THE WHALE - A HISTORY - Curated Transcript of BBC In Our Time podcast
https://www.bbc.co.uk/programmes/b00kfqm6
Last on Thu 21 May 2009 21:30 BBC Radio 4

This transcript was created by downloading the podcast from the BBC website and passing it to Assembly AI V2 (https://www.assemblyai.com/) and then manually editing the resulting raw transcript to assign voices, to correct spelling, and to introduce occasional time stamps. Edits have also been made to better communicate the factual content of the podcast, rather than capturing all the details of the audio record. Such edits are indicated in the transcript.

Comments and corrections are welcome, and sincere apologies are made for any substantial inaccuracies in the following transcript.

(Credits from the BBC Website)

In Our Time is hosted by Melvyn Bragg. Melvyn's guests on this podcast are:

Steve Jones, Professor of Genetics at University College London;

Eleanor Weston, Mammalian Palaeontologist at the Natural History Museum, London;

Bill Amos, Professor of Evolutionary Genetics at Cambridge University.

Transcript:

[Melvyn Bragg] Hello. Of all the whales in literature, the most famous is Moby Dick. Described by Herman Melville: "Moby Dick moved on, still withholding from sight the full terrors of his submerged trunk, entirely hiding the wretched hideousness of his jaw. But soon the fore part of him slowly rose from the water... and warningly waved his bannered flukes in the air. The grand God revealed himself, sounded and went out of sight." Melville's novel is one of drama and grim portent, but more extraordinary is the story of the whale itself, for the manner in which the whale has evolved is among the finest exemplars of the changes evolution can bring to bear upon life on Earth. With me to discuss the evolutionary history of the whale are Eleanor Weston a mammalian palaeontologist at the Natural History Museum, London, Bill Amos, Professor of Evolutionary Genetics at Cambridge University and Steve Jones, Professor of Genetics at University College London.

[Melvyn Bragg] Steve Jones, can you give us some context for the beginnings of what turned into the whale?

[Steve Jones] I think the whale, as well as being a sort of a magnificent creature and almost a swimming metaphor as well, as Melville uses him, is a classic example of what might happen to humans if we landed on a new planet. Because the whales were the first mammals, really, to go into the sea. And the sea was then 65 million years ago, or a bit a bit earlier than that, ... was then more or less empty. It had been pulsing with life, with the death of the dinosaurs at that time, many of the giant predatory lizards that were in the sea had disappeared. So there was an empty world waiting to be experienced. And in the very early days of whale evolution, animals, perhaps a little bit like seals, appeared. And then you can really almost see step-by-step now in this new world which they'd entered, there was endless ecological niches, as we would say, were available endless new ways of life, and they very, very rapidly took advantage of those and developed into enormous creatures, into creatures of medium sized, into rather small creatures. There's a rather interesting new piece of information which shows how astonishing the whale actually is. I'm sure most people listening to this program have heard about the amazingly well preserved early primate of 47 million years ago that turned up two or three days ago, and looking at that fossil tells us how boring our own evolution has been compared to that of the whale. Because when that primate was hanging around, what the ancestors of whales were like were actually land animals, more or less, or land animals that occasionally went into the sea. So all that's happened to us is we've grown a bit and a little bit smarter. These predatory mammalian animals, in just 50 million years or so, have become the largest creature, largest mammal, ever to have lived. And that's quite something. So being a whale is quite impressive, but quite new.

[Melvyn Bragg] Can you tell us about Artiodactyls?

[Steve Jones] Well, they're the hoofed creatures. They've been well known, of course, in Darwin's time. And indeed until quite recently, in fact even now, what most biologists did was to try and make trees of relatedness among different creatures, comparative anatomy, as it was called. It's called molecular genetics now (but it's the same stuff with a lot more money!) and they could draw quite effective and trustworthy trees that showed that humans and chimpanzees were related, that cows, pigs and deer were related. (These are animals with hooves - that last group.) And oddly enough, until the 1940s, if you looked at the classic trees of mammal relatedness in all the textbooks, it all fitted together more or less convincingly apart from the whales, which didn't seem to fit anywhere - they certainly don't have any hooves last time I looked. And we knew almost nothing then, 40 years ago, about their fossil record. We knew absolutely nothing about their molecular genetics, about their DNA. And in just half a century or so of research, they've changed from a complete evolutionary enigma to perhaps the most perfect example of Darwin's theory, as illustrated by fossils, by genes, and by the behavior of living creatures that we possess.

