into a rage. She goes inside the locust greenhouse and starts thrashing the breeding containers, but she accidently falls to the ground and becomes unconscious. When she wakes up, Virginie beheld a very unusual sight: the locusts were crawling over her body and tasting the blood from her wounds. Meanwhile, Gaston also discovered that these locusts were attracted to blood after his pet locust fed on a wound on his hand.

Virginie realizes that these locusts' taste for blood causes them to breed more and thus provide her with a way to turn her business around. She becomes obsessed with providing the rapidly multiplying locusts with food, from her own blood to that of nearby animals she killed. Virginie felt that this was her only lifeline to have any sort of success. However, at the same time her mental wellbeing was going from bad to worse, as she killed a neighbor's dog and cow to feed her locusts.

Movie poster. Image extracted from IMDb.

Later on, Virginie refuses to acknowledge the issues with her livestock feeding methods. Karim, who is a good friend of Virginie, tries to burn down the locusts' pods and she attempts to stop him. However, a swarm of locusts escapes from the

greenhouse and begins to attack them. Karim flees to the house (where Laura was also hiding). Virginie hears Laura's screams and goes inside the house, where Karim is being eaten alive by the locusts that broke through the windows. Fortunately, for Laura, her mother comes to her senses and realizes that the locusts need to be drawn away from her daughter if she is to survive the swarm. Virginie makes cuts on her hands and covers herself in blood, acting as bait to the swarm in an attempt to save her daughter. However, the locusts apparently lose their appetite and dissipates; Virginie and Laura both survive.

Virginie feeding the locusts in the greenhouse. Screen capture from the film (49:10).

Close-up of a locust (*Locusta migratoria*) feeding on Virginie's blood. Screen capture from the film (22:37).

INSECTS AS FOOD: A PROMISE FOR THE FUTURE

The human population is increasing at an unprecedented rate and meeting the basic food needs of almost 8 billion people is quite a challenge, with limited global croplands and challenges in cultivating those (Dou et al., 2016). This has always been more onerous for developing nations across the globe. Food produced for human consumption is constantly being lost or wasted: around one third of it, estimated in 1.3 billion tonnes, is lost every year, which has brought about a number of ecological impacts (Gustavsson et al., 2011). As global food demand grows exponentially and hunger remains a reality in many places of the Global South, new approaches and strategies are needed.

Insects are the most proliferous group of (visible) living creatures on the planet. The history of insects began in the Carboniferous period (or maybe even the Devonian), circa 350 million of years ago (Engel, 2015). Insects are the most diverse group of living organisms in sheer number of species and they play a vital role in the functioning of ecosystems providing many kinds of so-called "ecosystem services". These include: pollination, predation and parasitism of many crop pests, decomposition of organic matter, and honey production, not to mention the economic benefits and revenue generated. Insects have been put in "service" of humankind for ages (Riyaz et al., 2022).

Another use of insects is as food. Entomophagy is the term that refers to eating insects. Humans have harvested certain species of insects for food and feed, like maggots, grubs and locusts, for centuries (Gahukar, 2011). The practice of farming insects as a source of protein, vitamins, minerals and fat is most common in tropical countries in Latin America, Africa and Asia, but can also be found elsewhere, like Australia and New Zealand (Chung et al., 2002; Chung, 2010). About 1,900 different species of edible insects have been registered by the Food and Agriculture Organization (FAO,) being consumed by 80% of the world's nations (Ramos-Elorduy, 2009; FAO, 2012). FAO suggested that eating insects might be a solution to the environmental degradation caused by regular livestock production and some studies have since supported that assertion (Guiné et al., 2021). However, insect-eating is met with resistance in many

countries, notably in Europe and the USA. But the rising food demand might change that, enabling the mass rearing of edible insects as a source of protein in human food and animal feed in the near future (Lang & Nakamura, 2021).

A dish with roasted mealworms and locusts at a street-food market in Germany. Image extracted from Wikimedia Commons (ThomasWF, 2018).

Silkworm snack from Thailand. Image extracted from Wikimedia Commons (Jnpet, 2017).

Cricket-based energy bars in a Canadian store. Image extracted from Wikimedia Commons (Mateussf, 2019).

Amid the global food crisis, edible insects have the potential to bring some relief as an alternative source of protein and animal feed. Their mass production can provide an alternative chain of food supply in most parts of the world. The venture is not without challenges: choosing suitable insect species, housing and food requirements, and waste management must be considered and discussed with the experts beforehand. Edible insects such as locusts, if escaping in large numbers, can change their behavior into migrating swarms and, with their capacity to move quickly, can turn into devastating pests damaging everything on their way (Berggren et al., 2019). They will not eat people, though.

THE FILM INDUSTRY: PRESENTING SOPHISMS AS SCIENCE

Today, cinema is a prestigious cultural medium with the power to move people's perceptions and emotions. The reason most people watch films is to experience something outside their everyday lives, from the dawn of human civilizations to potential futures of space travel. Films can make people dream, inspire them, enable them to empathize with other people (fictional or otherwise), and maybe change something in their lives. Films can also speak for those who lack a voice; and not only people, but also nature, like endangered animals and plants on the verge of extinction.

Cinema is one of the most powerful media across the globe and can be an agent of change or a force behind some cause. Someone once said that with a great power comes great responsibility, after all. Thus, some topics should be dealt with more critically in films — science in particular. Many films present wacky concepts as their "scientific" background and, in a bid for easy writing and easier cash, some end up with nonsensical and flawed science. A number of movies have affected the prudence of common audience by presenting the negative aspects of our natural world and biodiversity. Movies like *Frogs* (1972), *Phase IV* (1974), *Jaws* (1975), *Grizzly* (1976), *The Savage Bees* (1976), *The Bees* (1978), *Arachnid* (2001), *Flying Virus* (2001), *Infested* (2002), *Bugs* (2003), *The Hap-*

pening (2008), *The Hive* (2008), *Camel Spiders* (2011), *The Bay* (2012), *Dragon Wasps* (2012), and many others have unnerved audiences worldwide. These movies have portrayed biodiversity erroneously and in a manner that could trigger false (and lasting) impressions about some species among the audience, which could have real consequences (Rasia, 2020). Particularly when dealing with endangered and ill-protected species, cinema should better ponder the message they are sharing with the audience.

The Swarm (2021) portrayed locusts as hematophagous and carnivorous even though locusts are mainly herbivores (they belong to the family of short-horned grasshoppers Acrididae, in the order Orthoptera). Furthermore, the films paints insect production for food in a terrible light. Desert locusts (*Schistocerca gregaria*) are often considered the world's most devastating pests, as they are very mobile and can turn an agricultural field into a deserted land (Bullen, 1966). The "fight back plan" against these dangerous pests could involve rearing or harvesting them for food and feed, which is something several nations across the globe are starting to practice (Egonyu et al., 2021).

CONCLUSION

There are a number of concrete aspects that will turn a good film to one with a legacy. Films that center on a scientific context, including documentaries concerning environmental issues like *The Human Element* (2018), must aim at providing profound scrutiny of our ecosystems and the rising environmental, climate and biodiversity concerns. Climate change, biodiversity loss and pollution are some of the boiling issues that trouble developed and developing nations alike (Bellard et al., 2012; Sánchez-Bayo & Wyckhuys, 2019; Riyaz et al., 2022).

Even in the present era of scientific and technological advances, we are persistently taking these issues for granted. As already discussed earlier, films have the power to move the audience, so topics going from ecological issues to global food security need to be present in a sensible manner that engages the public and gives them food for thought (Novacek, 2008).

REFERENCES

Bellard, C.; Bertelsmeier, C.; Leadley, P.; Thuiller, W.; Courchamp, F. (2012) Impacts of climate change on the future of biodiversity. Ecology Letters 15: 365–377.

Berggren, Å.; Jansson, A.; Low, M. (2019) Approaching ecological sustainability in the emerging insects-as-food industry. Trends in Ecology and Evolution 34(2): 132–138.

Bullen, F.T. (1966) Locusts and grasshoppers as pests of crops and pasture-a preliminary economic approach. Journal of Applied Ecology 3: 147–168.

Chung, A.Y.C. (2010) An overview of edible insects and entomophagy in Borneo. In: Durst, P.B.; Johnson, D.V.; Leslie, R.N.; Shono, K. (Eds.) Forest Insects as Food: Humans Bite Back. UN-FAO, Bangkok. Pp. 141–150.

Chung, A.Y.C.; Chey, V.K.; Unchi, S.; Binti, M. (2002) Edible insects and entomophagy in Sabah, Malaysia. Malayan Nature Journal 56(2): 131–144.

Dou, Z.; Ferguson, J.D.; Galligan, D.T.; Kelly, A.M.; Finn, S.M.; Giegengack, R. (2016) Assessing US food wastage and opportunities for reduction. Global Food Security 8: 19–26.

Egonyu, J.P.; Subramanian, S.; Tanga, C.M.; Dubois, T.; Ekesi, S.; Kelemu, S. (2021) Global overview of locusts as food, feed and other uses. Global Food Security 31: 100574.

Engel, M.S. (2015) Insect evolution. Current Biology 25(19): R868–R872.

FAO [Food and Agriculture Organization of the United Nations]. (2012) Insects for food and feed. https://www.fao.org/edible-insects/en/ (Date of access: 25/Apr/2022).

Gahukar, R.T. (2011) Entomophagy and human food security. International Journal of Tropical Insect Science 31(3): 129–144.

Guiné, R.P.; Correia, P.; Coelho, C.; Costa, C.A. (2021) The role of edible insects to mitigate challenges for sustainability. Open Agriculture 6(1): 24–36.

Gustavsson, J.; Cederberg, C.; Sonesson, U.;

van Otterdijk, R.; Meybeck, A. (2011) Global Food Losses and Food Waste. Extent, Causes and prevention. FAO, Rome.

Lange, K.W. & Nakamura, Y. (2021) Edible insects as future food: chances and challenges. Journal of Future Foods 1(1): 38–46.

Novacek, M.J. (2008) Engaging the public in biodiversity issues. Proceedings of the National Academy of Sciences 105(suppl. 1): 11571–11578.

Ramos-Elorduy, J. (2009) Anthropo-entomophagy: cultures, evolution and sustainability. Entomological Research 39(5): 271–288.

Rasia, L.L. (2020) Killer animals in films: reality vs fiction. Journal of Geek Studies 7(1): 23–27.

Riyaz, M.; Shah, R.A.; Packiam, S.M. (2022) Insect conservation and management: a need of the hour. In: El-Shafie, H. (Ed.) Global Decline of Insects [working title]. IntechOpen, London. Pp. 1–12.

Sánchez-Bayo, F. & Wyckhuys, K.A. (2019) Worldwide decline of the entomofauna: a review of its drivers. Biological Conservation 232: 8–27.

Acknowledgements

I would like to thank the teams of the Journal of Geek Studies and the Entomology Research Institute, Loyola College, Chennai, Tamil Nadu, India, for extended support and guidance.

About The Author

Muzafar Riyaz is a budding research scientist in Entomology, whose studies focus on the biodiversity of moths and their evolutionary history. He is also engaged in conservation and management of insects and wants to direct a movie someday.

Journal of Geek Studies

jgeekstudies.org

Did Dracula really transmit the plague? The history of bloodsuckers and their diseases

Julia Kasper
Museum of New Zealand Te Papa Tongarewa. Wellington, New Zealand.
Email: julia.kasper@tepapa.govt.nz

"*Diseases have spawn one of the most enduring and widespread monster myths in civilisation.*" (Dowling, 2016)

Vampires are some of the most persistent and best-known creatures in the western world. Different cultures have other names and appearances for similar monsters, e.g., the Chinese jiangshi, the Mexican chorti, or the Caribbean soucouyant.

Figure 1. Classic vampire: Bela Lugosi as Dracula in the eponymous 1931 film (Universal Pictures); public domain.

It was mainly diseases, pestering humanity in the past, that are responsible for their creation. Those diseases could appear without warning to cause huge pandemics and then retreat, sometimes for hundreds of years. Before the age of medical science, people were frightened and naturally turned to the supernatural to make sense of it.

Interestingly, vampire legends themselves have suggested that the power of the undead can be passed to their victims through their bite, much like a disease. In some modern stories vampirism is actually spread by a virus; some examples are *Underworld* (2003), *I Am Legend* (2007), *Daybreakers* (2009), and, quite obviously, *Vampire Virus* (2020). And there is also the Shadow Plague in the video game *Plague Inc.* (Ndemic Creations, 2012), which is not really spread by vampires but offers an interesting twist to vampirism and plagues.

However, I would like to go slightly back in time and give three examples of the best-known classic vampire stories which have implemented diseases into their plot.

DRACULA AND SLIGO'S CHOLERA OUTBREAK

Bram Stoker's mother, Charlotte Thornley, grew up as the daughter of a policeman, in Old Market Street, Sligo, Ireland, where she witnessed the cholera outbreak of 1832. –Sligo was hit by the disease worse than any other town in Europe: 1,500 people were killed within six weeks. Charlotte's family escaped the epidemic but it is said that she became haunted by what she saw during that time and told her son the stories of those horrors many times.

Bram Stoker, who was born in Dublin in 1847, wrote the novel *Dracula* in 1897. Simply put, it is the story of a Transylvanian vampire who travels to England in search of new blood. The parallels between the

cholera outbreak and his story are quite intriguing (see Table 1 for some examples).

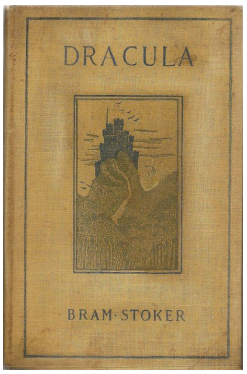


Figure 2. Left: Bram Stoker (1847–1912); unidentified photographer, public domain. Right: Cover of the first American edition of *Dracula*, published Doubleday and McClure, 1899; public domain.

As we all know, the origin of the vampire idea lies in the Balkans (I won't mention Vlad here), where we can still find deeply-rooted evidence for the bloodsucking legend of evil returners.

In Bulgaria for example, a 700-hundred-year-old skeleton was found with its teeth removed and stabbed through the chest with an iron rod, which is, as we all know, the best way to eliminate a vampire (nope, no Impaler in this article).

Strikingly, in Poland during the 17th and 18th centuries, the people of Drawsko came to the same conclusion as Stoker: suspected vampires were buried under very precautious circumstances. They had their teeth removed, or were found with sickles across their necks and stones under their chins to prevent them rising from the dead and biting the living. But actually, those Polish "vampires" were victims of cholera, which battered Poland during that time.

Figure 3. Individual (45–49-year-old female) with a stone placed directly on top of the throat. Source: Gregoricka et al. (2014).

Table 1. Some parallels between the stories Charlotte told her young son and the story in his novel.

Charlotte's Sligo stories	Bram's *Dracula*
Members of the catholic clergy recorded only occasional cases.	Crucifix and holy water, symbols of the catholic church, were used to fight the vampires.
People remembered a terrible smell, hanging over Sligo for months, even after the epidemic had ceased.	A rotting smell could be sensed at places associated with Dracula.
Cholera victims have been buried before they were actually dead.	The undead vampires sleep in coffins and crypts.
The first death of a cholera patient was on a spectacularly hot August 11th, accompanied by a thunder storm.	The count's arrival by ship also happened during a storm and his first victim was found on August 11th.

NOSFERATU, MASTER OF THE PLAGUE

Figure 4. Top: Max Shreck as Count Orlok on the disease-ridden ship, from the 1922 film (Prana Film). Bottom: Klaus Kinski as the Count in the 1979 version (20th Century Fox).

We can also find buried vampires that "arose" from other diseases, such as the plague. It is not surprising that another vampire story, similar to *Dracula*, but not quite the same, incorporated facts of epidemics with a different cause.

Friedrich Wilhelm Murnau (December 28, 1888 – March 11, 1931) could not use the name 'Dracula' and other facts of the book due to copyright issues with Stoker's estate, when he created his silent vampire film *Nosferatu* in 1922 (*Nosferatu – Eine Symphonie des Grauens*, in the original). (The name maybe comes from the Romanian word for vampire and the Greek 'nosophoros' [νοσοφόρος], meaning "disease-bearing".) Despite the changes, the story is still very similar to *Dracula*. Count Orlok wants to expand, travels with his coffins to Wismar, Germany, by ship via the Black Sea. He systematically kills the entire crew. When the ghost ship arrives with its cargo in Wismar, Van Helsing (interestingly this character was allowed to occur) discovers a logbook that says the plague was on board. Wismar is then flooded with rats from the ship – the plague on their tailcoat – and death spreads rapidly throughout the town. Meanwhile, Nosferatu devours lots of blood and is eventually defeated by love.

German film director Werner Herzog is responsible for the 1979 film *Nosferatu the Vampyre* (*Nosferatu: Phantom der Nacht*, in the original), with Klaus Kinski as the Count, as an homage remake of Murnau's masterpiece of German expressionist cinema.

BOX 1. Cruel movie facts.

Herzog used 11,000 rats for a scene in the remake. Travelling from Hungary to the Netherlands— because that was the only place where he was allowed to release so many rats — the conditions were so poor that the rats ate each other.

Herzog also insisted that the plain white rats be dyed grey. Therefore, the cages containing the rats, were submerged in boiling liquid for several seconds, causing half of them to die. The surviving rats immediately proceeded to lick themselves clean of the dye.

YELLOW FEVER IN *INTERVIEW WITH THE VAMPIRE*

Figure 5. Lestat giving his blood to Louis in *Interview with the Vampire* (Warner Bros, 1994).

New Orleans was nicknamed 'Necropolis' between 1817 and 1905 because during that time, approximately 10% of the city's population would die of yellow fever during the summer months (July–October). An ideal place for the protagonists of Anne

Rice's *Interview with the Vampire*, Louis (Brad Pitt in the movie adaptation), Lestat (Tom Cruise) and Claudia (Kirsten Dunst), to hide and kill. A flood of immigrants arriving at the port every day and people dying like flies gave the vampires a great stage to perform undetected.

The worst year was 1853, with 8,000 deaths. Patients bleeding through their eyes, nose and ears, or vomiting blood before dying, was not an unusual sight for citizens of the Necropolis.

Yellow fever was so strongly entangled with daily life in New Orleans in the 19th century that it shaped social structure. It was all about the question of who had survived the virus and was "acclimated" and who hadn't got it yet, who were ranked as "unacclimated". To get certain jobs, you had to be acclimated; marriages and neighbourhoods were based on the families' yellow fever status; and businesses could raise or fall due to immunity. Since there was actually no physical sign, people had to be inventive in order to prove that they were acclimated (think covid vaccine pass). Some people also actively tried to get infected, especially European immigrants, who had not been around the virus before and were considered bigger risks.

And although yellow fever was dictating daily life in New Orleans, the disease was so poorly understood that myths appeared along the Mississippi. Apart from the vampire stories, another myth was that black people were immune and this was deliberately used to justify slavery. Advocates of slavery argued that God had made black people immune to expand the cotton industry and the national economy, and to save white people from death with the comment "If black people are naturally resistant to yellow fever, black slavery is natural, even humanitarian, because it protects white people from labour in hot, swampy spaces that were prone to yellow fever." Very inconsistently to this argument, acclimated slaves sold for 25 to 50% more than unacclimated slaves.

INSECTS, ACTING AS VECTORS, CAUSED THE PANDEMICS

Cholera

Cholera is an infection of the small intestine by some strains of the bacterium Vibrio cholera. The transmission happens usually through the faecal-oral route where sanitation is very poor – either by drinking contaminated water or via flies contaminating food after hanging out in cesspits. Of the 120,000 species of flies (Order Diptera) presently known to science, only a few species of the families Calliphoridae (blowflies), Muscidae (houseflies), Fannidae (lesser house flies), and Sarcophagidae (flesh flies) eat faeces and transmit cholera.

Figure 6. Larva and adult female of a housefly, *Musca domestica*; illustration by Amedeo J. E. Terzi (1872–1956), public domain.

There were seven big cholera pandemics in the world (Table 2). The best-known outbreak was the one mentioned earlier in the mid-19th century, especially in London, where the solution was found. It was John Snow (no, not that one; this one knew stuff), an incredible physician, who revolutionised not only the application of anaesthetics but also the sanitation in the city.

Table 2. Big cholera outbreaks around the world.

1817–1824	China, India, Indonesia.
1829–1837	Egypt, Germany France,, Hungary, North America, Russia, United Kingdom.
1846–1860	Arabia, Cuba, France, Gran Canaria, Iran, Iraq, Ireland, Japan, Korea, Mexico, North America, Philippines, Russia, South America, Spain, Tunisia, United Kingdom.
1863–1875	Algeria, Austrian Empire, Belgium, Ganges Delta, Germany, Hungary, London, Mecca, Netherlands, Northern Africa, Russia, North America, Zanzibar.
1881–1896	Egypt, Hamburg, Japan, Persia, Spain.
1899–1923	Bulgaria, the Balkans, India, Philippines, Romania, Russia.
1961–1975	Indonesia, South America, USSR, with smaller outbreaks in Istanbul, Japan, Jerusalem, and the South Pacific.

Figure 7. Cholera victim exhibiting the bluish pallor characteristic of the disease; illustration by John William Gear (1806–1866), c. 1832, public domain.

Thanks to him, anaesthetics such as ether and chloroform were soon a standard procedure for surgery, although he rather used it in women in labour despite protests from the Church (but supported by Queen Victoria who, after seven children, apparently found the idea of sleeping through the birth rather appealing). Dr Snow did not believe in the miasma theory (the bad air that originated from foul matter), let alone in vampires who might have brought the bad air. Instead, he discovered that the contamination of water by faeces was the cause of cholera. His first action was to have all handles removed from public water pumps, where people literally passed the bacteria from one hand to the next.

Plague

At some stage, people made the connection between the plague and rats (actually the first hint can be found in the Bible). But it was only in 1894 that Alexandre Yersin, a Swiss/French physician and bacteriologist from the Pasteur Institute, discovered the Yersinia pestis bacterium. Four years later, the transmission of bacteria from rodents by flea bites was discovered by Jean-Paul Simond. Due to political rivalry around the discovery, however, this was only recognised another five years later, when the Oriental rat flea (*Xenopsylla cheopis*) was found in Sudan and described by Charles Rothschild and Karl Jordan in 1903.

The bacteria cause the production of a biofilm in the infected flea's foregut. So, when sucking blood, the flea cannot swallow but re-injects the host's blood back… together with the bacteria. Due to lack of food in the flea's belly, it bites more viciously, potentially resulting in increased spreading.

There are three forms of plague: Bubonic, Pneumonic, and Septicemic. Bubonic plague is the most common form. It is an infection of the lymphatic system, where bacteria rapidly spread to the lymph nodes and multiply. The pneumonic plague occurs when *Yersinia pestis* infects the lungs and can actually spread as an aerosol — breathing in *Y. pestis* suspended in respiratory

droplets from human to human. Septicemic plague occurs when plague bacteria multiply in the blood. It can be a complication of pneumonic or bubonic plague or it can occur by itself. When it occurs alone, it is caused in the same ways as bubonic plague; however, buboes do not develop. Patients have fever, chills, prostration, abdominal pain, shock, and bleeding into skin and other organs.

