NOVEL SPECIES RECORD OF *ULVA INTESTINALIS* (CHLOROPHYTA, ULVACEAE) FOR KAMCHATKA (NE ASIA) FROM AN ISOLATED INLAND LOCALITY

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ABSTRACT

A novel inland record of the green alga *Ulva intestinalis* was found in central Kamchatka, in a brackish stream originating from cooled waters of drilled thermal springs. This species was observed in May 2017, but not encountered again at the same site despite targeted search. Its occurrence in central Kamchatka was surprising given the natural environment, and was probably related to both the presence of thermal springs and human disturbance. The sporadic inland appearance of *U. intestinalis* in this region suggests it may be unable to maintain stable populations in this region, and experience repeated local extinctions and recolonizations.

RÉSUMÉ: Enregistrement d'une nouvelle espèce d'algue, *Ulva intestinalis* (Chlorophyta, Ulvaceae) dans la péninsule du Kamtchatka (Asie du Nord-Est) dans une localité isolée de l'intérieur des terres.

La nouvelle espèce d'algue verte *Ulva intestinalis* (Chlorophyta, Ulvaceae) a été trouvée dans le centre de la péninsule du Kamtchatka, dans un cours d'eau saumâtre provenant des eaux refroidies de sources thermales forées. Cette espèce a été repérée pour la première fois en mai 2017 et n'a plus été revue sur le même site malgré des recherches ciblées. Sa présence dans le centre du Kamtchatka contraste clairement avec le contexte environnemental naturel et était probablement liée à la fois, à la présence de sources thermales et à la transformation humaine de l'environnement. L'apparition sporadique d' *U. intestinalis* à l'intérieur des terres dans cette région suggère qu'elle pourrait être incapable de maintenir des populations stables dans cette région, de connaître des extinctions et des recolonisations locales répétées.

REZUMAT: Înregistrări noi ale speciilor de *Ulva intestinalis* (Chlorophyta, Ulvaceae) pentru Kamchatka (NE Asia) din localitatea izolată interioară.

O nouă înregistrare continentală a algei verzi *Ulva intestinalis*, a fost găsită în centrul Kamchatka, într-un curs de apă salmastru provenit din apele răcite ale izvoarelor termale forate. Această specie a fost observată în mai 2017, dar nu a mai fost întâlnită în același sit, în ciuda căutărilor direcționate. Apariția sa în centrul Kamchatka a fost surprinzătoare, având în vedere mediul natural și a fost probabil legată atât de prezența izvoarelor termale, cât și de perturbarea umană. Apariția sporadică a *U. intestinalis* în această regiune sugerează că ar putea fi incapabilă să mențină populații stabile în această regiune și să experimenteze extincții și recolonizări locale repetate.

INTRODUCTION

Many green algae in the genus *Ulva* L. are economically important; useful in the case of cultivated edible species, or causing grave economic damage in green tide algal blooms (Zhang et al., 2019; Fort et al., 2020; Harsha Mohan et al., 2023). Species with tube thalli, earlier placed in the genus *Enteromorpha* Link (Hayden et al., 2003), can colonize inland waters (Bliding, 1963; Li and Bi, 1998; Messyasz, 2009; Mareš et al., 2011; Rybak, 2015, 2018, 2021; Saber et al., 2018; Škaloud et al., 2018). Inland populations are generally found in hard, brackish waters of arid and semiarid areas that have hot summers, e.g., southeastern Europe (Zhakova, 2006; Zinchenko et al., 2021; iNaturalist, 2024; Romanov, unpubl. data), western and central Asia (Muzafarov, 1965; Nahucrishvili, 1986; Maulood et al., 2013; Zhakova, 2013; Tekebaeva et al., 2014; Sametova et al., 2019; Mohebbi and Zarezadeh, 2023; Romanov, unpubl. data), southern Ural (Yatsenko-Stepanova and Ignatenko, 2018), southern Siberia (Safonova and Ermolaev, 1983; Kuklin, 2017; Efremov, 2018; Tokar, 2018; Bazarova and Kuklin, 2021; Romanov, unpubl. data), Mongolia (Tsegmid and Baigal-Amar, 2018), and China (Li and Bi, 1998). Inland populations are also known from northeastern Siberia (Skvortsov, 1917; Kopyrina et al., 2020) and even in the lowermost locality of the Earth (-455 m below sea level) near Dead Sea (Barinova et al., 2004).

