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# Journal of Geek Studies

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**Cover art:** Bird Shot, by Barbara M. Tomotani & Rodrigo B. Salvador (2015).

A joke with the signature "barrel shot" from the James Bond series, substituting the agent's silhouette for that of a sad flycatcher (*Myiarchus barbirostris*), an endemic Jamaican bird.



## The birds of James Bond

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"The name is Bond, James Bond."

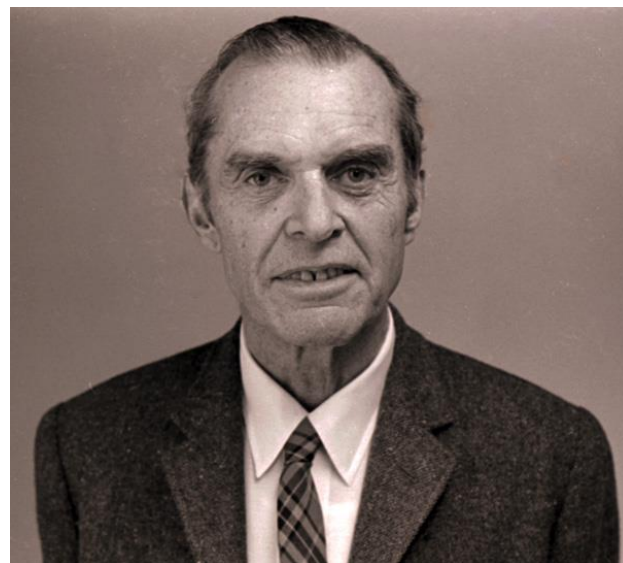
This particular British Secret Service agent is known worldwide through numerous books, comics, videogames and, of course, films. James Bond was created by Ian Fleming and the series now outlives its creator, continuing to grow on a somewhat constant rate. Fleming's superspy character was based on many people he met during the time he spent serving in the British Naval Intelligence Division during World War II. In his own words, James Bond "was a compound of all the secret agents and commando types I met during the war".

But what few know is where the name comes from. Actually, it was not invented by Fleming for the character; instead, it was borrowed from a real person. So who was the original James Bond and how Fleming came to know him and to borrow his name?

### LICENSE TO MAP

James Bond was born in Philadelphia on 4 January 1900. After his mother's death during his teens, in 1914, he moved with his father to England, going to Cambridge University and receiving his degree in 1922. Back in Philadelphia, after less than three years working for a banking firm, his love of natural history led

him to join an expedition of the ANSP (Academy of Natural Sciences of Philadelphia) to the lower Amazon River in Brazil. His father, Francis E. Bond, who led an ANSP expedition (when James was 11) to the Orinoco Delta, perhaps influenced James' decision, as well as his interest in the natural sciences.



*James Bond, in 1974. Photo taken at the ANSP by Jerry Freilich. (Source: Wikimedia Commons.)*

After the expedition to the Amazon, James Bond became a true **ornithologist** (see Box 1 for a glossary) and **curator** of the ANSP and started to publish many scientific papers on the South

American birds. Nevertheless, he soon decided that the focus of his studies would be the Caribbean birds and this became his life's work. He spent the next decades travelling through the Caribbean islands and studying their **avifauna**. The main result of his work in the region was the book "Birds of the **West Indies**" (1936), containing a scientific account (with descriptions, habits, geographic distribution etc.) of all the known species from the islands. The book was renamed "Field Guide of Birds of the West Indies" on its second edition (1947),

but reverted to the original name on the third edition (1961). Also, from the third edition onwards, the book featured color plates of the birds (by Don R. Eckelberry) and more simplified descriptions. This made the book more similar to modern field guides, making it a must for scientists and **birdwatchers** alike. After the final edition (1985), Bond kept the book updated via a series of 27 supplements. He finished revising a sixth edition shortly before his death (on 14 February 1989, after a years-long fight with cancer).

### Box 1. Glossary

**Alfred Russel Wallace:** Wallace (1823–1913) was a British naturalist known for independently conceiving the theory of evolution through natural selection. His work was published together with Charles Darwin's writings in 1858, one year before the latter published *On the Origin of Species*. Wallace, an expert on the study of the geographical distribution of animal species, is considered the "father of Biogeography".

**Avifauna:** The group birds inhabiting a given region.

**Biogeography:** Branch of Biology that studies the distribution of species in geographic space and through geological time.

**Biogeographic boundary:** A line that divides two faunal or floral biogeographical zones. This means that the animals or plants of one zone are completely different (or nearly so) from those of the other zone, indicating that they have distinct origins. The most famous of these boundaries is Wallace's Line (proposed by **Alfred Russel Wallace**), that runs through Indonesia separating the Southeast Asian and Australian types of fauna.

**Birdwatcher:** Birdwatching, or birding, is the observation of bird wildlife as a recreational activity. A birdwatcher might also be engaged in more serious projects, such as monitoring bird populations or providing environmental education.

**Curator:** The person who manages a museum collection. In James Bond's case, the ornithological collection of the ANSP.

**David Lack:** (1910–1973) Renowned British evolutionary biologist, famous for his work on Darwin's finches on the Galapagos.

**Endangered species:** A species which is in danger of becoming extinct.

**Endemic species:** A species that is only found in a specific geographic location, such as an island, province or any other defined (and usually relatively small) zone. For instance, the bird species *Regulus madeirensis* (popularly known as Madeira firecrest) is only found on Madeira Island. The extreme opposite of endemism is a cosmopolitan distribution, meaning that the species can be found across all or most of the world, such as house sparrows (*Passer domesticus*) and humans.

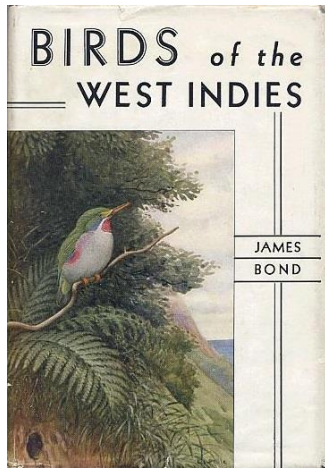
**Hybrid zone:** A region where two populations (subspecies) of a species or two distinct species coexist and cross-fertilize, giving birth to hybrid offspring.

**Introduced species:** A species living outside its native distributional range, brought there (intentionally or not) by humans.

**Mary Bond:** Mary Fanning Wickham Porcher Lewis (1898–1997) married James Bond in 1953. By that time, she was already a known poet and novelist. She also wrote memoirs of her life with her James, which was her second husband.

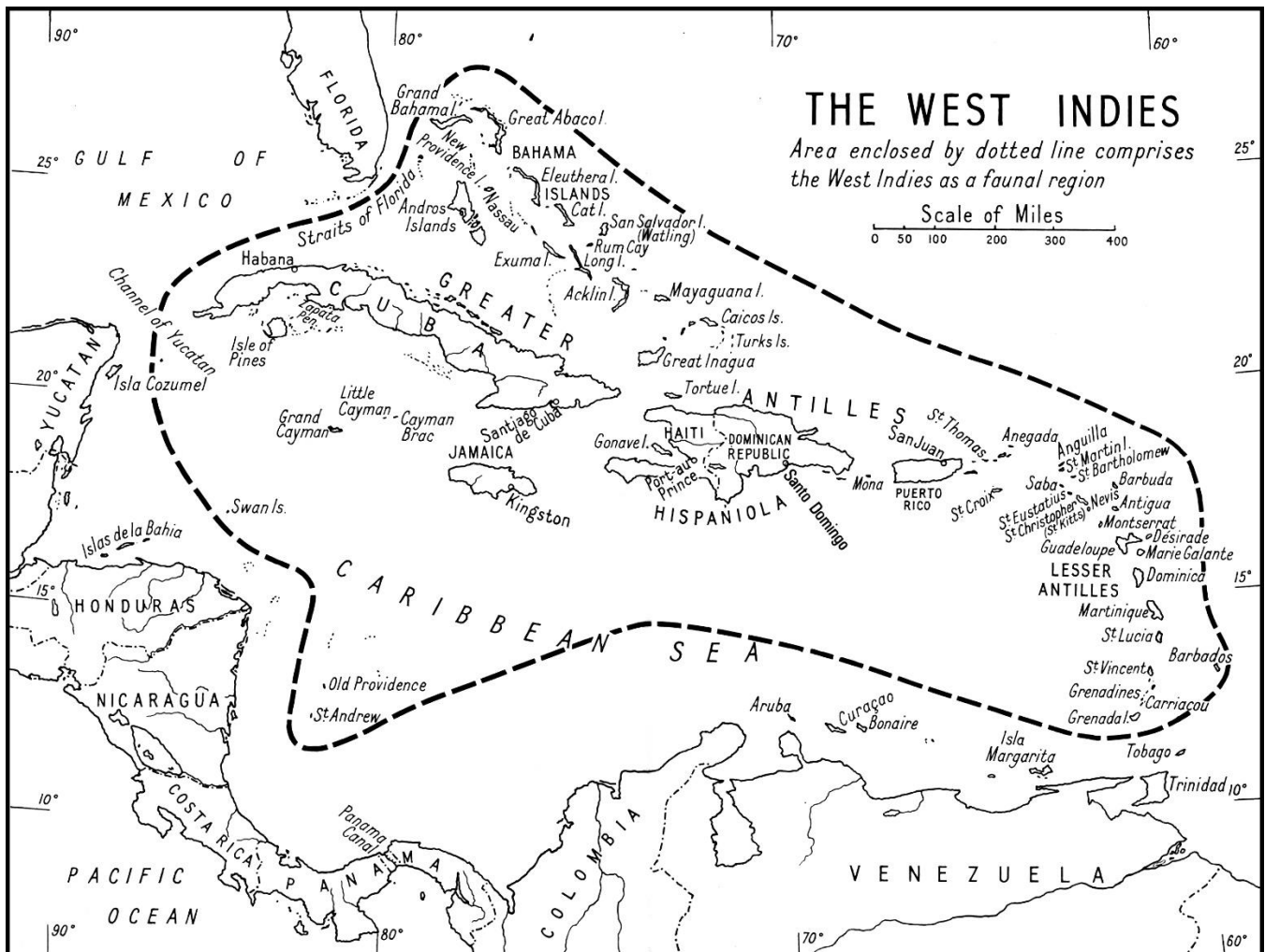
**Ornithologist:** A person who studies Ornithology, the branch of Biology devoted to the study of birds.

**West Indies:** The West Indies is a region including the islands of the Antilles and the Lucayan (or Bahamas) Archipelago. It received this name to distinguish it from the actual Indies (South and Southeast Asia) after the voyages of Christopher Columbus.



Cover of the first edition of "Birds of the West Indies", featuring the Jamaican tody (*Todus todus*).

From all the islands that James Bond visited, perhaps the one that most fascinated him was Jamaica, where he realized that the native avifauna was derived from North America, and not from South America as was previously supposed. This kind of study is part of the discipline known as **Biogeography** and led Bond, in 1971, to establish a **biogeographic boundary** between the Lesser Antilles and Tobago. This line separates two zones, the West Indies and South America, each with its own type of avifauna. This later led **David Lack** to propose, in 1973, the name "Bond's Line" for this boundary.



Map of the Caribbean Islands, showing the West Indies avifaunal region, encompassed by Bond's Line. (Source: Bond, 1993.)



Besides the books, Bond published more than 100 scientific papers and was awarded many medals and honors throughout his career. He is known today as the father of Caribbean ornithology. What he did not expect though, was the other Bond, which appeared in Jamaica of all places, and caused him a certain deal of consternation.

### GOLDENEYE

It was only in 1960–1961 that Bond discovered his fictional namesake from Ian Fleming's novels, after several novels had already been published (the first one, "Casino Royale", dates from 1953). This led his wife **Mary** to write the book "How 007 Got His Name" (published in 1966). In this book, she tells how she jokingly wrote a letter to Fleming saying that he had "brazenly taken the name of a real human being for your rascal!"

Fleming was a British novelist and spent a couple of months every year in his estate (named Goldeneye) on Oracabessa Bay, on the northern coast of Jamaica. He was interested in the Jamaican wildlife and had a growing collection of books on shells, birds, fish and flora. Also, as any keen birdwatcher on the Caribbean, Fleming used the "Field Guide of Birds of the West Indies" (he had the 2nd edition, from 1947) and was thus very familiar with the name James Bond. On his reply to Mary's letter, he explained that he "was determined that my secret agent should be as anonymous a personality as possible. (...) At this time one of my bibles was, and still is, Birds of the West Indies by James Bond, and it struck me that this name, brief, unromantic and yet very masculine, was just what I needed and so James Bond II was born." On a later interview, Fleming explained further his choice of name: "I wanted the

simplest, dullest, plainest-sounding name I could find, 'James Bond' was much better than something more interesting, like 'Peregrine Carruthers'. Exotic things would happen to and around him, but he would be a neutral figure – an anonymous, blunt instrument wielded by a government department."



The Goldeneye estate, as of 2011. (Source: Wikimedia Commons.)

On that letter to Mary, Fleming added that in return for using the name he could offer "your James Bond unlimited use of the name Ian Fleming for any purpose he may think fit. Perhaps one day he will discover some particularly horrible species of bird which he would like to christen in an insulting fashion." This never happened though. Finally, Fleming also invited the Bonds to visit him in Jamaica. This happened in 1964, when the Bonds were there researching and paid a surprise visit to Fleming. This was shortly before the novelist's death six months later, and luckily, this one-time meeting was captured in video for a future documentary. At first, Fleming was suspicious of Bond's identity and asked him to identify some birds. Bond, of course, passed the test with flying colors and Fleming had the happiest day of the rest of his life.

## FROM JAMAICA WITH LOVE

Jamaica, despite being a rather small country, has a very diverse avifauna. There are circa 320 bird species living in Jamaica, including migrants. From these, 28 are **endemic species**, 12 are **endangered** and 14 are **introduced**. Some of these species have fascinated James Bond, Ian Fleming and countless other tourists and birdwatchers. Moreover, since Ian Fleming was such a keen birdwatcher, birds sometimes featured in his stories (and later in the films), and a collection of bird trivia can be found in Box 2 further below.

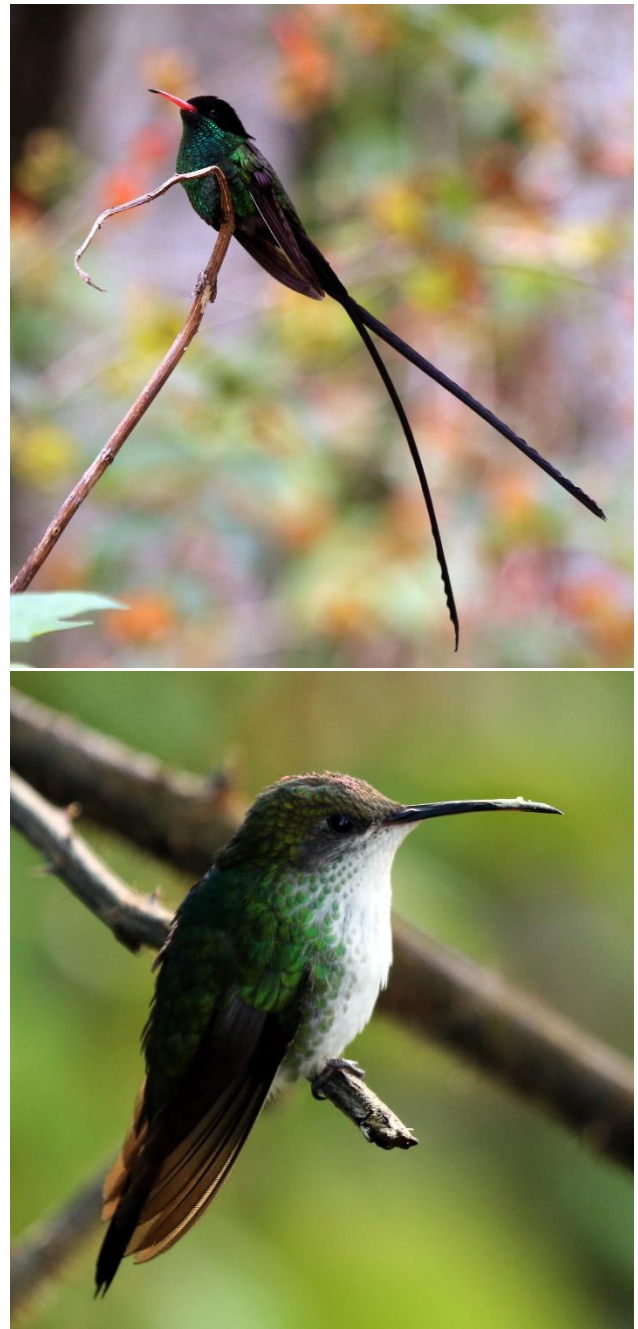
We will now briefly introduce some of the more interesting Jamaican birds and explore a little bit of their natural history and even folklore.

### Red-Billed Streamertail (*Trochilus polytmus*)

The red-billed streamertail, also known as doctor bird or scissortail hummingbird, appears in Fleming's short story "For Your Eyes Only" (1960). The first lines of the story are: "The most beautiful bird in Jamaica, and some say the most beautiful bird in the world, is the streamer-tail or doctor humming-bird." It is very hard to crown a "most beautiful" bird, but the red-billed streamertail is indeed remarkable. The feathers on the male's tail (the "streamers") are longer than their actual body and make a humming sound during flight. James Bond (the ornithologist) seems to agree; well, partially, at least: his book says that the "adult male is the most spectacular West Indian hummingbird".

This species is the most abundant and widespread bird in Jamaica and was actually selected as the country's national bird. Frederic G. Cassidy (1962–2000), who studied the evolution of the English language in Jamaica, says that the name doctor bird comes from the way the animals spear the flowers with their

beaks to feed. Still, the term "doctor" also carries a superstitious overtone (as in "witch-doctor") and Cassidy notes that natives referred to these hummingbirds as "god birds".



