Marine iguanas are threatened with extinction - How can revealing a revised taxonomy help to focus conservation efforts of these endemic island reptiles?

TEACHER VERSION

A GCSE case study from Galapagos Conservation Trust

Marine iguanas clearly offer important insights into evolutionary processes, but environmental changes mean that their long-term survival could be in jeopardy. Genetic studies have shown us that marine iguana populations on different islands are distinct from one another and there is evidence that there are several subspecies. We also know that some of these populations are already extremely small and face significant threats from marine pollution and predation by introduced species. Loss of these distinct populations could damage the marine iguana's chances of survival in the long-term. The situation is of great concern because marine iguanas occur on the Galápagos archipelago and nowhere else on earth – they have never been successfully kept outside of the islands. It is therefore vital that we monitor and manage these populations, because if they disappear from Galapagos, they are lost forever.

-Dr Amy MacLeod

Keywords: biodiversity, classification, Carl Linnaeus, taxonomy, phylogenetic classification, variation, environmental, genotype, phenotype, diversity, population, speciation, species, sub-species

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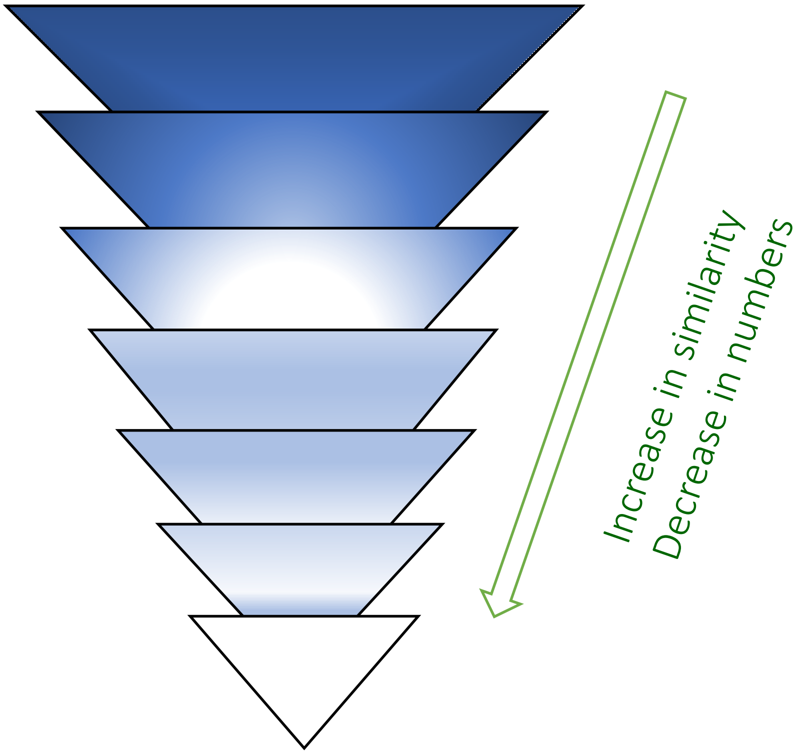
Back to basics: A revision of classification

Taxonomy is the science of classification, involving naming and categorising organisms into groups based on their similarities and differences. Carl Linnaeus first formulated the idea of the classification system, making it easier for scientists to study species, understand how they are related and to recognise biodiversity.

Question: There are seven recognised groups in the classification system. Can you remember them and their position in the hierarchy of classification? Write them next to or in the diagram below.



Kingdom, Phylum, Class, Order, Family, Genus, Species. For a handy way to remember this you can remember: King Phillip Came Over For Good Scotch!

Question: What is the name of the last group in the hierarchy of classification? Can you write a definition of the term used?

Species. A species is a group of living organisms with similar characteristics that can interbreed and exchange genetic information to produce fertile offspring.

The binomial naming system uses the genus and species to name each species. The Galapagos marine iguana belongs to the genus *Amblyrhynchus* and so is known as *Amblyrhynchus cristatus.* Using a universal name meant scientists throughout the world could recognise, name and classify species more easily.

