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Per Theodor Cleve (1840-1905): The Prolific Part-Time Protistologist and Oceanographer

Review paper

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Abstract. Per Theodor Cleve is known as a 19th century chemist, credited with discovery of two rare-earth elements. However, throughout his distinguished career as a chemist, he was also a protistologist. From 1863 to 1905, Cleve published prodigiously on protists, authoring over 70 works totaling about 2,500 pages, and he described numerous taxa, especially from the marine plankton. Notably, many of Cleve's works are still cited today. His work concerning the utility of certain protist species in characterizing water masses has been recognized in histories of Oceanography. However, Cleve is not a familiar name to many of us, as he has been consistently overlooked in histories of protistology. Here, first Cleve's life is summarized, and then his contributions to protistology, and oceanography, are reviewed to show his significant, and neglected, contributions to the fields.

Keywords: History of Protistology, diatoms, radiolaria, dinoflagelllates, desmids, biogeography

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INTRODUCTION

The last half of the 19th century was a period of tremendous advances in both biology and earth sciences. It was the era of Charles Darwin, Alfred Russel Wallace, and the Challenger Expedition. In protistology, many landmark works appeared such as Christian Ehrenberg's *Mikrogeologie* (Ehrenberg 1854-1856), Edouard Claparéde and Johannes Lachmann's *Etudes sur Infusoires et les Rhizopodes* (Claparéde and Lachmann 1858-1861), Otto Bütschli's *Protozoa* (Bütschli 1880-1889), Ernst Haeckel's monograph on the radiolaria of the Challenger Expedition (Haeckel 1887), and William Saville-Kent's *Manual of the Infusoria* (Saville-Kent 1880-1882). Among those active during that remarkable period was Per Teodor Cleve. It will shown here that he made significant contributions to protistology, but his name does not appear in the histories of protistology of Cole (Cole 1926) or Kudo (Kudo 1954) nor is he mentioned by Corliss in his historical accounts (Corliss 1978, 1979, 1991, 1997).

The relative obscurity of Cleve with regard to protistology is likely due to two main factors. The first is that although he published prolifically on protists over a long period time, he did not produce a monograph of major general interest such as those mentioned above. The second factor is that for Cleve, protistology was a hobby. His academic specialty, or his 'day job', was not biology; it was chemistry and he was actually a chemist of very considerable renown, for example, noted as a pioneer of chemistry in Smith's 1921 weekly series in *Nature*, "The Calendar of Scientific Pioneers". Cleve was Professor of Chemistry at the University of Uppsala from 1874 to 1905 and is credited with the discovery in 1879 of the

elements holmium (Thorton and Burdette 2015) and thulium (Arnold 2017). He was named a Foreign Member of the Chemical Society (London) in 1883, awarded the prestigious Davy Medal by the Royal Society (London) in 1894 (Anon. 1894), given an honorary doctorate by the University of Edinburg (Anon. 1896), and was the chairman of the Nobel Prize for Chemistry Committee from 1901 until his death in 1905 (Cleve and Cleve 1905).

Interestingly, the several honors bestowed on Cleve for his work as chemist were actually preceded by two honors for his work on protists. The first was in 1868, being named an Honorary Member of the Finnish scientific society, Societas pro Fauna et Flora Fennica (Anon. 1905-1906). Then, in 1879, Cleve was named an Honorary Member of the Royal Microscopical Society, the same year as Otto Bütschli, and Louis Pasteur were named as Honorary Members (Turner 1989). Thus, today famous for discovery of two new elements, Cleve was early in his career as a chemist, also recognized for his work on protists, specifically, diatoms and desmids. He would go on to publish a total of 72 protistological studies, describing a wide variety of protist taxa, and become known in oceanography through his proposal to use certain protist taxa as indicators of water masses. Here, first, the singular life of Per Teodor Cleve will be briefly described. The biographical sketch will be followed by a concise review of his protistological works, identifying his major works, those still regularly cited today. Finally, the regard in which Cleve has been held by protist taxonomists, since his time, and into the present era, will be shown through consideration of the number and variety of protist species named for Cleve. This essay will hopefully serve to both shine a light on a neglected worker, and show how much a 'part-time protistologist' could accomplish!