[Melvyn Bragg] That's one of the reasons we're concentrating on, because of the word you use, the perfect example. Can we just briefly introduce us to the fossil evidence? We'll be coming back to this in more detail later in the program, but just as an introductory statement about the fossil evidence available.

[05:30]
[Steve Jones] I think the fossil evidence is particularly impressive and it's also particularly emblematic because some of the earliest fossils of whales were found not

on the seashore, but high up in the Himalayas. And when you think about it, that's completely startling. It is, in fact, the case that the summit of Everest, not very long ago was actually at the bottom of the deep ocean. And the reason why Everest is so tall, of course, is because we now know, as Darwin didn't, that there are plates across the world which are crashing into each other, and there are oceans which have appeared and disappeared, sometimes more than once, and the first whale, called Pakicetus, was found in Pakistan, in the mountains of Pakistan [and] dates from something like 50 million or a bit more years ago. It was a small creature that lived part of the time on land, part of the time in the sea, and was really the first hint of where whales actually fit in the fossil record. Somewhere remarkably close, as it happens, to the ancestors of modern hippopotami.

[Melvyn Bragg] Eleanor Weston, so we have a mammal there... just over 50 million years ago, partly on land, partly on water. Can you tell us about the state it might have been in at that time from a fossil called Ambulocetus?

[06:50]
[Eleanor Weston] Yes, well, Ambulocetus, if you like, might be one step on from the very earliest whale, which you mentioned... Pakicetus, and that was because it was clearly amphibious. In fact, it's been referred to as the walking whale because it had four limbs that clearly could support itself on land. In other words, the legs were still attached to the backbone, but there was clear evidence that this animal lived in water.

[Melvyn Bragg] What is the clear evidence?

[Eleanor Weston] Well, for instance, an extraordinary development of the foot was that it was extremely long and broadened, so it actually acted a bit like a paddle, but the paddle was really just in the hind legs. So I suppose this animal was more like an otter, when you think about how they use their hind legs. But also the backbone was very flexible. There's evidence that it was already moving up and down, like modern whales, that they have a very distinctive way of swimming, where the tail (with a tail fluke) ... goes up and down, which is different to fish. So ... some traces of that were in this early amphibious whale. But we do still have evidence that it would have probably come out on land to maybe feed (that's slightly controversial) but perhaps [to] give birth. And yet it's found, geologically speaking, in sediments that are indeed marine. So Ambulocitus was one step on from the earliest whales, which we actually do find both in fresh water (the fossils are found in fresh water sediments) and marine sediments. So we're seeing some transition, if you like, into life in water.

[Melvyn Bragg] We're still talking millions of years, and Steve introduced us to 50 or 60 million years ago, and now you're sort of 40 or 50 million years ago.

[Eleanor Weston] I forgot to say, Ambiocetis is still very early. It's about 49 million years ago, whereas the earliest Pakicetus examples, which we think we call whales, are roughly around 50 million - I think the very earliest is 53 [million]. So it's quite a quick transition in terms of evolution. We're only talking about a million years where you've got quite well developed amphibious traits appearing.

[Melvyn Bragg] ...Can you tell us about fossils called Basillosaurids and how they fit into this story? I'm just trying to get the sort of outline pattern, a little map, before we go back and go in detail.

[09:27]
[Eleanor Weston] Well, Basillosaurus was about 10 million years later. They found these spectacular articulous skeletons of what you might call a sea serpent...

[Melvyn Bragg] So that's about 38-39 million years ago?

[Eleanor Weston] ...Yes, ... and they were clearly marine animals... almost... fully adapted to life in the water, and they they would have had what we believe is a tail fluke and moved around. But what was striking about them is they still had legs, very small legs that were detached from their backbone, that were, if you like, vestigial, but they had still some evidence that they functioned... there was a locking knee and muscle attachments, and [palentologists] actually thought, well, these legs clearly couldn't have supported the animal on land. So perhaps they were used to assist with something like copulation. But I suppose what's interesting is you have this remnant...

[Melvyn Bragg] As guiding factors in the copulation?...

