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Systemic biases in micropaleontology: A case study of calcareous nannofossil taxonomic names

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Abstract The names given to fossil genera and species describe physical characteristics, identify important geographic or stratigraphic information, or can be used to honor people. Yet taxonomy has a history of colonialism, with most taxa being named by men from Europe and North America. Compared to other paleontological subdisciplines, calcareous nannofossil micropaleontology is a newer field and is therefore assumed to have fewer entrenched biases. Here, I investigate the taxonomic etymology of calcareous nannofossils to determine how names reflect a known partiality in the geosciences, with a summary of taxon etymologies that demonstrates substantial geographic and gender biases. Despite many contributions from nannofossil paleontologists identifying as women, they are vastly underrepresented. Although international collaboration is crucial for acquiring data, trends also indicate a strong bias toward naming taxa after people, localities, and stratigraphy from Europe and North America. The propensity to use this limited range of descriptors indicates that paleontology and geosciences are plagued with implicit biases. Therefore, we must overcome social, cultural, economic, and geographic barriers to make calcareous nannofossil micropaleontology more inclusive and accessible for all genders, localities, and marginalized groups.

Keywords Micropaleontology, nannofossil taxonomy, etymology, systemic bias, representation, diversity, equity, inclusion

1. Introduction

Taxonomy is a crucial aspect of paleontology and appeases the innate desire to classify objects based on traits, real or imagined. It allows us to determine the evolutionary ancestry of extinct organisms and their environmental or ecological affinities. Therefore, a well-defined and strictly hierarchical taxonomic naming system ensures we speak a "common language" when comparing fossils despite temporal and spatial differences.

In many ways, taxonomy is a unique expression of paleontological creativity. A taxon's name may describe the fossil's basic morphology or crystal alignment, whereas some names provide essential information about the taxon's spatiotemporal characteristics. A name may convey honor, respect, gratitude, or even love between an author and another person or locality. Conversely, many taxon names can be insensitive or offensive, as evidenced by the historical use of the Linnean classification scheme to insult rivals or name indigenous taxa after colonialists and non-indigenous politicians (Rummy and Rummy, 2021). Furthermore, using Greek and Latin is a significant roadblock to equity as it relies on the cultural knowledge of those languages and favors the European-North American scientific establishment.

Taxonomy often reflects science's colonial past; for example, most African birds are named after people with European last names (Trisos et al., 2021). Paleontology is not immune to this culturally skewed history. Our understanding of the fossil record is biased by the dominance of researchers from Europe and North America who largely sampled their homelands and minimized the contributions of paleontologists and fossils from Africa, Asia, and Latin America (Raja et al., 2022). Paleontology in North America has also been based on extracting fossils from indigenous peoples/lands, generating long-lasting and wide-ranging harms (Monarrez et al., 2022).

Taxonomy also reflects gender disparity in the sciences. For example, 87% of Aloe species (a plant) are named after men compared to 13% that are named after women (Figueiredo and Smith, 2010; Heard, 2020). Because Latin is a gendered language, taxonomy is also one of the most prominent displays of these biases. By convention, nannofossil species named after men are given male suffixes and those named after women female suffixes. This is often without regard to how the person being honored self-identifies and does not allow for the inclusion of the broader lesbian, gay, bisexual, transgender, queer, plus individuals whose orientations differ from those who identify as heterosexual and cisgender (LGBTQ+) community (Rummy and Rummy, 2021).

Because calcareous nannofossil paleontology has only been an "established" science since the 1960s, it is possible that it has not been as influenced by these biases compared to other disciplines with a longer, more entrenched history. Calcareous nannofossil paleontology is thought to be a relatively diverse field because, in large part, it requires international deep-sea drilling partnerships to obtain data. In addition, during the 1960s and 1970s, several prominent women pioneered the study of calcareous nannofossil micropaleontology, including Katharina von Salis (Perch-Nielsen), Carla Müller, Denise Noël, Helene Manivit, and Hanna Górka. Today, numerous women continue to make substantial contributions to calcareous nannofossil taxonomy. Based on these observations, I hypothesized that the extent of the biases discussed above should not be as prominent in calcareous nannofossil taxonomy and, if present, it may reflect more significant systemic issues within this field of study.

