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Tuatara and their Living Fossil Label

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Abstract

The tuatara is often referred to as a 'living fossil' - which can be defined as a species that does not seem to have changed since the time its (extinct) ancestors were alive. I have reviewed literature that shows tuatara can neither be interpreted as identical to their Mesozoic relatives, nor in a state of 'evolutionary stasis' as is often assumed. While the description 'living fossil' may at first glance seem harmless, and even helpful for the tuatara's public profile - it evokes an aura of respect for the animal - the term and the assumptions that go with it have been confusing. Tuatara are the last surviving members of an order of reptiles called Rhynchocephalia, and retain characteristics in their morphology that are very similar to those seen in fossils up to 225 million years old. Yet they also have many features that scientists argue are specialised adaptations to their current environment. Assuming tuatara are primitive, or at a standstill in evolution, has led to inaccurate scientific reasoning. In a wider context, the term 'living fossil' groups an inexact number and kind of extremely different organisms, in an undefined way, in the already inexact science of evolution. In the 150 years since Darwin coined the term, the seeming persistence of 'living fossil' species has puzzled scientists and has fuelled debates of evolutionary theory. Using the term in science communication has been of both negative and positive consequence. The aesthetic concept of 'living fossils' has aroused keen interest in a selected number of species, and may have benefit for the conservation of those that are rare.

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List of Abbreviations

IUCN: International Union for the Conservation of Nature

DOC: Department of Conservation

Introduction: 'Living Fossils'- from Film to Thesis

As the artefact or creative component of this thesis, I produced a twenty-five minute film (a copy is provided on DVD) titled *Love in Cold Blood,* in partnership with fellow student Jane Adcroft. The aim of the film is primarily to emphasize the importance of captive breeding tuatara for conservation purposes. Jane and I structured our film around character-based storytelling to popularise the conservation message. The film's central tuatara characters, Henry and Mildred (and to a lesser extent, Albert), meet various challenges throughout their captive lives at Invercargill's Southland Museum. While this site is not the centre of New Zealand's overall tuatara conservation effort, it is New Zealand's best known and most publicly accessible tuatara captive breeding program. The behaviours of the tuatara "characters" are discussed in a personable, anthropomorphicised manner by their curator, Lindsay Hazley. I feel our film was successful in promoting the tuatara as an interesting creature to an audience of primarily non-scientists, because the audience response after the premiere screening (held on November 21st, 2009, at the Regent Theatre, Dunedin) was generally greatly enthusiastic.

I was, however, aware that our audience might already be keenly interested in the tuatara, because the species is popularly perceived as a 'living fossil' in New Zealand and around the world. There are countless examples of websites, books, periodicals and other media that call the tuatara a 'living fossil', such as *Tuatara: A Living Fossil* (Lutz, 2006). The tuatara named Henry from Southland Museum made many headlines last year when he mated for the first time in captivity, for example, '110-year-old living fossil becomes a dad', on website of CNN news (Gross, 2009). Possibly, the event of his mating was deemed more newsworthy because of his 'living fossil' label. In this way, the tuatara's status as a 'living fossil' helped us find the subject of our documentary - without Henry's story being published in the news media we would probably not have heard about it.

While researching the film, I discovered a need to clarify that the tuatara is not a 'living fossil' in the primitive sense of the word, rather, a survivor that has successfully adapted to its environment over time. This body of writing will complement the creative artefact by defining what is so extraordinary about New Zealand's tuatara. This in turn will reinforce the importance of tuatara captive breeding for its conservation, which is the principal subject matter of *Love in Cold Blood*.

Aims

In the background, I outlined the role the tuatara's 'living fossil' label had in directing my research. In the main body of my thesis I will address the following avenues of inquiry:

1. I will review why the tuatara is thought of as a living fossil, and describe how we may know of its history from New Zealand's fossil record. I also provide a context for its conservation.

2. Should the tuatara still be thought of as a living fossil? I will reveal that there is little reason to continue perceiving the tuatara as such, as there is evidence that shows it is a derived and specialized animal.

3. What is a living fossil? I will define the term, examining common criteria scientists have for bestowing the term on a species, and look at its history.

4. What does 'living fossil' mean to scientists, and to non-scientists? There is a range of problems with the concept of living fossils in science communication; I will summarize why the concept can be misleading. I will also present ways in which the term has been interpreted to positive effect, for example in raising awareness of tuatara conservation.

I will conclude by discussing the necessity of redefining the term 'living fossil' in articles of science communication.

Chapter 1: The Tuatara's Living Fossil Fame

The tuatara, given a Maori name translating to 'peaks on the back', has traditionally been referred to as a 'living fossil' (Robb, 1986). The tuatara is the only remaining member of the ancient reptilian order of Rhynchocephalia (Daugherty and Cree, 1990). There is recent contention about whether one or two living species of tuatara exist; *Sphenodon* is now perhaps best described as a single species with distinctive geographic variation (Hay *et al.*, 2009). *Sphenodon* has until now existed in published literature as *Sphenodon guntheri* (Buller, 1876) and the morphologically distinct *Sphenodon punctatus* (Gray, 1842). The latter is by far the more common kind of tuatara, but regardless of whether these two variants are two species or the same, tuatara now remain on only thirty-five offshore islands around New Zealand (Gaze, 2001).

The tuatara has become well known as "*probably the most primitive and unspecialised reptile in existence…[having] remained relatively unchanged for up to 200 million years*." (Robb, 1977). Their morphological similarity to their Mesozoic ancestors gave tuatara their 'living fossil' status (Apesteguía and Novas, 2003). The tuatara has a host of unique attributes, from its distinctive anatomy, to its slow metabolism and its relict distribution. It is often interpreted to be a primitive creature because of these.

Tuatara Anatomy and Biology

At first glance, the tuatara resembles a kind of lizard, however it possesses many physical features that set it far apart from its closest living relatives, the squamates. This has led to the skeletons of tuatara being described as replete with so-called 'primitive' characteristics (here, meaning something that is unchanged from the last common ancestor of tuatara and its relatives). One of the most notable of these is its beak-shaped head. Tuatara also have rear-pointing extensions on their ribs (uncinate processes) that have been described as a primitive feature (Moffatt, 1985). Structures called gastralia are also present, which are 'abdominal ribs' thought to be vestiges of a protective ventral armour (Robb, 1977). Other renowned 'primitive' features of the tuatara are their parietal or 'third' eye, and the lack of a copulatory organ in males (Bogert, 1953).

In addition, tuatara have a double row of teeth on the upper jaw; the teeth of the lower jaw fit into this. Their teeth are also tightly fused to the jawbone. This feature is termed 'acrodont dentition', and while it is one of the most unusual features of tuatara, it is, however, a derived feature of rhynchocephalians (Zug *et al.*, 2001). Thus, not all the distinguishing features of this unusual reptile are ancestral.