Figure 8. Illustration depicting the microscopic features of fleas; extracted from Ledermüller (1764).

The first pandemic happened in the Eastern Roman Empire in the 6th century and, along two centuries, caused 25 to 50 million deaths! The much better known one, the Black Death, was the second pandemic of bubonic plague in the Late Middle Ages (1340–1400). It started in Central Asia (Mongolia) in 1330, when Mongols attacked an Italian trading station. The fleeing Italians sailed on ships, unknowingly taking the Black Death back to Europe with them in the shape of the rat fleas. People fleeing from one area to another helped spreading the disease, which killed a third of the European human population.

There was also a third modern pandemic in the late 19th century. In 1894, 80,000 people died in Canton (Guangzhou), China; the plague reached Hong Kong via water-traffic. The most affected district in Hong Kong was Taipingshan, one of the poorest and most crowded areas at the foot of Victoria Peak, where the rich British colonisers resided. The Shropshire Light Infantry, aka the "Whitewash Brigade", was responsible for cleaning the district using harmful chemicals and lime (hence the name). They also burned household items and entire houses. The Chinese population refused western medicine and rumours were spread that infected (living) people had been burnt, that British soldiers would search the houses to rape women, and that the doctors made medicine out of the plague victims. The conflict between the Chinese community and the British government grew much stronger during that tragic year.

From Hong Kong, the plague spread rapidly to port cities throughout the world via shipping routes. For instance, to Chinatown in San Francisco from 1900 to 1904. The last major outbreak was recorded in Los Angeles in 1924, but the disease is still present in wild rodents.

Yellow fever

Yellow fever is caused by the yellow fever virus transmitted by the yellow fever mosquito… but wait, there is more.

The origin of the flavivirus lies in Africa, where it most likely developed in primates, but it was taken to the Americas by the slave trade. The first record was 1647 in Barbados, where it caused suffering to indigenous peoples and newcomers alike before spreading through the colonies, like Hispanola. Later the virus spread to Philadelphia, Mississippi, Louisiana and New York.

The virus causes fever, muscle pain, headache, shivers, and nausea in a short acute phase (3 to 4 days) and mostly that's it. In the critical toxic phase, which often leads to death, cells of the inner organs are at-

tacked, i.e., liver and kidneys, causing jaundice, abdominal pain, vomiting, bleeding from mouth, nose and eyes, blood in vomit and feces, and kidney failure. The blood in the vomit is responsible for the name "blood vomit" or "dark vomit" in many languages and supported vampire hysteria.

Figure 9. A patient in the final stages of yellow fever; image extracted from Pariset (1820).

Walter Reed, a US Army physician, is often credited for having fought yellow fever, but there actually were many scientists involved in finding its cause and cure. Reed proved in 1896 that yellow fever was not a result from drinking river water. He was probably not aware that Cuban epidemiologists had already proposed, in 1881, that a mosquito transmitted the disease by biting a human host. Now we know that mosquitoes may also pass on the virus through their eggs.

In 1901, Reed confirmed this hypothesis, which allowed the resumption and completion of work on the Panama Canal (1904–1914). In 1927, researcher Adrian Stokes induced yellow fever in rhesus monkeys from India and identified the virus, but died himself of it during his experiments.

Max Theiler, a South African-American virologist and doctor, survived yellow fever and developed immunity. In 1937 he developed a vaccine against yellow fever and was awarded the Nobel Prize in Physiology or Medicine in 1951.

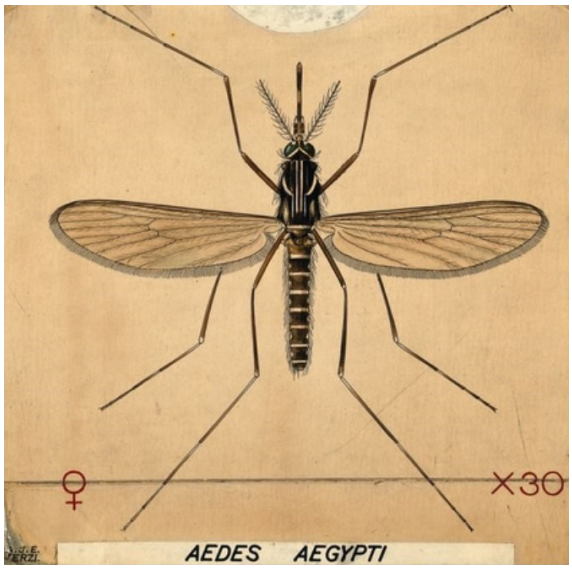


Figure 10. An adult female yellow fever mosquito, *Aedes aegypti*, which can also transmit dengue, zika and chikungunya; illustration by Amedeo J. E. Terzi (1872–1956), public domain.

OTHER "EVIDENCES" FOR THE LIVING DEATH

It is actually no surprise that people feared the undead, even if they have been buried, because when bodies decompose, they are literally all over the place. Back then, these decomposition processes have been very much misinterpreted.

It has been reported that noises can be heard from graves and that the soil looks disrupted. After reopening the graves, corpses have been found warm, flushed and swollen, which is caused by the action of microorganisms in the body, resulting in discoloration of tissue and body fluids as well as gas production, boating the belly. The pressure of the gas is forcing the darkened body fluids out of the mouth and nostrils, and the blood can re-liquify. This looks like the deceased has feasted on blood. The pressure of the gas is also responsible for noises, such as winds and shrieks, and even

a change of position after rigor mortis has passed. And as loose soil needs a while to settle, the eruption of the corpse can de-arrange the earth. Many people actually still believe the myth that fingernails and hair still grow after death. This is easily explained as the skin of the deceased shrinks - even the teeth can appear longer. What is more, the pressure in the corpse can result in an erection, having led to the myth that vampires have a great lust.

Figure 11. Le Vampire, by de R. de Moraine (1864), public domain.

Not all vampires were thought to physically leave their grave, but these stationary fiends were still thought to cause trouble aboveground. The foul decomposition volatiles were proof of a vampire's presence and considered responsible of carrying diseases, which led to the strategy of using smelly stuff like garlic as a protection.

In northern Germany and New England "after-devourers" stayed in the ground, chewing on the burial shrouds that were used to cover the faces of the dead, which led to the name "shroud eaters".

Now we know that the bacteria in the mouth can decay shrouds. By removing the teeth, stuffing its mouth with soil or a stone, the vampire would lose the ability to chew and thus die of starvation.

With the knowledge of the so-called Thanatology, we cannot only explain the changes in a decaying body, but also understand the mechanisms of insect activity on corpses. This enables us to interpret the succession of insect settlement and use this information for Forensic Entomology, which is the study of insects/arthropods in criminal investigation to estimate the post-mortem index, any change in position of the corpse, as well as the cause of death. Apart from Applied Taxonomy, many studies are necessary in order to calculate larval development timeframes effected by, e.g., temperature or chemicals.

REFERENCES

CDC [Centres for Disease Control and Prevention]. (2022a) Plague. Available from: https://www.cdc.gov/plague/index.html (Date of access: 03/Jul/2022).

CDC [Centres for Disease Control and Prevention]. (2022b) Yellow fever. Available from: https://www.cdc.gov/yellowfever/index.html (Date of access: 03/Jul/2022).

Clancy, P. (2021) How Bram Stoker's "Dracula" was linked to Sligo's cholera outbreak. Irish Central. Available from: https://www.irishcentral.com/roots/bram-stoker-dracula-sligo-cholera (Date of access: 01/Jul/2022).

Donella, L. (2018) How yellow fever turned New Orleans into the 'city of the dead'. National Public Radio, CODE SW!TCH. Available from: https://www.npr.org/sections/codeswitch/2018/10/31/415535913/how-yellow-fever-turned-new-orleans-into-the-city-of-the-dead (Date of access: 01/Jul/2022).

Dowling, S. (2016) Vampires are some of the most enduring monsters we have created. Diseases that plagued our ancestors played a part in their creation. BBC Future Available from: https://www.bbc.com/future/article/20161031-the-real-life-disease-that-

spread-the-vampire-myth (Date of access: 01/Jul/2022).

Fahert, F. (2017) The stranger who started an epidemic. Wellcome Collection, The Outsiders. Available from: https://wellcomecollection.org/articles/WsT4Ex8AAHruGfXH (Date of access: 09/Jul/2022).

Gregoricka L.A., Betsinger T.K., Scott A.B., Polcyn M. (2014) Apotropaic Practices and the Undead: A BiogeochemicalAssessment of Deviant Burials in Post-Medieval Poland. PLoS ONE,9(11): e113564. https://doi.org/10.1371/journal.pone.0113564

Ledermüller, M.F. (1764) Amusement microscopique tant pour l'esprit, que pour les yeux: contenant cinquante estampes dessinées d'après nature et enluminées, avec leurs explications. A.F. Winterschmidt, Nuremberg.

Little, B. (2016) The bloody truth about vampires. National Geographic. Available from: https://www.nationalgeographic.com/science/article/vampires-europe-new-england-halloween-history (Date of access: 01/Jul/2022).

NZ BioSecure. (2019) Medical Vectors. An Education Guide for Border Health and Integrated Pest Management. Southern Monitoring Services, Queenstown.

Kennedy, J. (2015) Revenants of the past: vampire burial in Medieval Europe. Available from: https://arcjohn.wordpress.com/revenants-of-the-past-vampire-burial-in-medieval-europe/ (Date of access: 09/Jul/2022).

Kroger, M. (2013) "Interview with the Vampire": New Orleans as the ideal location for vampires. Available from: https://urliterary-neworleans.wordpress.com/2013/04/09/interview-with-the-vampire-new-orleans-as-the-ideal-location-for-vampires-2/ (Date of access: 01/Jul/2022).

Pariset, E. (1820) Observations sur la fièvre jaune, faites à Cadix, en 1819 / par MM. Pariset et Mazet et rédigées par M. Pariset. Audot, Paris.

WHO [World Health Organization]. (2022a) Cholera. Available from: https://www.who.int/news-room/fact-sheets/detail/cholera (Date of access: 02/Jul/2022).

WHO [World Health Organization]. (2022b) Plague. Available from: https://www.who.int/news-room/fact-sheets/detail/plague (Date of access: 02/Jul/2022).

Wikipedia. (2022) Nosferatu. Available from: https://en.wikipedia.org/wiki/Nosferatu (Date of access: 03/Jul/2022).

About the author

Dr **Julia Kasper** is the insect curator at the Museum of New Zealand Te Papa Tongarewa and is specialised in Diptera (flies) taxonomy and Medical Entomology. Trained in Berlin in Forensic Entomology, she soon became interested in bloodsucking Diptera and other insects that transmit diseases, as well as the unique and sometimes bizarre dipteran fauna of New Zealand. That, mixed with her interest in historical and cultural aspects of Entomology, led to this article.

Journal of Geek Studies

jgeekstudies.org

The biology of vampires

João Pedro O. Krizek & Marcus Vinicius D. V. Muller
Instituto Federal de Educação, Ciência e Tecnologia de São Paulo, São Paulo, SP, Brazil.
Emails: jpokrizek@gmail.com; marcusvdvmuller@gmail.com

Vampires are mythological and folkloric creatures that have been catching people's attention for centuries (Fig. 1). They (fortunately or unfortunately) do not exist in the real world, but our intention in this article is to conduct a scientific interpretation of vampires as if they were real. Here, we examine some possible scientific explanations for vampirism, if it existed, particularly by looking at the biology of these fascinating creatures and proposing explanations based on real-world scientific knowledge.

In the first section, we discuss what could be the cause and origin of vampirism in humans. In the second section, we analyze different aspects of the vampire phenotype, such as aversion to garlic, sensitivity to sunlight, anticoagulant and anesthetic production, aversion to religious symbols, and others. In the third section, we look at how the fear of vampires and other imaginary creatures might be related to the evolutionary history of our species. Finally, in the fourth section, we approach vampirism from the perspective of criminal psychology, briefly discussing the biography of three real-life murderers who have their atrocities related to vampirism: The Impaler, The Blood Countess, and The Vampire of Sacramento.

THE CAUSE AND ORIGIN OF VAMPIRISM IN HUMANS

Vampirism, in humans, could be a syndrome caused by a virus, which we shall call NHV (Nosferatean Human Virus). When a vampire bites a human, if the victim does not die, they become a vampire. A possible explanation for this is that, upon contact with the victim's blood, a vampire's contaminated blood or saliva can transmit the NHV.

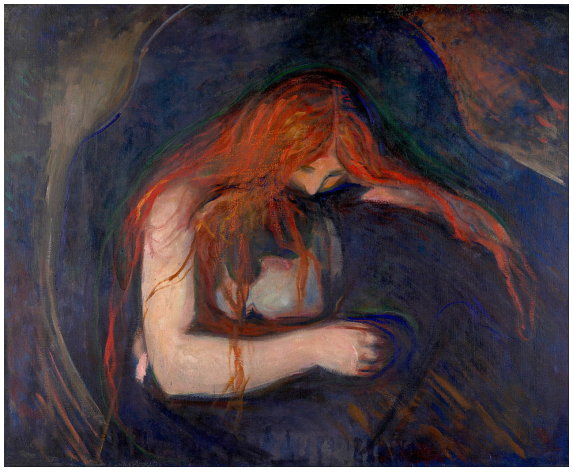


Figure 1. *Vampire*, by Edvard Munch (1895). Public domain.

Based on the biology of real viruses, we hypothesize that the NHV is approximately 90 nanometers in diameter. Its genetic material is made up of double-stranded DNA composed of 666 genes. The capsid – the protein coat that surrounds the viral genome – has a complex shape, resembling an inverted cross. A membranous envelope surrounds the capsid of the NHV. Viruses recognize, and subsequently infect, host cells by a "lock-and-key" fit between viral envelope proteins and specific receptors on the outside of cells (Reece et al., 2015). The viral envelope of NHV can contain numerous proteins, which function as "master keys" and, therefore, allow this virus to

recognize and infect practically any human cell, especially the host's neurons.

The origin of the vampire virus could have happened through a natural process called spillover. This is a process in which a pathogen – a disease-causing being – passes from one host species to members of another species; after this event, the pathogen can thrive, undergo adaptations, and propagate among the individuals of the new host species (Quammen, 2012). Thus, our hypothesis is that the NHV is a modified version of a virus that remained trapped for a long time in an extinct species of vampire bat, and that managed to migrate and adapt to human hosts. In real life, by the way, bats are one of the main reservoirs for viruses that are potentially terrible to humans. Hendra virus, Marburg virus, the rabies virus, most likely the Ebola virus, Nipah virus, and the SARS virus are all examples that appear to have originated from bats (Quammen, 2012).

In biology, we use the term "genotype" to designate the genetic makeup of an organism. "Phenotype" is used to refer to the totality of observable characteristics of an organism, which are the result of the interaction of its genotype with the external environment. Pale skin, sharp teeth, red mouth, aversion to garlic, and thirst for blood are all examples of characteristics that make up a vampire's phenotype. The phenotype is the external manifestation of a "hidden" genotype. However, much of a vampire's phenotype seems to be caused not by the manifestation of the genetic makeup of their human cells, but by the manifestation of the genetic makeup of the NHV "overwriting" parts of the human genotype. In other words, pale skin, sharp teeth, red mouth, aversion to garlic, and thirst for blood are all characteristics that occur after NHV infection and are caused by it. Vampirism, therefore, probably is a case of extended phenotype (Dawkins, 2016): the characteristics of vampirism are programmed into the NHV genotype, but extend beyond its viral body and manifest in its human hosts.

Through its extended phenotype, the NHV can manipulate its hosts' brain cells, making them thirsty for blood. Since this viral species is transmitted through the exchange of contaminated body fluids, by provoking bloodlust in humans, the NHV increases its chances of spreading. The ability of the NHV and other parasites to act as puppeteers of their hosts' behavior is simply a way that parasites have evolved to increase their survival and reproduction rates (Ricklefs & Relyea, 2014). Parasites can control the behavior of different animals. Carpenter ants (*Camponotus leonardi*), for example, live in nests in the forest canopy in Thailand. Ants sometimes move from the canopy to the ground, where they can be infected by the zombie-ant fungus (*Ophiocordyceps unilateralis*). Then, an infected ant moves into the understory vegetation, approximately 25 cm from the ground. Here, the "zombie ant" clings to a leaf and dies. Then the fungus produces a reproductive structure outside the ant's body, where the "spore rain" occurs and contaminates other ants on the forest floor (Andersen et al., 2009; Ricklefs & Relyea, 2014).

THE VAMPIRE PHENOTYPE

In this section, we analyze different aspects of the vampire phenotype.

Aversion to garlic. The fact that garlic works as a repellent against vampires is part of traditional knowledge. This could happen due to the presence of some chemical substance that occurs in this plant. Scientifically, compounds produced by plants are classified into two groups: primary and secondary metabolites (Evert & Eichhorn, 2013). Primary metabolites are molecules found in all plant cells and are essential for all plant life – examples include proteins and nucleic acids, DNA and RNA. Secondary metabolites, in turn, are restricted in their distribution, both within a plant and between different plant species, and confer different benefits to the plants in which they occur. Some secondary metabolites are known as alkaloids, which are pharmacologically important substances that exert remarkable physiological and psychological effects in humans. Examples of alkaloids

include morphine, cocaine, caffeine, and nicotine. Garlic and onions are part of the botanical family Amaryllidaceae. Plants in this group produce "amaryllis" alkaloids (Judd et al., 2008). Our hypothesis is that this different type of alkaloid triggers some exacerbated immune response in vampires, causing headaches and sensory overload. Therefore, the different species of Amaryllidaceae are important weapons of protection against vampires.

Sensitivity to sunlight. Vampires are quite sensitive to sunlight. A possible explanation for this is that these creatures have a blood disorder called erythropoietic protoporphyria. The most visible symptoms of erythropoietic protoporphyria in humans are lesions and blisters formed on the skin caused by contact with light (Lecha et al., 2009); the same could happen with vampires. To alleviate the symptoms of this disease, vampires usually only leave the house at night, which explains the fact that they are pale. Carriers of erythropoietic protoporphyria are also chronically anemic, which would justify their blood-rich diet, and have reddened mouth and teeth due to irregular production of the heme pigment, which gives erythrocytes (red blood cells) their color.

Superhuman strength. Vampires are stronger than uncontaminated humans. This could probably be due to muscle structure: a vampire's skeletal muscle could have longer fibers than the human equivalent. Furthermore, in real life, geneticists have identified some genes that contribute to the development of certain muscles in primates, such as chimpanzees, and found that they are turned off in humans, excluding exceptional athletes. Maybe the same is true for vampires. For example, the gene called MYH16 contributes to the development of large jaw muscles in primates. In humans, MYH16 is disabled; however, in vampires, MYH16 could become activated. Several humans have also lost another muscle-related gene called ACTN3. People with two functional versions of this gene are super speedsters (Hawks, 2009) – which could include vampires.

Nocturnal habit. In addition to avoiding exposure to sunlight, nocturnal habits can have other advantages for vampires (Crawford, 1934). In nature, nocturnal habits allow animals to avoid daytime predators. Harvestmen, crickets, beetles, moths, ants, bats, rats, and mice are animals that can find in nocturnal activity a way to avoid many daytime enemies. Similarly, vampires could avoid human hunters. Secondly, a nocturnal habit allows for capturing prey more easily. Uncontaminated humans are typically diurnal, and they are more vulnerable to being preyed upon at night during sleep; besides, human eyes do not see as well in the dark. Alligators, anacondas, vipers, owls, most bats, raccoons and female mosquitoes prefer to hunt at night for the same reason. Thirdly, a nocturnal habit makes it easier to detect victims by smell. Millipedes, cockroaches, and beetles are creatures with a well-developed sense of smell, and odors linger longer in the air at night, due to the higher humidity and the relative absence of updrafts; similarly to these animals, vampires must have a developed sense of smell. Furthermore, nocturnal vertebrates have eyes with a retina rich in rods – cells sensitive to low-intensity light. Bats, dogs, cats, crocodiles, and lemurs also have the *tapetum lucidum* (Latin for "bright tapestry, coverlet"), a membrane positioned inside the eyeball that acts as a retroreflector increasing the light available to the rods (Crawford, 1934). Due to their nocturnal habit, vampires are also expected to have a rod-rich retina and a *tapetum lucidum*.

Production of carmillin. Animals that feed on blood produce anticoagulant substances. For example, leeches produce a substance called hirudin (Markwardt, 2002) and vampire bats produce a substance called draculin (Apitz-Castro et al., 1995). Therefore, we assume that vampires produce something similar to the draculin found in bats, which we call carmillin, secreted in their saliva. It's probable that, like draculin, carmillin is formed by molecules of glycoproteins – proteins bound to one or more carbohydrates (Fernandez et al., 1998).

Production of vampirin. In addition to

anticoagulants, leeches and vampire bats produce other substances in their saliva, including anesthetics – to stop the victim from feeling pain – and vasodilators – to increase the diameter of the victim's blood vessels and increase blood flow. We assume that human vampires produce a special type of anesthetic, which we call vampirin. In addition to removing pain, vampirin can produce euphoric sensations and hypnotic states in victims.

Production of dracu-telomerase. The cells of any animal's body are constantly being renewed. Old and worn-out cells are replaced by new cells through the process of cell division – when a cell separates into two daughter cells (Alberts et al., 2013). When animal cells are grown in the laboratory, however, they stop replicating and die after a few generations (except for cancer cells). This happens because, with each cycle of cell division, the ends of the chromosomes, called telomeres, undergo shortening. In this way, telomeres tend to decrease in size as an individual gets older, putting a limit on their longevity. However, there is a dilemma: if the chromosomes of germ cells – those that produce sperm and eggs – became shorter with each cell division, essential genes would end up being deleted in the sex cells produced. This does not happen because an enzyme called telomerase promotes the elongation of telomeres in germ cells, restoring their original size and compensating for the loss that occurs during cell division (Reece et al., 2015). Except for germ cells, telomerase is inactive in most human cells; however, we hypothesize that, in vampires, a special type of telomerase is found in all cells, which we call dracu-telomerase. This very efficient enzyme enables the great longevity of vampires.

