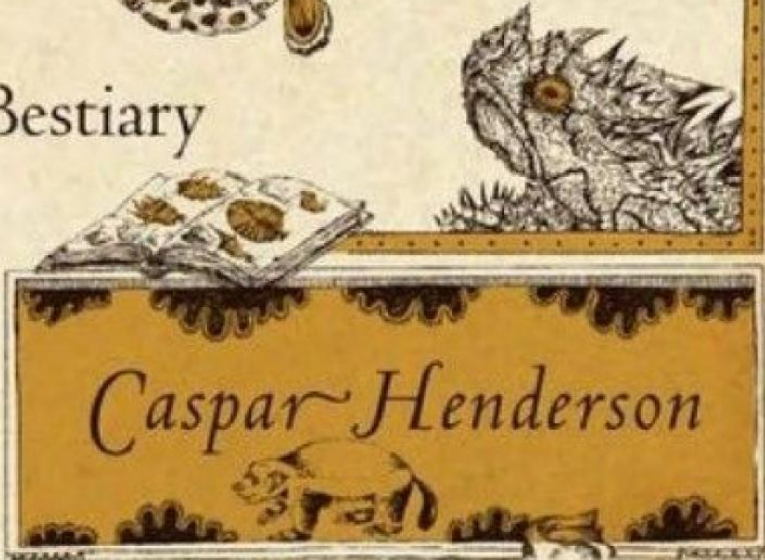


*The*  
**B**OOK  
*of*  
**B**ARELY  
I M A G I N E D  
**B**EING S

A 21<sup>st</sup> Century Bestiary

*Caspar Henderson*



THE BOOK  
*of*  
BARELY  
IMAGINED  
BEINGS

CASPAR  
HENDERSON

GRANTA

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# INTRODUCTION

On a bright afternoon in early summer a few years ago, my wife and I took our tiny new daughter out on a picnic. The air was so clear that everything seemed like a hyper-real version of itself. We sat down next to a bubbling stream on grass that glowed in the sunlight. After a feed our daughter fell asleep. I turned to a bag of books, magazines and papers which I tended to carry about in those pre-tablet days and which always contained far more than I had time to read on topics like ecological degradation, nuclear proliferation and the latest concessions made to torturers and criminals: the funnies.

Also in the bag that day was a copy of *The Book of Imaginary Beings* – a bestiary, or book of beasts, by the Argentine writer Jorge Luis Borges, first published in 1967. I had last looked at it almost twenty years before and had thrown it in as an afterthought. But as soon as I started to read I was riveted. There's Humbaba, the guardian of the cedar forest in *Gilgamesh*, the world's oldest known poem, who is described as having the paws of a lion, a body covered with horny scales, the claws of a vulture, the horns of a wild bull and a tail and penis both ending in snake's heads. There's an animal imagined by Franz Kafka which has a body like that of a kangaroo but a flat, almost human face; only its teeth have the power of expression and Kafka has the feeling it is trying to tame him. There is the Strong Toad of Chilean folklore, which has a shell like a turtle, glows in the dark like a firefly and is so tough that the only way to kill it is to reduce it to ashes; the great power of its stare attracts or repels whatever is in its range. Each of these – and many others from myths and fables from all over the world as well as several from the author's own imagination – is described in vignettes that are charming, weird, disturbing or comic, and sometimes all four. The book is a bravura display of human imagination responding to and remaking reality. As I say, I was riveted – until I dozed off in the sunshine.

I woke with the thought that many real animals are stranger than imaginary ones, and it is our knowledge and understanding that are too cramped and fragmentary to accommodate them: we have *barely imagined*<sup>1</sup> them. And in a time that we are now learning to call *the Anthropocene*,<sup>2</sup> a time of extinctions and transformations as momentous as any in the history of life, this needs attention. I should, said this niggling thought, look more deeply into unfamiliar ways of being in the world of which I had only an inkling. And I should map those explorations in a Book of Barely Imagined Beings.

Normally I would shrug off such a half-formed idea pretty quickly. But this one refused to go away, and over the months that followed it became an obsession to the point where I could no longer avoid doing some actual work. The result is what you are holding in your hands: explorations and sketches towards a twenty-first-century bestiary.

We typically think of bestiaries, if we think of them at all, as creations of the medieval mind: delightful for their bizarre and beautiful images illuminated in gold and precious pigments from far-off lands. The Ashmole Bestiary, a thirteenth-century manuscript in the Bodleian Library in Oxford, is a good example. In one picture, a man dressed in red is watching a pot on a fire he has made on a small island in the sea, unaware that the island is actually the back of a huge whale. Meanwhile, a high-castled ship sails by,

silhouetted against a sky entirely of gold. In another picture, barnacle geese, depicted in black, hang by their beaks from what look like green, red and blue Art Deco trumpets but are supposed to be flowers on a tree. The text is often as entrancing as the pictures. The asp is an animal that blocks its ear with its tail so as not to hear the snake charmer. The panther is a gentle, multicoloured beast whose only enemy is the dragon. And the swordfish uses its pointed beak to sink ships.

But there is more to bestiaries than this. Along with zany pictures, bizarre zoology and religious parables, they contain gems of acute observation: attempts to understand and convey how things actually are. Undaunted by (and unaware of) the limits of the knowledge of their time, they celebrate the beauty of being and of beings.

A full account of the inspirations and origins of the great illuminated bestiaries of the High Middle Ages would refer to the great scientific works of the ancients, especially Aristotle's *History of Animals* written in the fourth century BC and Pliny's *Natural History* of 77 AD. And it would record how, via a text called *The Physiologus* and through the turbulent years after the sack of Rome (which included a plague that may have killed as much as half the population of Europe), extracts from these and other sources were combined with Bible stories and Christian teaching and shoehorned into compendia of natural history and spiritual teaching. (It might, along the way, allude to masterpieces of the Dark Ages such as the Lindisfarne Gospels, decorated on the Northumbrian coast around 700 AD with braided animal figures from the pagan north as well as mandala-like designs from the sunlit eastern Mediterranean.) But I want to trace something else: an older and more enduring phenomenon - one that predates even images such as the scenes of abundant bird life and dancing dolphins painted in, respectively, Egypt and Crete more than a thousand years before Aristotle was born.

At around 30,000 years old, the paintings in Chauvet Cave in France are among the oldest known. These images of bison, stags, lions, rhinos, ibex, horses, mammoths and other animals were made by artists as skilful as any working today. We will never know exactly what they meant for their creators, but we can see that these artists had studied their subjects with great care. They knew, for instance, how the animals changed over the seasons of the year. As the paleoanthropologist Ian Tattersall writes, 'depictions sometimes show bison in summer molting pelage, stags baying in the autumn rut, woolly rhinoceroses displaying the skin fold that was visible only in summer, or salmon with the curious spur on the lower jaw that males develop in the spawning season. Indeed, we know things about the anatomy of now-extinct animals that we could only know through [their] art.'<sup>3</sup> And we know from handprints stamped or silhouetted on the cave walls that people of both sexes and all ages, including babies, took some part in at least some of whatever took place here. We can see that the animals *mattered* to these people. The same species recur, but there are no images of landscape; no clouds, earth, sun, moon, rivers or plant life, and only rarely is there a horizon or a human or partly human figure.



Lions in the Chauvet cave.

All this points to something obvious but which is, I think, so important that it is hard to overstate. And that is that for much of human history attempts to understand and define ourselves have been closely linked to how we see and represent other animals. Methods of representation may change but a fascination with other modes of being remains. The cabinets of curiosities of the sixteenth and seventeenth centuries, for example, are in obvious respects quite different from the bestiaries of the medieval period. Bringing together actual specimens and fragments of exotic animals, plants and rocks, they helped pave the way for more systematic study of the natural world in the eighteenth century when the taxonomic system that we still use today came into being. But, like the bestiaries, these cabinets still had the power to enchant, as their German name, *Wunderkammern* ('cabinets of wonders'), attests. Today our fondness for curiosities and wonders is no less. From the *Wunderkammer* to the Internet is a small step, and the latter - containing virtually everything - is both the servant of science and an everyday electronic bestiary. From giant squid to two-faced cats, what we know about animals and what we don't, the amazing things they can do and the things they can't, the ways they never stop being strange or surprising, feature constantly among the most shared articles and video clips on the web.

The following seems to be true: our attention is often momentary or disorganized, but fascination with other ways of being, including that of animals, is seldom far from our minds, and gushes up like spring water from within dark rock in every human culture. We may be shameless voyeurs, passionate conservationists or simply curious, but we are seldom indifferent. Like our ancestors, we are continually asking ourselves, consciously or unconsciously, 'what has this got to do with me, my physical existence, the things I hope for and the things I fear?'

The selection of animals in these pages is not intended to be representative of what there is in the world. Still less is this book an attempt at a comprehensive work of natural history. And while I have made every attempt to get the facts right, I have not tried to produce a systematic

overview of each animal but have, rather, focused on aspects that are (to my mind, at least) beautiful and intriguing about them, and the qualities, phenomena and issues that they embody, reflect or raise. In some respects, the arrangement resembles the one in a Chinese encyclopedia called the Celestial Emporium of Benevolent Knowledge imagined by Borges:



Ole Worm's cabinet of curiosities, circa 1655.

In its distant pages it is written that animals are divided into (a) those that belong to the emperor; (b) embalmed ones; (c) those that are trained; (d) suckling pigs; (e) mermaids; (f) fabulous ones; (g) stray dogs; (h) those that are included in this classification; (i) those that tremble as if they were mad; (j) innumerable ones; (k) those drawn with a very fine camel's-hair brush; (l) etcetera; (m) those that have just broken the flower vase; (n) those that at a distance resemble flies.

This book is envisaged as an 'aletheiagoria' - a new coinage so far as I know, which alludes to phantasmagoria (a light-projected ghost show from the era before cinema) but uses the word 'aletheia', the Greek for 'truth' or 'revealing'. It suggests (to me, at least) flickering 'real' images of a greater reality. I have tried to look at a few ways of being from different angles and, through 'a wealth of unexpected juxtapositions',<sup>4</sup> explore both how they are like and unlike humans (or how we imagine ourselves to be) and also how their differences from and similarities to us cast light on human capabilities and human concerns. The results are a little strange in places and, indeed, a little strained. Some of the analogies and digressions I have followed have

little to do with the animals themselves. They are deliberate attempts to use the animals to think with, but not to think only about the animals. And, for all the digression, there are themes or strands that weave the book together.

One theme of the book is how evolutionary biology (and the scientific method of which it is part) give us a richer and more rewarding sense of the nature of existence than a view informed by myth and tradition alone. Not only is it the case that, in Theodosius Dobzhansky's phrase, 'nothing makes sense except in the light of evolution'; it's also true that astonishment and celebration flourish when rooted in an appreciation of what can be explained. As Robert Pogue Harrison puts it, 'imagination discovers its real freedom in the measured finitude of what is the case'; it was Henry David Thoreau, a radical political activist as well as environmental visionary, who actually measured the depth of Walden Pond with a plumb line, not the 'practical' folk around him who said the pond was bottomless. In the words of Richard Feynman, 'Our imagination is stretched to the utmost not, as in fiction, to imagine things which *are* not really there, but just to comprehend those things which are there.' Thanks to evolutionary theory, the world becomes a transparent surface through which one can see the whole history of life.

Another theme is the sea. About two-thirds of the creatures headlining the chapters are marine. There are several reasons why this is so. For one, the world ocean is our distant origin and by far the largest environment on Earth, covering more than seven-tenths of its surface and comprising more than 95 per cent of its habitable zone. (Recall Ambrose Bierce's definition: 'Ocean, n. A body of water occupying about two-thirds of a world made for Man - who has no gills.') And yet this great realm is far less known to us than is the land. It is our 'job' to know it better. As Bill Bryson has observed, nothing speaks more clearly of our psychological remoteness from the seas, at least until comparatively recently, than that the main expressed goal of oceanographers during the International Geophysical Year of 1957-8 was to study 'the use of the ocean depths as the dumping ground of radioactive wastes.' Only quite recently have we gone from seeing the world ocean as peripheral to beginning to understand that it plays a central role in the Earth system, including its climate and biodiversity, and so in **our fate**.<sup>5</sup> And only recently have we begun to learn that the seas are rich with real rather than mythical beings that are strange and sometimes delightful in ways we would never have imagined - that there are, for example, creatures as tall as men which have no internal organs and thrive in waters that would scald us to death in moments, that there is a vast world of cold darkness in which almost all creatures glow with light, or that there are intelligent, aware animals that can squeeze their bodies through a space the width of one of their eyeballs.

Yet another strand running through the book concerns consequences of human behaviour. A few years ago I found myself in a snowstorm on a beach in the Arctic staring at a pile of fat, farting walruses. I was an afterthought, almost a stowaway, on an expedition of artists, musicians and scientists come by sailboat to the Svalbard archipelago (commonly known in English as Spitsbergen) to see for ourselves some signs of the momentous changes under way in the region, and to contemplate what's at stake. (The Arctic is warming more rapidly than anywhere else on Earth. The evidence overwhelmingly points to human activity as the cause.)

Walruses - bulky and comical on land but exquisitely agile and sensitive

in the water - are among my favourite animals. Indeed, my daughter may owe them her existence because it was with a drawing of a walrus on a napkin that I first beguiled her mother. I am not alone in my inordinate fondness for these beasts if the many films on the Internet of walruses performing aerobic manoeuvres in synchrony with trainers, playing the tuba and making very rude sounds are anything to go by. Nor is delight at walrus appreciation especially new. In 1611 a young one was displayed at the English court,

where the kinge and many honourable personages beheld it with admiration for the strangenesse of the same, the like whereof had never been seene alive in England. As the beast in shape is very strange, so it is of a strange docilitie, and apt to be taught.

But all this amusement hides an uglier reality. For most of the last four hundred years Europeans laughed at walruses and then killed them - for fun, but mainly for profit - driving many populations (though not the species as a whole) to extinction. In their first encounter, in 1604, English sailors quickly learnt that walruses were not only harmless but rich in oil and furnished with splendid tusks, and both fetched good money. In 1605 ships of the London Muscovy Company returned to Spitsbergen to spend the entire summer killing walruses, boiling down the blubber for soap and extracting tusks. By the 1606 season they were so experienced that they killed between 600 and 700 full-grown animals within six hours of landing.

We twenty-first-century visitors, prancing about with caring-sharing environmental sensitivity, meant no harm, we most truly did not. But we had to get photos, so photos we got. And in our excitement, each wanting to get closer, we panicked the animals and sent them tumbling for the sea. The ship's captain was furious: walruses need their rest, and we were ruining it. Individually well-meaning (or so we believed), we were, collectively, **small-time vandals**.<sup>6</sup> Writing in 1575, Michel de Montaigne asked:

Who hath perswaded [man] that this admirable moving of heavens vaults, that the eternal light of these lampes so fiercely rowling over his head, that the horror-moving and continuall motion of this infinite vaste ocean were established, and continue so many ages for his commoditie and service? Is it possible to imagine anything so ridiculous as this miserable and wretched creature, which is not so much as master of himselfe, exposed and subject to offences of all things, and yet dareth call himselfe Master and Emperour of this Universe?

This passage, which clearly influenced *Hamlet*, often comes to mind when I think of our experience with the walruses and other expeditions and experiments I have seen and participated in. It is a reminder of how thoughtless we can be of the consequences of our actions, but it also relates to another strand in the book.

Humans have much more powerful senses than we often realize. A young, healthy person can see a candle flame in the dark thirty miles away, and the human ear can hear down to the threshold of Brownian motion, which is caused by the movement of individual molecules. Still, other creatures have powers of perception - vision, hearing, smell and so on - that vastly exceed

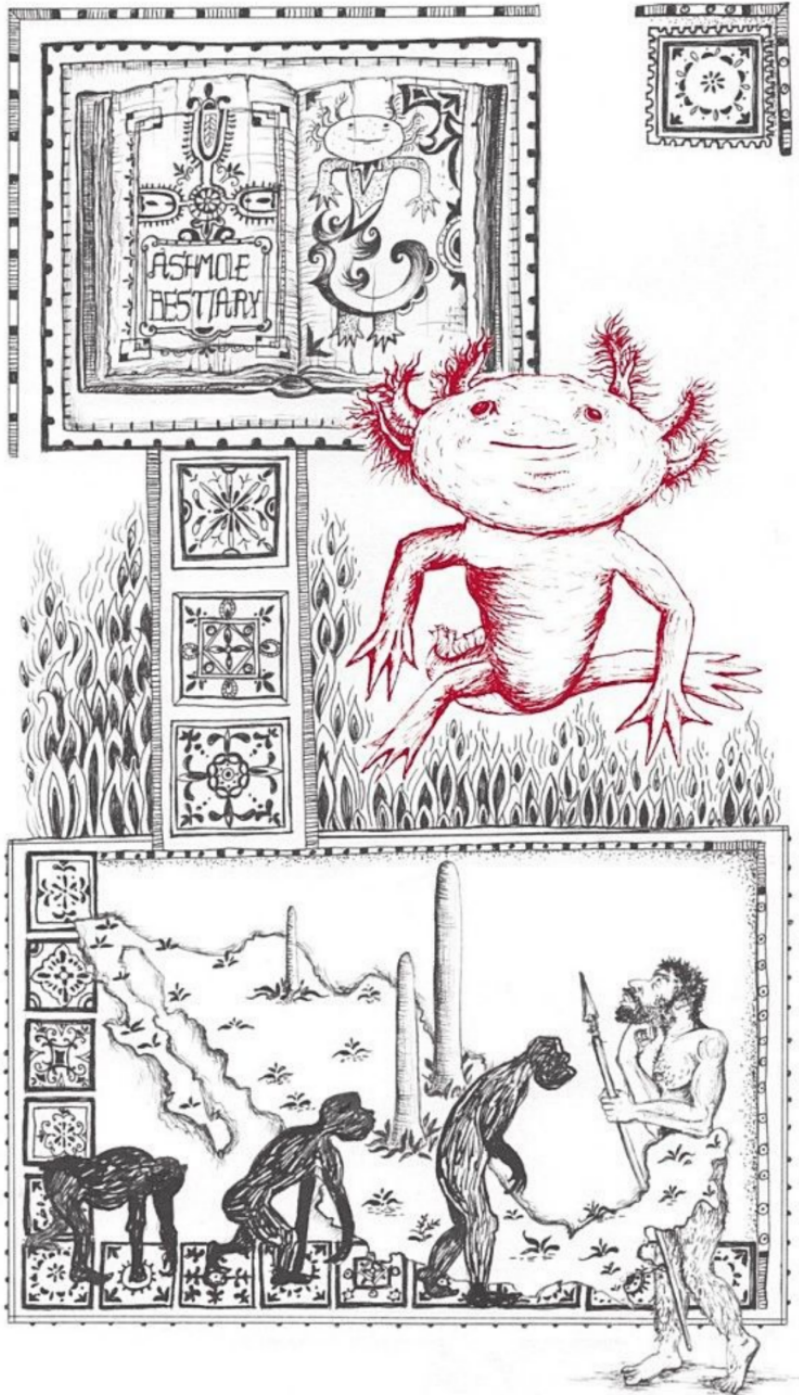
our own. In some ways their awareness of the world is superior to ours. And yet in at least one respect – consciousness – all (or virtually all) other animals seem to be greatly our inferiors. Not surprisingly we make a big deal out of human consciousness and **identity**.<sup>7</sup> But a greater appreciation of the evolutionary inheritance and capacities we share with other animals – and of how, in some ways they surpass us – can contribute to better ways of thinking about the nature of being human and being otherwise.