What Darwin didn't see - How has classification changed since time of Darwin?

Before more recent biological developments, scientists would classify species according to physical similarities and differences between organisms. This kind of data is called 'morphological data.' Advances in genetics and analysis of DNA now enables us to arrange species into groups based on their evolutionary origins and relationships: a system known as phylogenetic classification. From this we can draw evolutionary trees, where evolutionary links between species can be identified. Each group is called a taxa. Science has evolved to allow us a deeper understanding of evolution through time. You will discover later the implications of this knowledge for the conservation and management of species.

Setting the scene with iguanas – A little history of the marine iguana and its ancestor

The ancestor of the marine iguana colonised the Galapagos Islands over 8 million years ago. These iguanas travelled across the Pacific on rafts of vegetation thrown out to sea by violent storms on the South American mainland, later arriving on the barren, rocky shores of Galapagos. Around 4.5 million years ago the population began to split and evolve into 2 separate lineages (or groups) – the Galapagos land iguanas and the Galapagos marine iguanas.

Land iguana of South American mainland and Marine Iguana

Highly specialised and adapted to the harsh environment, they are the world's only sea-going lizard, found nowhere else on Earth. They can be found in colonies along the rocky coastlines, feeding on marine algae growing on black volcanic rocks, and basking in the warmth of the equatorial sun. Larger adults can dive to depths of 25m to feed and can stay submerged for 10 minutes. Excess salt consumed in their diet is sneezed out of special glands in their heads.

Marine iguanas can grow up to 1.5 m in length and live between 5 and 12 years, possibly even longer!

©Vanessa Green *left and middle*
Jill Hacker *right*

Question: Look at the map of the Galapagos Islands below. Would you expect the marine iguanas to have colonised most islands in the archipelago? Justify your answer.

Google maps

Yes, marine iguanas have colonised islands throughout the archipelago. As they can negotiate the marine environment, it would not be difficult for them to make short journeys between one island and another. They could also drift on floating vegetation, using the currents and wind to help.

Question: The Galapagos marine iguana has long been considered a single species. Would you expect there to be subspecies of iguana within the archipelago? Give reasons for your answer.
N.B. You may want to use the glossary of terms for the definition of subspecies.

Yes, you would expect to see subspecies of iguana within the archipelago. Each of the islands is slightly different, and it is likely that populations on each island would adapt to be slightly different from each other. We can see this in body size, where some islands have much larger iguanas than others. This adaptation and the fact that the islands are quite separate from each other would lead the populations to become different to each other and eventually become subspecies and perhaps species.

Teacher note: You may want to watch this short video clip about evolution of the marine iguana and their colonisation of the Galapagos islands.

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The Galapagos marine iguana has long been considered a single species with several subspecies that live across the Galapagos Islands. The accuracy of the subspecies units is important because the species is threatened with extinction and listed on the International Union for Nature (IUCN) red-list. This means that important populations of the species should be identified and monitored, to effectively protect it from extinction. Since there is often not enough time or money to monitor all populations, the most important ones should be identified as a priority. This decision is usually based on the taxonomy. When the taxonomy is not accurate, we might focus our efforts on the wrong groups, leading to negative effects on the conservation of the species.

For over half a century, the taxonomy made by scientist Eibl-Eibesfeldt has been used. This taxonomy was made well before any genetic information on the species was available and is therefore based entirely on measurements taken from iguanas on the various islands. Like all scientific work, the taxonomy of the marine iguana should be reviewed when new evidence is available. From the 1990s onwards, genetic and morphological data from marine iguanas has been gathered and the results of this data sometimes disagreed with the previous taxonomy.

Introduction

Your task: To use recent morphological and genetic data to identify subspecies of the marine iguana on the Galapagos Islands and to compare your results with previous data for recommendation of a revised taxonomy.

Finding data: How can variations between island populations be shown? What morphological measurements could be taken to show variations between populations of iguanas. What measurements are comparable?

Activity: Look at these images and think about morphological measurements that could be taken to highlight differences between populations. Jot your ideas down below.

