

# Who played a key role during the development of our modern-day taxonomy and how does the World Register of Marine Species contribute to this?

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**Abstract:** Our Western taxonomy officially began with Linnaeus. Nevertheless, equally important discoveries and research has been done long before the Linnaean system was introduced. Aristotle and Linnaeus are two of the most well-known names in history when discussing taxonomy and without them the classification system we use today might have never existed at all. Their interest, research and knowledge in nature was influenced by their upbringing and played a major factor in the running of their lives.

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## Introduction

The definition of taxonomy according to the Convention on Biological Diversity “Taxonomy is the science of naming, describing and classifying organisms and includes all plants, animals and microorganisms of the world” (2019). Aristotle and Linnaeus are two of the most well-known names in history when discussing taxonomy and without them the classification system we use today might have never existed at all. Their interest, research and knowledge in nature was influenced by their upbringing and played a major factor in the running of their lives.

Aristotle (384 BC-322 BC) was a Greek philosopher. He was born in Stagira, a small town in Macedonia, Northern Greece (Voultsiadou, Gerovasileiou, Vandepitte, Ganas, & Arvanitidis, 2017). At the age of seventeen, he went to Athens, and studied in Plato’s Academy for 20 years. Which is where he developed his passion to study nature. After the death of his tutor Plato in 347 BC, he went to Asia Minor and Lesbos Island, where he began to investigate living things and became the first scientist (Lennox, 2017). In 342 BC Aristotle returned to Macedonia to become tutor of Alexander, later known as Alexander the Great (Voultsiadou et al., 2017). In 335 BC he returned to Athens. Together with his friend Theophrastus (whom he met on Lesbos), they established their own school the ‘Lyceum’ (Lennox, 2017). After retiring, Aristotle returned to his mother’s birthplace Chalkis on the Island of Euboea, where he died in 323 BC. It was during his stay in Kalloni Bay on Lesbos Island that most of his marine research was done. Though it is believed that Aristotle continued his research until the end of his teachings at the Lyceum in Athens (Voultsiadou et al., 2017). His zoological studies provided a proper method for biological investigation. It was the first comprehensive studies of animals recorded at the time. It took until the 16th century before anything of a similar scope was done (Lennox, 2017).

Carolus Linnaeus (or Carl Linnaeus) was a Swedish naturalist and explorer. He was born on May 23rd 1707 and died January 10th 1778. He is considered the founding father of the taxonomy and was the first in history to create a uniform system for classifying and naming organisms. With his publication of *Systema Naturae*, he has laid the fundamental groundwork for his career and future taxonomy. He also created “binomial nomenclature”, which is a two-part naming method for species consisting of the Genus and species names.

He first went to Lund University in 1727 where he began his studies in medicine. He transferred to Uppsala University in 1728. Between 1730 and 1732 he taught botany in the garden of Uppsala University, which is how he was able to finance part of his bachelor. In 1732 Linnaeus was sent to Lapland on a research expedition by his university. Later that same year he went to Falun to visit his friend and fellow student Claes Sohlberg, this is where he met the governor. Linnaeus travelled again to Falun in the summer of 1734, his trip was by the governor, who he met during his last visit. Back then, Medical students in Sweden had to go abroad for their medical degrees. Linnaeus became engaged to Sara Elisabeth Moraea in spring 1735, her father Johan Moraeus worked as a physician in Falun. Shortly after his engagement, he began his trip with Sohlberg to finish his medical degree abroad. Together they travelled to Harderwijk in the Netherlands, here he finished his examinations and submitted his dissertation within two weeks, and received his medical degree. After receiving his medical degree, Linnaeus and Sohlberg travelled to Leiden. Where His manuscript *Systema Naturae* was published in 1735 with financial support from Jan Frederik Gronovius and Isaac Lawson (Müller-Wille, 2019). The publication of his *Systema Naturae* 10<sup>th</sup> edition (1758), introduced a hierarchical classification system (Ereshefsky, 1994), which consist out of the two kingdoms plants and animals for living things. Though he added a third kingdom for non-living things called minerals (Manktelow, 2010; Ruggiero et al., 2015). Each kingdom is further divided into Classes, Orders, Genera and species (Ereshefsky, 1994; Ruggiero et al., 2015). Linnaeus classification system is still used today, though additional ranks such as Phylum, Family and Variety were added (Müller-Wille, 2019).

In 1735 Boerhaave who is an acquaintance, introduced Linnaeus to George Clifford, who offered Linnaeus a position as curator of his botanical garden. While working for Clifford, Linnaeus had the opportunity to expand his *fundamenta Botanica*, which he published in separate publications: *Bibliotheca Botanica* (1736); *Critica Botanica* (1737); and *Classes Plantarum* (1738). Other publications of Linnaeus during his work for Clifford are *Hortus Cliffortianus* (1737), is a catalogue containing all species in Clifford's collection and *Genera Plantarum* (1737) (Müller-Wille, 2019).

In 1738 Linnaeus returned to Sweden, and moved to Stockholm to start a medical practice. In 1739 he married Sara Elisabeth. He practiced medicine until 1740, when a position at Uppsala University became available and he returned to studying botany. Linnaeus used his international contacts to create a network of correspondents and sent students on expeditions around the globe that provided him with seeds and specimens from all over the world. Linnaeus introduced the binomial nomenclature as part of a project for his students in which they had to identify the plants consumed by cattle. Binomial names served as labels by which species could be universally addressed. The binomial nomenclature first appeared in a publication by Linnaeus of *Species Plantarum* (1753). After his dead in 1778, Linnaeus's son Carl had been given custody of his collections. Unfortunately Carl died a few years later, and Sara Elisabeth sold the collections to Sir James Edward Smith (Müller-Wille, 2019), who is the founder of the Linnaean Society of London in 1788. Smith named the society after Carl Linnaeus, whose collections he bought. Linnaeus collections on botany and zoology have been in ownership of the Linnaean Society since 1829 (The Linnean Society of London, 2019).

Access to scientific information and papers was very limited before the interconnected network was created (Wolniewicz, 2012). However, today we have access to any scientific information, which is provided by multiple search engines, databases and websites. One of those databases is the World Register of Marine Species (WoRMS). WoRMS is part of the global species database and has been online since 2007 (Vandepitte et al., 2018). It is a freely and easy to access global database containing information on marine species (Vandepitte et al., 2015). The European Register of Marine Species (ERMS) was founded in 1998 (MarBEF Data System, 2019) and became available through Aphia in 2004 (Vandepitte et al., 2015). ERMS is a taxonomic list of species that occur in the European marine environment (MarBEF Data System, 2019). ERMS later developed into WoRMS. At the moment WoRMS gets their funding primarily from the LifeWatch project and is carried out by Flanders Marine

Institute (VLIZ; World Register of Marine Species, 2019d). Keeping the WoRMS database online and available to users is one of the main priorities (Vandepitte et al., 2018).

Originally developed at VLIZ, Aphia manages the Taxonomic Information System for the Belgian Continental Shelf (Vandepitte et al., 2015). Aphia is a taxonomic register and integrates information from several global species databases (GSD), regional species databases (RSD) and thematic species databases (TSD) (figure 1). Aphia can also harvest information from several other species registers such as AlgaeBase and FishBase (which are maintained externally by others) (World Register of Marine Species, 2019d). The AlgaeBase database contains information on terrestrial, marine and freshwater algae. Marine algae, in particular seaweeds contain the most complete data at present (Guiry & Guiry, 2019). FishBase is a global database containing information on fish species. The initial goal was to provide key information for 200 commercial species, now the goal is to provide key information on all known fish species. At present, FishBase contains more than 33,000 fish species (FishBase, no date). Within Aphia resides an online editing platform, which became available in 2006, that underpins the WoRMS database and other global, regional or thematic databases. Giving easy access and management of the database, therefore speeding up the process for editors to add new information or to change existing information (Vandepitte et al., 2015).

### Problem description

Databases like WoRMS are a very dynamic system. Due to rapid changes in the field of taxonomy, it is necessary to keep updating these databases. External registers like AlgaeBase and FishBase have not yet been completely synchronized into WoRMS by VLIZ. New entries have been added, and existing data might have changed, which is why new entries need to be added and a quality control of existing data is necessary. However, the WoRMS database will probably never be a 100% complete.

In his legacy Aristotle left us with information on traits (biological, distributional and ecological) of marine organisms. However a detailed analyses of fish traits has been given by Ganiyas et al. (2017), an analysis of all marine animals described by Aristotle has yet to be done (Voultsiadou et al., 2017). This research will be focusing on people who played a key role during the development of our modern-day taxonomy.

### Aim of research

This research will give an overview of people who had influence on the creation of our modern-day taxonomy. It will also show how WoRMS contributes to an easy and freely to access database for users, taxonomic experts and research.

### Research question

Main question:

Who were the major contributors to our modern-day taxonomy and how does the world register of marine species contribute to taxonomy?

- What contributions have been made to our modern-day taxonomic classification system?
  - What influence did Aristoteles have on our modern-day taxonomic classification?
  - How did Aristotle contribute to the World Register of Marine Species?
  - How many species did Aristoteles describe and specifically how many are marine species?
  - Which marine species did Aristotle describe and what traits of these species can be found today?
    - What role does this literature research have in the broader context of the project?
  - What influence did Linnaeus have on our modern-day taxonomic classification?

- How did Linnaeus contribute to the World Register of Marine Species?
  - How many species did Linnaeus describe and specifically how many are marine species?
  - How many species described by Linnaeus can be found in WoRMS?
- How does the World Register of Marine Species contribute to taxonomy?
- What influence does the World Register of Marine Species have on taxonomy?
  - How far is VLIZ/the scientific community in completing the world Register of Marine Species?

## Hypothesis

It is expected that my work will help to get closer to completing WoRMS and that not only VLIZ, but scientific institutes worldwide will play an important part in this. Though it will probably never be a 100% complete. Aristotle and Linnaeus are expected to be the main contributors, although more people probably had influence on the shaping of modern-day taxonomy.

## Material & methods

### *Taxonomy literary research*

Aristotle and Linnaeus are two of the most well-known names in history when discussing taxonomy and without them the classification system we use today might have never existed at all. It is crucial to know that names published before 1753 or 1758 are called pre-Linnaean, and are therefore not considered as valid names (Manktelow, 2010; Ruggiero et al., 2015). This is why the history of taxonomy will be explained in three broad groups: pre-Linnaean, Linnaean era, and post-Linnaean. Which together give an apprehensive overview on the development of taxonomy throughout history. Though the theory and discoveries of van Leeuwenhoek, Lamarck, Darwin & Wallace did not directly change taxonomy, their newfound knowledge did influence other people who later on made changes to taxonomy. Therefore they will be briefly mentioned in this report. Because of an ongoing debate about adding viruses to the classification scheme, this will also be briefly discussed.

### *Updating WoRMS*

The Aphia register will be used to harvest information from AlgaeBase and FishBase, which are externally maintained by others. Within Aphia resides an online editing platform that underpins the WoRMS database (Vandepitte et al., 2015). The AlgaeBase harvester will extract information from AlgaeBase and the FishBase harvester will extract information from FishBase, after which they both synchronise with available data in Aphia. Now a 'harvesting period' can be selected, and will show you all the available entries and modified entries during that period. The 'cached list' will show entries that need manual editing. After selecting a specific 'harvesting period' a quality control of existing taxonomic information and synchronizing data can be done in Aphia.

### *World Register of Marine Species*

The WoRMS database provided information on number of taxonomic editors, taxa information and species described by Linnaeus.

### *Aristotle species traits*

Information on traits that can be found today of marine species described by Aristotle will be arranged in a spreadsheet to give a clear overview. This data will be used in an ongoing research on Aristotle to compare traits he described with traits that can be found today. Using Marine Species Traits Wiki (2020) a spread sheet was created containing the Biological, Distributional, Ecological and Important to Society descriptors. Appendix V Contains species traits from *Palinurus elephas* and *Mytilus galloprovincialis*. Vocabulary descriptions can be found on the Marine Species Traits Wiki webpage. Since the site is still under development, definitions are not yet fixed. A "species list" (table 2) is

included in the data file, containing species described by Aristotle. The species in the “species list” and the individual tabs are colour coded, making it easier to recognize which species have been done and how much information they contain. The legend can be found with the “species list”. Hence, there are many descriptors, each species has its own tab in the data file. The data file contains a template with a complete table, which can be copied and pasted when a new species is added. After researching a few species, it was necessary to make some adjustments. To make the data sheet more complete, the descriptors spawning, incubation period, gestation period, egg loss, hatching, live-bearing individuals, mating, moulting, moult cycle, moulting size, moulting frequency, distribution, growth in captivity, growth in natural environment, feeding, preyed upon by, preys on, activity, native range, range expansion, toxic/poisonous, human use, threats, and ecosystem services have been added. See appendix IV for definitions. If possible, the life stage could be included per descriptor, stating “larva”, “juvenile”, “adult” or “all life stages”. Though if the descriptor “life stage” did not apply to the other descriptors, the box was coloured grey. When a descriptor does not apply to a specific species it was noted “not applicable”.