[10:29]
[Eleanor Weston] Yes, but you have and it's an external leg [in Basillosaurus], whereas I think today in modern whales, internally, we have a ... evidence to suggest that they had legs.... I think we're only talking about something like 18 inch long legs compared to a 40 foot long animal... ridiculous. But it's still interesting in the story of transition.

[Melvyn Bragg] How do you know it was 40 foot long from a fossil? ...

[Eleanor Weston] ...The most spectacular skeletons have been found in Egypt, which was actually thought to... be the southern shores of an ancient ocean. So that's why they've got some very good fossils. And I think they're so well preserved, they can estimate from working out all of different segments of the backbone being preserved, so they can determine things like that.

[Melvyn Bragg] Bill Amos, we're getting there, but [whales] not yet fully aquatic, really. They've had hooves, their legs have got very short, they're amphibious, but they're not fully aquatic. Now, about 30 million years ago, as I understand it, they became fully aquatic. Can you tell us how that happened and what the whale had to do in order to enable that to happen?

[11:39]
[Bill Amos] Well, I think Eleanor has already described a really fully aquatic form. When your back legs are only 18 inches long and your body's 40 foot long, you're going to struggle to do much on land at all. And they're already developing flipper like forelimbs, which are necessary for swimming.

[Melvyn Bragg] Indeed, you're developing flipper like forelimbs... How long does it take?

[Bill Amos] The evidence seems to suggest that all this happened incredibly quickly.

[Melvyn Bragg] Yeah, but "incredibly quickly" for you would be ... for the rest of us...

[Bill Amos] "Incredibly quickly" would be of the order of one, two, 3 million years? I think once you, as it were, ... remove yourself from the land to the point where you're spending your entire life at sea, which is the main transition which, for example, seals have failed to do. Seals still have to come ashore to breed, whereas the whales can give birth in the water. As soon as you do that, you lose the necessity for retaining your land locomotion and you can go from ... having forelimbs, which would have supported your weight and helped you sort-of move around like seals, do. You can have them as proper flippers and you can go over much more to the fish-like form and be able to be much more efficient when you're swimming.

[Melvyn Bragg] So what happens in the fish-like form? What other changes are there? It's in the sea, the legs are beginning to... well, they're very small then, and presumably they're getting smaller and smaller and turning into flippers. What else happens? How does it turn from the mammal into well, it's still a mammal... how does it turn into a whale? (The whale that we know.)

[Bill Amos] Well, all the other adaptations that a seal might like to have. So, for example, a tail fluke. Now, a tail fluke would be absolutely hopeless on land, it would get in the way whilst you were trying to haul yourself around on the shore. A tail fluke is by far the most efficient way of swimming...Seals swim pretty well, but they're nothing [compared] to a dolphin and so as soon as you can have a tail fluke, you can become much more streamlined...

[Melvyn Bragg] The dolphin is in the family of whales?

[Bill Amos] The dolphin is one of the members of the family of whales. ... So [to be fully aquatic] ... you don't want your back legs hanging out, they're doing absolutely nothing. The driving force is produced by your tail fluke so you can get rid of those [back legs] - you don't want extra drag. And then at the front, just like an aircraft has wings... and flaps to steer, the whales have these flippers which are used, really, to direct the way in which it's moving, with the main propulsion coming from the tail and these incredibly strong dorsal muscles that lie along the back that allow it to flex its back in a vertical position.

[Melvyn Bragg] Can you describe the tail fluke and tell listeners exactly what you're talking about with the tail fluke in a bit more detail?

[14:20]
[Bill Amos] Well, the tail fluke is this large, classic sort of... plate. It's made out of connective tissue, it's very robust, but it's rather like a very thick piece of neoprene, and it's a specialization that they've developed. It's, as it were, grown out from the side of the skin. I don't think, because it's soft tissue, it contains no bones beyond the end of the vertebra, it's not really preserved. So we speculate that this is what they had, but we don't know the development of it too much. Eleanor may know more.

[14:50]

[Eleanor Weston] No, but paleontologists have looked at the pattern in ...the size of the vertebrae which are part of the backbones, and they can see that, for instance, in Basillosaurus, that it's got the right arrangement that would indicate that it had a tail fluke, just that's by comparing it with what we know in modern...

[Melvyn Bragg] Sorry... just about what's the size of this? This [tail fluke] drives them, this is the ... engine, doesn't it?