THE SINGULAR LIFE OF PER TEODOR CLEVE

The following account is based largely on the brief memorial notice by Cleve's son-in-law the chemist Hans Euler and his daughter Astrid Euler Cleve (Euler and Euler 1905), and the substantial notice by Hans Euler (1906). In the latter, the Danish biologist Carl H. Ostenfeld who worked with Cleve in the early 1900's, is credited with supplying the text, and likely the bibliography, concerning Cleve's work as a biologist, which is to say as a protistologist. Unfortunately, there is little information available concerning Cleve's youth. He was born on February 10, 1840 in Stockholm, the youngest, and 13th child of F.T. Cleve and Sofia Ulrika Glansberg. He is said to have been, in contrast to his older siblings, an ardent naturalist and inclined towards academic pursuits. He graduated from high school and began attending Uppsala University in 1858. At the University, Cleve was apparently mentored by the chemist Lars Fredrik Svanberg, and despite his love for natural history, Cleve chose to pursue chemistry as it offered better career perspectives than geology or biology. In 1861, he published his first paper, "On some ammoniacal chromium compounds" in a journal of the Swedish Royal Academy of Sciences, *Öfversigt af Kongliga Svenska Vetenskaps-Akademiens Förhandlingar* (Cleve 1861). By 1862, Cleve managed to complete the coursework, and pass the examinations, to become a Doctoral Candidate in Chemistry and in 1863, at the age of 23, defended his doctorate and became a Docent in Chemistry at the University. Cleve took a position as Associate Professor of Chemistry at the Technological Institute in Stockholm in 1870. Early on, Cleve was a prolific author. By 1870, he had published ten papers on chemical topics, three papers on minerals, and six papers on protist taxa. In 1874, at age 34, he returned to Uppsala University to head the Chemistry Department when his mentor, Svanberg, retired. It was only after classes, and during his evenings, that Cleve devoted himself to his favorite work, protistology (Euler and Euler 1905). Cleve remained at Uppsala until his retirement in 1905 at age 65, when he became entitled to retire. From then on, he devoted himself entirely to work on protists and oceanography. It is said that of all the honors he received during his career, the one honor, which gave him the most joy, was that of being

named an Honorary Member of the Royal Microscopical Society. Sadly, Cleve died of pleurisy on June 18, 1905, just a few months after his retirement. Figure 1 shows Cleve through the ages, from a young Ph.D. at age 24 to the retired Professor, at 65 years of age, shortly before he died. Cleve left behind his wife of 31 years, Carolina Alma Cleve (1845-1927), his daughter Astrid Cleve (1875-1968) who followed her father's footsteps and worked on chemistry and extensively on diatoms, Agnes Cleve (1876-1951) who became a painter, and Célie Cleve (1882-1980) who became a journalist. Cleve also left behind a very considerable scientific production. Hans Euler's memorial notice (Euler 1906) lists 73 publications on topics of chemistry, and 63 publications on topics of "biology and hydrography", most of which concerned, at least in part, protists. In reality, Cleve's protist publications actually number 72, as some were missing from Euler's bibliography. In the following section, Cleve's work on protists will be summarized in some detail to show that he deserves not only the recognition he receives today as an important figure of 19th century chemistry, but also as a notable 19th century protistologist.

Fig. 1. Per Theodor Cleve. From left to right: at age 24 (1864) when was a university Docent; at age 38 (1878), a young Professor of Chemistry; at age 60 (1900), a renown chemist and protistologist; and at age 65 (1905), recently retired and shortly before his death.

THE PROTISTOLOGICAL WORK OF PER TEODOR CLEVE

As alluded to above, Cleve's protistology publications started to appear shortly after he began publishing his chemical work. His first works on protists, published in 1863, were studies of