Thermal springs, as well as manmade water bodies, often have temperature regimes and chemical compositions that contrast with surrounding aquatic habitats, analogous biogeographically to isolated islands or oases (Glazier, 2009). Thermal springs are widely recognized as key habitats and biodiversity hotspots (see references in Cantonati, 2022). In addition to species of algae and cyanobacteria (e.g., Elenkin, 1914; Doemel and Brock, 1971; Gromov et al., 1991; Nikitina, 2005; Cantonati et al., 2010; Beauger et al., 2022; see references in Cantonati, 2022), thermal springs can harbor populations of macroscopic algae, e.g., Characeae, far from their main distributional range dictated by climatic and other large-scale ecological factors (e.g., Langangen, 2000; Romanov and Chernyagina, 2018; Langangen et al., 2020; Romanov and Vishnyakov, 2023). The same seems to be true for some water bodies with artificial thermal effluents (Romanov et al., 2018). This paper describes a recent isolated record of *Ulva intestinalis* L. (formerly *Enteromorpha intestinalis* (L.) Link) from central Kamchatka, a humid continental area with subarctic climate, i.e., cold without distinct wet or dry seasons and having cold summers (Köppen-Geiger climate classification = Dfc, Peel et al., 2007), and mostly soft oligotrophic fresh waters (Litvinenko and Zakharikhina, 2020) that are unlike the normal inland habitats of *Ulva* (e.g., Messyasz and Rybak, 2010).

MATERIAL AND METHODS

Study area

The survey of aquatic habitats associated with thermal springs was done around Esso Village, located within Bystrinsky Nature Park, a section of the UNESCO World Heritage “Volcanoes of Kamchatka” area belonging to the Far East monsoon area (Kondratyuk, 1974) and having continental climate with a cold winter (below to –42°C), short warm summer (up to 32°C) and small annual precipitation (390 mm). The natural thermal effluents were altered after human changed the environment. Groundwater with a temperature at drill outlet of 72-100°C is collected from diverse outlets into a pipe and is released into a pool. The *Ulva* was found in the outflow on this pool (Fig. 1). The waters are siliceous (H_2SiO_3 – 169 mg.dm^{-3}), weakly alkaline to alkaline (pH 8.9-9.8), with a salinity of 1.0-1.5 g.dm^{-3}. Components are sulphates (SO_4), calcium, and sodium (Ca–Na), with trace components (As, B, F, Li). The nitrogen is the main dissolved gas (Kiryukhin et al., 2010; Muradov et al., 2013).

Sampling and laboratory study

The plants were collected by hand and stored in 70% ethanol. The images were taken using a Carl Zeiss Axiolab A microscope equipped with an AxioCam MRs-5 digital camera. A voucher specimen was deposited in the collection of algae of the herbarium of the Komarov Botanical Institute of the Russian Academy of Sciences (LE). The species was identified using key references (Bliding, 1963; Vinogradova, 1974, 1979; Moshkova and Hollerbach, 1986; Li and Bi, 1998; Ichihara et al., 2009; Mareš et al., 2011; Škaloud et al., 2018). Taxonomy follows the most recent reference for continental species (Škaloud et al., 2018). Although morphological variability of this genus complicates species identification and sometimes require genetic analyses (Bartolo et al., 2022; Steinhagen et al., 2023), the morphological traits of the studied population were clear enough for identifying our specimens as *U. intestinalis*.