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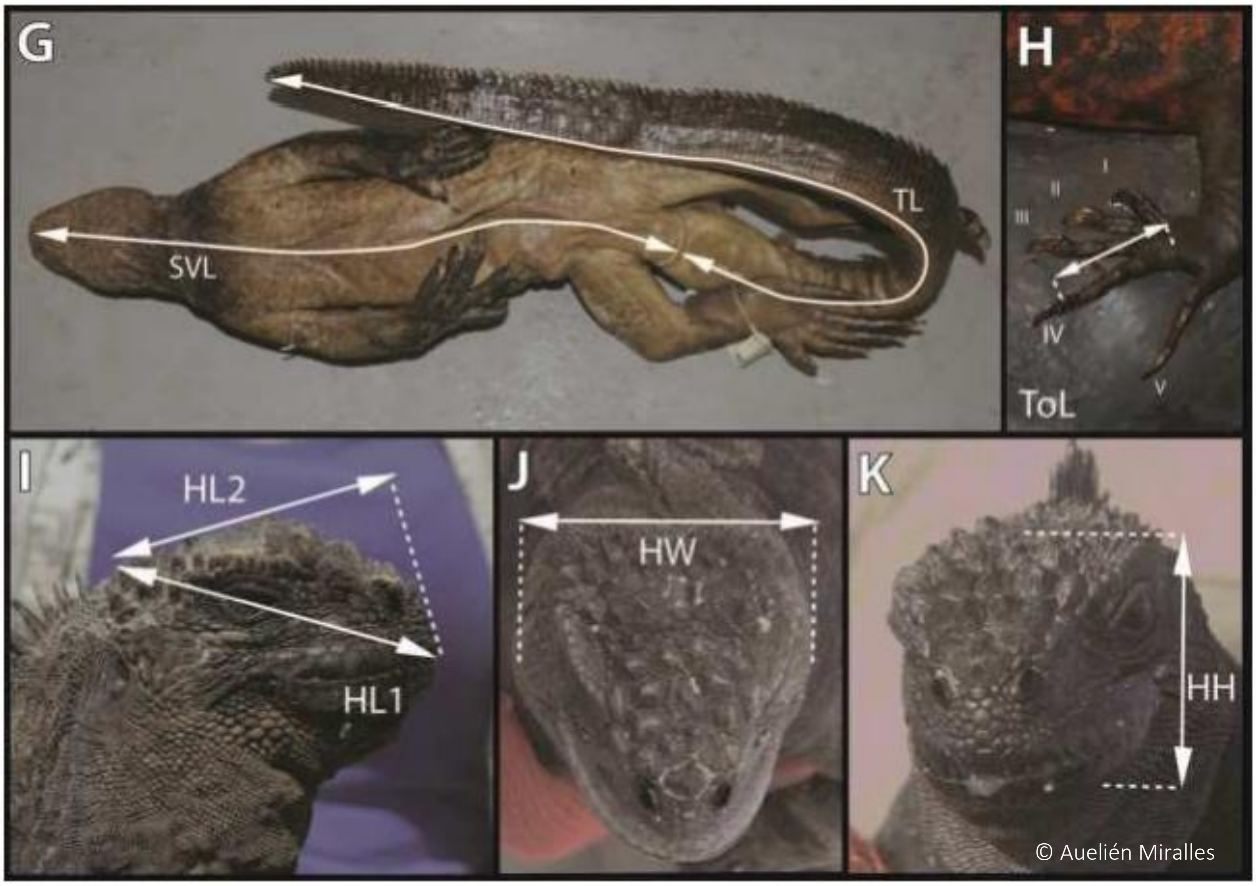
Now look at the images below. They show morphological measurements taken of iguana populations across the archipelago. How did your ideas compare?



SVL snout to vent length (the vent is the opening of the body where waste is expelled)
TL total length
ToL toe length
HL1/2 two ways to measure head length
HW head width
HH head height

Data section

Working with data activity: Using the excel worksheet provided, calculate the average for **each** morphological measurement for all iguanas sampled on **each** island.
Include data when the sex of the individual is marked as U – unidentified. It will mean that you have more data to work with.
Alternatively, if excel is not available, complete the partially filled table below, calculating the averages for the missing data. Use the raw data sheets to access numbers.

