How many species are there on Earth and why worry about it?

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Although the question of how many species exist on earth has been considered "fundamental to biology" (Costello et al., 2013: 413); its answer remains elusive, as the total number of described species remains uncertain. Understanding the reasons behind this ambiguity is central to appreciating the challenges involved in discovering how many species inhabit Earth. A variety of methods, that give a range of estimations, have been proposed in an attempt to answer the question of how many species there are on Earth. These methods are discussed, albeit acknowledging their limitations and the assumptions that they rely on. Furthermore, the importance of ascertaining the number existent species on earth is the subject of much debate. While some scholars argue this concern it is a waste of resources, others espouse its salience to modern science. A discussion of both sides is presented; reaching a conclusion that weighs up the importance of worrying about how many species there are on Earth.

The number of described species on Earth is imprecise, estimates range from 1.2-1.8 million, (Mora et al., 2011; Hammond, 1992) whilst 1.3 million have been catalogued (Bisby et al., 2012). This uncertainty is largely attributed to the likelihood that many species have been described more than once using different names known as synonyms (Stork, 1997). For example the ladybird; *Adalia decempunctatahas* has over 40 different names (Stork, 1997). Synonymy is common; Gaston and Mound (1993) found that in insect groups synonymy ranged from 7-80%. Synonyms often occur when natural variation within species leads taxonomists to give different names to different variations of the same species (Stork, 1997). Additionally it is difficult for taxonomists to check if their discovery has been previously described, as it is impractical to compare their discovery with other specimens housed in museums or herbaria worldwide (Stork, 1997). Overall, synonyms effectively inflate the number of described species, and current estimates may need to be lowered to account for this.

It is also important to recognise that the term "species" is ambiguous, (Agapow et al., 2004) leading to further uncertainty regarding the total number of described species. Taxonomists disagree on what defines a species, resulting in a variety of species concepts

(Lindenmayer and Burgman, 2005). The biological species concept is commonly used, and focuses on reproductive isolation as the main determinant of a species, whilst some taxonomists use the phylogenetic species concept, which uses evolutionary lineages to differentiate species (Lindenmayer and Burgman, 2005). Overall there are around 26 species concepts in use by different taxonomists (Wilkins, 2006). This variety of concepts creates an issue for calculating how many species there are because what is counted as a species using one concept might not be counted using a different concept. For example, when using the biological species concept 40-42 species of bird of paradise were counted in Australia but when using the phylogenetic species concept approximately 90 species were proposed (Cracraft, 1992). Therefore the number of species that are already described may have been influenced by different species concepts. Furthermore, it will be difficult to reach a precise total figure for the number of species on Earth whilst species are classified differently by different taxonomists. Overall, it is clear that currently the total number of species on Earth is uncertain. However many taxonomists have attempted to estimate the total figure using a variety of different methods.

One area of methodology to estimate the total number of global species is extrapolation from known macroecological patterns (Mora et al., 2011). For example, Raven ((1985) cited in May, 1992) cited the pattern that tropical regions claim about twice as many species of birds, mammals and other well documented macro fauna than those found in temperate regions. Temperate regions are better documented in terms of species than tropical regions, with two thirds of all described species being temperate (Raven, 1985 cited in May, 1992). If the ratio of mammals and birds between tropical and temperate regions is true for all species then the total number of species can be extrapolated using figures from the better sampled temperate regions, amplifying the currently described 1.5-1.8 million species to a total of 3-5 million (Raven, 1985 cited in May, 1992). Indeed, this method is limited, as it assumes that latitudinal gradient applies to all taxa. However, organisms including penguins, aphids and bees show richness peaks at intermediate or high latitudes, disproving this assumption (Gaston and Blackburn, 2002).

An alternative method of estimating the number of species is extrapolation from a sample. Erwin (1982) used data from a sample of canopy beetles, collected from the tree *Leuhea seemannii*, to propose that globally there could be 30 million arthropod species, a figure much higher than other methods suggest. Using sample data Erwin argued that the tropical tree *Luehea seemannii* has 163 host specific beetles. Erwin then relied on two assumptions to propose around 600 arthropod species were specific to each tropical tree: that the beetles represented 40% of all total arthropod species; and that there were twice as many species in the canopy than on the forest floor. Using this formula, and the estimation of 50000 tropical tree species, Erwin suggested there could be as many as 30 million species of tropical arthropods. However Erwin's method is criticised; his concept of host specificity is too simple as not all insects are specific to just one plant species (Stork, 1988), whilst his assumption that beetles represent 40% of tropical canopy arthropods is contested by Stork (1988) who argues 20% is more appropriate.