Tuatara probably have the slowest growth rates of any reptile (Cree, 2002), taking almost 15 years to become sexually mature. In the wild, on Stephens Island, female tuatara are only ready to lay on average eggs about every four years (Cree *et al.*, 1992). Egg gestation in gravid females may take up to 8 months in the wild, and their egg incubation takes 12–15 months (Cree, 2002). The longest recorded lifespan of adults is 80+ years; however, there is no way scientists can accurately age a tuatara once it has finished growing (Daugherty and Cree, 1990). Tuatara are renowned for their slow metabolisms and are active at an air temperature of 7° C, cooler temperatures than most other reptiles tolerate (Daugherty and Cree, 1990; Thompson and Daugherty, 1998). Their slow metabolisms, long life spans, and cool body temperature have been interpreted together to be primitive characteristics (Russell, 1998).

'Relict' Distribution

Eldredge and Stanley propose that living fossils could have survived for great lengths of time "*because of great niche breadth, broad geographic distribution, protection in a small, cloistered habitat or geographic area*." (Eldredge and Stanley, 1984). There is no contesting that the tuatara's realm is now extremely limited. The distribution and range of Sphenodontia was however once much more extensive than just New Zealand's islands (Daugherty and Cree, 1990).

The Ancestors of Modern Tuatara

The tuatara belongs to the class Reptilia, the order Rhynchocephalia and family Sphenodontidae. Because it is the only living representative of an entire order of reptiles and lives only in New Zealand, it has 'order-level endemicity' (Gibbs, 2006). Sphenodontians were a diverse group, flourishing 180–220 million years ago across Europe, Africa, Asia (China) and North and South America. They were already in decline during the age of the dinosaurs, and nearly all of them became extinct by the early Cretaceous period (Apesteguía and Novas, 2003). It is generally agreed that about 66 million years ago, there was a mass global extinction: a catastrophic disaster wiped out dinosaurs, and a plethora of mammals radiated. This was the end of the Mesozoic era in Earth's history. Many 'living fossils' have an aura of respect because their lineages stretch back through mass extinctions such as this. In the tuatara's case, with its oldest Rhynchocephalian ancestors' fossils dated at 225 million years old, this is taken to mean that its lineage has outlived whatever killed the dinosaurs. However, the tuatara are considered to be the most derived of the Rhynchocephalian lineage, following research on evolution of their skull structure and function (Jones, 2008).

The Tuatara Fossil Record

Worldwide, the tuatara's lineage has left behind a bewildering fossil record. Mesozoic fossils left by the Order Sphenodontia exist in Europe, Africa, Madagascar, India, China and both North and South America, but no traces of them have yet been found in the two places we would most expect them to appear- in Australia or Antarctica, the two land masses closest to New Zealand (Gibbs, 2006).

Throughout New Zealand's North and South Islands, as well as on some offshore islands, remains of tuatara have been found in caves, sand dunes, and Maori midden (rubbish) sites. However, the oldest of these are only 10,000 years old, which is extremely young in geological terms. In 2002, the fossil of a Sphenodontine jaw fragment was found at St. Bathans in Central Otago. The fossil was a significant find because it was dated to be 19–16 million years old, bridging a gap of nearly 70 million years in the Rhynchocephalian fossil record (Jones *et al.*, 2009).

New Zealand's fossils are a particularly fickle resource when it comes to piecing together the story of past life. New Zealand's rocks contain mostly marine fossils, for two reasons. Marine fossils are usually better preserved than terrestrial fossils. Additionally, New Zealand has had a particularly rough geological history, with frequent earthquakes and periods of partial or total submergence (Brazier *et al.*, 1990). The landmass giving rise to New Zealand is thought to have separated from the southern supercontinent of Gondwana sixty to eighty million years ago (Gibbs, 2006). Mammals were only just beginning to evolve around this time. The ancestors of tuatara would have existed on this ‘proto- New Zealand’, gradually becoming isolated from the rest of Earth’s landmasses as the continents repositioned to where they are today. New Zealand has been nicknamed a “liferaft” - along with tuatara, many unique bird and other reptile species exist only here (Daugherty and Cree, 1990). Recent arguments from molecular ecologists are in favour of the total submergence of this proto- New Zealand during the Oligocene (Campbell and Hutching, 2011), meaning a subsequent dispersal of tuatara ancestors would have been necessary. However they originally got here, their survival to the present day can be attributed to New Zealand’s original isolation from mammalian predators (Craig *et al*., 2000).

Tuatara Conservation

Decline of Tuatara

The tuatara first appeared in English scientific literature in 1831 (Gray, 1831), then in 1843, when Dr. Ernst Dieffenbach, a naturalist of the New Zealand Company, recorded it (Buller, 1876). Buller mentions Dr. Albert Günther, who in 1867 already took note of its rapid decline – “*Evidently restricted in its distribution, exposed to easy capture by its sluggish habits, esteemed as food by the natives, pursued by pigs, it is one of the rarest objects in zoological and anatomical collections, and one day may be enumerated among the forms of animal life which had become extinct within the memory of man*.” (Günther, 1867).

According to subfossil evidence, tuatara were once widespread throughout New Zealand (Crook, 1975). Their distribution is currently limited to 35 offshore islands after they became extinct on mainland islands in the early 1900s (Daugherty and Cree, 1990). Their mainland extinction came about through the work of a range of introduced mammalian predators, in particular, rats. Maori, as the first known inhabitants of New Zealand, brought with them *kiore*, the Pacific rat. This, together with fires, land clearing, and the destructive influence of pigs and dogs, all contributed to the tuatara’s mainland demise. Following this, 240 years ago European settlers came to New Zealand with Norway and ship rats, which further endangered tuatara. Early European naturalists were highly interested in the animal as soon as it was revealed, in 1867, that it was not a lizard, but in an order of its own and very unlike any other living reptile. Subsequently, numbers dwindled further, as animals were taken for displays in natural history museums all over the world (Daugherty and Cree, 1990).

The tuatara has been protected by law since 1895, but this has not prevented the movements of accidentally introduced mammal pests to the 'tuatara islands', which continued to decimate tuatara populations on their island havens throughout the twentieth century. When it was found that ten out of the previous forty island populations had become extinct within less than a century, passive conservation through legislative protection was exchanged for a more intense effort (Daugherty and Cree, 1990). The focus was on identifying and attacking the causes of tuatara decline, and setting up a successful nationwide management plan (Towns *et al.*, 2001; Cree and Butler, 1993; Gaze, 2001).

Present Conservation Efforts and Status

Considerable efforts have been made to remove the tuatara from the threat of extinction. Comprehensive rat eradication campaigns led by the New Zealand Department of Conservation (DOC) have been supported by ongoing research into the tuatara's reproductive biology and behaviour, by universities and other captive breeding institutions around the world. A gradual recovery of numbers of both species has been the observed result (Towns *et al.*, 2001). As numbers of tuatara raised in captive institutions increases, the translocation of animals to bolster and re-establish wild island populations (first undertaken by Nelson *et al.,* in 2002, for *S. guntheri*), is today becoming a more frequent occurrence. Not all translocated animals are bred in captivity; some are raised in captivity from eggs collected in the wild, and some translocations place animals directly from the wild to a different wild location without any extended period of captivity.