Diet and physiology. Vampires seem to be obligate hematophagous, meaning that they necessarily feed on the blood of other animals. Blood is a challenging nutrient source because it consists of a liquid phase, called plasma, which corresponds to approximately 78% of the blood, and a solid phase – constituted by the blood cells –, composed of 93% protein and only 1% carbohydrates, providing very low levels of vitamins and lipids (Zepeda Mendoza et al., 2018). In this way, vampires probably have numerous important physiological adaptations to this hyperproteic feeding habit. In mammals, energy flow, protein metabolism, and renal excretion processes constitute a set of closely related functions. The formation of urine begins with the filtration of body fluid in the kidneys. Nephrons are the functional units of the kidneys. Each nephron consists of a single long tubule and a ball of capillaries called a glomerulus. The blunt end of the tubule, expanded in the shape of a cup, is called Bowman's capsule and surrounds the glomerulus. The filtrate is formed when blood pressure forces fluid from the blood in the glomerulus into the lumen of Bowman's capsule (Reece et al., 2015). When proteins and nucleic acids are metabolized, they produce carbon dioxide, water, and urea (Schmidt-Nielsen et al., 1997). High-protein diets raise the concentration of urea in the blood. This compound can be toxic to cells and tissues, so it should not accumulate in the body. Thus, hematophagy in animals has over time selected for evolutionary specializations that would solve the problem of renal failure. Similar mechanisms must be in place in vampires. Some studies show that high-protein diets reflect on the size of the kidneys, making them larger, due to the greater workload received by the organ, a consequence of increased filtration of protein metabolites, especially urea (Gopal, 2013; Linhares et al., 2021). In this sense, vampires' kidneys might be proportionately larger, relative to body size, compared to uncontaminated humans' kidneys. Additionally, both the glomerular area and volumetric density of glomeruli are probably greater in vampires.

Vampire microbiota. In addition to morphophysiological adaptations, host-associated gut microbiota may play an additional, possibly equally important, role in the evolution of vertebrate dietary specialization (Ley et al., 2008). Microbiota is a symbiotic relationship between various microorganisms and their hosts. This microbiota contributes to the health and well-being of the host by generating microbial prod-

ucts and inhibiting the growth of pathogens. In contrast, the host provides several microenvironments that allow microbial growth. Colonization begins as animals are exposed to microorganisms from birth. An animal's body is not a uniform environment. Each region of the body differs chemically and physically from each other, being a selective environment, where the growth of certain microorganisms is favored or not (Madigan et al., 2014). Although the functional role of the gut microbiota of vampire bats has not been studied in detail, analyses with hematophagous invertebrates have shown that the gut microbiota contributes to the digestion of consumed blood, supply of nutrients absent in the blood (Graf, 2001), and immune protection (Indergand & Graf, 2000; Zepeda Mendoza et al., 2018). In humans, the composition of the gut microbiota and diet influence the type and number of compounds produced. Among these products are vitamins B12 and K, which are essential and not synthesized by humans, being produced by the intestinal microbiota and absorbed from the colon (Madigan et al., 2014). One study has isolated bacteria of the species *Aeromonas hydrophila* from fecal samples of vampire bats. These bacteria are hemolytic and thus, can aid in the digestion of blood (Hanning & Diaz-Sanchez, 2015). Studies also suggest that bacteria species of the genus *Helicobacter* help in the production of the urease enzyme, necessary in the metabolization of urea that is concentrated in vampire bats (Song et al., 2019). We hypothesize that the composition of the microbiota of human vampires is not entirely different from that of humans. Both must share some species, but at the functional level, they can be almost completely distinct. Thus, it's probable that the gastrointestinal tract of human vampires has a microbiota composed of microorganisms capable of assisting in the metabolization of ingested blood proteins, producing some nutrients absent in the blood, and generating protection against pathogens.

Aversion to religious symbols. We assume that the idea that vampires have an aversion to religious symbols – such as holy water and crucifixes – is a superstition. Despite this, we believe that vampires have an aversion to any object made of silver, including religious symbols made of it. This is probably because silver triggers an allergic response in these creatures. An allergy is an exaggerated response to a particular antigen – a molecule, generally considered foreign by the body and which induces the formation of antibodies. In vertebrates, mast cells produce histamine and other molecules that cause inflammation in response to infection and in allergic reactions. An acute allergic response can trigger a life-threatening reaction called anaphylactic shock. Here, substances released by mast cells trigger the contraction of the bronchioles in the lungs and the dilation of peripheral blood vessels, causing a sudden drop in blood pressure and inability to breathe. In this way, death can occur in a few minutes. In humans, bee venom, penicillin, peanuts, and seafood are some substances that can cause anaphylactic shock. In vampires, silver could be one such substance. People with severe hypersensitivities often carry syringes containing the hormone epinephrine, which quickly counteracts the allergic response (Reece et al., 2015).

FEAR OF VAMPIRES

The roots of most vampire stories go back to the superstitions around the world. In Eastern Europe, we can find stories of the reanimated dead known as *revenants* (Fig. 2), who came out of the grave to torment their relatives and neighbors. In Norse mythology, there are stories of creatures known as *draugr*, beings of superhuman strength who smelled foul and looked hideous, and who returned from the grave to haunt the dreams of the living. In Greek mythology, there is the myth of Empusa, daughter of Hecate, who attracted young men at night and feasted on their blood and flesh. Another Ancient Greek story involves Lamia (Fig. 3), lover of Zeus, cursed by his wife Hera and doomed to become a child-eating demon. In Mesopotamian and Judaic mythology, there is the myth of Lilith (Fig. 4), supposedly the primordial she-demon,

who was often depicted as subsisting on the blood of babies (Mahnke, 2017).

Figure 2. Drawing of an undead that rose from its tomb. Unknown author (ca. 1500). Public domain.

The fear of vampires does not reflect empirical reality, but the psychology of our ancestors. Many of our fears bear little relation to the objective dangers of the modern world but are remnants of our species' evolutionary history. Many people are afraid of flying, although traveling by car is eleven times more dangerous (Lewis, 1990). Some people are afraid of sharks, although they are four hundred times more likely to drown in their bathtub (Ropeik, 2010). Activists rightly fight for a ban on pesticide residues and food additives, even though they pose minimal cancer risks compared to the many natural carcinogens that plants have evolved to stop herbivory (Ames et al., 1990). Such risks are misestimated because they stem from our innate fears of heights, confinement, predation, and poisoning (Pinker, 2002). Other common fears are storms, large carnivores, darkness, blood, strangers, deep water, and leaving home alone – situations that endangered our ancestors. Fear is the emotion that enabled our ancestors to deal with the dangers they might encounter (Pinker, 1997).

Figure 3. *The Kiss of the Enchantress*, by Isobel Lilian Gloag (1890), depicts Lamia as half-serpent. Public domain.

In his book *The Descent of Man*, Darwin (1871: 43) reported how captive-bred monkeys exhibit a strong instinctive fear of snakes: "*I then placed the stuffed [snake] specimen on the ground in one of the larger compartments. After a time all the monkeys collected round it in a large circle, and staring intently, presented a most ludicrous appearance. They became extremely nervous; so that when a wooden ball, with which they were familiar as a plaything, was accidently moved in the straw, under*

which it was partly hidden, they all instantly started away. These monkeys behaved very differently when a dead fish, a mouse, and some other new objects were placed in their cages; for though at first frightened, they soon approached, handled and examined them."

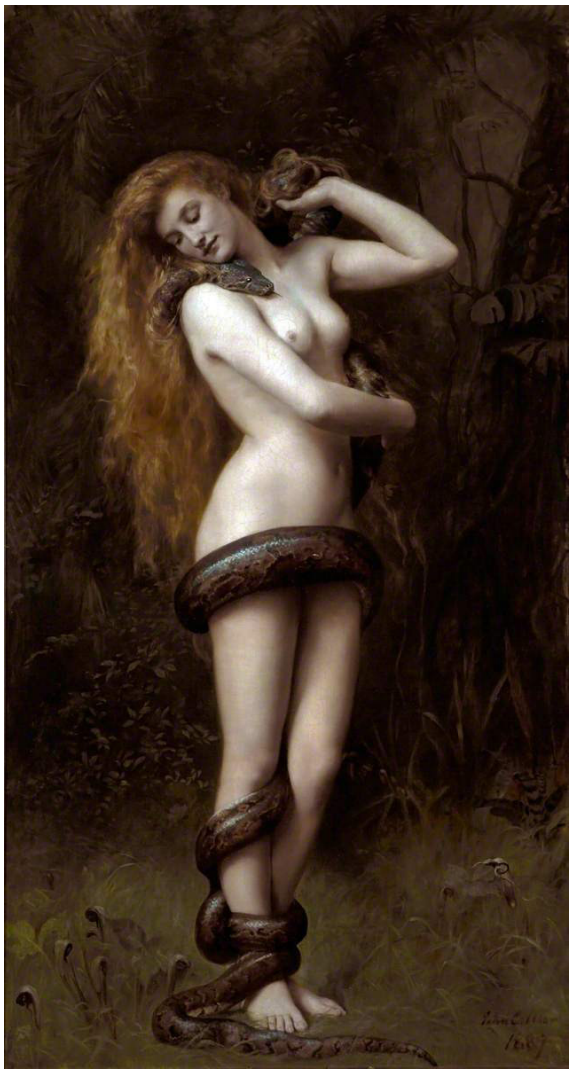


Figure 4. *Lilith*, by John Collier (1889). Public domain.

Similar to Darwin, Hebb (1946) found that chimpanzees scream when they see a snake for the first time. These behavioral responses are ingrained in these primates. The best evidence that fears are adaptations – and not just errors of the nervous system – is that animals that evolve on islands without predators (like dodos and kiwi) lose their fear and are easy prey for any invader (Pinker, 1997).

In his account, Darwin (1871: 43) observed that, despite the fear, "*One of the monkeys immediately approached, cautiously opened the bag a little, peeped in, and instantly dashed away*". The ape was taken by curiosity, in the same way that humans are drawn to horror, provided they are safe – for example, within fiction. Fear and fascination intertwine when there is no real danger. Our attention is preferentially captured by evolutionarily relevant dangers, and horror fiction monsters such as vampires capitalize on this tendency. It is obvious that such creatures did not exist in ancestral environments, but vampires represent an imaginative combination of threats that existed in prehistoric times – such as the threat posed by mammalian predators with sharp teeth and thirst for blood (Clasen, 2014).

The fascination that many people feel with vampires is likely the result of an adaptive tendency to pay attention to these dangerous creatures and learn about their behavior. This is the idea of the "Jurassic Park hypothesis" proposed by Barrett (2015). According to it, the modern horror story functions as a technology that involves monstrous beings that allow us to exploit an adaptive motivational system to learn about danger and to calibrate our responses to it. Consuming horror stories has all the benefits of learning about dangers and responses to it but without the risk of actual harm (Clasen, 2012). This probably also explains why horror story fans have shown themselves to be more psychologically prepared when facing the COVID-19 pandemic (Scrivner et al., 2021).

Most vampire stories have their genesis in our psychology and the human need to explain what we don't understand. For example, ancient Europeans used the vampire myth to explain why a corpse didn't decompose at the normal, expected rate. Before the development of modern medicine, porphyria and rabies were diseases used as an explanation for the growth of vampire mythology, because of the similarities between these diseases and vampiric characteristics. Today, we have a much deeper scientific understanding of how these diseases work, and what happens to the body after a

person dies (Mahnke, 2017). However, the answers don't dispel all the myths. Vampire stories refuse to die, and the fascination and fear of these creatures will always live within us.

REAL-LIFE VAMPIRES

In folklore and literature, the term "vampire" describes supernatural beings that conjure up the image of bloodthirsty "undead". In the field of psychology and criminology, however, "vampirism" has a very different meaning: it is a paraphilia in which people derive intense sexual pleasure from the act of drinking human blood (Schechter, 2003). As perverse as such sexual practice may seem, not all vampires are psychopathic criminals. Despite this, some of the most famous serial killers in the history of criminology possibly have practiced vampirism in addition to other abominations (Schechter, 2003). Three of these serial killers have their biographies summarized here: The Impaler, The Blood Countess, and The Vampire of Sacramento. The three are historical figures linked to vampirism, who broke with previous folk versions and promoted the modernization of these creatures in the media and literature.

Vlad III, The Impaler (1431–1476)

The most prominent figure linked to the modern idea of the vampire is Vlad III (Fig. 5), who ruled the Romanian principality of Wallachia, south of Transylvania, from 1456 to 1462. His father was known as Dracul, which in Romanian means "dragon". Vlad's nickname, Draculea, means "son of Dracul". Although he was not a true serial killer, Vlad killed his enemies with immense sadism. He became known as Vlad Tepes, which means "Vlad, The Impaler" because he preferred to execute his enemies by impaling them on stakes. It is Vlad's malevolent reputation that impressed Bram Stoker and motivated him to use The Impaler as inspiration for his legendary vampire (Mahnke, 2017).

Figure 5. *Vlad Ţepeş, the Impaler, Prince of Wallachia*. Unknown author (16th century). Public domain.

When impaling his enemies, Vlad displayed bewildering creativity. Using the weight of his victims as they slid down an oily, spiky stake, he impaled them through the mouth, anus, heart, or navel. Blinding, burning and scalping his victims were also some of his methods. According to legend, on April 2, 1459, in Brasov (Transylvania), he ordered the impalement of thousands of Saxons, with the stakes arranged around a table on which he calmly dined around the carnage (Schechter, 2003).

Modern historians, however, have discredited this hideous image of Vlad as a major slanderous critique exaggerated by his enemies and argue that Vlad's actions must be interpreted in the proper historical context. Despite being a remarkable leader, Vlad was likely cruel but no more so than other aristocratic warriors of his time (Schechter, 2003).

Elizabeth Báthory, The Blood Countess (1560–1614)

Born on August 7, 1560, at the foot of the Carpathian Mountains, Elizabeth Báthory (Hungarian name: Báthory Erzsébet) (Fig.

6) belonged to one of the oldest and noblest Protestant families in the Kingdom of Hungary. Heiress to absurd wealth, Elizabeth received a classical education, being fluent in Hungarian, Slovak, Greek, Latin, and German.

Figure 6. Copy of the original (lost) portrait of Countess Elizabeth Báthory. Unknown author (probably 16th century). Public domain.

Some rumors claim that as a child, Elizabeth suffered from terrible epileptic seizures. It is also likely that she witnessed various acts of violence during her childhood, including mistreatment of servants and occasional public executions. At the age of ten, she became engaged to Count Ferencz Nádasdy, a warrior and member of another powerful Hungarian family, and moved into his castle, which had a torture dungeon. On May 8, 1574, the bride and groom were married. Nádasdy, a lover of battles, spent little time on their property. Because of his cruel reputation, he has been nicknamed the Black Knight of Hungary.

Due to her husband's travels, Elizabeth and Nádasdy barely saw each other, and it took ten years for the couple to have their first child. When they met, the couple shared a common interest in torturing young maids. Supposedly, the earl once covered a young girl with honey so that she would be mercilessly bitten by insects. He even presented the countess with a sort of clawed glove, which she used to cut the flesh of her servants. It is therefore undeniable that the Black Knight was a strong inspiration for the psychopathic and impressionable young Elizabeth. Another possible influence on the countess was Anna Darvolya, a mysterious woman who came to stay at the castle in 1601 and who was reputed to be a witch (Telfer, 2017).

Between the time of her marriage and imprisonment in 1610, there are estimates that Elizabeth may have been responsible for up to 650 murders. Most of her victims were peasant women lured to the castle in search of employment. Additionally, several maids were constantly dying on Elizabeth and Nádasdy's property, but the authorities didn't care. For the ruling classes, the lives of young peasants did not have much value. At the time, the Hungarian legal code called *Tripartitum* limited the rights of peasants and serfs to next to nothing, while protecting the nobility who mistreated them (Schechter, 2003).

According to legends, Elizabeth cultivated the habit of killing virgin prisoners, filling a bathtub with their blood and bathing in it, as a way of preserving her youth. Supposedly, this cruel habit began when a maid made a mistake while bathing Elizabeth, the countess slapping the girl so hard that a little blood splattered her face. After cleaning it, Elizabeth would have noticed that her skin looked more youthful, producing her habit of bathing in the blood of virgins. However, apparently, this is not true. In Elizabeth's trial transcripts, none of the servants who testified made any mention of the alleged bloodbaths (Telfer, 2017). Despite this, the Blood Countess made frequent use of whips, scissors, pliers, needles, red-hot branding irons, and peg-lined cages, though she especially liked to tear off pieces of flesh from victims with tweezers or with her teeth (Schechter, 2003).

In 1604, Nádasdy fell ill and died, with

Elizabeth experiencing a prolonged period of stress. Around this time, the Blood Countess became even more fanatical about torturing and killing. For this, she had the help of Anna Darvolya, her guest; Ilona Jó, her children's nurse; Dorka, a friend of Ilona Jó; Katalin, a washerwoman; and Ficzkó, a disfigured young man (Telfer, 2017).

Like many of the serial killers who followed her, Elizabeth became a reckless and disorganized killer. With the depletion of young peasants in the region, Elizabeth began attacking the daughters of the gentry, attracting the attention of the authorities. Condemned to be walled up alive in her castle, she probably died of starvation in 1614.

Richard Chase, The Vampire of Sacramento (1950–1980)

Born in Sacramento, California, Richard Trenton Chase already manifested, at age of five, the three factors of the Macdonald (1963) triad (important danger signs considered predictive of, or associated with, violent tendencies, particularly concerning serial offenses): enuresis (bed-wetting), pyromania (setting fires), and early sadism (usually in the form of cruelty to animals). As a child, Chase tortured and killed small animals – birds, cats, and dogs – drank their blood, and devoured their intestines. He also occasionally injected rabbit blood into his veins. He believed that the blood of these animals would prevent his blood from turning to dust (Schechter, 2003).

Chase was affected by the rare Renfield's syndrome, so named by psychologist Richard Noll (1992) in reference to Dracula's assistant who fed on live animals: "*My homicidal maniac is of a peculiar kind. I shall have to invent a new classification for him, and call him a zoophagous (life-eating) maniac. What he desires is to absorb as many lives as he can, and he has laid himself out to achieve it in a cumulative way. He gave many flies to one spider and many spiders to one bird, and then wanted a cat to eat the many birds. What would have been his later steps?*" (Stoker, 1897: 59).

Renfield's syndrome worsens through four stages (Casoy, 2017). In the first stage, due to an incident, the child associates the taste or sight of blood with something attractive; in adolescence, there is a correlation between this attraction and sexual matters. In the second stage, the person drinks their own blood (hematophagy), often in self-harm. Then, the person drinks the blood of animals (zoophagy). Finally, the person drinks human blood, usually stolen from hospitals or laboratories; in rare cases, the person kills to achieve his goal. Such compulsion is associated with a strong sexual component.

Diagnosed as a paranoid schizophrenic and after spending several years living in mental institutions, in December 1977 Chase shot and killed his first victim, Ambrose Griffin, a middle-aged man who he encountered on the street. Then, he started breaking into houses. In January 1978, Chase killed a pregnant woman, Teresa Wallin, at her home, dismembered her body, and drank her blood using an empty yogurt cup. Circles of blood were found around the victim's body as if a wet bucket had been moved around the corpse. Four days later, he murdered Evelyn Miroth, her six-year-old son, and a visiting friend. The autopsy revealed that the woman was sodomized; a large amount of sperm was found in her rectum. After Miroth died, Chase stuffed her mouth with animal feces (Casoy, 2017). Chase also kidnapped Miroth's nephew, who was 22 months old. The child's corpse was found in an abandoned box in a vacant lot.

A classic disorganized offender, Chase left footprints and several clues wherever he went. When the police found his apartment, they found everything covered in blood, including the blenders that Chase used to prepare drinks with blood and guts. The Vampire of Sacramento was then indicted for six murders and sentenced to death in a gas chamber. He told the FBI criminalists that he killed to preserve his own life. He claimed that he needed to replenish his blood, which was turning to sand after being poisoned by his mother.

He also claimed that he was being pursued by Nazis who were associated with unidentified flying objects, who telepathically commanded him to kill. On Christmas 1980, Chase died by suicide by overdosing on Sinequan, a medication to treat depression and hallucinations (Schechter, 2003).

REFERENCES

Alberts, B.; Bray, D.; Hopkin, K. Johnson, A.; Lewis, J.; Raff, M.; et al. (2013) Essential Cell Biology. 4th ed. Garland Science, New York.

Ames, B.; Profet, M.; Gold, L. S. (1990) Dietary pesticides (99,9% all natural). Proceedings of the National Academy of Sciences 87: 7777–7781.

Andersen, S.B.; Gerritsma, S.; Yusah, K.M.; Mayntz, D.; Hywel-Jones, N.L.; Billen, J.; et al. (2009) The life of a dead ant: the expression of an adaptive extended phenotype. American Naturalist 174: 424–433.

Apitz-Castro, R.; Beguin, S.; Tablante, A.; Bartoli, F.; Holt, J.C.; Hemker, H.C. (1995) Purification and partial characterization of draculin, the anticoagulant factor present in the saliva of vampire bats (*Desmodus rotundus*). Thrombosis and Haemostasis 73: 94–100.

Barrett, H.C. (2015) Adaptations to predators and prey. In: Buss, D.M. (Ed.) Handbook of Evolutionary Psychology. Wiley, New York. Pp. 200–223.

Casoy, I. (2017) Arquivos Serial Killers: Louco ou Cruel? & Made in Brazil. Darkside Books, Rio de Janeiro.

Clasen, M. (2012) Monsters evolve: a biocultural approach to horror stories. Review of General Psychology 16: 222–229.

Clasen, M. (2014) Evil monsters in horror fiction: an evolutionary perspective on form and function. In: Packer, S. & Pennington, J. (Eds.) A History of Evil in Popular Culture: What Hannibal Lecter, Stephen King, and Vampires Reveal about America. Vol. 2. Praeger, Santa Barbara.

Crawford, S.C. (1934) The habits and characteristics of nocturnal animals. The Quarterly Review of Biology 9: 201–214.

Darwin, C.R. (1871) The Descent of Man, and Selection in Relation to Sex. John Murray, London.

Dawkins, R. (2016) The Extended Phenotype: The Long Reach of the Gene. Oxford University Press, Oxford.

Evert, R.F. & Eichhorn, S.E. (2013) Raven Biology of Plants. W.H. Freeman, New York.

Fernandez, A.Z.; Tablante, A.; Bartoli, F.; Beguin, S.; Hemker, H.C.; Apitz-Castro, R. (1998) Expression of biological activity of draculin, the anticoagulant factor from vampire bat saliva, is strictly dependent on the appropriate glycosylation of the native molecule. Biochimica et Biophysica Acta 1425(2): 291–299.

Gopal, P.K. (2013) Morphological adaptations in the kidney and urine concentrating ability in relation to dietary habitat in the three species of bats. World Journal of Zoology 8: 198–205.

Hawks, J. (2009) How strong is a chimpanzee? Slate. Available from: https://slate.com/technology/2009/02/how-strong-is-a-chimpanzee-really.html (Date of access: 27/Jul/2022).

Hebb, D.O. (1946) On the nature of fear. Psychological Review 53: 259–276.

Judd, W.S.; Campbell, C.S.; Kellogg, E.A.; Stevens, P.F.; Donoghue, M.J. (2008) Plant Systematics: A Phylogenetic Approach. 3rd ed. Sinauer Associates, Massachusetts.