[Bill Amos] Yeah. I mean, I don't think again, we don't know the development. We may be able to infer when they had flukes, but we don't know what the early flukes looked like. Presumably it was something like, for example, beavers have a flat tail that they use at least part in propulsion. We can imagine that it's much easier to generate a slight flattening [by evolution] rather than a lovely fully formed fluke. The fact is that if you look at fish's tails, if you look at all other swimming organisms that use a tail fluke as a method of propulsion, it tends to be roughly the same shape. And physicists, I'm sure, will tell you that that's the most efficient shape that you can have. So you start off with something that helps you generate a bit more force by a flattening of the tail, and then the genes wonderfully manage to come together to anything that enhances the efficiency will be selected. And so we can imagine that a fairly rapid transition to the modern fluke.

[Melvyn Bragg] These adaptations turning into a torpedo shape, the legs going, the fluke developing and going up and down so it can drive forward.... They didn't evolve gills. Why do you think that ... didn't happen?

[16:28]
[Bill Amos] Basically, you can think of evolution as driving change along a progressive series of steps and you can have ... what we call adaptive peaks. These are states which are clearly nicely formed and they work really nicely. Now then, if you want to breathe underwater, there are two ways of doing it, really. One is that you can take oxygen from the water and you can use gills, as fishes do. And the other is you can retain lungs and process air, which ties you to the surface. But it's such a completely different mechanism and evolution needs intermediary steps. It can't just suddenly flip from lungs to gills. So in order to get from one to the other would require you in some way releasing your need to go and fill your lungs with air and at the same time, with a high metabolism and a high oxygen requirement, swap your mechanism over and that, to me, is pretty much completely implausible.

[Steve Jones] I mean, evolution ...[via] natural selection is really nothing more than a series of successful mistakes. And you're basically every animal is a living fossil of all its ancestors and it's very hard to get from the summit of Everest to the summit of Kangchenjunga (which are two excellent places to be) without going down the valley in between them, and evolution has never managed to make the journey. What's interesting about the morphological, the shape and size evolution of whales, which is striking and is shown in the fossil record, is that when you look at the living creatures, the tips of the evolutionary branches, actually you can see precisely the same thing happening at the molecular level. For instance, we've talked about swimming and diving. Whales can do astonishing things. Sperm whales can stay down for more than an hour, they can dive to pitch blackness a mile below the surface. How do they do that? ...In their muscles, they've got a special protein, which we have a much feebler version of, called myoglobin, which can soak up massive quantities of oxygen when they breathe in. And they're much more efficient at turning over the air in their lungs than we are. They can expel 85% of it and replace it. We can only expel about a sixth of it. And this protein will hold on to oxygen for far longer than ours will, so it'll slowly let it out when they're deep down below. So that the shape evolution that ... so much impressed Herman Melville is accompanied by equally striking changes under the skin, as it were. And of course, in general, the fossils don't tell us that, but the living fossils, the animals themselves, really reinforce in the most astonishing way the lesson that comes from the rocks.

[Melvyn Bragg] This discovery, ... that the whale shared an ancestor with the hippopotamus. Can you explain how molecular evidence gets us there, Steve?

[19:14]
[Steve Jones] Well, molecular biology is really exactly ... like dissection, but you're dissecting with a much sharper knife. You're breaking the animal not into ... parts of its guts or cutting up its vertebrae, you're actually looking at the building blocks of the body. And because the building blocks, the chemical blocks, are the same in all creatures, every one of us is almost like a whale, and so is a bacterium, you can actually use the arrangement of those four DNA bases, as they're called, to look at patterns of kinship. And if you do that, what's really quite startling, if you look at the mammals as a whole, is how well the molecular tree fits in general with the trees traditionally made from fossils and from dissection of bodies. Whales are kind of special because when we started looking at them, or people started looking at them from the DNA point of view, there really wasn't much idea where they fitted. And it turned out that actually, rather surprisingly, they fitted close to a shared ancestor with a hippopotamus. And once you see that, of course, like everything, it's the benefit of hindsight. It's obvious, right? Hippopotami...

[Melvyn Bragg] It's not that obvious. Can you just tell us how obvious it is?