For the purpose of this study, *Marine invertebrate diversity in Aristotle’s zoology* (Voultsiadou & Vafidis, 2007), *Bivalve mollusc exploitation in Mediterranean coastal communities: an historical approach* (Voultsiadou, Koutsoubas, & Achparaki, 2010), and *Aristotle as an ichthyologist: exploring Aegean fish diversity 2,400 years ago* (Ganias, Mezarli & Voultsiadou, 2017) were studied, giving knowledge on taxa described by Aristotle. The different lists of species described by Aristotle that are provided by the above mentioned papers, were then compared to see if anything stands out.

#### *Traits literature research*

The following steps were taken when searching for information on species: (1) All species on the “species list” with exception of fish species have been searched on the BIOTIC database (Biological Traits Information Catalogue, 2020), and are already in the data file. (2) With exception of a few species, most of them can all be found in the SeaLifeBase database (SeaLifeBase, 2019), though they do not necessarily contain much or useful information. (3) the WRiMS database (World Register of Introduced Marine Species, 2020 b) and Invasive Species Compendium (Invasive Species Compendium, 2020) were searched for information on species that have been introduced by human activities outside of their native range, though it excludes species that expanded their native range naturally (World Register of Introduced Marine Species, 2020 a). (4) The Species plus database (Species plus, 2020) was searched and contains information on all species that are listed in the Appendices of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) and CMS (Convention on the Conservation of Migratory Species of Wild Animals). (5) The International Union for Conservation of Nature’s Red List of Threatened Species (The IUCN Red List of Threatened Species, 2020b) provides information on population size, habitat and ecology, use and/or trade, threats, and conservation actions (The IUCN Red List of Threatened Species, 2020a). (6) MarLIN (The Marine Life Information Network, 2020b) provides information on resources that support marine management, conservation, and education of the British Isles and North East Atlantic (The Marine Life Information Network, 2020a). (7) The OSPAR commission provides a list of threatened and/or declining species & habitats (OSPAR commission, 2020), which gives an overview of species that are protected under the OSPAR convention. (8) Searching for a species name at the website of the European Environment Agency could provide with information on the habitat directive. (9) Search the WoRMS database to check if there are any subspecies listed. (10) At last Google and Google Scholar were used to find sites and papers containing useful information about the species or species descriptors searched.

## Results

Firstly, an overview of the taxonomic history will be described. Below the history of taxonomy will be explained in three broad groups: pre-Linnaean, Linnaean era, and post-Linnaean. Which together give an apprehensive overview on the development of taxonomy throughout history. Secondly the WoRMS contribution to taxonomy will be discussed. Specifically focusing on how WoRMS (can) contribute to problems in taxonomy. Thirdly, how far is WoRMS from completion? Finally, which species traits have been described by Aristotle and what information is available on those today?

### History of taxonomy

Crucial to our modern day taxonomy is that “Today, every plant or animal name published before 1753 or 1758, respectively, is called pre-Linnaean and is thus not valid. Also early names published by Linnaeus himself are pre-Linnaean” (Manktelow, 2010), also mentioned in a paper by Ruggiero et al. (2015). Therefore this statement claims that taxonomy officially started with Linnaeus. Nevertheless, equally important discoveries and research has been done long before the Linnaean system was introduced. Table 1 gives an overview of the changes since the introduction of the Linnaean system.

**Table 1.** Major changes to the Linnaean system over the last 260 years (<sup>1</sup>Manktelow, 2010; <sup>2</sup>Kutschera, 2016; <sup>3</sup>Sapp, 2005; <sup>4</sup>Woese & Fox, 1977; <sup>5</sup>Woese, Kandler & Wheelis, 1990; <sup>6</sup>Cavalier-Smith, 1998; <sup>7</sup>Cavalier-Smith, 2018; <sup>8</sup>Ruggiero et al., 2015).

Linnaeus 1758	Haeckel 1866	Chatton 1937	Copeland 1956	Whittaker 1969	Woese 1977	Woese 1990	Cavalier-Smith 1993	Cavalier-Smith 1998	Ruggiero, 2015
	Protista <sup>2,3</sup>	Prokaryota <sup>3</sup>	Monera <sup>3</sup>	Monera <sup>3</sup>	Eubacteria <sup>3,4</sup>	Bacteria <sup>3,5</sup>	Eubacteria <sup>3</sup>	Bactetia <sup>6,7</sup>	Prokaryota: Bacteria <sup>8</sup>
					Archaeobacteria <sup>3,4</sup>	Archaea <sup>3,5</sup>	Archaeobacteria <sup>3</sup>		Prokaryota: Archaea <sup>8</sup>
			Protista <sup>3</sup>	Protista <sup>3</sup>	Protista <sup>3</sup>	Eukarya <sup>3,5</sup>	Archezoa <sup>6</sup>	Protozoa <sup>6,7</sup>	Eukaryote: Protozoa <sup>6,7</sup>
							Protozoa <sup>6</sup>		
Plantae <sup>1,3</sup>	Plantae <sup>1,3</sup>	Eukaryota <sup>3</sup>	Plantae <sup>1,3</sup>	Plantae <sup>1,3</sup>	Plantae <sup>1,3</sup>		Plantae <sup>1,3</sup>	Plantae <sup>1,3</sup>	Eukaryote: Plantae <sup>1,3</sup>
							Chromista <sup>6</sup>	Chromista <sup>6,7</sup>	Eukaryote: Chromista <sup>6,7</sup>
				Fungi <sup>3</sup>	Fungi <sup>3</sup>		Fungi <sup>3</sup>	Fungi <sup>3</sup>	Eukaryote: Fungi <sup>3</sup>
Animalia <sup>1,3</sup>	Animalia <sup>1,3</sup>		Animalia <sup>1,3</sup>	Animalia <sup>1,3</sup>	Animalia <sup>1,3</sup>		Animalia <sup>1,3</sup>	Animalia <sup>1,3</sup>	Eukaryote: Animalia <sup>1,3</sup>

### Pre-Linnaean

Our Western taxonomy officially began with Linnaeus. Nevertheless, equally important discoveries and research has been done long before the Linnaean system was introduced. Before our knowledge was written down, it was of great importance to know what plants are edible and which are poisonous and if they have a medicinal use. This knowledge was then passed on to family or tribe members (Manktelow, 2010).

Aristotle (384 BC-322 BC) was a Greek philosopher. It was during his studies at Plato's academy, where he developed his passion to study nature. His stay in Kalloni Bay on Lesbos Island is where most of his marine research was done. This is where he began to investigate living things and became the first scientist. Though it is believed that Aristotle continued his research until the end of his teachings at the lyceum in Athens (Voultsiadou et al., 2017). His zoological studies provided a proper method for biological investigation. It was the first comprehensive studies of animals recorded at the time (Lennox, 2017). Aristotle laid down the foundations of marine taxonomy, which are still echoing in our currently used system as shown in appendix I (Voultsiadou et al., 2017). As is mentioned by Voultsiadou et al. (2017) Very few records of animals are found prior to Aristotle's time. Therefore most descriptions of animals found in Aristotle's writings are not found in earlier written documents. In his work *Parts of Animals*, a set of rules were explained that he used to classify animals. Aristotle divided animals into two groups: *anhaima* (bloodless; invertebrates), and *enhaima* (blooded; vertebrates). Both invertebrates and vertebrates are still used today. Aristotle recognized the distinction between egg-bearing and live-bearing in the blooded group. But placed both bony fish and cartilaginous fish in the same group (*Ichthyes*) (Voultsiadou et al., 2017). As Linnaeus, Aristotle believed that species were created by god (Campbell & Reece, 2014).

Since the 13<sup>th</sup> century Lenses and spectacle glasses had been in use. However it took until the 17<sup>th</sup> century to develop microscopes, which made it possible to study the living world in more detail than ever before. It was Robert Hooke who first discovered microscopic fungi in 1665. Hooke was the first to publish a book on microscopy "*Micrographia*". As a draper in Delft, the Netherlands, Van Leeuwenhoek started using lenses to study the quality of cloth (Gest, 2004). After reading Hooke's book van Leeuwenhoek got inspired in the use of microscopes and started making his own. Van Leeuwenhoek was able to create microscopes that were able to observe objects at one-tenth of the size that Hooke had seen (Wessner, Dupont, Charles and Neufeld, 2017). This led to the discovery of unicellular organisms in 1674 by van Leeuwenhoek (Verma, 2017). Van Leeuwenhoek discovered sperm cells of animals, red blood cells, and bacteria. He was researching scrutinized pepper when he discovered tiny organisms, which he called 'animalcules' (Gest, 2004).

#### *Linnaean era*

Today the Linnaean system has been in use for more than 250 years and has been widely accepted by biologists (Manktelow, 2010). Carolus Linnaeus (1707-1778) is considered the founding father of the taxonomy and was the first in history to create a uniform system for classifying and naming organisms. During his lifetime he named approximately 4,400 animal species and 7,700 plant species (Epstein, 2019). The 10<sup>th</sup> revision of his *Systema Naturae* (1758) has laid the fundamental groundwork for his career and future taxonomy (Müller-Wille, 2019).

The *Systema Naturae* (1735) introduced a hierarchical classification system (Ereshefsky, 1994), which consist out of the two kingdoms plants and animals for living things (figure 1). Though he added a third kingdom for non-living things called minerals (Manktelow, 2010). Each kingdom is further divided into Classes, Orders, Genera and species (Ereshefsky, 1994). At the same time he also proposed a sexual system for plants. This is an artificial classification, which is based upon the number and arrangement of male and female organs in flowering plants, in this case stamens and pistils (Bremer, 2007). The sexual system of plants was replaced in 1998 by the Angiosperm Phylogeny Group, otherwise called APG-system (Royal Botanic Gardens, 2019). Linnaeus classification system is still used today, though additional ranks such as Phylum, Family and Variety were added (Müller-Wille, 2019).

In the publication of *Species Plantarum* (1735) Linnaeus introduced the Binomial nomenclature for the first time. Binomial nomenclature is a two-part naming method consisting of the genus and species

names. Binomial names served as labels by which species could be universally addressed (Müller-Wille, 2019) and give information on a species taxonomic position (Ereshefsky, 1994). Linnaeus used this for fieldwork and education. It was never meant to replace names from earlier sources (Manktelow, 2010).

With an increase in recognized genera, classification became much more complex than Linnaeus originally presented. The increase in the number of genera from 312 as recognized by Linnaeus to more than 50,000 today is associated with an increase in the number of ranks used in classification (Ereshefsky, 1994).

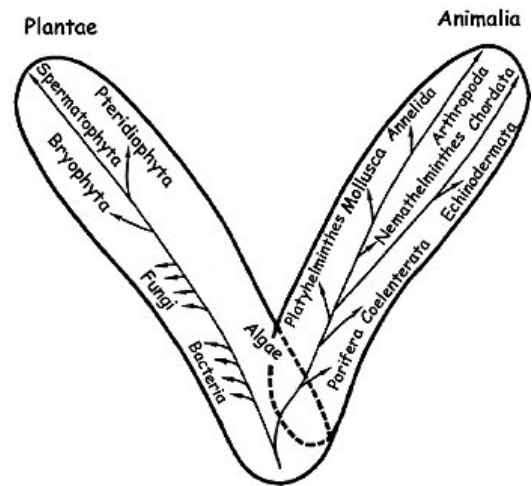
The Linnaean system was in accordance with a biological theory based on creationism and essentialism. He believed that god had created an original pair of each existing species and all other organisms are descendants of the original pair. This meant that no new species could arise and the diversity could never increase. Though Linnaeus's original biological theory on creationism and essentialism has been abandoned, the Linnaean system is still used today, with additional ranks. Linnaeus's theory behind the classification system has gone through drastic changes. Hence it was not god, but evolution, natural selection and other biological processes. Today the Linnaean system is used to sort species into higher taxa, thereby revealing the evolutionary history of a species (Ereshefsky, 1994).