All these strands mentioned here, and others, including the question of how we perceive time and value over time, connect to a central question: what are our responsibilities as citizens of the Anthropocene to present and future generations? Medieval bestiaries described both real and what we now know to be imaginary animals. They were full of allegory and symbol because for the medieval mind every creature was a manifestation of a religious or moral lesson. Since at least Hume and Darwin many of us no longer believe this. But as we increasingly reshape Creation through science and technology, not to mention our sheer numbers, the creatures that do thrive and evolve are, increasingly, corollaries of our values and concerns. The Enlightenment and the scientific method will, therefore, have made possible the creation of a world that really will be allegorical because we will have remade it in the shadow of our values and priorities. Perhaps the philosopher John Gray is right when he says that the only genuine historical law is a law of irony. This book – a stab at a bestiary for the Anthropocene, in which all the animals are real, evolving and in many cases threatened with imminent extinction – asks what we should value, why we fail to value and how we might change.

In *The Book of Imaginary Beings*, Borges describes the A Bao A Qu, a creature something like a squid or cuttlefish, which only stirs each time a human enters the dark tower in which it lives with the intention of making the arduous climb to the top:

... only when it starts up the spiral stairs is the A Bao A Qu brought to consciousness, and then it sticks close to the visitor's heels, keeping to the outside of the turning steps where they are most worn by generations of pilgrims. At each level the creature's colour become more intense, its shape approaches perfection, and the bluish light it gives off is more brilliant. But it achieves its ultimate form only at the topmost step, when the climber is a person who has attained Nirvana and whose acts cast no shadows. Otherwise, the A Bao A Qu hangs back before reaching the top, as if paralysed, its body incomplete, its blue growing pale, its glow hesitant. The creature suffers when it cannot come to completion, and its moan is a barely audible sound, something like the rustling of silk. Its span of life is brief, since as soon as the traveler climbs down, the A Bao A Qu wheels and tumbles to the first steps, where, worn out and almost shapeless, it waits for the next visitor.

One can interpret Borges's strange story in many ways or not at all. Here I'll call it an allegory, and stick my own crude meaning on it: unless we enlarge our imaginations to better take account of the realities of other forms of being as well as our own, we miss our main task.



1 'All the creatures in this world have dimensions that cannot be calculated.' (Zhuangzi c.300 BC)

2 The present geological epoch used to be called as the Holocene (derived from ὅλος - *holos* - whole or entire, and καινός - *kainos* - new) and referred to the 10,000 years or so since the end of the last Ice Age. In 2008 geologists agreed a new term, the Anthropocene, to acknowledge that humans are now the largest single influence on the Earth system. Typically, the new epoch is said to have begun with the large-scale combustion of fossil fuels

3 Perhaps, contrary to Plato's allegory of the cave, we sometimes only see the real once we have seen its shadow in art.

4 Italo Calvino uses the phrase 'wealth of unexpected juxtapositions' to describe Pliny's *Natural History*, which divides (for example) fish into: 'Fish that have a pebble in their heads; Fish that hide in winter; Fish that feel the influence of stars; Extraordinary prices paid for certain fish.' And so it is in the essays (in Samuel Johnson's definition: loose sallies of the mind, irregular indigested pieces) in this book.

5 The scale of human impacts on the ocean, the gravity of the consequences and an agenda for hope and practical action can be found in *Ocean of Life* by Callum Roberts.

6 There's a larger point here, encapsulated by the novelist Ian McEwan in his account (reported in a newspaper article and then included in his novel *Solar*) of a scene of chaos on an expedition like ours that he joined the following year. The ship's boot room, a store for gear against the harsh conditions outside, quickly descended into chaos as people grabbed what they wanted without regard to who it belonged to. If, McEwan asks, people widely regarded as sensitive, intelligent and talented can't even manage a boot room, what hope do they have of saving the planet? As the philosopher Raymond Geuss puts it, 'don't look just at what [people] say, think, believe, but at what they actually do, and what actually happens as a result.'

7 Douglas Hofstadter suggests the 'I' is actually 'a hallucination hallucinated by a hallucination'.

Spinoza thought that 'The ocean stands for God or nature, the sole substance, and individual beings are like waves - which are modes of the sea.' At the level of quantum mechanics, at least, Spinoza's intuition may be strictly true: 'The connections to all the things around you literally define who you are,' says the physicist Aaron O'Connell.



# AXOLOTL

*Ambystoma mexicanum*

Phylum: Chordata

Class: Amphibia

Order: Caudata

Conservation status: Critically Endangered

**... the Salamander, which feedeth upon ashes as bread, and whose joy is at the mouth of the furnace.**

Christopher Smart

**The history of the errors of mankind ... is more valuable and interesting than that of their discoveries. Truth is uniform and narrow ... but error is endlessly diversified [and] in this field, the soul has room enough to expand herself to display all her boundless faculties and all of her beautiful and interesting extravagancies and absurdities.**

Benjamin Franklin

The first time you see an axolotl it is hard to look away. The lidless, beady eyes, the gills branching like soft coral from its neck, and the lizard-like body kitted out with dainty arms and legs, fingers and toes, together with a tadpole-like tail make this creature seem quite alien. At the same time the large head, fixed smile and flesh-pink skin give it a **disconcertingly human**<sup>1</sup> appearance. Combined, such contradictory traits are fascinating. It's easy to see why one of the first European names for this creature translates as 'ludicrous fish'. The Argentine writer Julio Cortázar imagines a character gazing at an axolotl for so long and so intently that he *becomes* one.

The comparatively sober findings of scientific research provide another reason to marvel. Along with its newt cousins, the axolotl is able to regenerate entire severed limbs. Some specialists in regrow medicine believe that it may be possible one day to restore human limbs and even organs in ways derived at least in part from what we have learned from these creatures. If this does prove to be the case - and even if the potential for axolotl-like regeneration in humans is not as great as hoped - much will have been learned along the way about the workings of cells, which are perhaps the most complex objects in the universe apart from the human brain. And the knowledge gained will be another step in the emergence of unequivocally better ways of understanding life and the relation of the human to the non-human.

But before trying to address such matters, this chapter will digress into what humans have believed about the order of animals to which the axolotl belongs, the actual role that the ancestors of that order played in evolution, and some of the errors people have made in interpreting the past and the present.

The axolotl is a kind of salamander, one of about five hundred species alive today. For thousands of years people believed that salamanders had a special relationship with fire. The *Ashmole Bestiary*, an illuminated book of beasts made in England in the High Middle Ages, mirrors this: 'The salamander lives in the midst of flames without pain and without being consumed; not only does it not burn, but it puts out flames.'



A mythical fire-salamander.

Few medieval authors or readers would have thought to test this claim. They wouldn't have seen the need. They already knew that every beast in Creation was a lesson in God's plan - or several lessons at once. In the case of the salamander, St Augustine had, early in the Christian era, cited its fire-hardiness to bolster the case for the physical reality of damnation. 'The salamander', he wrote, 'is a sufficiently convincing example that everything which burns is not consumed, as the souls in hell are not.' Later commentators, by contrast, saw the animal's supposed non-combustibility as a symbol of righteousness: like the salamander, the chosen would withstand fire just as Shadrach, Meshach and Abednego had withstood the fiery furnace.

The union of salamander and fire actually predates Christianity and perhaps Judaism. 'Sam andaran' means 'fire within' in Persian, the language of Zoroastrians - early monotheists for whom fire was an important **symbol of the divine**.<sup>2</sup> But there was more to the salamander in ancient and medieval minds than fire. According to the *Ashmole Bestiary*, it is also an animal of mass destruction:

It is the most poisonous of all poisonous creatures. Others kill one at a time; this creature kills several at once. For if it crawls into a tree all the apples are infected with its poison, and those that eat them die. In the same way, if it falls in a well, the water will poison those who drink it.

These various attributes - fire creature, symbol of virtue, or poison - sit alongside each other in medieval European bestiaries. By the Renaissance, however, the connection with fire had come to dominate. An unburnable cloth from India is '**salamander wool**'<sup>3</sup> (this is probably an early mention of asbestos). For Paracelsus and other European alchemists, the salamander was the 'fire elemental', the essence of one of the four fundamental substances of the universe, which could be summoned to the practitioner's aid. A salamander amid flames also became a piece of branding for a king: a

Nike swoosh for Francois I of France competing with Henry VIII of England at the Field of the Cloth of Gold. In the following centuries, storytellers from Cyrano de Bergerac to J. K. Rowling have rejoiced in the fantastic qualities of the fire-living salamander. For some it is entirely make-believe. For others it is definitely real but extremely rare, like - say - the snow leopard today. The Renaissance artist, sexual predator and murderer Benvenuto Cellini provides a good example of this second view:

When I was about five years of age, my father happening to be in a little room in which they had been washing, and where there was a good fire of oak burning, looked into the flames and saw a little animal resembling a lizard, which could live in the hottest part of that element. Instantly perceiving what it was he called for my sister and me, and after he had shown us the creature, he gave me a box on the ear. I fell a crying, while he, soothing me with caresses, spoke these words: 'My dear child, I do not give you that blow for any fault you have committed, but that you may recollect that the little creature you see in the fire is a salamander; such a one as never was beheld before to my knowledge.' So saying he embraced me, and gave me some money.

It's easy to see that if your only knowledge of the salamander came from bestiaries and the stories they inspired then a real sighting such as the one Cellini recalls would seem to confirm it. The actual explanation - that they like to sleep in cool, damp places such as piles of logs, get carried along when the wood is taken in for burning and, far from sporting in the flames, are writhing in their death throes - would seem dull and unconvincing.

The ancient Greeks and Romans had been more empirical, if not always right, in their claims. When Aristotle refers to a salamander in his *History of Animals*, written in about 340 BC, he makes it clear that he is relying only on hearsay in claiming that they walk through fire and in doing so put the fire out. And in the *Natural History*, written more than four hundred years later, Pliny distinguishes the salamander (an amphibian) from lizards (which are reptiles), describing 'an animal like a lizard in shape and with a body starred all over; it never comes out except during heavy showers and disappears the moment the weather becomes clear.' This is a good description of the golden Alpine salamander and of some subspecies of the fire salamander. But Pliny also writes - in a passage that inspired later bestiaries - that a salamander is 'so cold that it puts out fire on contact' and that it can be toxic.

Pliny's *History* is full of things that seem fantastical and bizarre to our eyes. In Ethiopia, he writes, there are winged horses with horns, manticores, which have the face of a man, the body of a lion and the tail of a scorpion, and something called a catoblepas, which kills you if you look into its eyes. Even creatures we know to be real become fantastical. The porcupine, for example, can shoot its quills like spears. If a shrew runs across a wheel-rut it dies. Frogs melt away into slime in the autumn and coalesce into frogs again in the spring. The anthiaae, a kind of fish, rescue their hooked companions by cutting fishing lines with their fins.

But while Pliny accepts, or reports, many claims that are plainly false to us, he is not entirely gullible. He is for example scathing about astrology and the afterlife, which are items of faith for vast numbers of people today. And when he realizes he doesn't know something, he says so plainly. In the

case of the salamander he does at least start from observed reality. Salamanders are indeed 'cold-blooded' – more precisely, ectotherms, which means they take their temperature from their surroundings – so if found in a cool damp place they are indeed cool to human touch. You'd be ill-advised to lick a salamander, but it would be an exaggeration to call it more than mildly toxic. Fire salamanders, which are common on forested hillsides in southern and central Europe, extrude secretions onto their skin containing a neurotoxic alkaloid, Samandarin, when they think they are under attack. This can cause muscle convulsions, high-blood pressure and hyperventilation in small vertebrates. Perhaps this is their real 'fire within'.

The *Natural History* is a remarkable attempt, perhaps the first in the West, to compile all **knowledge**.<sup>4</sup> Still, Thomas Browne, the seventeenth-century English physician, is pretty unforgiving of what Pliny actually achieved: 'there is scarce a popular error passant in our days', he writes, 'which is not either directly expressed, or deductively contained in [it].' He tried to put the record straight with the *Pseudodoxia Epidemica*, or *Vulgar Errors* (the *Bad Science* of its day, it ran to six editions between 1646 and 1672). Browne identifies the causes of popular delusions as, variously, 'erroneous disposition, credulity, supinity, obstinate adherence to antiquity' and 'the endeavours of Satan', but most of his energy goes on demolishing the delusions themselves. The myth of the salamander is one of 'fallacious enlargement', and is easily demolished by a bit of solid English empiricism: 'We have found by [our own] experience, that it is so far from quenching hot coals, that it dieth immediately therein.'

Browne was a practical man but he was also fascinated by symbols and mysteries. His *Garden of Cyrus* is an exuberant vision of the interconnection of art, nature and the universe. For Browne, God is a universal geometer, who places the **quincunx**<sup>5</sup> (the X shape formed by five points arranged like the five spots on dice) everywhere in living and non-living forms. As W.G. Sebald notes, Browne identifies the quincunx everywhere: in crystalline forms, in starfish and sea urchins, in the vertebrae of mammals and the backbones of birds and fish and in the skins of various species of snake; in the sunflower and the Caledonian pine, within young oak shoots or the stem of the horsetail; and in the creations of mankind, in the pyramids of Egypt and in the garden of King Solomon, which was planted with mathematical precision with pomegranate trees and white lilies. Examples might be multiplied without end.

The salamander reappears in a riddle unearthed more than fifty years after Browne's death when the Swiss physician and naturalist Johann Scheuchzer found a fossil of a creature whose large skull resembled that of a human child, he declared it to be *Homo diluvii testis*, or man, witness to the Great Flood: 'a rare relic of the accursed race of the primitive world'. And this judgement stood for another hundred years until the French comparative anatomist Georges Cuvier examined it. The fossil, he declared in 1812, was definitely not human. A positive identification, however, wasn't made until 1831: *Diluvii testis* was a giant salamander of a type now extinct but related to the enormous creatures that are still found in a few Chinese and Japanese rivers.

Cuvier and others showed that many species that had once roamed the Earth were now extinct, and it was increasingly apparent that there had been vast periods of time before humans appeared. What, then, was our true place and role in Creation? For James McCosh, a philosopher in the once influential but now little remembered Scottish School of Common

Sense, the answer was clear: man was the culmination of a process that had produced the ideal form in nature. 'Long ages had yet to roll on before the consummation of the vertebrate type,' McCosh wrote in 1857; 'the preparations for Man's appearance were not yet completed. Nevertheless, in this fossil of Scheuchzer's there was a prefiguration of the more perfect type which Man's bony framework presents.'

Words and phrases like 'consummation' and 'perfect type' are out of fashion today. 'Prefiguration' less so. Amphibian fossils *do* prefigure much of what we see in modern vertebrates, ourselves included. The bodies of salamanders alive today (not to mention those of geckos, grebes and gibbons) share a lot with ours. Salamander limbs may be smaller and slimier than those of most people, but they have essential similarities: they are encased in skin and contain a bony skeleton, muscles, ligaments, tendons, nerves and blood vessels. There are big differences of course - their hearts, for example, have three chambers rather than the four found in reptiles and mammals - but what's a ventricle between friends?



The palaeontologist Richard Owen, a contemporary of both James McCosh and Charles Darwin, thought such similarities, or homologies as he called them, were evidence of 'transcendental anatomy', of a divine plan, with God as a carpenter running off creatures on his workbench as variations of archetypal themes. (He called this the 'axiom of the continuous operation of the ordained becoming of living things'.) But, Owen insisted, each species was separate: one did not evolve into another, and man stood outside as a unique creation. Darwin, by contrast, argued that the similarities seen in so many living creatures, including man, were better explained by **descent with modification**<sup>6</sup> from a common ancestor.

Most of us now accept that humans are continuous in an evolutionary sense but we continue to insist that there are essential differences in our way of being. As the anthropologist Loren Eiseley wrote in the 1950s, man is a 'creature of dream [who] has created an invisible world of ideas, beliefs, habits and customs which buttress him about and replace for him the precise instincts of lower creatures'. Eiseley thought that 'a profound shock at the leap from animal to human status is echoing still in the depths

of our subconscious minds’.

What could account for our apparently unique ability to be the carriers of such dreams in a way that creatures with superficially similar anatomy – like the salamander – are not? The answer pieced together by paleobiologists and geneticists over that last hundred years is, of course, that after diverging from a common ancestor with our nearest ape cousins, our hominid ancestors acquired much larger brains in a series of evolutionary spurts, notably in the last two million years, until they reached a form very close to ours less than 200,000 years ago. But there is a problem with such an account – at least I have stated it here.

The problem is not that this account is in any way misleading – it is not – but that it is too matter-of-fact; it fails to convey how singular it is that, after so many hundreds of millions of years of vertebrate life – much of it, as we shall see, filled with strange creatures resembling the axolotl – something as marvellous as the human brain evolved in such a comparatively short period of time.

People have looked for all kinds of ways to get around this counterintuitive truth. Among those that claim to be scientific here are two of the most delightfully absurd. In 1919 a distinguished English physical anthropologist named F. Wood Jones argued that large-brained proto-humans were actually tens of millions of years old and ‘utterly unlike the slouching, hairy ape-men of which some have dreamed’. They were, rather, ‘small active animals’ resembling tarsiers, already endowed with legs longer than arms, small jaws and a greatly enlarged cranium.

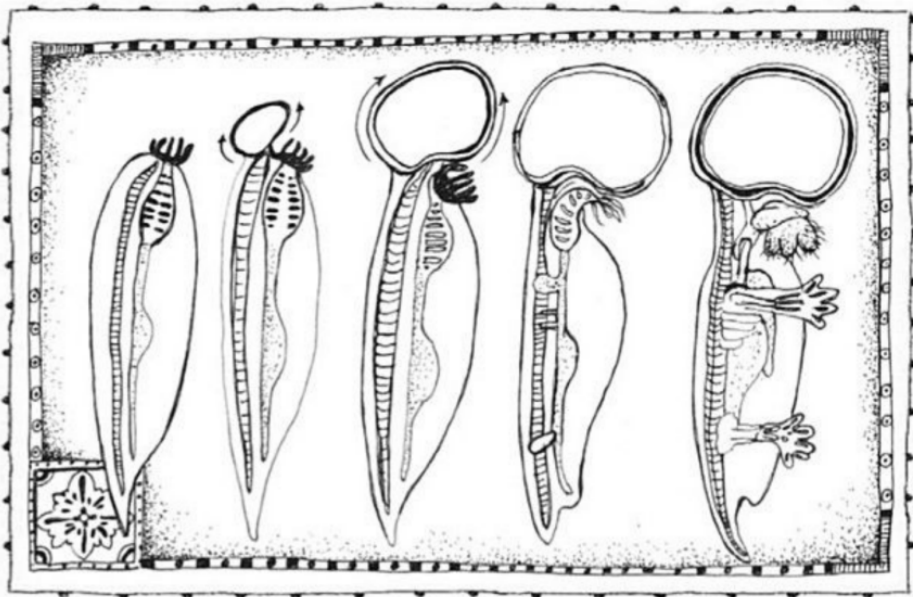


A Tarsier.

Even at the time he advanced it, Wood Jones’s hypothesis was at the outer edge of plausibility which is a pity, given how cute tarsiers are. Wilder still is the theory of initial bipedalism advanced by François de Sarre, which posits that human-like forms preceded not only all other apes but all tetrapods (that is, land animals with backbones: amphibians, reptiles, mammals and birds) and even fish. This homunculus, says this theory, actually evolved directly from an aquatic ‘pre-vertebrate’ that looked a bit like a lancelet, or amphioxus (a creature alive today that looks

like a small and simple fish with a nerve chord but no brain or spine). Humans, therefore, have retained the most primitive body shape of all terrestrial vertebrates, and all the others - stegosaurus, snake and salamander, cow, capybara and *coati*<sup>7</sup> - have evolved from it: we are the archetype from which all other vertebrates have arisen.

