



Research Article

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# Fishiness of Piscine Birds Linked to Absence of Poisonous Fungi but not Pizza



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## Abstract

What is a species? That is one of the main questions in evolutionary biology, ecology, and conservation biology. Another question is this one: Can the degree of fish-likeness in birds be linked to the absence of poisonous fungi? Sparked by recent major ornithological advances we set out to assess whether the reason that some birds are more morphologically like fish than others could be explained by the prevalence of fungi of mild to severe toxicity. Whereas birds of several taxonomic orders are partly or predominantly aquatic, few have adapted so strongly to an underwater lifestyle as penguins (Sphenisciformes). These both eat fish and look like fish (what is up with that?), and predominantly occur in the Antarctic region, where environmental conditions largely prohibit the growth of poisonous fungi. On the other hand, birds with traditionally bird-like morphology (e.g., *Gallus gallus*) as well as fish with fish-like morphology (e.g., *Engraulis* sp.) seem to mostly occur sympatrically with mushrooms on pizzas. We thus conclude that the absence of poisonous mushrooms has led to the pronounced fishiness of certain members of class Aves. Using a sophisticated statistical framework, we also uncover an unexpected inter-class taxonomic relationship, and predict that the evolution of volant penguins because of climate change is mediated through shifted fungal distributions. Our study brings new and important perspectives to different fields, including climate change and invasion biology.

**Keywords:** Climate change; Convergent evolution; European Union; Mushrooms; Other stuff; R; Sphenisciformes; Taxonomic sensations

## Introduction

In his pivotal contribution to the field of ornithology, Baldassarre [1] evaluated the weirdness of birds and illustrated that looking like a fish in birds is correlated with climate change [1]. This is quite surprising, because we do not know if fish themselves are even affected by climate change [2,3]—after all, they are under water. However, we are unsure about the claim that climate change may affect the fishiness of birds; no statistical analyses were done. In addition, it has been repeatedly stated that climate change may be a hoax on its own which may or may not be true—who knows, right [4,5]? At any rate, and in contrast to the above, based on previous data on the presence of poisonous mushrooms (Fungi, Basidiomycota) in the Antarctic region (probably none, but we will get back to this topic in the Discussion), we believe the fishiness of birds is correlated to fungal distributional patterns [6,7].

At the time we developed the original idea about fishiness of birds potentially being correlated to absence of poisonous mushrooms, one of the authors (D.H.) was eating pizza with four

cheeses, chicken, anchovies, and mushrooms. It was really a good one, and this prompted us to—just like the pizza—integrate all four parameters in this study: fishiness, birdiness, lack of fungal toxicity, and effects of prolonged heating. We note that integrative taxonomy approaches [8], and by extension approaches to integrate everything in research, are being increasingly employed, thus supporting the rationale for the work presented in this paper.

It is important to keep in mind that research has not always been this integrative, or cross-disciplinary. For example, Charles Darwin worked alone [9] and still published a relatively well-cited contribution to the field of theology and some other disciplines. We feel it is natural for humans to dangle up and down between extremes. This is true for scientists, just like it is for politicians (consider the formation of the European Union in the 1990s and early 2000s versus the current wish of some countries to leave again [10]).

All in all, in this study we present the results of our work with fishy birds (*fide* Baldassarre [1]). We hypothesize that, (1) despite

climate change, it is still cold in Antarctica and thus the presumed lack of poisonous fungi leads to fishy-looking birds. Further, with a clear correlation of pizza and lower latitudes [11], we hypothesize that (2) birdy-looking birds (as well as fishy-looking fish) will be more prevalent than fishy-looking birds on pizzas.

**Material and Methods**

**Sampling**

Based on current avian taxonomy [12] and higher classification following Jarvis et al. [13], we randomized our selection of birds of various shapes by letting a single observer (M.S.) throw darts on a paper print-out of the world bird list while blindfolded. This resulted in two members of Galloanseres (*Anas platyrhynchos*, *Gallus gallus*), whereas remaining species belonged to Neoaves: one member of Phoenicopteriformes (*Phoenicopus plasticus*) and three members of Passeriformes (*Erithacus rubecula*, *Hirundo rustica*, *Passer domesticus*). However, to ensure that decidedly fishy-looking species were represented, we also included two penguins (Sphenisciformes: *Aptenodytes patagonicus*, *Spheniscus* sp.) that narrowly escaped the darts. While this may be perceived as biased, we argue it is not. To further elaborate on piscine versus avian morphology, we included three representatives of Osteichtyes, namely Nemo fish (*Amphiprion ocellaris*), flying fish (*Exocoetidae* sp. indet.), and anchovy (*Engraulis pizzaialis*).