The Linnaean system no longer suffices today's complicated taxonomic classification. Nevertheless, it has had a major contribution to taxonomy, as we are still using the Linnaean system today. According to the Linnaean system species must be assigned a binominal name, consisting of a generic and a specific name. The binominal name serves as a guide, that way biologists know a species taxonomic position. Given that Linnaeus thought god created all species and no new taxa could arise, the classification system originally created by Linnaeus containing only 312 genera is more than reasonable. However, more recent estimates show there are more than 50,000 genera today, making it practically impossible to remember names, the system no longer tells much about the position of a species (Ereshefsky, 1994).

#### Post-Linnaean

Jean-Baptiste Lamarck (1744-1829) was a French biologist, botanist, zoologist, and naturalist. Lamarck was the first in history to propose the theory of evolution (Scoville, 2019). Before Lamarck's theory, people had believed that all species were created by god. With this theory he was the first to suggest that a species' lifestyle led to adaptations during their life, after which these adaptations will be passed on to their offspring (Campbell & Reece, 2014).

Charles Darwin (1809-1882), just like Linnaeus, had an interest in nature. His father was also a physician, who sent him to medical school. Darwin soon quit medical school, and went to Cambridge University. Shortly after his graduation Darwin embarked on the HMS Beagle in December 1831. During this trip he spent most of his time observing and collecting plants and animals. Darwin's theory of evolution came in development after being influenced by the work of others, and by his own travels. Almost three decades after his five-year voyage studying plants, animals and fossils, Darwin published his book "The Origin of Species" (1859) in which he proposed the theory of evolution by natural selection (National Geographic Society, 2019a). Though Darwin was not the first to suggest that earth underwent gradual changes to biological evolution, however he was the first to suggest natural selection. In his



**Figure 1.** The two kingdom system of living things introduced by Linnaeus (Drozdoz, 2017).

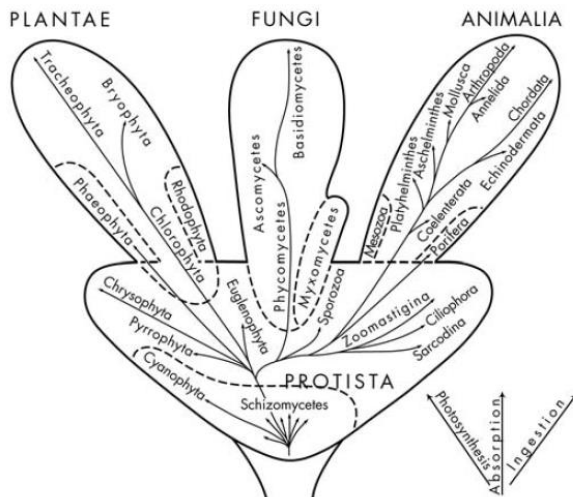
book "The Origin of Species" (Campbell & Reece, 2014). The process through which species adapt to their environment. Each individual is unique, which means that individuals within a population are all different in some way, creating natural variation within a species. This natural variation means that some individuals have traits that give them an advantage (National Geographic Society, 2019a). Individuals with a high fitness, have a higher chance at survival and will most likely reach sexual maturity and reproduce offspring. This is also referred to as "survival of the fittest", where individuals that are best adapted to the environment, will be most successful, and pass on their traits to the next generation (National Geographic Society, 2019b). Darwin suggested that when one species gets isolated into two groups, each group will adapt to its environments differently, favouring different traits. Many generations later, each group has changed in such a way that they can no longer reproduce with one another, from then on they are considered as separate species. Thus evolution is the creation of new species from a pre-existing species, hereby the changing of species over time happens by natural selection (Khan academy, 2020). Darwin developed his theory before the discovery of DNA. Darwin knew that species changed over time, but he did not know how this happened, of course we now know that these changes occur at genetic level (LiveScience, 2017).

Before Haeckel's proposal all unicellular organisms were assigned to either the animal or plant kingdom (Verma, 2017) and all living things that were not an animal such as fungi and bacteria were assigned to the kingdom Plantae (Mayr, 1998). Haeckel was the first to change this with his publication of 'General Morphology of Organisms' (1866). In which he introduced a three kingdom concept (appendix II), in which a third kingdom called Protista was added to the Linnaean two kingdom system. The kingdom Protista included eight divisions and all microscopic organisms known at the time. One of the divisions is Monera, which included micro-organisms, now known as bacteria. Cohn (1872) was the first to mention the kingdom Bacteria. However, Haeckel's three kingdom system was not replaced until 1969 by Whittaker (Kutschera, 2016).

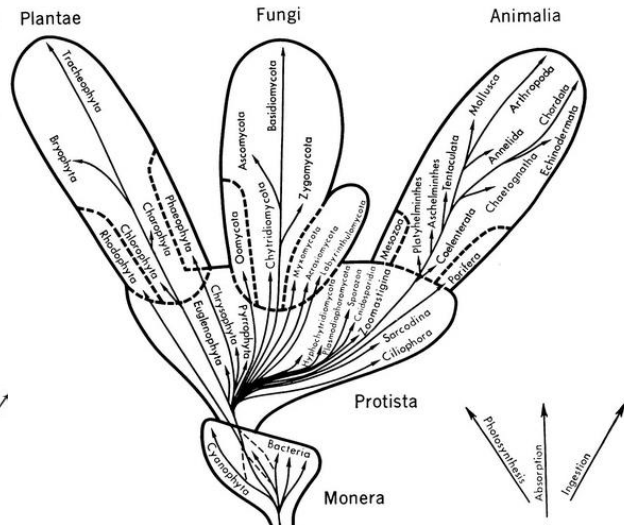
Chatton made a distinction between organisms according to the presence or absence of a nucleus. This distinction divided organisms in prokaryotes, without a nucleus and eukaryotes, with a nucleus (Verma, 2017).

Based on Chatton's prokaryote-eukaryote dichotomy Copeland (1956) proposed a four kingdom system (Verma, 2017). First of all, he proposed to add the new kingdom Mychota (known as Monera), which includes all prokaryotes. Secondly, he proposed to add the kingdom Protoctista (known as Protista), which include all eukaryotes that are not plants or animals. On the basis of the cell structure, he placed bacteria into the kingdom Mychota. Copeland now saw the Plant kingdom as a monophyletic group of vascular plants, who have a common ancestor. Nevertheless it still included unicellular organisms (Hagen, 2012).

According to Hagen (2012) the five kingdom concept was introduced by Whittaker in 1969 and relied particularly on prokaryote-eukaryote dichotomy for the organization of the five kingdoms. Alternately Whittaker first introduced a four kingdom system in 1959 (figure 2), taking a decade of critical reflections before introducing the well-known five kingdom system (figure 3).



**Figure 2.** The four kingdom system introduced by Whittaker, based on the three modes of nutrition and the distinction between unicellular and multicellular body plans. The dotted lines represent groups that include both unicellular and multicellular forms (Whittaker, 1959).



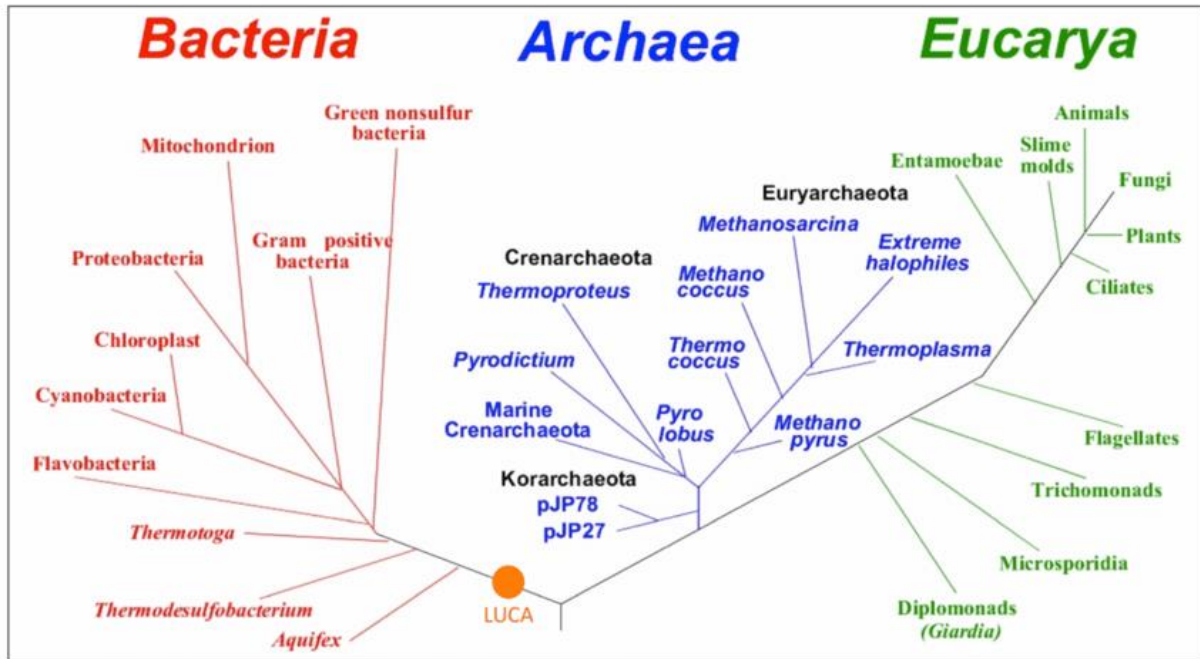
**Figure 3.** The five kingdom system of living things introduced by Whittaker (Drozdov, 2017).

The publication of Whittaker did not only intend to replace the Linnaean system, but also to dismiss earlier concepts on three or four kingdom systems, including Copeland's proposal for a four kingdom system. Hence the rejection of Copeland's proposal, Whittaker based his five kingdom system on two major statements made by Copeland. First of all, Copeland's detailed analysis on microorganisms helped to develop the distinction of unicellular and multicellular organisms. Secondly, Copeland's distinction between prokaryote and eukaryote cells (Hagen, 2012).

Whittaker did not agree with Copeland, who placed fungi, red and brown algae and numerous microscopic eukaryotes in the in the Kingdom Protocista. Whittaker believed that there was no ecological or evolutionary logic to place fungi and algae in the same kingdom. Hence the decision to add a fifth kingdom, called Fungi. Furthermore, he relocated unicellular algae and cyanobacteria to the kingdom Protista, while multicellular producers stayed in the kingdom Plantae (Hagen, 2012).

Microbiologist Carl Woese did experiments with ribosomal RNA sequencing and discovered that the kingdom Monera actually consisted out of two very different groups of organisms. Based on this RNA sequencing, Woese suggested a six kingdom classification in which Monera was replaced with Eubacteria and Archaeobacteria (CK-12, 2016; Woese, 1977).

Using RNA sequencing within the last few decades made it possible to trace evolutionary history back to the Last Common Universal Ancestor (LUCA), who lived about three and a half to four billion years ago. It was not until we compared to molecular level that it showed how all life could be divided into the three groups Bacteria, Archaea and Eukarya. With this knowledge, Woese, Kandler and Wheelis (1990) proposed to add a new higher rank called "domain" and created the phylogenetic tree of life (Koonin, 2014). This phylogenetic tree (figure 4) shows how all life originated from LUCA, which separates Bacteria from the other two groups. It also shows that Archaea and Eukarya are distant relatives (Woese, Kandler & Wheelis, 1990).



**Figure 4.** The universal phylogenetic tree of life as defined by comparative rRNA gene sequencing , showing the separation of Bacteria, Archaea and Eukarya (Madigan, Martinko, Stahl & Clark, 2012).

Cavalier-Smith (1993) suggested the eight kingdoms of life (table 2), which is significantly different from Woese’s six kingdoms. Though Woese (1977) had originally divided the kingdom Monera into the two kingdoms Eubacteria and Archaeobacteria, he renamed them to Bacteria and Archaea in 1990 as part of the domains. But Cavalier-Smith (1981) renamed them again to Woese’s original division of the Monera kingdom into Eubacteria and Archaeobacteria to clarify the difference between the two kingdoms.

