Newts full of deadly poison and the snakes that eat them.

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Nowhere is a perfect place live,[1] the deep ocean has crushing depths and no sunlight, deserts have plenty of sunlight but little moisture, and the arctic is bitterly cold. Every habitat on earth is unique and presents a unique challenge for anyone that wants to live there. The solution to a problem in the fetid water of a swamp may not work in a fast-moving river. Every evolutionary adaptation comes with its own set of drawbacks. Evolution is oftentimes described as a target chasing a moving target. Every evolved adaptation has a drawback to it, there is always a tradeoff; having a big smart brain means that you have to eat a lot of calories to provide the energy to run it, having the extreme speed like a cheetah does means that you won't have the stamina to run long distance, having the beautiful feathered tail of a peacock to attract mates also means that predators will have an easier time catching and eating you.

Tradeoffs are pretty crazy, let's talk about the Ivory-billed woodpecker. The ivory billed woodpecker was evolved to survive in mature pine forests in the northeastern part of Cuba. In these forests, the ivory-billed woodpecker was specialized to prey on pine beetles that were found in recently deceased mature pine trees. Pine trees have extraordinary lifespans, and the woodpecker ate nothing but beetles from recently dead trees. Deforestation and logging have reduced the average age of trees in the forests of Cuba, which led to the extinction of the ivory billed woodpecker. Since the bird was specialized in feeding from trees that died of old age. While it is true that the bird evolved a series of adaptations that allowed it to exploit a unique food source, the bird also suffered from the drawbacks of those adaptations. The ivory billed woodpecker was too specialized and couldn't find new food sources in a rapidly changing environment. By becoming incredibly specialized to survive in mature pine forests, the ivory billed woodpecker species sacrificed its ability to cope with a changing environment. But don't ascribe any agency to the species, it was simply a spontaneous population-wide genetic response that didn't work out for them aka – adaptation (Jackson 2010). The ivory billed woodpecker had an adaptation to find old trees, it cost them dearly when they couldn't find food in young forests. What if a species continues to adapt as its environment changes?

One predator-prey interaction sounds like it belongs in a science fiction novel about alien worlds. Consider the humble garter snake and the newt. The garter snake is a generalist predator that loves to eat anything it can fit into its mouth,[2] including newts, a type of amphibian that resemble lizards (Crews and Garstka 1982). The rough-skinned newt[3] really hates being on the garter snake's dinner menu, and overtime some of these newts' ancestors mutated[4] and started producing a highly potent and deadly nerve poison called Tetrodotoxin[5] in their skin (Brodie and Brodie 2001). Before I continue let me contextualize just how poisonous these cute little guys are[6] (Hague et. al 2018).

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[1] Except maybe San Diego

[2] Its jaws unhinge so it can eat anything from earthworms to amphibians to even other snakes

[3] Newts of the genus *Taricha*

[4] Mutation: Any change in DNA is a mutation and they have a wide range of effects; good, bad, and nothing!

[5] Tetrodotoxin is abbreviated as TTX

[6] See figure 1 if you don't believe me

TTX works on the muscles of vertebrates[7]. All skeletal muscles are made up of bundles of muscle cells that are tightly packaged together, and muscles produce force by contracting in unison. The body of vertebrate animals, you for example, use neurons to coordinate skeletal muscle firing. Neurons carry messages from the brain through the spinal cord and to the muscles, to tell the muscle fiber to contract. The messages are propagated down the spinal cord and to the muscle through the movement of sodium particles. These sodium particles move in and out of muscle cells and nerve cells through these special proteins called sodium channels embedded in the cell membrane of muscle cells.[8] Muscles need sodium channels to be working properly to contract and relax when the brain tells them to (Mukund and Subramaniam 2019). TTX interferes with the process by which muscles and nerves communicate, which can have devastating consequences for a poisoned animal.

Figure 1: California garter snake (top) and rough skinned newt (bottom).

TTX is an extremely powerful poison that affects sodium channels. Just one rough-skinned newt has enough TTX poison in its body to kill 100 full grown adult men. TTX works by binding to sodium channels that are present in muscles and nerves in vertebrates. TTX basically closes these channels and blocks sodium from moving through these channels, which prevents the tissue from working. Nerves won't fire, and muscles won't contract. This means that TTX will make the part its affecting go completely numb since nerves are used to sense changes, and TTX will paralyze any muscles that it affects (Lee and Ruben 2008).
Here's how TTX kills:

1. A predator attacks and eats a rough-skinned newt
2. The predator starts to feel their extremities go numb, losing feeling from toe to tip[9]
3. The predator's muscles start failing and going limp. Paralysis sets in
4. The predator dies of cardiac arrest and suffocation as the diaphragm seizes and the heart stops.