freshwater chlorophytes such as desmids (Cleve 1863a,b,c). In 1867, he published his first paper on diatoms. It concerned the diatoms of the Arctic, both marine and freshwater (Cleve 1867). Diatoms would soon become his major protistological expertise. By the end of his career, Cleve had described new species of diatoms from a very wide range of localities, literally from Arctic to Antarctic waters. In 1873, Cleve began publishing articles in English with a report on diatoms from surface waters of the Java Sea (Cleve 1873). It was followed by a report on diatoms of the Caribbean Sea, based on collections he himself had made in 1868-1869 (Cleve 1878). Interestingly, many of Cleve's subsequent publications concerning protists were in English, in contrast to his articles on topics of chemistry, most of which were in Swedish. Cleve's protist publications exclusively concerned diatoms up to the mid-1890's by which time he had become a recognized diatom expert and even a diatom merchant. He sold sets of slides with identified diatom species in collaboration with a renowned maker of slides containing artistic arrangements of diatoms, Johann Diedrich Möller (Burba 2007). The offering of the first set was noted in *Quarterly Journal of Microscopical Science* (Anon. 1877). An example of one of Cleve and Möller's slides is shown in figure 2. The slides would presumably have been used for teaching. Cleve was a regular and major contributor to the first journal devoted to diatoms, *Le Diatomiste*; he was listed on the cover as a 'collaborator' with other well-known diatom specialists of the late 19th century and in the journal, Cleve published many articles in French (e.g., Cleve 1890, 1891).

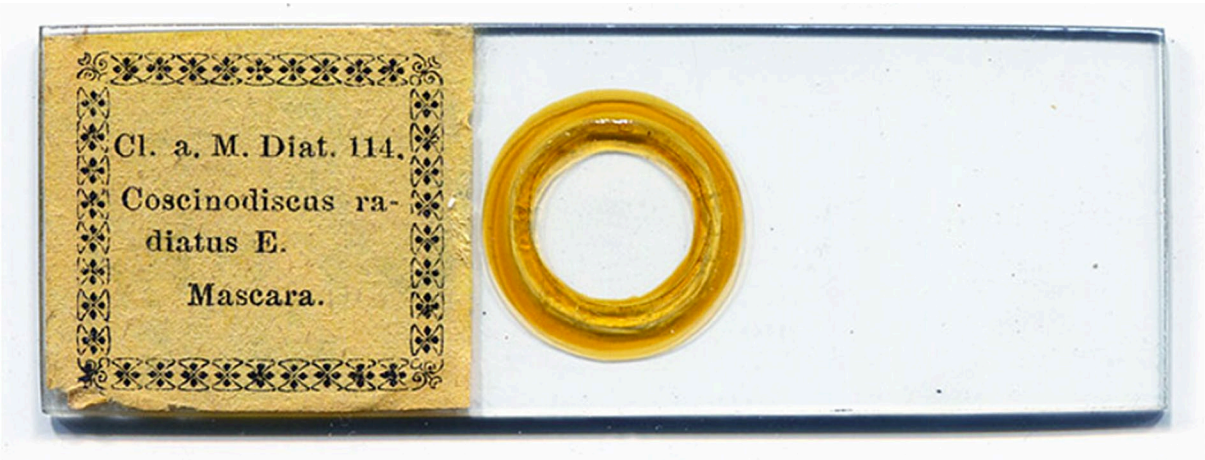

Fig. 2. One of Cleve and Möller's diatom slides. The label indicates that it is the Cleve and Möller slide 114 (Cl. a. M. Diat. 114) containing *Coscinodiscus radiatus* Ehrenberg in material collected in Mascara (Oran, Algeria). It is part of the set sold in 1878 (see https://hwpi.harvard.edu/diatoms/cleve-moller). The image of the slide is from http://microscopist.net/mollerjd.html

Cleve's diatom publications were, for the most part, taxonomic works. His major diatom monograph concerned naviculoid diatoms (Cleve 1894-1895). Many of his diatom publications, i.e., those concerning only diatoms, were reminiscent of Ehrenberg's publications in that they were detailed reports of species found in material sent to him by a members of a large network of correspondents, and the publications often included 'new species'. For example, one of his papers was a report on diatoms in material from both Greenland and Argentina and included several new species (Cleve 1881). Dr. N.O. Holst supplied the Greenland samples, and the samples from Argentina were supplied by Dr. O. Nordstedts. Again like Ehrenberg, Cleve worked on both recent and fossil forms (e.g. Cleve 1885, 1899a; Cleve and Jentzsch 1882). Throughout his career, Cleve described hundreds of 'new' species of diatoms. According to the WoRMS database (WoRMS 2024), Cleve is credited with 664 diatom species descriptions. Today, most of his 'new' diatom species are considered 'unassessed', meaning that Cleve's descriptions have not been critically examined, or are considered junior synonyms, that is, species previously described.