Male (top) and female (bottom) of the Red-Billed Streamertail (*Trochilus polytmus*). (Source: Wikimedia Commons.)

### **Jamaican Tody (*Todus todus*)**

The todies belong to the order Coraciiformes, a group that also includes kingfishers, rollers and bee-eaters. The Jamaican tody was at first believed to be a species of hummingbird. Later, it received the name of robin, due to its small size and round appearance. This early folk name still survives in Jamaica as *robin red-breast*, an allusion to the bird's red colored patch below the beak and a copy of the English name of another bird. Robin redbreast is the old name of the European robin (*Erithacus rubecula*), a totally unrelated species.

The Jamaican tody is a tiny bird that feeds on insects and fruits, nesting in excavated burrows. James Bond was especially interested in the nesting behavior of birds and studied this topic at length. He chose the Jamaican tody as the cover of the first edition of "Birds of the West Indies" (1936). It has a very small geographic distribution and its population seems to be steadily decreasing in the last decade.



The Jamaican Tody, *Todus todus*. (Source: Wikimedia Commons.)

### **Jamaican Poorwill (*Siphonorhis americana*)**

Also known as Jamaican pauraque, this nocturnal bird is a species of nightjar, of the family Caprimulgidae. The family name comes from the Latin *caprimulgus* (goatsucker) and reflects the absurd folk "lore" that these birds sucked milk from goats.

Very little is known about the Jamaican poorwill – it had been extinct long before Bond's studies, since 1859. It was driven to extinction by introduced rats and mongooses, alongside the usual human-caused habitat destruction. Since the birds nest on the ground, their eggs are easy prey for these introduced mammals. Nevertheless, there are some recent (1998) records of caprimulgids from the regions of the Milk River and the Hellshire Hills in the country, but they remain unconfirmed. Thus, a very small population of poorwills might still exist in these remote regions. Curiously, Bond had also previously alluded to the possibility of a surviving population of these birds on the semi-arid Hellshire Hills.



The Jamaican poorwill, *Siphonorhis americana*. (Source: Rothschild, 1907.)

### **Jamaican Blackbird (*Nesopsar nigerrimus*)**

The Jamaican blackbird (family Icteridae) is the only species in its genus and all of its names are rather misleading. Firstly, it is not an actual



blackbird (*Turdus merula*, family Turdidae), which is a species of thrush. Nevertheless, the family Icteridae is popularly known as “New World blackbirds”, so we can let this one slip. As for the scientific name, the genus name comes from the Greek *neso* (island) and *psar* (starling) and, as one might guess, this bird is completely unrelated to true starlings (family Sturnidae). Finally, the specific epithet (see Salvador, 2014, for a crash course in species’ scientific names) means simply “very black”, which might not be so descriptive of a “blackbird” after all.



The Jamaican blackbird, *Nesopsar nigerrimus*. (Source: Wikimedia Commons.)

Nevertheless, a local Jamaican popular name for this bird is “wild-pine sergeant” and is more accurate than the other names. These birds feed on insects they find in tree bark or bromeliads (locally known as “wild-pines”) and are adapted to climbing trees, similar to woodpeckers. They inhabit the montane forests of Jamaica and are arranged in pairs of birds, each pair occupying a vast territory. The severe deforestation caused

by mining, forestry, charcoal production and agriculture has led to an extreme habitat loss incompatible with the blackbirds’ large territories. The species is thus considered endangered, but only some very shy efforts have been made towards its preservation.

### **Sad Flycatcher (*Myiarchus barbirostris*)**

The sad flycatcher (together with the lesser Antillean pewee, *Contopus latirostris*) is commonly called little Tom-fool by the Jamaican people, for its habit of refusing to fly away when threatened. This flycatcher species inhabits the forests of Jamaica and, as their name imply, feed on insects. In fact, the genus name comes from the Greek *muia* (fly) and *archos* (ruler), while the specific epithet refers to the presence of rictal bristles. These bristles are modified feathers (that look like mammals’ whiskers) projecting from the beak; they not only provide tactile feedback (as whiskers do), but also supposedly protect the birds’ eyes as they consumes their wriggly insect prey.



The sad flycatcher, *Myiarchus barbirostris*. (Source: Wikimedia Commons.)

To avoid confusion, we must note here that the sad flycatcher is part of the group known as “New World flycatchers” or “tyrant flycatchers”

(the family Tyrannidae). The “Old World flycatchers” belong to another family, Muscicapidae, which is only distantly related to the Tyrannidae.

### **Jamaican Crow (*Corvus jamaicensis*)**

This bird is locally known as “jabbering crow” or “gabbling crow”, for it can produce a variety of jabbering sounds (besides the common “caw” of crows). Their incessant jabbering may also sound like indistinct human languages and, to the British, rather like Welsh people, which led to the birds being nicknamed “Welshmen” in a typical bout of Brit humor.

The Jamaican crows live mainly in the country’s uplands, but may come down to the lowlands during the dry season. They feed

mainly on fruit and invertebrates, but may occasionally eat other birds’ eggs and nestlings.



The Jamaican crow, *Corvus jamaicensis*. (Source: Internet Bird Collection, IBC155934. Courtesy of Ken Simonite.)

### **Box 2. Bond bird-trivia**

- Ian Fleming, in 1964, gave a first edition copy of “You Only Live Twice” as a gift to James Bond (the ornithologist). He signed: “To the real James Bond, from the thief of his identity”. This copy was auctioned for over \$80,000 in 2008.
- Fleming, used a large bird sanctuary, on Inagua, Bahamas, as the setting for the novel “Dr. No” (1958).
- The red-billed streamertail, or doctor bird (*Trochilus polytmus*), is featured in the short story “For Your Eyes Only” (see the main text for more information).
- In the film “Die Another Day” (2002), there is a scene in Havana, Cuba, where Bond (played by Pierce Brosnan) is examining the book “Birds of the West Indies”. The name of the book’s author (the real James Bond) is obscured on the cover. Later, Bond introduces himself as an ornithologist to Jinx (played by Halle Berry).
- The book “Birds of the West Indies” also appear in the biographical film “Goldeneye: The Secret Life of Ian Fleming” (1989) and on a teaser image of the still-unreleased film “Specter” (2015).
- In the episode “A Caribbean Mystery” (2013) of the TV series “Agatha Christie’s Marple”, Miss Marple meets Ian Fleming at a talk by James Bond on the birds of the West Indies. Before the talk, Fleming says that he is writing a book and needs a name for his protagonist. When the ornithologist introduces himself, Fleming has an insight, reaching for his notebook. The talk features guano, which is related to the plot of the Dr. No novel.

### **YOU ONLY LIVE TWICE**

Bond’s work with the Caribbean avifauna set the basis for ornithology in the region and most of his insights have been continuously proved accurate. As such, his influence in science shall remain relevant for a long time to come. Well, at least until humans have extinguished all the bird species in the region – unfortunately, birds live

only once and Jamaica has already lost three of its endemic species. Meanwhile, the other Bond also remain a relevant figure in popular culture and imagination, with his over-the-top stories, exotic locations, strange villains, Bond girls, fancy suits, weaponized cars and a number of crazy gadgets. James Bond has thus the (somewhat dubious) honor of having his name

twice immortalized in History, as a brilliant ornithologist and as a womanizing superspy. (We believe the latter is better remembered than the former though.)

But for those of you thinking that a birder's life is much duller than a spy's life, some words from the naturalist and writer Alexander F. Skutch (1904–2004) might change your mind or at the very least make you revisit your beliefs: “our quest of them [birds] takes us to the fairest places; to find them and uncover some of their well-guarded secrets we exert ourselves greatly and live intensely.”

## REFERENCES

- Avibase.** (2015) Bird Checklists of the World. Jamaica. Available from: <http://avibase.bsc-eoc.org/checklist.jsp?region=jm&list=clements> (Date of access: 02/Apr/2015).
- Bond, J.** (1993) A Field Guide to the Birds of the West Indies. Fifth edition (Peterson Field Guides). Houghton Mifflin Harcourt, Boston.
- Bond, M.F.W.P.** (1966) How 007 Got His Name. Collins, London.
- Cassidy, F.G.** (2006) Jamaica Talk: Three Hundred Years of the English Language in Jamaica. University of the West Indies Press, Kingston.
- Clements, J.F.; Schulenberg, T.S.; Iliff, M.J.; Roberson, D.; Fredericks, T.A.; Sullivan, B.L.; Wood, C.L.** (2014) The eBird/Clements checklist of birds of the world. Version 6.9. Available from: <http://www.birds.cornell.edu/clementschecklist/download/> (Date of access: 02/Apr/2015).
- Chancellor, H.** (2005) James Bond: The Man and His World. John Murray, London.
- Cruz, A.** (1978) Adaptive evolution in the Jamaican Blackbird *Nesopsar nigerrimus*. *Ornis Scandinavia* 9(2): 130–137.
- IUCN (International Union for Conservation of Nature).** (2014) The IUCN Red List of Threatened Species. International Union for Conservation of Nature and Natural Resources. Available from: <http://www.iucnredlist.org/> (Date of access: 03/Apr/2015).
- Lederer, R. & Burr, C.** (2014) Latin for Bird Lovers. Timber Press, New York.
- MI6-HQ.** (2015) MI6 – The Home of James Bond 007. Available from: <http://www.mi6-hq.com/> (Date of access: 02/Apr/2015).
- Parker, M.** (2015) Goldeneye. Where Bond Was Born: Ian Fleming's Jamaica. Pegasus Publications, Winnipeg.
- Parkes, K.** (1989) In Memoriam: James Bond. *The Auk* 106(4): 718–720.
- Rothschild, W.** (1907) Extinct Birds. An attempt to unite in one volume a short account of those birds which have become extinct in historical times – that is, within the last six or seven hundred years. To which are added a few which still exist, but are on the verge of extinction. Hutchinson & Co., London.
- Salvador, R.B.** (2014) Geeky nature. *Journal of Geek Studies* 1(1-2): 41–45.
- Skutch, A.F.** (1977) A Bird Watcher's Adventures in Tropical America. University of Texas Press, Austin.



## Modeling and analysis of a Zombie Apocalypse: zombie infestation and combat strategies

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Humanity can be quite creative when it comes to thinking up of interesting and fictional ways of being completely annihilated by (and also of ways of romancing) fantastical monsters. Though most people tend to believe that humanity's intelligence and sense of self-preservation will make us find creative ways to overcome nature's challenges, it is also believed that man will inevitably be creative in eventually deploying its own demise. In the present work, I will focus on one of the most popular apocalyptic themes of modern pop culture, the zombies.

Ogg (2011) comments how, in modern times, the zombie genre has evolved from a cult to a highly popular theme, estimating its monetary worth as over 5 billion dollars. Zombies are present in movies, books, comics, video games, television series, various toys and products, and even have their own parades.

The zombie apocalypse, though, should not be treated so lightly. After the initial hype, a zombie infestation is likely to bring some problems to civilization as we know it. As such, I believe that there is not sufficient work focusing on zombies and/or how to survive their

potential threat. (Though most people tend to believe that a zombie attack is unlikely, the effects of such attack would be relevant; thus, it should be better understood.) Here is presented a discrete-time model of a zombie apocalypse where some parameters are used to control the combat strategies deployed against the infestation.

### LITERATURE REVIEW

According to Brooks (2003), a zombie is a reanimated human corpse that feeds on living human flesh (or just brains, depending on the reference). Through a list of recorded attacks, Brooks suggest that zombies might have been in existence since 60.000 BCE (though such record is doubtful to say the least).

The stories about zombies probably originated in the Afro-Caribbean system of Vodou (or voodoo), where people were described as being controlled by a powerful sorcerer. The movie *White Zombie*, from 1932, is widely considered the first zombie movie, but it was the 1968 movie *Night of the Living Dead* that made the walking dead theme truly popular, giving birth to the zombie genre.



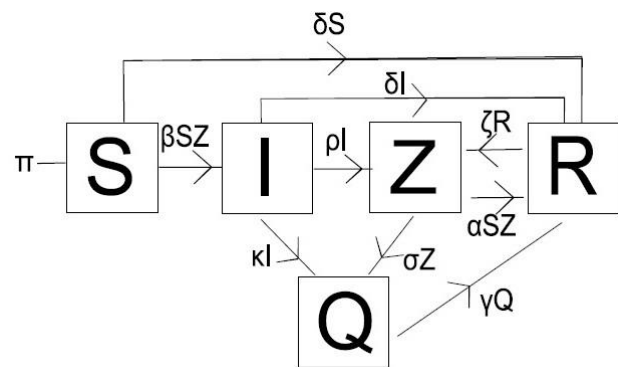
Contemporary zombies are depicted as mindless monsters that do not feel pain and have nothing but appetite for human flesh, wandering aimlessly intending to kill/eat (and, consequently, infect) people. For more information, interesting references are Brooks (2003), Munz et al. (2009) and Fobiya et al. (2013).

Some works were recently published focusing on zombie outbreaks. These books focus on self-defense and organization of the population against zombies, or against other humans after the zombie outbreak inevitably happens (Brooks, 2003; Fobiya et al., 2013).

A seminal work by Munz et al. (2009) proposed a mathematical model of a zombie outbreak. The authors used a structure known as an “Epidemic Model” for their work. Epidemic models are simplified means of describing the transmission of communicable disease through individuals, the earliest mathematical modeling of the spreading of diseases being carried out in 1766 by Daniel Bernoulli (for more info, see [http://en.wikipedia.org/wiki/Epidemic\\_model](http://en.wikipedia.org/wiki/Epidemic_model)).

After the work of Munz et al. (2009), many others developed their own models: Calderhead et al. (2010), Idu & Oladele (2010), Flanagan (2012), Blais & Witkowski (2013). These models differ from each other on some of their premises. Munz et al. (2009), for instance, considered four different scenarios: (1) the SZR scenario, where the population consisted of susceptible (or “normal”) humans (S), zombies (Z), and removed individuals (R; humans that died naturally or zombies that were destroyed); (2) the SIZR scenario, where a “latent infection” stage was added (I), where the individual took time before becoming a zombie; (3) the SIZRQ

scenario, where a quarantined area (Q) was created to contain both infected individuals and zombies (the flowchart of this last model can be seen on Figure 1); (4) the model with treatment, where a cure for the infection could be developed quickly, in a way that a treatment would be able to revert a zombie to its normal human self. The models of Munz et al. (2009) are similar to the well-known SI / SIS / SIR epidemic models (for more information, see Allen, 1994), where the population may consist of susceptible, infected and removed individuals (the removed are those that cannot be infected again).

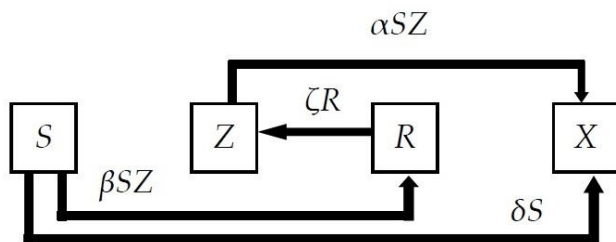


**Figure 1.** Flowchart of the SIZRQ model. Reproduced from Munz et al. (2009).

Both Calderhead (2010) and Idu & Oladele (2010) reproduced the SZR model. The former shows the difficulties in estimating parameters for predicting the outcome of a zombie outbreak, while the latter presents a hypothetical scenario where the dead could resurrect as normal humans in order to offer analogies with different kinds of studies (such as allegiance to political parties).

One of the biggest limitations of the model presented by Munz et al. (2009) was the fact that the destroyed zombie could always be

“resurrected”. Both Flanagan (2012) and Blais & Witkowski (2013) thus proposed a model where the zombie could be permanently removed. The model with permanent removal presented by Blais & Witkowski can be seen in Figure 2.



**Figure 2.** Model where individuals can be susceptible (S), temporarily removed (R), zombie (Z) or permanently removed (X). Reproduced from Blais & Witkowski (2013).

All the previous works showed that the zombie outbreak would have quite bad consequences for the human species, resulting on the extinction of the susceptible population. Most works also showed that the infection would act so fast that the natural birth and death rates would be pretty much irrelevant for the purposes of the simulation. Finally, the previous authors worked with the simulation paradigm of System Dynamics (SD), one of the earliest paradigms that works with “rates”, “levels” and “feedback loops” (for more information, see Pruyt, 2006).

I believe that a scenario where the human population becomes extinct is quite bad, and that simulation models should be less fatalist when treating such themes, proposing combat strategies instead of only showing the results of an outbreak. As such, I will present a simulation model based on the Discrete-Event Simulation (DES) paradigm where some combat strategies

will be explored, with the intention of developing the best course of action.