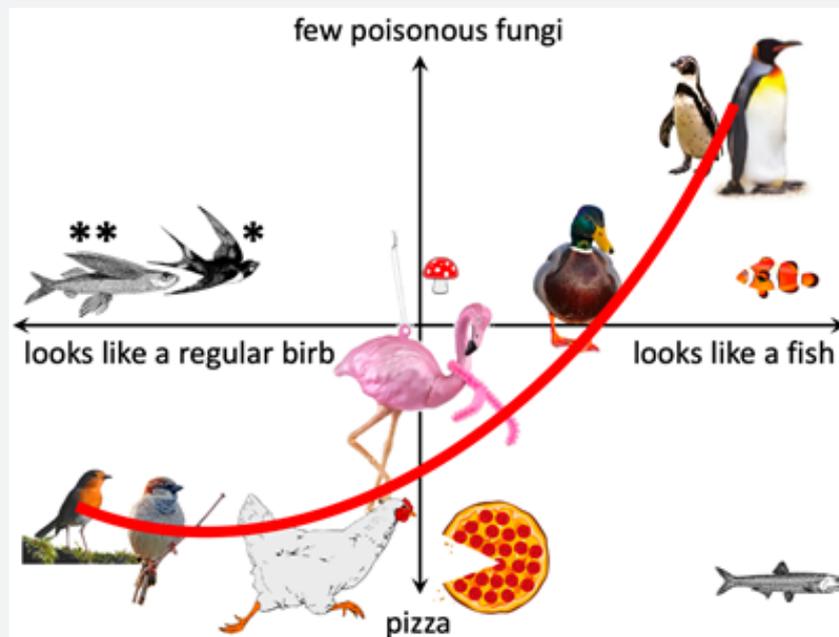
**Statistical Analyses**

The sampled taxa were ordered canonically in a two-

dimensional space along the axes of avian versus piscine morphology, and the lack of poisonous fungi versus pizza. We performed a principal component analysis (PCA) using the function “prcomp” from the stats package in R v. 3.6.1 [14] after logarithmization of everything, because, hey, non-normal distributions are nasty. We also considered running generalized linear mixed models (GLMM) because they are considered fancier but decided against that on the grounds of laziness. We did not include genomic sequence data in our analyses, and therefore did not have to consider a Bayesian framework, coalescence theory, or site frequency spectra [15-17]. These are all concepts that seem so simple at the surface but can give all sorts of complex results that are difficult to interpret; thus, morphology is better than molecules [18]. Hence, we only cared about  $p < 0.005$  and fitted an approximately quadratic trendline to our data using the Arc tool in Power point v. 16.16.21.

**Results**

Our PCA revealed that most of the variation in the dataset was partitioned along the first (59.3%) and second (34.8%) principal components (PCs), with loadings corresponding to poisonous funginess and pizza toppingness, respectively (Table 1). There is a clear bimodality in both PC scores, distinguishing on the one hand penguins (PC1, low funginess) and on the other hand anchovy and chicken (PC2, high toppingness). Plotting the scores for all taxa, a quadratic model explains the two-dimensional distribution of avian species ( $p \lll 0.05$ ) with low residual variation except for the outlier *H. rustica* (Figure 1).



**Figure 1:** The relationship between (a) morphology and taxonomy in fish and birds, (b) the effect of poisonous fungal prevalence, and (c) pizza. The red line represents an approximately quadratic model across birds of an increasing fishiness. For clarity, organisms are not to scale. For a description of the taxa, see Material and Methods. For PC scores, see Table 1. Positions are indicated with asterisks for the unexpectedly closely grouping \*barn swallow (*Hirundo rustica*) and \*\*flying fish (*Exocoetidae* sp. indet.).