Hanning, I. & Diaz-Sanchez, S. (2015) The functionality of the gastrointestinal microbiome in non-human animals. Microbiome 3: 1–11.

Lecha, M.; Puy, H.; Deybach, J.C. (2009) Erythropoietic protoporphyria. Orphanet Journal of Rare Diseases 4: 19.

Lewis, H.W. (1990) Technological Risk. Norton, New York.

Linhares, B.S.; Ribeiro, S.P.; de Freitas, R.M.P.; Puga, L.C.H.P.; Sartori, S.S.R.; Freitas, M.B. (2021) Aspects regarding renal morphophysiology of fruit-eating and vampire bats. Zoology 144: 125861.

Macdonald, J.M. (1963) The threat to kill. The American Journal of Psychiatry 120: 125–130.

Madigan, M.T.; Martinko, J.M.; Bender, K.S.; Buckley, D.H.; Stahl, D.A. (2014) Brock Biology of Microorganisms. 14th ed. Person, London.

Mahnke, A. (2017) The World of Lore: Monstrous Creatures. Penguin Random House, New York.

Markwardt, F. (2002) Hirudin as alternative anticoagulant – a historical review. Seminars in Thrombosis and Hemostasis 28: 405–414.

Noll, R. (1992) Vampires, Werewolves and Demons: Twentieth Century Reports in the Psychiatric Literature. Brunner/Mazel, New York.

Pinker, S. (1997) How the Mind Works. Norton, New York.

Pinker, S. (2002) The Blank Slate: The Modern Denial of Human Nature. Penguin Books, New York.

Quammen, D. (2012) Spillover: Animal Infections and the Next Human Pandemic. W.W. Norton, New York.

Reece, J.B.; Urry, L.A.; Cain, M.L.; Wasserman, S.A.; Minorsky, P.V.; Jackson, R.B. (2015) Campbell Biology. 10th ed. Pearson, London.

Ricklefs, R. & Relyea, R. (2014) The Economy of Nature. 7th ed. W.H. Freeman, New York.

Ropeik, D. (2010) How Risky Is It, Really?: Why Our Fears Don't Always Match the Facts. McGraw Hill, New York.

Schechter, H. (2003) The Serial Killer Files: The Who, What, Where, How, and Why of the World's Most Terrifying Murderers. Ballantine Books, New York.

Schmidt-Nielsen, K. (1997) Animal Physiology: Adaptation and Environment. 5th ed. Cambridge University Press, Cambridge.

Scrivner, C.; Johnson, J.A.; Kjeldgaard-Christiansen, J.; Clasen, M. (2021) Pandemic practice: horror fans and morbidly curious individuals are more psychologically resilient during the COVID-19 pandemic. Personality and Individual Differences 168: 110397.

Song, S.J.; Sanders, J.G.; Baldassarre, D.T.; Chaves, J.A.; Johnson, N.S.; Piaggio, A.J.; et al. (2019) Is there convergence of gut microbes in blood-feeding vertebrates? Philosophical Transactions of the Royal Society B 374: 1777.

Stoker, B. (1897) Dracula. Available from: http://www.dominiopublico.gov.br/pesquisa/DetalheObraDownload.do?select_action=&co_obra=3495&co_midia=2 (Date of access: 27/Jul/2022).

Telfer, T. (2017) Lady Killers: Deadly Women Throughout History. Harper Collins, New York.

Zepeda Mendoza, M.L.; Xiong, Z.; Escalera-Zamudio, M.; Runge, A.K.; Théze, J.; Streicker, D.; et al. (2018) Hologenomic adaptations underlying the evolution of sanguivory in the common vampire bat. Nature Ecology & evolution 2: 659–668.

Acknowledgments

We would like to thank the team of the Journal of Geek Studies for extended support and guidance.

About the authors

João Pedro O. Krizek is a biologist interested in ecology, sociobiology, and the philosophy of biology. He likes horror movies and true crime books. Member of the Ecology Department at the International Center for Vampire Extermination and Control (ICVEC). Under the guidance of Dr. John Van Helsing, he seeks an ultimate cure for vampirism.

Marcus Vinicius D. V. Muller is a biologist interested in zoology, physiology, and ecology. He likes horror stories. Member of the Physiology Department at the International Center for Vampire Extermination and Control (ICVEC). Under the guidance of Dr. John Van Helsing, he investigates diversity, zoogeography and evolution of tropical vampires.

Journal of Geek Studies

jgeekstudies.org

Cicadas in Japanese video games and anime

Rodrigo Brincalepe Salvador
Museum of New Zealand Te Papa Tongarewa. Wellington, New Zealand.
Email: salvador.rodrigo.b@gmail.com

If you ever watched an anime, chances are at some point you have heard an incessant buzzing sound in the background. Those are cicadas, the sound of summer in Japan. Summer only truly arrives when the cicadas start singing (Kendall, 2014).

Whenever it is summer in an anime, TV series, movie, or game, you can be almost sure to hear cicadas on the background. Their sound is an easy and straightforward way to set the atmosphere and impart the feel of a Japanese summer (McKirdy, 2019).

Many people don't pay much attention to nature, be it the real thing or in fiction, so if you think you have never heard cicadas, just go back to one of the almost-mandatory episodes in your favorite anime (summer holidays, festival/fireworks, beach trip) and check it out. They are so prominent that, as a Redditor put it, they are the best supporting character in every anime.

Figure 1. For instance, while I was writing this article, a new (summer) episode of *The Devil Is a Part-Timer!* came out, featuring this cicada with a rather generalized design. Screen capture from the anime (season 2, episode 05; Studio 3Hz, 2022).

The cultural importance of the sound of cicadas is nothing new in Japan. Sei Shōnagon herself makes several mentions to these animals in *The Pillow Book* (written through the 990s to 1002), like this one: "*(…) I had gone to Kiyomizu Temple for a retreat and was listening with deep emotion to the loud cry of the cicadas (…)*" (translation by I.I. Morris, 1967).

Not everyone likes cicadas, though. Their sound can be almost deafening at times and they can also cause damage to infrastructure (Cyranoski, 2007; McKirdy, 2019; Moriyama & Numata, 2019). Besides, they are usually not very pretty, to put it mildly, and they fly and collide with people walking by. Entomologists who research cicadas will tell you, however, that these creatures are among the "most charismatic insects" (Marshall et al., 2018: 4). Whether you agree with them or not, that's entirely up to you.

Figure 2. Urusai!!! Screen capture from *Gakuen Utopia Manabi Straight!* Screen capture from the anime (episode 07; Ufotable, 2007).

[1] Murasaki Shikibu is also famous for her metaphorical use of cicadas in *The Tale of Genji* (ca. 1020) comparing the robes of one of Genji's lovers to the empty husk left by a cicada after molting.

Love them or hate them, cicadas are still part of nature and also have a role in different cultures around the world. But what exactly is a cicada anyway? In this article, I'll go over their basic biology (what they are, how they live, etc.), showcase some common species in Japan, and tie it in with Japanese games and anime.

WHAT'S A CICADA?

Starting from the most general to more specific, cicadas are insects that belong to the Order Hemiptera. Hemipterans are also called "true bugs", and contain diverse groups like shield bugs, stink bugs, assassin bugs, bed bugs, kissing bugs, aphids, leafhoppers, treehoppers, and, of course, cicadas. Cicadas are a superfamily within the order Hemiptera, called Cicadoidea.

Within that superfamily, there are two families: Tettigarctidae and Cicadidae. The first one, Tettigarctidae, is mainly known from fossils and only two species of this family still live, both in Australia (Dietrich, 2003; Marshall et al., 2018). The rest of the 3,000 to 4,000 species of cicadas all belong to the family Cicadidae, and are distributed worldwide, being more common and diverse in the tropics (Brambila & Hodges, 2008; Sanborn, 2008). While the number doesn't look that impressive when compared to other insect groups, that's still a lot of species. As a comparison, the total number of mammal species is around 6,400 (Burgin et al., 2018).

The Tettigarctidae have a long evolutionary history, the oldest fossils date back to the final part of the Triassic period, circa 205 to 201 Ma (millions of years ago) (Grimaldi & Engel 2005; Moulds, 2018). Cicadidae, on the other hand, are a much younger group. They have been around since the Paleocene, a geological epoch that lasted from circa 66 to 56 Ma (Grimaldi & Engel 2005; Moulds, 2018).

Figure 3. An 19th-century naturalist illustration of cicada species, showing a bit of their diversity in India and neighboring regions. Image extracted from Distant (1889–1892: pl. 3).

Figure 4. Examples of fossil cicadas. The one on the left, *Minyscapheus dominicanus* (from the Dominican Republic), is preserved inside a piece of amber. The one on the right, *Miocenoprasia grasseti* (from France), is a "regular" fossil, preserved in stone. Images extracted from Moulds (2018: pl. 3, figs. 4, 5).

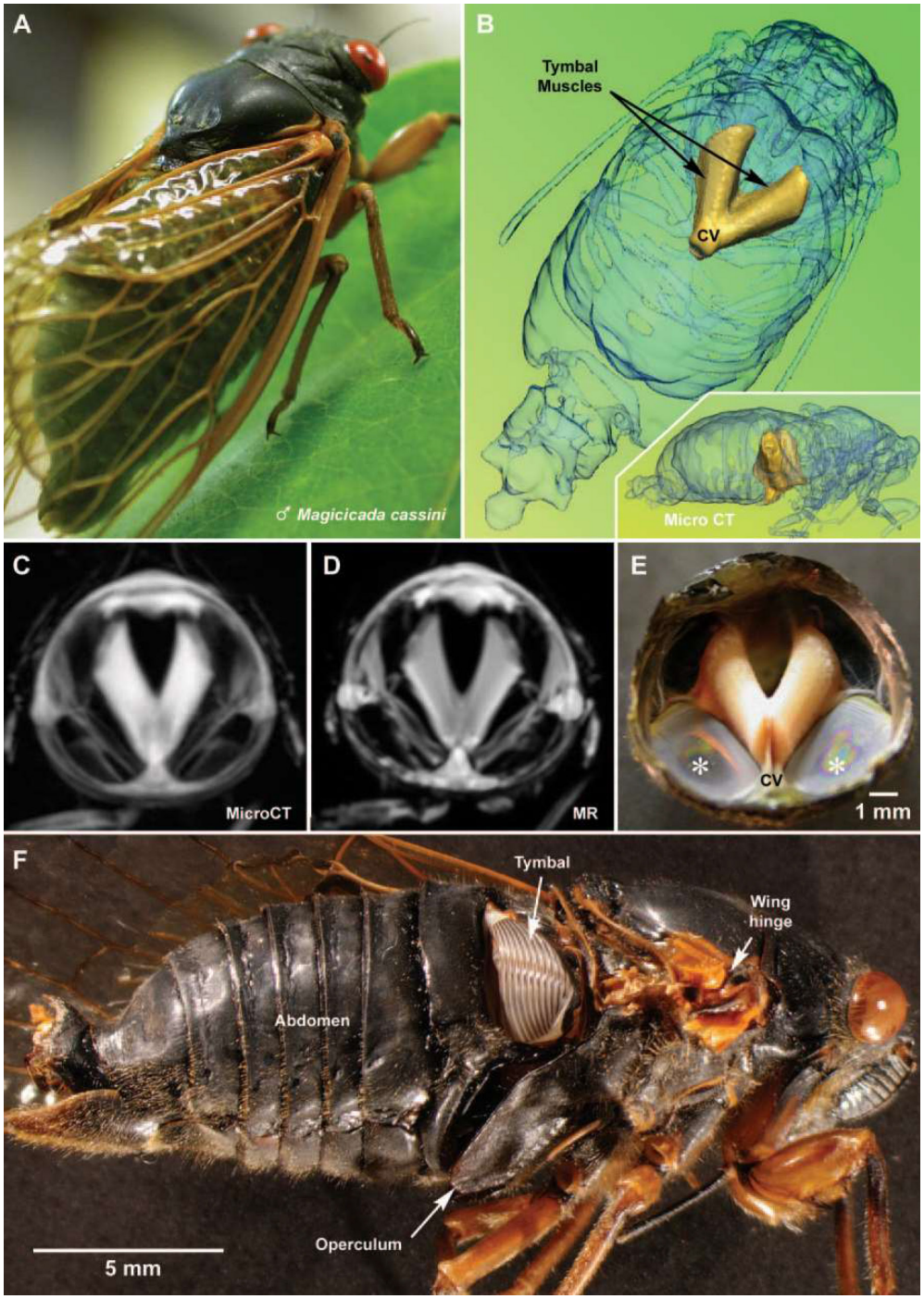


Figure 5. A. A male of the species *Magicicada cassini*. **B.** Same cicada, tomography scan with the tymbal muscles highlighted in yellow. **C–E.** A view of the muscles and tymbals (marked by an * in 'E') in cross-section. 'C' is a tomography scan, 'D' is a magnetic resonance image, and 'E' is a normal view of dissected specimen. **F.** Specimen with wing removed to show the location of tymbal in the first abdominal segment. Image extracted from Nahirney et al. (2017: fig. 1).

LIFE AND TIMES OF A CICADA

As all members of the order Hemiptera, cicadas are hemimetabolous animals. That means that the baby cicada that emerges from the egg (called a nymph) is a miniature version of the adult. They grow gradually, molting their old exoskeleton when they do, until they reach their final adult stage, called imago. That is different from the "most usual" holometabolous insects such as butterflies and beetles, which have a larval (maggot) stage, and then a pupa (or

chrysalis) stage when they undergo metamorphosis into the adult.

Cicadas, both nymphs and adults, feed by puncturing plants and drinking their sap. After hatching from the egg, the nymphs burrow in the ground and feed on the sap of roots (Dietrich, 2003). Nymphs stay underground for a long period, going through several molts. While most species have a life cycle that lasts from 2 to 5 years, some live was longer, emerging only after 13 or 17 years (Sanborn, 2008). The latter typically appear on the news (for instance, Wong & Sinnen, 2021).

After they emerge, they will cling to tree trunks and other surfaces and molt one final time. The empty husks we find are from this last molt. The adults will also cling to those surfaces while singing. Male cicadas sing during their reproductive phase to attract females. I mean, that is generally referred to as a "song", like for birds. However, several other nouns and verbs are commonly applied to whatever it is cicadas do: the neutral and perhaps more biologically accurate "call", but also "cry", "shrill", "chirping", and "buzzing".

Cicadas produce their song using a pair of specialized organs on the base of their abdomen, called tymbals (Fig. 5). The tymbals resemble ribbed membranes. The superfast contraction and relaxation of a pair of muscles inside the cicada's body make the tymbals rattle (buckling inward and then returning to their original relaxed state), thus producing the sound (Moulds, 2003; Nahirney et al., 2017). The region of the abdomen where the tymbals are located is hollow, so it works as an acoustic resonator (Moulds, 2003).

Each cicada species has its own song and the females recognize the songs of males of the same species (Moulds, 2003; Sanborn, 2008). That happens even when there is more than one species singing at the same time and when the songs of two species appear to be very similar to one another (Endo & Osawa, 2017).

With a bit of training, even we can recognize different species singing. That also means that we can discern the presence of a species in a given area solely by sound, just like we do when we hear the song of a blackbird or song thrush before actually seeing one. Of course, even though our ears work reasonably well with bird song, it is more difficult to deal with insects. So, researchers also use graphs that represent sounds, such as sonograms and oscillograms (Fig. 6).

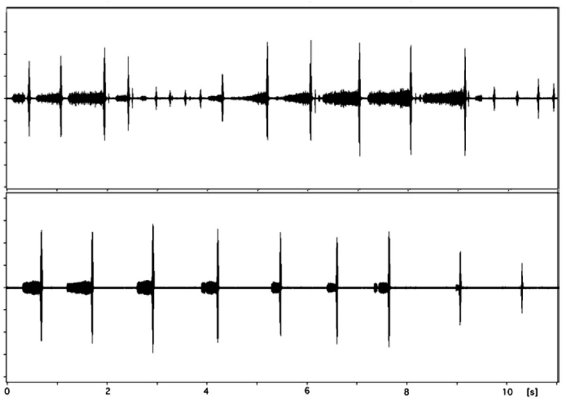


Figure 6. Visualization of cicada songs as oscillograms. Both songs are from members of the species *Cicadetta cerdaniensis*. The top one is by a Polish *C. cerdaniensis* and the bottom one by a Slovenian *C. cerdaniensis*, showing that there is even regional differences ("accents" if you will) in the song of the same species. Image extracted and adapted from (Gogala & Trilar, 2004: fig. 3b, d).

Male cicadas can "turn off" their hearing while they are singing, thus avoiding being deafened by their own song (Moulds, 2003). We're not so lucky. But even though their singing can be anywhere from annoying to unbearable to a few people, cicadas are not harmful insects in any other way, barred for a few crops and ornamental plants (Sanborn, 2008; Marshall et al., 2018). Curiously, the structure of cicada wings has served as inspiration for the creation of surfaces that are water-proof, antireflective (e.g., to reduce glare), or even antibacterial (Marshall et al., 2018).

JAPANESE CICADAS

The general Japanese word for cicada is セミ (semi), typically written in katakana in biological contexts. Each species of cicada has a name that is 'something'-semi, or

rather 'something'-zemi, because the 'se' becomes 'ze' in these compound words.[2] For instance, the species *Cryptotympana facialis* is called クマゼミ (kumazemi, or "bear cicada"), so named due to its large size. Some species are named after the sound they make, like *Hyalessa maculaticollis*, known as ミンミンゼミ (minminzemi, or "min-min cicada").

A few species can have completely unique names, like *Tanna japonensis* or ヒグラシ (higurashi). Yes, those higurashi; I'll get to it, hold on. This species also has a common name in English: evening cicada.

There are circa 35 species of cicadas in Japan (Hayashi & Saisho, 2015), the exact number depending on whether some populations are interpreted as subspecies or full species. They are distributed throughout 15 different genera, so it's a quite diverse assemblage. Some species are more widespread throughout the country, while others are restricted to certain regions. They also vary in the time they emerge and in the sound of their calls.

The go-to book on Japanese cicadas is Hayashi & Saisho (2015), though it is only available in Japanese. However, the second author of the book, has a handy website (http://zikade.world.coocan.jp/Zikade-e.html), where you can find some information and also hear to the calls of the different species of cicada.

So now, let's take a closer look in the two cicada species most commonly featured in anime, then one species that appears in the game *Fate/Grand Order*, and finally an (obvious) example of a fictional cicada.

Hyalessa maculaticollis

The min-min cicada is probably the most common background noise you hear in anime. They are shown singing throughout the day, often when it is very hot. Try hearing their call on the species' Wikipedia page and it will no doubt sound familiar to you.

And no wonder it is a common sound in anime: this species can be found throughout most of Japan, from southern Hokkaido to Kyushu (not to mention the Korean peninsula and adjacent eastern Russia and China; Hayashi & Saisho, 2015; Liu et al., 2017). Besides, they seem to perform well in human-altered environments and are therefore very common in urban areas (Nguyen et al., 2018).

Figure 7. *Hyalessa maculaticollis*, photographed on Mount Ibuki. Source: Wikimedia Commons (photo by Alpsdake, 2012).

The adults can be up to 6.5 cm long (including the wings) and start to sing in late July. The Japan Meteorological Agency keeps an eye (or an ear) out to record the first cicada cries heard and the date seems to be getting earlier every year, which is potentially an effect of climate change (Ellwood et al., 2012; Hayashi & Saisho, 2015).

[2] That's a phonetic process called Rendaku. If you're curious, here's a nice explanation: https://www.tofugu.com/japanese/rendaku/.

Tanna japonensis

The evening cicada, or higurashi, is the second most common species heard in anime. Particularly in the anime that has this species on the title, *Higurashi no Naku Koro ni* (Studio Deen, 2006), based on the eponymous visual novel.[3]

Higurashi (the cicadas, not the anime) are about 4.5 cm long, counting the wings, with females being a bit larger than males. It can be found from Hokkaido in the north to the Amami Islands in the south (Hayashi & Saisho, 2015). While this species is considered to be a late summer to early autumn species (singing from September to October), it can actually be heard from the end of June to the end of August (Hayashi & Saisho, 2015). That matches the story of the anime, btw, which takes place in June.

Figure 8. Female *Tanna japonensis*, photographed on the Yumihari Mountains. Source: Wikimedia Commons (photo by Alpsdake, 2012).

Males of *Tanna japonensis* sing mainly in the twilight hours of dawn and dusk, but sometimes also during the day (Hayashi & Saisho, 2015). Their song is simple, but somehow rather beautiful in a sense. No wonder higurashi have a special place in Japanese culture. Their song is considered to evoke a sense of melancholy and has been used in literature since early times. Sei Shōnagon mentions them, as expected of Japan's first super famous writer.

Figure 9. Artistic interpretation(?) of Sei Shōnagon. Screen capture from *Fate/Grand Order* (Delightworks/Lasengle, 2015–present).

Cryptotympana facialis

The kumazemi are big bugs, as their name implies. They can reach up to 7 cm in length, counting their wings. They can be found from the Kanto region[4] of Honshu in the north to the Yaeyama Islands near Taiwan in the south (Hayashi & Saisho, 2015). However, they are expanding northwards in Japan, as urbanization and increasing temperatures make more habitats suitable to them (Saito et al., 2016). In fact, *Cryptotympana facialis* is starting to displace other cicada species in urban areas like Osaka (Moriyama & Numata, 2019).

Kumazemi are gregarious and you can find many individuals perched and singing on a single tree trunk. In mainland Japan, they can be heard from early July to early September (Hayashi & Saisho, 2015). And the sound of these cicadas can be deafening. They start singing at sunrise until around 11 AM and their chorus can exceed 90 db (Cyranoski, 2007; Hayashi & Saisho, 2015; Moriyama & Numata, 2019). That is akin to the noise of a leaf blower, a jackhammer, or a concert; prolonged exposure to these levels of sound can result in hearing loss.

Their "song" can be really annoying to people, contrary to the min-min cicada and the higurashi. I suppose that's why we don't

[3] There are several other side stories, sequels, reboots-that-are-not-reboots, etc. in this series. Honestly, I watched only half of the first one.

[4] Curiously, they cannot be found in Kanto region of Gen. I.

hear kumazemi in anime.[5] Nevertheless, it makes an appearance in *Fate/Grand Order* — without the sound effects — during the 2022 Summer Event (US version), with Illya and Gudako[6] talking about how loud the cicadas are.

Figure 10. *Cryptotympana facialis*, photographed in Aichi prefecture. Source: Wikimedia Commons (photo by Alpsdake, 2013). Have you realized that this Alpsdake person is the one who took all the best photos of cicadas available on Wiki Commons?

Figure 11. Gudako is showing off her entomological knowledge in this scene. Though the translators have failed miserably; I can forgive the lack of italics, but the scientific name must start with a capital letter. Bad civ! Screen capture from *Fate/Grand Order* (Delightworks/Lasengle, 2015–present).