The theory of initial bipedalism claims that our lancelet-like ancestors evolved a bubble-like, gas-filled floating organ that helped control buoyancy. At first, this acted as a float, allowing the little creatures to float like champagne corks with their bodies suspended vertically in the water. Two pairs of limbs and a little tail evolved to help the animals steer themselves in the water and they began to look like vertically-poised floating embryos, with axolotl-like branched gills sticking out of the neck. The globular head, meanwhile, allowed space for a big brain to develop. This aquatic homunculus then evolved endothermy (warm-bloodedness), body hair, ears, prehensile hands and live birth, and became the first animal to colonize the land.



Early stages in the development of the aquatic homunculus.

If this theory is *absurd* it is at least splendidly and originally so. And the actual shapes of our proto-amphibian ancestors are no less strange and fascinating.

Many scientists used to think that the first vertebrates to venture onto land were something like coelacanths - ancient fish with stubby fins - and that they wriggled out of the water *before* they evolved legs as we think of them, or lungs. The model in mind was probably the 'walking fish' such as the mudskippers we see today. This is now known to be wrong (although mere wrongness doesn't stop it from being the basis for an inventive and funny beer advertisement, *noitulovE*). Lungs and limbs came first, but the creatures that evolved them were still wholly aquatic.

Our, and the salamanders', ancestors, the first tetrapods (four-limbed vertebrates), evolved in the Devonian geological period, roughly 365 million years ago. They lived in slow-moving, shallow waters of estuaries or coastal swamps, rich in food and places to hide. In these conditions, 'fishapods', able to do push-ups on proto-limbs to gulp fresh air from just above its river habitat, would have had an edge over those relying only on gills to extract meagre oxygen from the murky water. Flexible necks and multiple digits -

sometimes seven or eight on each 'hand' or 'foot' - evolved to help a body twist, finger and pick through the weeds and rotting logs.

What would their world have been like? Imagine yourself thrown back in time and washed up on the edge of a Devonian river mouth. It's warm, and you feel a little light-headed because the oxygen concentration in the air, at around 15 per cent, is lower than you're used to. But the water flows and the waves lap just as they always do, and this is reassuring. Looking at the sand beneath your feet, you half recognize something scuttling along the shallow lip of the water: it's a small version of the horseshoe crabs we know today. (Out to sea are placoderms - heavily armoured fish, some of them more than six metres (twenty feet) long and equipped with massive, powerful jaws. But they're out of sight so they don't trouble your glance.)

Moving inland, the vegetation on the riverbanks is bewildering. Nearby is something like a tree trunk: a tall round cylinder about eight metres (twenty-five feet) high with smooth sides and a rounded top. It vaguely resembles a saguaro cactus but without the spikes. This is the fruiting body of *Prototaxites*, the 'humungous fungus'. A little further away is a thicket of ... well ... nearly-trees, sporting fern fronds rather than needles or leaves, arranged in odd, symmetrical umbrella-shapes. There are also stumpy things that look like green traffic bollards in various stages of emerging from the ground. And there are shrub-sized clubmosses, their stems close-packed with green scales, looking like bendy policeman's truncheons. You see some strange insects on the ground and the plant stems, but there are none buzzing in the air - **flying insects**<sup>8</sup> will not evolve for another sixty millions years. And there's no birdsong, of course: there won't be any for another three hundred million years.

The meandering river mouth is a patchwork of weeds and deep pools. And there, through murky water, you glimpse something about the size of a ten-year-old child, poised delicately on short limbs that end in seven webbed digits. It has a tail rather like a newt's and a face somewhere between fish and frog. You are looking at *Ichthyostega*, and this species, or something very like it, may be our, and the salamander's, direct ancestor. This particular individual saw you coming, however, and quickly swims away: a ripple, then **silence**.<sup>9</sup>

Three or four thousand years ago in Mesopotamia people imagined that a being called Oannes, half-man and half-fish, rose from the sea to teach wisdom to mankind. *Ichthyostega* is emphatically not a supernatural being; it is just a tetrapod from the almost unimaginably remote past. And unlike Oannes, it does not 'teach' us anything in any direct sense. But if we allow it to exist on the water's edge of our conscious minds we may allow ourselves to learn more, feel more deeply about our own rootedness in antiquity and in the strange transformations that have unfolded deep in our past.



Ichthyostega

After *Ichthyostega* there is a break in the fossil record of about twenty million years before there is evidence of amphibians that were completely at home on land. This gap<sup>10</sup> may be filled one day. Whatever the precise details turn out to be, this transition was momentous: coming onto land from an environment where animals are essentially weightless was at least as great a challenge as the one an astronaut endures returning to gravity after a long time in space.

For over a hundred million years through the Carboniferous and Permian periods – five hundred times as long as anatomically modern humans have existed – amphibians were top predators on land. *Cacops* looked like a foreshortened crocodile crossed with a really big frog. *Eryops* resembled a monstrous salamander. *Prionosuchus* was, superficially, a dead ringer for a crocodile, only it was nine metres (thirty-three feet) long – much bigger than the largest saltwater crocodiles today. Other species kept the external gills of their larval stage into adulthood, like axolotls but well over twice the size. And at least one, *Diplocaulus*, had a head shaped like a large boomerang.

Amniotes – creatures whose eggs have protective membranes that prevent them from drying out on land – first evolved quite early in the Carboniferous. And, over time, descendants of the first amniotes evolved into reptiles (including the dinosaurs and later their descendants, the birds) and the beasts that eventually became mammals. Ultimately these new kinds of land-adapted vertebrates displaced amphibians in many niches on land, which is probably why this book was not written by a large frog. But it took a long time and there were bumps along the way. A little over 254 million years ago, for example, the greatest catastrophe in the history of life so far killed-off more than two thirds of all terrestrial vertebrates and 97 per cent of all marine life. Amphibians suffered even more than the amniotes. Even so, some survived.<sup>11</sup> And, having ceded much of the ground to reptiles and protomammals, the ancestors of modern amphibians made a virtue of life in the niches remaining available to them. They exploded again (over geological time) into a diversity of beings stranger than anything you'll find in a medieval bestiary.

Consider *Beelzebufo*, a warty 'toad from hell' of **Miltonic resonance**<sup>12</sup> as big as a super-size pizza. Behold *Nasikabatrachus sahyadrensis*, a rare purple frog as squishy as a bag full of jelly but tough enough to survive almost unchanged for 150 million years. Lo, the crab-eating frog, which lives in mangrove swamps and marshes, and is the only known modern amphibian which can tolerate salt water. Hail the Southern Gastric Brooding Frog, which – until it recently became extinct – swallowed its fertilised eggs and allowed the young frogs to develop into tadpoles and then froglets in the safety of its stomach before disgorging them on an eager world. *Ave*, the caecilians, an entire order which are neither frog, toad, nor salamander but, like the pelican of story, feed their young with **their own flesh**.<sup>13</sup> And let Earth rejoice in the salamanders, wondrous in their more than five hundred kinds.

It would take another Christopher Smart – the English poet best known for the *Jubilate Agno*, a paean to all creation (but most especially his cat Geoffrey) – to celebrate all these beings: to write a *Jubilate Amphibio*. And it would take another William Dunbar – the Scots author of the *Lament for the Makars*, a roll call of poets and friends taken by death – to lament the passing of so many in what, on current trends, looks likely to be the greatest amphibian extinction since the Permian.

The axolotl is a member of the Mole salamanders, a genus found only in North America, and one of a handful of species found only in the highland lakes of Mexico. There are two explanations for its name. One connects it to Xolotl, the Aztec god of fire, guide of the dead, and sometime bringer of bad luck. In a story associated with the legend of the Five Suns, Xolotl (who has backwards feet and the head of a dog) transforms into an axolotl. A second explanation says the name comes from *atl* and *xolotl*, the words for 'water' and 'dog' in the Nahuatl, the language of the Aztecs. As the popular names of other species of salamander, such as snot otter and mud puppy, testify, the larger salamanders can look a little like dogs underwater. This would be all the more the case if your idea of a dog is of the 'hairless' breed common in Mexico.

The axolotl makes at least two entrances into the theatre of European taxonomy. The first is via the pen of Francisco Hernandez, a sixteenth-century Spanish naturalist who recorded its native Nahuatl name and came up with *piscis ludicrus* - the ludicrous fish. The second is in 1789 when the English zoologist George Shaw, who was also the first European scientist to examine a platypus, assigned it a place in the Linnaean firmament. In 1800 the German naturalist Alexander von Humboldt shipped two live axolotls, along with fossilized giant elephant bones and other goodies, to Georges Cuvier - he of the giant primeval swamp salamander - in Paris. Cuvier decided axolotls were the larval form of an unknown air-breathing species, and seems to have left it at that. It was not until sixty years later that scientists, also in France (and benefiting from their country's attempted conquest of Mexico), first studied one of the axolotl's most remarkable features: the fact that it was a reproducing adult even though it looked like a 'tadpole' - that is, a juvenile - but that it could also, mysteriously, transform itself into what looked like another species altogether.

When a new species evolves which has traits as an adult that were previously seen only in juveniles the phenomenon is known as 'neoteny'. It can be observed in a variety of animals. Adult ostriches, for instance, have tufty wee wings similar in proportion and appearance to those of the baby chicks of their ancestors. Humans are reckoned to have as many as twenty neotenic traits, including a small jaw and **large head**<sup>14</sup> that make us look more like baby gorillas or chimps than 'proper' adult apes. But staying 'immature' doesn't mean you have to be small or sexually dormant. The ostrich is the biggest living bird, and humans are not exactly unsuccessful breeders.

The phenomenon of neoteny has been pressed into service to explain or connect all kinds of things, but it has not always been clear where science ends and where metaphors begin. Aldous Huxley, the author of *Brave New World* (1932), toyed with the increasingly fashionable idea that humans were **neotenic**<sup>15</sup> apes and that if human life were extended indefinitely we would become like other apes - hunched, hairy and sitting in our own mess on the floor. His inspiration, at least in part, was actual experimental work on axolotls undertaken by his older brother Julian, one of the leading evolutionary biologists of the first half of the twentieth century, who turned them into something that looked very like their relatives the Mexican tiger salamanders by injecting them with a hormone.

Aldous Huxley was wrong about what would happen if humans were able to live indefinitely, but his theory was, perhaps, no less grounded in reality than another idea popular in his time and still influential today: recapitulation theory. This notion, first put forward in 1866 by the German

naturalist Ernst Haeckel, and popularly known as ‘ontogeny repeats phylogeny’, holds that each creature replays the history of life in the course of its individual development up to the point at which its particular species first appeared. Humans, for example, start out at conception as tiny cells just like the first life, and progress via embryonic stages in which they are fish-like, complete with gills, through a mammal-like stage, complete with a tail, before finally emerging as the ‘advanced’ beings we are today.

Recapitulation theory also seemed to fit with the idea of progress popular in nineteenth- and early twentieth-century Europe and as such was extended to support ‘scientific’ racism and imperial expansion: the children of the ‘advanced’ European race, it was believed, were on the same level as the adults of indigenous populations, especially those in Africa who, in Kipling’s now notorious phrase, were ‘half devil and half child’. And the swarthy natives were (supposedly) very like the apish proto-men of the distant past. White children passed through these stages on their way to becoming the most advanced form of human being.



Many of the most astute minds of the age bought into this theory. Sigmund Freud added a new parallel: a healthy European child was going through the ‘primitive’ stage in which non-European adults and early man had got ‘stuck’ (as, he believed, had neurotic European adults). And an adult from a ‘primitive’ (non-European) culture and early man were, he said, like a normal modern child: they were ‘trapped’<sup>16</sup> in early stages of the unfolding. It inspired Freud’s colleague, the Hungarian psychiatrist Sándor Ferenczi, to write a book called *Thalassa: A Theory of Genitality* (1924), in which he argued that that much of human psychology is explained by our unconscious yearning to regress to the comforting confines of the womb-as-sea. Ferenczi saw the full sequence of human life – from the coitus of parents to the final death of the offspring – as a recapitulation of the gigantic tableau of our entire evolutionary past. Impregnation recapitulates the dawn of life. The fetus, in the womb of its symbolic ocean, then passes through all ancestral stages from the primal amoeba to a fully formed human. Birth recapitulates the colonization of land by amphibians and reptiles, while the period of latency, following

youthful sexuality and before full maturation, repeats the torpor induced by ice ages.

Haeckel's theory and the enthusiastic application of it in politics and psychology as well as in biology arose at the high point of European global expansion and conquest. The axolotl was present at a key time and place of that expansion's beginning: the Spanish conquest of Mexico. And though devastated by the consequences, it has survived as a captive (the axolotl reproduces very well in the lab and the aquarium) to play an unwitting role in the development of a more sophisticated world view which, we may hope, promises something better for both humans and salamanders.

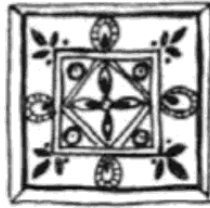
Hernán Cortés and his men entered the great central valley of Mexico in November 1519. The chronicler records:

When we saw all those towns and villages built in the water, and other great towns on dry land, and that straight and level causeway leading to [the city of] Mexico, we were astounded. These great towns ... and buildings rising from the water, all made of stone, seemed like an enchanted vision ... Indeed some of our soldiers asked whether it was not all a dream ... It was all so wonderful that I do not know how to describe this first glimpse of things never heard of, seen, or dreamed of before.

It must have looked a little like Venice, only with the twin cities, or *altepetls*, of Tenochtitlán and Tlatelolco dominating Lake Texcoco, the largest of five shallow bodies of water in a broad valley surrounded by volcanic mountains rather than a marsh and lagoon on the edge of the sea. Tenochtitlán (which the Spanish called Mexico), Tlatolco and the cities on the other lakes fascinated the Spanish with their rich markets, huge public buildings, hanging gardens, not to mention the prostitutes who painted their teeth black to enhance their allure.

The wealth of the cities, and their ability to muster armies numbering tens and possibly hundreds of thousands, depended on highly productive agriculture. *Chinampas* - sometimes called 'floating gardens' but actually artificial islands in the lakes - played a key part in this, supplying maize, beans, squash, amaranth, tomatoes and chilies in abundance. The waters surrounding them were rich in fish and other edible creatures, not least axolotls, which the locals ate with gusto.

The valley of Mexico is endorheic, which means it has no natural outlet to the sea. At a glance it looks flat but, like the bottom of a bathtub, one end is actually slightly higher than the other. The lakes that once covered much of it are all but gone, but when they did exist those at the higher end - Chalco, Xochimilco (both spring-fed) and Tlcofan - had the sweetest water. Downstream, the larger lakes and marshes of Texcoco, Xaltocan and Zumpango became saltier as water evaporated away.



The most productive agriculture needed the sweetest water, and this was also the favoured home of the axolotls (like almost all extant amphibians, they abhor salty water). Indeed Chalco and Xochimilco are their only recorded habitat, and they appear to have thrived there even with a substantial human presence.

The Spanish conquest is one of the most dramatic events in recorded history: Cortés and a few hundred men defeated an apparently mighty empire able to muster tens of thousands of troops. Cunning, audacity, speed and ruthlessness were key; but (as Napoleon Bonaparte would have appreciated) Cortés was also *lucky*. Yes, he had horses, steel swords and guns (quite unknown in the New World). And yes, crucially, he had the help of many local enemies of the Aztecs. But even more importantly he had something on his side that no one had yet learned to control: smallpox. The indigenous people had no immunity to the disease and died in enormous numbers. (Just how many has been disputed, but it may have been as many as four out of ten people in a matter of weeks.) The toll included a lot of the best leaders and soldiers, and those who survived were often terribly weakened. Agriculture all but collapsed, and those who escaped the worst effects of the disease starved - or, if they survived, were deeply traumatized. To amalgamate Paul of Tarsus and Jared Diamond, 'So abide these three: guns, germs and steel; but the greatest of these is germs.'

Contemporary accounts are harrowing. A Spanish monk wrote: 'as the Indians did not know the remedy of the disease they died in heaps, like bedbugs. In many places everyone in a house died and, as it was impossible to bury the great number of dead, they pulled down the houses over them so that their homes become their tombs.' When Cortés finally defeated the Aztecs in the last battle for Tenochtitlán, it was said the Spaniards could not walk through the streets without stepping on the bodies of smallpox victims.

Smallpox causes a painful rash on the skin and for the Aztecs the disease was *huey ahuizotl*, the great rash. *Ahuizotl* was also the name of a legendary lake creature that liked to eat human flesh - something like axolotl's horrible twin. It was said to look something like a dog or an otter, with human hands and an additional hand on its tail which it used to snatch

prey and drag it **beneath the water**.<sup>17</sup>



*Ahuizotl*

So much for the dark backward and abysm of time. Mexico City has long since metastasized into a sprawling, heavily polluted megalopolis with more than twenty million inhabitants. This transformation would not have been possible without one of the largest drainage programmes ever undertaken. The diminution of Lake Chalco, the axolotl's stronghold, began in colonial times (already, in one of the key battles of the conquest, the Spaniards had demolished a great causeway that had separated sweet and brackish water) and it finally gurgled away like water down a plughole through massive artificial tunnels in the twentieth century. A remnant of Lake Xochimilco, the animal's other home, survived a little longer; it was serviceable for the rowing and canoeing events of the 1968 Olympics. But now all that remains of it are a few polluted canals and reservoirs in which a small and critically endangered population remains.

The neoteny of axolotls and other gilled salamanders may once have been an excellent survival strategy: the ability of breeding adults to continue to live underwater in the highland lakes may have given them an advantage over cousins that matured to the land-dwelling stage. Now it is a disadvantage: the lakes are drained, polluted or subject to other human pressures that are driving these animals to extinction in the wild. Their continued survival is probably down to their appeal and their usefulness to human beings.

Axolotls have this advantage over many other species in a human-dominated world: many people find them cute. With strange, childlike faces and a resemblance to homunculi they are popular for the home aquarium trade. As for other uses, there are or have been two: food and scientific research. For centuries, axolotls were a valued part of local diets in Mexico. Whether or not they were once harvested sustainably, however, this is clearly no longer the case. As for their value to science, the picture seems more promising. The axolotl and other salamanders (and newts) are probably unique among vertebrates in being able to regrow a fully functioning arm or leg after an amputation. And they can do this repeatedly, regardless of how many times the part is amputated, and without a scar (sometimes, two will grow where one was before). They can even regrow parts of internal organs, including eyes and parts of the brain. Axolotls have the good fortune to be the easiest salamanders to breed, maintain and study in lab conditions. These properties, and others, make

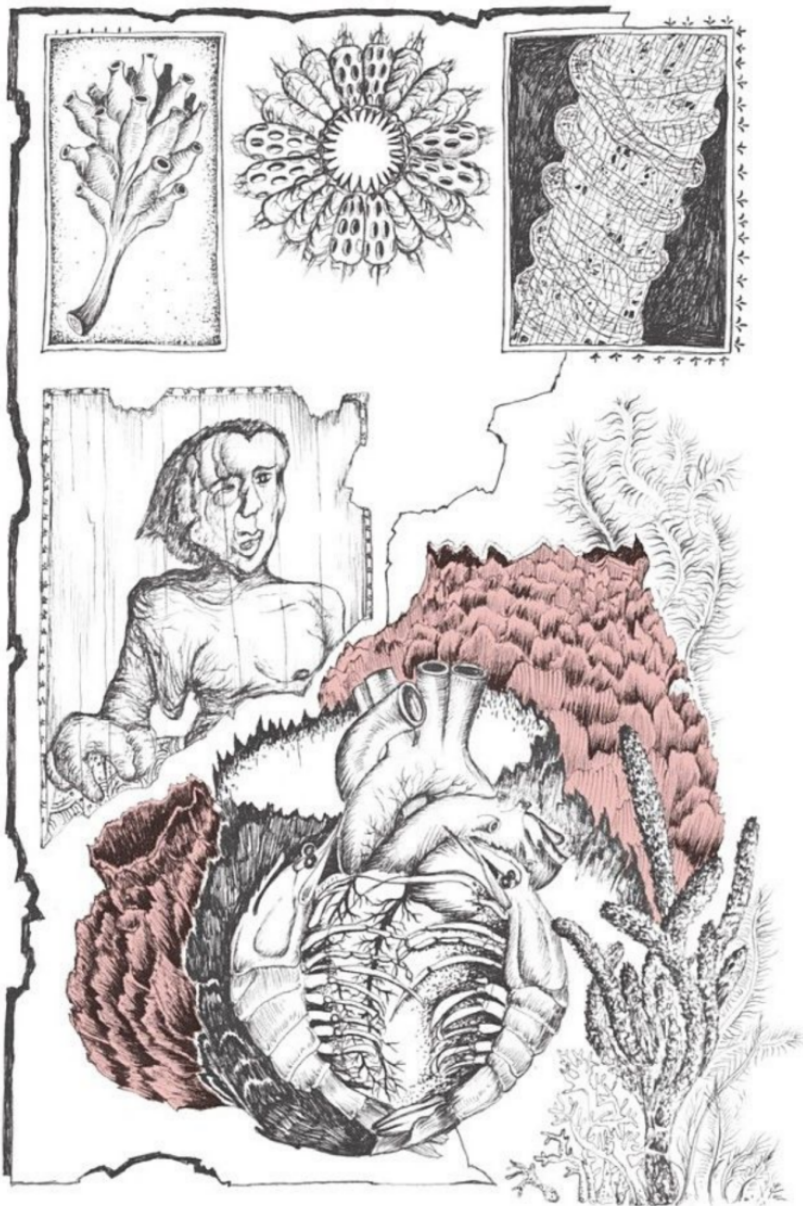
them ideal for the study of vertebrate limb development but, more than that, they have played a valuable role in the development of regenerative biology.