The International Union for the Conservation of Nature (IUCN) now no longer has a listing for the more common species, *S. punctatus*. The largest island population of *S. punctatus* occurs on Stephens Island in Cook Strait, where it is estimated that 30, 000 individuals live. Generally the remaining islands have populations ranging from 10 to 300 animals (Gaze, 2001). However, most of these islands are about the size of a tennis court, and in some small populations, the inhabiting tuatara have low levels of genetic variation (Hay *et al.*, 2003; MacAvoy *et al.*, 2007). This means whole populations are more vulnerable to extinction threats, for example, via accidental arrival of mammalian pests or disease.

In 2002, there were 17 holders of tuatara in New Zealand and 7 holders overseas, together caring for a total of over 800 tuatara in captivity. The main purposes of the captive holdings are captive breeding, research and advocacy (Blanchard *et al.*, 2002).

The indigenous Maori people of New Zealand regard tuatara as *taonga*, or living treasures, and various *iwi* (tribes) also partake in the conservation effort and give tuatara protection. Maori views of tuatara are not dissimilar from the connotations of respect the 'living fossil' concept can invoke (when interpreted in a non-scientific or figurative way), but are of a more spiritual, and even political, nature. Maori see tuatara as guardians of the stream of knowledge- the accumulation of this wisdom occurring through the long lifetime of the tuatara since its early arrival (Ramstad *et al.*, 2007). Maori traditional ecological knowledge of tuatara also requires emphasis as it is considered an important part of New Zealand's cultural heritage (Ramstad *et al.*, 2007). Reinforcing these values will in turn aid the tuatara conservation effort.

Practical Limitations of Studying Tuatara

Tuatara are creatures that are very difficult to study in the wild, due in part to their hard-to-access habitats. Researchers can only access the isolated islands they live on by boat or air, and then only when the notoriously unstable New Zealand weather permits it. The difficulty of studying tuatara is compounded by the fact that they are nocturnal, do everything very slowly, and that their lives span longer than most scientists' working careers (Daugherty and Cree, 1990). With respect to setting up new wild populations, biologist Dr. Nicola Nelson writes: "*Because tuatara are long-lived, late-maturing reptiles with slow reproduction, establishment of a self-sustaining population will take decades of monitoring to confirm.*" (Nelson *et al.*, 2002). The study of tuatara and the methods used in their conservation therefore require a lot of patience and careful prior planning, which should not be overlooked when considering the ecological significance of tuatara.

Chapter 2: A Well-adapted Survivor

A typical non-specialist interpretation of tuatara as 'living fossils' is a claim such as this: "*The tuatara has remained virtually unchanged over the past 140 million years. These living fossils make important study subjects for scientists that are trying to learn how ancient reptiles survived*." (Russell, 1998).

To claim an organism or structure within it has not changed over great stretches of time, we must refer to the fossil record. As continuous fossil evidence of the skeletal structures of tuatara is non-existent, it is very difficult to determine whether some of the structures could have been secondarily derived. Even if there are fossils to work with, determining the amount, and kind, of change that has occurred in a fossilised structure is frequently open to interpretation.

It has been suggested that scientists look to find morphological oddities in 'living fossils' like the tuatara, because it is already assumed to be primitive. 'Primitiveness' is in turn often assumed because tuatara are unusual. The great majority of 'primitive' features of tuatara may simply attract our attention because they are visually potent or otherwise interesting to us (Rock, *pers. comm.*).

The tuatara is our most well-studied reptile: by 1990, over 1500 scientific papers had been published on the tuatara (Daugherty and Cree, 1990). As a result, there is a wealth of information published on the reptile's anatomy and physiology. Its odd features have been interpreted both as evidence for tuatara being "*reptiles seemingly pre-adapted for extinction*" (Huey and Janzen, 2008), but also for their being the complete opposite - perfectly suited to where they live. The climate in New Zealand history underwent great fluctuations (Brazier et al., 1990); tuatara must have adapted over time with these changing environments or they would not have survived.

A Derived and Specialised Anatomy

There is debate in published science about the ‘primitiveness’ of each of the features of tuatara mentioned in Chapter 1. Though they have similar morphology to their many Mesozoic fossil relatives, tuatara have functional adaptations that are like those of modern snakes and lizards. These adaptations are “*particularly tailored to the climatic extremes*” of their remote habitat in New Zealand (Gans, 1983). The tuatara’s acrodont dentition is just one of many features of its skull that appears to be specifically adapted for its precision shearing bite (Gorniak *et al*., 1982).

Other morphological features are not unique to tuatara. Uncinate processes and gastralia, like those seen in the tuatara’s skeleton, are also to be found in birds (Bonney and Rohrbaugh, 2004) and crocodiles (Duncker, 1978). These structures could have appeared in the last common ancestor of birds and reptiles, so may be primitive if we define this as meaning ‘close to an original ancestral form’ (Rock, *pers. comm.*). Yet we do not extrapolate primitiveness onto birds for having interesting ribs.

Unlike skeletal features, characteristics that are not part of the skeleton will not fossilise (see ‘A Note on Fossils’ in Chapter 3). Thus, defining features of the tuatara, such as the lack of a copulatory organ, and its slow physiological processes cannot be said to have been preserved ‘from the age of dinosaurs’. The parietal eye is also not unique to tuatara- it has previously been described in lizards (reviewed in Tosini, 1997).

In the fossil record of tuatara ancestors, there is also distinct variation in morphology, described as a “*spectrum of forms*” (Fraser and Walkden, 1984). Scientists have struggled to agree on which fossil ancestor the modern tuatara most resembles. “*…there is a mosaic of primitive and derived characters present in the various members of the Sphenodontidae which cannot easily be reconciled together* ” (Fraser, 1986). Today, there is a widely-held view that the fossils most closely related to tuatara are *Cryosphenodon*- this is based on morphological comparisons of skulls (Jones, 2008).

Reproductive Biology

Biologists have mistakenly concluded that tuatara reproduce in a primitive manner (Cree and Daugherty, 1990). The reproductive cycle of female tuatara spans four years, longer than in most other reptiles (Daugherty and Cree, 1990). The cycle is believed to be an adaptation to the cool temperatures tuatara are exposed to (Cree *et al.*, 1992). The low metabolism of the tuatara, similar to that of local lizards, is another adaptation to New Zealand's climate (Gans, 1983).

Temperature is critical for egg survival in the tuatara nest. Soil temperatures between 18 and 22°C seem to have the greatest hatching success. Temperature also has a bearing on the sex of the hatchlings. For *Sphenodon punctatus*, nests at around 20°C produce mostly female offspring; while warmer temperatures produce more males. A similar pattern is found for *Sphenodon guntheri*. There is a fine balance in these patterns that is tightly attuned to the environment (Mitchell *et al.*, 2006).

The slow rates of growth and reproduction, and long lives that are common in 'living fossils', have been considered primitive features, perhaps because "…*we consider life histories differing from speedy mammals to be inefficient and thus primitive. This is a terrible misunderstanding of evolutionary mechanisms*." (Rock, *pers. comm*.).

