# Quantitative assessment of creature birdularity with implications for planetary feature nomenclature

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**Abstract**

Birds and bird-like creatures have played an important role in human culture dating back to our early history. While many interpretations of the nature and overall birdness of such creatures are presented in myth and legend, recent events within the planetary science community have highlighted the need to better define for our modern day what exactly constitutes a "bird-like creature." In this work, we develop a model to quantify a creature's *total birdularity* and demonstrate how it may be used to understand the mytho-avian population. We also present a more simplified method of assessing a creature's bird-like qualities, through comparison to Molaro's Birdness Scale. After analyzing our results, we propose that any creature with a total birdularity of ≥0.5, or equivalent Molaro's Birdness ranking of ≥6, may be appropriately considered a "bird-like creature." We hope this work will pave the way for more clear communication within the scientific community, and for future work on the nature of birds and bird-like creatures.

## 1. Introduction

Birds and bird-like creatures have played an important role in our culture dating back to early human history, influencing our traditions and beliefs, agricultural practices, tool development, and even fashion. The definition of what constitutes a bird-like creature is ambiguous, as evidenced by the myriad ways in which myths and legends from around the world depict their appearance and behavior. While interpretation and understanding of the nature of such creatures has historically been left to anthropologists, historians, and philologists, their invocation as signifiers for natural landforms on planetary surfaces has prompted recent interest from the scientific community. With the continued exploration of worlds within and beyond our solar system, the need to better define these terms is becoming increasingly important.

In the past, the body governing planetary feature nomenclature (the International Astronomical Union) has imposed controversial definitions of specific terms on the scientific community, leading to consternation both within the field and society at large. Conversely, in recent actions, it is the lack of definition of the term "bird-like" that is a cause of confusion amongst scientist on the Origins Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) team, whose nomenclature theme for asteroid Bennu is "mythological birds and bird-like creatures." Defining the quality "bird-like" through rigorous scientific analysis is critical to facilitating clarity in communication and in the scientific literature. To this end, we present a model to quantify a creature's *birdularity* and demonstrate how it may be used to understand the mytho-avian population.

## 2. Model

Many mythological creatures such as harpies and rocs are clearly recognizable as bird-like, while other cases, such as Pegasus, are more controversial. Ultimately, the difficulty comes in determining how much birdness is required to constitute a bird-like creature, which first requires establishing a quantifiable measure of bird-like qualities. *Total birdularity* is defined as the amount of overall birdness a creature

*Figure 1. (left) Photograph of a Strawberry Finch, also known as the Red Munia or Red Avadavat, by Shantanu Kuveskar (CC BY 4.0), and (right) a Roc, a mythological bird originating from the Voyages of Sinbad the Sailor and other Arabian folklore [1].*

exhibits and how similar to a bird it is. This quantity is primarily controlled by a creature's physical appearance. Its behavior may contribute to lesser extent, largely in the context of how its physical attributes (e.g., wings) dictate the typical behavior (e.g., flying) of its species. Various methods have been used by individual researchers to quantify different aspects of birdness in the past, but n o consensus was reached on which measurement was most accurate. Here we will demonstrate that the total birdularity (B) of an object can be fully described by:

$$B = \frac{1}{3}(\kappa + \beta + \gamma) \quad (1)$$

where $\kappa$ is the *Birddage*, or ratio of bird to non-bird components of an object by volume, and $\beta$ is the *Birdature*, a factor describing how bird shaped an object is. The value of $\beta$ has a value between zero and one, where zero is not at all and one is perfectly bird shaped. The *BWF factor* ($\gamma$) describes how many of the three most common avian attributes (beak, wings, and feathers) the object possesses:

$$\gamma = \frac{1}{3}\sum_{i=1}^{3} \tau_i \quad (2)$$

where $\tau$ is the object's integer number of attribute types. Each attribute must be counted separately, as some objects may have wings but no feathers (e.g., a bat), feathers but no wings (e.g., Quetzalcoatl), and so on. The resemblance of similar body parts, such as a pointed beak-shaped nose but no actual beak, are inherently reflected in the object's birdature and therefore do not contribute to Eq. (2). Each of the birddage, birdature, and BWF factors has a unitless value from zero to one and are equally weighted. Thus, birdularity also has a unitless value from zero to one, where zero is not at all bird-like and one is a bird.