Gaston, (1991) in contrast, emphasises the importance of considering the specialist knowledge of taxonomic experts when estimating the total number of species on Earth. Gaston compiled and analysed information and opinions from taxonomic experts, concluding that the total number of insect species is likely to be around 5 million, a figure that contests Erwin's (1982) larger estimation. However Bouchet (2006) argues that taxonomists are often making educated guesses of total species numbers and authors may copy each other's guesses in order to create what seems like a safe consensus on the total number of species. Additionally Erwin (1991) claims the database used by Gatson is anecdotal and non-scientific.

Another approach has been proposed recently by Joppa et al. (2011) who applied a model of taxonomic effort over time to estimate that 10-20% of flowering plants are left to be described. However the model could be flawed as species description is no longer solely based on taxonomists but is increasingly influenced by molecular methods (Mora et al. 2011). Also using data on past description, Costello et al. (2011) recently used a nonhomogeneous renewal process model to predict that 24–31% more marine species and 21–29% more terrestrial species are left to be discovered. They suggest that there are 1.8–2.0 million species on Earth, a significantly lower estimation than the others. Costello et al. (2011) recognise that this could be underestimation as the data used is biased toward well-known taxa in better studied areas.

In contrast, Mora et al. (2011) also recently published an estimation of total global species, reaching the highest estimation of 8.7 million, using a method that relies on the taxonomical hierarchy. Mora et al. describe how the higher taxonomic classification of species follows a 'consistent and predictable pattern from which the total number of species in a taxonomic group can be estimated' (p1). This pattern is validated within well-known taxa and is then used to extrapolate the number of species across all the kingdoms of life, reaching a total prediction of 8.7 million eukaryotic species. However this method again relies on an assumption; that the pattern for well-known diversity applies to the lesser studied groups.

This is a contested assumption as many argue that fungi, an understudied group, have much higher diversity than the 611000 fungi species that Mora et al. suggest (Blackwell, 2011).

Overall, there are a variety of methods that give a wide range of estimations for the total number of species on Earth. The disparity between the estimations suggests that we cannot be certain of total species numbers. Despite the limitations of estimation methods and the uncertainty involved in describing species, many argue that it is essential we endeavour to answer the question of how many species there are on Earth.

A powerful argument for finding how many species there are is that the number of species on Earth underpins the ecosystem services that humans depend on (May, 2011). May suggests that cataloguing all the species on Earth is fundamental for understanding the evolutionary and ecological processes that produce the biodiversity that supports humanity. Consequently, this knowledge will be increasingly important in understanding the threats facing humanity as species distributions change due to human activity. May also argues that further description of species could uncover their benefits for humanity. Additionally, discovering all the species on Earth plays a role in the well being of humanity, as it is important to satisfy the human desire to more fully understand our planet.

However, Erwin (1991) argues that determining the total number of species on Earth is like ‘reaching for the stars’ and that it is impossible for us to calculate the total number of species with the data we have. It is unlikely that we will discover all the species on Earth any time soon. Mora et al. (2011) estimate it could take 1200 years, 303,000 taxonomists and cost $364 billion. This tremendous time and economic effort can be considered too great for the gains of reaching a number. Furthermore, the rate of species description will eventually decline as it becomes harder or impossible to find the rarer inconspicuous species (Costello et al., 2011), suggesting that the effort required is even greater than Mora et al. proposed. Despite this, if there is international cooperation to share taxonomic knowledge, fill the missing gaps and increase the number of people that could identify new species, describing all the unknown species could be possible within the next century (Costello et al., 2011).

However, it is important not to forget that the total number of species on Earth includes prokaryotes, and the vast number of prokaryotes makes counting them an infinite task (Curtis et al., 2002). A litre of seawater is thought to hold around 20000 species of bacteria (Amaral-Zettler et al., 2010), whilst 30 grams of forest soil contains around 500,000 species (Dykhuizen, 1998). High speciation rates and low extinction rates allow new prokaryote species to form faster than species become extinct accounting for this high diversity (Dykhuizen, 1998). Therefore, it can be argued that, we should not waste time postulating about the number of species there are on Earth when it remains impossible to ever know the number of prokaryote species. However, we need to find some way of assessing general prokaryote diversity to ensure that this diversity does not become unstable due to human actions (Dykhuizen, 1998), and that the critical processes that prokaryotes provide, such as regulating the composition of the atmosphere, are maintained (Ward, 2002). Advances in molecular biology technology and models of estimation using this data could potentially give us a better idea of prokaryote diversity (Ward, 2002).

