Birds are sensitive indicators of climate change: they have been for 140 million years

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Abstract

Everybody loves birds. The fossil history of these animals dates back in time more than 140 million years and shows us that birds are just one kind of dinosaur; the only surviving branch of this part of the reptilian family tree. In addition to their longevity, we know that birds have lived through a number of periods of major climate change in Earth's history: the initial explosive evolutionary radiation of the living groups - the ancestors of the 10,000 living bird species - occurred 60 million years ago, during one of the hottest times in the geological record. We know that modern birds are super-sensitive to changes in temperature - seabirds, like albatross and auks for example, would be unable to fly if sea surface temperatures were to change by just a few degrees. In this short review I will examine the fossil record of birds and show how this major group of living vertebrates can be used to inform our future predictions.

1. Introduction

The 10,000 or so species of living birds capture everyone's imagination - for decades ornithology has been hugely popular. Each year, thousands of people participate in bird counts and surveys across Europe and everyone has noticed the same trends: birds are declining, in terms of both numbers of species and recorded individuals [1]. This is clearly related to climate change, be it changes in urban landscapes or fluctuations in temperature and availability of food resources. Indeed, a link between climate and numbers of bird species was noticed and written about by Charles Darwin probably the most influential biologist of the modern age [2].

We know from their basic biology that birds are susceptable to changes in temperature and oxygen in their surroundings. We also know that birds, as a vertebrate group, have a deep fossil record that extends back in time more than 140 million years (mya). The oldest known bird is the famous Archaeopteryx, from Jurassic lake sediments in Bavaria, Germany (Figure 1). However, this animal is anatomically quite different from the birds we know today – more comparable to small dinosaurs

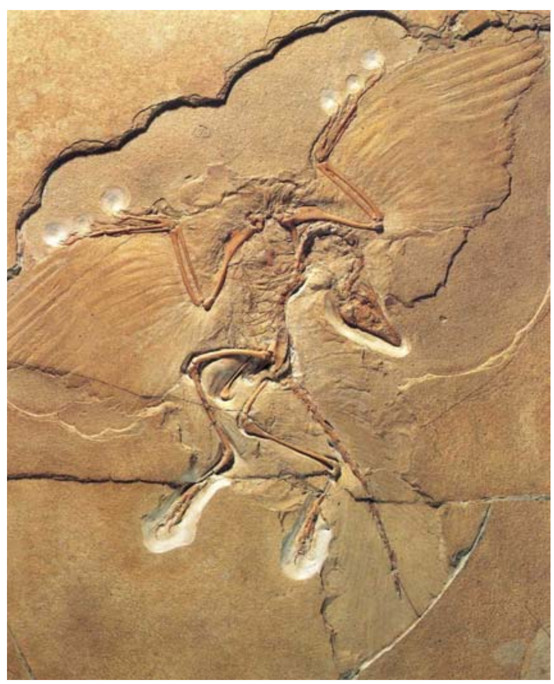
Figure 1- Photograph of the Berlin specimen of Archaeopteryx lithographica, probably the most famous of all fossils. This early bird retains a number of 'dinosaurian' features, such as teeth, separated fingers and a long bony tail.

like Compsognathus and Velociraptor in its possession of a long, bony tail, teeth and separate clawed fingers. Nevertheless, Archaeopteryx tells us about the evolution of the quintessential avian feature – feathers for flight – as well as the early development of bird biology.

Although widely accepted these days by biologists [3], the dinosaurian heritage of birds has been greatly debated and dates back to the work of Thomas Henry Huxley in the 19th Century [4]. Huxley made some early predictions about the anatomy of birds and the features that could be used to distinguish them from other vertebrate animals: all of Huxley's characters (i.e., light and hollow bones, fluffy body covering, including well-developed feathers, incubating eggs and taking care of young) have now been found in dinosaur fossils. The starting point of this discussion is thus that birds are living theropod dinosaurs [3]; I will review the reasons why birds make good indicators of climate change and then present two examples of my own work in this area. My first example draws on evidence from 'deep time', the early avian fossil record, while my second is much more recent – bird specimen data from around Ireland that was collected just over 100 years ago.

2. Why are birds sensitive indicators of climate change?

Avian biology has been the subject of intensive study since the time of Darwin [4] but we have only recently come to realise just how remarkable birds are in their anatomy and physiology. As any birdwatcher will tell you, these vertebrates are unique in two ways: their unique breathing system, and efficient flight. It is these key biological attributes that make birds sensitive to climate change.

In the first place, and unlike their mammalian counterparts, birds possess very small lungs compared to their overall body size. Instead they have a unique 'air sac' system: diverticulae of this system percolate over most areas of their bodies, invading the bones of the skeleton in most taxa [5]. The extent of this 'air sac' system can thus be measured directly by examining bird skeletons because the diverticulae leave marks, pnuematopores, on bones. The second thing about birds that we can potentially use to measure their response to climate change is their flight efficiency. Although the range of different flight styles seen across this group is of course huge, many birds – particularly marine taxa – exist very close to their maximum 'flight efficiency' [6]. Taxa like the Marbled Murrelet, found on the west coast of Canada and Alaska, fly using extremely rapid flapping and have high relative body masses. In many cases when zooming low across the ocean – looking not unlike wind-up toys – females of these small birds are also carrying relatively large eggs (huge compared to their body sizes). We know from observations and experimental studies on their flight performance that even a small change in sea surface temperature would dramatically affect the ability of birds like the Marbled Murrelet to do flapping flight. They are so heavy relative to their flight power that small aerodynamic changes on the sea surface would make them unable to fly. Thus, experimental work on the flight speeds and efficiency of marine birds has great potential to record their responses to climate change. This is something that I am working on at UCD with Canadian colleagues.