**Table 2.** The 8 kingdoms of life and their 10 subkingdoms (Cavalier-Smith, 1993).

<b>EMPIRE BACTERIA<sup>a</sup></b>		
Kingdom 1. EUBACTERIA <sup>a</sup>		
Subkingdoms:		
	1. Negibacteria <sup>a</sup>	2. Posibacteria <sup>a</sup>
Kingdom 2. ARCHAEBACTERIA <sup>a</sup>		
<b>EMPIRE EUKARYOTA</b>		
Superkingdom 1. ARCHEZOA		
Kingdom ARCHEZOA		
Superkingdom 2. METAKARYOTA		
Kingdom 1. PROTOZOA		
Subkingdoms:		
	1. Adictyozoa	2. Dictyozoa
Kingdom 2. PLANTAE		
Subkingdoms:		
	1. Viridiplantae (green plants)	2. Biliphyta (red algae and glaucophytes)
Kingdom 3. ANIMALIA		
Subkingdoms:		
	1. Radiata	2. Bilateria
Kingdom 4. FUNGI		
Kingdom 5. CHROMISTA		
Subkingdoms:		
	1. Chlorarachnia	2. Euchromista (cryptomonads, <i>Goniomonas</i> , heterokonts, and haptophytes)

For a while authors argued that the kingdom Protista is too diverse and needs to be split into several kingdoms too specify the boundaries between Protists, Fungi, Animalia and Plantae. This is why Cavalier-Smith (1993) suggested to split the kingdom into the three kingdoms Chromista, Protozoa and Archezoa and explained the boundaries between these three kingdoms and the kingdoms Plantae, Fungi and Animalia.

Cavalier-Smith (1981) described the difference of chromists from Protista and Plantae and argued for a separate kingdom, to prevent confusion. Chromists are different because they acquired the chloroplasts secondarily by enslavement of a red algae (which is a member of the plant kingdom) (Cavalier-Smith, 2010). This process is called secondary endosymbiosis (Cavalier-Smith, 1981). Cavalier-Smith defined Chromists by the following characters. firstly plastids need to be present (containing chlorophyll a and c), which are surrounded by a periplastidial membrane that is located within the rough endoplasmic reticulum (RER). Secondly tripartite or bipartite rigid tubular hairs need to be present on one or both flagella. Chromists also have a unique membrane topology, by which the thylakoids of the chloroplasts are separated by a four-layered membrane from the cytoplasm (Manevelde & Sym, 2011).

Cavalier-Smith (1993) gave the following description of the kingdom Protozoa:

Predominantly unicellular, plasmodial or colonial phagotrophic eukaryotes, wall-less in the trophic state. Primitively possessing mitochondria and peroxisomes (unlike Archezoa); when mitochondria and peroxisomes are both secondarily absent (Parabasalida, Entamoebida, Lyomonadea, and anaerobic ciliates only), hydrogenosomes and/or Golgi dictyosomes are present instead. Ciliary hairs are never rigid and tubular (unlike most chromists); haptonema absent (excludes nonphotosynthetic haptophytes). Chloroplasts, when present (some euglenoids and dinoflagellates only), contain neither starch nor phycobilisomes (unlike in Plantae), have stacked thylakoids, and usually have three, rather than two, envelope membranes. Chloroplasts are located in the cytosol, never within a smooth periplastid membrane inside either the lumen of the rough endoplasmic reticulum or a fourth smooth membrane (unlike Chromista); ejectosomes never of the double-scroll cryptist type (this excludes the cryptist *Goniomonas*); the few multicellular species have minimal cell differentiation and altogether lack collagenous connective tissue sandwiched between two dissimilar epithelia (unlike Animalia). (p. 967)

Scientists had already noticed that certain eukaryotic cells lacked mitochondria, and believed that these amitochondrial eukaryotic cells must have diverged prior to the endosymbiotic event. This discovery led to the proposal of the kingdom Archezoa by Cavalier-Smith (1998) to contain these amitochondrial eukaryotes. Archezoa could be distinguished from other eukaryotic ribosomes, as those typically have a size of 80S, whereas the ribosomes of Archezoa and prokaryotes only are 70S in size. This same method applies to the rRNA molecules of Archezoa. It was discovered later that some of the Archezoa contained a genetic residue of the mitochondrion, changing the theory on the origin of Archezoa, as they must have evolved after the endosymbiosis event. However, a research led by evolutionary biologist Karnkowska (2016), revealed the discovery of the first amitochondrial eukaryote in history.

Cavalier-Smith (1998) has been pressuring the need for a more simplified classification system since 1983. To simplify the system, he proposed the six-kingdom system. In which he placed Archezoa within the kingdom Protozoa, and Archaeobacteria within the kingdom Bacteria.

The most recent classification scheme was introduced by Ruggiero et al. (2015), who proposed a two-superkingdom (synonyms are empire and domain) with a seven-kingdom classification, based on Cavalier-Smith's six kingdom. The kingdoms Bacteria and Archaea are part of the superkingdom Prokaryota and the kingdoms Protozoa, Chromista, Plantae, Fungi and Animalia are part of the superkingdom Eukaryote (Ruggiero et al., 2015). This now forms the basis for the Catalogue of Life hierarchical classification.

Besides classification schemes, there are three codes which are used to assign scientific names: the International Code of Nomenclature for algae, fungi and plants (ICN), International Code of Zoological Nomenclature (ICZN), and International Code of Nomenclature of Bacteria (ICNB) (Ruggiero et al., 2015). The International Commission on Zoological Nomenclature (ICZN) was already founded in 1895, though it took until 1961 before the first edition of the ICZN was published (International Commission on Zoological Nomenclature, 2020). This code enables taxonomist, zoologists and biologists to determine the valid name to species, genus, family and subspecies (Ride, 1999).

The first edition of ICN was published in 1867 (International Association for Plant Taxonomy, 2014). The ICN gives recommendations on the scientific naming of algae, fungi and plants (International Association for Plant Taxonomy, 2020). The first edition of ICNB was published in 1958 (International Committee on Bacteriological Nomenclature, 1958), and is applied to all bacteria (Lapage et al., 1992). The International Committee on Taxonomy of Viruses (ICTV) was founded in 1966 (Siddell, 2019a), though earlier attempts at establishing a standardized nomenclature have failed, which resulted in an ongoing debate that lasted for decades (Siddell, 2019b). In October 2018 the ICTV finally approved additional ranks. It is not obligatory to assign above genus level, though when doing so scientific justification need to be provided (Siddell, 2019a).

With today's estimation of 1.9 million described species (Ower & Roskov, 2019), a number of changes have been made to account for the ever-expanding knowledge of species and the discovery of new species with DNA sequencing and fossils. Over time additional ranks have been added to keep up with the ever-expanding data on species. Currently the Linnaean system consist of the three domains Archaea, Bacteria and Eukarya (Epstein, 2019), followed by the five kingdoms Monera, Protista, Animalia, Fungi and Plantae (Hagen, 2012). Then each kingdom is divided into Phylum, Subphylum, Superclass, Class, Subclass, Infraclass, Cohort, Superorder, Order, Suborder, Infraorder, Superfamily, Family, Subfamily, Tribe, Subtribe, Genus, Subgenus, Species and Subspecies (Ereshefsky, 1994).

WoRMS contribution to taxonomy

Stability and universality in species names is one of WoRMS primary goals and ensures that species names are unique and distinct. This might be especially important when a species is commercially fished, has medicinal properties, is dangerous to humans or an endangered species (Horton, et al., 2017).

Von der Heyden, Barendse, Seebregts and Matthee (2009) studied the mislabelling of frozen fish products in South Africa. They tested 178 samples of fish fillets using mtDNA 16S rRNA sequencing and concluded that 50% was mislabelled. The most mislabelled species was Kob (*Argyrosomus japonicas*), of which 84% consisted of mackerel (*Gasterochisma melampus*), croaker (*Protonibea diacanthus*), and Warehou (*Seriola lalandi*). Dorado (*Coryphaena hippurus*) matched for 79% the other 21% was mislabelled as Yellowtail (*Seriola lalandi*). All samples of Barrucuda (*Sphyraena* spp) tested turned out to be mislabelled as king mackerel (*Scomberomorus cavalla*). Red Snapper (*Lutjanus spp*) were also mislabelled as River snapper (*L. argentimaculatus*) and Common bluestripe snapper (*Lutjanus kasmira*). Wahoo species were all mislabelled as King mackerel (*Scomberomorus cavalla*). Only the Kingklip (*Genypterus capensis*) had a 100% match and was not mislabelled. This mislabelling of fish is mostly caused by the processing and pre-packaging of fish, hereby implicating sustainable management and conservation of overexploited marine resources. When the given recommendation is only as good as the information available to the consumer, inadequate labelling will undo any effort of eco-labelling and consumer awareness.

Problems with the Linnaean system arise when taxonomic revisions are necessary due to DNA analysis or fossil records. These revisions can occur at multiple levels. Following the rules of the Linnaean system, when reclassifying a species to a different genus it is mandatory to assign a new generic name as well. For instance if scientist discovered that the species *Homo bubba* is part of the genus *Pongo*,

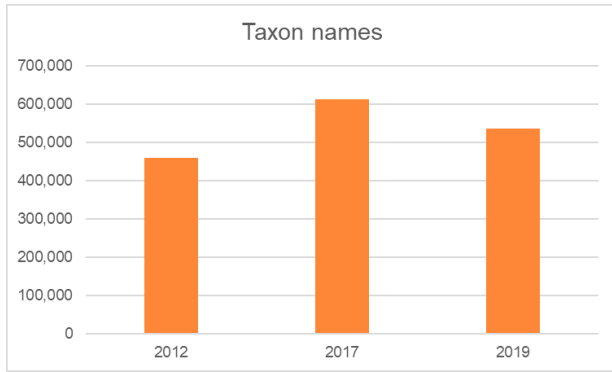
there are two possible outcomes. In the first case the genus is changed, though the species name remains the same. Which means the name is changed to *Pongo bubba*. In the second case the species name *bubba* already exist in the genus *Pongo* (Von der Heyden et al., 2009). The same name for different species must be avoided and thus a new binominal name must be assigned (Ereshefsky, 1994).

The Linnaean system has been around for more than 250 years, which has greatly influenced our modern taxonomy. Nevertheless, species that had been described by many authors were assigned different names, while belonging to the same species, vice versa, different names were assigned to the same species, leading to confusion (Costello, Bouchet, Boxshall, Arvanitidis, & Appeltans, 2000). First of all, when biologists cannot agree on the rank of a taxon, the Linnaean system forces them to give the same species different sets of names (Ereshefsky, 1994). In such case both names can be added to the same species in the database. Secondly, Scientist that discovered or described species predating the interconnected network, otherwise known as the internet, had limited access to scientific information (Wolniewicz, 2012). As a result authors assigning the same names to different species or different names to the same species.

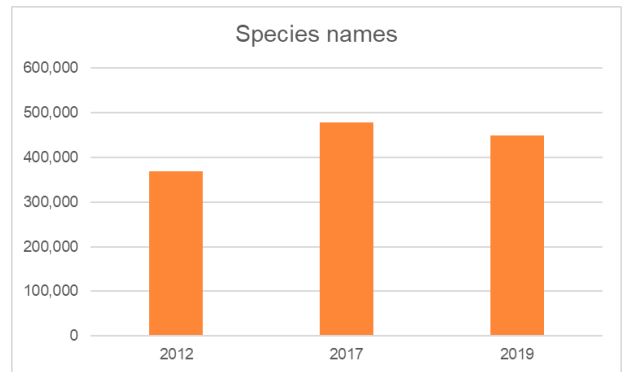
#### WoRMS completion

After the establishment of the WoRMS database in 2007, existing species databases were incorporated into WoRMS, making sure that taxonomic experts did not repeat their work. At the beginning, there were six RSD and 14 GSD integrated into WoRMS. By now, there are 80 GSD's, 23 RSD's, 10 TSD's and 6 External Global Species Databases (EGSD's) as shown in appendix III (World Register of Marine Species, 2019f).