## THE SIMULATION MODEL

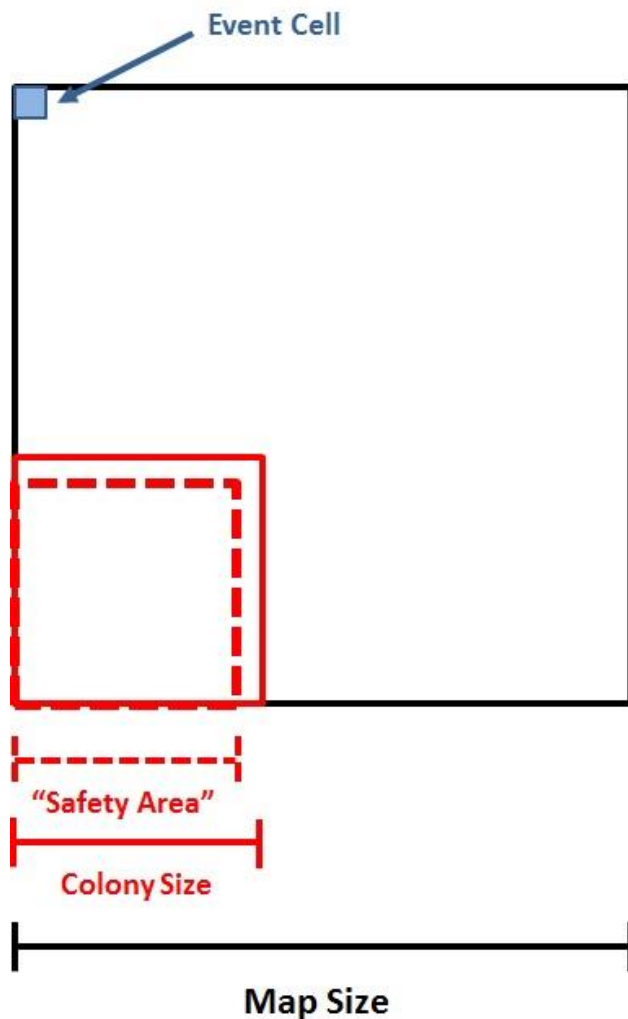
First, a “map” where the infection takes place is defined (Figure 3). The map is a square with side length  $m$ . Inside the map, a square area with side length  $c$  is defined as the human colony. Inside the human colony, another square with side length  $\mu \cdot c$  is defined as the “safety” area, where  $\mu$  is a “safety factor” between 0 and 1. Finally, the size of an “event cell” is defined as  $e$ . The event cell is where the events (encounters) of the simulation take place.

Inside the map, a number  $n$  of humans and  $z$  of zombies are randomly placed. The humans are distributed inside the colony while the zombies are distributed outside of it.

The simulation model is based on the Discrete-Event Simulation (DES) Paradigm. In the System Dynamics (SD) Paradigm mentioned above (used by all the previously cited authors), the infestation is modeled as a system of nonlinear equations, which causes a complex behavior of feedbacks that are continuous in time. The DES, in turn, focuses on the discrete events that cause changes on the states of the system, considering that no changes occur between events. One of the advantages of the DES is that, since no change occurs in the system outside of the events, the simulation can directly jump in time from one event to the next, usually running faster than the corresponding continuous simulation.

A great advantage of adopting the DES instead of the SD Paradigm for this simulation is that it is easier to insert and analyze

nondeterministic factors on the equations, such as the chances of a susceptible human being infected by a zombie on an encounter. It also becomes possible to simulate phenomena that follow probabilistic distributions, making them more realistic (and susceptible to chance).



**Figure 3.** Map of the simulation model.

On this model, I considered that the events happen in “turns”. On each turn, the following sequence of events happens:

- a) Humans move on the map;
- b) Zombies move on the map;

- c) The event cells that have individuals inside them are defined;
- d) The encounter inside each event cell is simulated;
- e) The status of each individual is updated;
- f) Turn restarts.

On this model, zombie infection was treated as a disease that only affects living beings, not as an act of necromancy. The disease is transmitted through contact with an infected individual. Six different categories of individuals were defined for my simulation: susceptible humans (S), active zombies (Z), inactive zombies (I), destroyed corpses (X), trained humans with weapons (W), and trained humans with vaccines (V). All humans start as susceptible humans. The difference between inactive zombies (I) and destroyed corpses (X) is that the latter are permanently removed from the simulation (killed), while the former can be cured back to human form, or reanimated as active zombies.

The movements of humans and zombies have the following rules:

- a) If the human is inside the safety area of the map, he/she moves randomly in any direction;
- b) If the human is outside of the safety area, he/she moves randomly with a slightly higher probability of returning to the safety area;
- c) Zombies always move randomly in any direction;
- d) Inactive zombies and destroyed corpses do not move.

After all the individuals have moved, the event cells that will be simulated are defined.

Each cell that has at least one individual inside will simulate the following events.

**(1) All humans have a chance of becoming a zombie, where the chance of this happening is:**

$$P_Z = i \cdot \left( \left( 1 - \left( \frac{1}{1 + 5 \cdot n_Z} \right) \right) - \left( 1 - \frac{2}{(1 + n_S + 2 \cdot n_V + 3 \cdot n_W)} \right) \right)$$

Where:  $i$  = infection rate;  $n_Z$  = number of zombies inside the same event cell as the human;  $n_S$  = number of susceptible humans inside the same event cell as the human;  $n_V$  = number of trained humans with vaccine inside the same event cell as the human;  $n_W$  = number of trained humans with weapons inside the same event cell as the human.

With this equation, it is possible to see that the higher the number of zombies in the same event cell as the human, the higher the probability of him/her being contaminated. Likewise, the higher the number of humans in the same event cell, the lower the probability of him/her being contaminated. It is also possible to see that trained humans with vaccines and weapons have a greater influence in the probability than simple susceptible humans.

As an example, the chance of a human being contaminated if he is alone with one zombie on the same cell is 83.3%. If there are two zombies, the probability goes to 90.9%. If there is only one zombie and one trained human with a weapon, the probability is only 33.3%.

**(2) All zombies have a chance of being “cured”, “defeated” (become inactive) or completely destroyed:**

The probability of a zombie being cured is calculated as:

$$P_{C1} = h \cdot \left( 1 - \frac{1.5}{(1 + n_V)} \right)$$

Where:  $h$  = cure rate.

The probability of a zombie being completely destroyed is calculated as:

$$P_{X1} = \frac{\left( 1 - \frac{1.9}{(1 + n_S + n_V + 2.8 \cdot n_W)} \right)}{(2 \cdot n_Z^2)}$$

And the probability of a zombie being “defeated” (becoming inactive) is calculated as:

$$P_I = \frac{\left( 1 - \frac{1.9}{(1 + n_S + n_V + 2.8n_W)} \right)}{(n_Z^2)}$$

**(3) All inactive zombies have a chance of being reanimated as zombies, cured, or being completely destroyed:**

All inactive zombies have a probability  $r$  of being reanimated if they are on the same event cell as another active zombie, where  $r$  is defined as a reanimation rate.

The probability of an inactive zombie being cured is calculated as:

$$P_{C2} = \frac{\left( 1 - \frac{1}{(1 + 3 \cdot n_V)} \right)}{(1 + 2 \cdot n_Z^2)}$$



The probability of an inactive zombie being completely destroyed is calculated as:

$$P_{x2} = \frac{\left(1 - \frac{1}{(1 + 0.3 \cdot n_S + 6 \cdot n_W)}\right)}{(1 + 2 \cdot n_Z^2)}$$

Four other important parameters for the simulation are: the time necessary for training and equipping humans to fight zombies and the percentage of the population that will be trained and equipped (respectively,  $T_W$  and  $\alpha_W$ ); and the time necessary for developing a cure and the percentage of the population that will be trained to administrate it (respectively  $T_V$  and  $\alpha_V$ ). After the first case of contamination (first susceptible human becomes a zombie), it takes a time  $T_W$  for the authorities to train and equip the population with weapons, and a time  $T_V$  to do the same with the vaccines.

One important point is that every zombie that is cured comes back as a susceptible human. It is considered that all equipment he had before being infected is lost, and he is no longer capable of fighting with the same efficiency after the contamination.

The objective of the simulation is to define the best strategy to contain a zombie infestation, considering:

- a) Which is the ideal size of a human colony;
- b) Once the first case of contamination is discovered, how quickly must the population be trained and equipped with weapons;
- c) Which is the best setup of weapons / vaccines to ensure the survival of as many humans as possible.

## SCENARIOS AND RESULTS

Once the model was finished, some scenarios were defined to test it.

I conducted many simulations, trying to understand how each parameter affects the results. One limitation found in the model is its high instability due to the stochastic events (more about this limitation is discussed on the next section). Because of this problem, the conclusions that can be drawn from the model are limited. I present here only the most relevant simulations conducted, and will further discuss their implications on the next section.

Firstly, some parameters were stipulated at the beginning of the tests and were not changed in any scenario. The infection, cure and reanimation rate were fixed respectively as **1.0**, **1.0** and **0.8**. The map and cell size were fixed respectively as **100** and **4**, the number of individuals was stipulated as **8,000** and the initial number of zombies was defined as **12**. Finally, the “safety factor” was defined as **0.9**.

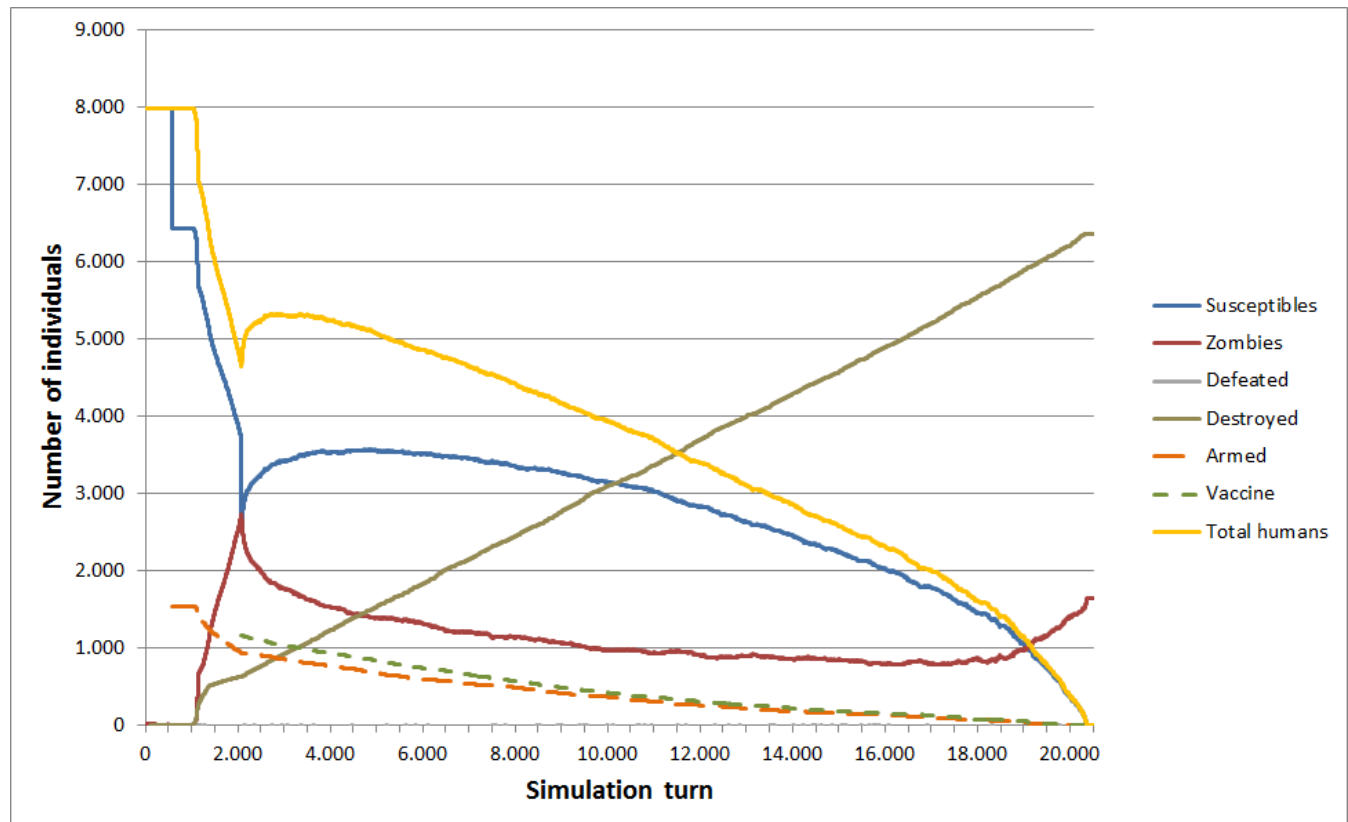
It is interesting to note that in no scenario zombies stayed inactive for long, being either reanimated, destroyed or cured very quickly.

On the first scenario (Figure 4), the time necessary to train and arm **20%** of the population was defined as **500 turns** after the first infection. The time necessary to develop the vaccine and train **30%** of the population on how to use it was stipulated as **2,000 turns** after the first infection. The colony side length was defined as **40** (40% of the map size).

As a result, humans were extinct after around 20,000 turns, with close to 6,500 individuals being destroyed and 1,500 zombies remaining at the end. After the zombies

“invaded” the human colony, the infection began to spread quickly. Once the population was trained and armed, the rate of infection got slower and the rate of zombie destruction got higher. Once the population was equipped with vaccines, the number of susceptible humans slowly rose for a while. Humanity’s demise was

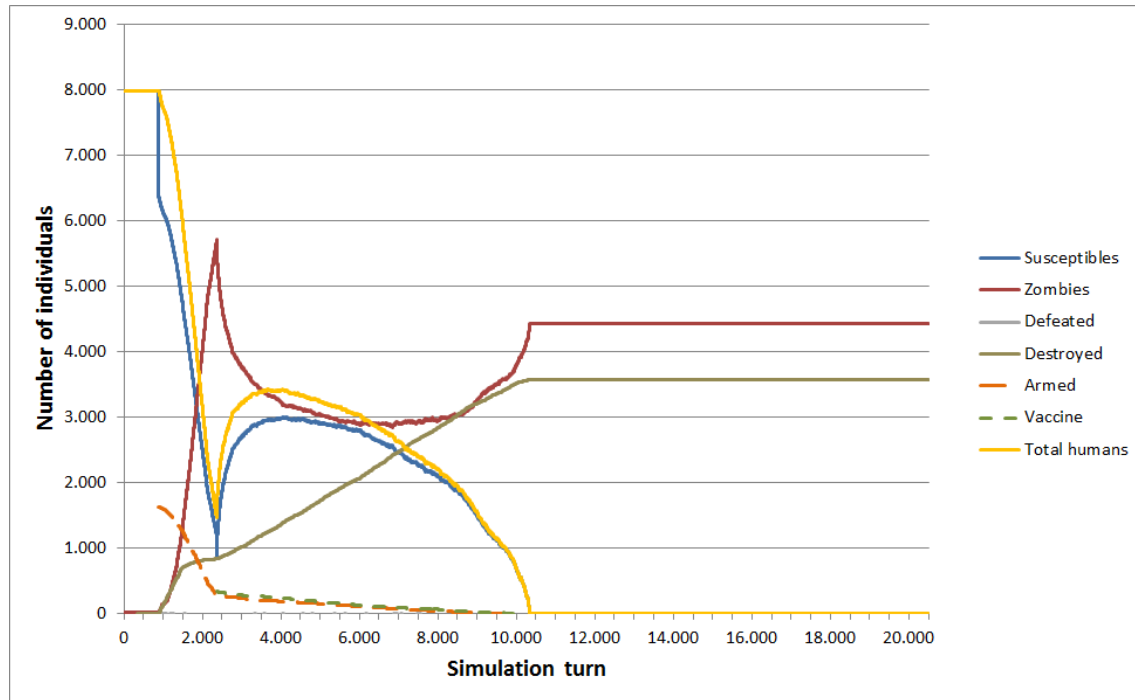
that the zombie infestation had already gotten out of control, with way too many zombies. Since a cured zombie comes back as a simple susceptible human, the number of humans that were equipped with weapons or vaccines slowly went down and humanity was overrun by zombies.



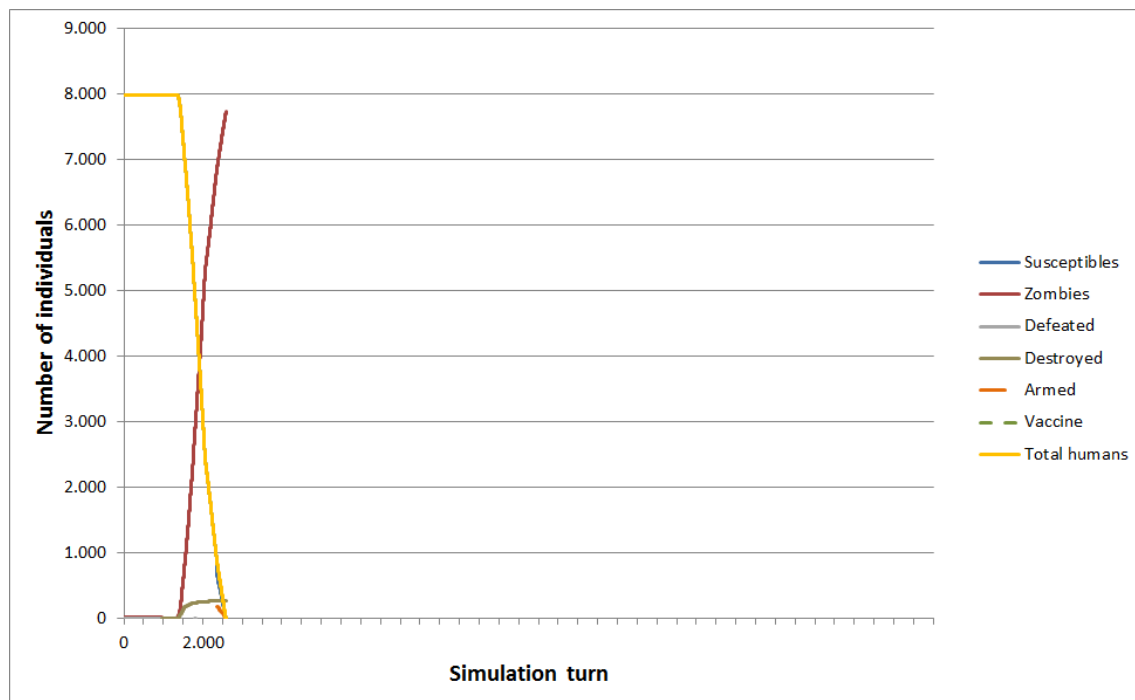
**Figure 4.** First scenario. – Infection rate: 1.0. Cure rate: 1.0. Reanimation rate: 0.8.  $T_W$ : 500.  $\alpha_W$ : 0.2.  $T_V$ : 2,000.  $\alpha_V$ : 0.3.  $n$ : 8,000.  $z$ : 12.  $m$ : 100.  $c$ : 40.  $e$ : 4.  $\mu$ : 0.9.