If a human loses a limb and survives long enough to heal, he or she will have a stump covered in scar tissue where the limb used to be. That makes us much like most other vertebrates. Salamanders (and particularly the axolotls on whom experiments are most often performed) are an exception. They somehow 'know' how much of a limb is missing and needs to be regrown. It happens something like this. Blood vessels in the remaining stump contract quickly and limit bleeding. Then, during the first few days, the wound transforms into a layer of signalling cells (called the 'apical epithelial cap'), while fibroblasts - cells that hold internal tissues together and give shape to a shape - break free from the connective tissue meshwork and migrate across the amputation surface to meet at the centre of the wound. The fibroblasts then proliferate to form a blastema - an aggregation of stem-like cells that become progenitors for the new limb.

The reconstruction of a limb by the blastema is similar to the formation that took place during the animal's original embryonic development, but with a difference. In an embryo, the sequence of events in limb development always begins with formation of the base of the limb (the shoulder or hip) and is followed by progressive building of more distal structures until the process terminates with the making of fingers or toes. But in the case of the axolotl, the site of amputation can be anywhere along the limb and regardless of where the wound is located, only those parts of the limb that were amputated regrow.

For thousands of years people believed that salamanders knew the secret of fire. This is not true, of course. But these strange creatures - and most especially the axolotl - may hold clues to the flame of life. For this alone they surely deserve a place in a contemporary bestiary.





1 A distant relation of the axolotl known as the Olm, or Proteus, also has pale pink, (European) human-like skin and external gills. It lives in streams in the limestone caves of Slovenia and is known as the 'Human fish'.

2 Zoroastrians do not worship fire itself. Rather, fire (along with water) is seen as an agent of purity: an individual who has passed the fiery test has attained physical and spiritual strength, wisdom, truth and love with serenity.

3 'This Salemandre berithe wulle, of which is made cloth and gyrdles that may not brenne in the fyre.' (William Caxton, 1481)

4 For all the knowledge he compiled, Pliny concluded that 'among all things, this alone is certain: that nothing is certain, and that there is nothing more proud or more wretched than man'.

5 Given sufficient enthusiasm one can find the quincunx almost anywhere, including the salamander. As the 'fire elemental', it can be connected to the tetrahedron, the perfect form which Plato believed was the element that constituted fire. The tetrahedron is a 3-simplex whose 4-simplex analog is the pentachoron, a four-dimensional body which can be orphographically projected onto a quincunx (as well as a pentagram and other shapes). You could almost do the same for the code of life itself if you look no further than Rosalind Franklin's 'Photograph 51', which shows DNA in cross section as something like a quincunx.

6 'If you know how to look, our body becomes a time capsule that, when opened, tells of critical moments in the history of our planet and of a distant past in oceans, streams and forests. Changes in the ancient atmosphere are reflected in the molecules that allow our cells to cooperate to make bodies. The environment of ancient streams shaped the basic anatomy of our limbs. Our colour vision and sense of smell has been molded by life in

ancient forests and plains.’ (Neil Shubin, 2008)

7 The coati, also known as the hog-nosed coon, the snookum bear or the Brazilian armadillo, is a kind of raccoon.

8 Insect flight evolved less than 300 million years ago, in the Permian. Songbirds evolved in the early Eocene, less than 56 million years ago.

9 A primordial being that looks like a fish may seem a little silly but consider that until two or three thousand years ago giant carp and sturgeon, many of them larger than a man and weighing a tonne or more, were not uncommon in many Asian and European rivers. They must have been impressive presences, and would surely have set people to wondering. A few species of giant fish have hung onto existence in the Mekong and some very remote rivers until very recently. Not all river-dwelling mythical beings are benign: the Nhang of Armenian lore, for example, is a river-dwelling serpent-monster with shape-shifting abilities that can lure a man by transforming itself into a woman, or changing into a seal and dragging him down to drown to drink his blood.

Following the 2003 invasion of Iraq, river carp were said to be growing to the size of men on all the dead bodies thrown into the Tigris and Euphrates.

10 Fossilization is rare in nature. Bill Bryson estimates that the entire fossil legacy of the approximately 300 million Americans alive, with 206 bones each, would amount to about fifty bones, or less than a quarter of one complete skeleton.

11 The last common ancestor of frogs, toads, salamanders and newts is the Elderly Frog of Dr Nicholas Hotton III, or *Gerobatrachus hottoni*. This amphibian Abraham, aka the frogamander, lived during the early Permian but was only discovered in 2007, a fossil in Don’s Dump Fish Quarry in Baylor County, Texas. The frog/salamander lineage split during the next 100 million years, before the break-up of the supercontinent Pangea. Ancient frogs and toads became better jumpers, while salamanders specialized in slithering.

12 . . Princely counsel in his face yet shon,  
Majestic though in ruin: sage he stood  
With Atlantean shoulders fit to bear  
The weight of mightiest  
Monarchies; his look

Drew audience and attention still as Night

13 The idea that the pelican feeds its young with its own flesh and blood was popular in medieval Europe, and the birds feature in bestiaries as a sign of piety and sacrifice and as a symbol of Christ himself. Caecilians do something similar for real. The young nibble fatty deposits on their mother’s skin using special teeth unknown in other modern amphibians. The skin is so nutritious that the young can increase their weight up to ten times in the week after birth. It is the only known case of dermatotrophy – the deriving of necessary nutrients from the consumption of skin – in the animal kingdom.

14 One of the most conspicuous differences between humans and other apes – brain size – is more accurately described as the result of heterochrony rather than neoteny. Brain and head growth in the chimpanzee fetus starts at about the same developmental stage and presents a growth rate similar to that of humans, but ends soon after birth. In humans, rapid brain and head growth continues for several years after birth.

15 Some scientists think that chordates, the phylum including all vertebrates, evolved as the result of neoteny. Among the nearest living relatives of chordates are sea squirts, or tunicates – sack-like marine filter feeders that superficially resemble sponges. As a larva, the sea squirt swims about, wriggling by means of a notochord, a rod-shaped body made of cells from the mesoderm that resembles a primitive backbone similar to the one in chordate embryos. Maturing, they stick onto rock and lose the notochord. The geneticist Steve Jones compares this life cycle of a sea squirt to that of an academic given tenure: after an active life, it settles on the sea floor and absorbs its brain.

16 For the radical environmentalist philosopher Charles Shepard (1982), contemporary Americans were childish adults suffering from ontogenetic crippling – culturally induced neoteny gone wrong.

17 Fear, mystery and an ambiguous border between life and death have a long history in these lands. The Tlatilco culture, which occupied the western shore of Lake Texcoco and the eastern shore of Lake Chalco from about 1200 to 200 BC, left behind some extraordinary, beautiful and haunting artefacts, including figurines that are two-headed or otherwise deformed. The name ‘Tlatilco’ was given to this culture by Nahuatl speakers, who arrived long after it had disappeared. It means ‘the place of hidden things’.



## BARREL SPONGE

*Xestospongia sp.*

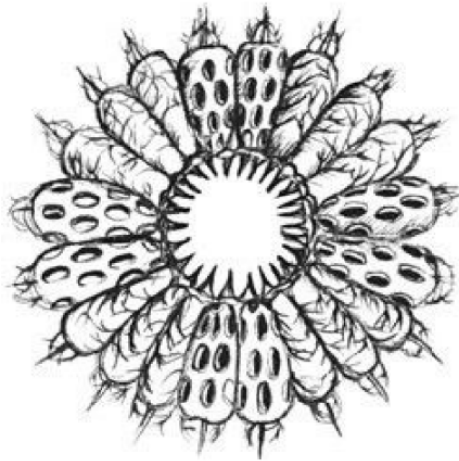
Phylum: Porifera

Class: Demospongiae

Conservation status: Many species: Not listed

From computer-generated recreations of the Cambrian ocean to the wildest actually existing tropical reefs, brightly coloured giant sponges make good scenery. Few people, however, would give them a leading role in the drama. We may know that, strictly speaking, they are animals, but their lack of eyes, mouths, organs and the power of movement means that they don't really *seem* like animals. Such associations as do come to mind are more likely to concern bath-time, Sponge Bob Squarepants or a person who is always asking for money, rather than the marvellous or symbolic qualities typically attributed to creatures in a bestiary. This chapter aims to change that.

There are thousands of species of sponges, so choosing one is hard. A good candidate is Venus's Flower Basket. The silica fibres in its fine tubular body are arranged in a regular, lace-like scaffold of great elegance and intricacy. Victorian collectors marvelled, and paid very high prices for the best specimens. Its mystique was enhanced by stories that tiny male and female shrimp, which take up residence when it is immature, become trapped as it grows and closes over at the top. Locked inside, the shrimp spend the rest of their lives inside a translucent filigree cage. The Japanese take this as a symbol of eternal love and partnership. My choice of sponge, however, is at the other end of the spectrum: a group of wonky giants known as barrel sponges that come in bruised lilacs, reds, maroons, greys and browns and are sometimes large enough for a human diver to climb inside. (Incidentally, you should not do this because it damages the sponge.) For the truth is that these odd-looking animals are masterpieces of design, and talismans for the emergence of all multicellular animals including ourselves.



For the seventeenth-century physician Thomas Browne, animals only made sense if they had a top, bottom, back and front, and for this reason he doubted the existence of creatures such as the *Amphisbaena*, a snake which supposedly had a head at both ends. Based on the evidence available to him, Browne's conclusion was reasonable at the time: all terrestrial animals visible to the naked eye, and virtually all fish, are symmetrical along a single plane. In contemporary classification they are known as 'bilateria' and are grouped with radially symmetrical animals, 'radiata', to form the 'eumetazoa' or 'true big animals'. 'Asymmetrical' creatures are only grudgingly included in the kingdom animalia with the qualification of either being 'mesozoa' (a 'wastebasket taxon' containing at least two unrelated groups, one of which, the rhombozoa, only exists in the kidneys of

octopuses and squids) or 'parazoa' - 'beside animals' such as sponges and placazoa.

When something alive is not quite symmetrical, instinct tells us that it's most likely a fungus or a plant (leaves and flowers may be nearly perfectly symmetrical but the overall form of a plant seldom is). If, by contrast, an animal is markedly asymmetrical then we tend to assume it must suffer from some weakness or **pathology**.<sup>1</sup> This rule of thumb holds good for most animals under the sea too: they are either bilaterally symmetrical (worms, walruses) or - a little weirdly, but still fitting the rule - radially so (jellyfish). But sponges are often stubbornly lopsided. This is surely one of the reasons we tend to see them as not fully animal, or 'primitive'.

Joseph Merrick, the Elephant Man, is thought to have suffered from Proteus syndrome, a rare disorder in which skin, bone and other tissues just keep on growing until the sufferer is scarcely recognizable as human. The photograph above, taken in 1889, was intended for dispassionate medical study but is hard to look at without twinges of horror and furtive fascination such as one might have felt at the freak-show where Merrick spent a part of his life. Look carefully, though, and you can see something important and moving. From his left eye, set between small areas of 'normal' temple and cheek (on the right hand side of the photo, of course), Merrick looks back at the viewer. He is calm and aware: a dignified human masked by stupendous deformity.



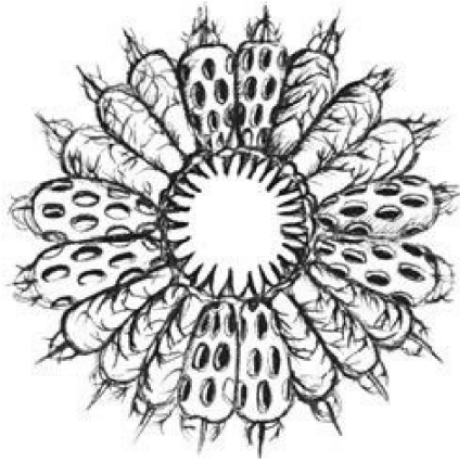
Joseph Merrick, 1889.

I sometimes think of this picture when confronting aspects of the natural world that seem especially strange. Pay a little more attention, the picture says to me, and you may see something remarkable and even beautiful in beings which prejudice tells you are ugly. To be clear, I am *not* suggesting equivalence between healthy sponges and humans, deformed or otherwise.

The differences are obvious and substantial. But even a creature as weird and apparently boring as a sponge holds wonders if only you look closely.

All sponges rely on ambient water movement to bring oxygen and food (which mainly consists of bacteria) to them, and to flush away waste. 'Leuconoid' sponges, which include barrel sponges and tube sponges, have made filter feeding into an art form thanks to a brilliant but simple natural design. A mature leuconoid sponge exploits the same effect as a chimney does: water, like air, moves more slowly close to the seabed, or ground, than it does just a little distance above it (on a reef this may not always be up: sponges grow on steep slopes and overhangs too). The circular opening at the end of the sponge furthest away from the seabed (the 'osculum' or 'little mouth') acts just like a chimney. The effect can be seen dramatically if a little dye is released into slow-moving water at the base of a sponge. Coloured water will shoot out of the top, like exhaust from the funnel of a steam train, **much faster**<sup>2</sup> than the water that the sponge took in. In addition, leuconoid and other sponges increase the efficiency of 'burn' by circulating water within enormous numbers of tiny chambers - tiny 'stoves' that honeycomb its chimney-body. Each chamber is lined with specialized cells called choanocytes which, by synchronous beating of tiny, whip-like organs called flagellae, maintain a water current that brings in food particles and whisks away waste. This allows the choanocytes to ingest bacteria suspended in the water (and then pass nutrients on to other cells within the animal).

In making use of something as simple as a difference in water speed, barrel sponges are exploiting energy from currents and tides that ultimately derive from the gravitational pull exerted by the Moon and Sun. And, in an arrangement also adopted by corals and numerous other animals, many sponges in shallow waters also harvest energy from the Sun more directly by providing a home inside their bodies for photon-loving algae, which pay the rent with oxygen and metabolites that the sponge needs. In many cases the algae produce significantly more oxygen than the sponge can actually use, with the result that the ensemble of sponge and symbionts contribute to the vibrancy of the ecosystem of which they are part. (Not all sponges are so generous: there are carnivorous and parasitic species.) Some barrel sponges live to be two thousand years old - as venerable, if not as big, as a California redwood. Other species transport light deep inside their bodies through transparent tubes to provision sun-loving algae that live there. They are the only animals known to do this - a submarine instance of 'rainbow body' through which light passes with ease (a condition that yoga masters envisage for humans but probably not for 'lower' animals). Sponges are Moon-Sun-plant creatures. In the very different conditions that prevailed in oceans some 160 million years ago, their remarkable qualities enabled them to form reefs over an area stretching from what is now Spain to Romania, larger than the coral-made Great Barrier Reef today.



But perhaps the greatest wonder is the insight sponges offer into how animal and human life as we know it came to be. The story starts with the discovery, first reported in 1907, that some species can be strained through a mesh so fine that only individual cells pass through and yet - in the right circumstances - form a new, fully functioning animal. And it continues with the realization that choanocytes, the cells central to a sponge's functioning, closely resemble single-celled animals called choanoflagellates.

Choanoflagellates are plankton: tiny protozoans that feed on even tinier bacteria. Thousands or even millions will be in a bucket of water hauled from coastal seas. They often thrive on their own but they also tend to form colonies of cells that are all alike but benefit by sticking together. This characteristic is far from unique; many bacteria and single-celled organisms do the same. What is unique is that the genes **choanoflagellates**<sup>3</sup> use to manufacture proteins that stick their cells together are very like the genes found in all multicellular animals for the same purpose. Indeed, the match is so close that it seems almost certain that we evolved from them.

Broadly speaking, a sponge only differs from a colony of choanoflagellates in that - in addition to choanocytes at the 'business end' of eating and excreting - it has multitudes of less than a dozen different kinds of cells that perform specialized functions such as building and maintaining a larger structure with collagen or silica rods, repelling pathogens or generating new cells. If you were reconstructing an early multicellular animal with just a few types of specialized cells that were easily derived from one basic cell type, it would look very like a sponge, albeit a small and simple one, not the giants such as barrel sponges we know today, which are adapted to **modern environments**.<sup>4</sup> The sponge, it turns out, is a good model for the first multicellular animals to have evolved from single-celled ones. Eumetazoa - more complex animals than sponges - have also evolved extracellular digestion and seal epithelia, a nervous system, a mesoderm, symmetry and a one-way gut.

The cooperation between cells in multicellular animals is one of the most astonishing phenomena in nature. Humans are made up tens of trillion individual cells of about two hundred different types (plus about ten times as many micro-organisms) and for the most part these **cooperate flawlessly**<sup>5</sup> for many years. But even as we contemplate - celebrate - this, we should not neglect the great realm of single-celled animals in which, abundant as they are, choanoflagellates are just a handful of the citizens. 'Protozoans' (from the Greek for 'first animals') exist in profusion alongside and inside all the animals in this bestiary, and embody more marvels than a bestiary could ever contain. At first sight they might seem like an ever-harder sell

than paying memberships to a sponge appreciation society. Some of the best known protozoans are those which cause diseases such as amoebic dysentery, leishmaniasis and malaria. But the great majority are harmless, and some play vital roles in global ecosystem functioning. Others exhibit particular wonders. *Physarum polycephalum*, a slime mold without a neuron, is able to memorize patterns of events. *Noctiluca scintillans*, a tiny marine dinoflagellate, glows in the dark thanks to thousands of bioluminescent spherical organelles in its cytoplasm; gathered in millions, it can illuminate a whole sea at night. Foraminifera can be highly selective in the colour or shape of sand grains they choose to attach to their tiny shells. *Tetrahymena thermophila*, a ciliate, has not two but seven sexes and since an individual can mate with others of any gender except its own there are twenty-one possible sexual orientations. (For more on single-celled marine organisms, see Chapter 19: Sea Butterfly.)

Thousands of years ago men learned to dive deep into blue water to search for coral, pearls and sponges. Today we can deep-dive in time as well as space. In tracing the origin of sponges we can also appreciate more truly the dimensions of the present moment. But how far back do we need to go?