3. Example one: back into 'deep time' and the avian fossil record

Because of the fossil Archaeopteryx (Figure 1) and its kin, we know that the fossil record of birds extends back deep in time. We also know, based on a huge number of new fossil discoveries over the last 10 years [7], that at least two earlier lineages of basal birds existed alongside the dinosaurs in the Cretaceous (100-65 mya) in addition to taxa that we recognise as anatomically modern (Figure 2). One of these two basal groups – enantiornithines – was at least as diverse in terms of numbers of species and morphological adaptations as living perching songbirds (Passeriformes). One key research question that I work to address at UCD is a 'why' question: why did only one of the three lineages of birds that we know about from the deep fossil record (Figure 2) survive the infamous Cretaceous-Tertiary (K-T) boundary extinction event? The answer to this question has proved hard to address using the fossil evidence available.

Taking data from bones as proxies for bird biology, I have argued that climate likely had an important part to play in avian survivorship across this extinction horizon [8]. Perhaps the antecedents of modern birds (Neornithes) were somehow better able to deal with the climatic changes that we know took place in the aftermath of this extinction event, almost certainly caused by the impact of a

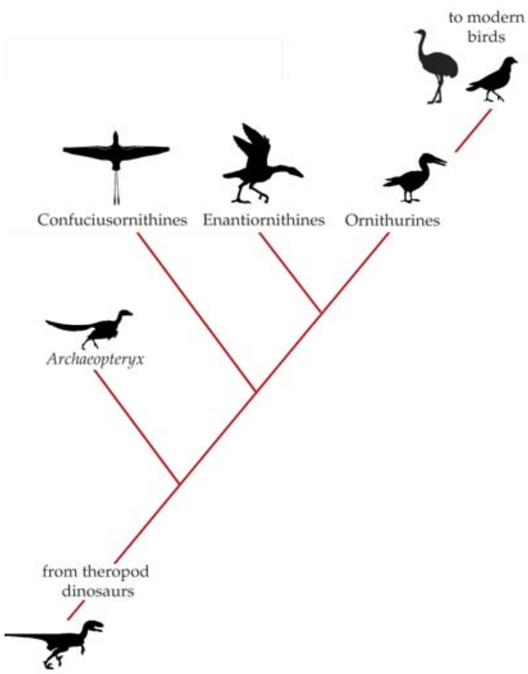

Figure 2 - The evolutionary tree for birds. This hypothesis is based on scores of anatomical features and tells us that at least two other lineages, other than the one leading to living birds, radiated during the Cretaceous. Only modern birds were able to survive the extinction event 65 million years ago.

huge meteorite off the coast of present-day Mexico. Certainly temperature and atmospheric oxygen were dramatically affected in the immediate aftermath of this impact. Preliminary data suggest that basal modern birds were both more aerodynamically and metabolically efficient than their earlier-diverging counterparts. We hope that by addressing such 'deep time' questions in avian evolution we can uncover clues to explain the current responses of birds to dramatic climate change today.

4. Example two: recent time, evidenced by the Barrington avian 'herbarium'

Richard Barrington (1849-1915) was a Dublin gentleman and keen ornithologist (Figure 3). For reasons known only to himself he maintained correspondence with lighthouse keepers and lightship captains around the Irish coast, and for almost 20 years they sent him records of birds that died impacting their lights. These records mostly comprise the legs and wings of birds that were mailed to Barrington until 1900 [8]: all of these specimens are housed in the Natural History Museum

Figure 3 - Richard Barrington (1849-1915) whose collection of bird wings and legs from around Ireland may yet have much to tell us about climate change.

(National Museum of Ireland).This collection of more than 3,000 flat bird pieces has earned the nickname 'Barrington's avian herbarium' – their preservation is similar to the way that plants are collected and preserved in museums and botanic gardens.

As well as being completely unique from an historical perspective, Barrington's bird collection is extremely important from both Irish and international viewpoints. Because birds were effectively sampled randomly (i.e., whenever individuals flew into lights) all year round from around the coast of Ireland across a 20 year timeslice, this collection has the potential to tell us a lot about changes in avian diversity around the turn of the 20th Century. It is this 'time resolution' of the Barrington collection, as well as its tight geographical control, that make these data unique in an international context. The island of Ireland presents us with a constrained case study within which we can test and evaluate species responses to climate change over time: of course temperature data are also known back to the turn of the century and beyond. This collection is exciting and presents yet another example of the utility of museums: of course, Barrington and his contemporaries had no idea that this data set would prove useful more than 100 years after he began collecting data for his own interest. And if his collection had not been preserved by the Museum in Dublin we would not have access to it today.

5. Conclusion and prospectus

My work at UCD has shown that the evolutionary diversification of birds has perhaps been in response to climate change, both at the 'deep time' level (i.e., more than 100 million years) and in more recent human history (i.e., over the last 100 years). In addition, we have the opportunity, being based in Ireland, to test more global hypotheses that predict the responses of species to fluctuations in climate, using unique natural history museum collections like the Barrington 'avian herbarium'.

Our work at UCD is ongoing in this area, within the research theme of Evolution and Population Biology(http://www.ucd.ie/bioenvsci/research/evolution.htm). As well as access to species responses to climate change (provided via evolutionary research), this field also a way for us to engage both with the public and with young people.

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