[Steve Jones] Well, hippopotami live spend a lot of their time in water ... like an early ancestor of a whale. They don't have any hair, like whales. ...Unlike ourselves, who keeps their testicles in a convenient bag outside the body, their testicles are internal, like whale testicles are. They communicate underwater, hippopotami [do], by squeaking and squealing, just like whales do. So once [scientists have] got the clue, it all begins to fit together. And the most astonishing first piece of evidence which tied the hippopotami to whales, about ... 15 years ago now, was the discovery that whales, hippopotamae and some of the hoofed mammals have within their DNA, inserted three or four little virus like particles, which are not present in many other mammals, suggesting that they descend from a common ancestor which had that virus like particle. And the virus looks rather like the AIDS virus, so suddenly, evolution joins together the tiniest creature and the most enormous, and that's kind-of moving, almost.

[Melvyn Bragg] Eleanor Weston, can we develop that? The discovery of the ankle bone, this hippopotamus thing, [the molecular evidence that Steve Jones has mentioned], other sources of evidence not quite as certain?

[21:46]

[Eleanor Weston] Well, I guess the story we have from fossils, firstly, what we as a paleontologist might have assumed would say the relationship between the hippo and the whale is that they looked alike simply because they both lived in water. So, in other words, they could have evolved the specialities that you were talking about independently, much later in time. But one thing that seems to be becoming clear is that whales ... are Artiodactyls. We mentioned before that they are cloven-hoofed mammals and they're things like cows, sheep, camels, even deer, all those sorts of things, and we just didn't know ... what was the ancestor of the whale, what was it related to. But if we speculate that a whale is an Artiodactyl, the Artiodactyla are defined by an ankle bone, something that they all share, which is this rather strange ... development that the animal could be very flexible because the bone had two trochleated [?], which just means like two cochneal-like facets[?] on both ends, which meant that it was highly developed and able to run. And it meant also that [the movement of] this animal ... would have been restricted to one plane. And this was an innovation in going back sort of 50 million or years ago, that animals had developed this ability to move quickly and be agile. And all of these cloven, hooved mammals have this character. So when molecular data suggested, quite surprisingly, that the hippopotamus might be the closest relative to the whale, [people] obviously asked, well, have the early whales got these ankle bones? Would that be the ultimate proof that the fossil records could demonstrate? And of course, whales today have lost their hind legs. So when evolutionary biologists want to compare characters, it's very, very difficult because the legs are obviously gone, but the very early whales, pakecitids [?] that we mentioned before did [have hind legs and] we've now found ankle bones - ... not just Pakecitus and Ambulacetus and one slightly later that we believe are indeed like Artiodactyls. Although the story isn't quite as straightforward as that because these ankle bones are very primitive in the sense that they're probably more primitive than any other known animal .....

[Melvyn Bragg] Bill Amos, so we've got the ankle bones, although that's under certain, not so much dispute, but it isn't quite as clear in Eleanor's mind as it might seem. Can you explain how the whales reuse things? I think it's called transfer of function and maybe concentrate on the whale's jaw mentioned by Melville at the beginning of the program, turning into the sonic boom.

[24:56]
[Bill Amos] Well, obviously, when you go from the land into the water, the whole hearing process changes dramatically and you go from a system where you've got a very light medium, which transmits sounds very well to a much denser medium. And what you find is that in the earliest fossils, there's now a fossil, one of the raoellids, I believe, which actually has the ear bone, which suggests that it could function both on land, in air, and underwater. But very rapidly, as soon as you go into the water system, they need to be able to hear underwater and the whole ear becomes much the earbones become much heavier and much denser and much more adapt to transmitting sound underwater. And it's at this point that we believe that they started thinking about actually developing the whole system that we know that whales have today, which is this method of effectively sonar - making squeaks and whistles and listening for the rebounding of those and also for communication.

[Melvyn Bragg] Can you tell us how that works? Can you give us some detail about how that works? So they make these squeaks and whistles, I've always thought of it ...

(because I know so little) rather romantically, in that [there are] these great booms going across half an ocean, and this sort of orchestra of whale sounds under the... No, it isn't like that, is it? Squeaks and whistles ...[only] takes me down 17ft...?

[26:16]
[Bill Amos] No, there is an astonishing diversity of sounds that whales are capable of making, and they make them for many, many different reasons. So, for example, there are the very low sounds that they use and there's evidence...[for example] ... [two groups of] colleagues of mine
were following different fin whales 500 miles apart, and one of [the whales] started calling and the other one. [The two groups of scientists knew this] just coincidentally [as] they were following both [of the whales] and the other [fin whale] started turning and [the two of them] ended up coming together and meeting. So they'd spoken to each other in some sense.