Tuatara Behaviour

Tuatara behaviour may also be assumed to be primitive because a host of its physical features have been interpreted to be so. Significant similarities have however been found between tuatara social behaviour and that of some modern lizards (Gillingham *et al.*, 1995). Any 'special' tuatara behaviour, such as the head nodding observed in courtship rituals, might therefore also be a relatively recent adaptation.

On their islands, tuatara inhabit burrows in the ground, to which adults retreat during the day. Burrows may be as close as one metre apart from each other if the population of tuatara on a given island is dense (Newman, 1987). Occasionally, tuatara co-habit with seabirds in burrows the birds have constructed; a well-documented phenomenon is the sharing of nests with fairy prions (*Pachyptila turtur*). 'Sharing' may not be the best word to use, as tuatara are known to devour fairy prion chicks (Markwell, 1998). With this opportunistic behaviour the tuatara could be considered to be finding a way of adapting to an environment. However, tuatara behaviour cannot be indicative of what went on in the past- these are things we cannot pass judgment on; there is nothing we can infer from the fossil record about the intricacies of living movements of extinct life forms.

There are many more reasons why we cannot ascertain whether the tuatara has remained unchanged since the Mesozoic (this is not an exhaustive list). In summary, the tuatara is not what we have supposed it is. The 'living fossil' label is an aesthetic explanation for curious, but not necessarily unique or preserved, features we cannot otherwise explain with our present knowledge. Indeed, as discussed in Chapter 2, the definition of 'living fossils' leads to many scientific assumptions.

Chapter 3: Defining Living Fossils

A Note on Fossils

Fossils are the traces or remains of ancient life from the geological past that have been preserved in sedimentary rock beds. The conditions under which fossilisation takes place are rare; it is a matter of chance that any given organism will leave behind a fossil. If a protective layer of some sort covers the organism's remains shortly after its death, fossilisation is more successful. As such the sea floor is a better source of fossils - this is where bones (or otherwise) may be quickly covered by soft mud and sands. Different structures become fossils more successfully than others; the soft parts of plants and animals decay rapidly after death. Generally, only the hard parts of organisms survive, such as bones, teeth, wood or shells; this means there is usually no information about what was the 'meat on the bones.' Organisms may become fossilised by freezing, mummification, or carbonisation. Alternatively, under rare circumstances, impressions of soft parts are left. Traces, for example of a footprint or track, also provide information (Brazier et al., 1990).

Fossils are uncovered naturally by weathering and erosion, where paleontologists may find them by chance; otherwise they are found by digging through sediments that have covered them over time. The number of fossils we can know about is limited by what humans can access of the Earth's rock layers.

There is a regular succession in rock strata, or horizontal layers. Geologists can determine relative ages of rock layers and the fossils in them, from many individual fossil beds containing fossils particular only to that layer. Some rocks contain traces of unstable isotopes, and the isotopes into which they have decayed. Where the amounts of these can be accurately determined, their ratio can be used to determine more specific geological ages. This technique is called radiometric age dating (Walker, 2005).

Because Earth's crust is always active, many things can complicate the record of life preserved as fossils. Sea level changes leave behind different patterns of sediments and breaks in the sequence of depositions. Tectonic forces may contort and crush surface materials. Finally, the effects of wind, water, and ice wear away rocks, leaving gaps in fossil records (Brazier et al., 1990).

Indeed, there are problems with relying on fossils to tell us about the evolution of life on Earth. The interpretation of a 'species' is subjective when they are extinct and fossilised. Extinct, fossilised ‘species’ may not equate to the classic biological definition of a species. What makes one organism a separate species from another is the inability to breed and create viable offspring (Mayr, 1942); a more contemporary definition of a species is a separately evolving lineage that forms a single gene pool (De Quieroz, 2005). But to know if viable offspring could be produced, organisms must be alive. “*Though the fossil record yields many insights into the mode of life of extinct organisms, it simply doesn't tell us the juicy details of who was sleeping with whom back in the Mesozoic*.” (Ward, 1992).

Nevertheless, Ward points out, paleontologists put fossils in species groups, solely on the basis of morphological similarity. The logic for doing this stems from the traditional view that since neontologists (who work with live biological material) use morphology and genetics to classify species, paleontologists should do the same. Whatever either paleontologists or neontologists decide is a species then is *probably* the same sort of entity as described by the other discipline (Schopf, 1984). Modern approaches to taxonomy employ molecular biology, however, in order for analysis to succeed, this requires DNA to be intact, which is often an impossible prerequisite when dealing with fossils.

Live material gives scientists a lot more to work with: they are able to probe into systems embedded in the ‘soft parts’ of organisms. For paleontologists, if the ‘hard parts’ do not contain what could be seen as a slight change, it means the species remains the same species. It follows that there is a risk of identifying an extinct species as being the same as a living one. Schopf (1984) believes this is a likely reason the belief in ‘living fossils’ has persisted.

What is a ‘Living Fossil’?

Living fossils are typically thought of as species alive today that have remained akin to their fossil ancestors; “*a relatively little morphologically modified representative of an archaic lineage*” (Schopf, 1984). The term can be applied to a large array of diverse organisms. Mosquitoes have been called ‘living fossils’ (Trebatoski and Haynes, 1969), as have orang-utans (Lewin, 1983), and sponges (Müller, 1998). The term seems frequently to be ‘defined’ with examples, and there are many interpretations of the term.

“*Living fossils are modern species manifesting the phenomenon of arrested evolution*,” write Eldredge and Stanley (1984). This seemingly specific definition appears on the back of their renowned casebook *Living Fossils*. But according to Thomson (1986), Eldredge and Stanley fail to deliver a definition of living fossils- as would be expected in a casebook - rather, they leave the definition as something to be discovered for oneself (while reading the 34 collected case studies). Each contributing author in the book defines living fossils in their own way, and it was unclear to Thomson what it was about living fossils that made them a potential subject of this casebook. He calls living fossils "*perhaps one of the most interesting but least studied problems of paleobiology*." (Thomson, 1986).

Schopf (1984) attempted to summarise the situation. He concluded that organisms are considered to achieve living fossil 'status' when they fit one or more (depending on the author) of the following criteria:

1. A living species that has persisted over a very long interval of geologic time.
2. A living species that is morphologically and physiologically quite similar to a fossil species, as seen over long intervals of geologic time.
3. A living species that has a preponderance of primitive morphologic traits.
4. A living species that has one of the above, and a relict distribution.
5. A living species that was once thought to be extinct.
6. An extant clade of low taxonomic diversity whose species have one or more of the properties of (1.), (2.), and (3.).

A solid and precise definition of living fossils is certainly elusive. Dr. Jenny Rock of Bangor University, Wales, summarises the many and various descriptions in the following way: "*The allegedly 'ancient' but extant species of plants and animals that have been lumped together as 'living fossils' comprise a group for which there are almost as many vague definitions as there are organisms classified within it... the most standard definition is that these organisms are primitive representatives of the past that have changed little from their fossil ancestors*." (Rock, 1995).