A principal component analysis suggests weightings of Birddage, Birdature, and BWF of 0.38:0.29:0.33, with this first principal component accounting for 67% of the variance. The effects of this alternate weighting are minor, swapping Hippogriff and Cockatrice, moving Gargoyle (non-avian) below Hieracosphinx, and swapping Airplane and Pegasus. These minor changes are probably not worth the increased complexity involved.

We considered egg-laying as an additional primary attribute of bird-like creatures; however, we were unable to verify the reproductive capabilities of some candidate bird-like creatures included in our analysis. Thus, we determined that its inclusion in the BWF (or BWFE, in that case) calculation would not be possible without weighting the individual attributes inconsistently between creatures with and without known reproductive capabilities. Future work will focus on developing refinements to the model in this area.

## 3. Method

To demonstrate how this model can be applied, we performed calculations assessing the birdularity of various real and mythological creatures. To perform our analysis, we used the open access tool Google Image Search, allowing us to observe the creatures' forms. For each creature, we assessed the range in visual representation by examining the images in the first approximately three rows of search results. We chose the image we felt was most representative in how its physical appearance was portrayed, and used it to calculate their birddage, birdature, and BWF values. The alphabetical list of creatures and their values are given in Table 1. Beyond three rows, more rare creatures could no longer be found, instead being

| Creature | Birddage | Birdature | BWF Factor | Birdularity |
|---|---|---|---|---|
| **Airplane** | 0.00 | 0.65 | 0.33 | 0.33 |
| **Angel** | 0.22 | 0.15 | 0.67 | 0.35 |
| **Archaeopteryx** | 0.50 | 0.95 | 0.67 | 0.71 |
| **Bat** | 0.00 | 0.90 | 0.33 | 0.41 |
| **Cockatrice** | 0.35 | 1.00 | 1.00 | 0.78 |
| **Dragon** | 0.00 | 0.40 | 0.33 | 0.24 |
| **Gargoyle *(non-avian form)*** | 0.00 | 0.85 | 0.33 | 0.39 |
| **Griffin** | 0.45 | 0.40 | 1.00 | 0.62 |
| **Harpy** | 0.75 | 0.85 | 0.67 | 0.76 |
| **Hieracosphinx** | 0.25 | 0.15 | 0.67 | 0.36 |
| **Hippogriff** | 0.65 | 0.65 | 1.00 | 0.77 |
| **Horse** | 0.00 | 0.00 | 0.00 | 0.00 |
| **Horus** | 0.07 | 0.05 | 0.67 | 0.26 |
| **Owlbear** | 0.30 | 0.20 | 1.00 | 0.50 |
| **Pegasus** | 0.15 | 0.15 | 0.67 | 0.32 |
| **Peryton** | 0.19 | 0.25 | 0.67 | 0.37 |
| **Platypus** | 0.10 | 0.05 | 0.33 | 0.16 |
| **Quetzalcoatl** | 0.10 | 0.35 | 0.33 | 0.26 |
| **Roc** | 1.00 | 1.00 | 1.00 | 1.00 |
| **Siren** | 0.75 | 0.85 | 0.67 | 0.76 |
| **Strawberry Finch** | 1.00 | 1.00 | 1.00 | 1.00 |
| **Tengu *(Japanese)*** | 0.33 | 0.15 | 1.00 | 0.49 |

*Table 1. Birdularity measurements for several creatures and objects in alphabetical order.*

replaced with images of nonsensical products, unrelated monsters, and drawings of anime characters from the website DeviantArt.com. These data were not used in the analysis. To help account for the inherent subjectivity of this process, calculations of birddage, birdature, and BWF were performed independently by multiple coauthors and averaged to determine the final values.