[Melvyn Bragg] Communicated 500 miles? Is that the record? I'm not being silly. I mean, is there any evidence...

[Bill Amos] It's the sort of distance that whales can communicate underwater. Because sound travels so well, particularly if you use the right frequency. And so this..ability to communicate, this is why everybody got so worried when the Navy started using these incredibly loud noises for all their various nefarious purposes, for tracking ships et cetera, there was a concern that whales would be unable to hear each other. And I mean, (a) you could damage their very sensitive hearing. They're designed to pick up somebody else speaking a long way away,

[Melvyn Bragg] ...turn towards a submarine if we're not careful.

[Bill Amos] Well, certainly there's evidence that whales have been certainly damaged, if not killed, by the power of some of the sonic booms that humans are making underwater. But that's just one kind of use. So they also use the sound in terms of locating objects. And experiments on dolphins in captivity show that they can discriminate incredibly finely between different shapes and different sizes of object. And you only have to see dolphins in captivity going off and chasing things, and the ability to catch a moving fish. They certainly don't use sight very effectively, they're using mainly the rebounding sonic, the very high pitched whistles and things, [are] very good over short ranges. They reflect off the fish and in fact, there's even thought that [whales] can stun fish and squid by making very intense sounds that are then focused. Many whales have a bulbous front end, sort of a large kind of a globe on the front of their heads, and this is mainly fatty tissue. The classic example is the sperm whale, this huge, great... what some people call the nose, rather strangely... but it's sort of huge, great square head that you see classically on Moby Dick. This is all contained with fat. And it's thought that this acts as a lens to funnel sounds made in the breathing tubes and can produce very highly directed sounds in front and potentially even stun the prey that they can then go and suck up. So, in fact, somebody once calculated that a sperm whale underwater is such a big object, 50 or 60 tons, that in order to eat a squid, it's just not worth it turning because it takes so much energy to turn that you've got to have a certain size of squid before it becomes worthwhile. So...certainly it can't afford to chase things. So this was quite a worry for scientists, [Melvyn Bragg] 50-60 tons, that brings us back to the reality, Steve Jones, but let's go back to the fossils! Now there is a sad line in your notes which, given you're such a champion of writer of explainer about Darwin, that you say the fossil record can look anti-Darwinian! It must have cost you blood to write that sentence...

[29:48]
[Steve Jones] Yes, Darwin himself says that he has a whole chapter in [One the] Origin [of Species] about the incompleteness of the fossil record and it's led to endless, endless arguments both for creationists, (you can't have an argument with creationists, it led to endless loud, meaningless squeaks from creationists, rather like ... a whale!) but also within within biology itself. It's clearly the case that in nearly all fossil records you do not get what Darwin would have liked, which is a slow gradual transition from one form to another. And you can interpret that in two ways - the way the Darwin did which is that actually most of the intermediate forms have been swept away by the accidents of time. And he has some very poetic stuff about ... looking across from the north downs of Kent to the south downs of Kent and pointing out that once there was a mountain in between them made of chalk which had been washed away with all its fossils. And you can see that in many ways, for example if you go to the battlefields of the First World War and look for the corpses of the men that we know that were killed there less than a century ago, many of them carefully buried, they've nearly all gone. So the fossil record really is incomplete. But there's an alternative view which Stephen J. Gould was very attached to, which is actually what's really happening in the fossil record is long periods of not much happening and then very rapid changes, so rapid that you probably won't see them among the dead bones themselves. It's Steve Gould, who was much criticized, people didn't like the idea, said that was "evolution by jerks" and then Gould came back and said "well, the alternative form was evolution by creeps". So you can see that biologists are just as childish as anybody else when it comes to arguing about the fossils. But the whales I do think give hope to us creeps, it does seem that we've got many of the intermediate forms.

