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PHYTOPLANKTON DISTRIBUTION AND WATER QUALITY INDICES FOR LAKE MEAD (COLORADO RIVER)¹

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SUMMARY

Phytoplankton samples were collected in Lake Mead 6 times from September 1970 to June 1971 for 8 stations at depths of 0, 3, 5, 10, 20, and 30 m. These samples were processed through a Millipore filter apparatus and 79 planktonic algae were identified. Algal divisions represented were Bacillariophyta, 42 species; Chlorophyta, 18; Cyanophyta, 9; Chrysophyta, 3; Cryptophyta, 3; Pyrrophyta, 2; and Euglenophyta, 2. Blue-green algae were dominant in late summer and fall; green algae, diatoms, and cryptomonads in winter; and green algae in spring. The early summer flora was best represented by the Chlorophyta, Cryptophyta, and Chrysophyta. Palmer's pollution-tolerant algae indices and Nygaard's indices were calculated from phytoplankton data. These indices suggest eutrophic conditions in Lake Mead, especially for Boulder Basin.

INTRODUCTION

Lake Mead formed by Hoover Dam is the largest man-made reservoir in the western hemisphere with great potential for supplying potable water for a large area of the growing, arid southwestern United States. This reservoir provides municipal and industrial water, water for irrigation, hydroelectric power, and a recreational area visited by over one million people each year. Therefore, it is desirable to maintain high quality water in the reservoir.

To date, only minimal effort has been made to investigate the hydrobiology of Lake Mead. Aside from the studies of the Environmental Protection Agency (8), Everett *et al.* (10), and Moffett (21), the biology of Lake Mead is relatively unknown. Moffett's fishery study of Lake Mead reported the dinoflagellate *Ceratium* as the most abundant phytoplankton. He reported total plankton volume as 0.0023 cu. in.³/ft³ of water. Additional data are available on the physical parameters of the lake, including its physical limnology (3,4,11,12,23,34,38).

By 1965, interest was mounting in the degree of pollution of Lake Mead. The Bureau of Reclamation conducted a spring study (April and May) of certain physical parameters (5), including dissolved O₂, CO₂, pH, electrical conductivity, and tempera-

ture. Two years later the Environmental Protection Agency (8) reported on plankton counts. Las Vegas Wash had the highest counts and a high algal growth potential was found immediately below Hoover Dam. Also, Everett & Qashu (11), using a more sensitive ¹⁴C primary productivity method, have found evidence of high algal counts just behind Hoover Dam. In the most recent report by the Bureau of Reclamation (6), it has been shown that chlorophyll *a* concentrations are greater in Las Vegas Wash during May than in Boulder Basin, a conclusion questioned by Everett (9).

This report on the phytoplankton of Lake Mead is an integral part of a major biological, chemical, hydrodynamic, and ¹⁴C primary productivity investigation of the lake. Parameters other than phytoplankton will be discussed in subsequent papers.

MATERIALS AND METHODS

Phytoplankton samples were collected from 8 stations in Lake Mead (Fig. 1) 6 times beginning in September 1970 and ending in June 1971. Sampling was accomplished utilizing a 3-liter, polyvinyl chloride Van Dorn sampler at approximately 0-, 3-, 5-, 10-, 20-, and 30-m depths. Water from the sampler was poured into 6-dram vials and Lugol's reagent was added to preserve planktonic species. All data are reported and discussed for 5-m samples unless otherwise stated.

The technique used to prepare samples for phytoplankton enumeration was similar to that of McNabb (20). Contents of the vials were poured into a Millipore filter apparatus model XX 1002500 equipped with a 0.45-μ grid Millipore filter. Each sample was aspirated for 15 min under low vacuum onto Millipore filters. The plankton was air-dried prior to mounting in immersion oil with a refractive index of 1.5150. Immersion oil rendered the filters transparent. Filters were then placed on microscope slides with cover glasses and sealed with nail polish to produce permanent slides (preparations) for enumeration of the phytoplankton.