To validate our model, we performed the first calculation on an actual bird. We chose the Strawberry Finch (Fig. 1, left), as the authors felt this was a particularly beautiful bird. First, we found that the birddage of the Strawberry Finch is 1, since the entire volume of the bird is a bird. Its birdature is also 1, since by definition a bird is bird-shaped. Finally, we found that the Strawberry Finch has all three of a beak, wings, and feathers, giving a BWF value of 1. This brings its total birdularity to 1. Next, we performed the same analysis on a Roc (Fig. 1, right) which is a mythical bird, and find it also scores a 1 for all three factors. While Rocs are mythological in nature, this is consistent with the fact that they are still birds. In both cases, our results suggest that a bird is bird-like, which is consistent with previous works on birds [2].

An additional validation was also performed by comparing the birdularity of a chicken (which has B=1) to that of a rotisserie chicken. A rotisserie chicken has a birddage of 1, however its birdature and BWF are reduced to 0.85 and 0.33, respectively, due to the fact that it is missing a head, beak, and feathers. This lowers its total birdularity to 0.73, which thankfully is still fairly bird-like and thus likely suitable to consume. The birdature of chicken nuggets ($\beta=0$) is certain to lower their total birdularity, however a full calculation was not possible owing to the fact that we were unable to determine what volume of bird an individual nugget contained and therefore could not assess its birddage. The comparison between a chicken, rotisserie chicken, and chicken nuggets provides a prime illustration of how well the birdularity model scales, lending confidence to its use in other applications.

In contrast, we compared these calculations to two other animals which may be sometimes said to be bird-like. The bat is a winged mammal, and in spite of its lack of feathers its fairly bird-like appearance earn it a birdularity of 0.41. The duck-billed platypus, on the other hand, has a birdularity of only 0.16, and thus despite its name is decidedly not duck-like. Finally, as a control, we also compared these to a horse, which has never been considered bird-like and has a birdularity of 0. The range of values from 0 to 1 for birds, bats, platypuses, and horses demonstrates the realistic range of birdiness observed throughout the animal kingdom and the accuracy of the birdularity model.

## 3. Bird Composition

In this study, we assume that all birds are birds, regardless of composition. By this, we mean that the intended or perceived physical form of a bird of any given composition is sufficient to assess birdularity, even if the true physical form is not, in fact, a bird. This is particularly important when considering the birdularity of mythological creatures. For example, for the purpose of this calculation, we assume that a roc is a bird in spite of the fact that it does not have a true (animal) physical form because it is not real. The roc is only "real" in a sense that it exists in the form of words in a story or in a painting. In this sense, the story or painting may be considered the roc's composition. It only makes sense when evaluating a painting of a roc that we evaluate the object it depicts, rather than the painting itself. A painting would have a birddage of zero, but, *if real*, the object in the painting would have a birddage of 1. In this same way, we would evaluate a statue or a muppet (e.g., Sam Eagle) of a bird as if it were a real bird, because it is its likeness to a real creature that is relevant, not its actual physical composition. To do otherwise would mean that one could not use a photograph of a bird to calculate its birdularity, but instead must be in the physical presence of the bird itself. This is not only impractical and (in some cases) dangerous, but such a constraint is more appropriate in the context of a discussion of linguistic philosophy than a rigorous scientific study.