[31:36]
[Bill Amos] I think one of the most exciting recent discoveries which sort of brings this story up to date is that we now understand much more about the genes that are involved in development. And because we now know the genes that are involved with limb development we can then go into whales and ask what's happened to those genes. And there are two really exciting genes. There's one which is involved with the development of the hind limb and a single mutation in this causes mice to lose their hind limb such that the limbs become these tiny kind of primordial couple-of-bones in the body wall which is exactly what they look like in whales. So it looks as if a single mutation can cause loss of hind limb. And this is if you look at the whales they all share the same mutation that the mice do. And there's a second gene which ... again ... causes problems in humans which is where humans have have a mutation which causes webbing between the fingers and often extra digits, which is exactly what you'd want if you had a paddle. Well it turns out that whales have this mutation as well, and it's not the only mutation that develops the flipper but certainly it shows you that the genetics can produce the sorts of forms that would be appropriate for aquatic life.

[Melvyn Bragg] Eleanor Weston, can I ask you, does the fact that unrelated creatures can look similar, is that a problem for palaeontologists?

[32:56]
[Eleanor Weston] Well, I think what you're getting at there is that you can look similar not because you're from ... common ancestry, you can look similar because you just adapt to a similar mode of life.

[Melvyn Bragg] Well, everybody thought the whale was a fish until a couple of years ago. It looks like a fish...

[Eleanor Weston] It's definitely a problem for paleontologists, but in some ways it's also a problem when you look at relationships, even using molecules, with this idea that things can be reversed, their function happens quite a bit. But ... to come back to the fossil record a little bit, I do think that though we can make lots of predictions from our modern animals about how related they are, we still do have a remarkable, say, 60 million years worth of evidence for types of animal, and you've got to still explain them. And it can also help us with what we sometimes call divergence time. We know if a whale or something like a whale existed 50 million years ago, that there's a common ancestor that's even earlier. And I may be going off the point a bit here, but I noticed when we were talking about the hippo and the whale being related, what you're really saying is that an animal that lived sort of 55 or 60 million years ago was a common ancestor, and it probably didn't look anything like either a hippopotamus or a whale. You're dealing with something completely different. So this whole element, this dynamic time element, is very important to bring that into your understanding of these relationships. But you are right, during that time, all manner of things like a hippopotamus could have gone into water several times within 60 million years. I mean, it may not have done. And likewise not just [the] hippopotamus. Another Artiodactyl, like one that you were mentioning,... that lived in forests looked ... like what we [would term a] "mouse deer" or "water chevrotain" today, and they were semi aquatic animals ... but of course, they independently evolved characters that would have meant that they lived in water, that would have been shared by whales and hippos and these mouse deer.

[Melvyn Bragg] Steve Jones, do molecular investigations bring a different sort of light to bear on this?

[35:27]
[Steve Jones] They do... sometimes molecular biologies are filled with insane self confidence, I often think. What happens in molecular biology [is that] people get stunned by the amount of data they can generate quickly. And it's nowadays, astounding... I think biologists really ... are amazed by what's happening now. The rate at which we can generate DNA sequences is going up - has gone up over the last ten years by thousands of times. So you have this wave of information that's coming forth and it's fatally easy to look at your print out (in the old days) or put it in your computer and to generate a family tree. But in fact, until recently, people just would generate a tree of relatedness between whales and hippos, and various other things, without using any statistical tests at all. And it turns out that actually there are millions of possible family trees and it's quite hard to be sure which one's right, and very often we don't know which one's right. I think the whale and hippo one is pretty impressive. It's also the case that there tends to be an assumption among molecular biologists that all this change is purely random. It just happens. It's like a clock, it ticks away, mutations appear and then they disappear as the individuals who carry them die off for random

reasons. That too is almost certainly not the case. You know, whales and ourselves each lack hair, but we don't lack hair because we share a recent common ancestor. We lack hair for different reasons which are quite independent and driven by natural selection. So there's a lot of assumptions in molecular evolution which are not generally present in paleontology. In paleontology you've got the bones staring you in the face, defying you to understand how they fit together. In molecular biology you have a lot of mathematics and I'm very, very dubious about mathematics.

[Melvyn Bragg] Do you want to say something, [Bill Amos]? Because I'd ask you a question if you don't.