It can be argued that trying to calculate the total number of species is not important, but that our focus should be on conserving species and avoiding species loss. Erwin (1991) suggests that it does not really matter how many species there are, the issue is the rate at which we are losing species. The current extinction rate is thought to be 100-1000 times the background level (Pimm et al., 1995), a rate that is largely unprecedented, except for during periods of mass extinctions, and that is attributed mainly to the ‘size, growth and resource demands of the human population’ (Gaston, 2005:239). It is important to avoid extinctions to maintain biodiversity for ecosystem services. The focus of research and resources should therefore not be on determining the total number of species but instead should be on conserving species and mitigating extinctions.

However, Stork (1993) argues that without knowing how many species there are, we cannot know how many we are losing or the distribution of extinction patterns, and therefore we cannot understand how to slow the rate of extinction. Mora et al. (2011) argue the rate of extinction is an incentive to discover all the species as it is likely that currently many species will go extinct before they are described. Additionally, many political decisions and conservation programmes require the number of species to inform their choices and objectives. For example, the Ugandan government conducted a biological inventory of 15000sq km of forest in order to choose the best sites for the protection of biodiversity (Howard et al., 1997). Evidence suggests biodiversity inventories are worthwhile when choosing protected areas, as conservation objectives are substantially more likely to be achieved (Balmford and Gaston 1999).

However it can be costly to conduct research for conservation decisions; the Ugandan forest biological inventory cost around $1 million (Howard et al., 1997). Additionally, collecting data on new species takes time, and areas in need of immediate conservation programmes could be lost (Possingham et al., 2007). Furthermore, conservation methods can be successful even when the species present are unknown. For example, efforts to conserve biodiversity surrogates such as well-known taxa or land classes are assumed to effectively conserve the unknown biodiversity (Rodrigues and Brooks, 2007).

The total number of species on Earth is currently unknown and enigmatic. Different methods suggest a range of estimations for the total but these methods are limited, and rely on assumptions, so cannot be quoted as the true figure. It is unlikely that a precise figure for the total number of species will be reached. Time and resources may be wasted on this tedious task when the focus should be on conservation and mitigating species extinction. Despite this, it can be seen that estimations and knowledge of species numbers can facilitate conservation efforts, and help us understand the effects of our actions on the ecosystems that humans rely upon. Consequently, a balance must be sought that maximises the success of conservation. Efforts to calculate the species on Earth should be conducted as an important conservation tool but these efforts should not compromise the resources for conservation more than necessary. Further research is necessary to find where this balance lies. Additionally, accurate methods of estimating species numbers should be developed, as they will guide conservation practices without the resource cost of describing all the species on Earth. Ultimately finding a balance, to achieve the most successful tools for conservation, should remain paramount as we attempt to mitigate biodiversity loss.

References

Agapow, P.M., Bininda-Emonds, O.R.P., Crandall, K.A., Gittleman, J.L., Mace, G.M., Marshall, J.C., and Purvis, A. (2004) The Impact of Species Concept on Biodiversity Studies, *The Quarterly Review of Biology,* 79(2): 161-179.

Amaral-Zettler, L., Artigas, L.F., Baross, J., Bharathi, P.A., Boetius, A., Chandramohan, D., Herndl, G., Kogure, K., Neal, P., Pedrós-Alió, C., Ramette, A., Schouten, S., Stal, L., Thessen, A., Leeuw, J. and Sogin, M. (2010) Chapter 12: A Global Census of Marine Microbes, in McIntyre, A. (ed.) *Life in the World's Oceans: Diversity, Distribution, and Abundance*, Oxford: Wiley-Blackwell.

Balmford, A. and Gaston, K.J. (1999) Why biodiversity surveys are good value. *Nature,* 398: 204-205.

Bisby, F., Roskov, Y., Culham, A., Orrell, T., Nicolson, D., Paglinawan, L., Bailly, N., Kirk P., Bourgoin, T., Baillargeon, G., Hernandez, F., (eds.) (2012) Species 2000 & ITIS Catalogue of Life, Species 2000: Reading, UK. (Digital resource) Available at: www.catalogueoflife.org/col/. (Accessed 25/10/12).

Blackwell, M. (2011) The Fungi: 1, 2, 3 … 5.1 million species? *American Journal of Botany*, 98: 426–438.

Bouchet, P. (2006) The magnitude of marine biodiversity, in Duarte, C.M. (ed.) *The exploration of marine biodiversity—scientific and technological challenges*, Bilbao: Fundación BBVA, 31-62.