On the second scenario (Figure 5), the colony side length was reduced to **24**. As a result, humans became extinct sooner, after around 10,000 turns, with close to 3,500 individuals being destroyed and 4,500 zombies remaining. Since humans were restricted to a smaller area, it is reasonable to assume that the infection spread more quickly after the zombies invaded the colony.

On the third scenario (Figure 6), the colony side length remained **24**, and the time necessary to arm the population increased to **1,000 turns**. As a result, humans became extinct very quickly. Once the population was trained and armed, the number of zombies was already overwhelming and there was nothing to be done. Humans became extinct after close to 1,000 turns and more than 7,500 zombies were left at the end.



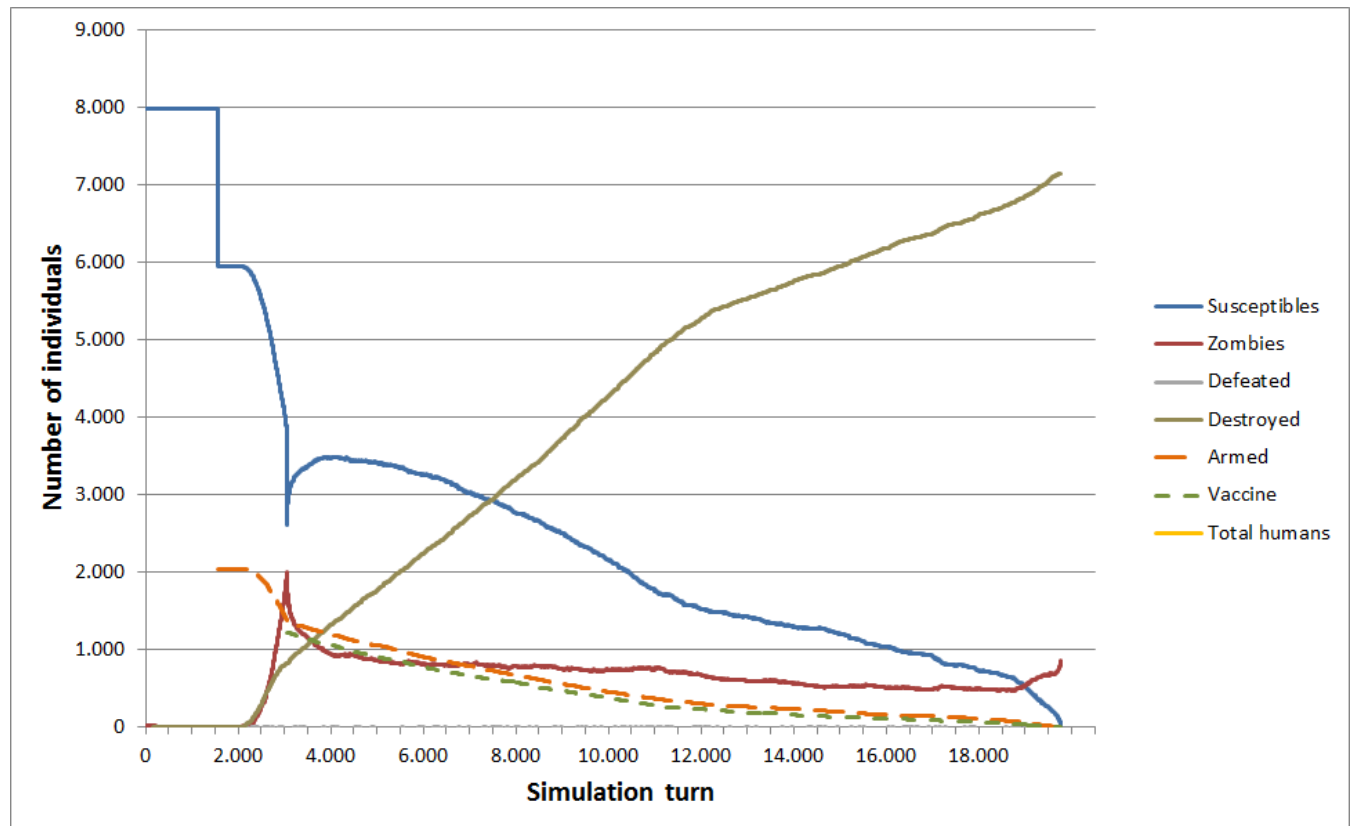
**Figure 5.** Second scenario. – Infection rate: 1.0. Cure rate: 1.0. Reanimation rate: 0.8.  $T_W$ : 500.  $\alpha_W$ : 0.2.  $T_V$ : 2,000.  $\alpha_V$ : 0.3.  $n$ : 8,000.  $z$ : 12.  $m$ : 100.  $c$ : 24.  $e$ : 4.  $\mu$ : 0.9.



**Figure 6.** Third scenario. – Infection rate: 1.0. Cure rate: 1.0. Reanimation rate: 0.8.  $T_W$ : 1,000.  $\alpha_W$ : 0.2.  $T_V$ : 2,000.  $\alpha_V$ : 0.3.  $n$ : 8,000.  $z$ : 12.  $m$ : 100.  $c$ : 24.  $e$ : 4.  $\mu$ : 0.9.

On the fourth scenario (Figure 7), the percentage of the population trained and equipped with weapons went up from 20% to **25%**, and the time necessary to do so returned to **500 turns** after the first infection. As a result, the initial surge of contamination was partially contained, with a peak of close to 2,000 zombies

at the time the vaccine was distributed (lower than in the previous scenarios). Similarly to the first scenario, though, the zombies slowly managed to contaminate humans equipped with weapons and vaccines, resulting, once again, on the extermination of humanity after close to 20,000 turns.



**Figure 7.** Fourth scenario. – Infection rate: 1.0. Cure rate: 1.0. Reanimation rate: 0.8.  $T_W$ : 500.  $\alpha_W$ : 0.25.  $T_V$ : 2,000.  $\alpha_V$ : 0.3.  $n$ : 8,000.  $z$ : 12.  $m$ : 100.  $c$ : 24.  $e$ : 4.  $\mu$ : 0.9.

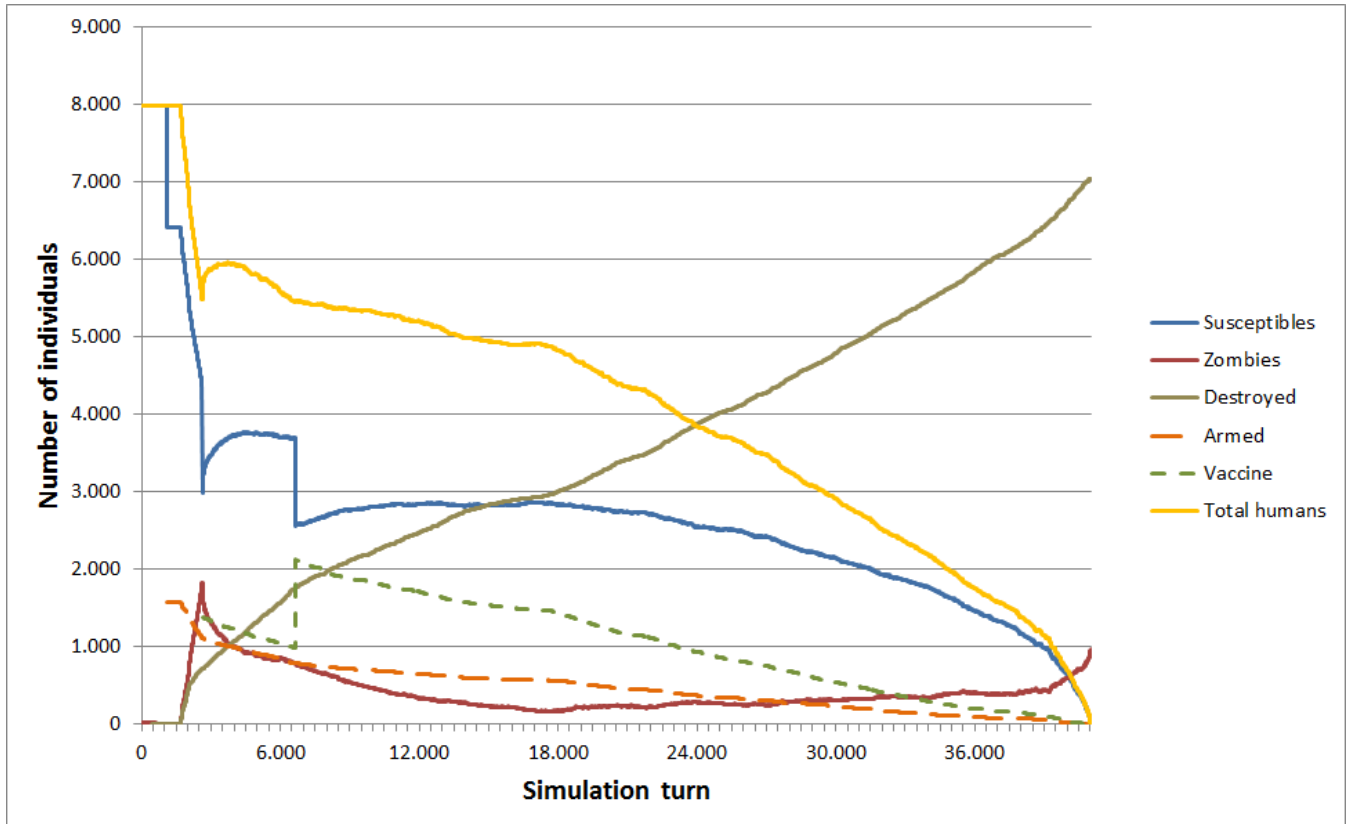
At this point, I was starting to get worried that humanity might not manage to survive a zombie apocalypse. As such, I started developing scenarios with more aggressive anti-zombie policies, where vaccines would be distributed more than once among the population. Also, I returned the colony size to **40**.

On the fifth scenario (Figure 8), the percentage of the population trained and equipped with weapons went back to **20%**, and the time necessary for this was kept at **500 turns** after the first infection. After an initial time necessary to develop the vaccine and train **30%** of the population on how to use it stipulated as  $T_{V1} = 2,000$  turns after the first infection, a



second time of distributing vaccines was stipulated as  $T_{V2} = 6,000$  turns. For my despair, though, humanity was once again exterminated

after a long battle. The zombies were close to be eradicated after 18,000 turns, but slowly regained the upper hand.



**Figure 8.** Fifth scenario. – Infection rate: 1.0. Cure rate: 1.0. Reanimation rate: 0.8.  $T_W$ : 500.  $\alpha_W$ : 0.20.  $T_{V1}$ : 2,000.  $\alpha_{V1}$ : 0.3.  $T_{V2}$ : 6,000.  $\alpha_{V2}$ : 0.3.  $n$ : 8,000.  $z$ : 12.  $m$ : 100.  $c$ : 40.  $e$ : 4.  $\mu$ : 0.9.

Finally, a sixth and last scenario (Figure 9) was created. Deciding to defeat the zombies at all costs, four moments of vaccine distribution were stipulated at turns **2,000**; **6,000**; **10,000**; and **15,000**. Finally, humanity managed to eradicate the zombies, but with the loss of 3,000 lives.

## CONCLUSION

Herein, a mathematical model of a zombie outbreak was successfully developed and tested. With the results of the simulation, it is

possible to draw the following conclusions (Table 1 summarizes the main results).

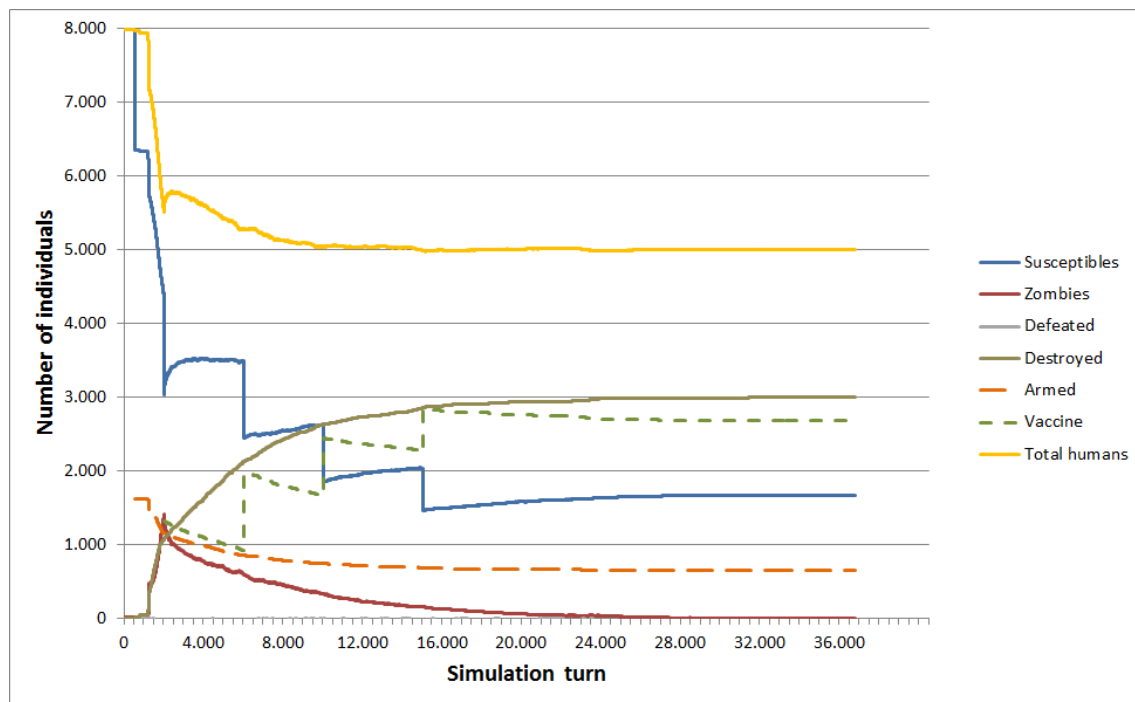
The size of the human colony impacts significantly the results of the outbreak, which varies according to the colony's organization. Unless the human settlement is capable of organizing itself quickly and efficiently to combat a zombie attack, the model recommends that you run away from highly populated areas if you want to survive. This conclusion is compatible with the study made by Alemi et al. (2015). Similarly, Brooks (2003) identify urban centers as one of the most

dangerous places to be when zombie outbreaks start. Since the objective of the present study is to preserve humanity, not individual survival, I believe it is important that urban centers be better prepared for outbreaks, to respond accordingly when they happen.

The model also suggests that it is important to react to a zombie infestation as quickly as possible to contain the initial outbreak, avoiding a “point of no return”, when the zombies slowly gain ground over the remaining humans. Initially, I believed that the model would be interesting to show the tradeoff between weapons (killing the zombies) and vaccines (avoid killing zombies while trying to cure them). It became evident, however, that zombies are quite dangerous when not quickly taken care of, since their numbers can grow exponentially. If humans want to survive, containing the initial

wave of zombies with weapons is unavoidable (interestingly, this topic was never touched upon in previous works).

In addition, I believe that the model has room for many improvements and is far from ideal if we want to actually develop anti-zombies combat strategies. One idea is to use yet another simulation paradigm, namely the “Agent Based Modeling” (ABM), which is much more recent than the SD and DES. The ABM is useful to simulate interactions of autonomous individuals acting according to simple rules. With such model, it would be possible to further develop human actions and strategies, for example: making humans walk in groups (preferably with one armed individual) and having a better logic in the direction of their movements.



**Figure 9.** Sixth scenario. – Infection rate: 1.0. Cure rate: 1.0. Reanimation rate: 0.8.  $T_W$ : 500.  $\alpha_W$ : 0.2.  $T_{V1}$ : 2,000.  $\alpha_{V1}$ : 0.3.  $T_{V2}$ : 6,000.  $\alpha_{V2}$ : 0.3.  $T_{V3}$ : 10,000.  $\alpha_{V3}$ : 0.3.  $T_{V4}$ : 15,000.  $\alpha_{V4}$ : 0.3.  $n$ : 8,000.  $z$ : 12.  $m$ : 100.  $c$ : 40.  $e$ : 4.  $\mu$ : 0.9.

**Table 1.** Summary of each scenario.

Scenario	c	Tw	aw	Tv	av	Number of vaccine distributions	Results
1	40	500	20%	2000	30%	1	Humanity exterminated after 21,000 turns
2	24	500	20%	2000	30%	1	Humanity exterminated after 10,000 turns
3	24	1000	20%	2000	30%	1	Humanity exterminated after 2,000 turns
4	24	500	25%	2000	30%	1	Humanity exterminated after 20,000 turns
5	40	500	20%	2000	30%	2	Humanity exterminated after 39,000 turns
6	40	500	20%	2000	30%	4	Zombies exterminated after 36,000 turns

Another problem with the model is that it is highly unstable and sensitive to modifications on its parameters, since most events are stochastic (from movement of the individuals on a big map, to the outcome of the encounters) and a different result of each event has a great and chaotic impact on the rest of the simulation (for instance, having two armed humans become zombies instead of none on an encounter). As such, most of the conclusions presented here should be approached carefully and, for that reason, I did not dare to present a curve of the impact of each parameter.

Most importantly, further work must be conducted to better define the parameters of the simulation. I do not have sufficient data to estimate the chances of a human being infected by a zombie upon an encounter, nor do I know how long it would take to develop a cure for the zombification. It is also quite possible that the impact of being trained and having a weapon in a zombie apocalypse is being overestimated on my model, since I probably would be quite unsettled if an undead was trying to eat my flesh.