Marine iguana morphological data sorted by island location

Average measurements (in mm)							
Island	G - TL	G - SVL	H - ToL	I - HL1	I - HL2	J - HW	K - HH
Darwin							
Wolf							
Fernandina							
Isabela							
Santiago							
Rabida	292	211	39	40	36	34	30
Santa Cruz	432	318	51	53	48	51	42
Espanola	424	252	47	49	44	41	36
Genovesa	325	205	36	38	34	34	29
Marchena	389	278	43	45	41	41	37
Pinta	328	240	40	43	37	37	34
San Cristobal - Loberia	454	292	50	43	48	44	43
San Cristobal - Punta Pitt	483	280	50	-	49	41	41

Average measurements (in mm)							
Island	G - TL	G - SVL	H - ToL	I - HL1	I - HL2	J - HW	K - HH
Darwin	275	171	35	33	30	27	25
Wolf	309	192	37	36	32	31	27
Fernandina	421	287	48	50	47	44	40
Isabela	533	330	59	59	53	55	51
Santiago	299	194	39	39	34	34	30
Rabida	292	211	39	40	36	34	30
Santa Cruz	432	318	51	53	48	51	42
Espanola	424	252	47	49	44	41	36
Genovesa	325	205	36	38	34	34	29
Marchena	389	278	43	45	41	41	37
Pinta	328	240	40	43	37	37	34
San Cristobal - Loberia	454	292	50	43	48	44	43
San Cristobal - Punta Pitt	483	280	50	-	49	41	41

Data response activity: Look at a sample of the raw data below used to calculate averages. It shows the realities of carrying out scientific studies in the field, where obtaining data can sometimes pose difficulties.

Animal ID	Island	Sex	G - TL	G - SVL	H - ToL	I - HL1	I - HL2	J - HW	K - HH
CAS 11510	Fernandina	F	412	295	47.3	46.9	44	40	36.3
CAS 11513	Fernandina	F	425	280	46.3	50.9	43.6	43.5	41
CAS 11512	Fernandina	F	395	265	46.6	50.9	45	42.8	39.5
CAS 11514	Fernandina	F	390	273	45	47	43.9	40.6	34.5
CAS 11511	Fernandina	M	485	320	54.2	52	57.2	50.9	47.4
CAS 10287	Isabela	F	400	225	44	41	36.1	34.2	31.8
CAS 10289	Isabela	U	311	174	35.1	29.3	26.3	27.5	24
CAS 10286	Isabela	U	379	225	44.8	40.9	36.4	34.9	33.9
CAS 10288	Isabela	U	310	178	36.5	33.9	32.8	28	24.3
CAS 10284	Isabela	U	201	151					
CAS 10285	Isabela	U	330	160					
SFM 64179	Isabela	M	800	440					
CAS 11260	Isabela	M	497	350	59	55.1	51.6	50.8	44.8
CAS 11257	Isabela	M	835	425	69.5	70.8	64.5	61.5	62
CAS 11258	Isabela	M		390	65.2	68.8	60	67.7	57.1
CAS 11259	Isabela	M	619	410	67.3	74.9	65.1	73.1	66.4
CAS 11254	Isabela	M	609	428	72.8	69.8	74.9	71.9	65.7
CAS 11256	Isabela	M	843	450	72.5	73.4	61.8	70.1	69.1
CAS 11255	Isabela	M	585	365					
CAS 65996	Isabela	M	426	284	51.9	47	40.5	41.2	39.5
CAS 65998	Isabela	M	592	372	61.6	61	53.8	55.5	53.1
CAS 65997	Isabela	M	650	427	63.9	67.5	62.8	63	57.4
CAS 11253	Isabela	U	765	480	81.7	79.6	72	77.3	69.2
CAS 11314	Isabela	U	453	370	58.6	67.5	53.7	62.1	59.5
CAS 11311	Isabela	U	535	320					
CAS 11313	Isabela	U	524	310					
SFM 57448	Santiago	M	362	229	39	39	33.2	32.5	31.5
SFM 57447	Santiago	M	411	257	45.8	44.2	38.1	40.5	35.1
SFM 57449	Santiago	M	351	221	36.9	37.5	33.2	32.6	28.3
SFM 57446	Santiago	M	431	270	45	46.8	42.3	42.9	40.1
SFM 57450	Santiago	M	415	278	44.7	50.1	44.2	43.6	38.2
CAS 12168	Santiago	U	160	108					
CAS 12169	Santiago	U	167	120					
CAS 104665	Santiago	U	215	144	28.4	28.3	23.9	23.4	20.9
CAS 104667	Santiago	U	258	170	35.7	35.4	31.5	29.8	25.5
CAS 104666	Santiago	U	223	140	33.5	31	27.8	25.7	22.8
CAS 10616	Rabida	F	305	229	39.8	39.7	35.8	35.7	30
CAS 10615	Rabida	F	315	230	39	41.4	37	32.8	29.6
CAS 10614	Rabida	M	367	271	44.8	46.8	40.3	42	35.3
CAS 10613	Rabida	M	324	250	43.7	41.6	38.2	37	33.7
SFM 25492	Rabida	U	224	163	27.1	28.1	27.3	23.5	19.5
CAS 11021	Rabida	U	217	125					