Cleve's protistological turn towards oceanography appear to have begun in 1893. It was in 1894 that he presented his account of the dinoflagellates and diatoms in plankton net tows

conducted himself in 1893, and others in 1894, as part of Swedish hydrographic investigations in Gulmar Fjord, on the West coast of Sweden. His report was entitled "Account of the Swedish hydrographic surveys, the years 1893-1894. II. Plankton surveys, Cilicoflagellates and Diatomaceae." Cleve stated that seasonal changes in the composition of the phytoplankton community, in terms of dominance by either dinoflagellates or diatoms, were evident, as well depth-related differences in community composition, and that both were relatable to differences in temperature and salinity (Cleve 1894). Cleve's study was one of the first to draw attention to the composition of the phytoplankton specifically, certain species of dinoflagellates and diatoms, as potentially important to fisheries, signaling the seasonal arrival of herring. Cleve then proposed the composition of the phytoplankton community as a useful marker of distinct water masses and currents, and, importantly, the value of investigating protists as an oceanographic topic, in an essay entitled "Microscopic marine organisms in the service of hydrography". It was published in *Nature* in 1896 (Cleve 1896), and re-printed in the *Journal of the Marine Biological Association* in 1897 (Cleve 1897). His essay put forward the important proposition that

> *".... the still obscure causes of the migration of fishes may be found to be intimately connected with the change of water containing different kinds of plankton."*

Cleve's 'different types of plankton' were characterized by the presence of a particular species, and most were conspicuous species of dinoflagellates or diatoms (see Table 1), these protist species were markers of entire, complex assemblages of organisms up to and including those exploited in fisheries. Cleve proposed a classification system of assemblages of planktonic organisms, eventually including not only dinoflagellates and diatoms, but also, ciliates, radiolaria, copepods, cladocera and gelatinous zooplankton (e.g. Cleve 1899b, c). Thus,

Cleve, overlooked in histories of protistology, is in the histories of oceanography, credited with having drawn attention to the existence of distinct of plankton assemblages, characterized by the presence of particular protist species (i.e., Schlee 1973, Mills 1989). In so doing, Cleve brought attention to the protists of the marine plankton, described as a 'valiant effort' (Lucas 1980). It must be admitted that Cleve's conviction that particular species were reliable indicators of the origin of water masses and currents led him to propose some oddities. Cleve declared that, based on his studies of plankton of the Benguela current, the Gulf stream waters crossing the North Atlantic do not originate in the Gulf of Mexico, as was believed in his time and is still known to be the case, but rather that Gulf Stream waters originate off the West coast of Africa as an undercurrent (Cleve 1900). It should be pointed out that Cleve's contribution to oceanography was not limited to his characterization of plankton assemblages and water masses. Cleve was also active in the foundation and early years of the International Council for the Exploration of the Sea (ICES), the oldest existing international oceanographic organization. For example, Cleve participated in the early survey cruise of the Swedish Hydrographic Surveys, on board the steamer Holsatia (fig. 3), sampling plankton in August of 1901 (Cleve and Pettersson 1903). Cleve also was involved in setting out the protocols for plankton sampling, that specifically included sampling for the protists of the plankton, to be employed in ICES surveys (Cleve and Ostenfeld 1903).

Table 1. In Cleve's typology of plankton communities, all were named for a protist species, with the exception of Desmoplankton, named for cyanobacterial genus *Trichodesmium*. From Cleve (1897) "A treatise on the Phytoplankton of the Atlantic and its tributaries and on the periodical changes of the plankton of Skagerak".