Costello, M.J., May, R. M., and Stork, N.E. (2013) Can We Name Earth's Species Before They Go Extinct?, *Science,* 339: 413- 416.

Costello, M.J., Wilson, S. and Houlding, B. (2011) Predicting Total Global Species Richness Using Rates of Species Description and Estimates of Taxonomic Effort, *Systematic Biology*, 61: 871-883.

Cracraft, J. (1992) The Species of The Birds-Of-Paradise (Paraisaeidae): Applying the Phylogenetic Species Concept to a Complex Pattern of Diversification, *Cladistics,* 8: 1–43.

Curtis, T.P., Sloan, W.T. and Scannell, J.W. (2002) Estimating Prokaryotic Diversity and Its Limits. *Proceedings of the National Academy of Sciences of the United States of America,* 99: 10494-10499.

Dykhuizen, D.E. (1998) Santa Rosalia revisited: Why are there so many species of bacteria? *Antonie Van Leeuwenhoek,* 73: 25-33.

Erwin, T.L. (1982) Tropical forests: Their richness in Coleoptera and other arthropod species, *The Coleopterists Bulletin,* 36: 74-5.

Erwin, T.L. (1991) How many species are there? Revisited. *Conservation Biology,* 5: 1-4.

Gaston, K.J. (1991) The Magnitude of Global Insect Species Richness, *Conservation Biology,* 5(3): 283-296.

Gaston, K.J. and Mound, L.A. (1993) Taxonomy, Hypothesis Testing and the Biodiversity Crisis, *Proceedings of the Royal Society B,* 251: 139-142.

Gaston, K.J. and Blackburn, T. (2000) *Pattern and process in macroecology*, Oxford: Blackwell Publishing.

Gaston, K.J. (2005) Biodiversity and extinction: species and people. *Progress in Physical Geography*, 29 (2): 239–247.

Hammond, P.M. (1992) Species inventory, in Groombridge, B. (ed.) *Global Biodiversity. Status of the Earth's living resources*, London: Chapman and Hall, 17–39.

Howard, P.C., Davenport, T. and Kigenyi, F. (1997) Planning conservation areas in Uganda's natural forests, *Oryx*, 31: 253–264.

Lindenmayer, D.and Burgman, M. (2005) What should be conserved? In: *Practical Conservation Biology.* Melbourne: Csiro publishing.

Joppa, L.N., Roberts, D.L. and Pimm, S.L (2011) How many species of flowering plants are there? *Proceedings of the Royal Society B,* 278: 554–559.

May, R.M. (2011) Why Worry about How Many Species and Their Loss? *PLoS Biology*, 9(8).

Mora, C., Tittensor, D.P., Adl, S., Simpson, A.G.B. and Worm, B. (2011) How Many Species Are There on Earth and in the Ocean? *PLoS Biology,* 9(8).

Pimm, S.L., Russell, G.J., Gittleman, J.L. and Brooks, T.M. (1995) The future of biodiversity, *Science,* 269(5222): 347-50.

Possingham, H.P., Grantham, H. and Rondinini, C. (2007) How can you conserve species that haven't been found? *Journal of Biogeography,* 34: 758–759.

Raven, P.H. (1985) Disappearing species: a global tragedy, *Futurist* 19: 8–14. Cited in: May, R.M. (1992) How many species inhabit the earth? *Scientific American,* 10: 18–24.

Rodrigues A.S.L. and Brooks T.M. (2007) Shortcuts for biodiversity conservation planning: the effectiveness of surrogates, *Annual Review of Ecology, Evolution, and Systematics,* 38: 713-737.

Stork, N.E. (1988) Insect diversity: facts, fiction and speculation, *Biological Journal of the Linnean Society,* 35: 321–337.

Stork, N.E. (1993) How many species are there? *Biodiversity and Conservation*, 2: 215-232.

Stork, N.E. (1997) Measuring Global Biodiversity and Its Decline, in Reaka-Kudla, M.L., Wilson, D.E. and Wilson, E.O. (eds.) *Biodiversity II: Understanding and Protecting Our Biological Resources*, Washington DC: Joseph Henry Press.

Ward, B.B. (2002) How Many Species of Prokaryotes are There? *Proceedings of the National Academy of Sciences of the United States of America*, 99(16): 10234-10236.

Wilkins, J. (2006) Species Concepts in Modern Literature, in Species, kinds, and evolution, *Reports of the National Centre for Science Education,* 26(4).