Permanent preparations were enumerated for the 6 depths sampled. Enumeration (identification and counts) involved 50 randomly selected fields of vision for 274 slides. If phytoplankters were numerous, counting was aided by a Clay Adams Differential Counter Model B + 120-4. In certain cases, identification was assisted by the observation of freshly collected organisms which were compared to specimens on permanent slides. Identification at the species level was occasionally difficult or impossible because organisms were damaged by processing. The taxonomic references used for identifications were Ahlstrom (1), Allegre & Jahn (2), Desikachary (7), Huber-Pestalozzi (13,14), Hustedt (15), Johnson (17), Palmer (25), Patrick & Reimer (27), Prescott (30), Smith (32,33), Taft & Taft (36), Tiffany & Britton (37), and Weber (39).

Palmer's (26) and Nygaard's (24) phytoplankton indices were

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FIG. 1. Location of Lake Mead (left) and sampling stations in Lake Mead (right).

calculated to establish the productive level of the lake. Trophic conditions of the lake were inferred from these data.

OBSERVATIONS AND RESULTS

Phytoplankton population counts. Examination of the organisms on permanent slides revealed 79 species of phytoplankton. These phytoplankton are listed by division and sampling station and are related to Palmer's (26) ranking of pollution-tolerant genera (Table 1). Species of Bacillariophyta were most numerous (42), followed by Chlorophyta (18), Cyanophyta (9), Chrysophyta, Cryptophyta (3 species each), and Pyrrophyta and Euglenophyta (2 species each).

Counts of individuals were made for each station at all sampling times and all 6 depths. Total number of organisms/liter were then calculated for all stations at each depth and sampling time. Percentage composition of species for the 7 divisions was calculated from the population counts. The 5-m data for each sampling time have been plotted to show the percentages by division (Fig. 2A-F).

The Bacillariophyta were found at all sampling times for all stations with maximum occurrence during the winter and late summer. In January 1971, diatoms reached a maximum percentage composition of 75% in Las Vegas Bay at 10 m with a population of 1.5×10^6 organisms/liter. The dominant species was *Mastogloia smithii*. Chlorophyta were present throughout the year at all stations and all depths, with the highest percentage composition conspicuously occurring in April. Of the 18 green algae, 10 were chlorococcalean species. Other chlorophytan orders represented were Volvocales (2 species), Tetra-

sporales (1 species), Cladophorales (1 species), and Zygnematales (4 species).

During the September and November sampling times, the major phytoplankton division was the Cyanophyta, with *Oscillatoria limnetica* the dominant species. Boulder Basin was the general area of large blue-green algal populations with up to 5×10^6 organisms/liter in surface samples (0 m) from Beacon Island in September. Blue-green algae were found in every sample taken from Boulder Basin, a situation not true for other collecting sites. Sampling times other than September and November in Boulder Basin yielded reduced numbers of blue-green algae.

Besides the Bacillariophyta, Chlorophyta, and Cyanophyta, large populations of the Cryptophyta were enumerated. This division showed a February-April maximum with 50% or more of the population composed of cryptomonads at specific stations. The Pyrrophyta, Chrysophyta, and the Euglenophyta were not observed to produce dominant plankton populations. *Ceratium hirundinella* was the most abundant and important dinoflagellate with its largest populations at Bonelli Landing and South Cove during June. It was consistently low in numbers in Boulder Basin. In the Chrysophyta, *Dinobryon divergens* was collected only in June samples. Collected at other times were species of the chrysophytan algae *Mallomonas* and *Chrysoidalis* which were present in small numbers. The Euglenophyta were never abundant, with a maximum of 2.9% composition at Bonelli Landing at 20 m in June.

Palmer's pollution-tolerant algae index. Palmer (26) has published a composite rating of algae tolerant of organic pollution, assembled from the reports

TABLE 1. (Continued)