Plankton community type	**typical species**	**current species name**
Triposplankton	*Ceratium tripos*	*Tripos muelleria*
Styliplankton	*Rhizosolenia styliformis*	same
Chaetoplankton	*Chaetoceros borealis*	same
Desmoplankton	*Trichodesmium*	same
Trichoplankton	*Synedra thalassiothrix*	*Thalassiothrix longissima*
Siraplankton	*Thalassiosira nordenskioeldii*	same
Didymusplankton	*Chaetoceros didymus*	same
Northern neritic plankton	*Leptocylindrus danicus*	same
Arctic coast plankton	*Coscindiscus bioculatus*	*Thalassiosira bioculata*
Concinnusolankton	*Coscinodiscus oculus*	same
Halosphaeraplankton	*Halosphaera viridis*	same

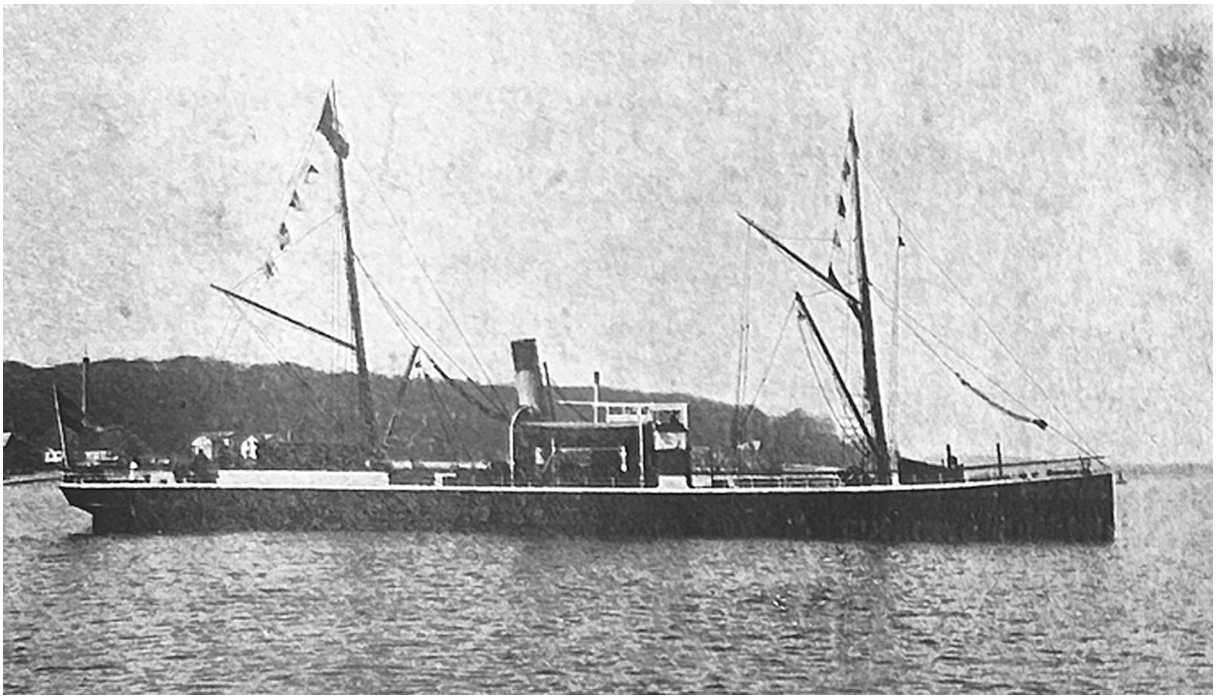

Fig. 3. The Swedish steamer *Nolsatia* used in a survey cruise in the Skagerack (the strait between Denmark, southern Norway and western Sweden) in August of 1901. Cleve sampled the plankton with a fine silk net, and recorded the presence of species of diatoms, dinoflagellates, tintinnid ciliates, and radiolaria; he classified the plankton assemblages encountered in terms of his typology given in Table 1 (Cleve and Pettersson 1903).