2. Data and Methods

2.1. Nannofossil Taxonomy Data Compilation

The overall objective of this study is to examine systemic biases in paleontology using calcareous nannofossils as a case study, so extant taxa with no fossil record were excluded from the analysis. I compiled a database of all Cenozoic and Mesozoic nannofossil genera and species listed on the Nannotax website (Young et al., 2023). The database contains the genus or species name, author, year of publication, etymology, and etymological category (see Section 2.2). The database also includes for each taxon a "Name Locality", which refers to the general geographic region from which the name was derived. For example, if the taxon was named after a person, place, or stratigraphic section from Europe, the "Name Locality" category will list "Europe". In total, there are 314 genera and 1702 species of calcareous nannofossil in the database, together with contributions from 120 authors of genera and 271 authors of species. The database file is archived on Zenodo (Schueth, 2023; https://doi.org/10.5281/zenodo.8074717).

Information in the database primarily came from the Farinacci and Howe (1969–2022) catalog of calcareous nannofossils, also hosted on the Nannotax website. While most modern taxonomists include etymologies in their species descriptions, many past authors did not. To determine these uncertain etymologies, I carried out an extensive internet search for the epithet of the Greek and Latin root words in online dictionaries. The Internet search primarily relied on websites with biographical information, obituaries, author lists of publications, and employment histories for academic institutions or petroleum companies. Most etymological information outside of Latin dictionaries came from memorials, obituaries, news articles, or association newsletters. It would be impractical to go over every instance in this paper; however, I provide two unique examples that illustrate how I determined uncertain etymologies.

Reinhardt (1961) did not include an etymology for the Mesozoic genus *Watznaueria* in his description. However, the suffix, as well as the unique root, shows that it was named after a person with the last name Watznauer. An internet search of "geologist" or "paleontologist" with "Watznauer" led me to Adolf Watznauer, a German geologist who was employed by the Freiberg University of Mining and Technology from 1953 to 1972. This information was gleamed from webpages, such as this German Wikipedia page: https://de.wikipedia.org/wiki/Adolf_Watznauer. In another example, Risatti (1973) named several new taxa but gave no etymology for any of them. For the taxon *Munarius lesliae*, I was able to deduce from Risatti's online obituary that this taxon was named after his mother, whose last name was Munarin, and his wife, Leslie. In this way, most taxon etymologies have been defined. However, some etymologies may be uncertain, and are noted as such in the comments in the databased, and 63 taxa have unknown etymologies that are marked as "**undet**" in the database.

2.1. Etymological Categories

The taxa were subdivided into the following categories: descriptive, age/stratigraphy, location/place, eponyms, or other. The selected categories are the same as, or similar to, those used by authors of similar studies (e.g., Mammola et al., 2022).

2.2. Systematic palaeontology

Descriptive etymologies are the most common etymologies in the database, and include fossil shape, size, unique features, extinction patterns in cross-polarized light, and crystallography of the coccolith or nannolith. Because etymologies for these types of names are easy to deduce (based on a translation from Latin), it was not necessary to list the etymology in the database for those taxa listed as "**descriptive**".

2.2.2. Age and Stratigraphy

While rare, some taxa are named after the stratigraphic position or geologic age of the strata in which they were found. For example, *Axopodorhabdus albianus* (Black, 1967) Wind & Wise, 1983 was named after the Albian stage/age of the Early Cretaceous and the genus *Speetonia* Black, 1971 was named after the Speeton Clay in England. The geographic origin of the corresponding name is listed in the database to highlight the biases of naming fossils after specific localities/stratigraphic sections. For example, 11 out of 12 Cretaceous stage names were derived from localities in France, with the 12th referring to a Dutch city.

2.2.3. Location/Place

In the database, taxa marked "**place**" refer to fossils named after type localities where the holotype specimens were discovered. They also can indicate other geographic information associated with that taxon. For instance, the species *Ramsaya swanseana Risatti*, 1973 is an example of the latter. The species name "*swanseana*" does not reference the type locality but instead the geographic location of the person the genus was named after, Anthony T. S. Ramsay. Ramsay lived and worked in Swansea, Wales (Risatti, 1973). In the database these "place-based" etymologies were given an additional label describing geographic regions (Africa, Asia, Europe, Latin America, North America, Oceania) from which their name was derived or labeled "ocean" if they were named after oceans or marine basins.