Species	Sampling stations								Palmer's generic ranking ^b
	BR ^a	LVB	BI	BL	UOA	LOA	TB	SC	
Pyrrophyta									
<i>Ceratium hirundinella</i> (O. F. Muell.) Dujardin	+		+	+	+	+	+	+	
<i>Peridinium</i> sp.		+							
Cyanophyta									
<i>Anabaena</i> sp.	+	+	+			+	+	+	22
<i>Anabaenopsis arnoldii</i> Apetk.	+	+	+	-			+	+	
<i>Chroococcus</i> sp.			+		+	+			
<i>Merismopedia glauca</i> (Ehr.) Naeg.	+	+	+	-	+	+		+	
<i>Microcystis incerta</i> Lemm.	+	+	+	-	+	+	+	+	
<i>Oscillatoria brevis</i> (Kütz.) Gomont	+	+	+						2
<i>Oscillatoria limnetica</i> Lemm.	+	+	+	-	+	+	+	+	
<i>Raphidiopsis curvata</i> Fritsch and Rich	+	+	+			+		+	
<i>Spirulina meneghiniana</i> Zan. ex Gomont		+							37
Euglenophyta									
<i>Euglena deses</i> Ehr.								+	1
<i>Phacus acuminatus</i> Stokes	+		+	-			+	+	11
Chrysophyta									
<i>Chrysidalis</i> sp.	+	+	+	-	+	+	+	+	
<i>Dinobryon divergens</i> Imhof	+		+	-	+	+	+	+	
<i>Mallomonas</i> sp.	+	+	+	-	+		+	+	
Cryptophyta									
<i>Chroomonas nordstedtii</i> Hansg.	+	+	+	-	+	+	+	+	
<i>Cryptomonas erosa</i> Ehr.	+	+	+	-	+	+	+	+	23
<i>Rhodomonas lacustris</i> Pascher and Rutner	+	+	+	-	+	+	+	+	

^a See Fig. 1 for names and locations of sampling stations.

^b Number for a genus from Palmer's pollution-tolerant genera list is given after the first species in a genus only. Lowest numbers are for most pollution-tolerant genera.

of 165 authors. One of his lists includes 60 of the most pollution-tolerant genera. Among these, 33 were found in Lake Mead (Table 1). Since the phytoplankton are listed by species in Table 1, the number after the first species listed for a genus indicates the placement of the genus in Palmer's list. The lowest numbers are for the most pollution-tolerant genera. Palmer also published 5 tables that list the most pollution-tolerant species of 5 genera: *Euglena*, *Oscillatoria*, *Nitzschia*, *Scenedesmus*, and *Navicula*. These represent 5 of Palmer's 7 most pollution-tolerant genera. The flora of Lake Mead contains at least 1 species in each of these 5 genera.

In the same report, Palmer constructs algal pollution indices which he developed for use in rating water samples for high or low organic pollution. Two indices are given, one for algal genera and the other for species. Palmer assigned each genus or species a pollution index value from 1 to 6. This value is determined by the relative number of total points credited to the listed algae based upon their point total in his list of pollution-tolerant genera or species. A score greater than 20 for a water sample signifies high organic pollution, while a score of 15-19 suggests probable evidence of high organic pollution. Values less than 15 indicate low organic pollution. The values from the application of Palmer's pollution index to the planktonic algae of

Lake Mead are tabulated in Table 2. These were obtained from the data for all stations at all depths. The genus-pollution index shows high organic pollution during September at Bureau Raft, Beacon Island, Lower Overton Arm, Temple Bar, and South Cove. At the same time the species pollution index shows clean water at these same stations (Table 2). This is only one example of the difference in rating when the two indices are compared.

Nygaard's phytoplankton indices. Nygaard (24) has attempted to classify the phytoplankton associations in a number of Danish lakes based upon 5 ratios:

1. The myxophycean index = number of species of Myxophyceae/number of species of Desmidiaceae
2. The chlorophycean index = number of species of Chlorococcales/number of species of Desmidiaceae
3. The diatom index = number of species of centric diatoms/number of species of pennate diatoms
4. The euglenophyte index = number of species of Euglenophyta/number of species of Myxophyceae and Chlorophyceae
5. The compound index = number of species of Myxophyceae, Chlorococcales, centric diatoms, and Euglenophyta/number of species of Desmidiaceae

Since there was an abundance of green and blue-green algae in September and June while diatoms

FIG. 2. Percentage composition of the divisions of phytoplankton and dominant species at 5 m for 8 stations at 6 sampling times (A-F).

TABLE 2. Values for Palmer's pollution-tolerant algae index as applied to Lake Mead algae.