## REFERENCES

- Alemi, A.A.; Bierbaum, M.; Myers, C.R.; Sethna, J.P.** (2015) You Can Run, You Can Hide: The Epidemiology and Statistical Mechanics of Zombies. Quantitative Biology. Cornell University Library. Available from: <http://arxiv.org/abs/1503.01104> (Date of access: 15/May/2015).
- Allen, L.J.S.** (1994) Some Discrete-Time SI, SIR, and SIS Epidemic Models. *Mathematical Biosciences* 124: 83–105.
- Blais, B. & Witkowski, C.** (2013) Zombie Apocalypse: An Epidemic Model. Available from: <http://terpconnect.umd.edu/~jzsimon/hlsc374/ref/Blais+Witkowski-handout-2013.pdf> (Date of access: 06/May/2015).
- Brooks, M.** (2003) *The Zombie Survival Guide: Complete Protection from the Living Dead*. Three Rivers Press, New York.
- Calderhead, B.; Girolami, M.; Higham, D.J.** (2010) Is it safe to go out yet? Statistical Inference in a Zombie Outbreak Model. Available from: <http://www.strath.ac.uk/media/departments/mathematics/researchreports/2010/6zombierep.pdf> (Date of access: 06/May/2015).

- Flanagan, K.M.** (2012) *Zombie Attack! An Introduction to Quantitative Modeling*. National Center for Case Study Teaching in Science. University of Calgary, Alberta, Canada. Available from: <http://sciencecases.lib.buffalo.edu/cs/files/zombie.pdf> (Date of access: 06/May/2015).
- Fobiya, A.; Ottoni, A.; Pazos, D.** (2012) *Protocolo Bluehand: Zumbis: Seu guia definitivo contra os mortos e os vivos*. Nerdbooks, Curitiba.
- Idu, E.I. & Oladele, R.O** (2010) *An Epidemic of Zombie Infection: A mathematical Model*. Available from: [https://www.unilorin.edu.ng/publications/oladele/Zombie\\_paper.pdf](https://www.unilorin.edu.ng/publications/oladele/Zombie_paper.pdf) (Date of access 27/Mar/2015).
- Levin, S.A.; Greenfell, B.; Hastings, A.; Perelson, A.S.** (1997) *Mathematical and Computational Challenges in Population Biology and Ecosystems Science*. Science, Vol. 275(5298): 334–343.
- Munz, P.; Hudea, I.; Imad, J.; Smith, R.J.** (2009) *When zombies attack! Mathematical modelling of an outbreak of zombie infection*. In: Tchuenche, J.M. & Chiyaka, C. (Eds.) *Infectious Disease Modelling Research Progress*. Nova Science Publishers, Hauppauge. Pp. 133–150.
- Ogg, J.C.** (2011) *Zombies worth over \$5 billion to economy*. Available from: <http://www.nbcnews.com/id/45079546/ns/business#.VRW2gvnF8pk> (Date of access: 06/May/2015).
- Pruyt, E.** (2006) *What is System Dynamics? A Paradigmatic Inquiry*. In: Größler, A.; Rouwette, E.A.J.A.; Langer, R.S.; Rowe, J.I.; Yanni, J.M. (Eds.) *Proceedings of the 24th International Conference of the System Dynamics Society*. System Dynamics Society, Nijmegen. Pp. 102.





## Turtles with cannons: an analysis of the dynamics of a Blastoise's Hydro Pump

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As any normal 10-year-old, I chose Charmander as my starter in Pokémon Blue. I would demolish any and every Pokémon that came after me and my little (pseudo-)dragon, but Blue's (or Green's, depending on which game you were playing) Squirtle and its evolutions would always put a big dent on my flaming lizard's health, even KO'ing him sometimes. Losing my beloved Charizard would leave me with an undertrained Pidgey and some other HM slaves, so Blastoise did leave a sour taste in my mouth growing up. As a kid, I had a hard time understanding how that big fat turtle/tortoise could hurt so much my giant fire-breathing monster, but now, as a bigger kid, I decided to take a more detailed look at Blastoise's power.

### HYDRO PUMP ESTIMATION

Bulbapedia (2015) states that Blastoise is 1.6 m tall and, from images from the anime, its shell was determined to be of ellipsoidal shape, with axes of around 1.32 m, 1.33 m and 1.42 m (Figs. 1–3). Its volume can then be calculated as follows:

$$Volume = \frac{\pi \cdot a \cdot b \cdot c}{6}$$

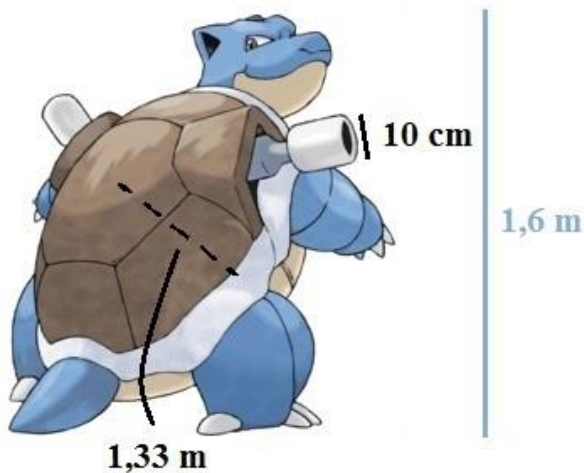
Where  $a$ ,  $b$  and  $c$  are the lengths of the axes, which yields an internal volume of 1.305 m<sup>3</sup>. If the carapace were filled half with organs and muscles and half with water, there would be approximately 653 liters of liquid stored in it. The cannon's diameter was assumed to be around 10 cm each.



**Figure 1.** Blastoise, as seen on the anime. Image modified from a screenshot.

To calculate how strong its water attack is, a Hydro Pump (which has 5 Power Points [PPs], meaning that the Blastoise can use Hydro Pump 5 times) was compared to a water cannon. Information about water cannons can be found in a study made by The Omega Research

Foundation (2000), which is an independent UK-based research organization (Fig. 4). This paper states that low pressure water jets have a pressure of about 150 psi (1.03 MPa), and some modern ones can have as much as 360 psi (2.48 MPa). As Bainbridge (2014) says, Pokémons are supernatural creatures that possess spiritual and supernatural powers (even Blastoses, I guess), so it will be assumed that the water in the shell is stored at 360 psi, the higher value.

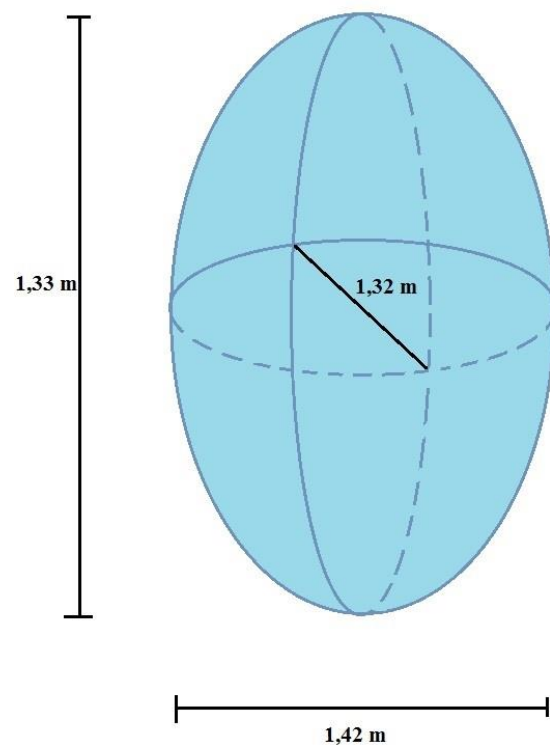


**Figure 2.** *Blastoise sideways. Image modified from the official art by Ken Sugimori. (Source: Bulbapedia.)*

As the cannons are short tubes and the only losses come from its entrances and exits, which amount to very little, the losses will be considered negligible. The time needed for the water to accelerate will also be considered negligible, since there is a big pressure gradient and no obstacles to the flow. This way, all this pressure would translate to momentum when the water left the two cannons, with the velocity being calculated as:

$$c = \sqrt{\frac{2 \cdot p}{\rho}}$$

In this equation,  $c$  is the velocity of the water that exits the cannon,  $p$  is the pressure at which the water is stored and  $\rho$  is the density of water. The equation is used to transform the stored pressure cargo into velocity when there is no vertical movement in the flow.



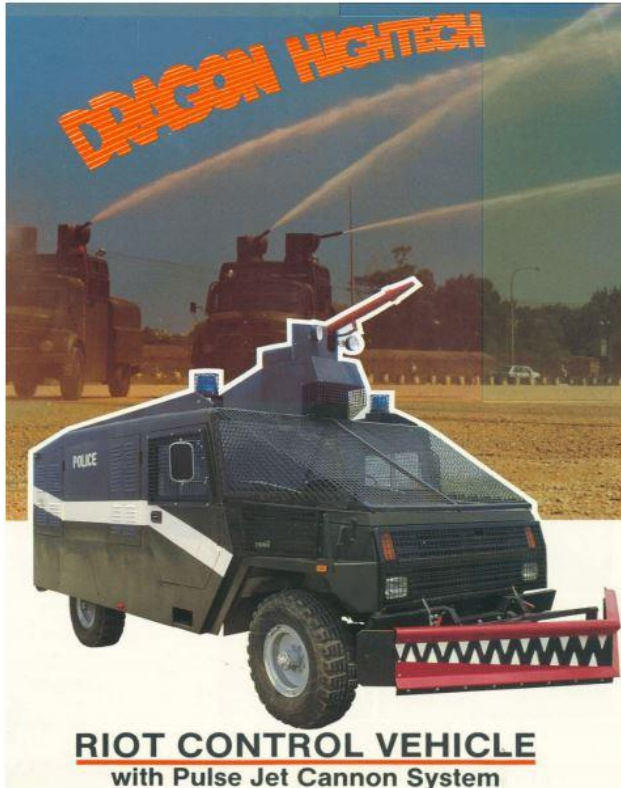
**Figure 3.** *The “Blastoise ellipsoid”.*

At 360 psi and the water density of 1000 kg/m<sup>3</sup>, the exit speed would be of 70.5 m/s, an astounding 254 km/h. However, all that might would be very short lived: if all the stored water is to be spent only in Hydro Pumps, each PP would last only 0.118 seconds, so Blastoses must be very good shots (no time to redirect the attack, which would explain the low accuracy for

Hydro Pumps). Its force and energy were calculated as follows:

$$F = -\dot{m} \cdot c$$

$$E = \frac{\text{Volume} \cdot \rho \cdot c^2}{2}$$



**Figure 4.** Modern Israeli pulsed jet Water Cannon. Image reproduced from: *The Omega Research Foundation* (2009).

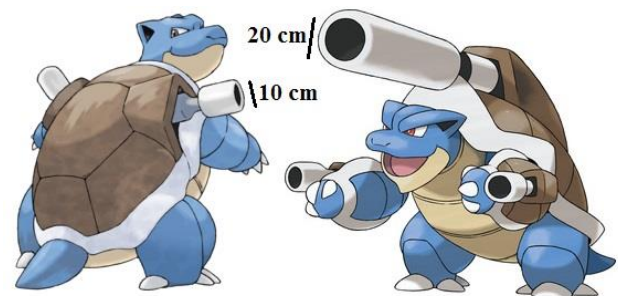
The first equation is the force exerted by the flow, which is given by the multiplication of minus its mass flow (negative, as the water is flowing out of Blastoise) by the velocity of the water. The second equation is the kinetic energy of the moving water, given by its volume, density and speed squared. That translates to a 78 kN impact for 0.118 seconds, and about 324 kJ of energy. While it does not pack as much

force as Ivan Drago's punch (about 130 kN according to Rocky 4; his "punching power" was shown as 1850 psi; the punch's area estimated at 0.01 m<sup>2</sup>, the approximate area of a closed human fist), energy wise, one PP would have the same energy as an average car (1300 kg) going at 80 km/h. That would be tough for a Charizard to handle.

So, after all, my Charizard really should avoid getting hit by one of those things. Some follow up questions do come to mind though, so let's see what else we can come up with.

### IS MEGA BLASTOISE'S HYDRO PUMP STRONGER?

For this analysis, let's assume that the pressure at which the water is stored in a Blastoise's shell is directly proportional to its Special Attack. Blastoise's base Sp. Attack is 85, whereas its Mega Evolution packs 135 (a regular Charizard has 109 base Sp. Attack, while its Y Mega Evolution has 159, so take that Blastoise!). The water pressure in Mega Blastoise's carapace would be of 571.8 psi (3.94 MPa). Another difference is in the cannon: while Blastoise has two 10 cm diameter cannons, Mega Blastoise has one that is significantly larger, assumed to be 20 cm in diameter, as seen in Figure 5.



**Figure 5.** Comparison between Blastoise and Mega Blastoise. Image modified from the official art by Ken Sugimori. (Source: Bulbapedia.)

With these assumptions set, the force of a Hydro Pump's PP would be of almost 250 kN, way stronger than Ivan Drago's punch, and the energy it would contain would be of 515 kJ. Overall, Mega Blastoise really is stronger than its non-Mega counterpart, with its Hydro Pump carrying approximately 60% more energy and exerting a force 3 times stronger.

### CAN A BLASTOISE FLY?

With that amount of force and energy being released, one wonders if a Blastoise could fly (Doduos can, why can't the turtle?). In order to calculate how high can a Blastoise go, the Pokémon was supposed to be in an upside down position and to fire its Hydro Pump downward, with the water jet now propelling the turtle upward. This maneuver was approximated to a simple variable mass system, and calculations without considering drag forces were, as stated in Peraire & Widnall (2009):

$$height = \frac{c^2}{g \cdot n} \left( 1 - \mu \cdot \ln \frac{1}{\mu} - \mu - \frac{(1 - \mu)^2}{2 \cdot n} \right)$$

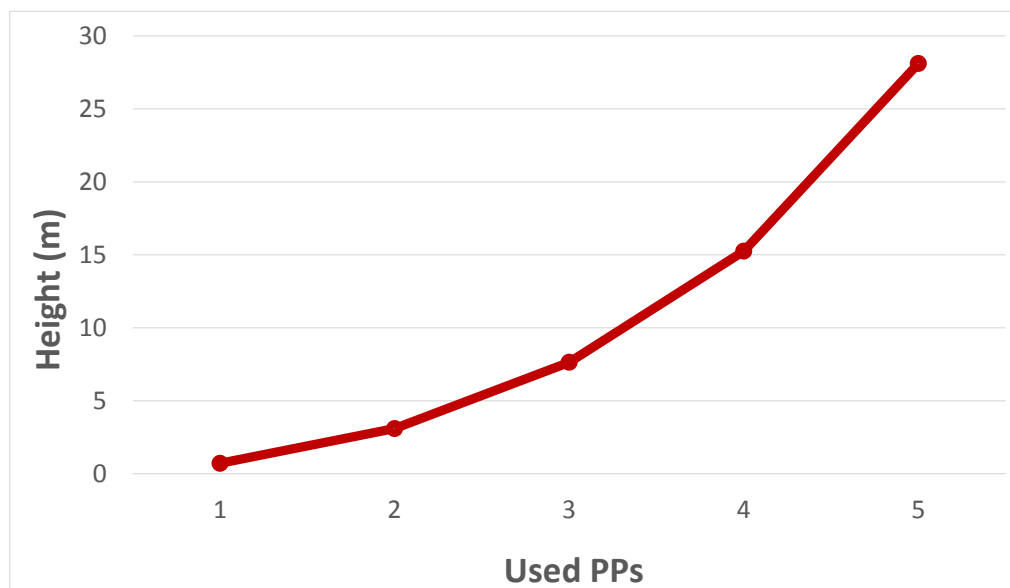
Where:

$$\mu = (m_0 - m_{water})/m_0$$

$$n = - \frac{c \cdot \dot{m}}{g \cdot m_0}$$

The first equation calculates how high a body with mass  $m_0$  goes when continuously firing downward a total mass  $m_{water}$  of propellant at a given velocity  $c$  and at a mass flow  $\dot{m}$  while being accelerated by a gravity  $g$  (9.8 m/s<sup>2</sup>). The auxiliary variables  $\mu$  and  $n$  are the mass fraction, which is the quotient of the final mass of the body after the propellant is expelled divided by its initial mass, and the thrust induced acceleration. In this study, the body is a Blastoise and the propellant is water.

The results are shown in Figure 6, a graph representing how high Blastoise goes according to how many PPs it uses.



**Figure 6.** Graph of achieved height versus number of PPs used for Hydro Pump.

Therefore, of course, the more Hydro Pumps used, the higher the Blastoise will go. When all five PPs are spent, Blastoise will fly as high as 28 m, which is about the height of a 10-story building. That will not get you from Pallet to Viridian, but it is pretty high for a turtle.

### HOW MUCH MUST A BLASTOISE EAT?

It was hard to find information on the efficiency of turtles, so a human was taken as basis of comparison. An average human has a mechanical efficiency of about 25%. As turtles are ectothermic creatures, energy-wise they are more efficient than humans, as they do not spend energy to stay warm. Its efficiency is then a little higher and, as a semi-wild guess, it was assumed to be 40%.

To most people's astonishment, freshwater turtles are not herbivores. They do eat plants, but fish is a main dish on their diet. Blastoses, as freshwater turtles, would then eat what should be easier for them to find: Goldeens. Goldeens weigh about 15 kg and inhabit the same water ponds a Blastoise would. Nutritionally, freshwater fishes have about 150 kcal per 100 grams, so with 40% efficiency a Blastoise would have to eat a little more than half a kg of Goldeen to use all 5 PPs of Hydro Pump, which is a little underwhelming, as we were expecting some mass extinctions to take place.

### CONCLUSION

After our analysis of a Blastoise, it was concluded that they do pack a punch. With each Hydro Pump averaging 78 kN in force and 324 kJ in energy, the impact could damage any fire lizards that stands on its way. Aside from that, Mega Blastoise was confirmed to be stronger than a regular one, and Blastoses do not need to go binge-eating Goldeens to use their attacks. The most important result, however, was that

turtles, even when equipped with super strong water cannons, in fact cannot fly.