At first glance, this much poison is just overkill, one rough skinned newt could kill a full-grown killer whale, and there is nothing nearly that big in the forests of the west coast (Martin 2008). This poses a problem for California garter snakes. Garter snakes like to eat newts, but like staying alive even more (Crews and Garstka 1982). So why has the rough-skinned newt evolved to be so toxic, especially when it's main predator is a two-foot-long snake?

Well, rough-skinned newts didn't evolve their super toxicity overnight, they have been slowly getting more and more poisonous overtime. The thing is, they evolved some poison originally, so garter snakes evolved resistance (Brodie, E. D., et. al. 2005). Some Garter snakes have evolved resistance to TTX by changing the shape of their sodium channels so TTX has a hard time

[7] Any animal with a spine is a vertebrate so maybe my ex is immune to TTX
[8] Cell membranes are the fat and protein rich protective layers that surround every cell in your body
[9] Garter snakes don't have any toes but bear with me

binding to their channels. TTX doesn't work as effectively on garter snakes that have a trait for resistance. Newts still don't like getting eaten, so as a population they evolved even more poison to overcome toxin resistant snakes. Snakes still loved eating newts, so the snakes evolved a different shaped channel and got more resistant. Now the snakes were super resistant, so the newts evolved to produce even more poison. Snakes that weren't resistant enough got wiped out so the rest of the snake population evolved even more resistance. This process is called an evolutionary arms race, where two species struggle between competing sets of co-evolving traits (Brodie 2005). The reason that the snakes evolved more resistance is because the mutant individuals in a population that had resistance to TTX were the only ones that could survive a run-in with a rough-skinned newt, and a mutant rough-skinned newt that was more poisonous than its peers was more likely to pass on its genes since its still toxic to eat. the reason the rough-skinned newts are super poisonous is because the local garter snakes are super resistant to poison (Hague et. al 2018).

Right now, you must be wondering, well what's the downside to being super resistant to deadly poison, I wish I was resistant to deadly poison all the time?[10] Like I said, some garter snake populations have evolved a TTX resistance gene, which changes the shape of their sodium channels, but it also reduces overall excitability of their skeletal muscle sodium channels, which means that they aren't as efficient at transferring signals from nerves to muscles in general. This makes TTX resistant snakes more sluggish since their muscles don't work as well, they're all around just slower due to their sodium channels not being as optimized for fast signal transduction (Hague et. al 2018)[11]. This resistance, conferred by the $Na_v1.4$ TTX[12] gene, allows the snakes to eat the poisonous newts. Individuals with the TTX resistance gene crawl slower, making them worse hunters of other prey and much worse at evading predators like skunks or opossums.[13] Although garter snakes that have TTX resistance gets the bonus that means that they can eat all the rough-skinned newts they want, having this trait also has the drawback of being much slower at crawling around on the forest floor making them worse at evading their own predators (Hague et. al 2018). There is give and take with any adaptation that a species can evolve.

Any environment has challenges that favors some traits over others. Animals in the deep ocean need to withstand the incredible pressures. Animals in the desert need to adapt to the incredible temperature variations and the low water levels. Animals in fetid swamp water need to adapt to the mud that can trap you, or the bacteria filled stagnant water. Evolutionary adaptations that respond to one selective challenge may disrupt other aspects of performance. The ivory billed wood pecker could find food anywhere in the forest when the trees were still old, but once deforestation and lumber companies came, they had no answer to trees falling before reaching the end of the tree's lifetime. The garter snakes of the west coasts evolved an amazing response to the incredible toxicity of rough-skinned newts but have become slower over time as a result of their adaptations. There are always drawbacks and tradeoffs to any adaptation and the good always comes with the bad. Natural selection is all about who can survive to reproduce in a harsh

[10] To be frank it would probably make it easier to stomach Dining hall food
[11] Signal transduction is the process by which a cell responds to signals, how a muscle contracts because a nerve told it to
[12] This is the formal name of the TTX resistance gene
[13] Snakes don't only eat newts after all

and unforgiving environment, that's it. There is no agency involved with evolution, the environment makes the decisions not the species that change as a response to a changing environment. Evolution is a spontaneous process that happens completely on its own, certain traits can definitely be prioritized over others depending on where the species is located; but that doesn't mean there is a conscious species wide genetic change. Every species on earth is continually evolving as long as there is a change in the frequency of a gene across a population, from the smallest bacteria to the massive Blue whale. Any adaptation a species develops comes about through evolution. Even adaptations that sound like super powers, like super toxin resistance, have their own drawbacks. Just like how super heroes have weaknesses, every species has its own kryptonite that comes with its evolved adaptations.

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Images

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