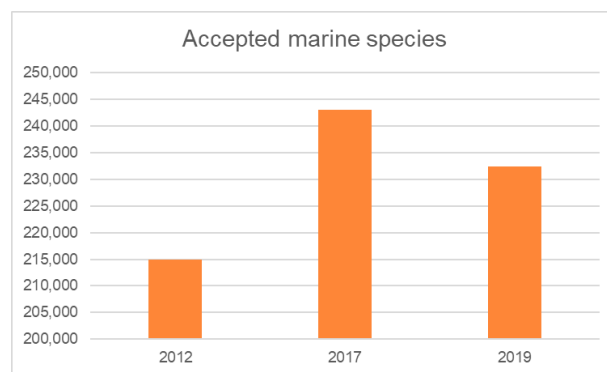
Back in 2008 when the WoRMS database was inaugurated, it had a 137 voluntary taxonomic editors who entered, edited and revised a 122,500 accepted names (Census of Marine Life & World Register of Marine Species, 2008). In 2012, the number of taxonomic editors had grown to 240. Then the WoRMS database contained 460 000 taxon names (from infraspecies to kingdom), of which 368 000 species names, of which 215 000 accepted marine species names (Costello et al., 2013). By 2017 a total of 278 taxonomic editors were working on WoRMS. By then WoRMS contained 613,449 taxon names (from infraspecies to kingdom), of which 479,092 species names, of which 243,081 accepted marine species names (Horton et al., 2017). Now, twelve years later, 288 taxonomic editors are working on WoRMS (World Register of Marine Species, 2019c), which currently contains 537,556 taxon names (from infraspecies to kingdom), 448,656 species names (LifeWatch, 2019), and 232,476 accepted marine species of which 97% are validated by a taxonomic expert (World Register of Marine Species, 2019c). Technical improvement to the database caused inconsistencies to the number of taxon names, species names and accepted marine species, as marine species with undocumented marine environment flags are no longer counted this year (see figure 5-7). This is due to incomplete environment information dates back to the ERMS database, when the database consisted of only marine species. Back then, many of the taxa received the environmental flag 'unknown' when the species occurred in multiple environments. Since the development to WoRMS, a large quantity of non-marine data has been added, with freshwater and terrestrial environmental flags. Marine species with an environmental flag 'unknown' used to be included in the marine species count (World Register of Marine Species, 2019e).



**Figure 5.** Taxon names by year.

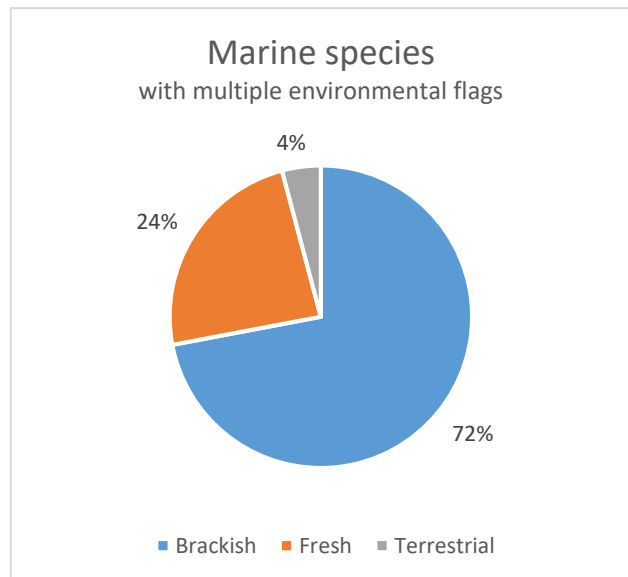


**Figure 6.** Species names by year.



**Figure 7.** Accepted marine species by year.

Using the advanced search tool of the WoRMS database a total of 5,906 species described by Linnaeus can be found in WoRMS (World Register of Marine Species, 2019b). Considering that during his lifetime Linnaeus named approximately 4,400 animal species and 7,700 plant species (Epstein, 2019), it is clear that there are less species in the WoRMS database. However, this might be explained by multiple reasons. Firstly, the environmental information is incomplete. This is why it is now mandatory to assign environmental flags to new taxa. In WoRMS the environmental flags marine, freshwater, brackish and terrestrial can be checked in any combination. When the environmental flag is incomplete the taxa is not shown in search results. Secondly, names published before 1758 are pre-Linnaean and considered not valid in the field of taxonomy (Manktelow, 2010). This means the species will be listed under a different author, who described the species after 1758. Linnaeus described 4,691 species that are marine and can contain multiple other environmental flags as shown



**Figure 8.** Marine species with multiple environmental flags, of all marine species described by Linnaeus 72% occurs in a brackish, 24% occurs in a fresh and 4% occurs in a terrestrial environment.

and can contain multiple other environmental flags as shown

in figure 8 (World Register of Marine Species, 2019a). As Aristotle is pre-Linnaean and thus not considered a valid author in taxonomy. Thereby you will not find Aristotle as an author in the WoRMS database.

Aristotle marine species traits

Information on traits that can be found today of marine species described by Aristotle will be arranged in a spreadsheet to give a clear overview. This data will be used in an ongoing research that will be done by Arvanitidis, Dekeyzer, Gerovasileiou, Vandepitte and Voultziadou. It is about Aristotle species traits that will be compared with traits that can be found today.

As is mentioned by Voultziadou et al. (2017) Very few records of animals are found prior to Aristotle's time. Therefore most descriptions of animals found in Aristotle's writings are not found in earlier written documents. In his legacy Aristotle left us with information on traits (biological, distributional and ecological) of marine organisms. However a detailed analyses of fish traits has been given by Ganias et al. (2017), an analysis of all marine animals described by Aristotle has yet to be done (see table 3). Therefore traits from 20 marine species have already been collected, though not all are complete yet, and 30 more marine species are still missing from the data file. However, fish species have not been included in this count.

**Table 3.** The table below gives an overview of marine species described by Aristotle that have not been analyzed prior to this research article and will be used in an ongoing investigation on traits of marine organisms. Voultziadou and Vafidis (2007), Voultziadou et al. (2010), Ganias et al. (2017), and Vandepitte (personal communication, December 2019) provided information on marine taxa described by Aristotle.

Marine species	
<i>Sarcotragus foetidus</i>	<i>Bonellia viridis</i>
<i>Hippospongia communis</i>	<i>Calappa granulata</i>
<i>Spongia lamella</i>	<i>Eriphia verrucosa</i>
<i>Spongia officinalis</i>	<i>Maja squinado</i>
<i>Spongia zimocca</i>	<i>Homarus gammarus</i>
<i>Actinia equina</i>	<i>Ocypode cursor</i>
<i>Anemonia viridis</i>	<i>Pontonia pinnophylax</i>
<i>Alcyonium palmatum</i>	<i>Palinurus elephas</i>
<i>Pelagia noctiluca</i>	<i>Pinnotheres pisum</i>
<i>Pholas dactylus</i>	<i>Liocarcinus depurator</i>
<i>Mytilus galloprovincialis</i>	<i>Potamon fluviatile</i>
<i>Ostrea edulis</i>	<i>Scyllarus arctus</i>
<i>Pinna nobilis</i>	<i>Squilla mantis</i>
<i>Loligo vulgaris</i>	<i>Antedon mediterranea</i>
<i>Argonauta argo</i>	<i>Paracentrotus lividus</i>
<i>Eledone moschata</i>	<i>Sphaerechinus granularis</i>
<i>Octopus vulgaris</i>	<i>Cidaris cidaris</i>
<i>Todarodes sagittatus</i>	<i>Brissus unicolor</i>
<i>Sepia officinalis</i>	<i>Microcosmus sabatieri</i>
<i>Cerithium vulgatum</i>	<i>Monachus monachus</i>
<i>Charonia variegata</i>	<i>Balaenoptera physalus</i>
<i>Haliotis tuberculata</i>	<i>Phocoena phocoena relicta</i>
<i>Patella caerulea</i>	<i>Physeter macrocephalus</i>
<i>Phorcus turbinatus</i>	<i>Caretta caretta</i>
<i>Hermodice carunculata</i>	<i>Echeneis neucrates</i>

Aristotle is pre-Linnaean and thus not considered a valid author in taxonomy, thereby you will not find Aristotle as an author in the WoRMS database. The papers *Marine invertebrate diversity in Aristotle's*

zoology (Voultsiadou & Vafidis, 2007), *Aristotle as an ichthyologist: exploring Aegean fish diversity 2,400 years ago* (Ganias, Mezarli & Voultsiadou, 2017) and *Aristotle's scientific contributions to the classification, nomenclature and distribution of marine organisms* (Voultsiadou et al., 2017) were studied, giving knowledge on taxa described by Aristotle.

Comparison of the different papers mentioned earlier (appendix VI), show differences in the number of taxa identified to species level. *Potamon fluviatile* is present in the latest version (Gerovasileiou, & Voultsiadou, 2019), but not mentioned in any earlier papers. *Silurus aristotelis* was mentioned in the latest overview (L. Vandepitte, personal communication, December 2019) as well as by Gaines, Mezarli and Voultsiadou (2017), but not by Voultsiadou et al. (2017) and Voultsiadou & Vafidis (2007). *Echeneis naucrates* is only ever mentioned by Voultsiadou et al. (2017). Gaines et al. (2017) only focused on marine fish, which all overlap with the marine fish mentioned by Aristotle species list (L. Vandepitte, personal communication, December 2019) as well as with Voultsiadou et al. (2017). With the exception of *Silurus aristotelis*, which is not mentioned in Voultsiadou et al. (2017). Voultsiadou & Vafidis (2007) are missing all marine fish species, *Pelagia noctiluca*, *Eriphia verrucosa*, *Potamon fluviatile* and *Microcosmus sabatieri*. The species *Veretillum cynomorium*, *Bolinus brandaris*, *Hexaplex trunculus*, *Stramonita haemastoma*, *Arca noae*, *Cancer pagurus*, *Holothuria forskali*, *Halocynthia papillosa* and *Phallusia mammilata* are only ever mentioned by Voultsiadou & Vafidis (2007). *Sphaerechinus granularis* is mentioned in the other papers, but is not written entirely the same.

## Conclusion

### *Taxonomy*

It is clear that the major contributors to taxonomy are all connected and influenced each other. They read each other's work and then made changes to the already existing classification scheme, hereby slowly expanding the scheme, and making it more complex.

### *WoRMS contribution*

It is true that there are a lot of problems with the Linnaean system, though the WoRMS database can give a clear overview of all that occurred over time. Mislabelling happens after processing and pre-packaging of fish, which is a problem in efficiency in fish factories were they are processed, WoRMS can nevertheless assist at an international level in the use of universal species names on labels, by persuading them into using the WoRMS database as a baseline for species names on labels. In the case of revisions, the WoRMS database may provide useful information on existing genus and species names, but also on previously used names. Due to nomenclature rules the same names were assigned to different species or different names were assigned to the same species. In such a case, WoRMS records this, though it does not solve the problem.

### *WoRMS completion*

The ocean covers about 71% of the earth's surface (Smithsonian Institution, 2020). Before a clear inventory on the number of species existed, estimates on marine species ranged from 0.3 to 100 million (Appeltans et al., 2012). Now more precise estimates range from 0.3 to 2 million marine species. While biologists had more than 250 years to discover and describe species, only 232,476 accepted marine species are recorded in WoRMS (Horton, Kroh & Vandepitte, 2017). Therefore, the WoRMS database is far from completion. A study by Fontaine, Perrard & Bouchet (2012) showed that it takes about 21 years for a species to be described after discovery. WoRMS editors add almost 2000 new marine species to the database each year (Horton, Kroh & Vandepitte, 2017). The WoRMS database might still be far away from completion. However, as part of this research, the AlgaeBase synchronization within WoRMS was finalized in November 2019 (Dekeyzer, 2019).

