Short communication

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The first finding of aegagropilious, or algal balls, in the oldest freshwater Lake Baikal

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ABSTRACT. Free-floating algal aggregations, or aegagropilious, are a rare phenomenon known from some freshwater or marine environments worldwide. In September 2014, unusual green algal balls were washed ashore in Ludar Bay on the west coast of the northern basin of Lake Baikal. The paper describes these algal aggregations and characterizes their composition. The Baikal algal balls mainly consisted of green filamentous algae of the family Cladophoraceae, such as *Cladophora glomerata*, *Rhizoclonium* sp., and *Chaetomorpha* sp. Other prominent components of the balls were numerous filaments of *Spirogyra* and *Oedogonium.* These taxa are known for their rapid growth in response to nutrients increase. As the result of the hyperproduction of filamentous benthic algae in the coastal zone of Lake Baikal, new living forms such as aegagropilious-like aggregations have been occurring. The algal balls signify the adaptive capacities of the Lake Baikal algal communities and might retain their functioning in the natural ecosystem's self-purification processes.

Keywords: algal balls, aegagropilious, photogranules, FAB, green filamentous algae, *Spirogyra*, Lake Baikal

1. Introduction

Free floating, detached spherical masses of algae were described from many parts of the world in freshwater and marine habitats (Ballantine et al., 1994; Thiel and Gutow, 2005; Wakana et al., 2005; Boedeker and Immers, 2009; Boedeker et al., 2010; Babich and Zaika, 2011; Cooke et al., 2015; Mathieson et al., 2015; Tsutsui et al., 2015). Algae that form free-floating balls are called by the term aegagropilious (Linnaeus 1753), which refers to their resemblance to bezoar, the masses found in the gastrointestinal tracts of goats, *Capra aegagrus* (Erxleben) (Cooke et al., 2015). The most famous algal balls are formed by an extremely rare freshwater alga, *Aegagropila linnaei* (Kützing), also known as lake balls, or Marimo, popular in the souvenir and aquarium trades and depicted on postage stamps from Japan and Iceland (Wakana et al., 2005; Boedeker and Immers, 2009; Boedeker et al., 2010; Togashi et al., 2014).

In addition to *A. linnaei*, several aegagropilious algae are known to form aggregations like loose-lying balls and spherical forms. Among them, there are at least 18 green, 11 brown, and 25 red taxa (Bach and Josselyn, 1978; Kurogi, 1980; Hoek van den et al., 1984; Littler et al., 1989; Ballantine et al., 1994; Cooke et al., 2015; Mathieson et al., 2015; Tsutsui et al., 2015).

Ball formation occurs by the mechanical action of free-floating thalli rolled against a substratum, either by rocking at the lake bottom or by more vigorous wave action in shallow marine environments (Hoek van den et al., 1984; Togashi et al., 2014; Cooke et al., 2015; Mathieson et al., 2015).

Under the conditions of the active hydrodynamic regime in the Lake Baikal littoral zone, the well-developed benthic algal flora is represented by attached mats forming so-called algal belts, the design of which varies in depth depending on the taxa prevailing in their composition. Traditionally, in the open littoral zone of Lake Baikal, there are five algal belts dominated by certain species (Izhboldina, 2007). Although the same species can form both mat-like and ball-like aggregations (Togashi et al., 2014; Cooke et al., 2015; Tsutsui et al., 2015, etc.), the latter are not typical for the Lake Baikal algal communities.

The present short communication aims to characterize the first findings of the green algal aegagropilious-like aggregations discovered in Lake Baikal.

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2. Materials and methods

Algal balls were found on the shore of Ludar Bay (55°27'01.0"N 109°11'10.1"E) on the west coast of the northern basin of Lake Baikal in September 2014. The following instruments measured the surface water temperature, conductivity, and pH: HI 98501 Checktemp; Hanna Instruments, Woonsocket, Rhode Island, USA. About 10 algal balls were collected from an area of 60 x 20 m.

Twenty algal balls were collected and dried at room temperature; five algal balls were kept in a glass jar with filtrated lake water in natural daylight for the microscopic analysis. In the laboratory, samples were analyzed under an Olympus CX 21 light microscope using a ToupView 3.7 digital camera at magnifications ranging from $\times 40$ to $\times 400$. Species were identified using keys (Izhboldina, 2007; Rundina, 1998; Timoshkin, 2001; Popovskaya et al., 2002). The taxonomy is given according to (Guiry and Guiry, 2022).