Station	Sept. 1970		Nov. 1970		Jan. 1971		Feb. 1971		Apr. 1971		June 1971	
	GPI ^a	SPI ^b	GPI	SPI	GPI	SPI	GPI	SPI	GPI	SPI	GPI	SPI
BR ^c	24	11	23	11	22	14	18	8	15	11	13	6
LVB	—	—	20	11	21	14	18	8	17	6	23	11
BI	23	11	18	17	15	11	11	14	13	6	15	11
BL	14	7	22	8	22	17	15	11	10	9	16	6
LOA	21	9	26	15	14	11	15	11	14	11	6	7
UOA	—	—	18	8	9	6	13	8	12	6	6	5
TB	24	4	21	11	21	11	11	7	18	9	11	5
SC	26	11	21	11	15	14	15	11	17	14	9	5

^a GPI refers to Palmer's genus-pollution index.^b SPI refers to Palmer's species-pollution index.^c Refer to Fig. 1 (map).

persisted at most times of the year, the above indices, except for the diatom index, are applicable only to collections during those two months. In general, Nygaard considers lakes with associations giving a compound index value of less than 1.0 as unproductive and those of 3.0 or more as highly productive which could signify eutrophication. He considered diatom index values greater than 0.4 as indicators of productive waters.

Values for Nygaard's indices for the September and June phytoplankton collections are given in Table 3. In compiling these values the data for all depths at each sampling station were used. When it was possible to calculate values, most were in the highly productive or eutrophic range. The average diatom value for September is 0.64 and for June is 0.60. The calculated diatom-index values for all other sampling times were either equal to or greater than the values for September and June.

DISCUSSION

The 79 species of phytoplankton found in Lake Mead represent a low number such as would be expected of a eutrophic body of water. This is indeed a small number when compared to the 199 species reported by Morgan (22) for Flathead Lake, Montana, an oligotrophic lake. A striking observation is the presence of only 3 species of desmids.

According to Rawson (31), oligotrophic lakes are typically rich in the Chlorophyceae, including desmids. But, as Ström (35) points out, a lack of desmids can be expected in contaminated waters and such an absence of desmids is an indicator of eutrophication. Pearsall (29) states that desmids occur in calcium-deficient lakes. Lake Mead is high in calcium with more than 80 ppm during most of the year.

Even though diatoms outnumber blue-green algal species 42 to 9, blue-green algae had far greater population sizes, especially in Boulder Basin at all depths in the late summer and fall. In late summer, populations of *Oscillatoria limnetica* reached 5×10^6 organisms/liter. While blue-green algae were dominant in the late summer and fall in Boulder Basin, they decreased markedly in numbers during the winter and spring and were absent from the 5 other stations during these latter 2 seasons. Two of the blue-green algal species, *Anabaena* sp. and *Microcystis incerta*, are problem species because of their potential to produce blooms and a fast-death factor, respectively. *Microcystis incerta* is listed as a toxic plant by Kingsbury (18).

In the winter, diatom and cryptophyten species are codominants with diatom populations as large as 1.5×10^6 organisms/liter at 10 m in January at Las Vegas Bay. The 3 diatom genera in greatest

TABLE 3. Values for Nygaard's ratios as applied to Lake Mead for September and June sampling periods.

Station	Index									
	Myxophycean		Chlorophycean		Diatom		Euglenophyte		Compound	
	Sept. 1970	June 1971	Sept. 1970	June 1971	Sept. 1970	June 1971	Sept. 1970	June 1971	Sept. 1970	June 1971
BR	0.4	0	0	0	2.00	0.40	0	0	0	0
LVB ^a	—	3.0	—	3.0	—	0.22	—	0.17	—	9.0
BI	0	0	0	0	0.33	0	0.11	0	0	0
BL	0	0	0	0	0.43	0.33	0	0.20	0	0
LOA	0	0	0	0	0.43	0.67	0.83	0	0	0
UOA ^a	—	0	—	0	—	2.00	—	0	—	0
TB	0	0	0	0	0.40	0.17	0.41	0	0	0
SC	0	0	0	0	0.22	1.00	0.08	0	0	0

^a No sampling done at this station during September.

TABLE 4. Number of stations distributed by degree of organic pollution for the 6 sampling times according to Palmer's pollution-tolerant index.