History of Living Fossils in Evolutionary Science

Living fossils have been a problem of paleontology and biology ever since the term was coined by Charles Darwin. In *The Origin of Species* he describes "*anomalous forms*" that "*may almost be called living fossils*." (Darwin, 1859). The existence of 'living fossils' was immediately seized upon by Darwin's critics as a flaw in his theory. There was a view that life 'should' have evolved from primitive to more complicated forms of life and that organisms resembling ancient fossils should certainly not still be around. Ward (1992) believes Darwin himself never quite figured them out. He supposed they must persist by "*…inhabiting confined or peculiar stations, where they have been subjected to less severe competition, and where their scanty numbers have retarded the chance of favourable variations arising*."

Despite lacking an exact definition, 'living fossils' have influenced evolutionary theory. Critics of Darwinism, and Darwin himself, found problems with his theory of evolution because of discontinuous nature of the fossil record (Ward, 1992). The 'survival of the fittest by means of natural selection' scenario implied that life should gradually evolve, in a continuous manner- referred to as 'phyletic gradualism.' Yet the fossil record is deposited in layers, or strata, which are discrete. Life, as deposited in the rocks, appeared to have evolved in fits and starts - in Darwin's day there was very little evidence of the "*insensible gradations*" he assumed must be there.

To George Gaylord Simpson, the concept of 'living fossils' had been part of the 'conventional wisdom' of paleontology since the phrase was introduced (Simpson, 1953). So, Simpson questioned why it would be that organisms have different rates of evolution. At the time he wrote his influential book, *Major Features of Evolution*, he could look at fossils and their living descendants only from the outside in- as molecular biology was still in its infancy. From his research into fossilised structures and organisms, Simpson divided the changes he saw into two categories. Morphologic rates of change were what happened to the physical structures of a species over time. Taxonomic rates of changes described what went on at the level of groups of species; Simpson was interested in how often and why species would replace each other. His morphologic and taxonomic rates correlated with each other- if one species quickly accumulated change in say, their tooth structure, over a period of time, it followed that this would drive the development of a new adaptation. New species would appear relatively quickly in the fossil record as a result. Simpson was, like Darwin, convinced that evolution must occur in a gradual and overall steady manner, so was surprised to find what he deemed to be three distinct rates of evolution (Ward, 1993). The one relevant to living fossils was called bradytely, and defined as a state of 'arrested evolution.' However, with evidence available from fossils, he could not explain why the morphology and species groups of the 'slow evolvers' appeared to remain the same. The idea of species existing in perceived stasis became an unexplained mystery in the Darwinian model of evolution (Ward, 1992). It must be noted that the unpredictable and incomplete nature of the fossil record (as previously detailed) has a bearing on what Simpson and his contemporaries would have been able to collect and look at, and this is the only evidence they had available to draw their conclusions from.

The scientific status of living fossils was elevated with the arrival of 'punctuated equilibrium'. A landmark paper by paleontologists Niles Eldredge and Stephen Jay Gould proposed a new mechanism for evolution (Eldredge and Gould, 1972). They supposed that morphological changes in species, giving rise to a new species incapable of interbreeding with the other, occurred in relatively short events (geologically speaking). The new species would then remain the same morphologically, until the next brief period of change leading to another speciation. This was a completely different concept to the 'phyletic gradualism' idea that science had been working with since Darwin, and it redefined 'living fossils.' With the publishing of this landmark paper, the concept of arrested evolution was 'corrected.' Stanley defined living fossils not as something that had extraordinarily stopped evolving, but as being "*expert at avoiding extinction*" (Eldredge and Stanley, 1984). In this model, the amount of change in a lineage of organisms would be related to the number of speciation events it had undergone. 'Living fossils,' perceived to have not undergone much change since appearing in the fossil record, would simply be a long-lasting group- now defined as one that did not commonly speciate.

However, as Eldredge and Gould developed punctuated equilibrium in part as a response to the 'problematic' pattern of stasis and sudden appearance in the fossil record, this model actually relied on the terminology and concept of 'living fossils', leading to this 'phenomenon' being accepted rather than questioned.

There is evidence today that supports parts of both explanations for evolution - gradual and punctuated; the study of evolution is not an exact science. ‘Living fossils’ however, remain undefined and have led to unclear communication of science. And while some scientists today have revealed their skepticism, and begun to acknowledge the tuatara as a “so-called living fossil” or similar, ‘living fossils’ have largely also led to confusion within science.

Chapter 4: Mixed Meanings of Living Fossils

Scientific (Mis)interpretations

In the previous chapter, I outlined the confusing range of ways living fossils have been described. The vagueness of the concept has had consequences for how science is interpreted and carried out. It has been argued that the category or classification of 'living fossils' has no scientific validity, and is "*representative of a century of 'bad science' or research run-amuck from the two biggest banes of science: a priori assumptions and human bias*." (Rock, 1995).

In 1984, Schopf raised awareness of the "... *now more than 40-year-old view that one can obtain reliable data on rates of species evolution by looking at 'living fossils*.'" (Schopf, 1984). The tuatara has been researched in a way that relies on it presenting "*very archaic*" anatomical features (Dawbin, 1980). The picture might have changed by today as there have been numerous publications that clearly outline why tuatara are not maladapted relicts (Gans, 1983; Benton, 1986; Cree and Daugherty, 1990). However, recent studies still use the tuatara as a primitive outgroup; i.e. they determine how other species measure up to the assumed primitiveness of the tuatara. Alibardi and Gill (2007) find that "...*studying the epidermis in primitive reptiles [such as tuatara] can provide clues regarding evolution of the epidermis during land adaptation in vertebrates*." The tuatara may be useful as an outgroup for comparisons based on it being different, but not on the basis of being representative of an unchanged state.

Obtaining reliable data is only one element of science. Another part, arguably the most crucial, is the conclusions that are drawn about results in context with what is already known. In evolution, it is now known that molecular evolution (microevolution) does not occur at the same rate as morphological changes (macroevolution). The link between these two rates is different for every species, yet there are relationships- and these are being studied in broad range of sciences. This year, a 'surprisingly' paradoxical discovery was made: "*Tuatara have the highest rate of molecular change recorded in vertebrates*," conclude Hay *et al*. (2009). "*The tuatara... coexisted with dinosaurs and has changed little morphologically from its Cretaceous relatives*," they write. The authors supposed that the tuatara 'should' have a slow rate of molecular evolution, because tuatara have very slow metabolic and growth rates, long generation times and slow rates of reproduction. The apparent discovery value in this research comes about by assuming tuatara are slowly evolving ‘living fossils’: “*Given this high rate of molecular evolution, the stable morphology of tuatara over tens of millions of years is remarkable*.” (Hay *et al*., 2009). The paucity of tuatara fossils in New Zealand has already been discussed - there is very minimal evidence supporting its constancy of shape since the Mesozoic. What Hay *et al*. found did show that tuatara are not as ‘frozen in time’ as they were expected to be; challenging the common view of tuatara. However, the point here is that the expectation that they were *supposed* to evolve slowly is what made the discovery such a ‘revelation’, which subsequently was widely publicised. This is not necessarily negative for the tuatara (as will be discussed later), but it is unorthodox for a scientific study to seem more important because of a non-scientific aesthetic. This paper was subsequently criticised: it is argued that the rate of molecular evolution observed by Hay *et al*. is likely to be an overestimate, because the dataset used was not large enough to estimate an accurate rate of evolution (Miller *et al*., 2009).