2.2.4. Eponyms

The second most common type of taxon etymology is the honorific eponym derived from personal names; species eponyms are gendered based on the perceived gender of the honoree. By convention, all genera are given the Latin female gender regardless of the gender of the person they are named after. I subdivided eponyms to "**PersonM**" for taxa named after men, and "**PersonF**" for those named after women. Gender identity is an issue for eponyms, so I attempted to discern gender identity using personal experience, published biographies (such as those found on professional websites), or in the case of deceased honorees, written memorials (e.g., H. Manivit's memorial published in the INA Newsletter in 1991). Please note that my intention is not to misgender anyone in this research; however, this is difficult to address when many honorees are no longer living.

2.2.5. Other

Many taxa were also named after boats, mythology, and fictional characters; these are marked "**other**" in the database. Additionally, some taxa have uncertain etymologies, despite an exhaustive search. As a result, these names are labeled as "**undet**" in the database.

2.3. Methods

Using the database, each category was analyzed to identify time-related trends. However, it should be noted that the number of publications per year varies through time, presenting a caveat. There were several instances where many new taxa were described in one year, whereas the following year had very few or no new taxa published. To account for the variability in the number of taxa published yearly, a 5-year moving average was calculated for each category. This entailed using time series analysis to smooth out highly variable data and derive half-decadal trends.

3. Results

3.1. Taxonomic Publication Dates and Authors

Most nannofossil genera and species were published in the late 1960s through the early 1980s, with a mean/median publication date of 1973/1971 for genera and 1981/1977 for species (Figure 1). Of the 279 individuals listed as authors in the database, twenty were authors for a majority (57%) of all taxa; the top ten taxon authors for each category are listed in Table 1. These authors named a total of 143 (46%) and 1012 (59%) of all genera and species, respectively. Of the top twenty authors, only three are women: Katharina von Salis (Perch-Nielsen), Jackie Lees (Burnett), and Denise Noël, and together they authored only 10% of all nannofossil genera and species.

3.2. Categorization of Genera and Species Names

Most genus and species names are descriptive (70% and

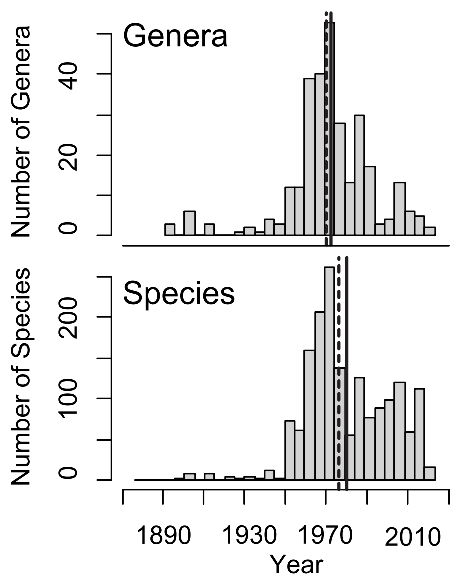

Figure 1: Histograms showing taxon publication dates. The black vertical line is the mean value, and the dashed vertical line is the median value. Publication dates range from 1890 to 2020, with most taxa published between 1960 and 1980. Mean/median publication dates for genera and species respectively are 1973/1971 and 1981/1977. Note that both the median and mean for species is a few years younger than that of genera.

63%, respectively; Figure 2). The most common categories for genus/species are Person-Male (14%/20%), Place (4%/8%), and Person-Female (5%/5%). For eponyms, most of taxa are named after men (76% for genera, 79% for species; Figure 2). In addition, several prominent female nannofossil micropaleontologists are represented amongst people after which taxa were named (Table 2). The most common people honored with epithets are listed in Table 2.

3.3. Categorical Trends

The proportion of genera and species with descriptive names, male eponyms, and female eponyms were plotted against the corresponding 5-year moving average for each category (Figure 3). The findings indicate that proportions of taxa with descriptive names have declined in recent years. In contrast, the number of taxa named after women has increased, although it has only rarely peaked above 20% (Figure 3). There has also been a more recent decline in the number of taxa named after women (Figure 3), although this may reflect fewer publications in recent years (Figure 1). The proportion of women eponyms has also increased since 1950, especially noted by proportions >20% since 2010 (Figure 4). Therefore, in more recent years, a taxon was more likely to be named after a woman, and women were more likely to be honored with an eponym than in previous decades (Figures 3 and 4). Despite these trends, men are still overall more likely to be honored with an eponym than women.