Question: Suggest 3 elements of the data set that show the difficulties of sampling populations 'in the field.'

Small sample sizes on some islands, missing data in some sections, unable to sex iguanas, uneven data set size.

Estimating the age of marine iguanas is difficult. Generally, they are categorised as (sexually mature) males, (sexually mature) females and juveniles.

Images taken from the study are shown below.

Distinguishing juveniles from females is tricky, as the differences are not always obvious. Sometimes behavioural clues are used (e.g. females digging burrows) and body size. Generally, if they are big enough and don't look male, they are recorded as females.

Question: Why do you think it is important to be able to identify the sex of the animals?

Scientists may wish to directly compare body size of a certain group, such as adult males, across different islands. If they mistake females as males their body size records will not be accurate. They may also want to know whether there are enough male and females at a colony to see if populations are balanced or not.

Data analysis activity:

<u>Information about figure:</u> This figure shows results of **genetic data analysis.** Here researchers used a type of genetic data called "microsatellites" (sections of repeating DNA bases, e.g. ATATAT, that can be present or absent in individuals) to group individuals into natural populations. The figure is an outcome of that research, which shows individuals from one population in one colour. The program that makes these figures does not use information about the origin of the individuals and uses only microsatellite frequency data to group the animals into populations.

From this data scientists have identified 12 subspecies of marine iguana, meaning populations have become genetically diverse enough to be separately classified. The size of the boxes represents the number of samples in the dataset. *Because so few individuals from Roca Redonda were tested, the results were not conclusive and so these animals are grouped with those from the nearby island of Wolf.*

Using the genetic and morphological data **sorted by location** table, answer the following questions to help you understand how scientists use this information to revise a new taxonomy for the marine iguana.

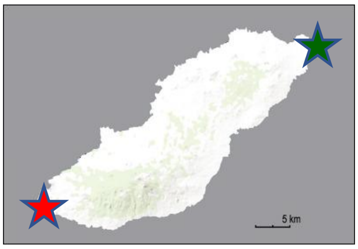
Question: Explain the relationship between morphological and genetic data for the islands Santiago and Rabida. What does the data show?

Both sets of data show that populations of iguanas on Santiago and Rabida are the same subspecies.

Question: a- Look at the <u>morphological data</u> for San Cristobal. Explain whether data shows that the populations are quite similar morphologically, using data to justify your answer.

Data shows that the populations are quite similar morphologically. For example, average snout length results are similar - 280 and 292, toe length the same and head length results 48/49.

b- Now look at the <u>genetic data</u> for the same populations. Do results agree with morphological data? Why might this happen? The map of the island may help you explain your theory.