Sampling time	Number of stations		
	High organic pollution	Probable high organic pollution	Low organic pollution
Sept. 1970 ^a	5 (BI, BR, LOA, SC, TB)	0	1 (BL)
Nov. 1970	6 (BL, BR, LOA, LVB, SC, TB)	2 (BI, UOA)	0
Jan. 1971	4 (BL, BR, LVB, TB)	2 (BI, SC)	2 (LOA, UOA)
Feb. 1971	0	5 (BL, BR, LOA, LVB, SC)	3 (BI, TB, UOA)
Apr. 1971	0	4 (BR, LVB, SC, TB)	4 (BI, BL, LOA, UOA)
June 1971	1 (LVB)	2 (BI, BL)	5 (BR, LOA, SC, TB, UOA)

^a Only 6 stations sampled.

abundance were *Mastogloia*, *Cyclotella*, and *Stephanodiscus*. Hutchinson (16) has reported that lakes with large populations of blue-green algae in the summer generally have *Melosira granulata* at other seasons. This agrees with our observations on Lake Mead since *Melosira granulata* was never found in the June and September samplings but was present in low numbers at other times. The principal cryptophytes were *Chroomonas nordstedtii* and *Rhodomonas lacustris* which were continuously present.

Chlorophytes were numerous in the spring but their densities were less than that of the fall blue-greens. When all depths are considered, green algae are codominant with the diatoms which decrease in numbers from their winter maximum. The most abundant green algae are *Ankistrodesmus falcatus*, *Chlorella vulgaris*, and *Scenedesmus quadricauda*, all species of the order Chlorococcales.

Ceratium hirundinella and *Dinobryon divergens* were the most abundant species in the Pyrrophyta and Chrysophyta, respectively. *Ceratium hirundinella* reached its greatest population size in June at Bonelli Landing, a relatively unproductive site. Lowest counts for this species were at the 3 stations in Boulder Basin. This distribution suggests that *C. hirundinella* is sensitive to polluted waters because the Boulder Basin stations are known to have higher nutrient levels than Bonelli Landing (9). Thus we are suggesting that *C. hirundinella* is an indicator of water quality, in this case indicating high water quality at Bonelli Landing. Everett (9) has reported Bonelli Landing to have the clearest water in the lake with a light compensation point of 25 m.

Dinobryon divergens was found only in June samplings. The reasons for the limited appearance of this species remain unknown. Pearsall (28) has suggested that *Dinobryon* increases when diatoms decrease. It was true that diatom populations were lowest in June samplings.

Palmer's pollution-tolerant algae index (26) and Nygaard's ratios (24) were applied to the phytoplankton samples in an attempt to classify the trophic level of Lake Mead. Contradictory results about the trophic level were obtained when Palmer's genus-pollution index and species-pollution index

values were compared. According to the values obtained for the species-pollution index, the lake exhibited low organic pollution at all stations for all sampling times. By contrast, the values for the genus-pollution index, when the values for all stations are considered, showed high organic pollution during the September, November, and January samplings, probable high organic pollution for the February sampling, mixed results (4 stations probable high, 4 stations low) for the April sampling, and low organic pollution for the June sampling (Table 4). Thus a gradation from high to low organic pollution is shown when the data for the 8 stations are considered from September through June. The blue-green algae and diatoms contribute most to the high organic pollution and as the diatoms replace the blue-greens in the flora, the pollution level is reduced. By June the blue-greens and diatoms were conspicuously reduced in numbers and the pollution level was low. At this time, the green algae were dominant with *Dinobryon* as a subdominant.

During the collection period 46 samplings were made at the 8 stations. For 16 of the samplings the pollution level was the same according to both genus and species pollution-tolerant indices. From September through the following June there was a progressive increase in the number of stations with identical pollution levels: September (1), November (1), January (2), February (3), April (4), and June (5). This can be explained in part by the absence of the same species listed by Palmer in his species-pollution index for the earlier months and the presence of the same species listed for months such as April and June. For example, *Oscillatoria* is given a high value in the genus-pollution index, but none of the species of *Oscillatoria* are listed in the species-pollution index. However, *Scenedesmus quadricauda* is abundant during the spring and it appears in both the genus and species indices with identical point values.

While Nygaard's indices are frequently used to determine trophic level from the presence of algal species, only 2 of Nygaard's 5 indices could be applied because of the absence of desmids. In addition, the euglenophyte index is of limited value in this study because of the low number of euglenoids enumerated.