Retaining and extrapolating assumptions about ‘living fossils’ can however have undesired consequences. Eldredge and Stanley describe the typically low diversity of ‘living fossil’ lineages (Eldredge and Stanley, 1984). However, believing the tuatara to have low diversity has been detrimental to this very feature. Species diversity was simply not expected in a ‘living fossil’ so New Zealand legislation protecting tuatara had originally only covered one species, *Sphenodon punctatus*. Creating a conservation plan had also been complicated because the tuatara has had a debated taxonomic history - since its discovery, its classification has changed numerous times. In 1990, it was discovered that this had nearly resulted in the disappearance of one entirely disregarded tuatara species, *Sphenodon guntheri* (Daugherty *et al*., 1990). The extreme isolation of this species away from other populations - *S.guntheri* lives only on North Brother Island - with the added factor of a very small population living there, is thought to have caused this still-contended speciation event relatively recently (Hay *et al*., 2003). In 2009, this classification has been reconsidered after re-evaluating genetic studies (Hay *et al*., 2009).

These two cases, although they illustrate how tuatara studies have been influenced by perceptions of primitiveness, also demonstrate that tuatara are changing - although perhaps exaggerated by recent studies, their molecular rate of change is by no means static. Their high level of geographic variation may also signal the emergence of a different species.

Non-scientific Interpretations

Since its conception, the idea of 'living fossils' has provided critics of the theory of evolution with a plethora of ammunition. Because they imply evolutionary stasis, 'living fossils' can also be taken to mean that there is no evolution at all. Creationism is a popular Christian sect which is based on a literal interpretation of the creation myth found in the book of Genesis. As Internet use has increased, people rely on information from online sources more frequently (Savolainen, 2001). When 'living fossils' is typed into the Google search engine, within the first five hits there is usually a Creationist website. The most prominent of these appears to be www.living-fossils.com/index.php, which 'comprehensively proves' that evolution is false (Oktar, 2009). There are also around 2,000 'fan videos' of living fossils on popular video sharing websites such as YouTube; most of these advocate Creationism (Google Videos, 2009). The opinions of fundamentalist Creationist groups throughout twenty-first century America have not been mild: "*…we discovered that basal to the many forms of infidelity is the philosophy of evolution.*" (Riley, in Larson, 1985). The teaching of evolutionary theory even became outlawed in 13 American states, and in 1927 the movement resulted in a court case informally referred to as the 'Scopes Monkey Trial' (Larson, 1985).

Today, after over a century of heated controversy (including an outlawing also of Creationist teachings), there have been modifications to ideas of Creationism to accommodate some workings of evolution. However, a relatively recent study "*…found that only one-half of American adults believe that the theory of evolution has any basis in fact*," (Ward, 1993), and the movement looks set to persist for the time being. Ken Ham, of the Answers in Genesis foundation, has 160 employees and an annual budget of over $150 million. He tours schools all over the United States of America, teaching children to be suspicious of biologists, paleontologists and geologists, that humans existed together with dinosaurs, and that Earth has only been in existence for 6000 years (Prothero, 2007). For the foreseeable future, science communicators may have to contend with localised public skepticism of science, which is partly associated with extended misinterpretations of what 'living fossils' signify.

'Living fossils' of course also have positive connotations; the mystery that belongs with the term is probably the main reason it persisted as a concept. In the foreword to Peter Douglas

Ward's book, 'On Methuselah's Trail: Living Fossils and the Great Extinctions', Steven Stanley writes: "*…discovery of living fossils sparks our imagination. From time to time every paleontologist harbors a secret fantasy in which a wondrous new species of biological group thought to be extinct turns up… Discoveries of living fossils impel the public even further, towards science-fiction. They add a measure of credence to claimed sightings of the Loch Ness Monster and Big Foot.*" (Stanley, in Ward, 1992).

Living fossils, in a somewhat romantic sense, evidently inspire a sense of awe and respect for greatly aged lineages. If this motivates both scientists and the general public to pursue science, then 'living fossils' indeed help realise an ultimate goal of science communication.

The 'living fossil' concept may also have great conservation benefits for a given species. As many species with the 'living fossil' tag are often rare, their being in a special category generates increased awareness of their dwindling numbers. 'Living fossil' species appear to have an inherent high level of newsworthiness. A recent headline from the internet is "*Aquarium snaps world's first photos of young coelacanth*," published by The Japan Times Online (Iwaki, 2009). In 2008, the tuatara named "Henry" at Southland Museum in Invercargill, New Zealand was observed mating for the first time in captivity. Headlines about the event soon snowballed globally with over 200 media featuring the story (Hazley, *pers. comm.*). These headlines caught my attention, and are what sparked the idea for the film I co-produced as the artefact to this thesis. In this way, I may be able to say I have helped create another cycle of raised awareness about the tuatara, as a result of its initial newsworthiness.

Twelve factors in newsworthiness are timeliness, proximity, exceptional quality, possible future impact, prominence, conflict, the number of people involved or affected, consequence, human interest, pathos, shock value, and titillation component (Whittaker, 2007). Of these, 'exceptional quality' and 'prominence' may apply to a discussion of why living fossils are newsworthy. 'Exceptional quality' refers to how uncommon an event is. 'Prominence' means an already famous subject is more newsworthy than a more everyday, ordinary subject. 'Living fossil' species are usually uncommon as well as famous, so any events concerning them will make the news frequently. In our film, we also exploited the components of human interest, shock value, and titillation, telling the story of Henry and Mildred in a way that caught the audience's attention. I believe our film was popular because the already present components of newsworthiness that apply to living fossils combined with those unique to the story in *Love in*

Cold Blood. Thus, with the purpose of communicating with the general public, using the term 'living fossil' is practical because it makes news easily; it is of value here as it fulfils the aim of directing extra public attention towards what might be a rare species.

However, there are plenty of rare plants, animals, fungi and other life forms that do not have a 'living fossil' tag. Certain animals elicit strong emotional responses from people. Conservation efforts directed towards 'charismatic megafauna' such as large mammals often result in success (Stokes, 2007). This phenomenon has been nicknamed "*survival of the cutest*" (ScienceBuzz, 2007). In much the same way as large, photogenic or human-like animals apparently have more conservation success, perhaps focusing conservation efforts and science grant funding on organisms labeled 'living fossils' is at the expense of species not deemed as such.

There has also been an extra complication with tuatara taxonomy that may have swayed research-funding bodies. Hay *et al*. write: "*Determining the taxonomic status… that accurately reflects the levels of differentiation at or near species level can be difficult*" when populations exist only on islands, and most importantly that this question "*becomes more than academic when considering species with high conservation importance resulting from their unique features or rarity*." (Hay *et al*., 2009). Perhaps if tuatara had been classified as one species earlier, studies specific to the putative *S. guntheri* species would not have been funded; freeing up funds for other studies on other species. The successfully funded studies are of course never a waste of time or money, but the nature of scientific funding means that where there are "winners" there must be "losers."