3.4. The Location of Origin for Taxonomic Names

Most genera and species are named after a place, person, or stratigraphy from Europe or North America (Figure 5). On average, the proportion of taxa named after Euro-American people and places rarely dips below 80% and is almost always 100% (Figure 5). The observed trend has been consistent through the studied interval, although descrease from 80% to 60% between 2016 and 2020.

4. Discussion

4.1. Trends in Nannofossil Taxonomic Names

The Deep Sea Drilling Project (DSDP) commenced in 1968, and the discoveries revolutionized calcareous nannofossil micropaleontology through identification of many new species found in the marine records recovered by the program. Publication of new calcareous nannofossil genera and species peaked in the 1980s and has generally declined since (Figure 1). On average, most calcare-

Table 1: The top 10 authors of genera and species and the number of taxa in each category they authored.

Genus Author	Number of Genera	Species Author	Number of Species
Wise	17	Lees (Burnett)	104
Black	15	Bown	78
Wind	14	von Salis (Perch-Nielsen)	57
Deflandre	12	Bukry	51
Noël	12	Bergen	47
Bown	10	Black	43
Lees (Burnett)	9	Wise	40
von Salis (Perch-Nielsen)	8	Deflandre	38
Thierstein	8	Wind	35
Lambert	7	Varol	32

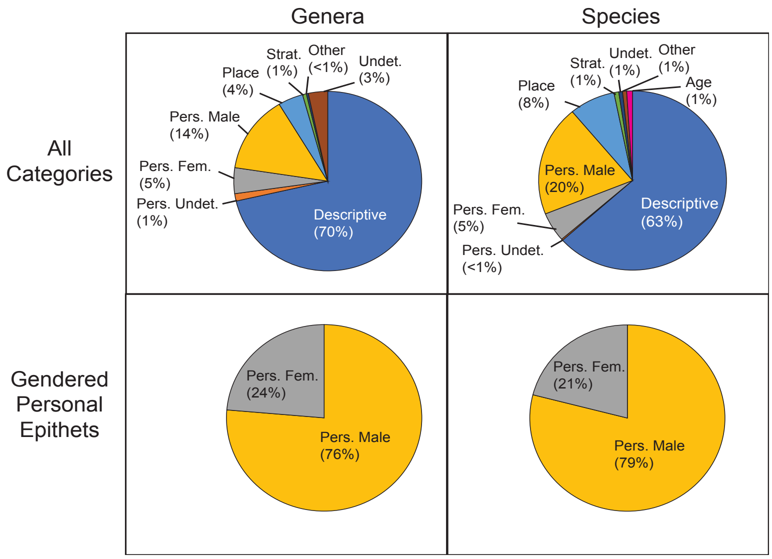

Figure 2: Pie charts representing the breakdown in generic (left) and species (right) names by category. The top row shows the breakdown of all categories. Most taxa have descriptive names, but the second most common category of epithets is personal names with the male suffix (Pers. Male). The bottom row shows the breakdown in the percentage of eponyms between those named after men (or, more accurately, have the male suffix) and those after women (have the female suffix). For both genera and species, men represent >75% of all eponyms.

ous nannofossil genera were named earlier than species. Thererarely were more than 10 genera named each decade after 1980, whereas several hundreds of species have been named in each subsequent decade (Figure 1). Therefore, any purposeful attempts to reduce bias in taxon names in more recent years may be overshadowed by today's lower publication rates, although species may show less biased names because more have been published in recent years (Figure 1). I have attempted to mitigate this by comparing proportions rather than absolute counts and applying moving averages to the data.

Few taxonomists authored most taxa (Table 1), reflecting the level of specialization required to do taxonomic work. However, people honored with taxonomic eponyms are more evenly dispersed (Table 2). Only three individuals, David Burky, Denise Noël, and Milton Bramlette, have six taxa named after them, and twenty-three individuals were honored with three or more eponyms (Table 2). The disparity between the distribution of taxonomic eponyms and the top authors suggests that eponyms are likely more reflective of the calcareous nannofossil community. Therefore, it is plausible that the trend in eponym data through time reflects systemic biases, or lack thereof, in the nannofossil community.

Descriptive names make up most epithets, and while 70% of genera are descriptive, only 63% of species are (Figure 2). This difference is likely a result of a higher number of species relative to genera; as a result, there is more opportunity to use non-descriptive names. The distribution of non-descriptive epithets shows that taxonomists are most likely to name a species or genus after a man (Figure 2).