Like the min-min cicada above, the kumazemi is also shifting its seasonal schedule and hatching earlier. This is related to the rainy season, which is happening earlier every year because of climate change (Moriyama & Numata, 2011, 2019).

As a weird side note, female kumazemi in Osaka were laying eggs inside optical fiber cables, mistaking them for twigs (Holden, 2007). That was causing major losses every year and it has led to the development of a new type of cable that is resistant to kumazemi (Itou et al., 2010).

FICTIONAL CICADAS

It can't be helped, I must also talk about the potentially most prominent of fictional cicadas in Japanese pop culture, the Pokémon Ninjask or テッカニン (Tekkanin).[7]

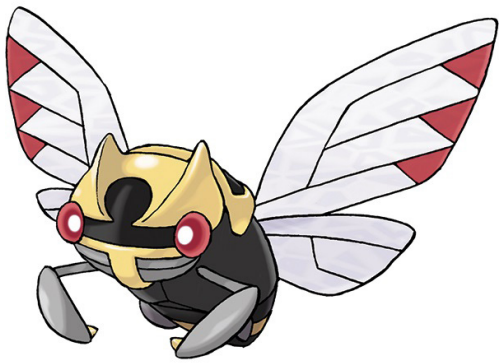


Figure 12. Ninjask, official artwork from *Pokémon* (The Pokémon Company). Source: Bulbapedia.

Bulbapedia (2022) says Ninjask is similar to the species *Megatibicen dorsatus*. This is ether a rather naïve assertion or an extremely biased take, because *M. dorsatus* is a species found only in the central region of the USA (Sanborn & Phillips, 2013). Now why would Pokémon designers choose an American cicada of all things, when these

[5] But do let me know if you have heard it in an anime before.

[6] That is the correct way of playing. If you went for Gudao instead, please review your choice.

[7] Even though it's not one of the most famous Pokémon, I'd say the other Japanese cicada monsters (like the Boring Bug from *Dragon Quest* or the Dream Cicada, Oily Cicada, and Cicada King from *Yu-Gi-Oh!*) are even less known. Also, I'll focus solely on Ninjask here, which is the adult cicada. Nincada is the nymph and Shedinja is the empty husk left behind after molt.

insects are so important in their home country? They didn't, of course.

Ninjask was based on Japanese cicadas, more specifically those of the genus *Auritibicen* (エゾゼミ or ezozemi). There are 24 species in this genus, most of them living in China, but with representatives in eastern Russia, the Korean Peninsula, and Japan (Lee, 2015; Wang et al., 2018). The species in this genus all look very similar to one another and can be distinguished by fine anatomical features (Lee, 2015). Notably, *Auritibicen* cicadas have a particular color pattern on their "backs" (on the mesonotum, on the dorsal surface of the thorax) that looks like a 'W', with the "arms" of the W varying in length (Wang et al., 2018).

Figure 13. Ninjask sprite from *Pokémon HeartGold/SoulSilver* (Game Freak, 2009). Source: Bulbapedia.

Figure 14. *Auritibicen flammatus*, photographed in Niigata province. Source: iNaturalist (rivavui, 2019).

In Japan, there are six species of ezozemi (Hayashi & Saisho, 2015; Lee, 2017): *A. bihamatus* (コエゾゼミ or koezozemi), *A. esakii* (ヤクシマエゾゼミor Yakushima ezozemi), *A. flammatus* (アカエゾゼミ or akaezozemi [red ezozemi]), *A. japonicus* (エゾゼミ or ezozemi), *A. kyushyuensis* (キュウシュウエゾゼミ or Kyushu ezozemi), and *A. shikokuanus* (シコクエゾゼミ or Shikoku ezozemi). Some have a pattern on their mesonotum that more closely resembles Ninjask's upside-down 'Y' pattern. These cicadas are about 4 to 6 cm in length (with their wings folded) and can be seen and heard from mid-July to the end of August (Hayashi & Saisho, 2015; Wang et al., 2018).

CONCLUSION

That's it — all that you wanted (and didn't want) to know about Japanese cicadas. Now, I don't expect to turn anyone into a cicada enthusiast (I'm not even one myself!). But I do hope that the next time you hear cicadas singing, be it IRL or in an anime,[8] you'll pay closer attention to it. Maybe you'll remember some random facts from this article or perhaps you'll even be able to identify what species it is.

REFERENCES

Brambila, J. & Hodges, G.S. (2008) Bugs (Hemiptera). In: Capinera, J.L. (Ed.) Encyclopedia of Entomology. 2nd ed. Springer, USA. Pp. 591–611.

Bulbapedia. (2022) Ninjask. Available from: https://bulbapedia.bulbagarden.net/wiki/Ninjask_(Pok%C3%A9mon) (Date of access: 15/Aug/2022).

Burgin, C.J.; Colella, J.P.; Kahn, P.L.; Upham, N.S. (2018) How many species of mammals are there? Journal of Mammalogy 99(1): 1–14.

Cyranoski, D. (2007) Flying insects threaten to deafen Japan. Nature 448: 977.

Dietrich, C.H. (2003) Auchenorrhyncha. In: Resh, V.H. & Cardé, R.T. (Eds.) Encyclopedia of Insects. Academic Press, USA. Pp. 66–73.

[8] This website has a nice compilation of cicadas in anime: http://www.russelldjones.ru/cicada.htm, though it unfortunately seems it hasn't been updated in a while. You'll notice that while some anime will have very generic-looking cicadas (like Fig. 1 above), in some cases you'll actually be able to identify the species.

Distant, W.L. (1889–1892) A Monograph of Oriental Cicadidæ. West, Newman & Co., London.

Ellwood, E.R.; Diez, J.M.; Ibáñez, I.; Primack, R.B.; Kobori, H.; Higuchi, H.; Silander, J.A. (2012) Disentangling the paradox of insect phenology: are temporal trends reflecting the response to warming? Oecologia 168: 1161–1171.

Endo, N. & Osawa, N. (2018) Asymmetric song responses in coexisting Japanese cicadas. Bioacoustics 27: 201–214.

Gogala, M. & Trilar, T. (2004) Bioacoustic investigations and taxonomic considerations on the *Cicadetta montana* species complex (Homoptera: Cicadoidea: Tibicinidae). Anais da Academia Brasileira de Ciências 76: 316–324.

Grimaldi, D. & Engel, M.S. (2005) Evolution of the Insects. Cambridge University Press, New York.

Hayashi, M. & Saisho, Y. (2015). 日本産セミ科図鑑:　詳細解説、形態・生態写真、鳴き声分析図. The Cicadidae of Japan. Revised ed. Seibundo Shinkosha, Tokyo.

Holden, C. (2007) Debugging Japan's cables. Science 317: 1301.

Itou, N.; Ohno, M.; Sayama, T.; Takeda, D.; Shiobara, S.; Okada, N. (2010) Development of new cicada-resistant aerial optical drop cable. IEICE Technical Report 110: 39–44.

Kendall, P. (2014) 5 facts about the special significance of cicadas in Japan. Japan Today. Available from: https://japantoday.com/category/features/5-facts-about-the-special-significance-of-cicadas-in-japan (Date of access: 14/Aug/2022).

Lee, Y.J. (2015) Description of a new genus, *Auritibicen* gen. nov., of Cryptotympanini (Hemiptera: Cicadidae) with redescriptions of *Auritibicen pekinensis* (Haupt, 1924) comb. nov. and *Auritibicen slocumi* (Chen, 1943) comb. nov. from China and a key to the species of *Auritibicen*. Zootaxa 3980(2): 241–254.

Lee, Y.J. (2017) Resurrection of *Auritibicen shikokuanus* (Kato, 1959) stat. rev. & comb. nov. (Hemiptera: Cicadidae: Cryptotympanini) from Ehime and Hiroshima of Japan. Journal of Asia-Pacific Biodiversity 10: 59–64.

Liu, Y.; Qiu, Y.; Wang, X.; Yang, H.; Hayashi, M.; Wei, C. (2017) Morphological variation, genetic differentiation and phylogeography of the East Asia cicada *Hyalessa maculaticollis* (Hemiptera: Cicadidae). Systematic Entomology 43: 308–329.

Marshall, D.C.; Moulds, M.; Hill, K.B.R.; Price, B.W.; Wade, E.J.; Owen, C.L.; et al. (2018) A molecular phylogeny of the cicadas (Hemiptera: Cicadidae) with a review of tribe and subfamily classification. Zootaxa 4424: 1–64.

McKirdy, A. (2019) What's a Japanese summer without the noisy cicada? The Japan Times. Available from: https://features.japantimes.co.jp/cicada/ (Date of access: 20/Aug/2022).

Moulds, M.S. (2003) Cicadas. In: Resh, V.H. & Cardé, R.T. (Eds.) Encyclopedia of Insects. Academic Press, USA. Pp. 186–188.

Moulds, M.S. (2018) Cicada fossils (Cicadoidea: Tettigarctidae and Cicadidae) with a review of the named fossilised Cicadidae. Zootaxa 4438: 443–470.

Moriyama, M. & Numata, H. (2011) A cicada that ensures its fitness during climate warming by synchronizing its hatching time with the rainy season. Zoological Science 28: 875–881.

Moriyama, M. & Numata, H. (2019) Ecophysiological responses to climate change in cicadas. Physiological Entomology 44: 65–76.

Nguyen, H.Q.; Andersen, D.K.; Kim, Y.; Jang, Y. (2018) Urban heat island effect on cicada densities in metropolitan Seoul. PeerJ 6: e4238.

Saito, M.U.; Kurashima, O.; Ito, M. (2016) Climate change and the northward shift of *Cryptotympana facialis* in Japan: evidence from national survey data. Climate Research 68: 13–23.

Sanborn, A.F. (2008) Cicadas (Hemiptera: Cicadoidea). In: Capinera, J.L. (Ed.) Encyclopedia of Entomology. 2nd ed. Springer, USA. Pp. 874–877.

Sanborn, A.F. & Phillips, P.K. (2013) Biogeography of the Cicadas (Hemiptera: Cicadidae) of North America, North of Mexico. Diversity 5: 166–239.

Wang, X.; Hayashi, M.; Wei, C. (2018) Revision, phylogeny and phylogeography of the cicada genus *Auritibicen* (Hemiptera: Cicadidae), with descriptions of ten new species. European Journal of Entomology 115: 53–103.

Wong, K. & Sinnen, C. (2021) Brood X cicadas are emerging at last. Scientific American. Available from: https://www.scientificamerican.com/article/brood-x-cicadas-are-emerging-at-last1/ (Date of access: 22/Aug/2022).

Acknowledgements

I'm grateful to Dr. Julia Kasper for the comments and suggestions to the manuscript. And to Alpsdake, whoever they are, for making their fantastic photos available on Wiki Commons.

About the author

Dr. **Rodrigo Salvador** is a biologist that specializes in the study of land snails. Nevertheless, he is also interested in other invertebrates, including insects. In spite of his long-term exposure to cicada sounds in anime, he never even once thought about writing about them. That is, until in the latest FGO summer event, Gudako somehow knew the scientific name of the singing cicadas.

Journal of Geek Studies

jgeekstudies.org

Arludo: bringing science and math to students through games

Interview with Michael Kasumovic

Arludo was founded by Michael Kasumovic, an evolutionary biologist, researcher and professor at the University of New South Wales, Australia. It is a bit difficult to define what Arludo is in a single word; broadly put, it is a game studio that also offer educational material and services, and are also great at science outreach. As themselves put it, they are "working to change the way students see and use science in their daily lives." But it all starts with video games.

They already have over 30 mobile games on their portfolio[1] and their new title, *Inglorious Baskers* has just been released on iOS and Android systems. We wanted to know more about this mysterious sciency game studio, so we interviewed Dr. Kasumovic to understand Arludo better and to get a glimpse behind the scenes. Join us and see what we found out.

[1]Take a look at their titles on the App Store or Google Play.

Your new game *Inglorious Baskers* is out now. It is a lizard survival game where the typical tag "survival" in gaming jargon goes well into the territory of ecology. Could you explain what exactly the game is about and what does a lizard need to do to survive?

The game is all about being a lizard! But more seriously, we wanted to create a fun game that provides players an opportunity to understand how animals need to balance different aspects of their lives. Of course, scientists will understand this as life-history theory – how animals use their time and energy to maximise their own fitness.[2] But students generally don't think about these things so don't really understand life-history theory. Additionally, it's hard to collect data that show how animals make trade-offs to maximise their fitness.

That's why we created *Inglorious Baskers*, it was an opportunity to create a survival game where players need to manage the most basic things – getting food, staying away from predators, and for ectotherms,[3] basking in the sun so that your body heats up to allow you to be more active. By playing, students see how difficult it is to manage three simple things. Our goal is that by learning how to balance these three things and seeing these trade-offs occur in the data, students can better understand how animals survive, and how selection can act on this survival to lead to the evolution of different life-history strategies.

What was the inspiration for *Inglorious Baskers*?

It was a conversation with Megan Head![4] Megan is a friend and colleague of mine and wanted to have a game made to explore life-history theory. We chatted a lot and came up with the idea of making it about lizards. Megan has worked on lizards and we haven't had a game using lizards yet, so it was perfect!

[2] This is evolutionary fitness. Roughly put, it is a measure of an individual's reproductive success.

[3] Ectotherms are animals that depend on external environmental heat sources to control their body temperature.

[4] Dr. Head is an evolutionary biologist working in the Australian National University, Canberra (http://meganlhead.weebly.com/).

How much science have you weaved into the game? And how do you balance the educational part of the game with gameplay and fun?

The game is full of science – we don't hold back! The entire gameplay is based on real research and the behaviour of real animals. There is a lot of research done on lizards, but this one[5] also explored how an individual's basking behaviour is affected by an immune challenge. So we definitely needed to incorporate it! Although the models by which individuals lose energy or heat is not accurate, the concepts are. Sometimes you need to balance learning and fun, because the point is to get a theme across, not that it is exactly based on a specific animal.

But in terms of balancing learning and fun, it's generally easy because we separate them a little. What I mean by that is that the game largely focuses on discovery, and we don't bother students with "learning" when they are trying to figure out the game. Although, that's what they are intuitively doing. We just create a few rules about how things interact, and the let students figure the game out. So for this aspect, we rely more on ensuring the game is fun to play.

The learning part comes after when students explore the data they helped collect by playing the game. Each of our games anonymously collect data as students play. These data can vary from reaction times, to behavioural decisions that players make. But we collect those and display them in real time. This way, students can see the decisions they made at a class level to understand the concepts they were discovering.

This is how we balance the learning in all our games. It's discovery while playing the game, and reinforcement through data that helps solidify the learning afterwards.

You're an evolutionary biologist yourself and an Associate Professor in the University of New South Wales. Are lizards the topic of your research?

Not at all! But it doesn't mean that I don't find them interesting. We try to maximise the diversity of organisms that we use in our games. We've used lizards in *Inglorious Baskers*, birds in *Hungry Birds*, spiders in *Spinder*, and crabs in *Reservoir Crabs*. We usually pick the organism that is studied well for the question that we want to answer.

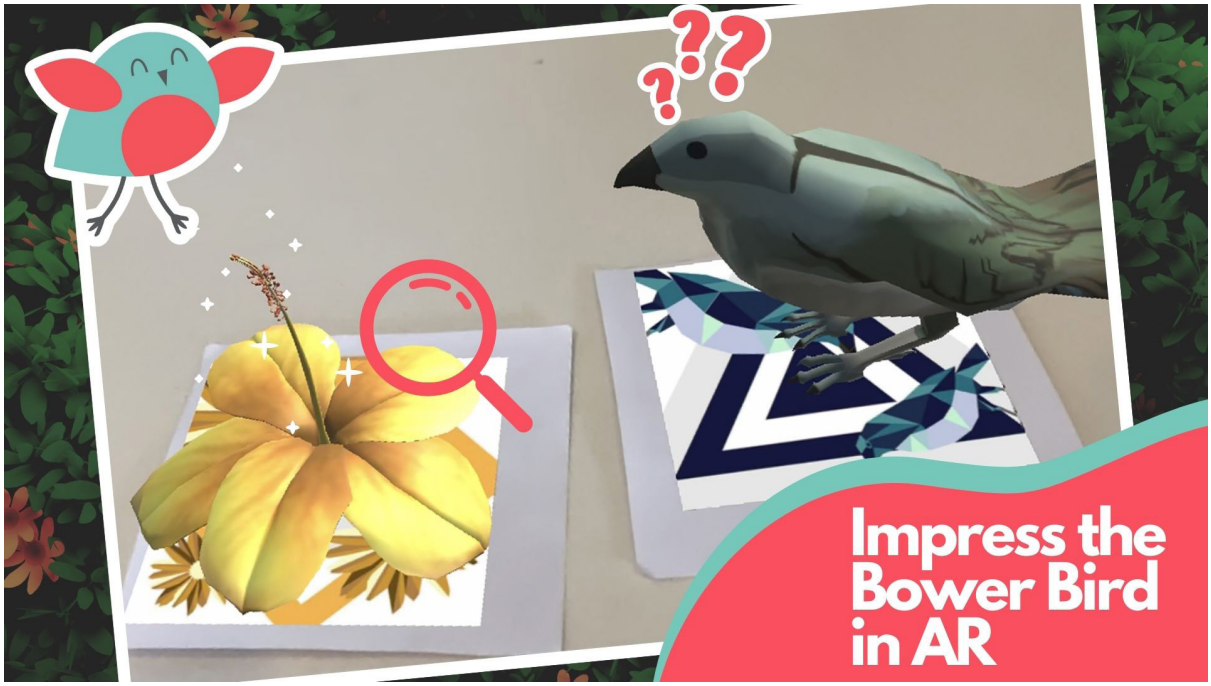
And when a perfect organism doesn't exist, we make one up! That's what we've done in *Xenon Crowe* and *Cha Cha Island*. The way we move forward in games is really similar to my research – we use the organism that best tells the story. I used to work on birds, but I have done most of my research exploring mate choice and evolution using spiders and crickets. And now my students are working on mites. Researching a variety of organisms keeps it fun!

So let us go back in time for a bit and venture into some origin stories. What led a university professor to start a game studio? How did that happen?

You're making me think back 7 years ago now! I first started thinking about using games when I noticed my students seemed bored using the same kinds of experiments I performed during my undergrad. Then I noticed that students use all this technology in their daily lives, but other than digitising content, the way that students learn hasn't really changed at all. So I thought I would try something really simple using a game system called Aris (which doesn't exist anymore). It allowed you to create a location based game using the GPS in a phone using simple if-then statements.

So, I had some fun and created a mating game where students were spiders and had to find mates and avoid predators in their environment. When I think back at it, I took students out of their classroom and into a

[5] Duran, F.; Boretto, J.M.; Ibargüengoytía, N.R. (2020) Decrease in preferred temperature in response to an immune challenge in lizards from cold environments in Patagonia, Argentina. Journal of Thermal Biology 93: 102706.



field to make them run around pretending to be spiders. It could have gone so badly! But they had a great time and finished in about 15 minutes (they were exhausted!). We had a phenomenal conversation about the costs associated with mate searching and the different strategies individuals used to maximise their fitness.

This experience changed their perspective and helped them understand these invisible theories they were learning about. It was definitely the most engaging conversation I had in a really long time. It was at that point where I felt I was on to something and I had to give it another go. That's when I hired some student game developers and we made our first few games. Seven years later, some of these folks are still working for me and now we have a really awesome team.

Arludo already has some 30 games in its portfolio. Which ones are your greatest hits or all-time favourites?

Blue Steal is the first game we created, and I still have a warm spot in my heart for it. It's a simple game that uses augmented reality to bring female bower birds to life. Students work in groups that are racing to impress their female using the objects they are given. But what they don't know is that they don't have enough objects to impress her, and that they need to steal objects from other groups.

One of my favourite things is watching the class figure it out. One student from one group hesitantly walks over to another group and they realise that other groups have different objects. Seconds later, this information filters to the rest of the class and chaos ensues! As a lecturer, I see mating strategies 'evolve' in real time – students are stealing objects from one another, others are trading. Some groups begin hording and hiding their items, lying about what they have. It's so much fun talking about the different strategies students used as they speak from experience!

But I do have two other favourites. *Bards & Bandits* is a game that uses the Prisoner's Dilemma to teach students about what affects trust. This was our first multiplayer game and probably why I like it so much. But *Inglorious Baskers* is definitely our most visually exciting game, so I am really proud of what we've built. But we have some great new games coming out which I'm really stoked about. All of this is so much fun!

Besides the games, Arludo also of-

fers courses for parents and students and support for teachers. Could you explain what's on offer and how people can get a hold of it?

We've had different worksheets and programs for students for a while as we've tried to figure out the best way to help students, teachers, and families. All of our offerings can be found at arludo.com. But we're going to be adding so much more very soon!

We're really lucky that we recently received a grant – it's going to allow us to do what I've wanted to do at a scale that would have taken us years. With this new funding, we'll be creating professional development courses that help parents and teachers get up to speed in running and analysing experiments in real time. We're also creating a Discord server full of scientists that students, parents, and teachers can interact with in real time. And these scientists will also run incursions where students can learn and run experiments with them. We're really excited to be able to offer everyone access to scientists in real time so they can all experience exactly what it's like to be a scientist. I think that's what's missing in society – that transparency of what we do which shows how exciting and rewarding science really is.

But one of the things I'm most excited about is the national game design challenge we're running in Australia in 2023. In this challenge, groups of students can submit ideas for a new science game. We'll have a whole learning module to help teachers administer the lessons, and at the end, students will have a new game idea they can submit into the challenge. The top 3 teams win monetary prizes, and the first place team will work with us to bring their game to life. I'm so excited to see what students design!

If everything goes the way we plan next year, then we'll soon be expanding outside of Australia. That being said, we already have users all over the world and anyone can download our games and use our digital worksheets. But our goal is to make science accessible to everyone by translating all our games and worksheets different languages. That'll take some time, but we'll get there!

What has been your experience in classrooms so far? How do people respond to your games and course, be they teachers, students or parents?

It's just a joy seeing students faces when

they play our games. They are always bit reluctant to start, thinking it will be a 'boring educational game'. But they quickly get into it because we're more about making learning exciting than older educational games. Students start talking to one another. They share tips and commiserate their losses. A whole class really gets into it – even online!

Just like students, parents and teachers are always a bit hesitant to use games to teach – I mean, games are what their kids waste their time on at home! But what they don't realise is that the games we create are actually interactive experiments. In our games, students are scientists discovering the rules of the world we created. As they explore this world, they also collect data that we visualise in real time. This allows students to reinforce what they learned through data. And it also helps them become data literate. Which parent or teacher would not want that?

In your opinion, what makes a science-based or educational game good?

I love videogames. Always have. What makes a game great is the challenge, and the desire to improve to beat that challenge. But to do that, you need to figure out the rules of the game and learn the skills you need to beat it. To me, this is exactly what science is like.