**Table 1:** Characteristics of the studied taxa, and their principal component (PC) scores for PC1 and PC2.

Taxon	Distribution	Morphology	PC1 (poisonous funginess)	PC2 (pizza toppingness)
<b>Aves</b>				
Penguin	Antarctic	Piscine	-13.42	-6.82
Duck	City ponds	Avian	3.26	2.38
Chicken	Farms	Avian	5.23	16.63
Robin	Forest	Avian	1.34	-3.02
House Sparrow	Everywhere	Avian	7.81	-0.56
Swallow	Predominantly sky	Avian	-0.39	-4.58
<b>Osteichthyes</b>				
Nemo fish	Great Barrier Reef	Piscine	5.09	-7.29
Flying fish	Ocean and air	Avian	4.23	-1.65
Anchovy	Pizzas	Piscine	2.48	23.69

### Discussion

We have come a far way from observational research in ornithology [19-22]. We are strong believers of research based on a well-supported rationale, good hypothesis formulation, and well-developed statistical analyses. In this paper, we have accounted for all three pillars of this belief. (1) The rationale is supported by an overwhelming number of studies across many fields calling for integrative work [23-32], which is exactly what we aimed to do. (2) Our hypothesis was based on data from 67 authors [6,7,33-35] (3) Our statistical approach is sound. In other words, there is no reason to assume that the work presented here may be inaccurate. We can demonstrate a clear relationship between the presumed lack of poisonous fungi and fishy-looking birds ( $p < 0.05$ ; Figure 1), which makes total sense, given the low ambient temperature across most of the distribution of Sphenisciformes.

On the other hand, there seems to be no such relationship for birdy-looking fish ( $p > 10$ ; Figure 1), such as the flying fishes (family *Exocoetidae*), which occur predominantly in tropical and subtropical waters, at latitudes where poisonous fungi are presumed to thrive—albeit in terrestrial habitats. The close grouping of flying fish and barn swallow (Figure 1) indicates that similarities in morphological and life-history traits may have erroneously been interpreted as homoplasies [18,36]. However, our more sophisticated statistical framework suggests that instead these traits may be synapomorphies that reflect an unexpectedly close evolutionary relationship, leaving *Exocoetidae* as a relictual avian lineage [37]. This calls for further taxonomic evaluation, but based on our preliminary findings, we tentatively propose that family *Exocoetidae* is moved to a basal position within superfamily *Sylvioidea* [38] *incertae sedis*, pending further evaluation.

As for predisposition towards inclusion as pizza topping, we found a strong taxonomic disparity, with certain bird and fish species of high PC2 score (Table 1). In fact, *G. gallus* even runs

towards the pizza (Figure 1), indicating an innate proclivity for toppingness. We acknowledge that the piscine sampling must be considered restricted compared to the avian, especially since the number of fish species [39] is triple that of bird species [12]. For example, there is recent evidence of the use of tuna (*Thunnus* spp.) flour in pizza base [40]. However, we have found no empirical evidence, published in either reputable or predatory journals, that the occurrence of tuna as topping would not just be cat food marketed as something more palatable.

With the advances of bird migration phenology due to climate change [41,42], we may also expect shifts in the distribution of poisonous mushrooms, even though phenological changes can be geographically asymmetric and responses in distribution changes vary between taxa [43,44]. To date, only one poisonous mushroom has been found in Antarctica. That is, like, literally one record: *Galerina antarctica* [45]. Fruiting bodies of these macro fungi (stems with caps), the “mushrooms”, are otherwise never reported in Antarctica [34]. The hyphae of this mushroom are living underground, but environmental conditions—temperature and moisture—are not allowing mushroom-formation. Who would have thought? Climate change may change these conditions to become favorable (or not, see [4]).

In addition, a climate-driven expansion of the ice-free area in Antarctica from less than 1% currently to potentially 25% by the end of the century has been projected [46]. In this scenario, where the polar ice caps melt, the resulting invasion of poisonous fungi to the Antarctic region may thus exert a strong selection pressure on penguins to evolve a less fishy morphology. This would result in a marked decrease in weirdness (*vide* Baldassarre [1]), although we want to point out that birds can be weird in more ways than one [47]—fungi, too, now that we think about it [48,49]. Given that flight ability in birds can be lost remarkably rapidly [50], we postulate that climate change scenarios may soon lead to the (re-)evolution of volant penguins, and by extension the plausible expansion of Sphenisciformes ranges to pizza topping habitats.

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#### Author contributions:

D.H. and M.S. provided equal intellectual input into conception, design, analyses, and writing. C.D. oversaw the research, but deceased prior to submission and thus could not confirm authorship.



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