Table 2: List of all people with more than three taxa named after them. Values are sorted from the highest to lowest. Of all people honored with more than three taxa, women, denoted in bold, make up 15%.

Taxon Epithet Honors:	Number of Taxa
Noël, Denise	5
Bukry, David	4
Reinhardt, Peter	4
Stradner, Herbert	4
Covington, Mitch	3
Górka, Hanna	3
Hay, William W	3
Thierstein, Hans	3
Varol, Osman	3
von Salis (Perch-Nielsen), Katharina	3
Watkins, David	3
Arkhangelsky, Andrey	2
Bown, Paul	2
de Kaenel, Eric	2
Deflandre-Rigaud, Marthe	2
Frank, Tracy	2
Gartner, Stefan	2
Kamptner, Erwin	2
Nicholas, Chris	2
Pearson, Paul	2
Prins, Ben	2
Stover, Lewis	2
Svábenická, Lilian	2
Wind, Frank	2
Wise, Woody	2

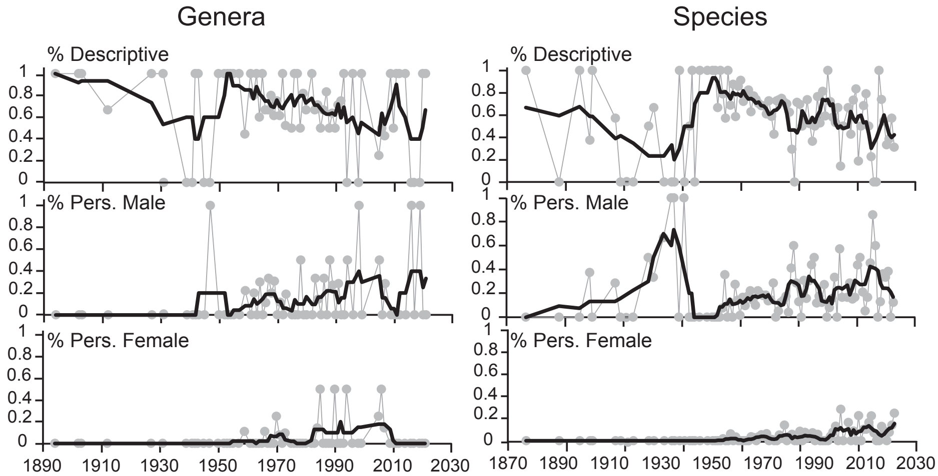

Figure 3: Trends in main categories of epithets plotted against publication year for genera (left) and species (right). All plots include the raw data (gray circles) and a five-point moving average (black line). Top: The proportion of descriptive names. Note how the proportion of descriptive epithets has declined in recent years for both species and genera. Middle: The proportion of male eponyms. Bottom: The proportion of female eponyms. Specifically, these plots indicate that the proportion of species named after women has increased since ca. 1950, but for both genera and species, men are much more likely to be honored with an eponym than women.

There has been an overall decline in the number of genera and species with descriptive epithets through time (Figure 3). A similar trend has been observed in the taxonomy of other flora and fauna (Figueiredo et al., 2010; Mammola et al., 2023). The reduced frequency of descriptive names may indicate that scientific Latin and Greek usage is waning, and that there is a general lack of education in these languages (Figueiredo et al., 2010; Mammola et al., 2023). Without experience with Latin or Greek, it is easier for authors to add a Latin suffix to a geographic location or personal eponym than it is to determine correct Latin adjectives and conjugation. For example, I co-described several species of Cretaceous calcareous nannofossils that used a variety of epithet types (Lees, Schueth, and Howe in Schueth and Lees, 2019). One taxon, *Pharus clarescopoli*, was named from the Latin "becomes bright at the end of an axis." Another taxon, *Gartnerago waszczakii*, was named after a mentor of mine. In the latter, a simple appending of the "*ii*" Latin suffix to the surname was all that was needed to make the name valid, whereas the former required experience and knowledge of scientific Latin. Without the background, education, or cultural association with Latin, descriptive names are a significant hurdle for many modern taxonomists.