[Bill Amos] Well, it was to carry on Steve's point, which is that these molecular trees work very nicely when the evolution is progressing very nice and evenly in the "creeping" sort of way, as we discussed earlier. The problem is that with whales, and in fact with the whole mammalian radiation, is that when a group of animals gets an innovation either becoming warm blooded and furry, like current mammals, and giving birth to live young or in terms of whales finding a whole new environment with all the exciting possibilities, what tends to happen is that they completely run wild and produce lots of different forms very quickly, because there are lots of different things that they can do. This produces what we call a "star phylogeny", lots of lineages, all arising over a very short period of time. And of course, because they arise over a short period of time, trying to find out which came first is very difficult because all the branches at the base of the tree are very close together. And that's what's given rise to a lot of the controversy about the ways in which the different whale families are related to each other.

[Melvyn Bragg] Eleanor Weston do you see limitations in the molecular evidence?

[38:35]
[Eleanor Weston] There are limitations, but of course there's limitations in the fossil evidence.

[Melvyn Bragg] Let's stick with the molecular...

[Eleanor Weston] I guess with the molecular evidence, what you've got to remember is that many of the species that existed are not alive - you can't get molecules from them. They're extinct. So actually I've heard figures of ... a ratio ... in whale evolution of nine to one, whereby nine, the majority, represents extinct species [to one representing non-extinct species]. So when you're looking at the degrees of relatedness with these animals, most of them don't exist, so your molecular data is only representing a tiny fraction of the species that evolved and are obviously all part of this evolutionary story.

[Melvyn Bragg] At this stage, Steve Jones, you started by saying it's a phenomenal and perfect example of evolution. ...Can you just summarize and tell us why what we've heard, [and] explaining [to] the listeners, why it's so phenomenal and why it's so perfect? Why are you, unusually for you, using superlatives?

[39:39]
[Steve Jones] In some ways because it all fell. ... It's like ... dealing a hand of cards. Suddenly all the right cards came out. In the last ten or 15 years. 20 or 30 years ago,

we knew almost nothing. But now, I think if you read the Origin of Species, which I actually do recommend, what Darwin did in the Origin was to bring together bits of information which did not seem, before the book to be related to each other: stuff about pigeons, stuff about fossils, stuff about animal breeding, stuff about new kinds of creatures in different parts of the world. And people knew all this, but it didn't make a story. And Darwin called the book one long argument. And what the whales do is they are one chapter, a very impressive chapter in that long argument, which brings together totally different kinds of evidence, all of which fits more or less. The fossil stuff has been, as I said, spectacularly increased in the last ten or 15 years, and it fits. And then the molecular stuff which is now pouring out of the machines, also fits. But the modern stuff also fits. If you look at the adaptive, the way that whales have adapted to go beneath the water, we've heard a lot about flippers and so on, but when we look at the molecular genetics of the way they deal with oxygen shortage. The way they can deal with ....You get a stitch, you get lactic acid building up in your muscles, if you exercise too hard. [But it] doesn't worry them because they got a new biochemical pathway. Another interesting thing which molecular genetics has come out with, which fits ... with the idea that you lose limbs if you're not using them because they're expensive, whales can't smell. They've got just the remnants of the smell system that we have. That's been lost because there are no smells under the ocean. So all these totally different kinds of data suddenly come together in a harmonious tale. And what's more, Herman Melville wrote a book about it!

[Melvyn Bragg] Bill Amos, can you give us briefly (I'm sorry, we're near the end of the program, unfortunately) some idea of the size of the biggest whales and the diversity of these creatures.

[41:39]
[Bill Amos] I think the diversity ....if you say "what's your whale?" people might think of a blue whale, which is the largest organism, it has these amazing throat pleats, and it's also got the baleen, which it uses. And a lot of people will say, "what do whales feed on?... They feed on plankton". In fact, the baleen whales are just one group of whales and they do feed on not just plankton, but small fish, anything that they can scoop up in large quantities and sieve. But then the sperm whale, of Herman Melville's Moby Dick, has these huge jaws, which it probably doesn't actually use for feeding. [It] feeds on squid at deep depths and probably just sucks the squid in. But then we've got a whole range of dolphins, including highly specialized dolphins that live in rivers, fresh water, armed with very long snouts, almost blind with these batteries of tiny little needlesharp, teeth ideal for catching fish in cloudy waters. We've got beaked whales, very poorly understood, their mouths - they probably can't even open their mouths in some species - are just formed into long tubes at the front and they suck up squid rather like a child eating spaghetti. So we've got a huge diversity of different [whales].

[Melvyn Bragg] Thank you very much. Thanks, Bill Amos, Eleanor Weston and Steve Jones.