### REFERENCES

- Bainbridge, J.** (2014) "Gotta Catch 'Em All!" – Pokémon, Cultural Practice and Object Networks. *The IAFOR Journal of Asian Studies* 1(1): 1–15.
- Bulbapedia.** (2015) Blastoise (Pokémon). Available from: [http://bulbapedia.bulbagarden.net/wiki/Blastoise\\_\(Pok%C3%A9mon\)](http://bulbapedia.bulbagarden.net/wiki/Blastoise_(Pok%C3%A9mon)) (Date of access: 20/May/2015).
- Munson, B.R.; Young, D.F.; Okiishi, T.H.** (2004) *Fundamentos da Mecânica dos Fluidos*. Edgard Blücher, São Paulo.
- OMEGA Foundation.** (2000) *Crowd Control Technologies (An appraisal of technologies for political control)*. European Parliament, Directorate General for Research, Luxembourg.
- Peraire, J. & Widnall, S.** (2009) Lecture L14 – Variable Mass Systems: The Rocket Equation. Available from: [http://ocw.mit.edu/courses/aeronautics-and-astronautics/16-07-dynamics-fall-2009/lecture-notes/MIT16\\_07F09\\_Lec14.pdf](http://ocw.mit.edu/courses/aeronautics-and-astronautics/16-07-dynamics-fall-2009/lecture-notes/MIT16_07F09_Lec14.pdf) (Date of access: 08/Jun/2015).
- SELFNutritionData.** (2015) Fish, bass, freshwater, mixed species, cooked, dry heat. Available from: <http://nutritiondata.self.com/facts/finfish-and-shellfish-products/4209/2> (Date of access: 09/Jun/2015).





## Shells and bytes: mollusks in the 16-bit era

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Mollusks are one of the most diverse groups of organisms known to science. Humanity has described more than 80,000 species of snails and slugs (gastropods), clams, oysters and scallops (bivalves), squids and octopuses (cephalopods), tusk shells (scaphopods) and their less-known kin (*e.g.*, polyplacophorans and aplacophorans), and many more are waiting to be discovered (Chapman, 2009). These soft-bodied and most often shell-bearing animals present a wide variety of shapes, colors and behaviors that has fascinated mankind for ages. Used as currency, tools, jewelry, medicine, and extensively collected and depicted in many different ways, mollusks are strongly tied to human history. It is not surprising that they were, and still are an important part of different cultures everywhere (Simone, 2003; Sturm et al., 2006).

Naturally, in our everyday lives, some of us portray mollusks and their shells in paintings and decoration. They are present in ordinary objects, such as stamps and coins (Robertson, 2011; Todd, 2011). In modern culture, more specifically in the history of video games, the presence of mollusks is a remarkable one. In the late 80s, the so-called fourth generation of consoles (the 16-bit era) began, and with it,

many vividly colored games came to be (Kent, 2001). Higher resolution allowed for digital artists to depict characters and draw backgrounds with richer detail. Mollusks showing up in 16-bit era games were naturally part of underwater scenery art, but some were given fairly important roles as memorable characters, plot devices, fierce antagonists and fearsome bosses. Herein we number some of these appearances and take the opportunity to discuss the real-world inspirations that probably originated these 16-bit representations. For practical reasons, only games that had an international or at least an English-language release are included in the following list.

### THE CONSOLE WAR

Several platforms existed in the 16-bit era, but the clash between its two greatest consoles was what we could call its “main event” (Fig. 1). The Sega Genesis (also known as the Mega Drive) was launched in Japan in 1988. Its greatest worldwide competitor, the Super Nintendo Entertainment System (short SNES, known as Super Famicom in Japan), was released two years later, in 1990 (Kent, 2001). Games developed for the SNES and Mega Drive platforms marked a generation. Some were the

starting point for very successful franchises, and many of them depicted mollusks.



**Figure 1.** Clash of titans. Super Nintendo Entertainment System (top) versus Sega Genesis (bottom). Photos by Evan Amos, extracted and modified from Wikimedia Commons.

## FINAL FANTASY

One of the most famous RPG franchises of gaming history, Final Fantasy includes several 16-bit titles such as Final Fantasy IV (1991), Final Fantasy V (1992) and Final Fantasy VI (1994), among others. These games have since been adapted for more recent platforms such as PlayStation, GBA and mobile. With a multitude of elaborately designed enemies (based on the beautiful artwork by Yoshitaka Amano), Final Fantasy games for the SNES include many mollusk-themed foes. Some of them received special attention from the developers, participating in some of the most memorable moments in the entire franchise (Fig. 2). The enemy names listed below are exactly as they

appeared in the SNES, and may not coincide with more recent versions.



**Figure 2.** The very first boss in Final Fantasy VI, **Whelk** (left) ambushes two Imperial soldiers and female protagonist Terra (right). And yes, do not attack the shell: it may have great scientific value! (Screenshot from the actual game.)

**Final Fantasy IV** (FFIV) mollusk enemies are not exactly remarkable in terms of the game's plot, but have curious design nonetheless. **FangShel** and its recolor **EvilShel** (Figs. 3A and 3B, respectively) are apparently based on bivalves in the family Pectinidae, commonly known as scallops (Fig. 5C). **Mindflayer** (Fig. 3C) is a Lovecraftian monster of sorts with a head somewhat resembling a squid (a teuthid cephalopod); mindflayers are also recurrent enemies in the Dungeons & Dragons role playing game franchise, and have a similar design. **Octomam** (Fig. 3D) is a huge colorful octopus-like creature with a crazy smile. It is one of the game's bosses. Some species of blue-ringed octopus, such as *Hapalochlaena lunulata* (Fig. 5E), have a similar pointy mantle (the actual head of octopuses roughly corresponds to the region near the eyes; Jereb et al., 2005), and a comparable color pattern.



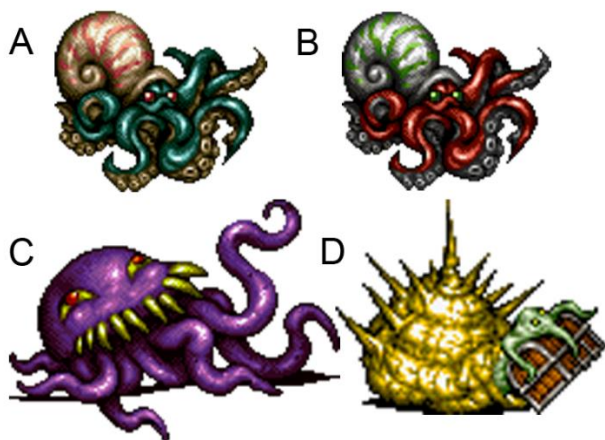
**Figure 3.** Mollusk foes from Final Fantasy IV and V (sprites from the mobile versions of both games). **A.** FangShel. **B.** EvilShel. **C.** Mindflayer. **D.** Octomam. **E.** Aquathone. **F.** Ammona. **G.** Sucker. **H.** Luneta. **I.** Mindflayer (FFV). **J.** Octoraken. **K.** MooglEater. **L.** RockGarter. **M.** Slug.

Fortunately, **Final Fantasy V's** (FFV) roster of enemies had more mollusk representatives. **Aquathone** (Fig. 3E) and its recolor **Ammona** (Fig. 3F) are apparently based on reconstructions of ammonites (ancient extinct

cephalopods; Fig. 5A), judging by its shell sculpture, cephalic hood (the triangular plate over its head, right above the eyes) and the numerous thin tentacles. **Sucker** (Fig. 3G) and its recolor **Luneta** (Fig. 3H) are apparently based



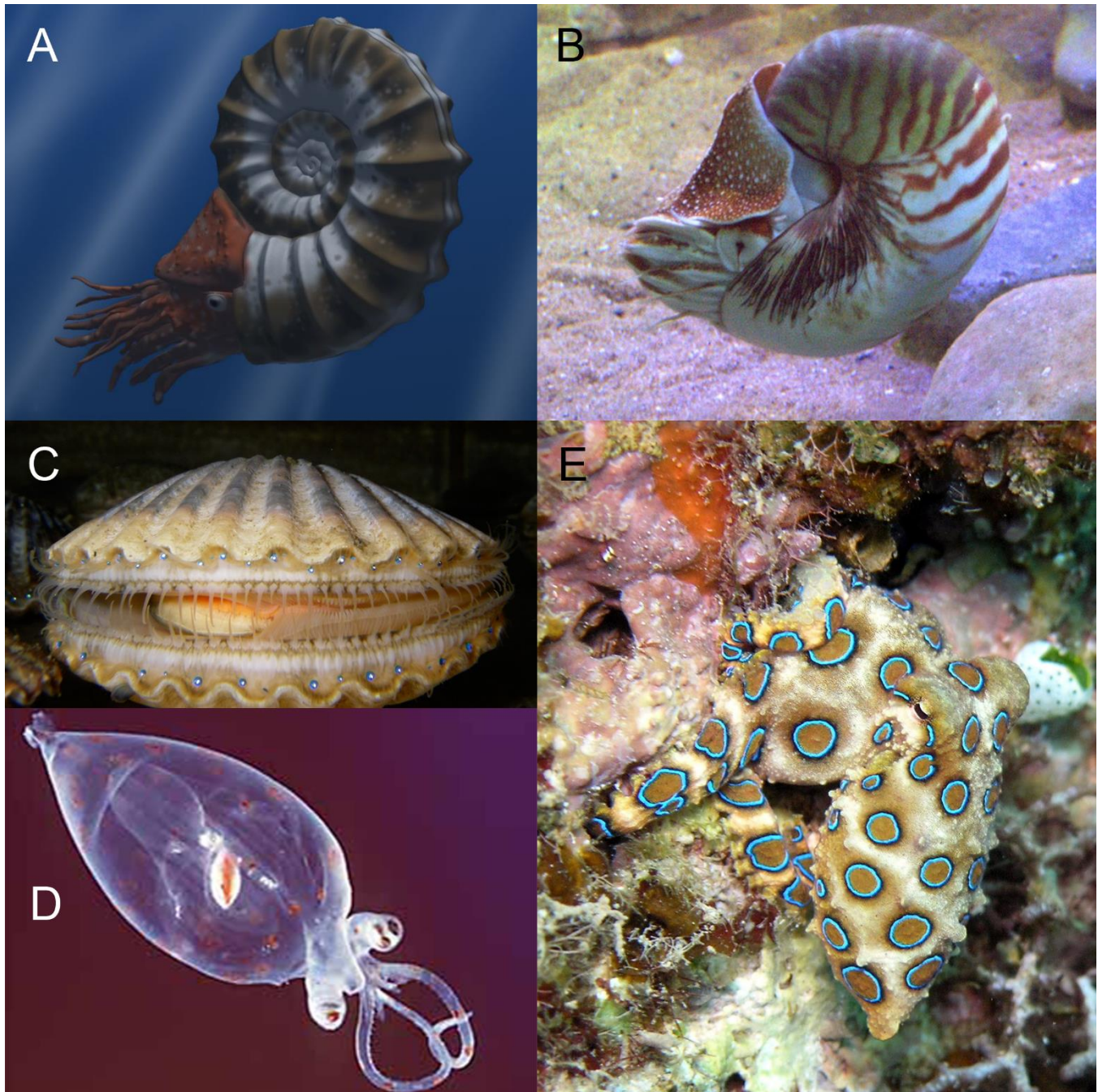
on squids. Both have very clear tentacles with enlarged tips, and curiously vitreous bodies, through which their inner organs can be seen. A translucent body is a characteristic of some squid groups, like glass squids (family Cranchiidae, Fig. 5D). There is yet another **Mindflayer** (Fig. 3I), though its head resembles squids with smaller fins, such as some species in the family Cirroteuthidae. The last cephalopod representatives are **Octoraken** (Fig. 3J) and its recolor **MooglEater** (Fig. 3K), which are surprisingly realistic octopuses. Finally, **RockGarter** (Fig. 3L) and **Slug** (Fig. 3M) are different colored versions of a gastropod-based design. They are apparently simple representations of terrestrial gastropods pertaining to the limacoid clade, which is a grouping of air-breathing land snails and slugs that share a common ancestor. Coincidentally, there is a species of keelback slug (family Limacidae), *Bielzia coerulans*, in which juvenile specimens have a brown colored body while adults are completely blue.



**Figure 4.** Mollusk enemies in Final Fantasy VI (sprites from the mobile version of the game). **A.** Nautiloid. **B.** Cephaler. **C.** Ultros. **D.** Presenter.

Though the mollusks in **Final Fantasy VI** (FFVI) were not as numerous as in the preceding titles, some were given far more important roles. In fact, the very first boss in the game is none other than **Whelk** (Fig. 2), a scary giant gastropod. It surely looks like a terrestrial snail (despite the odd position of the eyes) but not much else can be said on the real world animal that inspired its design. The **Presenter** (Fig. 4D) is a recolored version of Whelk, with a different head-foot (it's actually holding a treasure chest), and not much more can be said about it as well. Other minor enemies worth noting include **Nautiloid** (Fig. 4A) and its recolor **Cephaler** (Fig. 4B), which as the names may indicate are probably based on cephalopods. The shell color pattern of both resemble actual species of nautiloid cephalopods, such as *Nautilus pompilius* (Fig. 5B), though the arms with suckers do not.

Finally, the most (in)famous of all these mollusk antagonists, and perhaps the most well-known mollusk in the Final Fantasy franchise, **Ultros** (Fig. 4C) is a purple octopus-themed creature with an odd "smile" and rolling eyes. It is undoubtedly a comic relief character, with a total of four (hilarious) appearances in the game. The most important encounter involves the cherished Opera House scene. Ultros denominates itself an octopus, though it lacks the characteristic arm suckers of most real-life cephalopods. It can spit ink, however, as it has an ink-related attack that can render player characters blind. Since FFVI, Ultros is a recurrent character/enemy in the franchise.



**Figure 5.** Plausible real-life inspirations for 16-bit Final Fantasy molluks. **A.** A digital reconstruction of the ammonoid *Asterocheras obtusum* by Nobu Tamura. **B.** A live specimen of *Nautilus pompilius*. **C.** A live individual of the scallop *Argopecten irradians*. **D.** Photo of a glass squid (Cranchiidae) juvenile by Uwe Kils. **E.** A photo of the blue-ringed octopus *Hapalochlaena lunulata*, by Jens Petersen. (All images were extracted and modified from Wikimedia Commons; images are public domain unless otherwise stated.)



## SUPER MARIO

Super Mario is a world famous game series that actually predates the SNES, coming from the 8-bit generation of consoles. Nevertheless, the world's most famous plumber evolved amazingly well into the 16-bit era, with several successful titles such as the remakes of Super Mario Bros. 2 and 3, Super Mario World, and Super Mario RPG: Legend of the Seven Stars, in the early to mid-1990s.



**Figure 6.** Blooper the squid welcomes Mario to the underwater world in the SNES version of Super Mario Bros. (Screenshot from the actual game.)

A humble yet persistent mollusk antagonist in the series, **Blooper** is present in almost every underwater stage in several Mario titles. It is pretty much a squid-like creature (Fig. 6), and its main offensive strategy (as is the case in most of the earliest Mario's enemies) consists of causing damage upon contact. A very basic maneuver, of course, but a pretty dangerous one in confined spaces crowded with other enemies. Blooper is loosely based on real world squids. It possesses enough features to be recognized as a cephalopod (the class of mollusks that includes octopuses, squids and their allies) and more

specifically a Teuthida (the order that includes squids and their allies). It has arms and tentacles with suckers, and fins on both sides of the body (not exactly a head), conferring it a pointy silhouette, but not much else can be inferred from its relatively simple and stylized design.

## BREATH OF FIRE

**Breath of Fire** (BoF) is a roleplaying game series that had its first installment launched in 1993 for the SNES. The sequel, *Breath of Fire II*, came a year later. Both games are focused on the adventures of Ryu, a dragon-descendant warrior on a continuous quest to uncover the history of his clan. As is the case in most RPGs, both BoF games had quite varied enemy lists. A few of these opponents were apparently based on mollusks.

The earliest mollusk-themed appearance in the first game is **Tentacle** (Fig. 7A), which would be followed much later by its recolored version **Nautulis** (Fig. 7B). They are probably based on reconstructions of ammonites (Fig. 5A), very similarly to some Final Fantasy monsters (see above). **Squid** and **Octo** (Figs. 7C and 7D, respectively) are cephalopod twins, and two game bosses no less. Judging by the shape of the mantle and fins, both were based on squids, but their real-world affinities beyond that are uncertain.

**Breath of Fire II** had a few more mollusk adversaries, starting with **Amonica** (Fig. 7E) and **Cuttlecb** (Fig. 7F). They look like an odd crossover between a cephalopod (tentacles and arms, very large eyes and an evident, uncovered siphon) and a marine gastropod belonging in the superfamily Trochoidea, judging by the rounded pyramidal outline of their shells. **Roadslug** (Fig.

7G) and **R-Slug** (Fig. 7H) are heavily stylized representations of terrestrial gastropods in the limacoid clade (see the Final Fantasy section above). Finally, the only mollusk boss in the game is **Babaruku** (Fig. 7I), the evil high priest of St. Eva in its Lovecraftian might. It looks like a mindflayer of sorts, a nasty human-octopus hybrid, but not much else can be said on its possible real-life counterpart.



**Figure 7.** Molluscan enemies from *Breath of Fire* and *BoF II* (sprites from the actual games). **A.** Tentacle. **B.** Nautulis. **C.** Squid. **D.** Octo. **E.** Amonica. **F.** Cuttlecb. **G.** Roadslug. **H.** R-Slug. **I.** Babaruku.