### *Aristotle species traits*

An analysis of all marine animals described by Aristotle has yet to be done (see table 2). Therefore traits from 20 marine species have already been collected, though not all are complete yet. However a detailed analyses of fish traits has been given by Ganiyas et al. (2017), an analysis of another 50 marine species had yet to be done (table 2). Therefore information on traits has been collected for the following 20 species: *Balaenoptera physalus*, *Bonellia viridus*, *Caretta caret*, *Eledone moschata*, *Homarus gammarus*, *Loligo vulgaris*, *Maja squinado*, *Monachus monachus*, *Mytilus galloprovincialis*, *Octopus vulgaris*, *Ostrea edulis*, *Palinurus elephas*, *Pholas dactylus*, *Physeter macrocephalus*, *Pinna nobilis*, *Pinnotheres pisum*, *Sepia officinalis*, *Spongia lamella*, *Spongia officinalis*, and *Squilla mantis*. As the data that has been collected is not finished yet and will be used in an ongoing research on comparing species traits described by Aristotle with information that can be found today, no conclusions can be drawn yet on species traits. With the spreadsheet setup and method description, a basic format and approach has been created. Therefore it can be used in the ongoing research. Though information has been collected on 20 species, the data is still incomplete. Read the 'notes' in the spreadsheet to see where more information could be found. Comparison of the different papers mentioned earlier (appendix VI), show differences in the number of taxa identified to species level. Before drawing any conclusions, E. Voultziadou (personal communication, January 5, 2019) was approached and helped to answer some of the questions that had risen after comparison of the different papers. Voultziadou and Vafidis (2007) was the first paper on Aristotle's marine invertebrates, thus explaining why fishes were not included yet. Gaines et al. (2017) specifically focused on all fish species that were described by Aristotle (including marine-and freshwater species), which fully overlap with more recent data, with the exception of *Silurus aristotelis*. *Silurus aristotelis* is not mentioned in Voultziadou et al. (2017), hence the paper only focused on marine species. *Potamon fluviatile* only shows up in the most recent data from (Gerovasileiou & Voultziadou, 2019). It is a freshwater species crab and was therefore not included in the papers on marine species or fishes. *Sphaerechinus granularis* is misspelled by Voultziadou & Vafidis (2007), where they wrote it as *Shaerechinus granularis*. *Veneridae sp.* (prev. *Arca noae*), *Muricidae sp1*, *sp2* and *sp3* (prev. *Bolinus brandaris*, *Hexaplex trunculus*, *Stramonita heamastoma*), and *Holothuriidae sp.* (prev. *Holothuria forskali*) were identified to family level, and therefore not included anymore in the most recent data, as it is focused specifically on species level. The species *Alcyonium palmatum* is mentioned by Voultziadou & Vafidis (2007), but under the name *Veretillum cynomorium*. After comparison of the species *Pelagia noctiluca*, it turned out to have been misplaced by the name *Alcyonium palmatum* by Voultziadou & Vafidis (2007).

### Discussion

As explained before, this paper only mentioned the major contributors to taxonomy and changes made to the kingdoms classification. It does not provide a full overview. Therefore it is recommended to expand the literary research in the future to cover all contributions made from pre-Linnaean to post-Linnaean. But also include adaptations to hierarchical levels, nomenclature codes, and discoveries that led to changes in taxonomy. Manktelow (2010) has already made such an overview, but his writings are very straightforward, and not very profound. From my results it is clear that contributor's changes to the classification scheme are connected, as this is not specifically researched in this paper, this could be looked into in the future. As shown in table 1 there have been many changes over the last 260 years, giving a clear overview of introduced classification schemes. However it was not very clear what the most recently recognized classification scheme is. Though this could be very different throughout the world.

The development of microscopes made it possible to study the living world in more detail than ever before. This led to the discovery of unicellular organisms in 1674 by van Leeuwenhoek. Nevertheless, Linnaeus did not acknowledge this in his classification system, which remained in use until 1866 when Haeckel proposed a third kingdom called Protista, which includes all unicellular organisms. Before

Haeckel's proposal all unicellular organisms were assigned to either the animal or plant kingdom (Verma, 2017).

Nomenclature rules cause the same names to be assigned to different species or different names to be assigned to the same species. Therefore it is recommended that the ICN, ICZN and ICNB revise these nomenclature rules, to solve these problems.

As explained in the material and methods, certain steps were taken to find information on the researched species. However, few more steps could be added, as most of the information on physiology, CITES, FAO-ASFIS, Habitat Directive, MSFD Indicators and OSPAR is still missing, due to insufficient information and knowledge. At the moment information on these traits was only added whenever I happen to come across by coincidence when searching for other traits.

As part of an ongoing research the Marine Species Traits Wiki (2020) website was used to create a spread sheet containing the Biological, Distributional, Ecological and Important to Society descriptors. After using the descriptors from Marine Species Traits Wiki, it was noticed that the given descriptors are mostly based on egg-bearing species. Due to these shortcomings, new descriptors have been added to the table. Therefore it is recommended to expand Marine Species Traits Wiki with new descriptors, to make it more universally applicable.

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ceptreason=&rComp=%3E%3D&tRank=220&pname\_remember\_shown=1&marine=1&brackish=&fresh=&terrestrial=&fossil=&image=&basionym=&context\_checked=&context\_in=0&context\_ex=0&nType=&nComp=begins&nName=&person\_id=0&action\_id=&session\_year=1996&session\_month=1&session\_day=1&session\_year\_end=2019&session\_month\_end=11&session\_day\_end=27&action=search&rSkips=0&adv=1

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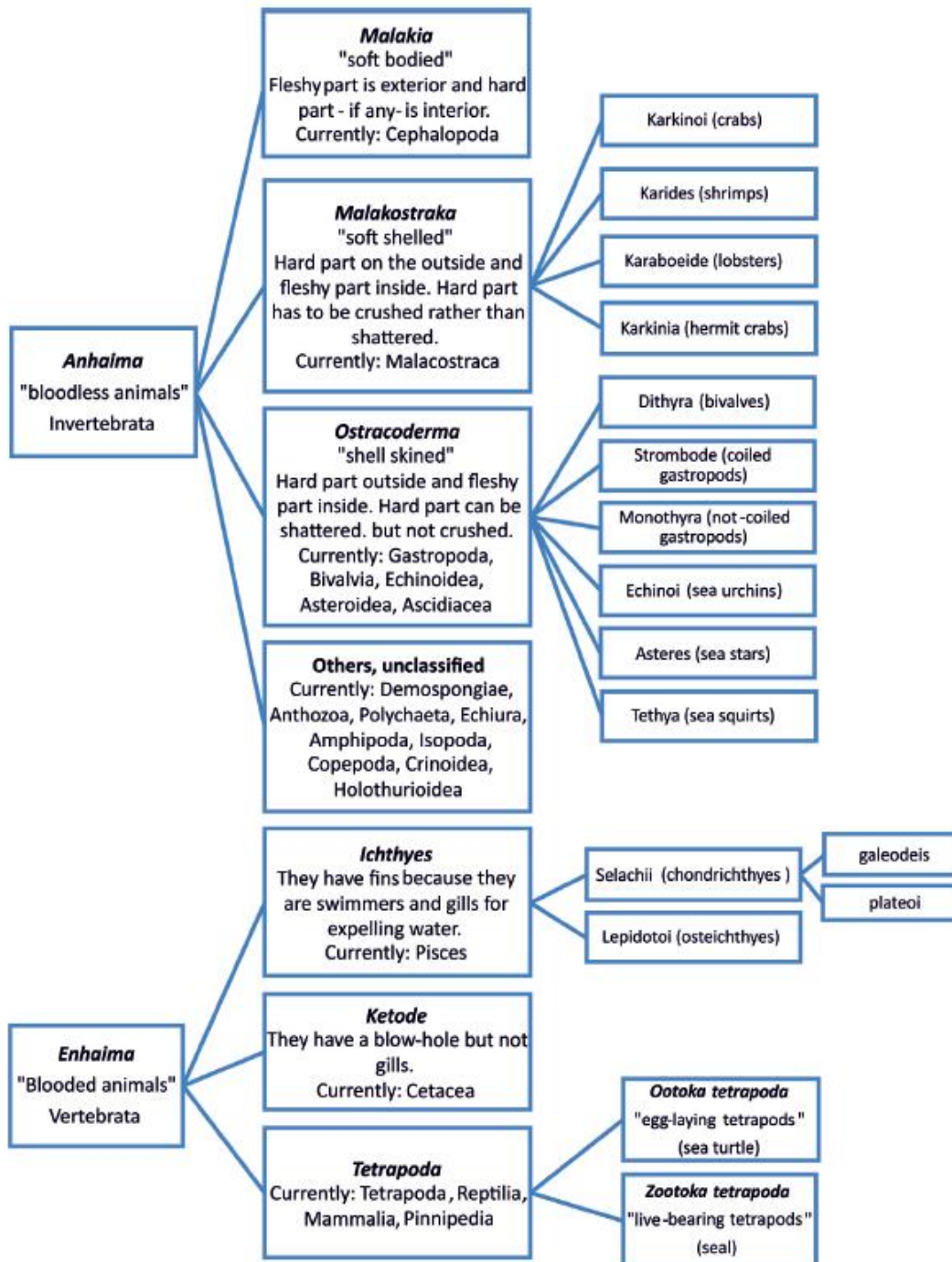
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## Appendix I: Aristotle's classification



Schematic representation of Aristotle's marine animal taxonomic classification including the diagnostic characters for each group. Bold italics indicate Aristotle's names Latinized and the English translation of these names are inside quotation marks. The general morphological characters and the corresponding current taxa are given for each animal group (Voultsiadou et al., 2017).

Appendix II: Three kingdom concept

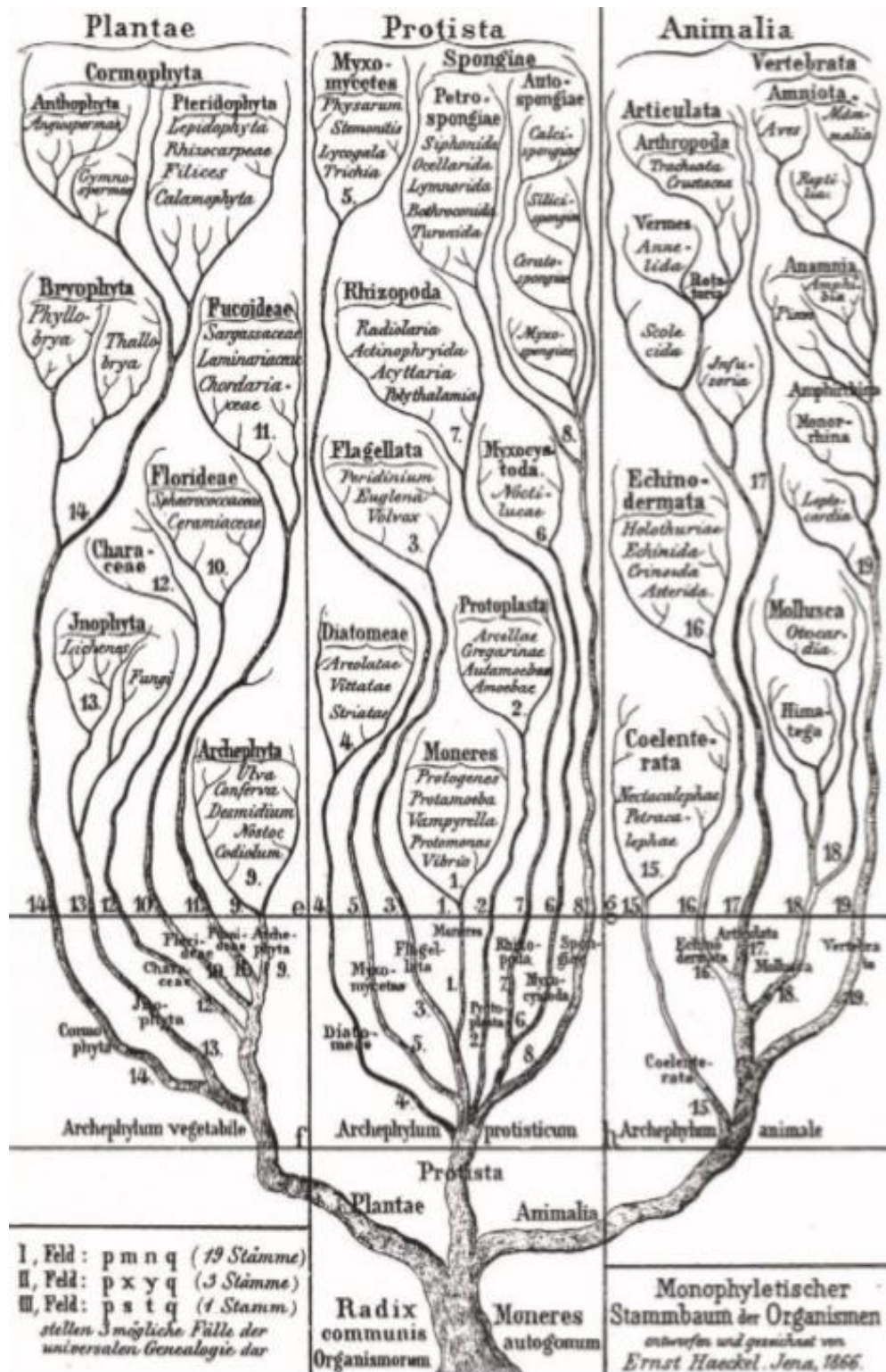


Figure 5. Reproduction of Ernst Haeckel's genealogical oak tree depicting the Kingdoms Plantae (plants), Protista (micro-organisms) and Animalia (animals) (Kutschera, 2011).