The idea that the world is **vastly old**<sup>6</sup> took firm root in Western thinking following the publication in 1795 of James Hutton's *Theory of the Earth*. Hutton showed that diastrophism – the squeezing, tearing and subduction of the Earth's surface that produces continents, mountains and ocean basins – had begun very far into the past. He could not say precisely how far – famously noting only that 'we find no vestige of a beginning, no prospect of an end' – but he knew it was massively more than the few thousand years that most Europeans had previously thought.

The discovery of 'deep time', as we now call it, made possible Darwin's momentous idea, published sixty-six years after Hutton's *Theory*, that, given enough time, endless forms of life could evolve from a few or one. But the geological record also contained what seemed like an intractable puzzle, which became known as Darwin's dilemma: the earliest animal fossils (dating from the period we now call the Cambrian) were already abundant, diverse and anatomically complex. Could such life forms really have emerged fully formed as if from nothing?

Hutton's omission and Darwin's dilemma have now been largely addressed. By the last decades of the twentieth century scientists could divide the Earth's past as confidently as the crowns of Portugal and Spain had once divided the world beyond Europe between themselves, but with more justification and precision. All the fossils known to Darwin and his contemporaries belong to what we now call the **Phanerozoic eon**<sup>7</sup> – the 'age of visible life' – that began a little over 543 million years ago. The Phanerozoic was preceded by an eon four times as long, called the Proterozoic, the 'age of earlier life'. And it is in traces of life across this vast length of time – made accessible with technologies and techniques developed in the late twentieth century – that the answer to Darwin's doubts has been found. Before the Proterozoic was the Archaean, which began 3.8 billion years ago following the formation of continental crusts formed on the molten planet. And before *that* was the Hadean, Earth's first eon since it reached its present size, perhaps after a collision more than 4.5 billion years ago with Theia, a Mars-sized body that smashed into the Earth, sheered off molten rock that became the Moon and sent our planet spinning.

Within this broad framework the key stages in the emergence of life before the Cambrian go as follows. Life as we know it may be nearly four billion years old. The first eukaryotes may have evolved more than 2.7 billion years ago. They may have been forming colonies between about 2.1 and 1.9 billion years ago. Over the next billion years or so – sometimes called the ‘boring billion’ – the deep seas were stagnant and sulphurous, thanks to bacterial waste products, and eukaryotes were limited to a thin layer of surface water in oceans. Even here, life was no picnic, thanks to low levels of oxygen for much of the time, a shortage of vital nutrients and frequent upwellings of toxic waters from the depths that killed eukaryotes en masse. At some point, however, relatively favourable conditions allowed for the evolution of simple, sponge-like multicellular organisms, which are distinguished from colonies by specialization of different types of cell within the whole. Exactly when this happened is debated, but some evidence points to as much as 900 million years ago. It is likely that the evolution of multicellularity occurred several times independently to produce plants, animals, fungi and chromista.

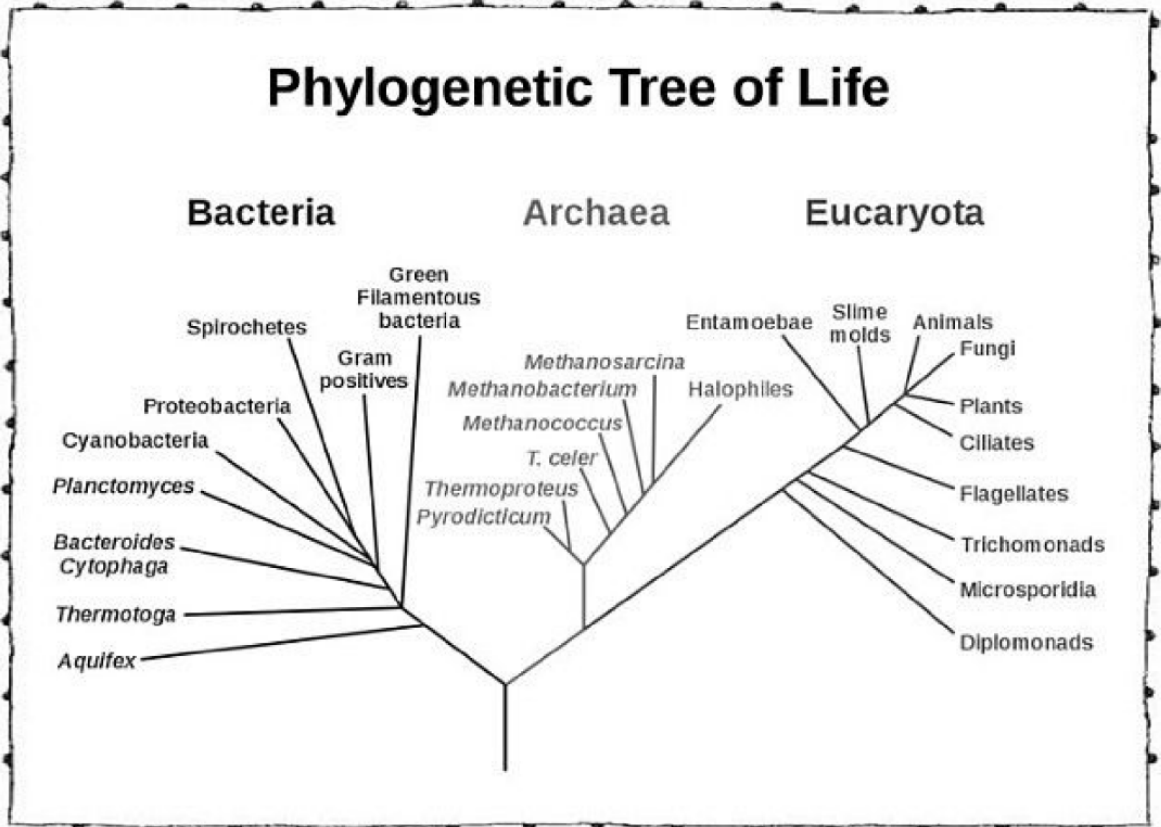
Even if we accept the idea of deep time as a reality, it is still hard to *understand* because its dimensions are so far outside our normal cognitive range. Many attempts to do so rely on analogy. So, for example, if all Earth history is a twenty-four-hour day then anatomically modern humans evolved about three seconds before midnight and Gilgamesh, the oldest known written story, was set down less than a tenth of a second ago. Or if the Earth’s history is the length of an old English yard (which is the distance from the King’s nose to the tip of his outstretched hand) then one gentle stroke of a nail file on the middle fingernail erases the entire record of humanity. Or human history with respect to life on Earth is as deep as the displacement of the smallest seabird floating on top of a wave over the deepest part of the ocean.

Such analogies may help us think about deep time, but do they help us *feel* it? I’m not convinced. A better option is a walking meditation among ancient rocks so that their solidity and presence can be felt through vibrations in your feet, legs, hips and spine as you walk. And a good place for that is Scotland’s far north-west, where in some places metamorphic rocks from the Archaean form a magical landscape. **Promontories**<sup>8</sup> such as Stac Pollaidh and Suilven rise from these older rocks like the foundations of our own vanishingly brief moments of awareness.

There is no shortage of definitions of life out there. Biologists, though, typically define living organisms as systems that *do* certain things – among them, metabolize, grow, respond to stimuli, reproduce and evolve through successive generations. Of all these, metabolism (that is, the ability to extract energy from the environment and put it to work for the organism’s own ends) may be the most fundamental and the most ancient. And on this count bacteria and another domain of microbes called archaea (together known as ‘prokaryotes’) are the amazing performing fleas in the big top of life. By comparison, all the ‘higher’ forms – animal and animalcules, plants, fungi and chromista (together ‘eukaryotes’) – are as pedestrian as, well ... sponges. Microbes not only discovered the metabolic pathways that we eukaryotes later adopted (respiration, photosynthesis and fermentation) as well as at least one we did not (chemosynthesis), they also evolved a rainbow of biochemical variations on each that we do not begin to match. Microbes dominated the Proterozoic and arguably they still largely determine the course of life today. They are, as the microbiologist John

Ingraham puts it, 'our inventors, progenitors and keepers'. (They are also our disposers: death is not the end, it's just a case of being metabolically different.) In the big picture - the cycles of life on Earth - microbes are the beginning and end of all. Or, as the palaeontologist Andrew Knoll asserts, 'eukaryotes are the icing and prokaryotes are the cake'.

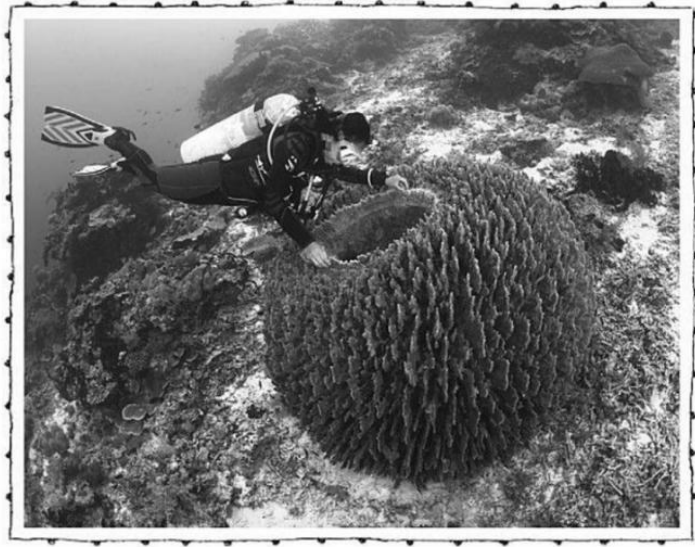
Is it really true that (to vary the metaphor from patisserie to brewery) life on Earth is basically a giant microbial vat and eukaryotic organisms are merely the bubbles on its surface? Are we - the froth - deluded in valuing ourselves so highly?



From Hallucigenia to Kim Jong-un, animals exhibit stupendous and sometimes delightful diversity in bodily form. But in terms of genetic diversity we are only a twig on the tree of life (located in this diagram on the top of the right hand branch)

There's a story that Albert Einstein was asked whether Beethoven's Ninth Symphony could be expressed purely in mathematical notation. 'Of course!', he answered, 'but what would be the point?' Perhaps we can see prokaryotes as **primal tones**<sup>9</sup> from which, as in the first bars of the Ninth, eukaryotes emerge in rhythms, keys, melodies, harmonies and other qualities that did not previously exist. The deep resonances of microbial life continue even as the **symphony of 'higher' life**<sup>10</sup> unfolds.

Demosponges, the class to which the barrel sponge belongs, are the oldest still existing multicellular animals for which there are unambiguous traces in the Cryogenian, or 'snowball Earth', period of the late Proterozoic. These early sponges played some of the first chords in the transition to the full musical score of life as we know it today, and it is likely that all other multicellular animals are derived from an early off-shoot of this line. So next time you come across a sponge, consider that something that was more like this than it is like you was your direct ancestor. Consider that it is a being of untold wonders, and that it is we who depend on processes it pioneered: it is we, not it, who are the spongers.





1 Subliminally, humans register even the smallest variations in body layout and tend to see the most symmetrical human faces and bodies as the most beautiful.

2 A study of *Leuconia*, a small leuconoid sponge about 10 centimetres tall and 1 centimetre in diameter, measured water entering each of more than 80,000 intake canals at 6 cm per minute. Inside more than 2 million flagellated chambers the water slowed to 3.6 cm per hour, just one hundredth the speed, maximizing time for choanocytes – specialized feeding cells – to extract food particles from the water. Waste water was expelled through a single osculum at about 8.5 cm per second – more than eight thousand times as fast as it circulated in the chambers and 85 times as fast as it entered the sponge in the first place.

3 Choanoflagellates also have the components for the three main functions of neurons: carrying electrical signals along their bodies, signalling to their neighbours with neurotransmitters and receiving those signals.

4 We need to keep in mind when looking at ‘primitive’ organisms such as sponges that we are not seeing their ancient ancestors, but something that for all its characteristically ancient features, has coevolved to be part of the modern world. As Martin Brasier notes, the sponges that we see today are highly adapted to the world of worms, shrimps and brittle stars.

5 ‘Where cooperation fails, as it does in cancer, the disease’s existence is a pathological mirror of our own. Down to their innate molecular core, cancer cells are hyperactive,

survival-endowed, scrappy, fecund, inventive copies of ourselves.’ (Siddhartha Mukherjee)

6 The intuition that the world is very old predates eighteenth-century Europe. Avicenna (Ibn Sina, 973–1037) and Shen Kuo (1031–1095) speculated that geological time was immensely long, as did Leonardo da Vinci. In Hinduism a single day of Brahma lasts billions of years. Greek philosophers believed the world was infinitely old.

7 For an explanation of the divisions in geological time see Appendix II.

8 ‘Where the dust blows through these heights there once shone a silent sea.’ (Hanshan)

9 The sheer length of the first movements of the symphony of life known as the Proterozoic would try most listeners. Perhaps a better musical comparison than Beethoven’s Ninth would be an extended version of the primordial sludge in the opening bars of the prelude to Wagner’s *Das Rheingold*. Works that go a little further towards imitation of the actual time involved include John Cage’s *Organ<sup>2</sup>/ASLSP*, which will take 639 years to perform, and Jem Finer’s *Longplayer*, which will last a thousand years.

10 ‘It’s as if we are digging through the world’s greatest sonic masterpiece and only finding parts of a score here and there in the fossil record.’ (Kevin Zelnio)



# CROWN OF THORNS STARFISH

*Acanthaster planci*

Phylum: Echinoderma

Class: Asteroidea

Conservation status: Not listed

## If you look into infinity what do you see? Your backside!

Tristan Tzara

The drug-addict, drunk, wife-shooter and writer William Burroughs used to tell a story about a man who teaches his anus to talk. The orifice<sup>1</sup> eventually takes over his life and kills him. Wildlife can be as least as weird as the imagination of Burroughs. Consider the Crown of Thorns starfish. Instead of a head it has an anus on the top of its body, while its mouth – a round hole equipped with inward-pointing teeth at the centre of the radiating arms – is in the middle of its underside.

This positioning is less unusual than you might think. Having a mouth underneath and an anus on top is ideal if you want to eat crud on the seafloor, and this is how the ancestors of the Crown of Thorns started out. Many of its distant cousins, among them starfish and sea cucumbers, still pursue that lifestyle. (On the abyssal plains, the so-called desert of the deep sea floor, large herds of sea cucumbers are constantly grazing on the detritus that has fallen from above. They are the night-soil men of the deep in a holothurian heaven.) Unlike these animals, however, the Crown of Thorns is no longer a scavenger, having acquired a taste for living flesh. Dressed in brilliant shades of purple, blue, orange red, white and grey and with anything from seven to twenty-three (but usually about fifteen) rays around a central dome, it bristles with poisonous spikes – a submarine version of Pinhead, the extradimensional being in the horror film *Hellraiser*.

Many creatures in the garden of earthly delights that is a tropical coral reef have more charm than the Crown of Thorns. (Pfeffer's Flamboyant Cuttlefish, which turn itself startling hues of purple and pink at will while posturing like an actor in Noh theatre, is one of my favourites.) But few are more compulsively unsettling than the Crown of Thorns, and few are as like us in their power to consume and destroy once they set to work.

The claim may seem odd in view of our obvious differences. The Crown of Thorns crawls over the reef on thousands of tiny podia – tube-feet, through which it also breathes, that extend and flex like hydraulic parts as they fill and empty with fluid from sacs inside the animal's arms. Gliding along about as fast as the minute hand on a clock (a little faster if it puts on a turn of speed), it moves more like a millipede than (as one might suppose) a severed human hand pulling itself by the fingers over the seabed. Once it gets into position around its favourite food of freshly growing coral, the Crown of Thorns wraps its arms around its object of desire in a grip of death, extrudes one of its two stomachs<sup>2</sup> through its mouth and spews digestive juices over the polyps, turning them into a gooey mess which it sucks back inside itself. When Crown of Thorns starfish swarm in large numbers they can devastate a reef in a few days. And thereby hangs a true tale resembling many a B movie about monsters from the deep.

Until the 1960s few marine scientists had seen, let alone studied, the Crown of Thorns starfish. It was known to eat coral but thought to be quite rare. Then a large-scale infestation was observed munching its way through the reefs surrounding a small cay on Australia's Great Barrier Reef that was popular with tourists. By the end of the decade they were reported in huge numbers on large areas of the GBR and seen attacking many other reefs throughout the Indo-Pacific.

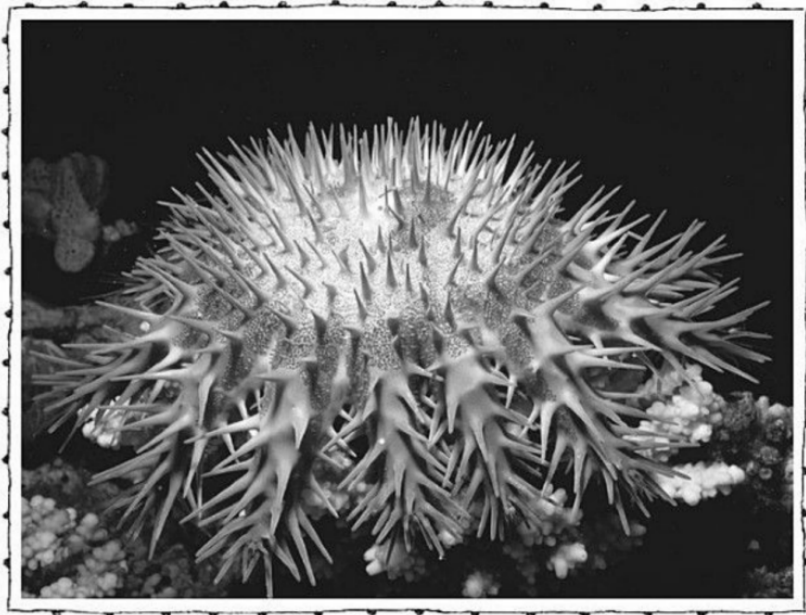
The press cried apocalypse. In July 1969 the *New York Times* reported that the Crown of Thorns threatened the food supply and even the physical existence of many tropical islands. It quoted the conservationist Richard

Chesher: 'if the starfish population explosion continues unchecked, the result could be a disaster unparalleled in the history of mankind.' In November of that year *The Economist* reported that coral reefs across the Pacific were 'crumbling, and the economies of whole regions could crumble with them'.

It looked like precisely the kind of payback predicted by environmentalists such as Rachel Carson and Barry Commoner: human thoughtlessness was upsetting the 'balance of nature', transforming the hitherto obscure Crown of Thorns into a predator without limits by eliminating whatever it was that normally kept it in check or by altering nutrient and chemical balances in the seas. In the end catastrophe was averted: Crown of Thorns numbers crashed and many reefs made what looked like a full recovery. People discovered new respect for the resilience of coral reefs, and greater appreciation of how patchy is our understanding of them.

But, as in many a B movie (or indeed Dark Age epic such as *Beowulf*), a worse horror was waiting out of sight. By the first decade of the twenty-first century scientists were warning that, barring deep cuts in emissions of greenhouse gases, global warming and ocean acidification would devastate the world's remaining coral reefs within a century and for the indefinite future.

Since our early days we humans have been intimate with the sounds, smells and sights of forests and savannah, riverbanks and seashores; for hundreds of thousands of years we have lived, breathed and touched their moods and textures. By comparison, our feel for the underwater tropical world is recent and sketchy. True, for thousands of years communities living close to reefs have been perfectly able to identify<sup>3</sup> many different kinds of fish and other animals living on the reefs. True, also, that for hundreds of years at the very least, some communities have understood the importance of protecting reefs from over-exploitation by not fishing at certain times of year in order as to allow stocks to recover. Many have also experienced reefs as places of magic, myth and creation. But a sense, shared by large numbers of people who live nowhere near them, that coral reefs are places of great beauty and worth only arose in the context of the scientific transformations of the last 150 years.



A Crown of Thorns starfish.