Only the diatom index provides adequate values for judging the trophic level. Nygaard lists values for the diatom index of 0.0–0.3 (less productive) and 0.4–1.75 (more productive). Our values range from 0.0 to 5.0, indicating a wide range of productivity of the lake during the sampling period. Of the 46 sampling times, 36 diatom indices are greater than 0.4 and 10 are less. Seven of the values that are 0.4 or less are for June and September. These low values occur because of the small number of centric diatoms, *Stephanodiscus*, *Cyclotella*, and *Melosira* relative to pennate diatoms. It is concluded from the diatom index that the lake is in the more productive range or in a eutrophic condition.

Six out of 16 values were calculated for the euglenophyte ratio. These show 4 stations in the less productive range and 2 in the more productive range. Such low values for the euglenophyte ratios are attributed to the low number of euglenoids in the samples.

An overall assessment of the trophic condition of Lake Mead suggests eutrophication has occurred or is in progress. Nygaard's diatom index shows Lake Mead to be in the more productive range of lakes generally. Although there is disagreement between Palmer's genus-pollution tolerant index and species-pollution tolerant index in regard to organic pollution, the genus-pollution tolerant index also places the lake in the productive range during September, November, and January. The continuous presence of blue-green algae in Boulder Basin and the periodic absence of blue-greens at all other stations suggest that Boulder Basin is the most productive region of the lake. This observation agrees with remote sensing information (19) from the Earth Resources Technology Satellite (ERTS-1) which shows Boulder Basin as a different appearing region of the lake. Also, Everett (9) has concluded from data on primary productivity that Boulder Basin is eutrophic. While the entire lake may not be eutrophic now, such a condition appears to exist in Boulder Basin.

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TWO SPECIES OF THE CHLOROPHYTE GENUS *OSTREOBIMUM* FROM SKELETONS OF ATLANTIC AND CARIBBEAN REEF CORALS^{1,2}

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SUMMARY

Two species of the siphonaceous chlorophyte Ostreobium inhabiting the aragonite skeletons of Atlantic and Caribbean reef corals were studied. Ostreobium quekettii Bornet & Flahault has been previously reported from these locations, but the species is here amended to include filament forms previously described under the name *O. reineckeii* Bornet. *Ostreobium constrictum* sp. n. is described here for the first time. The 2 sympatric species are distinguished on the basis of filament morphology and chloroplast form.

INTRODUCTION

This paper treats the 2 species of the chlorophycean genus *Ostreobium* which inhabit the skeletons of Atlantic reef corals. *O. constrictum* sp. nov. is described here for the first time, while *O. quekettii* Bornet & Flahault is amended to include plants previously described under the name *Ostreobium reineckeii* Bornet. A new genus description taking all described species into account and a key for species identification are provided.

Five species have been described and reported previously within the genus (3,4,21): *O. quekettii* Bornet & Flahault, *O. reineckeii* Bornet, *O. brabantium*

Weber-van Bosse, *O. duerdenii* Weber-van Bosse, and *O. okamurai* Weber-van Bosse. *O. quekettii* (including *O. reineckeii*) is worldwide (5) within carbonate substrates of all types, while the latter 3 species have been reported (7,12,21) only from corals or calcified red algae from tropical Indo-Pacific locations. The plants bore into carbonate substrates producing irregularly shaped tunnels which they subsequently occupy. Because of this mode of life they are known as boring, endolithic algae.

The genus *Ostreobium*, first reported by Bornet & Flahault (4), was included within the order Siphonales (Chlorophyta) by Fritsch (5), and this affiliation was confirmed by Jeffrey (9) on the basis of pigment composition. Fritsch (5) placed the genus within the family Phyllosiphonaceae on the basis of its morphology and presumed production of aplanospores. Related genera are *Phyllosiphon* Kühn and *Phytophysa* Weber-van Bosse, both of which are endophytes found most commonly within tropical vascular plants (5). Comparative life cycle studies have not been performed.

The species of *Ostreobium* discussed here were obtained from preparations made from Atlantic and Pacific corals, and studied in comparison with drawings and descriptions by Bornet & Flahault (4), Setchell (17), Weber-van Bosse (21), and Hackett (7). Exsiccata samples of *O. quekettii* (23), obtained from the Farlow Reference Library, Harvard University,

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