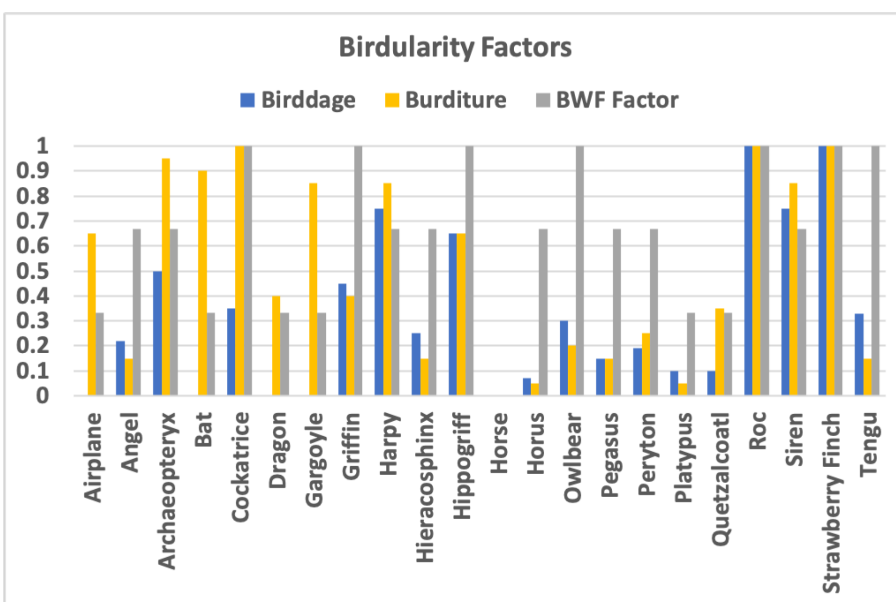


*Figure 2. Birddage, birdature, and BWF measurements for all creatures in alphabetical order.*

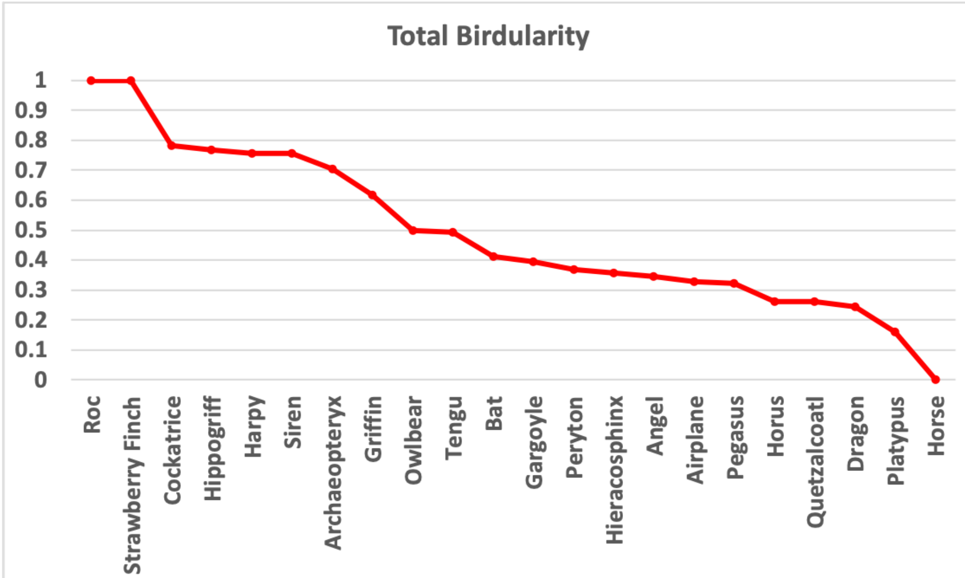


*Figure 3. Total birdularity for all creatures in descending order.*

**4. Results and Discussion**

The birddage, birdature, and BWF factors of analyzed creatures are shown in Figure 2 in alphabetical order. Their total birdularities are shown in descending value in Figure 3. Some of the results are unsurprising. For example, the harpy and siren both have the body of a bird and the head (and sometimes torso) of a woman. They are both undoubtedly bird-like, which is reflected in their high birdularity rating. The cockatrice also is high in birdularity, though examination of its individual factors shows that it actually has a significantly lower birddage value. This is due to the fact that much of its body is made up by volume of its snake component, however it does retain a very high birdature and therefore is still very bird-like in nature. Some creatures were more unexpected, for example the peryton and Pegasus are both characterized by having wings, and yet both have <0.5 birdularity.