Early modern science paid little attention to tropical marine life, but such study as there was largely consisted of ever more detailed and sophisticated cataloguing of individual wonders once they had been hauled from the sea and pinioned on the collector's table. The *Ambonese Curiosity Cabinet*, published in 1705 some three years after the death of its author **Georg Eberhard Rumphius**,<sup>4</sup> the 'blind seer of Ambon', is one of the great works of that time, containing hundreds of precise verbal descriptions and fine line drawings of tropical marine organisms that compare well with anything produced today. (Rumphius describes the Crown of Thorns, which he terms *Stella marina quindecim radiorum*, as 'found very rarely and 4 to 5 inches wide, divided all around into 12 or 14 branches ... with a russet shell, and covered with sharp spines about the length of a finger-nail ... It dwells in the very deep Sea, where it is full of rough stones ... If one is hurt by its spines it will cause very bad burning and great pain, which is why it is left unmolested.')

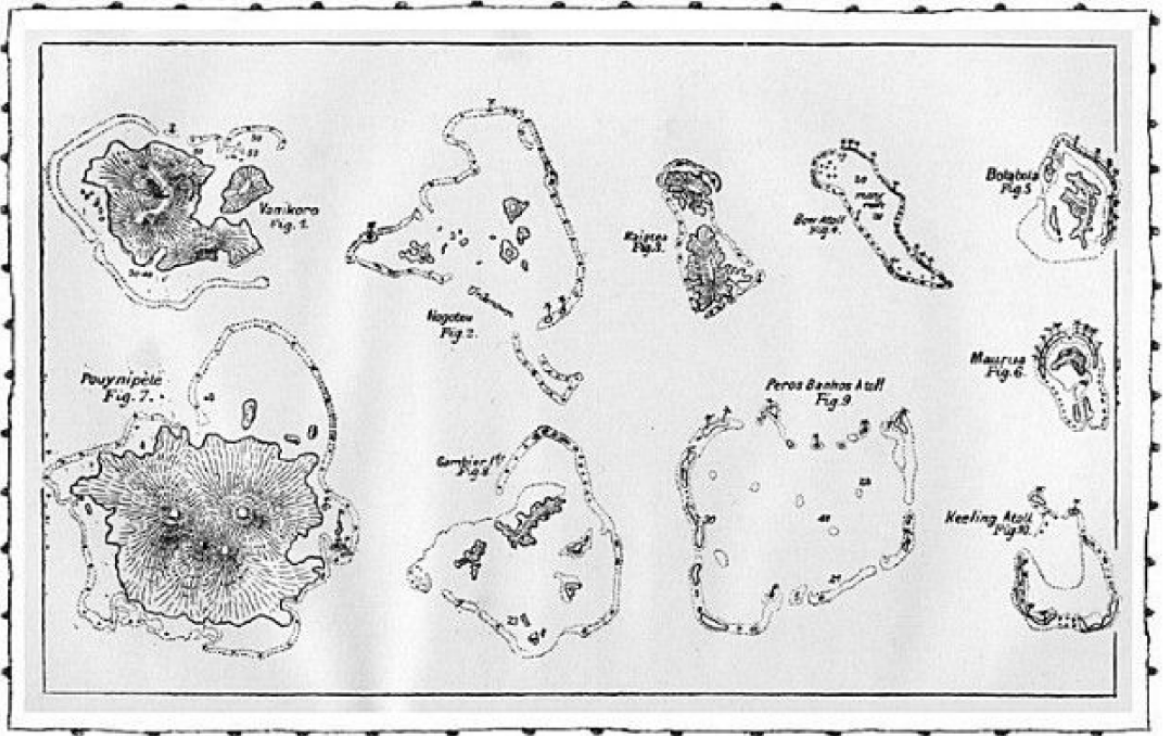
But work of this kind, remarkable as it is, explains next to nothing about how these forms originate and how they connect in the great web of birth, death and transformation. And it was only in the mid nineteenth century that scientists took the first steps in putting such a vision together. In the late 1830s Charles Darwin suggested that coral atolls accrete on gradually subsiding seamounts and volcanoes, keeping up with the sea surface as, in some places, the seabed falls over vast periods of time. (Subsidence is a natural process in parts of the ocean floor as the Earth's tectonic plates slide and jostle; corals grow to get closer to the sunlight.) Some of the humblest organisms in the sea - coral polyps - have evolved to thrive in such challenging circumstances with the consequence that they built the largest life-made structures on Earth, thousands of times bigger than the Great Pyramids. The hypothesis was daring in the extreme, and so far ahead of its time that it was only proved beyond reasonable doubt in the 1950s. It required a depth and breadth of vision - a grand view of life that unites the very large (the geological forces at work across oceans and continents) with the minute (a typical coral polyp is no bigger than the nib of a pencil) - that prefigured and informed the theory of natural selection which Darwin finally published twenty years later. Reefs achieve exuberant

life as a result of intense struggle between organisms but they also exemplify symbiosis and cooperation among life forms - an apparent riddle at the heart of their ridiculous beauty.

That aesthetic appreciation of coral reefs grew alongside greater scientific understanding is evident in a description by Alfred Russel Wallace of Ambon Bay, the very same place from which Rumphius had hauled so many of his curiosities more than 150 years before. In Wallace's eyes these forms were part of a vivid living world rather than specimens on a dissector's table:



The clearness of the water afforded me one of the most astonishing and beautiful sights I have ever beheld. The bottom was absolutely hidden with a continuous series of corals, sponges, actiniae, and other marine productions of magnificent dimensions, varied forms and brilliant colours ... In and out of them moved numbers of blue and red and yellow fishes, spotted and banded and striped in the most striking manner ... It was a sight to gaze at for hours, and no description can do justice to its surpassing beauty and interest. For once, the reality exceeded the most glowing accounts I had read of the wonders of a coral sea.



Charles Darwin saw that in some circumstances corals could accrete fast enough to maintain reefs and atolls close to the surface even as the mountains beneath them sank into the depths.

The rapture felt by Wallace went mainstream after World War Two when the development of scuba made it possible first for scientists and then for thousands of ordinary people to observe coral reefs with an intimacy that our ancestors could never have imagined. (Crossing this **threshold**<sup>5</sup> can evoke an overwhelming sense of awe and set the heart racing, especially if - like me - you are a poor diver, never far from the edge of terror.) In little more than half a century we have come to know a whole new world much more different from our own than the Americas seemed to Europeans at the end of the fifteenth century, a place of unsurpassed richness: great 'forests' in miniature containing around a quarter of ocean biodiversity in much less than 1 per cent of the total area.

But the discovery of this world was also when we witnessed its destruction. Since World War Two many of the world's richest reefs, especially in Southeast Asia and the Caribbean, have been all but destroyed by over-exploitation and pollution. In large parts of the Philippines, where reefs were once abundant, it is fair to joke, as does one travel guide, that 'if you dive here you may see some truly horrible things before you dissolve' in the sheer mass of chemical and human waste. For all the efforts, some of them heroic, to protect what remains (and there are still astonishing treasures tucked away), there appears to be a near inescapable trend towards destruction of this ecosystem faster than any other on Earth: a speeded-up Sixth Extinction before our eyes that leaves us holding onto a few pieces of broken wreckage.

Human activity, taken as a whole, has been vastly more destructive of reefs than any starfish run amok. Can we at least appreciate the Crown of Thorns not as destructive monsters but for what they actually are (or at least were): parts of a wondrous whole?

Star-shaped beings are not new on Earth. Rocks nearly two billion years old contain the beautifully named Eoastrion, or 'little dawn star', a tiny

fossil that does indeed look like a microscopic star. And multi-pointed starbursts feature in the gallery of bristly and pointy entities in rocks laid down a billion years or so later. But neither, of course, was remotely like the sea stars we think of today. The first was a bacteria, the second an algal spore.

The earliest fossil sea stars found so far date from the Ordovician geological period (from about 488 to 445 million years ago). This was a time before fish had evolved jaws and when scorpions the size of basket-ball players lurked in the silt. Nautiloids with shells as much as three metres (ten feet) long were top predators. Trilobites, with eyes on stalks, sought safety under elaborate spiny armour. Animal life had not emerged onto land, and the land plants that did exist were mostly mosses and liverworts. Sea stars probably evolved from organisms that looked similar to crinoids: the enigmatic sea lilies and feather stars that still grow on the seabed today. Like the crinoids, they are members of a phylum known as **echinoderms**,<sup>6</sup> which first evolved no later than the Cambrian (542 to 488 million years ago) and which today comprise 6- 7,000 species, ranging from sea cucumbers (lumpy sausages of enormous size and very strange habits) through sea urchins (the spikiest, bristliest things that you do not want to tread on) to the Basket and Brittle stars. Today, the Crown of Thorns is one of about 1,600 living species of sea star, or Asteroidea to give the class its correct scientific name.

The earliest echinoderms were bilaterally symmetrical - they had a left and a right, a front and back end - through their entire lives. Many echinoderms are still bilateral as larvae, and swim freely in the ocean like baby fish. At some stage early in the evolutionary history of the phylum, however, most species became sedentary as adults, attaching themselves to the seabed as do the sea lilies we know today. Later, the ancestors of sea stars stopped holding on to the seabed and started to move freely across it, but kept the new radial symmetry their ancestors had acquired. When a modern sea star larva matures, the left side of its body grows at the expense of the right side, and eventually takes over the whole to grow with pentaradial symmetry, in which the body is arranged in five parts around a central axis. Sea cucumbers start as bilaterally symmetrical larvae, go through a stage of fivefold symmetry as they grow, and become bilaterally symmetrical again as adults. Such metamorphoses - more imagination-stretching than most things in Ovid - show that Haeckel's theory of recapitulation theory (described in Chapter 1, Axolotl) only describes a small part of what occurs in the animal world.

And sea stars play amazing variations on an essentially pentaradial body form. Some, like the Crown of Thorns, have dense rows of spines for protection. Others have no spines at all. Some, like the Pincushion star, don't even have arms, and look more like pentagons. In most cases arms, also known as rays, are typically present in multiples of five up to as many as fifty in the case of *Helicoilaster*. (There is a sea-lily *Comanthina schlegelii*, with 200.) But other numbers, including odd numbers such as eleven, are also seen. The length of the arms with respect to the body, and their shape also vary greatly. Members of the *Zoroaster* genus have long flexible ones resembling elephant trunks. The largest known sea star, the Sunflower starfish, could have come straight out of a troubled dream of Vincent Van Gogh. Ranging in colour from bright orange, yellow and red to brown and even purple, and typically radiating 16-24 velvet-textured rays, the Sunflower can span as much as a metre.

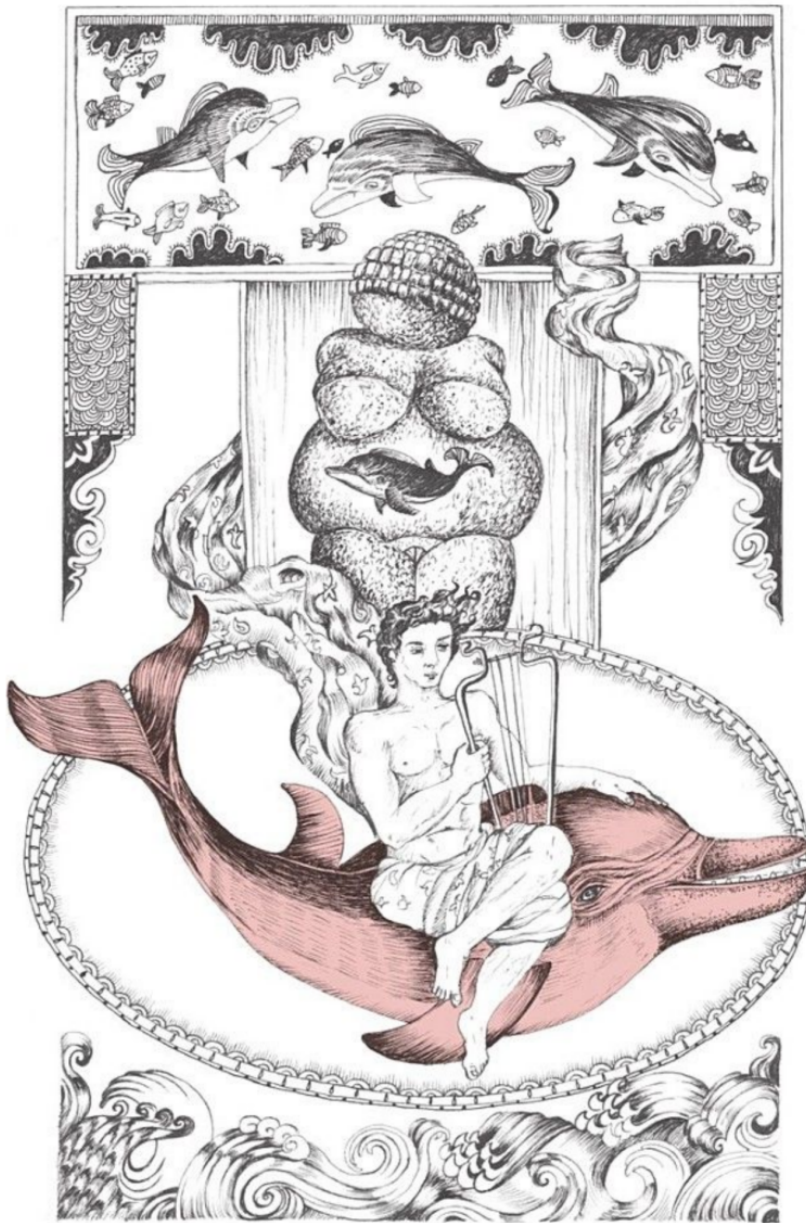


First cousins to sea stars are the basket stars and brittle stars, collectively known as Ophiuroids. These can be even more otherworldly than sea stars. *Gorgonocephalus*, or the Gorgon's Head, for example, really does resemble a seething mass of snakes. Other ophiuroids are more delicate: they pick, feel and spread themselves over corals, gorgonians and other organisms like courtesans in feather boas. Recently, explorers discovered a seamount near Antarctica covered in tens of millions of brittle stars packed ray tip to ray tip, in a massive underwater 'city', alongside other strange species such as giant bubble gum coral.

Unlike most chordates - or, indeed, our still more distant relations the molluscs, which include intelligent animals such as cuttlefish and octopuses - echinoderms have not gone to the trouble of evolving brains. Instead, they have a radial nervous system: a net of interconnected neurons spread throughout their body and are able to process some information. The absence of a concentrated knot of neurons, *aka* brain, does not mean they are completely unaware of the world around them. Sea stars are sensitive to touch, temperature and orientation through their tube feet, spines and pedicellariae (the small wrench- or claw-shaped structures on their skin). Each arm on a sea star has a short sensory tentacle at the end that responds to chemicals and vibrations in the water, and a tiny eyepot with which it can perceive light and movement, although it cannot form an image. Many starfish also have individual photoreceptor cells spread across their upper bodies. And there is at least one species of brittle star that is densely dotted with eyespots with sophisticated optics which may be united together via its nervous system to act like a single great compound eye. The lenses of its eyes are made of calcite crystals, otherwise only found in the long-extinct trilobites. We can, literally, be seen by stars, using one of the oldest technologies of vision on the planet.

We humans credit ourselves with foresight and if we credit what the science tells us, the outlook for reefs and the people who depend on them is very bad. Direct pressures on tropical coral reefs such as destructive fishing practices and indirect ones such as global warming may, if not massively reduced, put most remaining reefs (which are already a much diminished remnant of what existed a few decades ago) at risk of destruction by around 2050. Nothing like this will have hit reefs in 55 million years, and recovery after previous catastrophes took millions of years. Still, the total collapse of coral reefs in the twenty-first century is not an absolute certainty. Some pockets may show surprising resilience, and when other pressures are removed reefs can recover even from a **direct hit**<sup>7</sup> from a hydrogen bomb in a matter of a few decades. For this reason, conservation initiatives such as the establishment of networks of marine protected areas with local community involvement are well worth trying. In some circumstances, active intervention to regrow coral reefs may make sense.

Starfish are tough. Recent experiments show that at least one species – the Purple Ochre sea star, *Pisaster ochraceus* – may do just fine in the warmer, more acidic waters almost certain to be the norm towards the end of this century. The scientists who undertook the study caution that we cannot assume that other starfish will do the same. However, some sea stars, or their ancestors, survived the Ordovician-Silurian extinction event, the third largest in the Earth's history since life became multicellular and the Permian-Triassic extinction, the largest extinction event in the history of life in which 96 per cent of marine species were exterminated, as well the Cretaceous-Tertiary extinction that wiped out the dinosaurs, pterosaurs and plesiosaurs. Far into the Earth's future, starfish should be around to bury us, along with new forms even stranger than the Crown of Thorns.



1 Burroughs's story has a true and more comic precursor in the life of Joseph Pujol (1857–1945). Pujol, who became famous as 'Le Pétomane' (the fartomaniac), could inhale through his sphincter and release the air under control to produce a wide variety of sounds. His performances before royalty and the foremost citizens of the day included renditions of 'O Sole Mio', 'The Marseillaise', and an impression of the 1906 San Francisco earthquake. Pujol retired from the stage in horror at the inhumanity of the Great War and worked for the rest of his life in a biscuit factory.

2 Sea stars digest with two stomachs known as the cardiac stomach and the pyloric stomach. The cardiac stomach is a sack-like organ located at the centre of the body and may be everted out of the organism's body to engulf and digest food.

3 To take one example, the distinctions made among different marine and terrestrial creatures by the Groote Eylandters off the north coast of Australia correspond closely to distinctions drawn in modern biology.

4 Rumphius, a botanist for the Dutch East India Company, lost his wife and daughter to earthquake, his botanical drawings to fire, an entire book on animals to the sea, and his sight to glaucoma.

5 'The only line more definitive and mysterious than the one between the mirror-like surface of the sea and the world of the reef below is the boundary between life and death.' (Osha Gray Davidson)

6 The echinoderm phylum shares some essential features with the chordate phylum, which includes axolotls, humans and zebrafish. As deuterostomes, we all, as embryos, develop an anus before we develop a mouth: we all come into being arse-first.

7 'Mike', the world's first hydrogen bomb, vapourised Elugelap Island and other parts of

the Enewetak Atoll on 1 November 1952. Despite the contamination, corals have recolonized much of the gap. This recovery depended on (among other things) the presence of large numbers of healthy corals elsewhere. More recently, dramatic coral-bleaching events, caused by unusually high temperatures and leading to morbidity and widespread death in many reefs, have on occasion been followed by dramatic recoveries, at least for now.



# DOLPHIN

*Delphinidae*

Phylum: Chordata

Class: Mammalia

Order: Cetaceae

Conservation status: some species Critically Endangered, others Least Concern or not listed

**Dolphins ... follow men's voices, or gather in shoals when music is played. There is nothing swifter in the sea. They often leap over ships in their flight.**

An English bestiary of the thirteenth century

**For they work me with their harping-irons, which is a barbarous instrument, because I am more unguarded than others.**

Christopher Smart

Some experiences can give rise to joy so powerful that it transforms your sense of what it is to be alive. Among these are surviving a brush with death, and witnessing acts of great beauty. Such, at least, is my experience. Once, I sailed in a small boat in a storm so violent that some of those on board with much more experience than I feared we would not get through. When, a couple of days later, we did make it into port – battered and exhausted but essentially fine – I felt as if reborn, my body made of sunlight. Another time, with a different crew and in a different place, I encountered wild dolphins at play. In calm weather and deep water just off a remote mid-ocean island we spent a good part of an afternoon in a dinghy watching a large pod put on an amazing show of jumps, somersaults, twists and other capers. Every now and then, one or two came right alongside us and gently splashed two young children leaning over the gunwales. The children would squeal with delight, and the dolphins would power away and then stop to look back at the hilarity they had caused.