4.2. Gender Bias in Calcareous Nannofossil Taxonomy

As stated, confirming a person's gender identity was beyond the scope of this study. I am at times agnostic to the true gender identity of either the group of authors or the eponym honorees, despite a sometimes extensive effort to determine this (see Section 3.1). It is entirely possible that some people identified as "men" or "women" (i.e., have a male or female suffix in the epithet) may not identify as such. It is also generally assumed that the author of the taxon would have taken their honoree's identity into account, but there is no explicit rule for doing so. That said, comparing the eponyms named after men and women show most eponyms are based on males (76–79%; Figure 2). In contrast, only 15% of the top 20 taxon authors are women, which is similar to, albeit slightly less, than the proportion of female eponyms. However, there is an increasing trend in women being honored with an eponym. The proportion of women was 0% (ca. 1950), 20% (ca. 1970–1990), and 30–60% since 2000 (Figure 4). The increase in the proportion of women honorees may indicate conscious efforts to reduce gender bias, or an increase in the number of women geoscientists (Bernard and Cooperdock, 2018).

A counterargument to the presence of gender bias in taxonomy is that these proportions reflect the gender distribution of calcareous nannofossil micropaleontologists. This argument can further be supported using Table 2, where there is a relatively even distribution of genders honored by names. This is also seen in the broader geoscience community, where PhDs earned by women in Earth sciences have steadily increased from ~20% (ca. 1985) to 50% (ca. 2015; Bernard and Cooperdock, 2018). If the data reported herein reflected the demographic makeup of

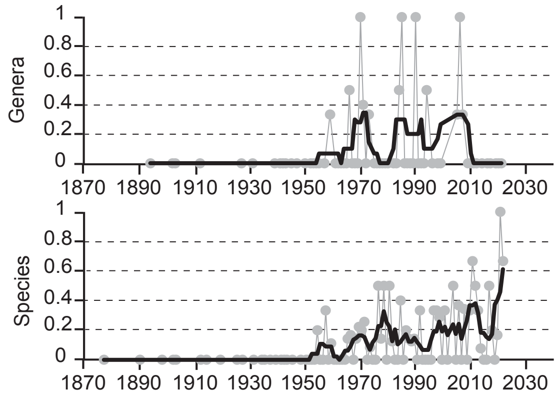

Figure 4: Proportion of female:male eponyms where gray represents the data, and the black solid line is the five-point moving average. Overall, there is an increasing trend toward naming more taxa after women. Women generally were not honored with eponyms until the 1950s and the proportion of women honored with species epithets has steadily risen. The exception is the lack of genera named after women since 2010.

paleontology, I would expect similar proportions in eponyms, but this is not the case. We have had less than 30% female eponyms in recent years, and no genus has been named after a woman since 2010 (Figure 4). Given the inverse relationship between Earth science data and that presented herein, I argue that the eponym data reflect a gender bias towards naming taxa after men.

4.3. Geographic Bias in Nannofossil Taxonomy

An overwhelming majority of taxon names are derived from locations in Europe or North America (Figure 5). Although it varies from year-to-year, on average, taxa are more than 80% likely to be named after a person or locality in Europe or North America (Figure 5). The average has declined in recent years, especially among species; however, the proportion is still >60% (Figure 5). These data show a clear bias in epithets towards Europe and North America, which is surprising given the international nature of calcareous nannofossil micropaleontology. Such biases are prevalent across paleontology and are likely skewing the interpretation of the history of life (Raja et al., 2021).

The years during which fewer European-American epithets were published correlate with increased studies of calcareous nannofossils from outside of those regions. For example, an increase in African-derived names in the late 2000s corresponds to the publication of results from the Tanzanian Drilling Project (TDP), which led to the discovery of a calcareous nannofossil lagerstätte with exceptional nannofossil preservation and the subsequent naming of several new taxa after people and places in Tanzania (e.g., Bown and Dunkley Jones, 2005; Lees, 2007). While the TDP represents a unique case where exceptional preservation led to the discovery of numerous new species, it still shows that work focused on areas outside of Europe and North America increases the likelihood that authors will use more geographically inclusive names.

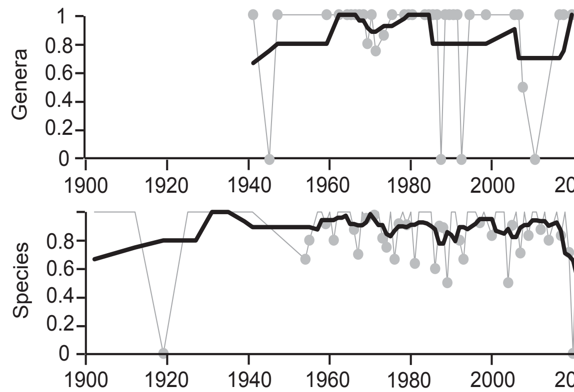

Figure 5: The proportion of European-North American genera and species names through time. Although this has been relatively steady for genera through time, species have seen a slight decline (on average). The latter went from >80% to <60% during the mid-2000s.