Figure 4 shows that the birdularity has a roughly linear trend with each of the birddage, birdature, and BWF factors. The birdature as a function of birddage (Fig. 5, left) is also linear for most creatures, indicating that creatures that are more bird by volume tend to be more bird-shaped. In this case, the most notable outliers are those who have zero total birddage, as well as the cockatrice (for reasons discussed above) and the archaeopteryx (see below). The BWF as a function of birddage (Fig. 5, right) follows more of a power law trend, as the BWF increases in discrete increments. This causes the volume of bird a creature possesses to increase rapidly with BWF, suggesting that creatures with greater BWF factors will be more birdular overall. There was no trend between birdature and BWF.

Some creatures were difficult to assess due to their particular nature. The archaeopteryx is a dinosaur whose name means "old wing," and who is sometimes referred to as "the first bird." It was a transitional species between non-avian dinosaurs and modern birds, and therefore in some ways is inherently bird-like. Yet, they are distinct from modern birds in both chronology and cultural perception, and thus we assigned it a conservative birddage of 0.5 yielding a total birdularity of 0.7. Had we assigned it a birddage of 1, it would have been consistent with the linear trend in Figure 5 (left), but instead is an outlier similar to the cockatrice.

The gargoyle was also challenging to assess. On one hand, most people envision a gargoyle to have a demon or goblin-like form with large bat-like wings. This type of gargoyle has a birdularity of 0.39, similar to that a bat itself. However, while this form is predominant in popular culture and literature, real gargoyles do exist in a myriad of forms, including actual true bird forms with birdularities of nearly 1. In this sense, gargoyle is explicitly a composition and

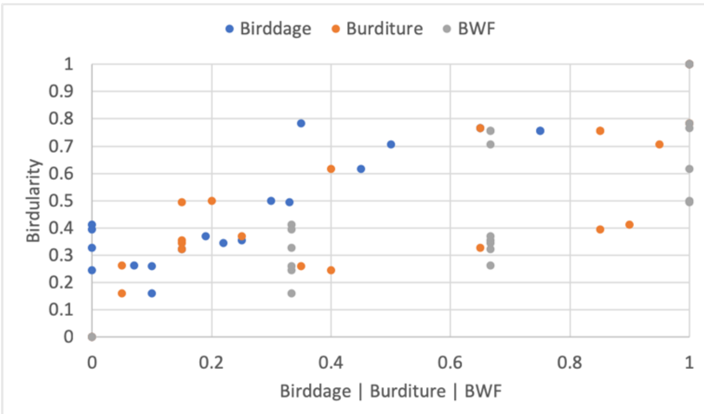


*Figure 4. Birdularity as a function of birddage, birdature, and BWF.*

therefore should not be considered as a type of creature at all. However, since the word gargoyle is commonly invoked both in describing both architechural features and as a type of mythological or magical creature, its case is somewhat ambiguous. As such, we can only conclude that invocation of a gargoyle as a bird-like creature is context-dependent, and, when relevant, the birdularity of a gargoyle given in Table 1 and Figures 2-5 may be considered a lower limit to account for its high variance in appearance.