Loberia population

Punta Pitt population

The genetic data doesn't agree with the morphological data. This can happen because environmental conditions for both populations are quite similar but the populations don't interbreed with each other and so they are genetically different, even though their physical adaptations are similar.

Question: Look at the map below and genetic data to describe the relationship between the position of islands which share a subspecies.

Islands that are close to one another are more likely to share a subspecies because the animals can easily move between the islands and interbreed with each other. Examples include: Floreana and Española, Isabela and Fernandina, Santa Cruz and Seymour Norte. (This mixing prevents speciation from happening.)

Question: Are there any surprising subspecies, given the location of the islands/populations?

San Cristobal island is an interesting case because here there are two subspecies on one single island. All other subspecies have their own island(s).

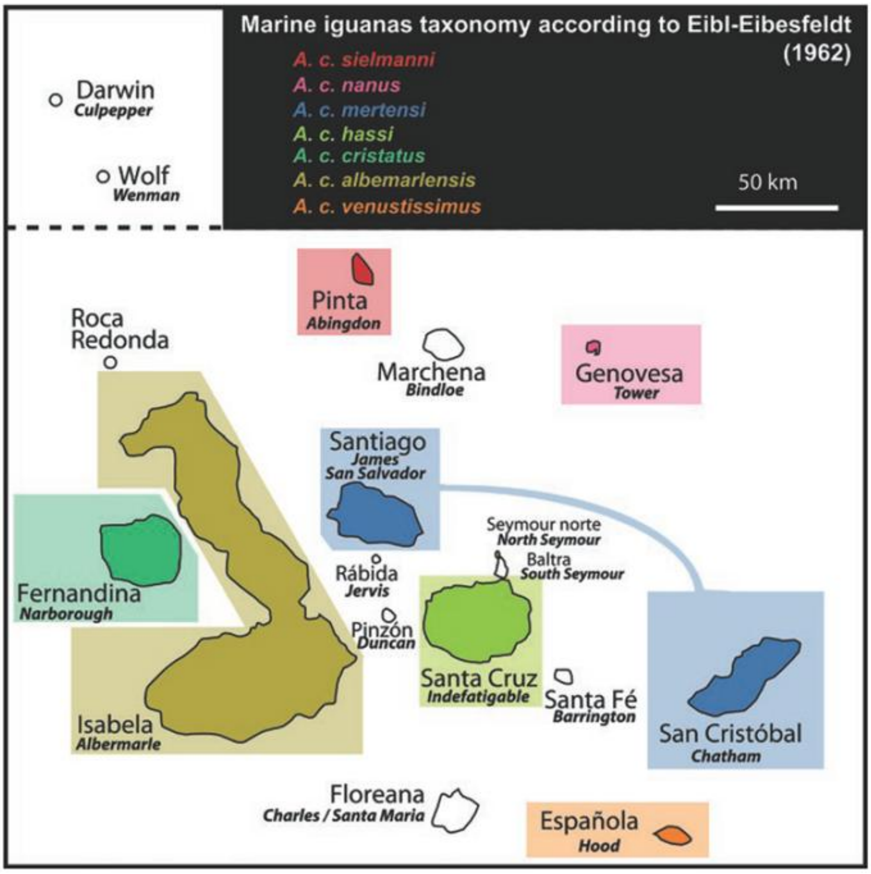
Final analysis and recommendations:

Using both the genetic data and your analysis of the morphological data, you now need to assess whether we should make changes to the old taxonomy made in 1962. This will help focus future conservation efforts and strategies.
Compare your ideas to this taxonomy by Eibl-Eibesfeldt shown below. For each subspecies, you must decide whether you advise:

a) keeping the subspecies
b) merging them with another subspecies ***or***
c) splitting the subspecies and naming a new one

For islands that previously had no subspecies, you must decide whether another existing subspecies occurs there or if a new subspecies should be recognised. When you decide on a new subspecies, you can name it and add it on to the species name: *Amblyrhynchus cristatus* (new name here)

One example has been part completed for you.