### DEMON'S CREST

First released in Japan in 1994, the game had a sinister plot involving rival demon lords fighting over ancient magical gems of power. This, as well as the fantastic organ music, creepy characters and enemies and beautifully-drawn gloomy scenarios gave the game one of the darkest tones of its generation.

Amidst this demonic war for absolute supremacy, an underwater stage boss – named

**Holothurion** (Fig. 8) – actually posed a serious threat as a horrendous giant sea snail. His arsenal of menacing moves included creating overwhelming water currents that tossed the player character around (even toward deadly shell spikes or its huge uninviting mouth), and spitting chunks of an apparently toxic ink-like substance. It could also retract its body into the shell as a defensive maneuver – a very “snailly” move indeed.

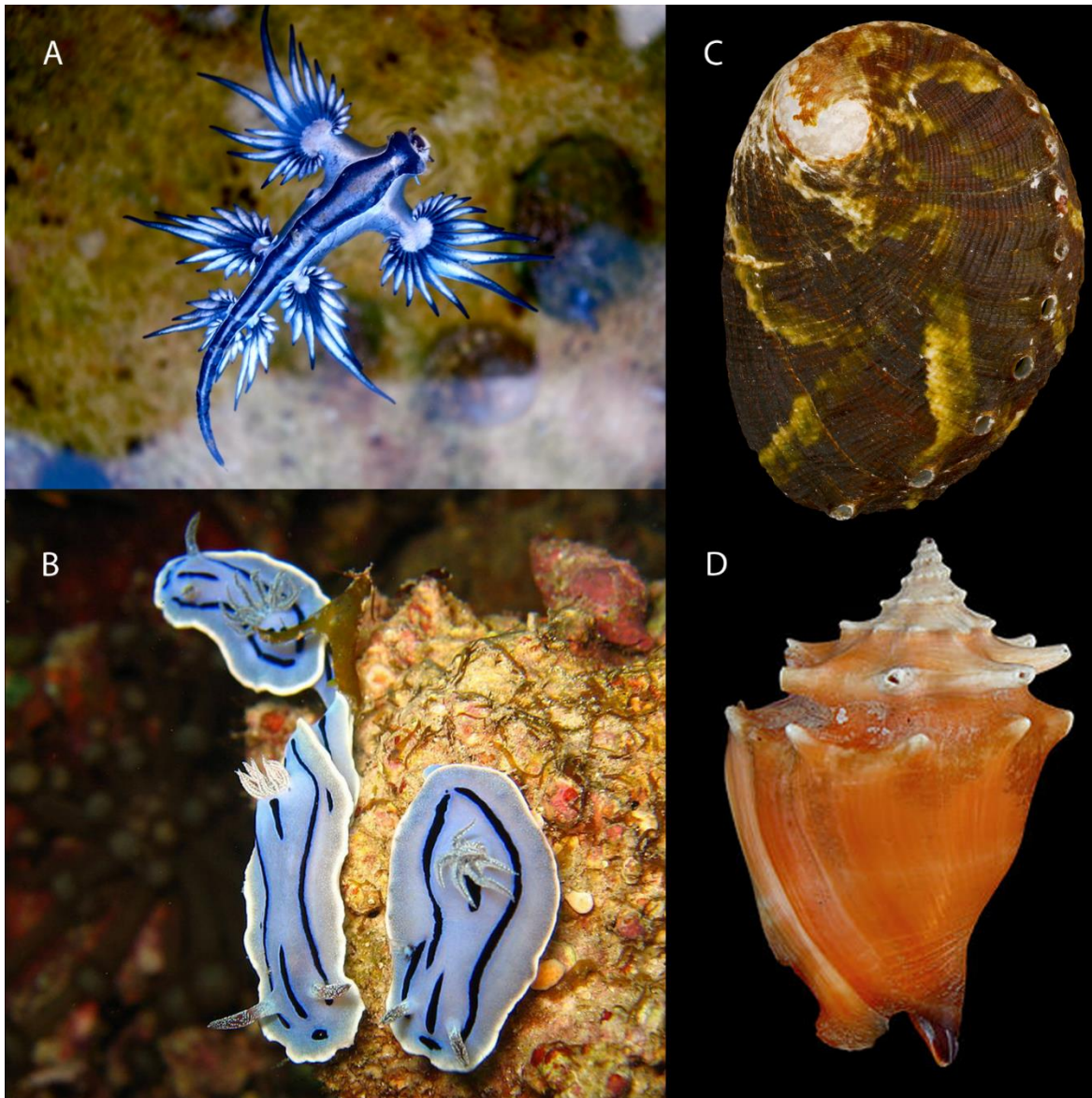


**Figure 8.** Top: *Demon's Crest* protagonist Firebrand (in his green water-dwelling form, to the left) battles Holothurion, the giant demonic snail (right). (Screenshot from the actual game.) Bottom: Original artwork of Holothurion from the game.



Despite the hyperbolic boss-like size, *Holothurion* looks to be an amalgam of marine and perhaps terrestrial snail species. It has a bulky, orange-colored shell, with spines on the body whorl's (the largest shell whorl) shoulder and on the upper portion of each whorl. This outline and color is reminiscent of some iconic strombid species like the queen conch, *Lobatus*

*gigas* or the West Indian fighting conch, *Strombus pugilis* (Fig. 9D). The shell's aperture (opening) has an unusual outline, and a clear, long siphonal canal is apparent. The series of holes observed on the shell's dorsum are found in a few gastropods (Fig. 9C), such as abalones (family Haliotidae; Poutiers, 1998).



**Figure 9.** Possible real-world inspirations for *Holothurion*. **A.** The sea slug *Glaucus atlanticus* (photo by Sylke Rohrlach). **B.** Three specimens of the sea slug *Chromodoris willani* (photo by Juuyoh Tanaka). **C.** Dorsal view of an empty shell of the abalone *Haliotis varia*. **D.** Dorsal view of an empty shell of *Strombus pugilis* (both shell photos by H. Zell). (All photos extracted and modified from Wikimedia Commons.)

The demonic snail's body, or rather its soft parts, is a matter of further discussion. The blue coloration is not itself rare, but it is more common in non-shelled species such as nudibranchs (sea slugs). Besides being possibly similarly blue, the sea slugs *Glaucus atlanticus* (Fig. 9A) and *Chromodoris willani* (Fig. 9B) both may have darker blue lateral stripes with an adjacent, lighter stripe just below it. The posterior portion of Holothurion's foot has a few "spiky" appendages. They could be part of a very bizarre operculum (a structure that closes the shell aperture when the animal retracts into the shell), if they weren't actually mobile structures that react to the snail's mood. This may be another similarity with some nudibranchs, which have comparable posterior appendages (gills; as in *C. willani*), some of which can be contractile or retract into a cavity (Fahey & Gosliner, 2004). The demonic snail's head looks like that of most shelled marine gastropods, with a single pair of cephalic tentacles. They are probably eye-bearing, though there are no discernible eyes on the in-game sprite. This somehow contradicts the official artwork (Fig. 8), which depicts two pairs of cephalic tentacles most similar to a land snail, and the upper pair appears to bear eyes at the tips. In any case, after such an in-depth analysis, I can only conclude that such a freakish molluscan gestalt could only be brought into existence by demonic forces.

### DONKEY KONG COUNTRY

The Donkey Kong Country series featured 3 games in the SNES platform. It is a very successful franchise that began as a very dynamic platformer. The game protagonists and

antagonists are animal-based: simian protagonists (the Kongs) and their animal buddies face off against an evil crocodile gang and their allies in richly-designed, nature-themed scenarios.



**Figure 10.** A common underwater enemy, Clambo (at the bottom) throws pearl bullets at the Kongs. (Screenshot from the actual game.)

The first game of the series was released in 1994. It is the only one among its 16-bit counterparts to include mollusks. **Clambo** (Fig. 10) is a pearl-spitting bivalve, a stationary opponent waiting to hit any simian swimmers with vicious underwater pearl bullets. Well, in fact and contrary to what the name indicates, Clambo might be an oyster (family Ostreidae), and not an actual clam. Judging by the thick shell with strong undulated sculpture, it could be a zigzag oyster (genus *Lopha*). Alternatively, it could indeed be a clam, a giant clam in the genus *Tridacna* (Fig. 12A). Tridacnids have a somewhat similar shell outline and are known to produce pearls, though not of the nacreous (iridescent) type (WJC, 2013). Giving the name some credit, the second option seems more plausible.

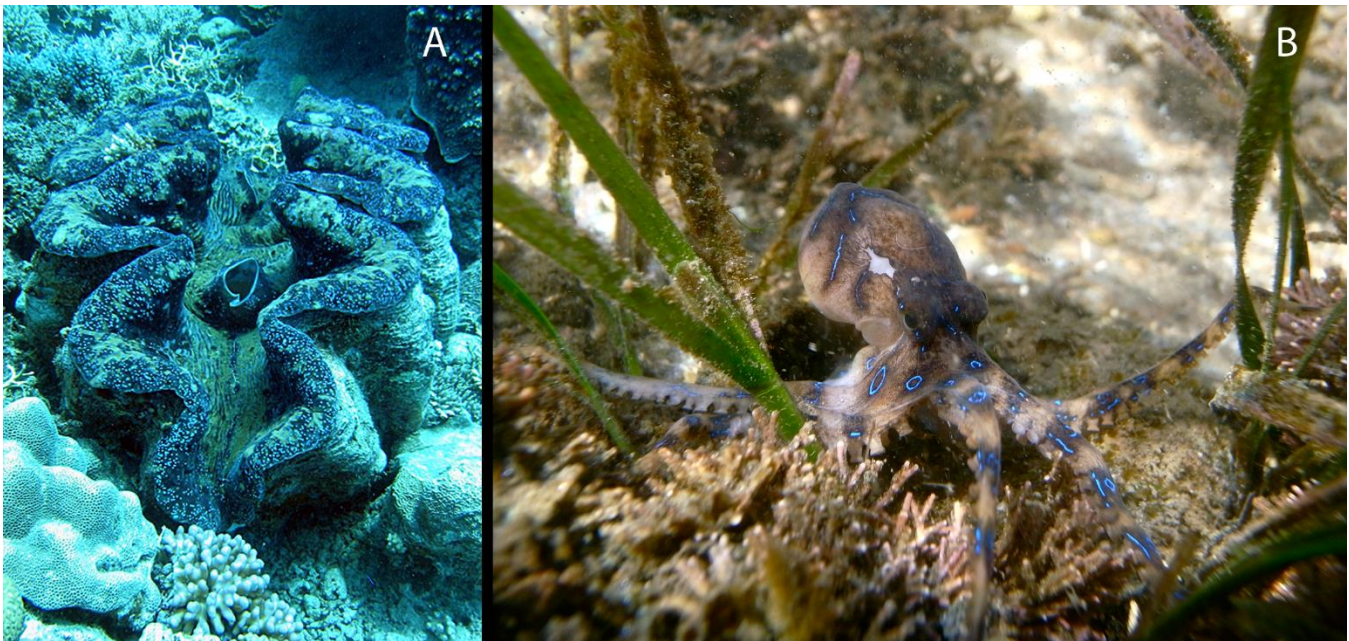




**Figure 11.** Touching the cephalopod Croctopus (bottom left) could prove deadly. (Screenshot from the actual game.)

**Croctopus** (Fig. 11), a swirling and rather deadly cephalopod, is another recurring mollusk enemy and perhaps the most fearsome (and sometimes annoying) one in the game. Its

offensive abilities are not the fanciest of the franchise, merely consisting of inflicting damage to the player characters upon contact. It is, however, invincible and often very fast-moving, and will invariably damage the player characters upon touch despite the circumstances (even while riding your favorite swordfish buddy, for instance). Surely, it was a foe to avoid. Croctopus' design is loosely based on Indo-Pacific blue-ringed octopus species belonging to the genus *Hapalochlaena* (Fig. 12B). Blue-ringed octopuses are venomous animals, and their venom is nothing short of a cocktail of deadly substances. Accidents involving humans are often fatal, so any resemblance between Croctopus' offensive power and real life is -not- a coincidence (Sheumack et al., 1978; McMichael, 2013).



**Figure 12.** Possible real-life inspirations for Clambo and Croctopus, respectively. **A.** A live specimen of *Tridacna* (public domain image). **B.** A blue-ringed octopus, *Hapalochlaena maculosa* (photo by Sylke Rohrlach, extracted and modified from Wikimedia Commons).



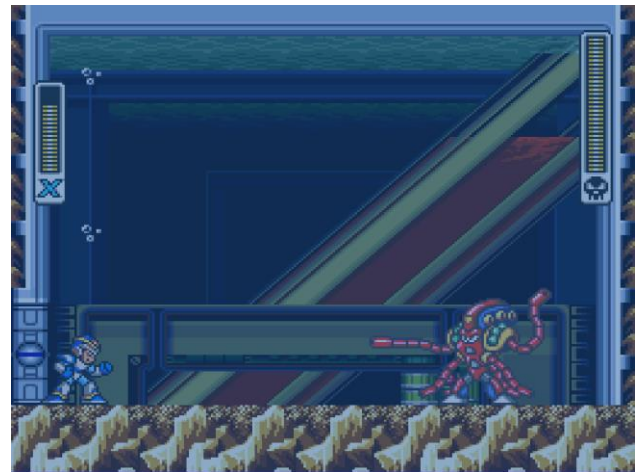
Another enemy worth mentioning is **Squidge**, a fast-moving, translucent creature. Despite the name, it does not have much to do with squids, being more of a jellyfish (a cnidarian) with an odd pair of angry eyes. It moves around by agitating its gelatinous body in an umbrella-like fashion, and its tentacle-like posterior appendages are more akin to cnidarian oral arms, lacking the typical suckers of cephalopod arms and tentacles.

### MEGA MAN X AND X2

The first Mega Man X game was released in Japan in 1993 and in North America a year later. Set in a dystopian future, the game's plot comes down to an Aasimovian conflict between evil robots (mavericks) aimed at destroying their human creators and the ones that wish to defend them. Bosses in the X series were mostly animal-themed. Their design was based on lizards, mammals, fish, insects, birds and, of course, mollusks.

**Launch Octopus** (Figs. 13, 15A) was the underwater stage boss in the first game. Featuring six torpedo-firing arms (which adds to eight members if you count the legs), and the power to produce powerful whirlpools, this octopus-themed enemy could give the player a good headache. It had more weaknesses than a normal Mega Man boss would however; it was vulnerable to two of X's weapons, one of which (boomerang cutter) could sever his awesome arms, greatly crippling his combat ability. In any case, assigning this robotic foe to a single cephalopod species or genus is no easy task. There is a small hint to a possible biological correlation, though: his arms have a single row of suckers, or rather, devices that look like

suckers. Uniserial suckers are characteristic of some octopod families, like Eledonidae, Amphitretidae and Megaleledonidae (Strugnell et al., 2014). Amphitretids have vitreous bodies, and Megaleledonids inhabit arctic environments. Both facts cannot be applied to Launch Octopus, leaving Eledonidae as the most plausible option.



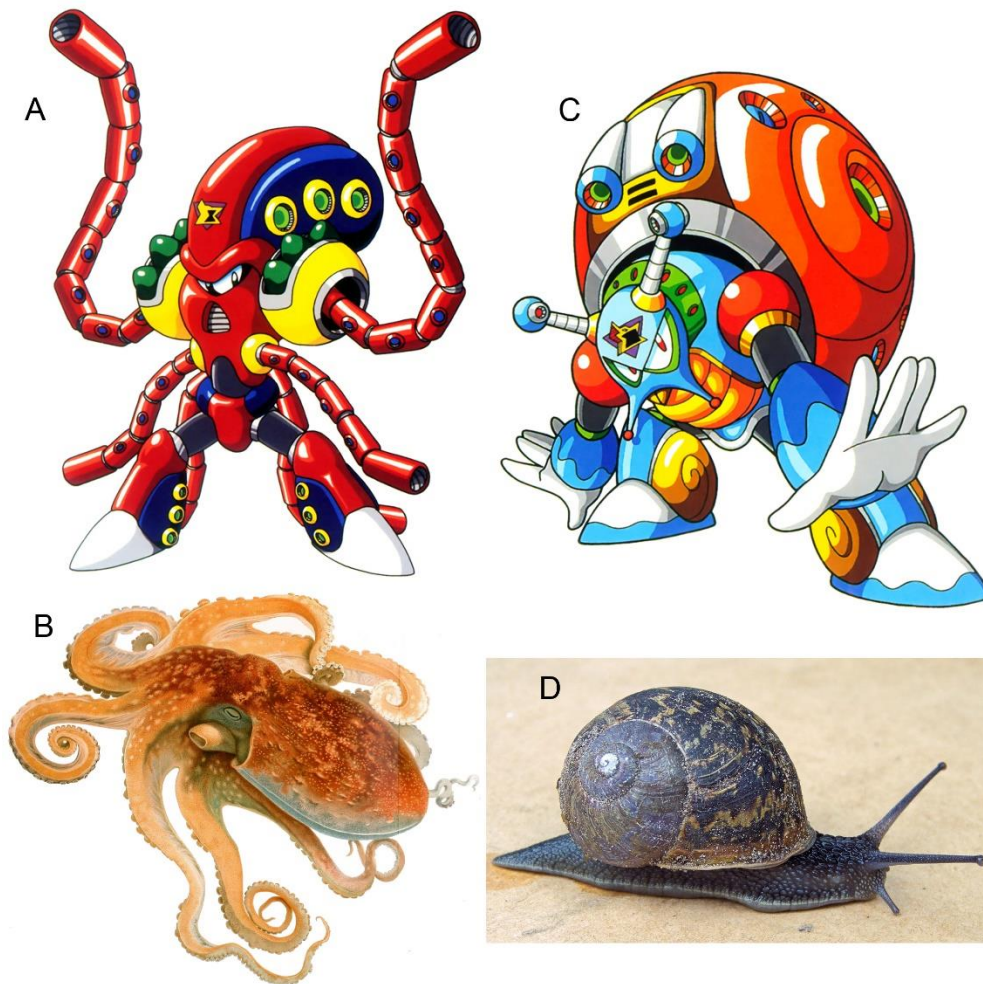
**Figure 13.** Mega Man X (left) versus Launch Octopus (right). (Screenshot from the actual game.)