The recent decline in the average proportion of Euromerican-derived names could be due to the calcareous nannofossil community's purposeful attempts to make the science more equitable. Historically, the International Nannoplankton Association meetings were held in Europe or North America, but since 2010 have included locations in Japan, the Philippines, and Brazil, which shows a clear and intentional attempt to make calcareous nannofossil research more inclusive. Yet, given the data outlined in Figures 5 and 6, taxa are still overwhelmingly named after people, places, and stratigraphy in Europe and America. Although significant progress has been made regarding inclusion and diversity, more work is needed.

4.4. Systemic Issues in Nannofossil Paleontology

Outside of descriptive names, nannofossils are more likely to be named after men, places, or stratigraphy from Europe and North America. I must stress that I am not attempting to accuse any taxonomist of purposefully excluding women, nor specifically refusing to name taxa for places outside of Europe and America. What I have illustrated herein mirrors the trends seen in the geosciences at large, where women only hold 10% of academic positions (Holmes et al., 2015), are less likely to receive positive letters of recommendation than men (Dutt et al., 2016), and there is entrenched favoritism towards white men (Dutt, 2020; Marín-Spiotta et al., 2020).

Taxonomy requires experience and specialized knowledge that must be passed on from established taxonomists. Because calcareous nannofossil taxonomy started in Europe and North America, the first taxonomists were more likely to train students in those areas. Additionally, it is cost prohibitive for people outside of those areas to travel or study in entrenched taxonomic schools. This preselects a biased group of taxonomists who are like those who are already established in the discipline. Taxonomic work also requires powerful microscopes, high-definition cameras, and access to scanning electron microscopy, creating significant roadblocks to equitability. The cost of this equipment is outside the financial capacity of most researchers without considerable funding. These barriers block access to aspiring paleontologists without economic means and preselects those with careers in the petroleum industry or academic institutions in the United States and Europe.

The locations where calcareous nannofossil research occur are likely significant sources of bias. Until the advent of DSDP, most publications on nannofossil taxonomy described species from type sections in Europe or North America, and this still occurs today. Calcareous nannofossil research on localities outside Europe and North America are often published in low-impact, regional journals that many nannofossil specialists will not see. The dominance of taxa named after people and places in Europe and North America (Figure 5) is direct evidence that there is a need for further inclusion of nannofossil paleontologists from around the world.

5. Conclusions and Recommendations

My research into the etymologies of calcareous nannofossil names has shown how extensively systemic biases overshadow our science. A way to reduce bias is through targeted efforts to make taxonomy and epithets more inclusive. Recent publications of numerous dinosaur fossils discovered in China use Mandarin or a mix of local languages and Latin in the Linnaean system (Trisos et al., 2021). For example, the dinosaur genus *Beibeilong* is derived from the Mandarin for "baby dragon" (Pu et al., 2017). A similar allowance in calcareous nannofossil taxonomy could open the field up to those outside of the Euromerican hegemony. At an extreme end, the most equitable path forward would be to do away with Latin and Greek all together, or even allow multiple names for a single taxon in different languages (as suggested by Trisos et al., 2021), but this creates issues with communication between different researchers. The nannofossil taxonomic community should work to eliminate the gendered suffixes of eponyms to be more inclusive of the LGBTQ+ community (Rummy and Rummy, 2021). Requiring the use of more descriptive epithets, providing resources for learning scientific Latin, or being mindful of representing more diverse people and places are easily achievable goals.

The scientific community should strive to lessen the economic and educational roadblocks inherent in nannofossil taxonomy. The financial and academic support of researchers in underrepresented communities and nations should be at the forefront of efforts. Research authored by those outside of Europe and America must be read, understood, and cited. We must also acknowledge and celebrate the contributions of the many women calcareous nannofossil paleontologists. Implementing these steps can create a future of inclusive, equitable science that celebrates efforts from people of all races, genders, ethnicities, and socio-economic backgrounds.

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