## Appendix III: Databases

Global Species Databases (GSD)	
World List of marine Acanthocephala	World Mangroves database
World List of Actiniaria	World List of Merostomata
World Amphipoda Database	World List of Merostomata
AnnelidaBase Under construction	MolluscaBase
World List of Antipatharia	World List of Monogenea
World List of Appendicularia	MilliBase
Ascidacea World Database	World Database of littoral Myriapoda
World Ascothoracida Database	World List of Lophogastrida, Stygiomysida and Mysida
World Asteroidea Database	World List of Mystacocarida
DiatomBase	World List of Myxozoa
World List of Bochusacea	Nemys: World Database of Nematodes
World List of Brachypoda	World Nemertea Database
World List of marine Brachyura	World List of Octocorallia
World List of Bryozoa	World List of Marine Oligochaeta
World List of Cephalochordata	World Ophiuroidea Database
World List of Ceriantharia	World List of Orthonectida
World List of Cestoda	World Ostracoda Database
World Cetacea Database	World Paguroidea & Lomisoidea database
World List of Chaetognatha	World Placozoa Database
World Ciliophora Database	World Polychaeta database
World Cladocera database Under construction	World List of Polycystina (Radiolaria)
Global Compositae Database Under construction	World Porifera Database
World of Copepods database	World List of Priapulida
World List of Corallimorpharia	Pycnobase: World Pycnogonida Database
World List of Crinoidea	World Remipedia Database
World List of Cubozoa	World List of Rhizocephala
World Cumacea Database	World List of Rhombozoa
World Echinoidea Database	World List of Scleractinia
World List of Echiura	World List of Scyphozoa
World Euphausiacea Database	World Sipuncula database
World Foraminifera Database	World List of Staurozoa
World Gastrotricha Database	World List of Tanaidacea
World List of Gnathostomulida	World List of Tantulocarida
Hemichordata World Database	World List of Tardigrada
World List of Holothuroidea	World List of Thaliacea
World Hydrozoa Database	World List of Thermosbaenacea
World Marine, Freshwater and Terrestrial Isopod Crustaceans database	World List of Trematoda
World List of Kinorhyncha	World List of turbellarian worms: Acoelomorpha, Catenulida, Rhabditophora
World List of Leptostraca	World List of Xenoturbellida

World List of Loricifera	World List of Zoantharia
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Regional Species Databases (RSD)	
African Register of Marine Species	Chinese Register of Marine Species
Belgian Register of Marine Species	European Register of Marine Species
Belgian Register of Marine Species (2020) Under construction	Gulf of Mexico Register of Marine Species
Black Sea checklist for Ocean-Ukraine & Sibema	Hong Kong Register of Marine Species
Canadian Register of Marine Species	Marine Species of the British Isles and Adjacent Seas (MSBIAS): a checklist of species derived from the UNICORN and Marine Recorder applications
Checklist Azores	Marine Species Register for the North Western Atlantic Ocean
Checklist Greece	New Zealand Register of Marine Species (volume I)
Checklist Iberian	Register of Antarctic Marine Species
Checklist Ireland	Register of Antarctic Species
Checklist Israel	Scheldt Species Register
Checklist Poland	The Arctic Register of Marine Species (ARMS) compiled by the Arctic Ocean Diversity (ArcOD)
Checklist Sweden	Chinese Register of Marine Species

Thematic Species Databases (TSD)	
Belgian Introduced Marine Species (under construction)	UNESCO-IOC Register of Marine Organisms (URMO)
Freshwater Gastropods of the European Neogene database (FreshGEN)	World Register of Deep-Sea species (WoRDSS)
IOC-UNESCO Taxonomic Reference List of Harmful Micro Algae	World Register of Introduced Marine Species (WRiMS)
North Sea Benthos Project (NSBP)	World Register of Marine Cave Species (WoRCS)
North Sea Benthos Survey (NSBS)	

External Global Species Databases (EGSD)	
AlgaeBase	The Reptile Database
FishBase	World Rotifera database (FADA)
Phylum Ctenophora: list of all valid species names	

World Register of Marine Species. (2019) Species Databases. Retrieved from <http://www.marinespecies.org/subregisters.php>

## Appendix IV: Definitions

Below you can find definitions of all the new descriptors that were added to the data file.

descriptor	definitions
Spawning	Free spawning is defined as the release of sperm into the environment, whereas broadcast spawning is defined as the release of both eggs and sperm into the environment. Males can free spawn, pseudocopulate (release sperm directly on females or transfer a spermatophore), or copulate (release sperm within a female's reproductive tract). Females can broadcast spawn, brood eggs on an external surface, or brood eggs internally (after internal fertilization). By definition, broadcast spawning is always accompanied by free spawning but not vice versa; in many taxa males release sperm, but fertilization is either internal or on some external surface of the female (Birkhead & Møller, 1998).
Incubation period	Embryo development of egg-laying individuals (Quora, no date).
Gestation period	Embryo development of life-bearing individuals (Quora, no date).
Egg loss	Number of eggs lost during embryo development
Hatching	Hatching of egg-laying individuals
Live-bearing	Viviparous animals refer to the animals that give birth to develop live young individuals. These animals possess special organs which supply nutrients for the development of the embryo (Panawala, 2017).
Mating	A mating system describes how male and female interactions are built around choosing mates (Breed & Moore, 2015).
Moulting	The shedding or casting off of an outer layer or covering and the formation of its replacement (Encyclopaedia Britannica, 2017).
Moult cycle	A species can moult periodically (for instance annually).
Moulting size	How much did the species grow from before the moulting until after the moulting?
Moulting frequency	How many times does the species moult?
Distribution	Depending on their history and their dispersal capabilities, species can either occupy large areas or be restricted to small regions. This can be native as well as alien or invasive (Mexican biodiversity, no date).
Growth in captivity	First generation offspring (F1) means specimens produced in a controlled environment from parents of which at least one was conceived in or taken from the wild, most often called born in captivity. Second generation offspring (F2) and subsequent generation offspring (F3, F4, etc.) means specimens produced in a controlled environment from parents that were also produced in a controlled environment, most often called born and bred in captivity. A controlled environment means an environment that is manipulated for the purpose of producing animals of a particular species, that has boundaries designed to prevent animals, eggs or gametes of the species from entering or leaving the

	controlled environment, and the general characteristics of which may include, but are not limited to, artificial housing, waste removal, health care, protection from predators and the artificial supply of food (European Commission, 2019).
Growth in natural environment	Growth of wild living species.
Feeding	How does the species feed; feeding techniques?
Preyed upon by	This species is eaten by a number of other species.
Preys on	This species eats a number of other species; similar to food type/diet
Activity	When is the species actively feeding or reproducing?
Native range	Native range is defined in the 1981 act as: the locality to which the animal or plant of that type is indigenous, and does not refer to any locality to which that type of animal or plant has been imported (whether intentionally or otherwise) by any person (Scottish Natural Heritage, 2019).
Range expansion	Expansion of their natural geographical range. Can occur naturally or true human invention (accidentally or on purpose).
Toxic/poisonous	Is the species toxic or poisonous for humans or other animals?
Human use	Is it a human resource? What do we use it for or gain from it?
Threats	An indication of imminent harm, danger, or pain (Collins, 2020).
Ecosystem services	Ecosystem services are the direct and indirect contributions of ecosystems to human well-being (TEEB D0). They support directly or indirectly our survival and quality of life. According to TEEB, ecosystem services can be categorized in four main types: Provisioning services are the products obtained from ecosystems such as food, fresh water, wood, fiber, genetic resources and medicines. Regulating services are defined as the benefits obtained from the regulation of ecosystem processes such as climate regulation, natural hazard regulation, water purification and waste management, pollination or pest control. Habitat services highlight the importance of ecosystems to provide habitat for migratory species and to maintain the viability of gene-pools. Cultural services include non-material benefits that people obtain from ecosystems such as spiritual enrichment, intellectual development, recreation and aesthetic values (Biodiversity Information System for Europe, no date).
Subspecies	A category in biological classification that ranks immediately below a species and designates a population of a particular geographic region genetically distinguishable from other such populations of the same species and capable of interbreeding successfully with them where its range overlaps theirs (Merriam-Webster, 2020).

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Distribution descriptors:							
Depth	non specific	5-70 m	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Elevation		not applicable					
Environment		marine	<a href="https://www.iucnredlist.org/species/169975/1281221">https://www.iucnredlist.org/species/169975/1281221</a>				
Habitat: environmental position	all life stages	epifaunal, demersal	<a href="http://www.marlin.ac.uk/species/detail/1145">http://www.marlin.ac.uk/species/detail/1145</a>				
Habitat: physiography		open coast, offshore seabed	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Habitat: salinity		full (30-40 psu)	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Habitat: substratum	adult/juvenile	bedrock, large to very large b	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Habitat: tidal streams and water flow	non specific	naturally occurring P. elephas	Hunter, E. (1999). Biology of the european spiny lobster, <i>Palinurus elephas</i> (Fabricius, 1787)(Decapoda, Palinuridea). <i>CRUSTACEANA-INTE</i>				
Habitat: tolerance							
Habitat: wave exposure	all life stages	extremely exposed, very exp	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Habitat preferences	adult/juvenile	Artificial (man-made), Bedro	<a href="https://www.marlin.ac.uk/species/detail/1145">https://www.marlin.ac.uk/species/detail/1145</a>				
Province	all life stages	neritic	<a href="https://www.iucnredlist.org/species/169975/1281221">https://www.iucnredlist.org/species/169975/1281221</a>				
Vertical biological zone or Zonation	all life stages	circalittoral	<a href="https://www.marlin.ac.uk/biotic/browse.php?sp=4113">https://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Distribution		South and west coasts of the	<a href="http://www.marlin.ac.uk/species/detail/1145">http://www.marlin.ac.uk/species/detail/1145</a>				
Ecological descriptors:							
Body shape							
Flexibility	non specific	none (<10 degrees)	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Fragility	non specific	intermediate	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Growth form	non specific	articulate	<a href="http://www.marlin.ac.uk/species/detail/1145">http://www.marlin.ac.uk/species/detail/1145</a>				
Height (above substratum)							
Supporting structures and enclosures	adult/juvenile	exoskeleton	<a href="https://eol.org/pages/46516728">https://eol.org/pages/46516728</a>				
Ecological interactions							
Ecophysiology: oxygenation tolerance							
Ecophysiology: growth rate	non specific	12 m/year	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Growth in captivity	adult	ovac (1965) reported growth	Hunter, E. (1999). Biology of the european spiny lobster, <i>Palinurus elephas</i> (Fabricius, 1787)(Decapoda, Palinuridea). <i>CRUSTACEANA-INTE</i>				
growth in natural environment	adult	Between 1966 and 1974, Hep	Hunter, E. (1999). Biology of the european spiny lobster, <i>Palinurus elephas</i> (Fabricius, 1787)(Decapoda, Palinuridea). <i>CRUSTACEANA-INTE</i>				
Ecophysiology: photosynthetic pigment(s)		not applicable					
Ecophysiology: temperature tolerated	non specific	12°C-16°C; preferred 11°C	<a href="https://www.sealifebase.ca/summary/Palinurus-elephas.html">https://www.sealifebase.ca/summary/Palinurus-elephas.html</a>				
Feeding	adult	Campillo & Amadei (1978) ex	Hunter, E. (1999). Biology of the european spiny lobster, <i>Palinurus elephas</i> (Fabricius, 1787)(Decapoda, Palinuridea). <i>CRUSTACEANA-INTE</i>				
Feeding method/behaviour	all life stages	omnivore	<a href="http://www.marlin.ac.uk/species/detail/1145">http://www.marlin.ac.uk/species/detail/1145</a>				
Food type/diet	adult	echinoderms, small gastropo	<a href="http://www.marlin.ac.uk/species/detail/1145">http://www.marlin.ac.uk/species/detail/1145</a>				
Food type/diet	adult	In feeding trials, fresh fish w	Hunter, E. (1999). Biology of the european spiny lobster, <i>Palinurus elephas</i> (Fabricius, 1787)(Decapoda, Palinuridea). <i>CRUSTACEANA-INTE</i>				
Food type/diet	non specific	A full list of recorded stomac	HUNTER, E., 1994. Fishery biology of the crawfish <i>Palinurus elephas</i> , in South Wales and Cornwall. Final report to MAFF Chief Scienti				
Preyed upon by	non specific	Scorpaena, Epinephelus mar	<a href="https://eol.org/pages/46516728">https://eol.org/pages/46516728</a>				
Preys on	non specific	Ophiuroidea, Plantae,	<a href="https://eol.org/pages/46516728">https://eol.org/pages/46516728</a>				
Mode of life: dependency	all life stages	independent	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Mode of life: sociability	adult	gregarious	<a href="http://www.marlin.ac.uk/species/detail/1145">http://www.marlin.ac.uk/species/detail/1145</a>				
Mode of life: support	adult	substratum; Encrusting speci	<a href="https://www.marlin.ac.uk/species/detail/1145">https://www.marlin.ac.uk/species/detail/1145</a>				
Movement: dispersal potential (adult)	adult	>10 km	<a href="http://www.marlin.ac.uk/biotic/browse.php?sp=4113">http://www.marlin.ac.uk/biotic/browse.php?sp=4113</a>				
Movement: migration	adult/juvenile	active	<a href="http://www.marlin.ac.uk/species/detail/1145">http://www.marlin.ac.uk/species/detail/1145</a>				
Movement: mobility	adult/juvenile	swimmer, crawler	<a href="https://www.marlin.ac.uk/species/detail/1145">https://www.marlin.ac.uk/species/detail/1145</a>				
Activity	adult	nocturnal; more active at nig	<a href="https://www.marlin.ac.uk/species/detail/1145">https://www.marlin.ac.uk/species/detail/1145</a>				