These two incidents from my own direct experience have no particular connection except that both were transfigured by joy. The first didn't involve dolphins but, having experienced both, I understand a little better the power of stories that recur from ancient times until today in which humans (and other creatures such as whales) are **saved from drowning**<sup>1</sup> by dolphins.

Think of a dolphin and the chances are that the Bottlenose, *Tursiops*, comes to mind. These are the easiest to train and most often kept in captivity. But there are nearly forty other species, and they vary considerably in size, shape and colour. The smallest (Maui's dolphin) is the size of a wild boar, while the biggest (the orca) can grow as big as a bus. Several, including Common dolphins, have ballooning, melon-shaped foreheads and beaky snouts similar to the Bottlenose, but others (notably, some of the smaller species) have much less prominent snouts, and daintier faces. When it comes to skin colour, the gunmetal grey that we associate with the Bottlenose is not typical. Common dolphins are often dark slate along their spine, snout, fins and tail, but buff-to-mustard on their sides, and light grey on their hind flanks: curvaceous and muted variants of the dazzle camouflage of World War One fighting ships. Several species are black and white in the manner of Holstein cows but with the difference that the contrasting patches are symmetrical and elegantly shaped: on the Dusky dolphin, black and white curve around each other like flames; on the Hourglass dolphin a broad, horizontal, white band along each side of an otherwise black body is squeezed in the middle as if between a giant black finger and thumb.

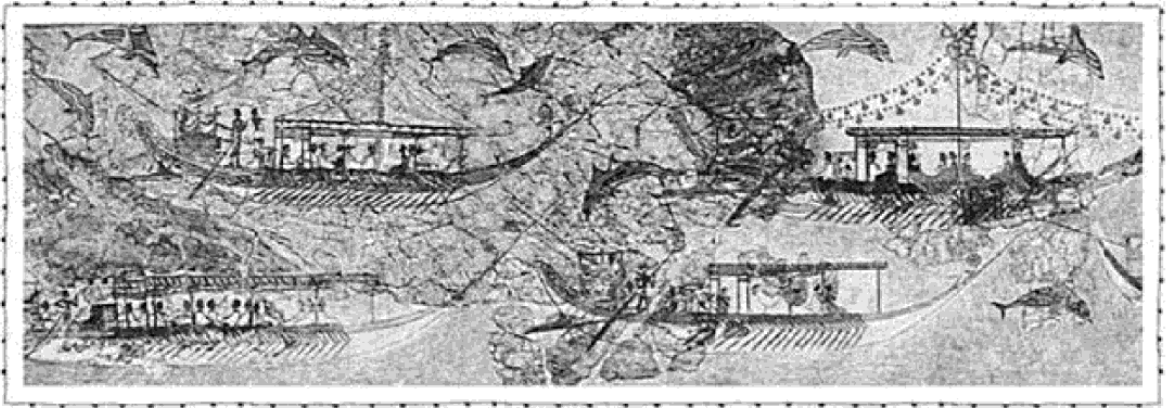
We'll probably never know when or how people and dolphins first met. Early modern humans foraging along coastlines and estuaries would surely have encountered the beached bodies of river dolphins and pelagic dolphins that were dead or dying, and in some cases fed on them. (Neanderthals living in caves on the Rock of Gibraltar had already acquired a taste for

them.) But people would also, over hundreds of generations, have spent a lot of time watching dolphins fishing and at play out at sea or in the wide rivers. And just as earlier generations of humans of the savannah would have learned much about hunting and scavenging from watching other predators there, so early coastal foragers would have observed dolphins in pursuit of fish and learned from their techniques, such as corralling fish and driving them towards shore where they are easier to catch. It wouldn't have taken long for two such curious and intelligent species to have learned to work together. Far from being antagonistic, then, many of our earliest encounters may have been cooperative and playful.

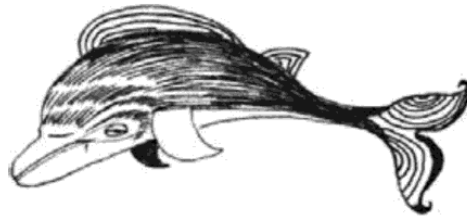
Certainly, the practice of humans and dolphins **fishing together**<sup>2</sup> was well established by the historical period. Pliny the Elder describes cooperative fishing for mullet in a marsh at Latera in what is now southern France, and gives a clear sense that the dolphins were as confident and in control of the situation as the humans. 'Dolphins', he writes, 'are not afraid of humans as something alien.' Similar interactions are reported on the coast of Brazil and Burma going back to at least the nineteenth century.

Respectful, and sometimes playful, relations with dolphins seem to have been common at one time or another in many places that the species co-exist. The Wurundjeri people of southeastern Australia, for example, held dolphins to be sacred. Killing dolphins was therefore forbidden and the Wurundjeri would only take fish they believed the dolphins did not need. They would also consult dolphins on important questions by the use of telepathy, and believed that the spirits of their dead would transform into dolphins and remain offshore to help and guide family members who stayed as humans on land. The anthropologist Douglas Everett reports that the Pirahã, a remote Amazonian tribe known for an exceptionally simple way of life and for having no concept of time, number or religion as we think of them, greatly enjoy games with river dolphins or porpoises. According to Aristotle, dolphins and small boys in the Greece of his day would develop strong mutual attachments and the dolphins would give the boys exhilarating rides.

The oldest known representation of a celebratory relationship with dolphins comes from the Minoan civilization centered on Crete. In the 'flotilla fresco' painted at Akrotiri about 3,500 years ago, dolphins are paired with running deer as great leaping animals, full of life, in one of the most beautiful and serene depictions in the history of art of humans at home in the world. Later Greek civilization linked dolphins with the divine. Apollo, the god of harmony, order and reason, was said to have taken the form of a dolphin when he travelled from Crete to the mainland to establish the seat of the oracle at Delphi (itself named for the dolphin). When, in winter, Apollo left Delphi for Hyperborea, he would leave the oracle in the care of his brother Dionysus, the god of wine and ecstasy, who had the power to turn people into dolphins.

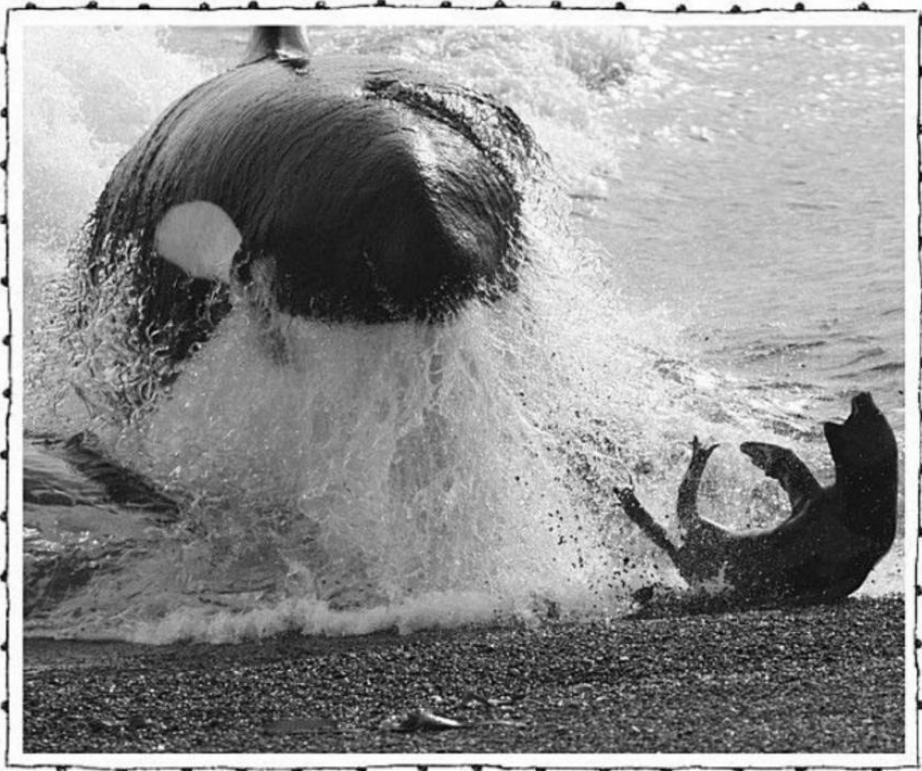


Detail from the 'flotilla fresco' at Akrotiri on the island of Santorini - an image from the Minoan civilization circa 1,500 BC.



Today, most people will agree with the general proposition that dolphins are amazing animals, worthy of particular attention. But *what* exactly is special about them and *how* precisely we should treat them are matters of dispute. One of the sharpest differences of opinion concerns an annual cull in Taiji in Japan, in which thousands of dolphins are slaughtered (ostensibly to reduce competition for local fishermen, but also for sale rebranded as whale meat) and a smaller number are taken alive for sale to entertainment complexes and aquaria around the world. In 2006 leading marine scientists called for a moratorium on this practice. Dolphins, they said, are 'highly intelligent, self-aware and emotional animals with strong family ties and complex social lives ... [and] inhumane treatment and killing of these highly sentient mammals' must stop. But Japanese fishermen carried on, as the 2009 film *The Cove* showed. And other practices, which may be at least as destructive of dolphins in the long run but are more insidious, continue. Tens, perhaps hundreds of thousands of dolphins die each year when they become trapped in nets set by fisherman who are trying to catch something else, or as a result of other human acts of carelessness. The effects on the health of dolphins (not to mention whales and other marine animals) of pollutants such as mercury and PCBs are uncertain but they are likely to increase the number of still births, developmental problems and general morbidity. And masking these horrors, as misleading as the 'smile' on a dolphin's face (which is not an expression of emotion but simply the shape of its mouth), are the aquaria and fun parks around the world where hundreds of thousands of people still flock to see captive dolphins - denatured, shrink-wrapped slaves - being drilled through acrobatic routines.

and with lots of foreplay - they rub, caress, mouth and nuzzle each other's genitals. Both males and females have a genital slit, so penetration is possible in both sexes, and the penis, the tip of the nose (the beak), lower jaw, dorsal or pectoral fin, and tail fluke are all used. Female Spinner dolphins have been observed riding 'tandem' on each other's dorsal fin, the female beneath inserting her fin into the genital slit of the other and the two swimming together in this position. Spinner dolphins of both sexes sometimes engage in orgies of more than a dozen individuals, known as 'wuzzles'. Some dolphin species engage in 'beak-genital propulsion'. Dolphins can make strong enough sounds to stimulate each other at close range. Spotted dolphins perform 'genital buzzing', in which an adult directs a rapid stream of low-pitched clicks at the genital area of another, usually a calf. Genital buzzing usually occurs between males, but also in heterosexual courtship in this species. Male Bottlenose dolphins even try to mate with other animals including sharks and sea turtles, inserting their foot-long hooked penises into the soft tissues at the back of the turtle's shell.



Killer whale hunting a seal.

Along with all other cetaceans, dolphins are descended from animals that looked something like a cross between a wolf and an exceptionally agile hippo (which may be their closest relation on land). These ancestors evolved to hunt rather like crocodiles do, lurking in murky shallows ready to pounce. And their descendants are of course ruthless, brilliant hunters. Orcas, the 'killer whales' which are actually the largest members of the dolphin family, take this to a spectacular extreme when they rush up to grasp young seals basking on a beach or taking refuge on an ice floe. Sometimes an orca will repeatedly toss a broken seal, like a cat playing with a mouse. The prowess of dolphins as hunters means they only have to 'work' for a few hours a day, which is why they have so much time to socialize.

Just because dolphins are highly social does not mean that they are not

sometimes extremely aggressive towards each other. Males gang up to rape females, and sometimes kill calves that are not their own. But in general they are great cooperators and communicators. Young dolphins are dependent for an extended period on their pod for care and education. Mothers in at least some species use a kind of 'baby talk' to communicate with their offspring, and 'carry' them by positioning them in their slipstream (as a result, the mother only swims three-quarters as fast for the same effort but the calf's average speed is increased by nearly a third). Mothers even share childcare with each other.

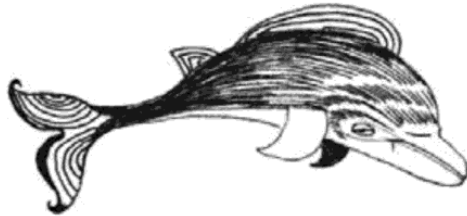
There's some evidence that, at least in some species of dolphin (and toothed whales), every individual has its own characteristic whistle sound to identify itself to others. Others in its pod will imitate that sound when responding or trying to get that individual's attention. In short, each dolphin has a name. It is also evident that not only are dolphins self-aware but they can have a keen sense of the capacities of others. When including a human in a game of tag or piggy-in-the-middle, for example, they will make allowance for the human's vastly inferior swimming ability, giving the human a chance to play in a game in which he or she would otherwise be hopelessly outclassed. They pass on group-specific knowledge - 'culture' - and are adept at **teaching new things**<sup>6</sup> to each other and to humans. Researchers conclude that many species of dolphins have a well-developed theory of mind.

Another aspect of dolphins' lives that we are still only beginning to appreciate is the role that sound plays in their lives. At a relatively trivial (but pleasing) level, dolphins often make a particular flat-toned whistle when they ride the bow waves of boats, which some marine biologists suggest is the equivalent of a child going 'wheeee!' But the matter goes far beyond that. In the sea, where sound travels four times as fast as it does on land and light dissipates in a short distance, sound serves them for both 'vision' and 'language'. And their ability to echo-locate with sound gives them powers of perception beyond anything so far achieved by humans with the most advanced technology. It opens a world of communication we are just beginning to understand.

To produce the sounds with which they 'see' objects, dolphins have a series of air sacs underneath their blowhole. They can use the air in these sacs to create clicks that last less than a thousandth of a second. These clicks are projected off the parabolic surface of the front of the skull and pass through fatty tissue shaped rather like a melon which the dolphin probably alters in shape rather as we do the lenses of our eyes. The clicks then pass out through the water, bounce off an object and return as echoes that are retrieved through the dolphin's lower jaw and pass along as vibrations to its inner ear. The clicks vary in intensity and frequency. Lower **frequencies**,<sup>7</sup> which sound like a creaking door, give a rough sense of an object and are used for ones that are further away. Higher-frequency clicks, which sound more like a high-pitched buzz, produce more detail. Depending on circumstances, dolphins emit between 8 and 2,000 clicks per second. The most rapid clicks sound like a buzz to our ears. But dolphins can distinguish each one: they don't send out a new click until the first one returns.

Those clicks and squeaks - focused outwards through the forehead, bouncing off objects and received again as vibrations in the jaw from where they pass to the ears - can locate objects many kilometres away, but they can also penetrate the skin of a human or dolphin a few metres away to

'see' a beating heart or the movements of a baby in the womb. According to some reports, dolphins have recognized women as pregnant before the women themselves knew, treating the women as they do pregnant dolphins. They can distinguish textures and shapes of objects that are distant and hidden from view: small shapes made of wood from identical ones made of plastic or of metal, and discs made of copper from those made of aluminium. They can detect differences of thickness of just a few tenths of a millimetre (less than the thickness of a human finger-nail) from ten metres, or thirty feet away, a feat that requires them to discriminate returning echoes less than a millionth of a second apart.



'Echo-location' seems like an inadequate word to describe these superhuman abilities, which resemble hearing and seeing but are also unlike either and in some ways surpass both. Occasionally humans approach delphic powers of perception. Ben Underwood, the 'dolphin boy', became completely blind as a result of retinal cancer at the age of two but learned to navigate around his neighbourhood with ease by clicking his tongue and listening to echoes bouncing off surrounding objects. He could even play table football merely by listening for where the ball was. The percussionist Evelyn Glennie, who is profoundly deaf but grew up surrounded by music, learned to register even the subtlest vibrations through her body and has become an internationally celebrated orchestral musician. Achievements like these are extraordinary in human terms but all dolphins habitually do much more.

The extent to which dolphins use sound to 'speak' is far less well understood than how they use sound to 'see' things. One researcher claims to have identified 186 different whistle types, of which twenty are especially common. The whistles, she says, can be put into five classes which are typically associated with different kinds of behaviours. There is good evidence that dolphins also communicate with each other by body position and gesture. Dolphins can clearly say more than 'it's me!' and 'wheeee!' but how much their utterances resemble human language or constitute a communication system of a quite different kind is not yet clear.

According to some studies, Bottlenose dolphins in captivity have learned sixty or more different signals for (human) nouns and verbs - enough to construct around 2,000 sentences which they demonstrably understand. But as Carl Sagan (who died in 1996) put it, 'it is of interest to note that while some dolphins are reported to have learned English ... no human being has been reported to have learned dolphinese.' This may be about to change, or at least we may learn to meet them about halfway: at the time of writing, experiments were under way to 'co-create' a language that uses features of sounds that wild dolphins normally use to communicate with each other.

Although it now looks as if John Lilly may have been over-optimistic about our ability to communicate with dolphins, his view was at least an advance on one that was firmly entrenched in Western thinking until at least the late twentieth century. Even the iconoclastic philosopher Martin Heidegger

(1889–1976) was conservative when he said that humans are the only beings on Earth that are ‘world-forming’. Everything else was either ‘without world’ (inanimate objects such as stones) or ‘poor in world’ (all non-human animals). Non-human animals, said Heidegger, were entirely captive to their encircling environment and released into activity only by features of that environment that disinhibited their instinctual drives. Only humans, he said, freed from such captivity by their conceptual and linguistic powers, had the ability to stand outside life and see it ‘as-such’, aware of the finitude of life and the imminence of their own death.



Our growing understanding of dolphins (and other intelligent animals) casts some doubt on Heidegger’s view. We can already see that dolphins have a communication system that is complex and subtle, and that their lives are rich in meaning. As the linguist James Hurford argues, ‘mental representations of things and events in the world come before any corresponding expressions in language; the mental representations were phylogenetically prior to words and sentences’. And, as the philosopher Alasdair MacIntyre observes, dolphins may not use words but they do share our fate as ‘dependent rational animals’. They are extremely adept at the ‘simple’ things that, in the end, make humans happy too – notably, endless play. They are anything but ‘poor in world’.

In the beginning, perhaps, was not the word but the gesture. And, as those in the emerging field of biosemiotics argue, we are beginning to see beyond the painted theatre-set where human language ostensibly directs meaning to a larger world in which human language is just one phenomenon in a web of meanings. Perhaps the revelation does not stop with dolphins.

Dolphins remind us that we too (and not we only) are essentially

sympathetic creatures. David Hume had a musical metaphor for this facet of our nature: 'humans resonate among themselves like strings of the same length wound to the same tension'. This is not our whole truth, but it is part of it. We may recall the modest humanism of Boccaccio in the preface to the *Decameron*, which was written at a time of plague and betrayal: *umana cosa é aver compassione degli afflitti* - it is human to have compassion for the afflicted. Dolphins present us with possibilities of friendship and hope, which, as Aristotle's younger contemporary Epicurus suggested, may be the greatest virtues of all, even if he didn't have another species in mind.