One interesting outcome of these results is the concept that birdularity of a creature can be significantly enhanced by the addition of only a single avian body part. For example, adding wings to a horse to create Pegasus raises its birdularity significantly, but it has a lower birdularity than an angel because the body of a horse is larger and therefore the wings make up a smaller part of the total creature. However, the outcome of how bird-like a creature is varies strongly with which creature and which body part. For example, Horus (Fig. 6, left) is an Egyptian god primarily identified in modern culture as a god with the head of a falcon. In fact, many ancient Egyptian deities has the heads of birds (or other animals), and some even had full bird forms which themselves constituted individual deities separate from the original. However, in the capitavian (bird-headed) depiction of Horus, it is clear that the deity is a man with the head of a bird rather than a bird with the body of a man, a distinction which is reflected in his low birdularity. Yet, in a Twitter poll 86% of respondents (out of a total of 66) answered that Horus is more bird-like than an angel, even though an angel (Fig. 6, right) has a higher birdularity. Its higher birdularity is largely due to the fact that an angel's wings make up a larger part of its body than only the head. Angels are typically depicted with feathered wings, but they are clearly recognizable as human-like, and therefore most would agree they are not a bird-like creature. What makes Horus seem more bird-like than an angel, even though they are both humanoids, is unclear. To add further complexity, 44% of poll respondents (out of a total of 27) answered that Horus is more bird-like than a heirocasphinx, despite the fact that both creatures have the same avian attribute (the head), and 37% answered that the two were equally bird-like. Only 19% of respondents answered that the heirocasphinx was more bird-like than Horus, suggesting that many interpret the creature to be predominantly defined by its feline aspects.

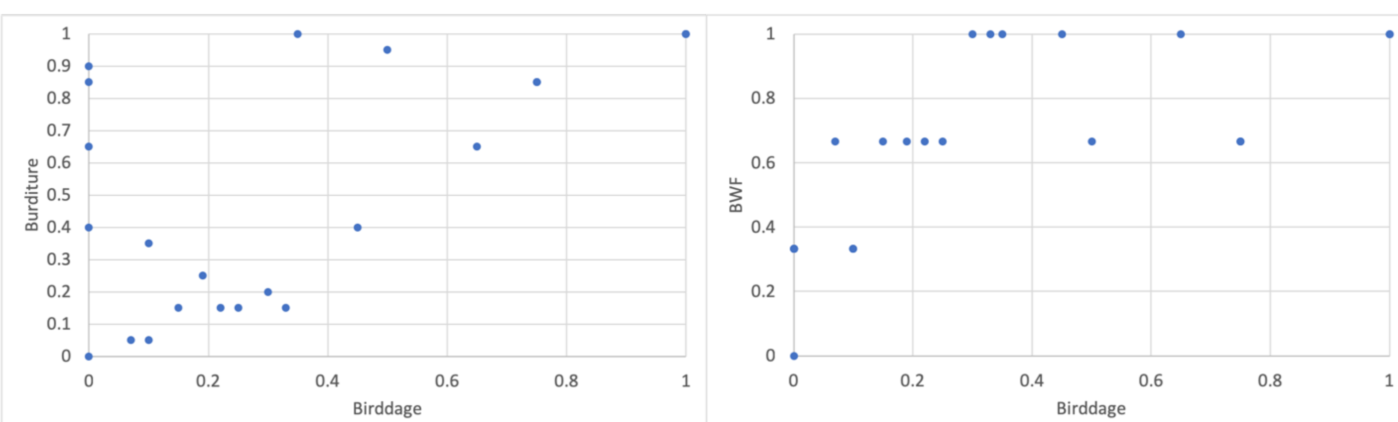


*Figure 5. Birddage as a function of (left) birdature and (right) BWF.*

*Figure 6. (left) Horus, an Egyptian god with the head of a falcon, and (right) an angel watching over two children.*

This leads us to the somewhat controversial question of Icarus and Daedelus, which have roughly the same birdularity as an angel (0.36). This is very high for a creature that, in fact, is actually just a human. The fact that their wings were manufactured rather than constituting a natural part of their body leads many to draw a distinction between *true* and *artificial* birddage and birdature, arguing the latter should not count towards total (*true)* birdularity. On the other hand, assessment of the birdularity of an airplane suggests non-living objects can be fairly bird-like in nature, leading then to the question of whether or not a machine may constitute a "creature." However, detailed discussion of artificial birdness and birdularity of machines is beyond the scope of the present work.