Cleve's oceanographic studies led him to expand his expertise in protistology to include groups other than what he termed 'vegetable forms' (i.e. chlorophytes, diatoms and dinoflagellates) to include the 'animal forms', tintinnid ciliates and radiolaria that he encountered in plankton samples. Cleve's major work with regard to tintinnids is his article "Some Atlantic Tintinnodea" (Cleve 1899a) in which he described 11 new species of tintinnid ciliates. The article containing Cleve's most significant contribution to our knowledge of radiolaria is likely his report on samples gathered during the Swedish Expedition to Spitzbergen in 1898 (Cleve 1899b), reviewed in detail by Bjørklund et al. (2014) in which Cleve described 10 new species of radiolaria. The number of species descriptions of different protist taxa, currently considered valid first descriptions credited to Cleve, is shown in Fig. 4. Descriptions of diatoms are clearly his numerically greatest contribution to protistology. However, he is also credited with the respectable numbers of new species of tintinnid ciliates, radiolaria, desmids, dinoflagellates and phaeodaria. In total, Cleve is currently credited with the valid first description of 130 species of protists (data from WoRMS Editorial Board 2024). Most of Cleve's publications focused on, or featuring in least in part, protists appeared after 1890 (Fig. 4) when he was a well-established chemist, just a few years from retirement and thus able to devote most of his time to protistology and oceanography. Many of his works during the last phase of his life were large data reports listing occurrences of a multitude of species found in samples from Northern European waters.

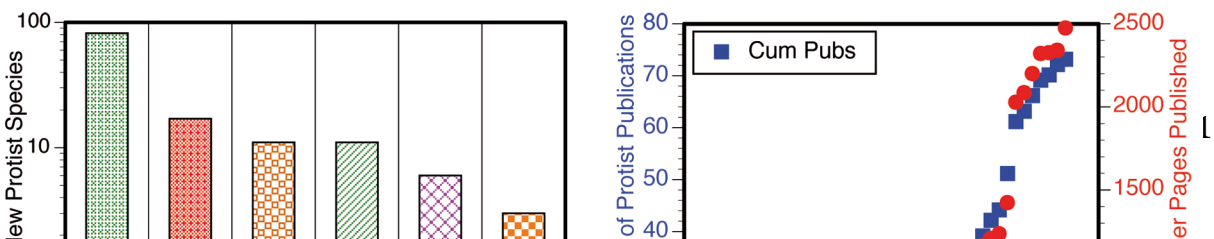

Fig. 4. Numbers of protist species, by taxon, first described by Cleve, currently recognized as valid first descriptions (left panel) and the temporal trends of Cleve's publications, in whole or in part, devoted to protists (right panel), in terms of cumulative number of publications (Cum Pubs) and cumulative number of pages published (Cum Pages).

The PROTISTOLOGICAL LEGACY OF PER TEODOR CLEVE

The legacy of Cleve's protistology work is not restricted to the species he described or to the impressive quantity of his publications. Many of his studies, the last of which date to 123 years ago, are still cited today. Table 2 lists the ten publications of Cleve that have received the most citations over time since publication, and the number of citations these works have received since 2020. No doubt many of us would be pleased if told that our own papers were going to be cited in the 22nd century!

Table 2. The ten most cited publications of Cleve. The publications are listed in descending order of the total number of citations since publication (∑cites), and also shown are citations of each from 2020 to 2024 (recent cites). Citation data is from Google Scholar in October 2024.

∑cites	recent cites	Reference
965	116	Cleve P.T. (1894-1895) Synopsis of the Naviculoid Diatoms. *Bihang Kong. Svenska Vetenskaps-Akademiens Handl.* **26**:1-194, 5 plates; **27**:1-219, 4 plates
504	62	Cleve P.T., Grunow, A. (1880) Beiträge zur Kenntniss der Arctischen Diatomeen. *Bihang Kong. Svenska Vetenskaps-Akademiens Handl*. **17**: 1-121, 7 plates.
206	14	Cleve P.T. (1873) On diatoms from the Arctic Sea. *Bihang Kong. Svenska Vetenskaps-Akademiens Handl.* **13**:1-28, 4 plates.
164	10	Cleve P.T. (1899) Plankton collected by the Swedish Expedition to Spitzbergen in 1898. *Bihang Kong. Svenska Vetenskaps-Akademiens Handl.* **32**:1-48, 4 plates
134	22	Cleve P.T. (1891) The diatoms of Finland. *Act. Soc. Pro Fauna Flora Fennica* **8**:1-68, 3 plates.
128	6	Cleve P.T. (1901). Plankton from the Indian Ocean and the Malay Archipelago. *Bihang Kong. Svenska Vetenskaps-Akademiens Handl.* **35**:1-58, 8 plates
106	14	Cleve P.T. (1881) On some new and little known diatoms. *Bihang Kong. Svenska Vetenskaps-Akademiens Handl.*, **18**:1-28, 6 plates
97	4	Cleve P.T. (1900) The seasonal distribution of Atlantic plankton organisms. *Göteborgs K. Vetensk. Vitterh. Samh. Handl*. **17**:1-368.
96	8	Cleve P.T. (1900) Notes on some Atlantic plankton organisms. *Bihang Kong. Svenska Vetenskaps-Akademiens Handl.* **34**:1-22, 8 plates.
93	12	Cleve P.T. (1873) Examination of diatoms found on the surface of the Sea of Java. *Bihang Kong. Svenska Vetenskaps-Akademiens Handl.* **11**:1-13, 3 plates.