## EEL ... AND OTHER MONSTERS

Phylum: Chordata  
Class: Actinopterygii (ray-finned fishes)  
Order: Anguilliformes  
Suborder: Muraenidae (morays)  
Conservation status: Not listed

**A spring of love gushed from my heart  
And I blessed them unaware**

Samuel Taylor Coleridge

**I missed my chance with one of the lords of life**

D.H. Lawrence

**T**he Snowflake eel, a kind of moray, is harmless if you leave it alone and refrain from drinking its blood (which is toxic). With its delicate markings - black polka dot on grey-white ground or delicate mottling in black, white and yellow - it is a favourite with aquarists. But the beauty is an uneasy one, and something sinister lurks in the scientific name for their genus, *Echidna*, which is derived from an ancient Greek mythical being who, according to Hesiod, was both beautiful and terrible:

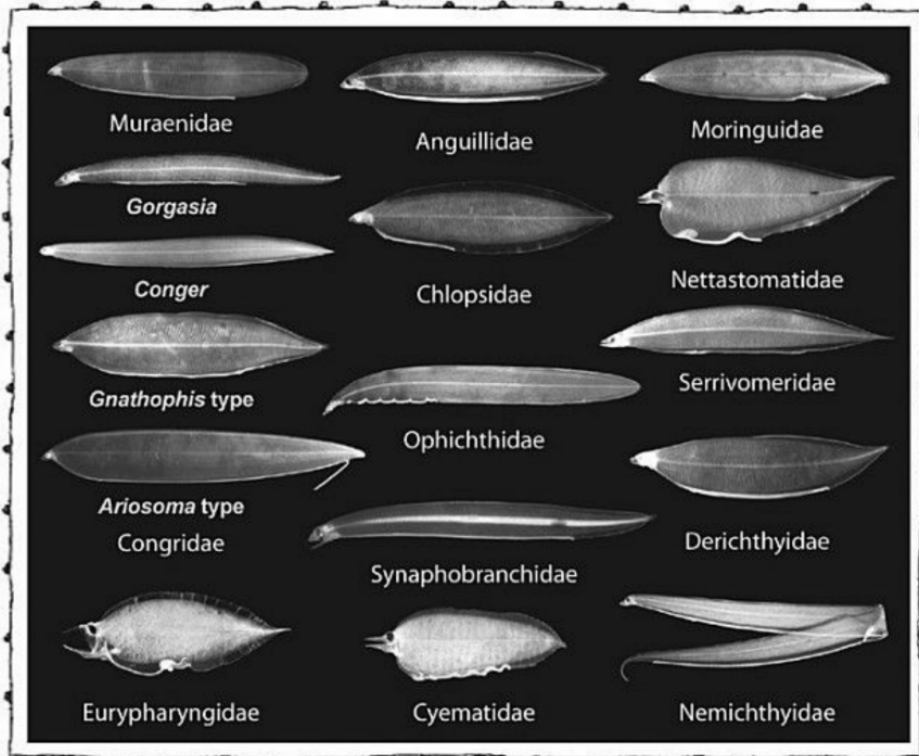
fierce Echidna who is half a nymph with glancing eyes and fair cheeks, and half again a huge snake, great and awful, with speckled skin, eating raw flesh beneath the secret parts of the holy earth. And there she has a cave deep down under a hollow rock far from the deathless gods and mortal men.

Compared to this, the Snowflake and other Moray eels are pussycats. And yet many people shudder at the sight of them. Part of the reason for this is surely their superficial resemblance to snakes, which primates so readily fear. Another may be the eels' mouths, which are constantly open, suggesting that they are ready to strike. But this is not, I think, the whole story. An eel's eyes, bulging and unblinking, look like those of a corpse, and the way the animal moves its body - gracefully, without limbs or prominent fins - is disturbingly sensual. Saltwater eels are **uncanny**.<sup>1</sup>

Freshwater eels, the *Anguillidae*, tend to be significantly smaller and are generally regarded as less spooky. But they are still enigmatic. Even though humans have probably been trapping and eating them for as long as they have been fishing in rivers, it is only quite recently that people have worked out what they actually are and where they come from. Aristotle believed they were derived from earthworms which, he thought, themselves emerged spontaneously from mud. Only in 1777 did the Italian biologist Carlo Mondini prove eels to be fish, but even then their origin and life cycle remained obscure. A hundred years later a young medical student named Sigmund Freud dissected hundreds in a search for male sex organs and eventually gave up. And it was not until 1896 that the Italian zoologist Giovanni Battista Grassi saw a leptocephalus - a tiny, transparent leaf-like creature which had long been regarded as a different species - transform into a glass eel (the translucent juvenile form of an eel that is recognizably related to the adult), proving that the two creatures were the same. The following year Grassi identified the gonads of the male eel: a looped, frilled ribbon inside the animal that had been noticed by previous biologists but not recognized as the testes.

Finally, in 1922, the Danish scientist Johannes Schmidt discovered that the leptocephali of the European eel (*Anguilla anguilla*) were born in the Sargasso Sea, as much as 7,000 kilometres (4,000 miles) away, and the main pieces of the puzzle locked into place. Mature eels swim all the way from Europe to the Sargasso. There they spawn, and from the fertilized eggs emerge the leptocephali, which then ride on currents all the way back to Europe. As these tiny creatures approach the coasts and rivers that their

parents had left more than a year before, a combination of chemical and temperature cues triggers them to transform into glass eels. When these glass eels enter freshwater they transform again into elvers - miniature versions of the adult eels. As the elvers grow they become, first, brownish-yellow and then, after five years or more, silver and white, and sexually mature. It is these silver eels that migrate back to the Sargasso to spawn. Freshwater eels undertake a journey no less epic than salmon, which mature in the ocean and return to their native river to breed, but they do it 'the other way round'.<sup>2</sup> But while the broad terms of the freshwater eel's life cycle<sup>3</sup> are clear, the processes governing these metamorphoses are still far from fully understood. In some respects the eel is no less mysterious than it was.



The larvae of eels - leptocephali - vary greatly in form, and grow to sizes ranging from about 60 mm to more than 200 mm. They are totally transparent. This image shows leptocephali of freshwater eels of the family *Anguillidae* and 12 families of marine eels.

There are many variations on the theme 'eel'. The *Anguillidae* are just one of nineteen families in the *Anguilliformes*, or true eels, an order that evolved in the time of the dinosaurs and has around 600 extant species today ranging from rivers, coasts and coral reefs to abyssal depths. Some of their names say more, perhaps, about the imagination of the marine scientists who thought them up than they do about the creatures themselves, but they are worth entertaining. There's a whole group of eels with bill-like protuberances known as Duckbilled eels (one of them is 'the black sorcerer'). There is an eel whose jaws are shaped into an elegant curved 'beak' resembling that of an avocet. There is an Abyssal cutthroat eel, whose larvae have telescopic eyes. There is a Rusty spaghetti eel. There is a Froghead eel. Some species in the Conger family grow up to three metres (ten feet) long and are bold predators, but the family also includes the Garden eel which clusters together with others of its kind in groves that resemble seagrass: at the first sign of danger, they withdraw

rapidly and almost simultaneously into the sand like the horns of a thousand snails recoiling to a distant vibration. Recently, a vast congregation of strange, greenish-white eels was found living happily right next to scorching hydrothermal vents on the sides of a giant underwater volcano rising from the depths of the Pacific. Some families of eels, having lost even vestigial fins, look very like actual sea snakes and often mimic their markings. Others look like large worms.

Then there are creatures which look like eels but are really something else. These include the Electric eel (which is more closely related to catfish), the Rubber eel (a caecilian, or amphibian, also misleadingly known as a Sicilian worm), the Wolf eel (more closely related to a perch than an eel, its stony face is one of the scariest of any living thing), and the Umbrella mouth gulper (which tempts prey by dangling its own glowing-pink, flashing-red, tentacle-covered tail in front of its huge mouth). There is even an 'eel shark': truly, this animal looks like something arising from the very lowest reaches of the human brain; its 'misshapen' teeth and twitching, jerky movement give it the appearance of something not really alive at all. And, of course, there are hagfish: blind, jawless, four-hearted creatures with cartilaginous skeletons, they produce large quantities of slime and are particularly fond of burrowing up the anuses of dead animals which they then devour from the inside.



Snowflake eels are members of the morays, the largest of eel families with about two hundred member species, most of them living in the shallower parts of warmer seas. Morays tend to be similar in shape, with a narrow fin running all the way along their backs from head to tail, but as adults the species vary greatly in size: some are shorter than your arm, a few are more than twice as long as a human is tall. They are night hunters (of small fish and invertebrates), and they have wide jaws and sharp teeth suited to ripping prey. (Their teeth are regularly and assiduously cleaned by shrimp that nimble in and out of the moray's mouth like ballet dancers in the jaws of a mechanical stage dragon.) Many are well camouflaged right down to the inside of their gaping mouths, but colouration varies according to habitat. The Zebra moray is chocolate black with vertical white stripes. The Dragon moray (also known as the Leopard or Tessalated moray) has shimmering black, yellow and red markings and two tubular nostrils sprouting just forward and above its eyes. The Giraffe moray has markings very like those of ... you guessed it. The Golden dwarf needs little further

description. The Ribbon moray has a body of gorgeous royal blue and golden yellow jaws when it is young (and male) and turns yellow all over as it becomes older (and female). It lures its prey with leafy green appendages like fishtails on the front of its top jaw, waving these in the current while it conceals its powerful body in the sand.

Until very recently the conspicuous success of morays was something of a mystery. Most carnivorous fish engulf prey into their mouths by opening them quickly from a closed position and thereby creating a sucking effect. But morays' mouths are already open most of the time. Further, their visible jaws are actually quite small and weak given the animal's size. How, then, do they sustain themselves? The answer, observed in 2006 for what was believed to be the first time, is bizarre. Moray eels have a second set of jaws deep at the back of their throat which shoot forward at high speed, grab the prey and rapidly protract backwards again, pulling the prey down into the oesophagus as the animal closes its mouth. This extraordinary ability to 'vomit' up a second set of fearsome teeth gives the moray the best of both worlds: it can reach out to grab its prey without moving far from its narrow hiding place.

There is nothing else in the world quite like these highly mobile pharyngeal jaws. Snakes are able to ratchet prey down their throats by alternately pivoting their left and right jaw arches over it, but they do this with just a single set of jaws. Some other bony fish have a set of crushers deep at the back of the throat, but these remain firmly in place behind the head. The only thing that comes close to the moray is an imaginary being created with the aim of arousing the maximum horror and disgust in its viewers: the monster in the 1979 film *Alien* and its sequels. In trying to imagine something truly horrific - a being that 'rapes' and impregnates with a nightmare 'embryo' which in turn feeds on human viscera like a medieval demon before it bursts out and destroys - the creators of *Alien*<sup>4</sup> summoned something that resembles, at least in part, a natural being - the eel - that in evolutionary terms is highly successful.

That they are **half human**<sup>8</sup> is precisely one of the things that makes them so frightening and so compelling.

Some good may come of this. Stories that locate the monstrous as close to humans as the jugular vein let other animals off the hook; they reduce the obstacles to seeing non-human animals *for what they are* and not as metaphors for something else. Creatures of the deep such as abyssal eels, hagfish, devil fish or giant isopods may continue to arouse unease, especially when we see them for the first time. This is understandable. Their faces were never 'designed' to be seen by anything on the planet's surface, and they *are* strange to us. Seeing them undoubtedly fires odd connections in the brain. But if we look a little deeper into their nature and their evolutionary origin we can move beyond the kind of dismay felt by Richard Jefferies. These 'monsters' of natural selection, existing in spaces and over periods of time we are only beginning to appreciate, can actually help us expand our sense of beauty, or at least what it is to be astonished.



The mouth of a Lamprey.





1 The psychologist Ernst Jentsch (1906) suggested a feeling of the uncanny arose in a context of 'doubts [as to] whether an apparently animate being is really alive; or conversely, whether a lifeless object might be, in fact, animate.' Sigmund Freud (1919) argued that a sense of the uncanny was often created by entities that aroused sensations we wish to keep hidden, especially sexual ones. In Hentai, a tradition in Japanese pornographic art, a woman is sometimes depicted in a tub full of Japanese eels, *Anguilla japonica*, being penetrated through various orifices.

2 Eels are 'catadromous': they spend their adult lives in freshwater and return to the ocean to breed.

3 One fact beyond doubt is that the number of 'common' European eels is between one and five per cent of what it was in the 1970s. This is a result of overfishing, habitat destruction and pollution. The species - a much-prized food for millennia - is now critically endangered.

4 H.R. Giger, the Swiss artist who created the monster for the film director Ridley Scott, said that he had no knowledge of the eel's pharyngeal jaws. One of the models for his monster, at least in its 'baby' version, is the set of figures depicted in Francis Bacon's *Three Studies for a Crucifixion* (1944). These have grey eyeless heads that are mostly a mouth emerging from a long writhing neck. Certainly, the monster in *Alien* is more than just eel. It also combines features like those of an insect and a humanoid skeleton like

the figures in Pieter Breugel's *The Triumph of Death*.

5 The Final Solution was envisaged as one small step towards Generalplan Ost, which would have organized the elimination of many tens of millions of Slavs and others in Eastern Europe.

6 When the US arsenal peaked in 1960 it was the equivalent of 975,714 Nagasaki-sized ('Fat Man') bombs (at 21 kilotonnes) or 1,366,000 Hiroshima-sized ('Little Boy') bombs (at 15 kt). The Soviet arsenal of deliverable nuclear weapons was significantly smaller than the American one in 1960, but grew fast. By 1964 it had reached about 1,000 megatonnes, or about 13 per cent of the US total. By 1982 it was nearly 75 per cent greater than the US 'throw weight' in that year, but less than the Americans had had in 1964. The largest single thermonuclear weapon ever tested, the Soviet 'Tsar Bomba' in 1962, yielded 52,000 kt or nearly 2,500 times the yield of Fat Man.

7 'A nuclear holocaust, widely regarded as "unthinkable" but never as undoable, appears to confront us with an action that we can perform by cannot quite conceive.' (Jonathan Schell, 1982)

8 Zombies and vampires are not the only humanoid representations of terrifying evil, of course, nor are they new: in *Capital*, Karl Marx envisages capitalism as a vampire feeding on the life blood of the people.

'Monsters' that are totally human appear in works such as Cormac McCarthy's *The Road* (2006). In science fiction the most monstrous beings tend to be partly human and partly either the products of our own worst fears (e.g. *Forbidden Planet*, 1956) or the products or slaves of technology. In *Alien Resurrection* (1997), for example, the heroine Ripley has been genetically combined with the monster, and in *Star Trek* the Borg are half-human, half-robot. Even the pigoons - the vengeful genetically modified pigs in Margaret Atwood's grimly comic *Oryx and Crake* (2003) and *The Year of the Flood* (2009) - have human tissue in their brains.

9 The earliest trace of fire in the fossil record dates to about 470 million years ago. At this time, the Middle Ordovician, vegetation on land was dense enough and the atmospheric concentration of oxygen (a waste product of plants) sufficient for fire to be possible.

Most of us will never see Earth's most magnificent creatures in person. We will never swim with a Blue whale. The closest we'll get to a Snow leopard at play is a few minutes of documentary film. But there is one marvel that almost all of us can see just by stepping outside: feathered flying dinosaurs. Every Swift on the wing, every treetop Blackbird in song is a reminder that the descendants of these massive reptiles took to the air in flight.

Humans can fly too, of course, thanks to sophisticated and heavy machines that consume huge external reserves of energy. But **free flight**,<sup>1</sup> using our own bodies and muscle power, seems likely to remain a dream, albeit an endlessly compelling one.

There have, however, been real creatures whose natural history indicates just how strange something that weighs as much as a human probably has to look in order to be capable of powered flight. These are the pterosaurs - winged lizards that lived at the same time as the dinosaurs - and, specifically, the greatest giants of the order such as Quetzalcoatlus (pronounced Ketzal-co-at-lus). This late-Cretaceous beast was as tall as a giraffe and had the wingspan of a Spitfire but probably weighed no more than a heavyweight boxer.

Before picturing Quetzalcoatlus in more detail, it's worth reflecting on just how extraordinary it is for something that weighs as much as we do can fly. Humans are picayune compared to elephants or whales but we are behemoths compared to almost every being that can fly: most birds and bats weigh only a few grams. And being large is a huge **handicap**<sup>2</sup> if you want to take to the air. A thought experiment suggested by Richard Dawkins shows why. Imagine a hippopotamus shrunk a thousand times so that it is about the size of a flea. Because mass shrinks by the third power (the cube) while its surface areas only reduces by the second power (the square), the flea-sized hippo will weigh one billionth (a thousandth *times* a thousandth) as much as its full-size cousin but have one millionth (a thousandth *times* a thousandth) its surface area. Thus, its surface area will be one thousand times as great as its full-sized cousin with respect to its weight. The happy result is that a flea-sized hippo can hitch a ride on a passing gust and float through the air with the greatest of ease. Of course, we might not notice it passing.



The Great bustard (*Otis tarda*) is the heaviest extant bird that can fly. But this male is just showing off.

The **most massive**<sup>3</sup> flying bird still in existence is probably the Great bustard. Once common in grasslands from Mongolia to Spain, bustards are now vulnerable to extinction thanks to the conversion of the grasslands that they like into farmland, and their tendency to fly into electric power lines at high speed. Adult males can have a wingspan of 2.4 metres (8 feet) and weigh around 12 kg (26 lb), but have supposedly been recorded at up to 21 kg (46 lb), or roughly the weight of a five-year-old child. In the breeding season, having no chins, they grow splendid feathery beards on their necks, like Victorian gentlemen gone slightly awry.

Andean condors can have bigger wingspans than Great bustards - in some cases more than 3 metres (10 feet) - but none have been recorded at more than 15 kg (33 lb) in weight. The biggest recorded wingspans among living birds, at up to 3.5 metres, or 12 feet, are those of the Wandering Albatross and the Southern Royal Albatross: adult males in these species can weigh 11 kg. Long before man, there were birds even larger than this. The biggest found so far in the fossil record are the teratorns. One of them, *Aiolornis incredibilis*, had a wingspan of up to 5 metres, or about 20 feet.

In recent years Andean condors have dwindled in numbers but they are faring better than their slightly smaller California cousin, which has almost crashed out of existence. Like the Great bustard, the California condor did not find twentieth-century civilization amenable: so many of them got zapped on power lines that by the mid 1980s less than two dozen remained out of what had once been a population of thousands. (By some accounts, **native peoples**<sup>4</sup> had already put the bird into steep decline in pre-industrial times by killing so many in order to use their feathers in ceremonial headdresses.) Since 1986, however, the California condor has made a modest comeback thanks to a captive breeding programme. One highlight in my very short non-career as a natural history radio reporter was an assignment to visit condor chicks being raised at the Los Angeles Zoo, slap bang in the middle of several hundred square miles of concrete. The wee ones were receiving early lessons in life skills such as power-line avoidance from Condor adults that were actually glove puppets. I was warned to stay well out of sight because if the chicks see a human they fall hopelessly in



Lunch.

Early pterosaurs thrived on a rich diet of insects plucked from the Triassic skies. As they broadened their diet to include fish, crustaceans and other animals so they increased in diversity and form. In all more than a hundred species, ranging from the size of a blackbird to that of a small aeroplane, flourished and died out over many tens of millions of years.

So many different kinds over such a long period of time. It's not surprising that some people muddle them up. Take that pinnacle of British film-making, *One Million Years B.C.* When Raquel Welch, as Loana the Fair One, bathing one day, is snatched into the air by a *Pteranodon* (the one with a very pointy back to its head) which drops her bleeding into the sea after it is itself attacked by a *Rhamphorhynchus* (the one with the long tail ending in a lozenge), the sequence is not precisely historical. *Rhamphorhynchus* died out some fifty million years before the first *Pteranodon* evolved, and Raquel Welch is not nearly that old.

The real pterosaur story goes something like this. First came the genus *Dimorphodon*, the short-wing big heads, and *Anurognathus*, the fabulous flying frog heads. Then came *Eudimorphodon*, the first of the long snouts, and *Rhamphorhynchus*, the true prow-beaks. Then came *Pterodactyls*, long-armed and short-tailed, and *Ornithocheiroids*, soarers resembling albatrosses and frigate birds (but bigger: some had wingspans of 7 metres, or 22 feet). Then came the *Ctenochasmatoids*, which had long legs for wading, flexible necks and bills for straining (at least one species, *Pterodaustro*, was probably bright pink thanks to a diet like a flamingo's), and *Dsungaripterus*, shell-crackers with tough beaks resembling giant tweezers. At last came the *Azhdarchoids*, the group of giant toothless

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