According to the IUCN, conservation programmes should aim to retain the entire range of diversity found in natural populations (IUCN, 1980). In a future where global resources dwindle and our climate changes, humans will focus more and more on their own survival, and the conservation of non-human biodiversity will need all the help it can get to compete with our demands. There is not the scope here to speculate what sort of conservation clout 'living fossils' would be considered to have, in the wider context of preserving complete global biodiversity, but it is a multidisciplinary question for the near future.

Discussion

Today's tuatara has adapted to its ever-changing habitat in New Zealand. The tuatara is just one example of a wide variety of species described as 'living fossils,' a concept that has persisted yet never been entirely defined.

The concept of 'living fossils' is an exceptionally unexplainable notion, arising from areas of science that are already, in general, subjective. Ernest Rutherford held anything that was not mathematics or physics in very low regard, famously describing biologists, geologists and paleontologists as 'stamp collectors' who merely record details and stories (Benton and Harper, 2009). In contrast to the absolute certainties of physics and mathematics, in these sciences, a 'general consensus' is reached about how and why things have happened.

Paleontology, the study of life's history, despite being based on what is gleaned from the fossil record (a somewhat incomplete resource that can only be interpreted subjectively), does have unique merits. No other science can help us understand our origins, the great ages of rocks, and the shape and tempo of evolution on the same scale. "*The key value of paleontology has been to show us the history of life through deep time – without fossils this would be largely hidden from us*." (Benton and Harper, 2009). The point however remains that the limitations of studying fossilised species constrain the judgments able to be made from them. Fossils are "… *not so useful for evolutionary purposes, where one must deal with the equivalent of biological species in order to make assessments of rates of evolutionary change*." (Schopf, 1984). The rates of change in the fossilised hard parts of an organism "… *in no way necessarily represent variation and change in other elements of the organism…we may only say that a particular structure appears to have changed little over time, and cannot extrapolate from this, a primitive organism*." (Rock, 1995). Given the subjectivity involved in defining changes in lineages of organisms throughout geologic history, it is perhaps impossible to strictly define 'living fossils' in the context of the sciences that surround the term.

Frequent misinterpretations of this vague aesthetic have led to false assumptions in research on tuatara and other organisms. Within scientific arguments, there are dangers of circular reasoning when making assumptions of primitiveness from unique structures: a primitive organism may be assumed, with further analysis yielding more 'primitive' features simply because they were being looked for (Rock, 1995). The tuatara, being the most well-studied reptile in New Zealand, has certainly received much attention for being so morphologically unusual.

Although, from a paleontological point of view, tuatara could be said to be in evolutionary stasis (if its morphology is compared with evidence available from its most similar fossil ancestors) - the tuatara is also a well-adapted species, which challenges the scientific and vernacular definitions of a 'living fossil.' There may be other discrepancies in the histories of other well-known 'living fossils,' such as the coelacanth or horseshoe crab, which may challenge our perceptions in the same way. Had the focus of this project been extended I would have liked to discuss organisms such as these, in order to place the tuatara's situation in a broader context.

Is it time for a re-definition?

'Living fossil' is itself an archaic term. A 'fossil' is by definition something that has remained past the limits of its usefulness, such as a theory that is discredited. The issues of science communication with 'living fossils' lie not just within science itself, but also outside of science entirely, one example being religious fundamentalists employing the term to back up their anti-scientific ways of thinking. The consequences of keeping 'living fossils' in scientific vocabulary are therefore worth discussing.

If we lose the term we might also lose a certain fascination with evolutionary science. Stanley (in Ward, 1992) proclaims that a living fossil is "*a kind of time machine that allows us to glimpse part of a lost biological world*". There is no reason for science not to celebrate that these organisms hold structures that evolution 'got right the first time around.' The whole issue could "*…arguably be of minimal harm leaving this discussion to be a little fuss over nothing*." (Rock, 1995). Indeed, the problem lies not with the words, 'living fossil' – the issue is more with how the term is chosen to be interpreted. As there are so many different, unrelated organisms considered to be living fossils, we can only look at them in a case-by-case manner and not make general statements about their evolution.

Is there anything special and common to 'living fossil' species, once inherent 'primitiveness' is ruled out? The term implies a sense of belonging to a unique group; but it is one with boundaries that are loose. Schopf (1984) theorised that typical 'living fossils' were not necessarily ancient species, but species with a few primitive but prominent features. However, having preserved morphological traits alone does not necessarily make 'living fossils' unique. "*Should we be able to prove a certain conservation of traits in our selected 'living fossils', they still deserve no special significance because of this. There are many organisms that have 'anciently conserved' traits; I believe they are generally not included with the 'living fossil' elite because they are both numerous and ubiquitous*." (Rock, 1995).

Importantly, survivorship seems to be a common feature of 'living fossils' that warrants conservation (with respect to biodiversity). In this context, 'living fossils' may be defined as phylogenetic relicts. As representatives of lineages that have no longer existed elsewhere on Earth for a great deal of time, studying these lineages because they are not closely related to others, is no less fascinating nor important if 'living fossil' organisms are no longer seen as primitive. Stanley, in Ward (1992) muses, "*... by any definition they are sole survivors… the only living representatives of geologically ancient categories of life*." Another apt re-definition of 'living fossils' could be "*opportunists, adapted to a place where most others cannot survive*," or " *…members of long, actively evolving lineages that have persevered and/ or lucked out, surviving the earth's changes*." (Rock, *pers. comm.*).

In our film *Love in Cold Blood*, we took care to avoid describing the tuatara as a living fossil, or to state that it has not changed over time. Instead we aimed to convey in the words of our script that its kin has remained in New Zealand for a long time, while dying out in all other parts of the world. The relevant section of script is contained in Figure 1 below.

TIMECODE	*NARRATION*
00:03:08:00	But there's more to Henry than meets the eye…
00:03:17:00	Henry may be one hundred and eleven, but in a tuatara timeline he could be just middle- aged.
00:03:29:00	To Maori, these long-living *taonga** are *kaitiaki* …guardians of knowledge.
00:03:44:00 00:03:51:00 00:03:55:00	Tuatara have witnessed continents form and break, ice ages come and go, and the extinction of dinosaurs.
00:04:00:00 00:04:18:00	They are the last survivors of an ancient lineage of reptiles- that died out everywhere else 65 million years ago. …and now, tuatara are found only in New Zealand.
	*taonga= treasure

Figure 1: Excerpt from *Love In Cold Blood* transcript. Relevant descriptions of tuatara as a 'survivor species' are highlighted.