The table below shows the species traits of *Mytilus galloprovincialis*.

<b>Species importance to society:</b>							
CITES		not evaluated	<a href="https://www.sealifebase.ca/summary/Mytilus-galloprovincialis.html">https://www.sealifebase.ca/summary/Mytilus-galloprovincialis.html</a>				
FAO-ASFIS							
Habitat Directive							
IUCN Red list		not evaluated	<a href="https://www.sealifebase.ca/summary/Mytilus-galloprovincialis.html">https://www.sealifebase.ca/summary/Mytilus-galloprovincialis.html</a>				
Native range		the native species range is in t	<a href="https://www.cabi.org/isc/datasheet/73756">https://www.cabi.org/isc/datasheet/73756</a>				
Range expansion		into the Atlantic has been natu	<a href="https://www.cabi.org/isc/datasheet/73756">https://www.cabi.org/isc/datasheet/73756</a>				
Invasive species		<i>Mytilus galloprovincialis</i>	<a href="http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions">http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions</a>				
Abundance		abundant in its native range	<a href="https://www.cabi.org/isc/datasheet/73756">https://www.cabi.org/isc/datasheet/73756</a>				
Impact		<i>M. galloprovincialis</i> is consider	<a href="https://www.cabi.org/isc/datasheet/73756">https://www.cabi.org/isc/datasheet/73756</a>	the success with which i	Saarman, N. P., Kober, K. M., Simison, W. B., & Pogson, G. H. (2017). Sequence-bas		
Invasiveness_1		uncertain, invasive, uncertain,	<a href="http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions">http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions</a>				
Location type_1		North Pacific Ocean (united Sta	<a href="http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions">http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions</a>	species is also found in	<a href="https://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions">https://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions</a>	Mediterranean and Black sea, China	
Occurrence_1		reported, established and stab	<a href="http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions">http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions</a>				
Origin_1		alien	<a href="http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions">http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#distributions</a>				
Pathways/vector		The Mediterranean mussel, <i>M</i>	<a href="https://www.cabi.org/isc/datasheet/73756">https://www.cabi.org/isc/datasheet/73756</a>	Introduction to these re	<a href="https://www.cabi.org/isc/datasheet/73756">https://www.cabi.org/isc/datasheet/73756</a>		
location type_2		China, Hong Kong (introduced)	<a href="https://www.cabi.org/isc/datasheet/73756">https://www.cabi.org/isc/datasheet/73756</a>				
MSFD Indicators		Annex 2 Black Sea Biodiversity	<a href="http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#attributes">http://www.marinespecies.org/introduced/aphia.php?p=taxdetails&amp;id=140481#attributes</a>				
OSPAR							
<b>Extra descriptors:</b>							
Toxic/poisonous							
Human use		commercial	<a href="https://www.sealifebase.ca/summary/Mytilus-galloprovincialis.html">https://www.sealifebase.ca/summary/Mytilus-galloprovincialis.html</a>				
Threats		<i>Vibrio coralliilyticus</i> it represe	<a href="https://www.ncbi.nlm.nih.gov/pubmed/30300739">https://www.ncbi.nlm.nih.gov/pubmed/30300739</a>				
Ecosystem services							

## Appendix VI: Species lists

	<b>Vandepitte, 2019</b>	<b>Voultsaidou et al., 2017</b>	<b>Gaines, Mezarli &amp; Voultsiadou, 2017</b>	<b>Voultsiadou &amp; Vafidis, 2007</b>
1	Sarcotragus foetidus	Sarcotragus foetidus		Sarcotragus muscarum; unaccepted
2	Hippospongia communis	Hippospongia communis		Hippospongia communis
3	Spongia lamella	Spongia (Spongia) lamella		Spongia agaricina; different name, same species
4	Spongia officinalis	Spongia (Spongia) officinalis		Spongia officinalis
5	Spongia zimocca	Spongia (Spongia) zimocca		Spongia zimocca
6	Actinia equina	Actinia equina		Actinia equina
7	Anemonia viridis	Anemonia viridis		Anemonia viridis
8	Alcyonium palmatum	Alcyonium palmatum		Alcyonium palmatum (prev. Veretillum cynomorium)
9	Pelagia noctiluca	Pelagia noctiluca		Alcyonium palmatum
10	Pholas dactylus	Pholas dactylus		Pholas dactylus
11	Mytilus galloprovincialis	Mytilus galloprovincialis		Mytilus galloprovincialis
12	Ostrea edulis	Ostrea edulis		Ostrea edulis
13	Pinna nobilis	Pinna nobilis		Pinna nobilis
14	Loligo vulgaris	Loligo vulgaris		Loligo vulgaris
15	Argonauta argo	Argonauta argo		Argonauta argo
16	Eledone moschata	Eledone moschata		Eledone moschata
17	Octopus vulgaris	Octopus vulgaris		Octopus vulgaris
18	Todarodes sagittatus	Todarodes sagittatus		Todarodes sagittatus
19	Sepia officinalis	Sepia officinalis		Sepia officinalis
20	Cerithium vulgatum	Cerithium vulgatum		Cerithium vulgatum
21	Charonia variegata	Charonia variegata		Charonia tritonis; unaccepted
22	Haliotis tuberculata	Haliotis tuberculata		Haliotis tuberculata
23	Patella caerulea	Patella caerulea		Patella caerulea
24	Phorcus turbinatus	Phorcus turbinatus		Monodonta turbinata; unaccepted
25	Hermodice carunculata	Hermodice carunculata		Hermodice carunculata

26	Bonellia viridis	Bonellia viridis		Bonellia viridis
27	Calappa granulata	Calappa granulata		Calappa granulata
28	Eriphia verrucosa	Eriphia verrucosa		Cancer pagurus
29	Maja squinado	Maja squinado		Maja squinado
30	Homarus gammarus	Homarus gammarus		Homarus gammarus
31	Ocypode cursor	Ocypode cursor		Ocypode cursor
32	Pontonia pinnophylax	Pontonia pinnophylax		Pontonia pinnophylax
33	Palinurus elephas	Palinurus elephas		Palinurus elephas
34	Pinnotheres pisum	Pinnotheres pisum		Pinnotheres pisum
35	Liocarcinus depurator	Liocarcinus depurator		Polybius depurator
36	Potamon fluviatile; accepted			
37	Scyllarus arctus	Scyllarus arctus		Scyllarus arctus
38	Squilla mantis	Squilla mantis		Squilla mantis
39	Antedon mediterranea	Antedon mediterranea		Antedon mediterranea
40	Paracentrotus lividus	Paracentrotus lividus		Paracentrotus lividus
41	Sphaerechinus granularis	Sphaerechinus granularis		Sphaerechinus granularis
42	Cidaris cidaris	Cidaris cidaris		Cidaris cidaris
43	Brissus unicolor	Brissus unicolor		Brissus unicolor
44	Microcosmus sabatieri	Microcosmus sabatieri		Halocynthia papillosa & Phallusia mammilata
45	Scyliorhinus canicula	Scyliorhinus canicula	Scyliorhinus canicula	
46	Scyliorhinus stellaris	Scyliorhinus stellaris	Scyliorhinus stellaris	
47	Mustelus mustelus	Mustelus mustelus	Mustelus mustelus	
48	Mobula mobular	Mobula mobular	Mobula mobular	
49	Squalus acanthias	Squalus acanthias	Squalus acanthias	
50	Anguilla anguilla	Anguilla anguilla	Anguilla anguilla	
51	Conger conger	Conger conger	Conger conger	
52	Muraena helena	Muraena helena	Muraena helena	
53	Atherina hepsetus	Atherina hepsetus	Atherina hepsetus	
54	Hirundichthys rondeletii	Hirundichthys rondeletii	Hirundichthys rondeletii	

55	Carassius carassius	Carassius carassius	Carassius carassius	
56	Cyprinus carpio	Cyprinus carpio	Cyprinus carpio	
57	Phycis blennoides	Phycis blennoides	Phycis blennoides	
58	Cepola macrophthalma	Cepola macrophthalma	Cepola macrophthalma	
59	Coryphaena hippurus	Coryphaena hippurus	Coryphaena hippurus	
60	Labrus mixtus	Labrus mixtus	Labrus mixtus	
61	Dicentrarchus labrax	Dicentrarchus labrax	Dicentrarchus labrax	
62	Mugil cephalus	Mugil cephalus	Mugil cephalus	
63	Mullus barbatus barbatus	Mullus barbatus barbatus	Mullus barbatus	
64	Mullus surmuletus	Mullus surmuletus	Mullus surmuletus	
65	Perca fluviatilis	Perca fluviatilis	Perca fluviatilis	
66	Chromis chromis	Chromis chromis	Chromis chromis	
67	Sparisoma cretense	Sparisoma cretense	Sparisoma cretense	
68	Sarda sarda	Sarda sarda	Sarda sarda	
69	Scomber colias	Scomber colias	Scomber colias	
70	Scomber scombrus	Scomber scombrus	Scomber scombrus	
71	Anthias anthias	Anthias anthias	Anthias anthias	
72	Diplodus sargus sargus	Diplodus sargus sargus	Diplodus sargus sargus	
73	Oblada melanura	Oblada melanura	Oblada melanura	
74	Pagellus erythrinus	Pagellus erythrinus	Pagellus erythrinus	
75	Pagrus pagrus	Pagrus pagrus	Pagrus pagrus	
76	Sarpa salpa	Sarpa salpa	Sarpa salpa	
77	Sparus aurata	Sparus aurata	Sparus aurata	
78	Trachinus draco	Trachinus draco	Trachinus draco	
79	Uranoscopus scaber	Uranoscopus scaber	Uranoscopus scaber	
80	Xiphias gladius	Xiphias gladius	Xiphias gladius	
81	Silurus aristotelis; accepted		Silurus aristotelis	
82	Syngnathus acus	Syngnathus acus	Syngnathus acus	
83	Zeus faber	Zeus faber	Zeus faber	
84	Monachus monachus	Monachus monachus		
85	Balaenoptera physalus	Balaenoptera physalus		

86	Phocoena phocoena relict	Phocoena phocoena relict		
87	Physeter macrocephalus	Physeter macrocephalus		
88	Caretta caretta	Caretta caretta		
89	Echeneis neucrates	Echeneis naucrates	Actinopterygii (class)	
90		Muricidae sp1 (family)		Bolinus brandaris
91		Muricidae sp2 (family)		Hexaplex trunculus
92		Muricidae sp3 (family)		Stramonita haemastoma
93		Veneridae sp. (family)		Arca noae
94		Holothuriidae sp. (family)		Holothuria forskali