3. Results and discussion

The coast of Lake Baikal where green algal balls were observed neither was inhabited nor was exposed to any regular infrastructure or use. Boulders and pebbles were a prevailing substrate at the study site. The surface near-shore water temperature was 9.2 °C; conductivity – 122.4 µs cm^{-1}, and pH 8.3. On the day of sampling at the study site, the wave height was about 1-1.5 m. The algal balls were not numerous; their distance from each other was about 2 m, most of them were 1.5-2 m above the shoreline. The aggregations had a near-spherical shape with the diameter varying from 3 to 12 cm; they were free-floating, and most of them were just washed ashore (Fig. 1). The fresh balls, after draining, weighed 28.7 ± 12.3 g (n = 4) and 7.02 ± 2.8 g (n = 4) when air dried. The size and structure of the balls was rather similar to those reported in the literature (e.g., Togashi et al., 2014; Cooke et al., 2015; Mathieson et al., 2015). All freshly washed algal balls had a bright green color, were not hollow and consisted of tightly intertwined filamentous thalli of *Cladophora glomerata* (Linnaeus) Kützing, *Chaetomorpha* sp. Kützing, *Rhizoclonium* sp. Kützing, *Spirogyra* sp. ster. 1 Link, *Spirogyra* sp. ster. 2, *Spirogyra* sp. ster. 3, *Oedogonium* sp. ster. Link ex Hirn, and *Cladophora* cf. *floccose* C. Meyer. All these taxa, except for *Spirogyra* and *Oedogonium*, are historically common for the first vegetative belts in Lake Baikal (Izhboldina, 2007). The vegetative cells of *Spirogyra* sp. ster. 1 were 34.0-47.5 µm wide, 84.0-284.0 µm long, with 3-5 chloroplasts, and plane transverse walls. The vegetative cells of *Spirogyra* sp. ster. 2 were 38.0-41.0 µm wide, 60.0-80.0 µm long, with 1 chloroplast, and plane transverse walls. The vegetative cells of *Spirogyra* sp. ster. 3 were 85.0-92.0 µm wide, 200.0-520.0 µm long, with one chloroplast, and plane transverse walls. The vegetative cells of *Oedogonium* sp. ster. were 30.0-35.5 µm wide and 50.0-67.0 µm long. Due to a lack of fertile specimens, the species identification of conjugates was not possible.

Filaments of *Ulothrix zonata* (Weber et Mohr) Kützing, *Stigeoclonium tenue* (C. Agardh) Kützing were less abundant but rather regular in the algal balls. Another constant components were fragments of *Nitella flexilis* (Linnaeus) C.Agardh. To a lesser extent, there were *Chara contraria* A.Braun ex Kützing and *Chara* cf. *fragifera* Durieu de Maisonneuve.

Many colonies of *Didymosphenia* M. Schmidt were present in the algal balls. Cells of *Cymbella* C. Agardh, *Encyonema* Krammer, *Cocconeis* Ehrenberg, *Fragilaria*

Fig.1. Photographs of algal balls in situ washed ashore and collected in Ludar Bay on the west coast in the northern basin of Lake Baikal, September 2014.

Lyngb. were abundant on the thalli of *Cladophora* spp. and *U. zonata*. Among other diatoms that were present in a noticeable amount, there were *Navicula tripunctata* (O.F. Mueller) Bory, *N. cryptocephala* Kützing, and *N. radiosa* Kützing.

The upper layer of the bigger-sized algal balls included needle leaf fragments, fine particles of detritus and sand. The scares qualitative analysis of the fauna in the algal balls revealed various macro- and meiofauna taxa belonging to Oligochaeta, Amphipoda, Gastropoda, Polychaeta, Crustacea, Nematoda, and Harpacticoida.

Some algal balls were found dried on the shore; they lacked pigmentation, and their upper layers were rather fragile. Supposedly, these algal balls were washed ashore and already partly dried some time before our observations. However, after exposure of these balls in a jar with filtrated Lake Baikal water for a few months at natural light source, individual filaments and pulls of filaments of *Oedogonium* sp. ster., *Spirogyra* spp., and *Rhizoclonium*-like began to protrude from the balls by several centimeters. This observation indicated that the algal balls retained enough water for the species to last for some time even after being washed and kept ashore. Apparently, after reoccurring in the water or being exposed to water splashes, at least the filamentous algae contained in the algal balls have the potential to persist.

Most of the known reports of algal balls indicate the predominance of taxa belonging to the family Cladophoraceae (Wakana et al., 2005; Boedeker and Immers, 2009; Boedeker et al., 2010; Cooke, et al., 2015; Tsutsui et al., 2015). As a rule, such balls are represented by a single species, although often include fragments of other algae and higher aquatic plants (Ballantine et al., 1994; Babich and Zaika, 2011; Togashi et al., 2014). Baikal algal balls were mainly represented by taxa of the Cladophoraceae family such as *C. glomerata*, *Rhizoclonium* sp. and *Chaetomorpha* sp. Mass development of these species, which is also often referred to as filamentous algal bloom (FAB) (Vadeboncoeur et al., 2021), is associated with eutrophication of aquatic ecosystems, leading to irreversible successional processes not only in coastal communities but also in the entire aquatic ecosystem (e.g., Higgins, 2008; Ozersky et al., 2013).

In addition to *Cladophora* spp., Baikal algal balls always had numerous filaments of *Spirogyra* and *Oedogonium*, which, as indicated above, continued to vegetate even after several months of keeping the balls under laboratory conditions. These taxa are known for their rapid growth in response to increasing nutrients input into the environment (Rundina, 1998; Gubelit and Berezina, 2010). The atypical mass proliferation of *Spirogyra* during the past decade along a substantial part of the Lake Baikal shoreline (Kravtsova et al., 2014; Timoshkin et al., 2015; 2016; Volkova et al., 2018), as well as a local mass development of *C. glomerata* in some areas of the lake (Kobanova et al., 2016), are evidence of algal hyperproduction in response to the high anthropogenic load on the shallow Lake Baikal zone (Kobanova et al., 2016; Kulikova et al., 2021).

4. Conclusions

The algal hyperproduction in the coastal zone of Lake Baikal might have led to occurrence of new living forms such as metaphyton or free-floating algal mats (Volkova et al., 2018), photogranules consisting of filamentous cyanobacteria and filamentous green algae (Volkova et al., 2020), and green algal balls described here. The emergence of such aggregations may indicate the adaptivity of coastal communities and might retain their functioning in the natural self-purification processes of Lake Baikal shallow zone.

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Conflict of interests

The author declares no conflict of interests.

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