As the film was scripted well before I had completed my research into living fossils, in hindsight I feel these sentences are too generic and there is still a margin for confusion. Specifically, the sentence "*Tuatara have witnessed continents form and break, ice ages come and go, and the extinction of dinosaurs*" (Fig.1., shaded section) requires revision - as it states that tuatara, as they are today, have seen these events pass. If I had had the opportunity, I would have liked to change it to a sentence such as, "*The ancestors of tuatara have witnessed continents form and break, ice ages come and go, and the extinction of dinosaurs*." This would allow for the evolution of an ancestral proto-tuatara over time, becoming the tuatara we know and make films about today. The sentence mentioned above also is figurative, a result of creating an item of simplified communication of science. Tuatara ancestors would literally not have witnessed continents break apart in front of their eyes, as might be inferred, rather generations of tuatara ancestors would have developed from a lineage old enough to have been living on the continents when they were in a different arrangement to that of today.

I also found the small amount of information in the highlighted paragraphs insufficient to define what the tuatara really is – a surviving, derived species; not an unchanged relict. The narrated script of our film is inherently over-simplified, as diction requires sentences to be short, and messages to be instantly understood. The narration script should support yet not detract from (or "talk all over") the images being presented at the same time. The nature of our story – a humorous, anthropomorphicised tale about captive tuatara – meant we followed a structure that did not allow much time for detailed depictions of tuatara evolution. Working with these restrictions, I feel we could not completely clarify what is so extraordinary about the tuatara's existence in the context of this twenty-five minute film.

The difference in wording between 'living fossil' and 'survivor' may at first glance seem subtle. But the emphasis in the latter concept may prove to be less confusing, because 'survivor' is not a paradox like 'living fossil.' An organism cannot physically be alive and fossilised at the same time. Science requires precise communication that is able to be accurately understood; it follows that miscommunication within science is able to create a skewed view of reality in the public. Given that 'living fossils' have been confusing for scientists, it is not surprising that the concept of 'living fossils' has survived as an item of "vaguery" for so long in the minds of the public also. As 'living fossils' have been talked about as a phenomenon for one hundred and fifty years, and stimulated so much interest, it will probably not make much difference if we attempt to re-define it or replace it with 'survivor.' Whatever associations are attached to it will not disappear overnight.

Being more specific may be a way forward. Descriptions of 'living fossils' in articles of science communication could be accompanied with backup comments about what feature(s) an organism has that make it such a survivor. As a stand-alone descriptor, I believe 'living fossil' is simply too vague to be meaningful. To be more specific with Stanley's aforementioned quote, the long-preserved structures, not the whole 'living fossil,' might be what provide the window to the past. With the tuatara, Charles Daugherty and Alison Cree perfect such a description, so it is not possible to infer the tuatara is an unchanged, evolutionary 'leftover': "*Tuatara have… earned the title 'living fossil'… But if this term implies that they are unchanged relicts that are doomed to extinction, then it is wrong. Tuatara are highly specialised, unique in many aspects of their biology, and well suited to the sometimes hostile New Zealand environment. Perhaps these characteristics make the tuatara a prime candidate for our national symbol.*" (Cree and Daugherty, 1990).

Conclusion

I set out in this written component to augment the basic idea presented in the film – that the tuatara is the sole surviving species of what was once a diverse order of reptiles, the Sphenodontia. The tuatara is often misinterpreted as having stopped evolving or as remaining in a primitive state, because of its status as a 'living fossil.'

'Living fossils' are not easily defined, yet they have been so influential a notion that evolutionary theories have been designed to accommodate their existence. They have been a source of confusion ever since the conception of the term.

If we view 'living fossils' alongside an old-fashioned view of evolution, there are negative repercussions for science communication. Within science, presuppositions of primitiveness or low diversity have been simply inaccurate, or in the case of the latter, actually detrimental to tuatara conservation. Outside of science, we are faced with complete misinterpretations of evolution, which lead to propagation of potent anti-scientific ideas.

'Living fossils' have, however, also been a source of inspiration, which can be used to promote species. When we come across the term 'living fossil' I believe we must perhaps 'take it with a grain of salt' – and learn to instinctively enquire why it is called such. As well as being critical, we may also let the term 'living fossil' inspire us to look at the varied ways evolution has worked for an organism, letting it become a sole survivor like the tuatara. In this way perhaps the most useful way of re-defining 'living fossils' is as 'phylogenetic relicts.'

Glossary of Terms

A Priori: is an adjective commonly used to modify the noun ‘knowledge.’ The terms *a priori* and *a posteriori* are used in philosophy to distinguish two different types of knowledge, justification, or argument. *A priori knowledge* is known independently of experience, and *a posteriori* knowledge is proven through experience.

Bradytelic species: a population of species presumed to be evolving extremely slowly.

Clade: a group of organisms consisting of a single common ancestor and all of its descendants.

Cretaceous: a geologic period; the youngest period of the Mesozoic era, spanning 80 million years, from around 145- 65 million years ago.

Derived: refers to a trait that is present in an organism, but was absent in the last common ancestor of the group of organisms in question.

Extant: not extinct; surviving.

Gastralia: dermal bones found in the ventral body wall of crocodilian and *Sphenodon* species. They are found between the sternum and pelvis, and are not articulated with the vertebrae. They are attachment sites for abdominal muscles and provide support for the abdomen.

Mesozoic: one of a group of divisions of time called a ‘geologic era.’ Following the Paleozoic era, the Mesozoic era lasted roughly 180 million years: from 251 million years ago to when the Cenozoic era began 65 million years ago. Mesozoic means ‘middle animals’, and is often referred to as the ‘Age of Reptiles,’ as this was the fauna dominant then.

Order: part of a ranking system used in the classification of animals, the hierarchy of which is as follows: Kingdom, Phylum, Class, Order, Family, Genus, Species.

Paleontology: thee study of prehistoric life and the evolutionary history of organisms. Rather than conducting experiments to observe effects, paleontologists seek to explain causes by comparing anatomy, fossils and environmental histories.

Phylogenetics: the study of evolutionary relatedness between groups of organisms (e.g. species, populations) through the use of morphological data and molecular sequencing.

Punctuated equilibrium: a theory in evolutionary biology, which proposes that evolution occurs in localized, rare speciation events, with sudden branching into distinct species. It contrasts with the theory of phyletic gradualism proposed by Darwin, where one species gradually transforms into the next.

Relict: an organism that was abundant in a large area in the past but now inhabits only one or a few small areas.

Sphenodont: the lineage of ancient reptiles from which modern tuatara are descended. The tuatara alive today are the sole survivors of this order. 'Sphenodont' means wedge-toothed in Latin.

Squamate: a 'scaly reptile' or member of the largest recent order of reptiles, which includes lizards and snakes.

Symplesiomorph: A character shared by a number of groups, but inherited from ancestors older than the last common ancestor.

Strata: the sequence of discrete layers of rock in the geological record.

Subfossil: a fossil which has not completed the fossilization process, either because of lack of time, or because it was not buried in optimal fossilization conditions.

Taxon (sing.)/ Taxa (pl.): a population, or group of populations of organisms that are generally agreed to be phylogenetically related. Common characters differentiate the unit (e.g. a genus, a family, an order) from other such units.

Uncinate processes: either separate bones or projections from the ribs of birds, some dinosaurs and tuatara. An uncinate process on a rib overlaps the rib posterior to it, providing bracing to the rib cage.

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