As scientists, we see a problem that interests us, and we challenge ourselves to understand it. But to understand the problem, we need a certain set of skills to be able to design experiments to allow us to figure out more about how the problem works. So we learn those skills, only to figure out that we need to learn more to figure out new aspects about the problem we didn't know existed initially. It's like a videogame with no ending!

So, what I think makes a great game is the same thing that makes great learning: an engaging task that draws you into wanting to discover more and improve who you are. This is why I think games can be natural teachers. The problem is, most games are created to have fun, and most learning games are created to transfer information (which doesn't work). Realising that you need both aspects – fun and discovery – helps create a feedback loop that leads to real learning. And that's what great games have.

Regarding all those parents and teachers out there curious about this whole science and gaming crossover, what is your

message to them? How can they start down that road?

I have a simple message: learning should be fun.

I realise that our curricula are filled with information that students need to learn to be able to graduate. But I feel that somewhere along the way, we forgot how much fun learning through discovery can be. So we made it facts that students need to memorise. And all the educational technology out there focuses on this idea – how do we get kids to memorize as much as possible.

But this is becoming less and less relevant as technology becomes more advanced. We already have global organisations stating that it's not general knowledge that is the most important aspect, but the learning of skills. But you can't learn skills by just reading or watching something. You learn them by doing. That's why I feel we need to shift how we teach so we can provide students with the skills they need for their future careers.

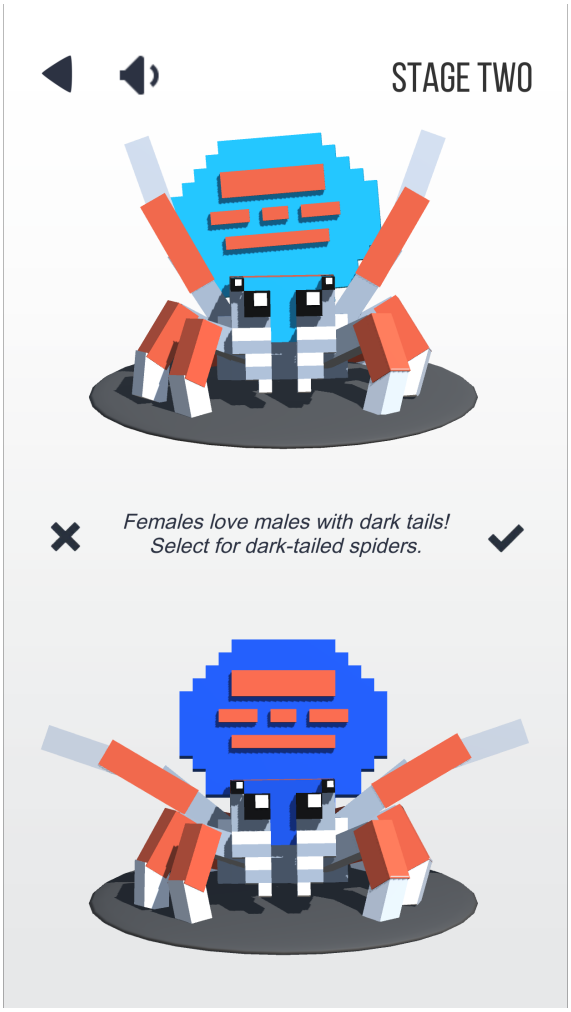
And how do they start? Come visit us! Just download any one of our games and give it a try – they are all free and there is nothing for you to prepare. You don't even need to make a lesson out of it. Just let your students play for 15 minutes and have a conversation about what they did and why. You'll quickly see how much they learned, and most importantly, how much fun they had doing it. Once your convinced, you can try a lesson.

But pretty soon, we'll have dozens of free videos with amazing science communicators on YouTube. Each of these will give students an idea of what is possible through science and the diverse careers science can lead to. It's going to be exciting!

And what about all the students whose interest in science might be sparked by a game? How can they keep that interest alive?

They should join our Discord server! I'm not kidding. This is exactly the problem that we are trying to solve: students that get interested by something about science often have no one to talk to and don't know where to go to find out more information about that topic. So their interest just wanes and disappears. As parents and teachers, we've missed this great opportunity to excite them about learning.

Our Discord server will have scientists that can act as mentors to help direct students towards better learning pathways. What I love about what we're creating is that these opportunities to meet scientists were limited to people that live in cities with parents that know academics. We're changing that so any student anywhere will be able to chat with a scientist – no matter if you're living on a farm in Western NSW or on a small island of the coast of Australia, we'll have someone kids can chat with to excite them about what is happening in the world around them.



About the Team

Arludo is a team of scientists, educators, game designers, programmers, videographers, animators and artists creating a way for people to interact with science in the most engaging way possible. They've created 30 different games with worksheets that teach biology, psychology, maths, and soon, entrepreneurship and game design! They've even had a really successful science show on Twitch – #BatteryLow – where they had over 150,000 join them to play videogames with scientists online. They'll have some incredible initiatives coming soon, so follow them on Twitter, Instagram, TikTok, and YouTube. And don't forget to join their Discord Server too!

Journal of Geek Studies

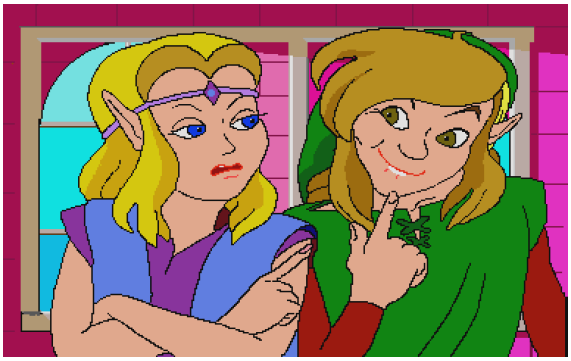
jgeekstudies.org

The Two-Dimensional Knapsack Problem, or how to optimize your inventory to fight zombies

João Vitor Tomotani
Independent Researcher. São Paulo, SP, Brazil.
Email: tjvitor@gmail.com

INVENTORIES IN RPGS AND ADVENTURE GAMES

Video games came a long way to be at where they are today. From the CRT Amusement Devices invented by physicists Thomas Goldsmith Jr. and Estle Mann in 1947, to the OXO / Noughts and Crosses / Tic-Tac-Toe developed by Alexander Douglas in 1952, until we arrive at the Magnavox Odyssey, the first home console created by Ralph Baer in 1972, the same year Atari released its first product, the coin operated *Pong* (Dillon, 2011).



Was this long journey worth it? Screenshot from *Link: The Faces of Evil* (Philips Interactive Media, 1993); extracted from Zelda Wiki (http://zelda.wikia.com/).

The story of items and the inventory systems in video games started not long after that. It is probably mandatory, though, to cite the *Dungeons & Dragons* system of rules, developed by Gary Gigax and Dave Arneson in 1974, as a huge reference. In their system for pen and paper games, Gigax & Arneson (1974) created rules for carrying capacity and encumbrance, which considered the weight of the objects carried (even considering the weight of money in the form of gold pieces, a practice that thankfully is not very popular in games today).

The *Dungeons & Dragons* system was a huge inspiration for programmer Will Crowther that, in 1976, developed the text adventure game *Colossal Cave Adventure*. The game was expanded in 1977, with the help of Don Woods, an appreciator of J.R.R. Tolkien and high fantasy elements. In this game, you could type commands to execute actions and interact with objects such as keys and bottles. This interaction included collecting and later using such objects. *Colossal Cave Adventure* is one of the most influential games of all time, and later had a graphical version developed, *Adventure* for Atari 2600, famous (among other reasons) for the first "Easter Egg" (Salvador, 2017).

All these adventure and RPG games influenced another wave of games like *Akalabeth: World of Doom* (1979), *Wizardry: Proving Grounds of the Mad Overlord* (1981) and *Might and Magic Book One: The Secret of the Inner Sanctum* (1986), the first games of respectively the *Ultima*, *Wizardry* and *Might and Magic* video game series. Considered the establishers of the computer RPG genre, they further developed the idea of collecting items and using them whenever needed.

From all those popular and influential titles, many other video games and other very famous items and inventory screens appeared. I will talk more about these now and about one of them in particular.

Screenshot from *Akalabeth: World of Doom* (California Pacific Computer Co., 1979); extracted from OldGames (https://www.old-games.com/).

The Legend of Zelda inventory screen (Nintendo, 1986). Screenshot from the game; extracted from Video Games Database (https://www.mobygames.com/).

INVENTORY TYPES AND THE VISUAL GRID INVENTORY PROBLEM

There are many different types of video game inventories, and ways these inventories are "limited" by the programmers (DellaFave, 2014).

One of the most famous inventory types is the classic "Rule of 99" inventory, usually associated with JRPGs like *Final Fantasy*, *Dragon Quest* and *Pokémon*. This very simple inventory considers that the maximum number of copies you can carry of an item is a specific number defined by the game, usually 99 (though other random numbers may be possible — I am looking at you, *Tales* series). Also, this inventory type usually considers that all items are shared and can be used freely at any time between all party members (also with some notable exceptions).

Oh yeah… I guess there is this MissingNo. glitch as well… Screenshot from *Pokémon Red & Blue* (Nintendo, 1996); extracted from wikiHow (https://www.wikihow.com/).

Another classic inventory type is the weighted inventory, particularly popular among western RPGs like *Fallout* and *The Elder Scrolls*, and in line with the encumbrance rules of Gigax & Arnerson (1974). In the weighted inventory system, each object is assigned a numerical value representing its weight. A character can carry a limited total weight before being affected by a status such as fatigue or reduced movement.

Finally, and most important for this article, there is the visual grid inventory type. In this inventory system, instead of having an infinite amount of space to store items, you have a grid to organize them in. In this inventory system, the size and shape of each item may or may not vary. One example of grid where sizes and shapes do not vary is the *Baldur's Gate* inventory system, where curiously a character could carry at most 16 suits of full plate armor or 16 pearls.

The visual grid inventory system is present in many games, but probably was popularized by the action-RPG *Diablo* and the survival horror game *Resident Evil*.

The visual grid inventory brought an interesting dynamic to video games. Now

you had limited inventory space and had to plan carefully what was worth bringing to underground dungeons or to the zombie apocalypse — a small dose of realism in worlds full of demons or zombies.

Diablo 2 (Blizzard Entertainment, 2000) inventory. Screenshot from the game; extracted from Diablo Wiki (https://diablo.fandom.com/).

Organizing your equipment became a challenge on itself, and a challenge well studied by academics, as we will see.

THE TWO-DIMENSIONAL KNAPSACK PROBLEM

The Knapsack Problem is a classical problem in combinatorial optimization, being part of the broader class of Cutting and Packing (C&P) problems. In the Knapsack Problem, a set of entities are given, each having a **value** and a **size**, and the objective is to select one or more entities so that the sum of the sizes does not exceed a given limit (the size of the knapsack), while the sum of the values of the selected entities is maximized (Martello & Toth, 1990). Knapsack problems have been studied by academics and practitioners for over a century, being able to model many industrial (and survival horror) situations. For instance, Salkin & de Kluyver (1975) discussed its many different applications in industrial situations such as cargo loading, project selection, and budget control, while also presenting others, like capital budgeting and selecting journals in a library. But no mention was made on how to select equipment for a survival horror scenario.

A mathematical formulation of the knapsack problem is:

$$maximise \sum_{j=1}^{n} p_j x_j,$$

$$subject\ to \sum_{j=1}^{n} r_{ij} x_j \leq b_i, \qquad i = 1, \dots, m,$$

$$x_j \in \{0,1\}, \qquad j = 1, \dots, n.$$

where x_j is the binary variable that defines whether item j is "placed in the knapsack" or not; p_j is the profit obtained by placing item j in the knapsack; r_{ij} is the units of resource i consumed by placing item j in the knapsack; and b_i is the limit available (or budget) of resource i. As can be seen by this formulation, it is possible to have m different constraints (also called knapsack constraints), so that this problem can be called multidimensional knapsack problem (MKP), m-dimensional knapsack problem, multiconstraint knapsack problem, among other names (Chu & Beasley, 1998).

The "simple" knapsack problem is very similar to the weighted inventory dilemma a player faces when deciding which items to carry. Each item has a different numerical value attributed to it, representing its **weight** or **size**, and we, the players, internally and empirically evaluate each item's usefulness, and attribute to them a **value** (or **profit**).

BOX 1. NP-Hardness.

In computational complexity theory (field in theoretical computer science and mathematics, that studies and classifies problems according to their resource usage when trying to solve them computationally), NP (non-deterministic polynomial time) is a complexity class used to classify decision problems – problems with a yes/no answer.

A decision problem is classified as P (polynomial time) if it can be solved "quickly" (note that we use the term "quickly" VERY lightly here), that is, if there is an algorithm that can solve this problem in polynomial time (as opposed to, for example, exponential time).

On the other hand, a decision problem is classified in NP if, given a candidate answer to the problem, it can be verified in polynomial time (there are also other complicated definitions here for NP problems, that involve solving them in polynomial time using nondeterministic Turing Machines, but we will not go down this path).

A practical example of a NP problem is a Sudoku. The decision problem (yes/no problem) can be: "given a sudoku puzzle, does it have a solution?" It may take a long time to find this answer. On the other hand, if the solution for the Sudoku is given, verifying whether the solution is correct is much quicker.

Other classic example is the problem of integer factorization – that is, the decomposition of a composite number into a product of smaller integers. Factoring the number is a very hard problem. But verifying whether a solution is true is as simple as multiplying the factors and confirming the solution.

A problem is classified as NP-hard, if it is at least as hard as the hardest problem in NP.

This "simple" knapsack problem is also known as one-dimensional knapsack problem. A variation of this problem considers that, instead of a subset of items with one or more one-dimensional constraints represented by a single number, the items instead are a subset of shapes that are to be packed into a larger shape (or multi-dimensional knapsack if you will). The most studied version of this problem is the orthogonal two-dimensional knapsack problem (2KP), where the input consists of a set of n small rectangles (thus "orthogonal"), each with their own width w, height h and profit p, to be placed without overlaps into a large rectangle of width W and height H, aiming to maximize the total sum of profits P. While the one-dimensional knapsack problem is known to be solvable in pseudopolynomial time by dynamic programming, the 2KP is strongly NP-hard (Caprara & Monaci, 2004).

Hard indeed. *Resident Evil 4* (Capcom, 2005) inventory screen. Screenshot from the game; extracted from Reddit (https://i.redd.it/6whpbicewnd01.jpg).

By considering the geometry and the orientation of the pieces (or, in our definition, items), additional complexities can be added to the problem. Bortfield & Winter (2009) made a list of possible constraints and classified previous studies considering two criteria: (1) the type of stock of pieces: unconstrained knapsack problem, where the number of copies per type is not fixed; constrained knapsack problem, where there is an upper limit of copies allowed; and doubly constrained knapsack problem, where both an upper and lower limit of copies per piece are defined; and (2) the problem subtype: orientation constraint, whether pieces can be rotated or not; and a guillotine cutting constraint, that considers whether pieces can be reproduced through a guillotine cut – this is more specific to the Cutting and Packing class of problems (C&P; see Box 2), to which the knapsack problem is a subtype.

Most studies on the two-dimensional knapsack problem consider only rectan-

gular shapes (orthogonal two-dimensional knapsack problem, or 2KP). There is also a variation of this problem that consider the existence of irregular shapes, like the study from Del Valle et al. (2012). The present article will not consider this much more complicated variation, though I advise that in case of a zombie apocalypse, all optimization is valid.

BOX 2. Cutting and Packing Problems.

Cutting and Packing problems (C&P) is the name given for a broad range of problems that follow a similar logical structure, under different names, in the literature. Some examples are cutting stock and trim loss problems; bin packing, strip packing, vector packing, knapsack problems; vehicle loading, pallet loading, container loading problems; and capital budgeting and memory allocation problems. With few exceptions, scientific work on this topic started around the 1960s, with a fast-growing volume of articles dealing with different variations of the C&P in management science, engineering science, information and computer sciences, mathematics and operational research fields (Dyckhoff, 1990).

Dyckhoff (1990) classified the C&P according to several other characteristics: Dimensionality (whether one or more dimensions of the geometry are considered); Quantity measurement (if the dimensions are discrete or continuous); Shape of figures (form, size, orientation, regular or irregular forms); Assortment (shape and number of the permitted pieces); Availability (lower and upper bounds of quantities for each piece, sequence orders for the placement of pieces, dates to be cut or packed); Pattern restrictions (minimal distance between pieces, frequency and orientation of small pieces); Assignment restrictions (number of assignment stages, number, frequency or sequence of patterns, dynamics of allocation); Objectives of the C&P; Status of information and variability (problem data is deterministic, stochastic or uncertain, and whether the data is strict or may be variable).

ZOMBIE APOCALYPSE INVENTORY MANAGEMENT HEURISTICS

In this article, I explore solutions to the two-dimensional knapsack problem as applied to *Resident Evil*, hoping to aid people during virtual zombie apocalypses. But before we start, we need a crash course in heuristics.

Heuristics are techniques designed for problem solving, based on previous experiences and knowledge from similar problems. Heuristics employ a practical method, aiming to provide a good enough solution for the problem at hand within a reasonable time. They are not guaranteed to find an optimal solution, though, and are not able to recognize an optimal solution if one is found; also, no distance to the optimal solution can be computed or guaranteed.

Heuristic algorithms are usually divided into constructive heuristics and improvement heuristics. Constructive heuristics build solutions by adding elements until the solution is completed, or the process is interrupted or finished with no feasible solution found. Improvement heuristics, on the other hand, start with an initial solution – a complete solution obtained by a constructive heuristic or a randomly generated one – and this initial solution is improved by applying small consecutive changes, until a stopping criterion is met. Oliveira et al. (2016) discussed the existing heuristics applied to the two-dimensional rectangular strip packing problem (a problem within the C&P problems), classifying them as follows (this is a very brief summary of some of the methods, a much more extensive literature review is made by Oliveira et al., 2016[1]).

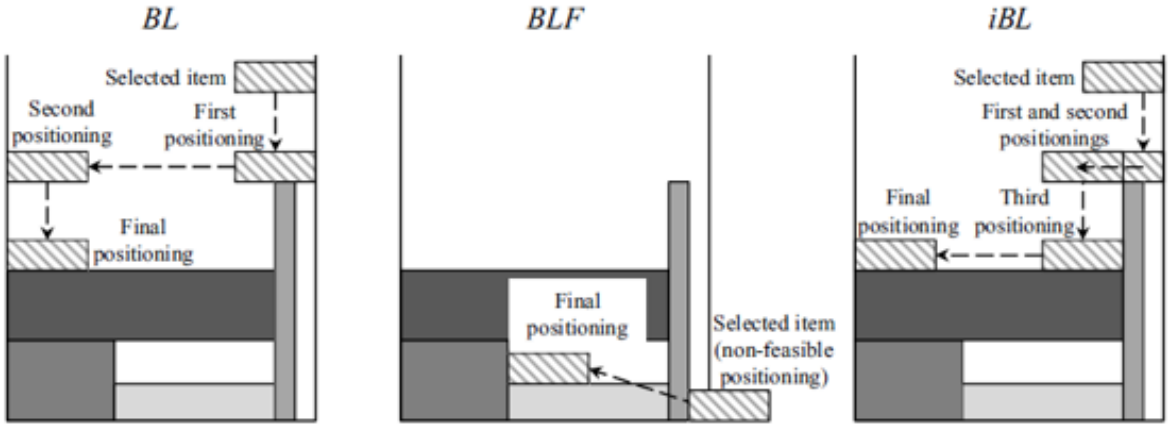
Constructive heuristics

- **Positioning-based heuristics:** the oldest heuristics in academic literature. They are flexible and able to

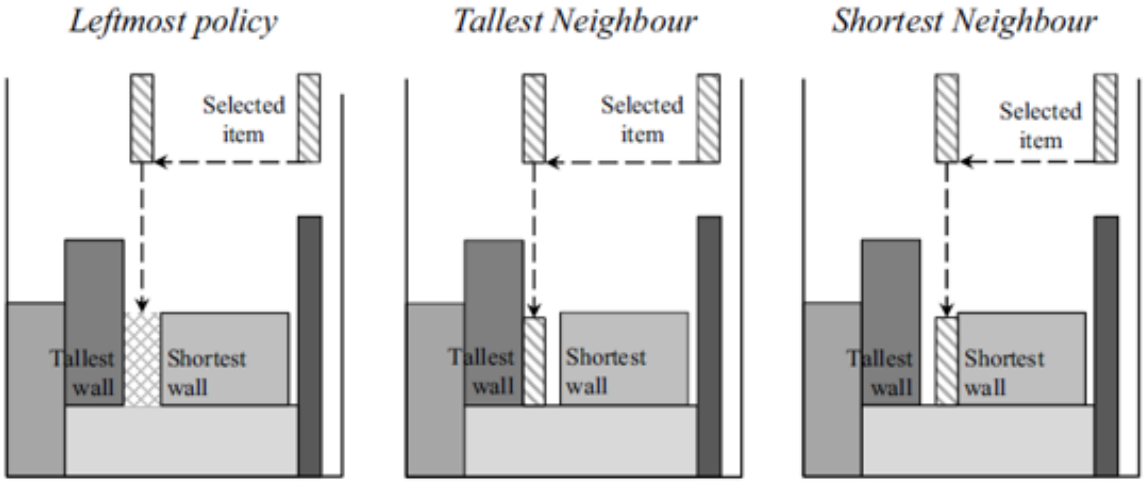
[1] Those authors also briefly comment on metaheuristics applied to the C&P problems, but a more specific review on metaheuristics is made by Hopper & Turton (2001), where tabu search, simulated annealing, genetic algorithms, among other metaheuristics applied to the 2D Strip Packing Problems, are discussed.

incorporate most usual constraints of the problem. The Bottom-Left heuristic (BL), proposed by Baker et al. (1980), was the first positioning-based heuristic ever proposed and the most well-known (Oliveira et al., 2016). This heuristic is very fast, but as a drawback is unable to fill "holes", or empty spaces surrounded by pieces. Many heuristics were proposed to solve this issue; one of the most famous is the Bottom-Left-Fill (BLF) proposed by Chazelle (1983). The BLF consider all empty spaces as admissible for placing new pieces, even when surrounded by other pieces, and always results in solutions that are equal to or better than the BL. This search for empty feasible spaces, though, is much more complex and demanding of computational time. Finally, the Improved Bottom-Left (iBL) proposed by Liu & Teng (1999) always prioritize the down movement over the left movement, moving only the necessary minimum to the left when moving down is not possible.

- **Fitness-based heuristics:** these heuristics focus on the empty spaces, searching for the best-fit between the piece to be placed and the empty spaces available. The Best-Fit heuristic (BF) proposed by Burke et al. (2004), for example, locates the lowest free space available, then searches for a piece that will perfectly fit that



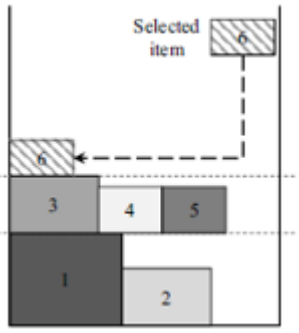
Examples of how the bottom-left (BL), bottom-left-fill (BLF), and improved bottom-left (iBL) heuristics work. Figure reproduced from Oliveira et al. (2016: fig. 3; CC BY 4.0).