Island	Old subspecies	New subspecies (if different)	Comment on reasons
Darwin	No previous	*A.c culpepperanni*	No genetic data, but morphological data shows sufficient difference for a subspecies.
Wolf		A new subspecies should be recognised or merged with Darwin until more data is available	
Fernandina		Merged with the subspecies on Isabela	
Isabela		Merged with the subspecies on Fernandina	
Santiago		Merged with species on Rabida and Pinzon	
Rabida		Merged with species on Santiago and Pinzon (not previously identified)	
Pinzon		Merged with species on Santiago and Rabida (not previously identified)	
Santa Cruz		Keep the previous subspecies	
Pinta		Keep the previous subspecies	
Marchena		A new subspecies should be recognised (not previously identified)	
Genovesa		Keep the previous subspecies	
Floreana		Merged with species on Española (not previously identified)	
Española		Merged with species on Floreana (not previously identified)	
Santa Fe		A new subspecies should be recognised (not previously identified)	
San Cristobal		Split subspecies and name the new one	

Question: Finally, scientists usually finish studies by noting which data are still missing. If you wanted to improve this study, what data might you want to collect?

Collect more morphological data from islands where little or none is currently available.

Glossary

Biodiversity: Made from the words 'bio' meaning biology and diversity, it refers to the large number of species of organisms, and in the variation of individual characteristics within a single species.

Classification: In biological terms, is the act or process of arranging animals and plants in taxonomic groups according to similarities.

Colonisation: A biological term for the spread of plants and animals into new areas. Colonisers are species that begin living in habitats that they were not previously found in.

Genetic data: Genetic data is information which comes from analysing the DNA of living organisms. There are many different ways to look at DNA, and each is appropriate for answering some questions but not others.

Genetic divergence: Is when a species separates genetically into two or more descendent species.

Genotype: Is the genetic heritable identity of an organism. It can also refer to a particular gene or set of genes an organism has.

Haplotype: A haplotype is a group of genes inherited together from a single parent.

Environment: Is the surroundings or conditions that a living thing inhabits, including the air, water and land on which they live.

Morphological: The form and structure of organisms.

Morphological data: This is data which is collected by closely examining the structures on living things, and could include measurements like head width or length, and counts like the number of scales around an eye. Before genetic data were available, all studies which tried to categorise living things into taxonomic groups used morphological data.

Natural selection: Originally proposed by Charles Darwin, it describes the process by which organisms best adapted to their environment tend to survive and transmit their heritable traits to succeeding generations.

Phenotype: An organisms' actual physical characteristics such as eye and hair colour, but also health, general disposition and behaviour. Most phenotypes are influenced by both genotype and environment.

Polymorphism: The presence of genetic variation within a population.

Taxonomy: Is the branch of science which involves describing species, subspecies and other taxonomic groups. Taxonomists often use both genetic and morphological data as evidence for these groups, and they publish descriptions of new species which others use in order to recognise that species.

Trait: In science - a genetically determined characteristic or condition.

Speciation: Is the formation of a new and distinctive species that occurs when a group becomes isolated from others within the population and is unable to share genetic information. Isolating barriers may be geographical, ecological or reproductive ones.

Species: A group of living organisms with similar characteristics that can interbreed and exchange genetic information to produce fertile offspring. This definition cannot always be used (e.g. in a situation where the interbreeding cannot be tested) and so other definitions are often used.

Subspecies: A taxonomic group below the level of a species, and it is used for groups that are obviously distinct but not different enough to be considered full species. These groups may be on their way to becoming full species in the future.

Variation: The differences in the characteristics of individuals within a population. Differences may be due to genetics, environment or a combination of both.

Acknowledgements:

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Reference/data material:

Miralles, A., Macleod, A., Rodríguez, A., Ibáñez, A., Jiménez-Uzcategui, G., Quezada, G., Vences, M. & S.Steinfartz (2017): Shedding light on the Imps of Darkness: an integrative taxonomic revision of the Galápagos marine iguanas (genus *Amblyrhynchus).* – Zoological Journal of the Linnean Society, XX: 1-33.