Snails may not be the quickest animals out there. One might assume they would not make for astounding enemies in a quick-paced shooter/platformer like Mega Man X2. Well, **Crystal Snail** (Figs. 14, 15C), a snail-themed maverick, proves this theory wrong. Possessing an invulnerable shell with rocket-like propellants, it can fly around the screen, and even change its trajectory in midair. It can also spit a gooey mucous substance that crystalizes upon contact, imprisoning Mega Man in a shiny crystal coffin. To top it off, Crystal Snail has an amazing time-slowing special ability, which turns the world into a sluggish hell while it moves freely. On a first glance, Crystal Snail's design is based on a terrestrial gastropod,

bearing two pairs of cephalic (head) tentacles and a characteristic shell. The shell itself is bulky, and seems to be somewhat planispiral (coiled in a single horizontal plane). There are several species with planispiral shells, but most are not that bulky or rounded. It seems more likely that the maverick's design was based on a more common species such as the garden snail (*Cornu aspersum*), and the shell's odd coiling axis is merely an artistic interpretation.



**Figure 14.** Mega Man X (right) versus Crystal Snail (left). (Screenshot from the actual game.)



**Figure 15.** Mega Man X foes and their plausible natural inspirations. **A.** Launch Octopus (official game art by Capcom). **B.** The Eledonid cephalopod, *Eledone cirrhosa* (public domain image from a 1896 monograph by Jatta Giuseppe). **C.** Crystal Snail (official game art by Capcom). **D.** The common garden snail, *Cornu aspersum* (image by Rasbak, extracted and modified from Wikimedia Commons).

## CHRONO TRIGGER

Released in Japan and North America in 1995, Chrono Trigger became a commercial success, and received extensive critical acclaim. It was an interesting RPG, with an innovative combat mechanics and an enticing plot revolving around time travel and apocalyptic events.



**Figure 16.** The Rainbow shell (center) harbored in Guardia's treasury. (Screenshot from the actual game.)

An interesting, optional aspect of the game's plot, the **rainbow shell** (Figs. 16, 17A) was a huge specimen that remained hidden in a series of unnatural pre-historic caves in 600 A.D, guarded by a plethora of dinosaur enemies and a fearsome *Tyrannosaurus*-like boss. There it lied, waiting to be discovered by Crono, the game's silent protagonist, and his friends. Once claimed by the heroes and after a series of plot twists involving the kingdom of Guardia in a future timeline, the rainbow shell became part of the royal treasure. It was, in fact, its most important piece, and could also be used as raw material to fabricate some of the game's most powerful

gear and weapons (such as the Rainbow blade, Crono's top weapon).

At first glance – and considering the “ancient pre-historic cave” context – the rainbow shell looks like a fossilized ammonoid, an ancient shelled cephalopod. Indeed, some ammonoids are among the largest shelled mollusks that ever lived (Monks & Palmer, 2002). Given its coiling axis and the strong axial sculpture (with thick, sequential ribs), as well as its huge size (it took no less than 8 soldiers to move it out of the cave!), the rainbow shell could have pertained to the family Desmocerotidae, like species in the genus *Parapuzosia*, which could reach over 3 m in diameter (Teichert & Kummel, 1960). Ammonoid fossils with an iridescent shade (a rainbow-like shine) are not unheard of (Fig. 17B), and could have inspired Akira Toriyama's artwork and in-game sprite.

## SONIC THE HEDGEHOG

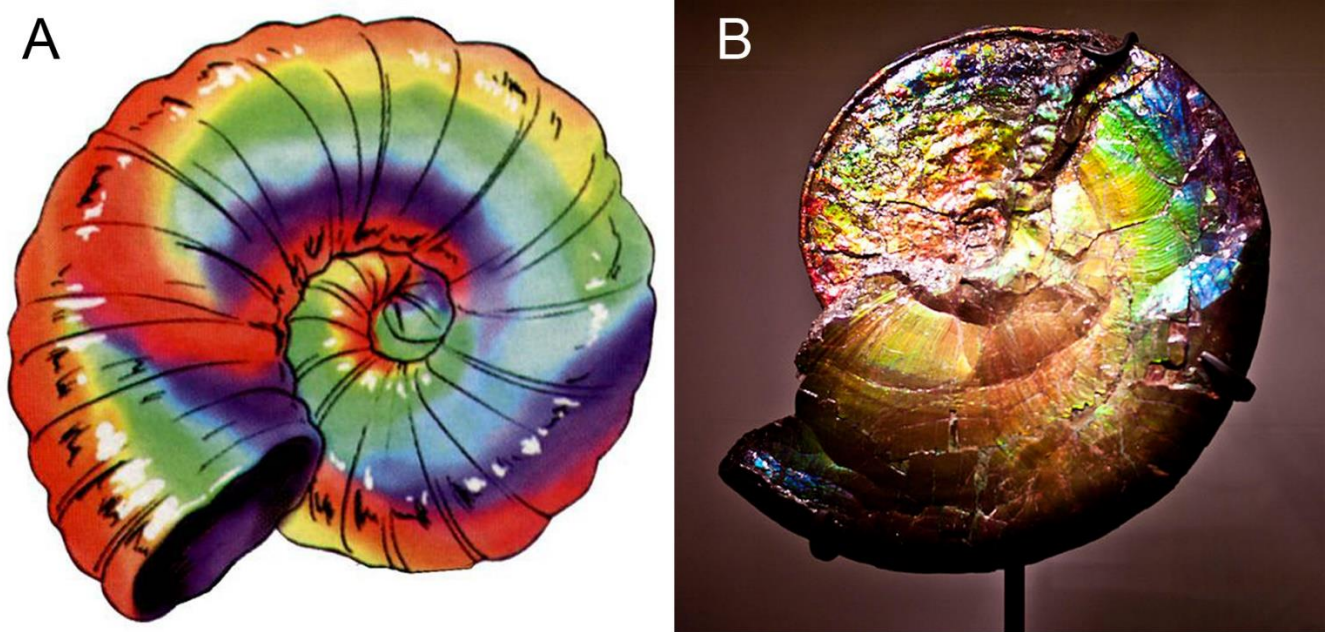
One of the most famous series in the 16-bit era and greatly cherished by Sega Genesis owners, Sonic the Hedgehog had many successful titles in the early to mid-90s. Sonic games were very agile platformers, with colorful and complex ambiances full of twists and turns, challenging enemies and bosses. Enemies in the series were mostly robots created by the infamous Dr. Ivo "Eggman" Robotnik. The (not so) good doctor based some of his creations on mollusks, of course.

In Sonic the Hedgehog 2, **Octus** (Fig. 18A) is an octopus-like robot that jumps using its robotic arms, and tries to hit Sonic with energy projectiles. It is obviously based on a cephalopod, but not much else can be inferred. In sonic the Hedgehog 3, **Clamer** (Fig. 18B) and



**Snail Blaster** (Fig. 18C) were, respectively, bivalve and snail (a terrestrial gastropod) based artillery robots. While they're not attacking the

protagonists, both can hide inside their shells, which offer considerable protection.



**Figure 17.** Iridescent lookalikes. **A.** The Rainbow shell (official Chrono Trigger art by Akira Toriyama). **B.** An iridescent ancient ammonite fossil on display at the American Museum of Natural History, New York (image by James P. Fisher III, extracted and modified from Wikimedia Commons).

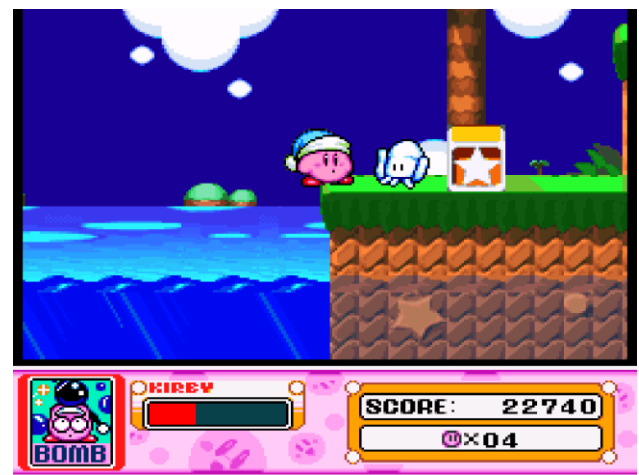
### OTHER HONORABLE MENTIONS

**Earthworm Jim 2 (1995):** A smaller and recurrent enemy in the Level Ate stage, it appears to be based on terrestrial gastropods.

**Joe & Mac 2 (1994):** Had some minor unnamed mollusk-themed antagonists.

**Kirby Super Star (1996):** A minor, white squid-like enemy called **Squishy** (Figs. 18D, 19) is present throughout the game. It is similar to Super Mario's Blooper in some ways.

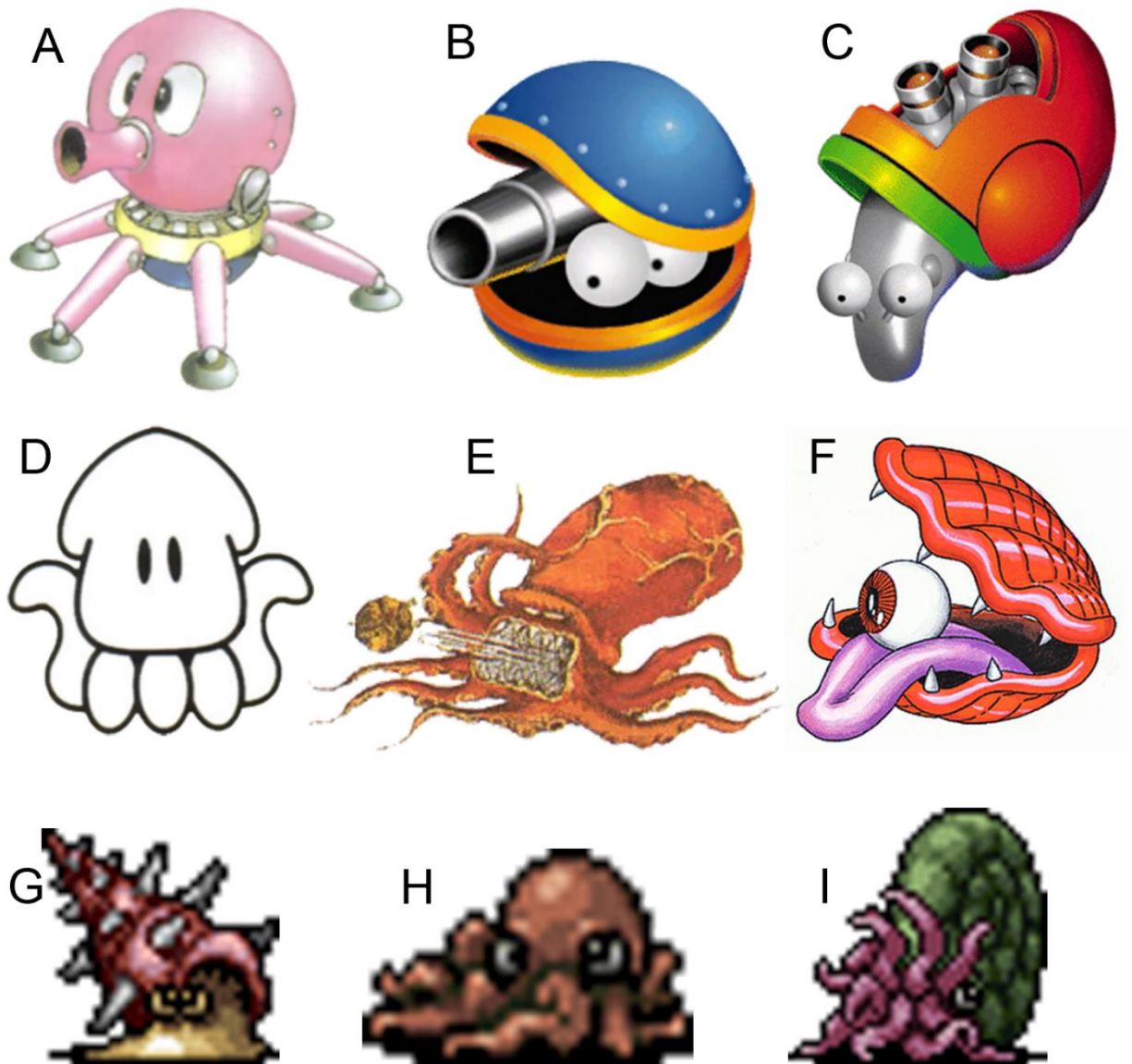
**The Legend of Zelda: A Link to the Past (1991):** A very common mollusk antagonist called **Octorok** (Fig. 18E) attacked the protagonist by spiting rocky projectiles. It is a stylized octopus, apparently, and has a Dark World counterpart called **Slarok**.



**Figure 19.** Kirby (left) and Squishy (right) have a nice conversation by the sea in Kirby Super Star. (Screenshot of the actual game.)

**Lufia II (1995):** A few of the game's antagonists were mollusks, namely **Evil Fish** (an octopus, Fig. 18H), **Drill Shell** (a marine snail with a spiky shell, Fig. 18G) and **Ammonite** (yet another ammonoid-based monster, Fig. 18I).

**Super Ghouls n' Ghosts (1991):** A devilish red-shelled clam named **Eyeball Clam** (Fig. 18F) attacked the protagonist by spitting eyeballs towards him. It is surely based on real-life clams (probably tridacnid, see Donkey Kong above).



**Figure 18.** Sonic the Hedgehog's mollusk enemies, and some additional honorable mentions. **A.** Octus (official art from Sonic the Hedgehog 2). **B.** Clamer (official art from Sonic the Hedgehog 3). **C.** Snail Blaster (official art from Sonic the Hedgehog 3). **D.** Squishy (official art from Kirby's Dream Land). **E.** Octorok (official art from The Legend of Zelda: A Link to the Past). **F.** Eyeball Clam (official art from Super Ghouls n' Goblins). **G.** Drill shell (sprite from Lufia II). **H.** Evil Fish (sprite from Lufia II). **I.** Ammonite (sprite from Lufia II).

## REFERENCES

- Chapman, A.D.** (2009) Numbers of Living Species in Australia and the World, 2nd ed. Australian Biological Resources Study, Canberra.
- Fahey, S.J. & Gosliner, T.M.** (2004) A Phylogenetic analysis of the Aegiridae Fischer, 1883 (Mollusca, Nudibranchia, Phanerobranchia) with descriptions of eight new species and a reassessment of phanerobranch relationships. *Proceedings of the California Academy of Sciences* 55(34): 613–689.
- Jereb, P.; Roper, C.F.E.; Vecchione, M.** (2005) Introduction. In: Jereb, P. & Roper, C.F.E. (Eds.) *Cephalopods of the World. An annotated and illustrated catalogue of cephalopod species known to date. Volume 1. Chambered nautiluses and sepioids (Nautilidae, Sepiidae, Sepiolidae, Sepiadariidae, Idiosepiidae and Spirulidae)*. FAO Species Catalogue for Fishery Purposes No. 4, Vol. 1. FAO, Rome. Pp. 1–37.
- Kent, S.L.** (2001) *The Ultimate History of Video Games: From Pong to Pokémon and Beyond – The Story Behind the Craze that Touched Our Lives and Changed the World*. Three River Press, New York.
- McMichael, D.F.** (2013) Mollusks – classification, distribution, venom apparatus and venoms, symptomatology of stings. In: Bücher, W. & Buckley, E.E. (Eds.) *Venomous Animals and Their Venoms, Vol III: Venomous Invertebrates*. Elsevier, Amsterdam. Pp. 373–393.
- Monks, N. & Palmer, P.** (2002) *Ammonites*. Smithsonian Books, Washington D.C.
- Poutiers, J.M.** (1998) Gastropods. In: Carpenter, K.E. (Ed.) *The Living Marine Resources of the Western Central Pacific, Vol. 1: Seaweeds, corals, bivalves and gastropods*. Food and Agriculture Organization of the United Nations (FAO), Rome. Pp. 363–686.
- Robertson, R.** (2011) Cracking a queen conch (*Strombus gigas*), vanishing uses, and rare abnormalities. *American Conchologist* 39(3): 21–24.
- Simone, L.R.L.** (2003) História da malacologia no Brasil. *Revista de Biologia Tropical* 51(3): 139–147.
- Sheumack, D.D.; Howden, M.E.; Spence, I.; Quinn, R.J.** (1978) Maculotoxin: a neurotoxin from the venom glands of the octopus *Hapalochlaena maculosa* identified as tetrodotoxin. *Science* 199(4325): 188–189.
- Sturm, C.F.; Pearce, T.A.; Valdés, Á.** (2006) The mollusks: introductory comments. In: Sturm, C.F., Pearce, T.A., Valdés, Á. (Eds.) *The Mollusks: A Guide to Their Study, Collection, and Preservation*. American Malacological Society, Pittsburgh. Pp 1–7.
- Strugnell, J.M.; Norman, M.D.; Vecchione, M.; Guzik, M.; Allcock, A.L.** (2014) The ink sac clouds octopod evolutionary history. *Hydrobiologia* 725: 215–235.
- Teichert, C. & Kummel, B.** (1960) Size of endoceroid cephalopods. *Breviora Museum of Comparative Zoology* 128: 1–7.
- Todd, J.** (2011) Conch shells on coins. *American Conchologist* 39(1): 12–13.
- WJC (World Jewelry Confederation).** (2013) *The Pearl Book. Natural, Cultured & Imitation Pearls — Terminology & Classification*. CIBJO, Milan.



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