Examples of application of the best-fit (BF) heuristic with different placements. Figure reproduced from Oliveira et al. (2016: fig. 4; CC BY 4.0).

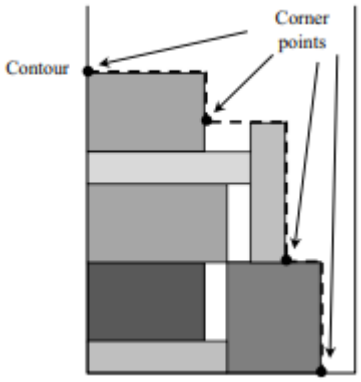
space. If there is no such piece, then the next largest piece that fits the space is chosen and placed. The location of the placement can also have different rules: leftmost policy, next-to-tallest policy, or next-to-shortest-policy.

- **Level-based heuristics:** these heuristics are very different from the previous two types, addressing a specific real-world problem where the level orientation of the layouts is a constraint, for instance when planning display of goods on supermarket shelves (Oliveira et al., 2016). The strategy for these heuristics is to place the pieces on parallel levels, where the height of each level is defined by the tallest rectangle placed on it. One example is the heuristic proposed by Coffman Jr et al. (1980), the Next-Fit Decreasing Height (NFDH), in which rectangles are sorted by non-increasing height, and placed one at a time on the current open level, in the leftmost position, until there Is not enough space to accommodate a new rectangle, and a new layer is opened. As mentioned, level-based heuristics address specific real-world problems, but has the limitation of not necessarily being ideal to optimize space in a knapsack for an end-of-world crisis.

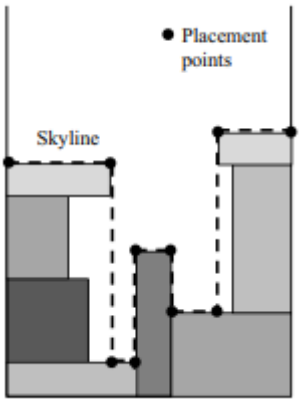


Example of an application of the next-fit decreasing height heuristic (NFDH). The numbers on the blocks are the order they are placed. Figure reproduced from Oliveira et al. (2016: fig. 8; CC BY 4.0).

- **Profile-based heuristics:** the profile or contour is a concept introduced by Scheithauer (1997), consisting of a polygonal line starting from the left side of the large rectangle where the pieces are being placed, and ending on the bottom or right side of it, composed by vertical and horizontal edges. This concept was first introduced to build exact methods, but later its potential for developing heuristics was identified by other authors. One example is the study of Wei et al. (2011) that proposed the "Iterative Doubling Binary Search" heuristic (IDBS). In that work, a profile (called skyline) composed of the edges or extension of edges of already placed rectangles defined the feasible placement points. Then, the IDBS analyzed where to place the next rectangle, according to several criteria using a scoring method.



Example of a contour line. Figure reproduced from Oliveira et al. (2016: fig. 9; CC BY 4.0).

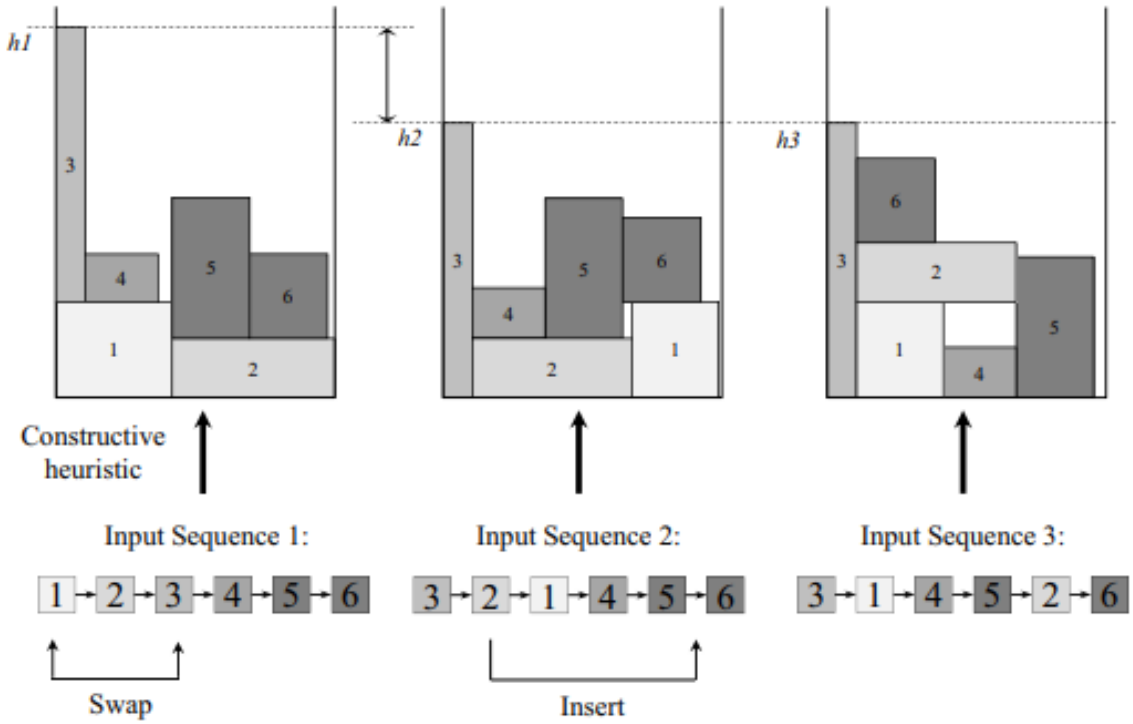


Example of a skyline, used for the IDBS proposed by Wei et al. (2011), with the feasible placement points highlighted. Figure reproduced from Oliveira et al. (2016: fig. 11; CC BY 4.0).

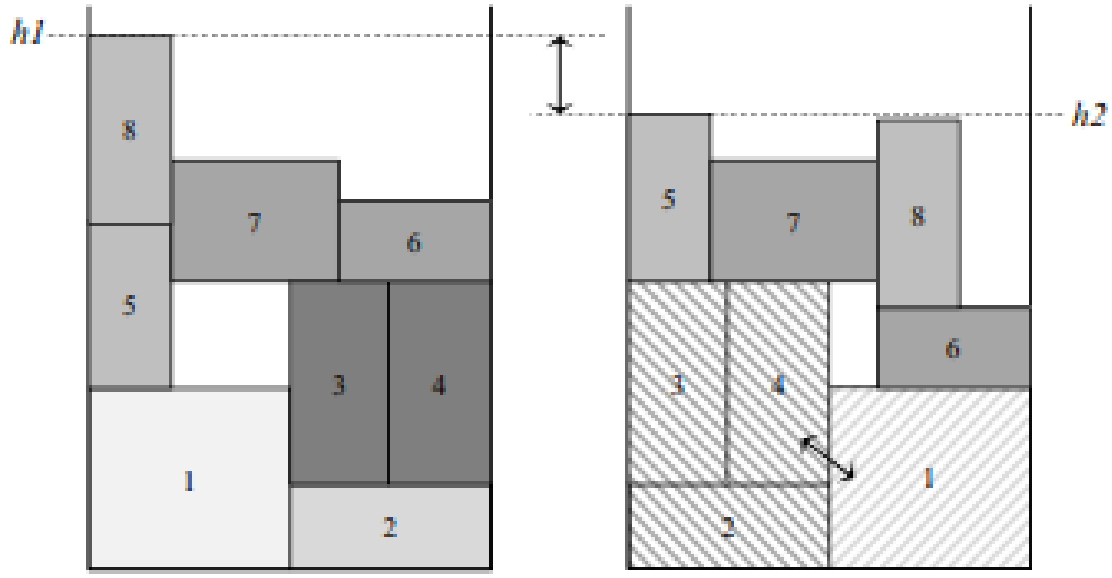
Improvement heuristics

- **Search over sequences:** improvement heuristics based on the search over sequences strategy resort to modifications to the used sequence as the basis for the constructive heuristic. There are two different operations, the insert operation – where a rectangle is taken out of the sequence and re-inserted in a different position – and the swap operation – in which two rectangles exchange their positions in the sequence. The most basic search strategy is the Local Search (LS), in which an incumbent solution is tested and, if better than the current "best solution", accepted. The search stops when a previously defined number of changes are tested without improvement to the solution. Pure local search methods are known for getting stuck in local minima (solutions that are better than any other solution that can be generated from it, but with no guarantee of global optimality) and, because of that, it is common for them to be combined with metaheuristic methods, like genetic algorithms, tabu search, or simulated annealing, to avoid being stuck in those solutions.

- **Search over layout:** in this improvement heuristic, modifications are operated directly over the layout of the solution, changing the position of two or more pieces based on their current placement. One example is the algorithm proposed by Alvarez-Valdes et al. (2005), which defines a fitness value for each piece, based on how well it occupied the space, and then uses this value to define candidates to be replaced.



Overall structure of an improvement heuristic that searches over sequences. Figure reproduced from Oliveira et al. (2016: fig. 12; CC BY 4.0).



Example of search over layout heuristic, where rectangle 1 is exchanged with rectangles 2, 3 and 4, resulting in a better solution. Figure reproduced from Oliveira et al. (2016: fig. 14; CC BY 4.0).

TESTING HEURISTICS FOR THE RESIDENT EVIL INVENTORY MANAGEMENT PROBLEM (REIMP)

One important difference of the proposed Resident Evil Inventory Management Problem (REIMP) when compared to typical C&P explained above, is that C&P usually focuses on minimizing the space occupied in a deposit when placing all pieces (henceforth called "items"), instead of maximizing the profit by placing only a limited amount of items. The two-dimensional rectangular strip packing problem considers that the "container" has all dimensions but one fixed (in other words, the "height" of the deposit is limitless), and the idea is to minimize the height of the configuration of pieces, while pieces can be stacked indefinitely. As such, there is no need to consider the concept of "profit" of each item since all of them must be placed. In the REIMP, however, the value empirically attributed to each item is important and must be considered for the best solution.

The characteristics of the REIMP are:

- The items are all rectangular, with sides varying from 1 to 8 units of length, with only integer values allowed. The items cannot change their orientation (cannot be rotated). Though the non-rotation premise differs from what is possible in RE, this was considered to simplify the problem;
- Each item is assigned a "profit" value. The profit of each item is proportional to its area, to avoid having very small items with very large values, which could skew the quality of the analysis. The profit is an integer value, and is calculated by multiplying the area of the item by a random factor between 1 and 4 (not necessary an integer factor);
- The 2D knapsack (henceforth called "inventory" as per common sense) is a square of side of 24 units of length. The size of the knapsack is variable, and this square of 24 units of length is obviously different from the inventory in RE, but the knapsack problem can be changed in our program;
- 100 items were generated randomly, and the objective of the REIMP is to maximize the total profit of items placed in the inventory;
- Other 2KP characteristics apply, such as: items cannot overlap; items cannot be placed partially; items can be placed next to each other with no

gaps.

For this problem, the following heuristics were tested:

- Bottom-Left Heuristic (BL);
- Improved Bottom-Left Heuristic (iBL);
- Improvement Heuristic based in the search over sequence technique, that consists of reordering the priority that the pieces of a first solution are tested, based on the height of the pieces (IH). This improvement heuristic was applied to the solutions obtained by the BL (IHBL) and iBL (IHiBL). Strictly speaking, this is technically not really an improvement heuristic, since it does not consist of small and consecutive changes being applied to an existing solution until a stopping criterion; rather, it is more in line with a new priority rule for a new constructive heuristic;
- A routine that filled gaps once a first solution was defined, using a "brute force" approach (FG). This routine was possible due to the small size of the problem. This improvement was applied to the solutions obtained by the BL (FGBL) and iBL (FGiBL).

For the testing, 10 instances of 100 items each were generated. For each instance, the six heuristics were tested: BL, iBL, IHBL, IHiBL, FGBL, and FGiBL. The problem was modeled in VBA.

Since it is not possible to fit all items in the inventory, it is necessary to define the order that the pieces are tested and placed, or their priority. For this, all heuristics considered that the "Factor" of each item can be considered as the priority for that item (the factor being the profit divided by the area). In case of two items having the same factor, the tiebreaker was the area – the larger ones being tested first.

A disadvantage of this strategy is that testing the items according to their factor guarantees that we are prioritizing items according to their profit to area ratio, but we are not looking into their shape. As such, there will be situations where large empty spaces are formed, since items with very different sizes are placed side to side. This can be mitigated by our Improvement Heuristic (IH), which changes the orders that the shapes are placed. Once a solution was found for the BL and iBL, this IH was applied to both (IHBL and IHiBL, respectively). This heuristic considered all the items that made the first solution, and reorganized them according to their height. Once this new order is defined, the same constructive heuristics are performed, considering this new order. This solution improved the organization of the pieces, reducing empty spaces. Then, once all previously placed items are placed again, the items that did not manage to fit the first solution are tested again, according to their factor.

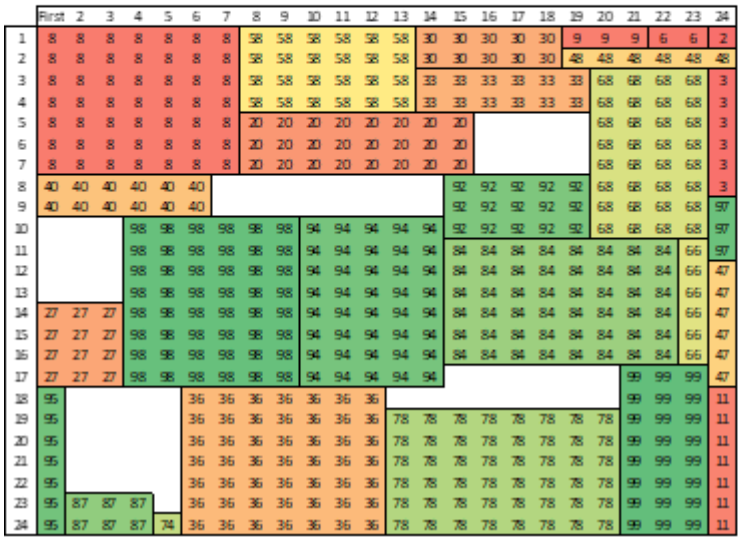
Finally, the FG heuristic was applied to both the BL and iBL solutions. As mentioned before, this brute force approach checks all remaining pieces in order of their factor, and all empty spaces, trying to fit the remaining pieces.

The figures below show these six heuristics tested for one of the instances of the problem. Finally, the Table 1 shows the results obtained for the ten instances.

As can be seen in Table 1, for all cases but one, the Improvement Heuristic provided better or equal results than the original solution they started with. Comparing the BL and iBL heuristics, though, it is unclear which performs better with only ten instances of relatively small size; it depends on the configuration of the items. Finally, the FG routine presented better results with very few exceptions. Since this routine only tries to place additional items in the empty spaces, it will never present a worst result than the original ones and could be used after the IHBL or IHiBL.

Additional ideas could be tested to improve upon these results. For instance, heuristics that delete one of the items from the inventory – possibly the largest one – to see if the new arrangement reduces the number of empty spaces.

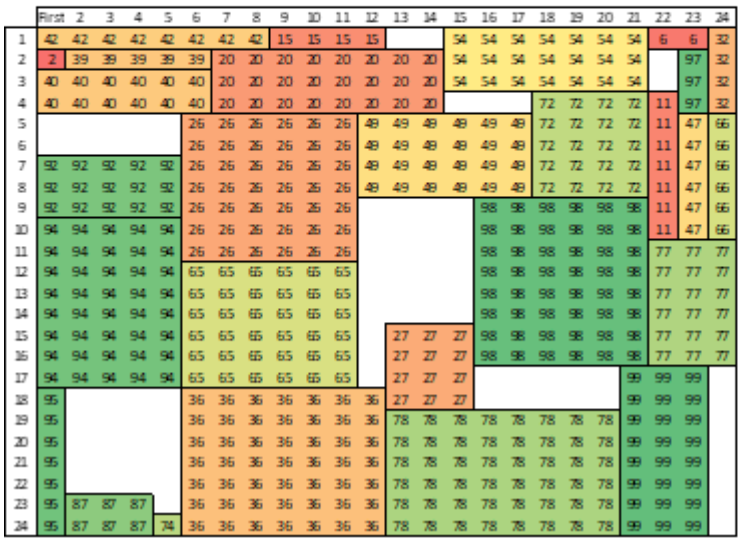
TOTAL VALUE: 1817



Piece	Width	Height	Profit	Area	Factor
95	1	7	28	7	4,0
87	3	2	24	6	4,0
74	1	1	4	1	4,0
36	7	7	195	49	4,0
78	8	6	190	48	4,0
99	3	8	95	24	4,0
27	3	4	46	12	3,8
98	6	8	183	48	3,8
94	5	8	152	40	3,8
84	8	6	175	48	3,6
92	5	3	54	15	3,6
40	6	2	43	12	3,6
11	1	7	25	7	3,6
8	7	7	172	49	3,5
68	4	8	108	32	3,4
20	8	3	81	24	3,4
47	1	6	20	6	3,3
66	1	6	20	6	3,3
58	6	4	79	24	3,3
33	6	2	39	12	3,3
97	1	3	9	3	3,0
30	5	2	29	10	2,9
3	1	6	17	6	2,8
48	6	1	17	6	2,8
9	3	1	6	3	2,0
6	2	1	4	2	2,0
2	1	1	2	1	2,0

Result for instance 1 of the BL heuristic.

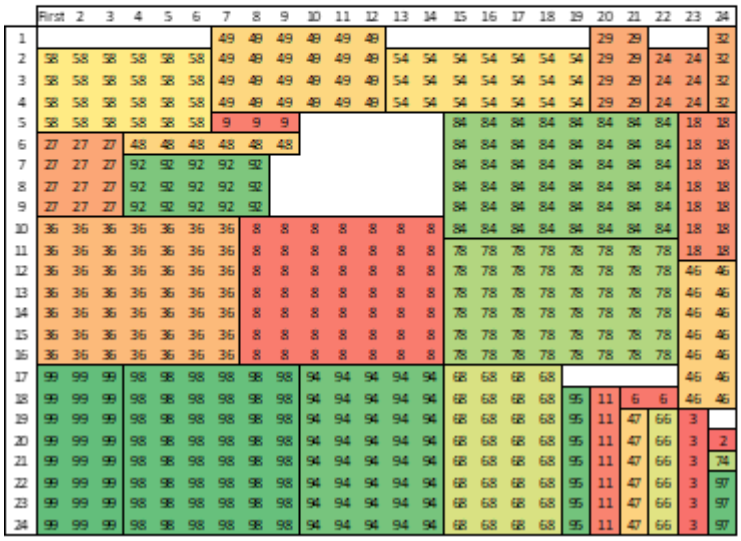
TOTAL VALUE: 1798



Piece	Width	Height	Profit	Area	Factor
95	1	7	28	7	4,0
87	3	2	24	6	4,0
74	1	1	4	1	4,0
36	7	7	195	49	4,0
78	8	6	190	48	4,0
99	3	8	95	24	4,0
27	3	4	46	12	3,8
98	6	8	183	48	3,8
94	5	8	152	40	3,8
65	6	6	135	36	3,8
26	6	7	154	42	3,7
49	6	4	88	24	3,7
77	3	6	66	18	3,7
72	4	5	73	20	3,7
92	5	3	54	15	3,6
40	6	2	43	12	3,6
11	1	7	25	7	3,6
20	8	3	81	24	3,4
47	1	6	20	6	3,3
66	1	6	20	6	3,3
54	7	3	69	21	3,3
97	1	3	9	3	3,0
32	1	4	9	4	2,3
6	2	1	4	2	2,0
2	1	1	2	1	2,0
39	5	1	9	5	1,8
42	8	1	14	8	1,8
15	4	1	6	4	1,5

Result for instance 1 of the iBL heuristic.

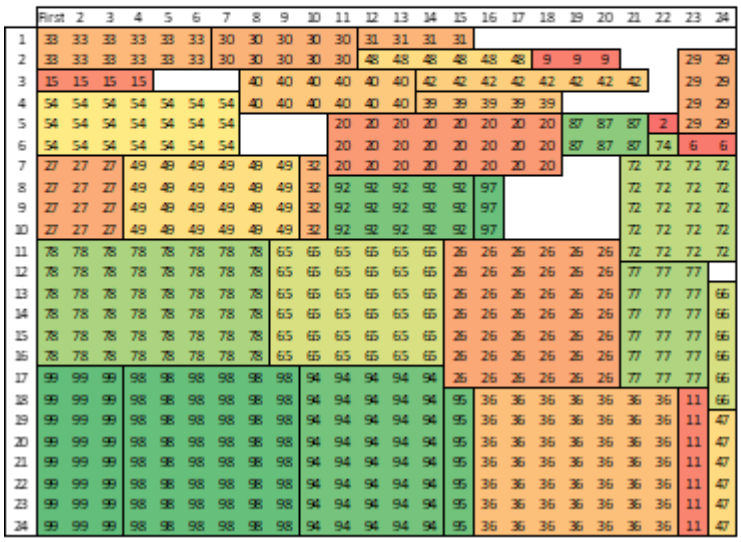
TOTAL VALUE: 1893



Piece	Width	Height	Profit	Area	Factor
99	3	8	95	24	4,0
98	6	8	183	48	3,8
94	5	8	152	40	3,8
68	4	8	108	32	3,4
95	1	7	28	7	4,0
36	7	7	195	49	4,0
11	1	7	25	7	3,6
8	7	7	172	49	3,5
78	8	6	190	48	4,0
84	8	6	175	48	3,6
47	1	6	20	6	3,3
66	1	6	20	6	3,3
3	1	6	17	6	2,8
27	3	4	46	12	3,8
58	6	4	79	24	3,3
92	5	3	54	15	3,6
97	1	3	9	3	3,0
74	1	1	4	1	4,0
48	6	1	17	6	2,8
9	3	1	6	3	2,0
6	2	1	4	2	2,0
2	1	1	2	1	2,0
49	6	4	88	24	3,7
54	7	3	69	21	3,3
46	2	7	44	14	3,1
18	2	7	42	14	3,0
29	2	4	23	8	2,9
24	2	3	17	6	2,8
32	1	4	9	4	2,3

Result for instance 1 of the IHBL heuristic.