One manner of gauging the esteem of a researcher is to consider the number of species named for the person. Granted that it is an honor granted only by taxonomists, but it is nonetheless an indicator. Famously, there are hundreds of species named for Charles Darwin (e.g. Milicic et al. 2011). As stated above, those who have written on the history of protistology have overlooked Cleve's work. However, protist taxonomists have honored Cleve many times. There appear to be at least 34 species of protists that have been named for Cleve, based on searching the WoRMS database for original species names including the term "clevei". New generic combinations, that represent a new name simply due to assignment to another genus, were excluded. As on might expect, most of the species are diatoms. However there are also desmids, dinoflagellates, tintinnid ciliates and radiolaria named for Cleve. The temporal distribution of these taxonomic acts honoring Cleve (fig. 5) is remarkable, beginning early in his protistology career, with a desmid named for him (Wittrock 1869) and continuing into recent years, with the last being a radiolarian (Ikenoue et al. 2017).

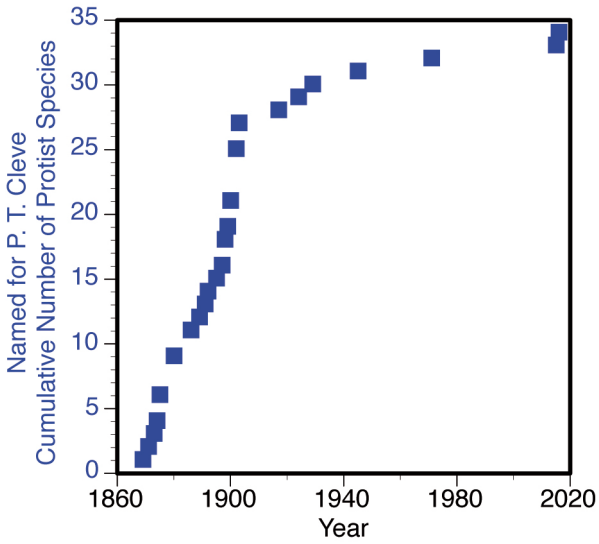

Fig. 5. The cumulative number of protist species named for Cleve as function of year of publication. Note the numbers of species descriptions include those later designated as junior synonyms as all the descriptions honored Cleve.

It would be remiss to omit mention of Cleve's remarkable scientific artwork, certainly part of legacy. Cleve's publications on protists included a total of 119 plates; a few plates were illustrations of copepods, but most plates showed various protist taxa. Many of Cleve's protist plates contained quite striking illustrations. Some examples of Cleve's protist illustration are shown in Figure 6.