Perhaps the most surprising result is the low birdularity of dragons, which some had hypothesized would be moderately bird-like. In some ways they are similar to a cockatrice, however they have four legs instead of two, and the form of their bodies is more similar to a large dinosaurs or lizard (e.g., the Komodo dragon) than to a chicken. Even dragons from various Asian cultures, which tend to be leaner in shape and often lack legs, are more serpent than bird-like. This, combined with their zero birddage value, gives them an overall very low birdularity. In contrast, bats also have zero birddage and an equivalent BWF, but a much more bird-like shape and therefore higher birdularity.

## 5. Molaro's Birdness Scale

As demonstrated above, a full assessment of a creature's birdularity can provide valuable insight into their overall birdness, and in fact their very nature. Yet, it can be cumbersome to perform, which provides a challenge when one needs to know how bird-like something is while in the field, during a telecon, or in the middle of an urgent debate. A simpler way of estimating a creature's birdularity is needed in these cases, such that the assessment can be accomplished more rapidly and without debate amongst colleagues. For this purpose, we have created the *Molaro's Birdness Scale* (Table 2, Fig. 7). This scale does not measure total birdularity itself but aims instead to capture a representative set of creatures spanning a range of values. By comparing a given creature to those on the scale, it provides a more qualitative way of assessing their inherent birdness without the burden of a full calculation.

The scale begins with the Strawberry Finch, which has high inherent birdness due to the fact that it is a bird. At the lowest ranking is a horse, which is not bird-like in any sense. Two creatures, the angel and the heriocasphinx (Fig. 7), are listed under ranking 4 to highlight the variation in avian body-parts that contribute to the total population of creatures with bird-like qualities. Both creatures have the same birdularity value, but the angel provides a comparison to humanoid creatures with avian body parts, and the heirocasphinx to creatures with bird-like qualities or body parts but lacking specifically in wings.

| Molaro's Birdness Scale | |
|---|---|
| **Strawberry Finch** | 10 |
| **Cockatrice** | 9 |
| **Harpy** | 8 |
| **Griffin** | 7 |
| **Owlbear** | 6 |
| **Bat** | 5 |
| **Angel** | 4 |
| **Heirocasphinx** | 4 |
| **Pegasus** | 3 |
| **Dragon** | 2 |
| **Horse** | 1 |

*Table 2. Molaro's Birdness Scale ranking how bird-like creatures are, where 1 is not bird-like at all and 1 is a bird.*

## 6. Conclusions

The model of total birdularity presented here provides a quantative method for assessing a creature's overall inherent birdness and determining how bird-like it is. We have validated the accuracy of the model and demonstrated how it may be used to understand the nature of different creatures. We have also presented a simplified method for assessing a creature's birdness through comparison to Molaro's Birdness Scale. Once a creature's location on the Birdness Scale is ascertained, a rapid judgement of how bird-like it is may be made. This, of course, leads to the final question of how much birdness is required to be considered a "bird-like" creature. Given the outcome of our analysis above, we suggest that an object or creature must have a total birdularity of $\geq 0.5$ to constitute a "bird-like creature," as this demonstrates that it is more bird-like than it is non-bird-like. This equates to ranking on Molaro's Birdness Scale of $\geq 6$. When performing a full calculation, we recommend rounding the birdularity up to account for variance in the creatures' physical forms. For creatures with especially high variance, such as gargoyles, and whose birdularities represent a lower limit, a lower threshold ($B \geq 0.4$, Birdness ranking of $\geq 5$) may be more appropriate when determining their status as bird-like creatures. We encourage the community to take advantage of these measures when assessing the quality and/or appropriateness of individual planetary feature names, or in the context of planetary or astronomical nomenclature generally. While there is much to learn about the inherent birdness of creatures, this study provides a solid foundation upon which to build future work, or simply to build an argument.

*Figure 7. Reference images for the Molaro's Birdness Scale (Table 2).*