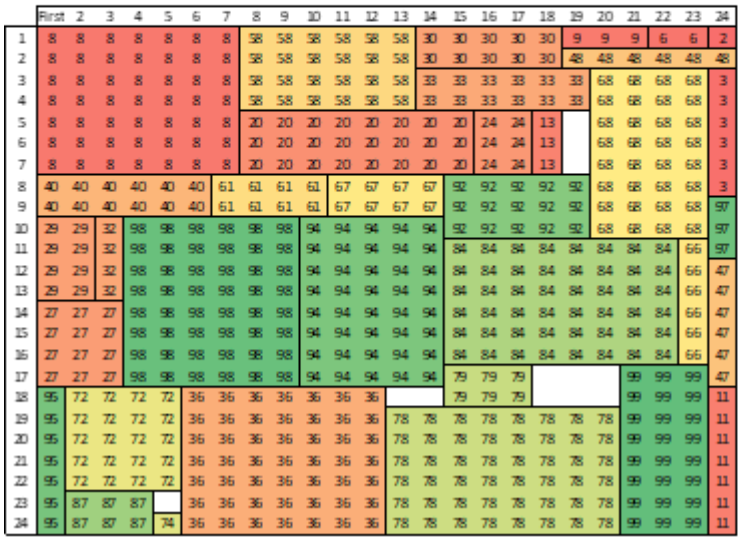
TOTAL VALUE: 1918



Piece	Width	Height	Profit	Area	Factor
99	3	8	95	24	4,0
98	6	8	183	48	3,8
94	5	8	152	40	3,8
95	1	7	28	7	4,0
36	7	7	195	49	4,0
26	6	7	154	42	3,7
11	1	7	25	7	3,6
78	8	6	190	48	4,0
65	6	6	135	36	3,8
77	3	6	66	18	3,7
47	1	6	20	6	3,3
66	1	6	20	6	3,3
72	4	5	73	20	3,7
27	3	4	46	12	3,8
49	6	4	88	24	3,7
32	1	4	9	4	2,3
92	5	3	54	15	3,6
20	8	3	81	24	3,4
54	7	3	69	21	3,3
97	1	3	9	3	3,0
87	3	2	24	6	4,0
40	6	2	43	12	3,6
74	1	1	4	1	4,0
6	2	1	4	2	2,0
2	1	1	2	1	2,0
39	5	1	9	5	1,8
42	8	1	14	8	1,8
15	4	1	6	4	1,5
33	6	2	39	12	3,3
30	5	2	29	10	2,9
29	2	4	23	8	2,9
48	6	1	17	6	2,8
9	3	1	6	3	2,0
31	4	1	6	4	1,5

Result for instance 1 of the IHiBL heuristic.

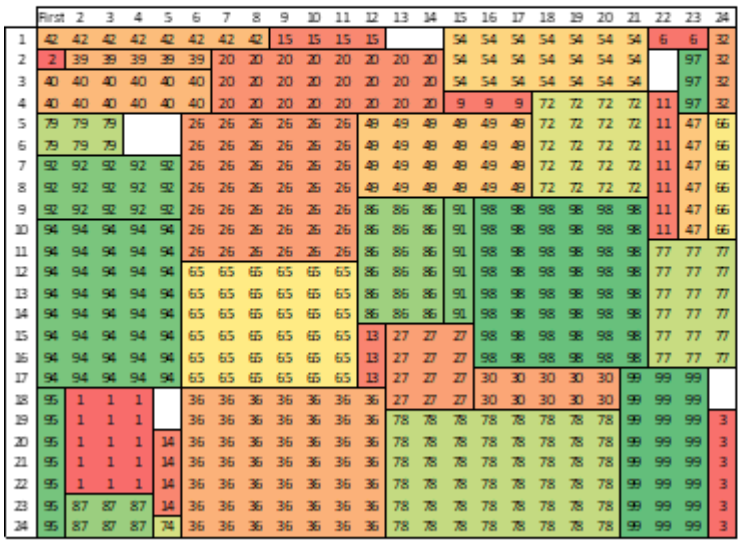
TOTAL VALUE: 2002



Piece	Width	Height	Profit	Area	Factor
95	1	7	28	7	4,0
87	3	2	24	6	4,0
74	1	1	4	1	4,0
36	7	7	195	49	4,0
78	8	6	190	48	4,0
99	3	8	95	24	4,0
27	3	4	46	12	3,8
98	6	8	183	48	3,8
94	5	8	152	40	3,8
84	8	6	175	48	3,6
92	5	3	54	15	3,6
40	6	2	43	12	3,6
11	1	7	25	7	3,6
8	7	7	172	49	3,5
68	4	8	108	32	3,4
20	8	3	81	24	3,4
47	1	6	20	6	3,3
66	1	6	20	6	3,3
58	6	4	79	24	3,3
33	6	2	39	12	3,3
97	1	3	9	3	3,0
30	5	2	29	10	2,9
3	1	6	17	6	2,8
48	6	1	17	6	2,8
9	3	1	6	3	2,0
6	2	1	4	2	2,0
2	1	1	2	1	2,0
72	4	5	73	20	3,7
29	2	4	23	8	2,9
24	2	3	17	6	2,8
79	3	2	17	6	2,8
61	4	2	21	8	2,6
67	4	2	21	8	2,6
32	1	4	9	4	2,3
13	1	3	4	3	1,3

Result for instance 1 of the FGBL heuristic.

TOTAL VALUE: 1992



Piece	Width	Height	Profit	Area	Factor
95	1	7	28	7	4,0
87	3	2	24	6	4,0
74	1	1	4	1	4,0
36	7	7	195	49	4,0
78	8	6	190	48	4,0
99	3	8	95	24	4,0
27	3	4	46	12	3,8
98	6	8	183	48	3,8
94	5	8	152	40	3,8
65	6	6	135	36	3,8
26	6	7	154	42	3,7
49	6	4	88	24	3,7
77	3	6	66	18	3,7
72	4	5	73	20	3,7
92	5	3	54	15	3,6
40	6	2	43	12	3,6
11	1	7	25	7	3,6
20	8	3	81	24	3,4
47	1	6	20	6	3,3
66	1	6	20	6	3,3
54	7	3	69	21	3,3
97	1	3	9	3	3,0
32	1	4	9	4	2,3
6	2	1	4	2	2,0
2	1	1	2	1	2,0
39	5	1	9	5	1,8
42	8	1	14	8	1,8
15	4	1	6	4	1,5
1	3	5	48	15	3,2
86	3	6	56	18	3,1
30	5	2	29	10	2,9
3	1	6	17	6	2,8
79	3	2	17	6	2,8
9	3	1	6	3	2,0
14	1	4	7	4	1,8
91	1	6	10	6	1,7
13	1	3	4	3	1,3

Result for instance 1 of the FGiBL heuristic.

	Instance 1	Instance 2	Instance 3	Instance 4	Instance 5	Instance 6	Instance 7	Instance 8	Instance 9	Instance 10	Average
BL	1,817	1,765	1,690	1,718	1,770	1,526	1,557	1,459	1,577	1,694	1,657
IHBL	1,893	1,806	1,637	1,825	1,806	1,645	1,736	1,466	1,660	1,741	1,722
iBL	1,798	1,640	1,687	1,599	1,595	1,746	1,700	1,743	1,644	1,677	1,683
IHiBL	1,918	1,869	1,790	1,901	1,800	1,775	1,700	1,786	1,736	1,677	1,795
FGBL	2,002	1,886	1,871	1,930	1,858	1,766	1,821	1,602	1,741	1,901	1,838
FBiBL	1,992	1,803	1,897	1,942	1,876	1,915	1,780	1,855	1,741	1,832	1,863

CONCLUSION

As I discussed in a previous study (Tomotani, 2015), a zombie outbreak would probably have very damaging effects to human society as we know. Considering this, it is very important to know different optimization techniques that can be useful when planning for apocalyptic scenarios. Curiously, very few optimization studies focus on said scenarios, instead prioritizing industrial and supply chain problems to maximize profit. I emphasize that dealing with a zombie apocalypse capable of ending humanity is probably an issue as relevant as making rich people even richer and propose that more efforts should be directed to this area.

REFERENCES

Alvarez-Valdes, R.; Parreño, F.; Tamarit, J.M. (2005) A GRASP algorithm for constrained two-dimensional non-guillotine cutting problems. Journal of the Operational Research Society 56(4): 414–425.

Baker, B.S.; Coffman Jr, E.G.; Rivest, R.L. (1980) Orthogonal packings in two dimensions. SIAM Journal of Computing 9(4): 846–855.

Bortfeldt, A. & Winter, T. (2009) A genetic algorithm for the Two-dimensional Knapsack Problem with rectangular pieces. International Transactions in Operational Research 16: 685–713.

Burke, E.K.; Kendall, G.; Whitwell, G. (2004) A new placement heuristic for the orthogonal stock-cutting problem. Operations Research 52(4): 655–671.

Caprara, A. & Monaci, M. (2004) On the Two-dimensional Knapsack Problem. Operations Research Letters 32: 5–14.

Chazelle, B. (1983) The Bottomn-Left Bin-Packing Heuristic: An Efficient Implementation. IEEE Transactions on Computers C-32(8): 697–707.

Chu, P.C. & Beasley, J.E. (1998) A genetic algorithm for the Multidimensional Knapsack Problem. Journal of Heuristics 4: 63–86.

Coffman Jr, E.G.; Garey, M.R.; Johnson, D.S.; Tarjan, R.E. (1980) Performance bounds for level-oriented two-dimensional packing algorithms. SIAM Journal on Computing 9(4): 808–826.

Del Valle, A.M.; Queiroz, T.A.; Miyazawa, F.K.; Xavier, E.C. (2012) Heuristics for two-dimensional knapsack and cutting stock problems with items of irregular shape. Expert Systems with Applications 39(16): 12589–12598.

DellaFave, R. (2014) Designing an RPG Inventory System That Fits: Preliminary Steps. Available from: https://gamedevelopment.tutsplus.com/articles/designing-an-rpg-inventory-system-that-fits-preliminary-steps--gamedev-14725 (Date of access: 06/Feb/2022).

Dillon, R. (2011) The Golden Age of Video Games. Routledge, London.

Dyckhoff, H. (1990) A typology of cutting and packing problems. European Journal of Operational Research 44(2): 145–159.

Gigax, G. & Arneson, D. (1974) Dungeons & Dragons. Tactical Study Rules, Lake Geneva.

Hopper, E. & Turton, B.C.H. (2001) A review of the application of meta-heuristic algorithms to 2D strip packing problems. Artificial Intelligence Review 16: 257–300.

Liu, D. & Teng, H. (1999) An improved BL-algorithm for genetic algorithm of the orthogonal packing of rectangles. European Journal

of Operational Research 112(2): 413–420.

Martello, S. & Toth, P. (1990) Knapsack Problems: Algorithms and computer implementations. John Wiley & Sons, West Sussex.

Oliveira, J.F.; Neuenfeldt Júnior, A.; Silva, E.; Carravilla, M.A. (2016) A survey on heuristics for the two-dimensional rectangular strip packing problem. Pesquisa Operacional 36(2): 197–226.

Salkin, H.M. & de Kluyver, C.A. (1975) The Knapsack Problem: a survey. Naval Research Logistics Quarterly 22(1): 127–144.

Salvador, R.B. (2017) History's first Easter egg. Journal of Geek Studies 4(2): 63–68.

Scheithauer, G. (1997) Equivalence and dominance for problems of optimal packing of rectangles. Ricerca Operativa 83: 3–34.

Tomotani, J.V. (2015) Modeling and analysis of a Zombie Apocalypse: zombie infestation and combat strategies. Journal of Geek Studies 2(1): 10–25.

Toth, P. (1980) Dynamic programming algorithms for the Zero-One Knapsack Problem. Computing 25: 29–45.

Wei, L.; Oon, W.C.; Zhu, W.; Lim, A. (2011) A skyline heuristic for the 2D rectangular packing and strip packing problems. European Journal of Operational Research 215(2): 337–346.

About the author

João Tomotani, MSc., is an engineer that works with Supply and Inventory Planning (or, as he likes to put it, Excel spreadsheets). He is terrible with horror and survival horror games, movies, books, etc., and would definitely be one of the first to die in case of a zombie outbreak.

Journal of Geek Studies

jgeekstudies.org

Testing the Astolfo Effect on newly-released servants in *Fate/Grand Order*

João Vitor Tomotani[1] & Rodrigo Brincalepe Salvador[2,3]

[1] *Independent Researcher. São Paulo, SP, Brazil.* [2]*The Arctic University Museum of Norway, UiT – The Arctic University of Norway, Tromsø, Norway.* [3]*Department of Arctic and Marine Biology, Faculty of Biosciences, Fisheries and Economics, UiT – The Arctic University of Norway, Tromsø, Norway.*
Emails: tjvitor@gmail.com; salvador.rodrigo.b@gmail.com

Back in 2021, we wrote an article defining the Astolfo Effect. That is what happens when a pop culture representation of a character (fictional or otherwise) becomes more popular than the original. We named it after Astolfo, one of Charlemagne's paladins and arguably an obscure character in the works that make up the *Matter of France* and in later literature related to it (such as *Orlando Furioso*, in which Astolfo plays an important role). Astolfo only achieved great popularity due to his incarnation in the light novel/manga/anime *Fate/Apocrypha* and the game *Fate/Grand Order* (henceforth FGO).

We won't explain what Fate is here because if you're reading this, chances are you are well-versed in this matter. If not, we'll refer you to our original article (Tomotani & Salvador, 2021), where you'll find the full story.[1]

But to summarize the Astolfo Effect, we hypothesized that the most obscure characters (e.g., Astolfo and Bradamante) present in FGO would have more hits related to their Fate version on a Google Images search when compared to their original versions. Furthermore, those FGO-related Google hits would appear sooner rather than later in the search. Conversely, widely popular characters (particularly in cinema and TV, such as Sherlock Holmes) would have fewer hits about their FGO incarnations and those would appear later in a Google search.

In our 2021 article, we have demonstrated that the Astolfo Effect is real. The article was well received on Reddit[2] and it was used as basis for a video on klidge's YouTube channel.[3] As a result, we received several comments from our readers, some of whom proposed interesting ideas to further study this important subject. For instance, to verify how big and widespread the Astolfo Effect is and how fast it acts. So, this article, our dear reader, is one of such studies – a natural follow-up to our 2021 article.

THE ASTOLFO EFFECT IN REAL TIME

One of the suggestions we received[4] was to investigate how fast Fate-related content would overtake the real deal in the results

[1] Really, it's a cool article, so go take a look: https://jgeekstudies.org/2021/12/28/the-astolfo-effect-the-popularity-of-fate-grand-order-characters-in-comparison-to-their-real-counterparts/

[2] https://www.reddit.com/r/grandorder/comments/rqsw6i/article_the_astolfo_effect_the_popularity_of/

[3] https://www.youtube.com/watch?v=s_TjFU33PRY

[4] Thanks, Azzaciel!

of a Google Images search. To investigate that, we had to wait until new servants were announced for the Japanese version[5] of the game (we accompanied the live broadcasts on FGO's official YouTube channel). Then, we ran a search soon after each announcement and several further searches at pre-determined intervals afterwards.

The core methodology of this study is the same as in our 2021 article: we ran the searches on Google Chrome, with clean cache, cookies, and history, using an Incognito tab with SafeSearch deactivated. Images of any size and publication date were allowed in the results. A VPN client was used to obtain an IP address from Michigan, USA. We used the Latinized version of the servant names as given by the Fate Grand Order Wiki (https://gamepress.gg/grandorder/servant-availability), with the exception of Sen no Rikyū, for which we also included the spelling 'Sen no Rikyuu'. We only used brand-new servants, that is, excluding alternate versions (e.g., summer) and characters from elsewhere in the Type Moon universe. The following servants were used in this study: Kyokutei Bakin (a.k.a. Takizawa Bakin; Fig. 1), Minamoto no Tametomo, Xu Fu, Sen no Rikyū, Yamanami Keisuke, and Iyo.[6] Xu Fu and Keisuke already had official artworks from their previous appearances as NPCs in FGO, so their results need extra care to interpret (the situation is quite different for Tametomo, who had his first appearance in another event, but only one month before his official release as a servant, making this effect negligible). But the others are rather obscure, making them perfect for testing the Astolfo Effect.

Figure 1. Kyokutei Bakin in FGO and in real life. The resemblance is… nonexistent. FGO's official Stage 4 artwork by TAKOLEGS (2022); extracted from Fate/Grand Order Wiki (https://fategrandorder.fandom.com/). Portrait of Bakin by 長谷川雪旦 (unknown date); extracted from Edo Guide (https://edo-g.com/).

[5] New stuff comes first to the Japanese game; the other servers are well behind it in content, so when things are released for them, they are already old news. Or, as the community puts it, North America has Clairvoyance EX.

[6] We could not include Huyan Zhuo and Huang Feihu because we were both on holidays when they were announced.

After the search results were obtained, we counted the number of images (among the first 50 results) that were related to the FGO incarnation of the characters. Those images could be official artwork, fanart, memes, etc., as long as they were clearly related to FGO. We conducted the first search 3 hours after the announcement, then 24 hours, and then every 24 hours to a maximum of 552 hours (23 days). A table summarizing all results (from the present study and our 2021 article) can be seen in the Supplementary File to this article.

RESULTS

As expected, the results for Xu Fu and Keisuke did not change much (Fig. 2). They had already been released over two years ago as NPCs, so there were already plenty of Fate-related images out there. Also, they were quite popular in the Fate fanbase even as NPCs. There was a little increase in the number of hits, mostly due to the new arts for the ascensions but nothing expressive. Besides, as the other members of Shinsegumi, Keisuke has many representations in other media, like the otome game series *Hakuoki*.

Next, we have Kyokutei Bakin, in which the results were overtaken by Fate-related content (more than 50%). He is also known by the name Takizawa Bakin and, at the moment of writing, the Fate-related hits searching by that name make up less than half the search results (among the first 50 hits). On the other hand, Minamoto no Tametomo and Sen no Rikyū (both spellings) had only a modest increase of Fate-related content in relation to their real-world counterparts.

In these cases, we have a few complicating factors. Bakin the servant was a well-received character, while the other two had a more tepid reception. Besides, one can argue that Rikyū is the most famous person of the bunch, being the guy who most influenced the Japanese tea ceremony and having more content online about him in the West. Tametomo's search results were likewise not related to FGO, rather being famous ukiyo-e paintings (Fig. 3) – many of them based on novels written by Kyokutei Bakin, by the way.

Finally, there's Iyo. It is a very common name and one that can be used for anything. So, the search results were a mixed bunch, similar to what we had in our 2021 study for the servants David and Arash (both awfully common names) and for Paris (there is a

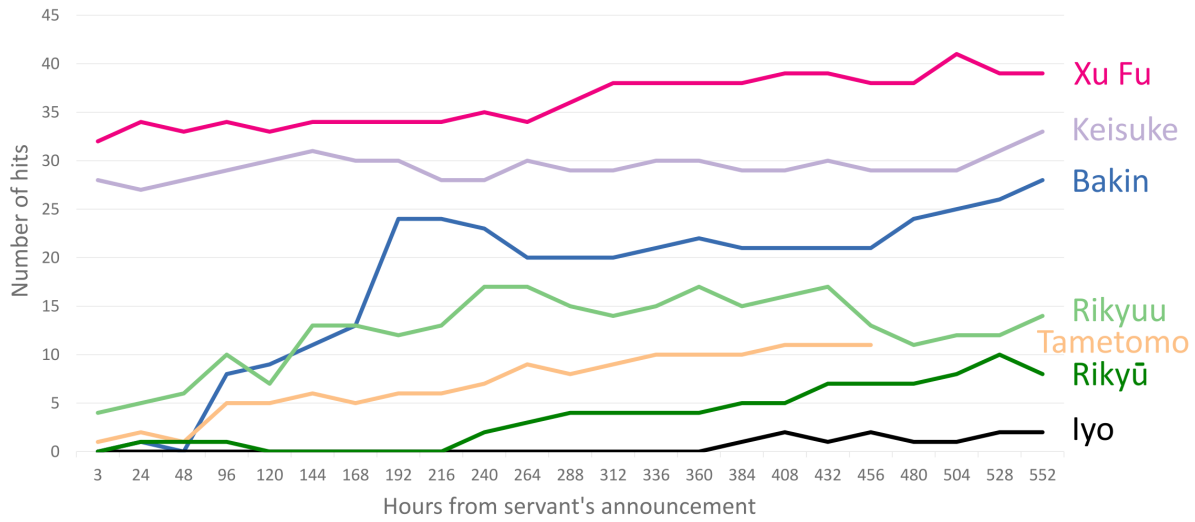


Figure 2. Graph showing the number of hits for each newly-released servant in Google Images searches. The searches for Minamoto no Tametomo stopped earlier than the rest due to reasons (we forgot to do them).

Figure 3. Tametomo, by Utagawa Kuniyoshi (1844); image extracted from https://ukiyo-e.org/, original at the Museum of Fine Arts, Boston, USA.

rather famous city with this name). Results included the wrestler IYO SKY, a band, and restaurants, so there was little space for FGO's Iyo.

FUTURE PREDICTIONS

We suspect that, as time goes by, more Fate-related results will accumulate for each of these characters (except Iyo). Thus, they will eventually achieve similar levels to what we found for other servants (Tomotani & Salvador, 2021). That means the Astolfo Effect will keep acting on them. Also, these more obscure characters are great in creating interest about their real-world counterparts (Salvador, 2019), which is always a good thing.

One bias of the present study is that all servants were Japanese (except Xu Fu). Thus, going forward, it would be interesting to analyze how the Astolfo Effect affects Western servants.[7]

Furthermore, we can say that the Astolfo Effect (expectedly) works much faster for servants that are a success with the public, like Bakin. And it is slower for unloved servants. This is a new find (though rather obvious, in retrospect) and one that now becomes a corollary to the Astolfo Effect.

REFERENCES

Salvador, R.B. (2020). Ancient Egyptian royalty in Fate/Grand Order. Journal of Geek Studies 7(2): 131–148.

Tomotani, J.V. & Salvador, R.B. (2021). The Astolfo Effect: the popularity of Fate/Grand Order characters in comparison to their real counterparts. Journal of Geek Studies 8(2): 59–69.

SUPPLEMENTARY FILE

Table S1. Results of the Google Images search per FGO servant (including the results from Tomotani & Salvador, 2021).

[7] At the moment of writing, Britomart, a Western servant, has just been announced.

Acknowledgements

We are very grateful to Azzaciel who gave us the idea for this article.

About the authors

João Tomotani, MSc., is an engineer and Rin simp since the 2006 FSN anime, who likes to make huge Excel spreadsheets to study stupid phenomena. After failing the first time for an Ereshkigal, he finally managed to get his NP2 Eresh, together with an Ishtar. He is currently saving for the Space Ishtar banner to add to his Rin collection. He also loved Xu Fu.

Dr. **Rodrigo Salvador** is a researcher at the Arctic University of Norway and a fan of the epics *Orlando Innamorato* and *Orlando Furioso*. He named one of the species he discovered after Astolfo: *Gallirallus astolfoi* or Astolfo's rail. He doesn't particularly care about any of the servants released after Roland (a.k.a. Orlando) and Charlie and would rather they be more characters from the Roland-verse.