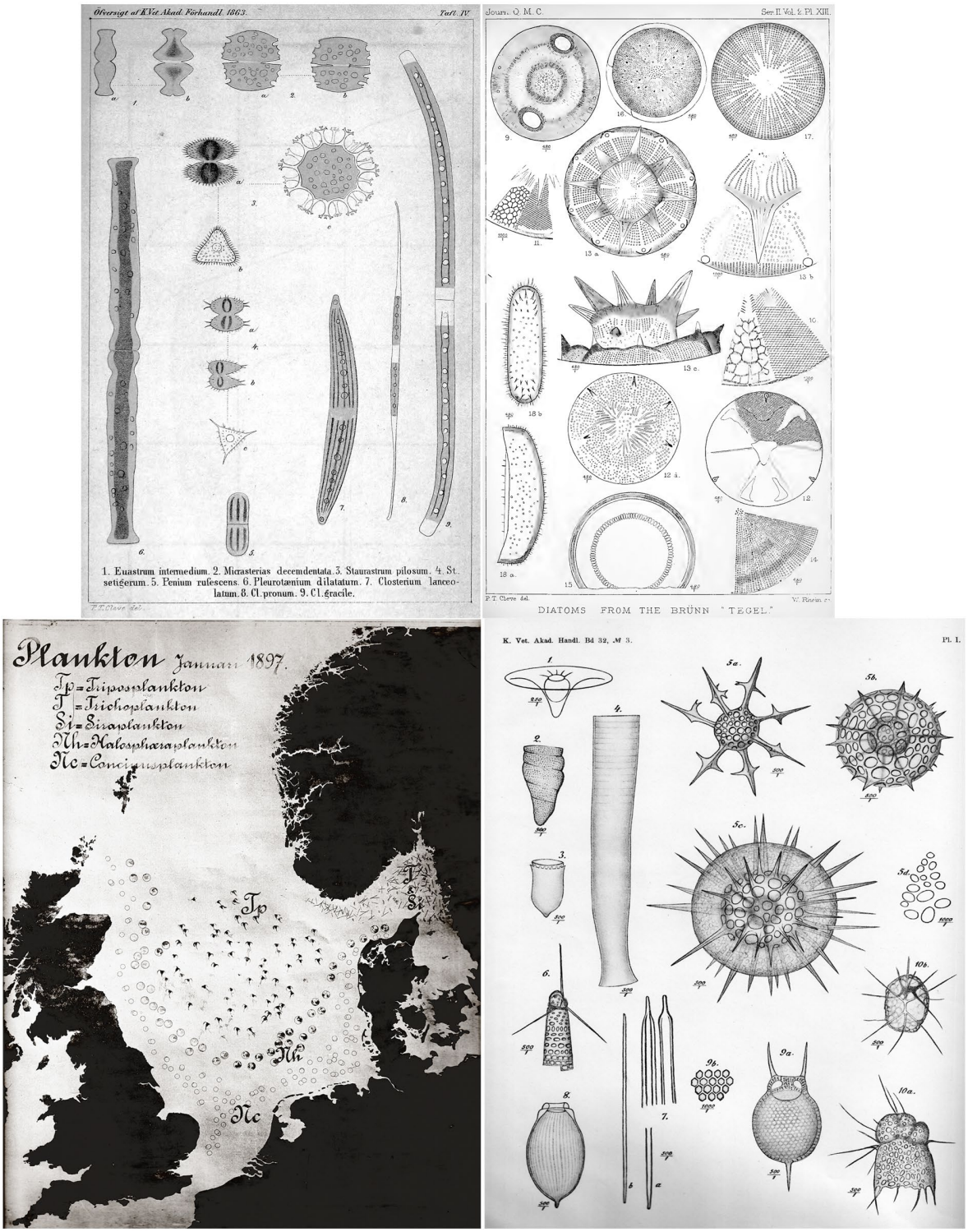

Fig. 6. Examples of Cleve's scientific illustrations from the beginnings to near the end of his studies of protists: Desmids from Cleve 1863b (top left); fossil diatoms from Cleve 1885 (top right); a map of the North Sea showing the distribution of different plankton assemblages in January 1897 from Cleve 1897 (bottom left); and a plate from Cleve's 1899 report on the plankton collected by the Swedish Expedition of Spitzbergen showing tintinnid ciliates, radiolaria, and phaeodaria (bottom left).

CONCLUSION

Per Teodor Cleve was truly a unique protistologist. The famous chemist had a long, very productive career as a protistologist, all the while working on protists only in his spare time. He wrote on protists in his native Swedish, and often in English, but also in German and in French. He published detailed, richly illustrated descriptions of desmids, diatoms, dinoflagellates, tintinnid ciliates, and radiolaria. Cleve promoted study of the protists of the marine plankton as a useful topic in both oceanography and in fisheries science. Although best known as a chemist, hopefully it is shown here that Per Teodor Cleve deserves to be considered as an important protistologist of the last half of the 19th century.

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