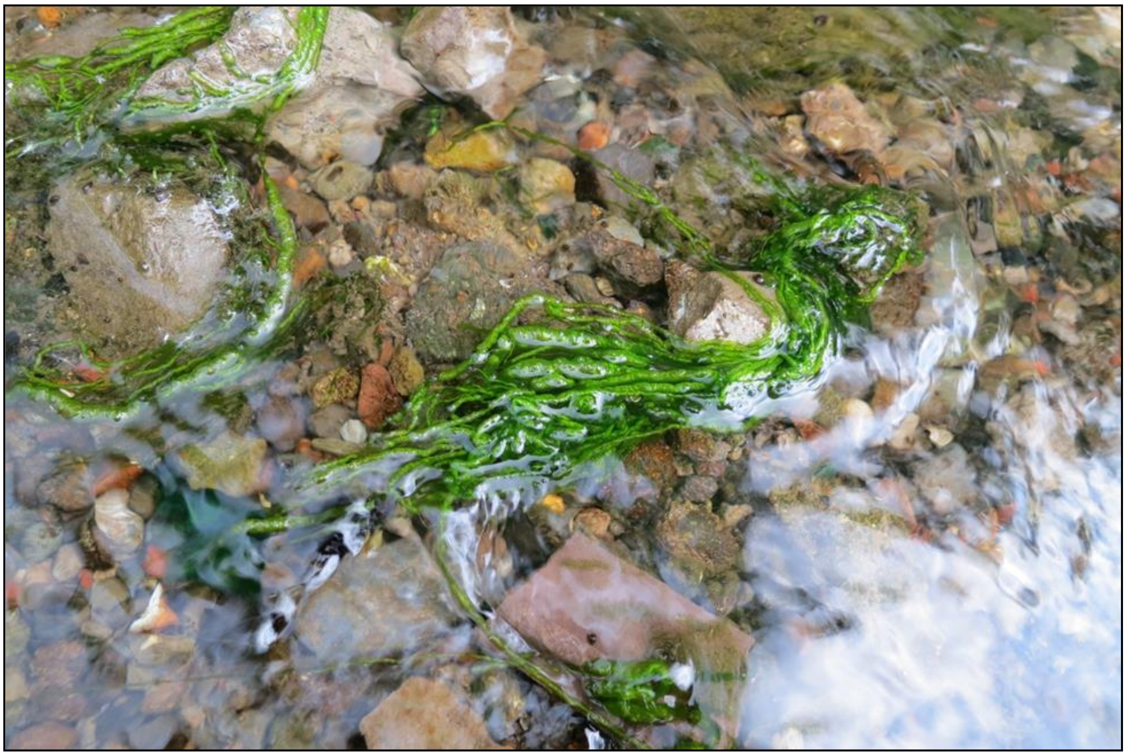

Figure 1: General appearance of *Ulva intestinalis* in a stream flowing from the swimming basin collecting water from the drilled thermal springs in the villages of Esso, Kamchatka during May 2017.

RESULTS AND DISCUSSION

Studied plants, their description and habitat

Studied specimens

Kamchatka Krai, Bystrinsky District, settlement of Esso, a stream outflow from the pool receiving water from thermal effluents, 55.924135° N, 158.701082° E, 490 m a.s.l., attached to the stones, at the depth of few cm, mainly in upper water layer, at water temperature of 22-23°C, 29 May 2017, abundant, O. A. Chernyagina (LE).

Description of specimens

The light fresh green wrinkled tubular thalli were harboring air bubbles inside, attached to the stones in clusters, up to 10 cm in length, less than 0.5 cm in width, had more or less uniform width throughout most of the plant, gradually narrowed to the base, unbranched at general appearance, very rarely shortly branched (Figs. 1 and 2). The branches were not filiform. They were always short in comparison with main tube width. No branches of second order and proliferations were found. Cells were placed without any order throughout thallus, and only short irregular lines of cells could be spotted at short branches and in basal parts of plants. Cells were more or less isodiametric to somewhat elongated, up to 2 times longer of width, 9.0-10.7 x (4.8)5.4-8.4 μm. Almost exclusively one pyrenoid per cell was traceable.

The studied specimens were in good agreement to descriptions of this species (see list of references in “Materials and methods”), but did differ with smaller cell size. They were overlapping in this trait expression, but were not identical in all characters with *Enteromorpha intestinalis* f. *saprobia* Vinogr. reported from the Sea of Japan and the Black Sea (Vinogradova, 1974; Moshkova and Hollerbach, 1986).

Habitat and frequency of occurrence

The ice-free stream (Fig. 1) from the large water-cooling swimming pool collecting cooled waters from drilled natural thermal springs called Esso springs after their use for house heating. The plants were found in May 2017 only, and not found at the same site in August 2017, nor during subsequent visual surveys conducted 2-3 times per year in 2018-2024 by O. A. Chernyagina.

Ecology and distribution of *U. intestinalis* in neighboring regions

The closest known inland localities of *U. intestinalis* are from thermokarst lakes in the basin of the Lena River in NE Siberia (Skvortsov, 1917; Kopyrina et al., 2020) similar climate, i.e., cold, without dry season and with very cold winter (Köppen-Geiger classification = Dfd, Peel et al., 2007), and in urban stream in Primorye Territory (Kukharenko, 1989) from cold, with dry winter and warm summer (Dwb; Peel et al., 2007). In southern Siberia, this species was found in hardwater, circumneutral to alkaline, slightly to properly brackish, mesotrophic and eutrophic lakes, ponds, endorheic rivers in steppe and forest-steppe (Tripolitowa, 1928; Pirozhnikov, 1929; Yakubova, 1953; Andreev et al., 1963; Khalfina, 1964; Ermolaeva, 1967; Safonova and Ermolaev, 1983; Safonova and Shishkina, 1986; Sviridenko, 2000; Kipriyanova and Romanov, 2010; Efremov and Sviridenko, 2016; Sviridenko et al., 2016; Tokar, 2018; Romanov, unpubl. data), as well as in rivers with elevated sulphates, brackish endorheic lakes, and in drainage waterbodies of the ash yard of big thermal power in steppe landscapes (Kuklin and Zamana, 2011; Kuklin, 2017; Bazarova and Kuklin, 2021). These sites are sited in areas with two types of climate: mostly cold, without dry season, with warm summer and mostly cold, with dry winter, with cold summer (Dfb and Dwc; Peel et al., 2007). The continental sites of this species are broadly spread across Eurasia, but seem to be concentrated in arid and subarid regions with brackish water bodies (see all references cited above).

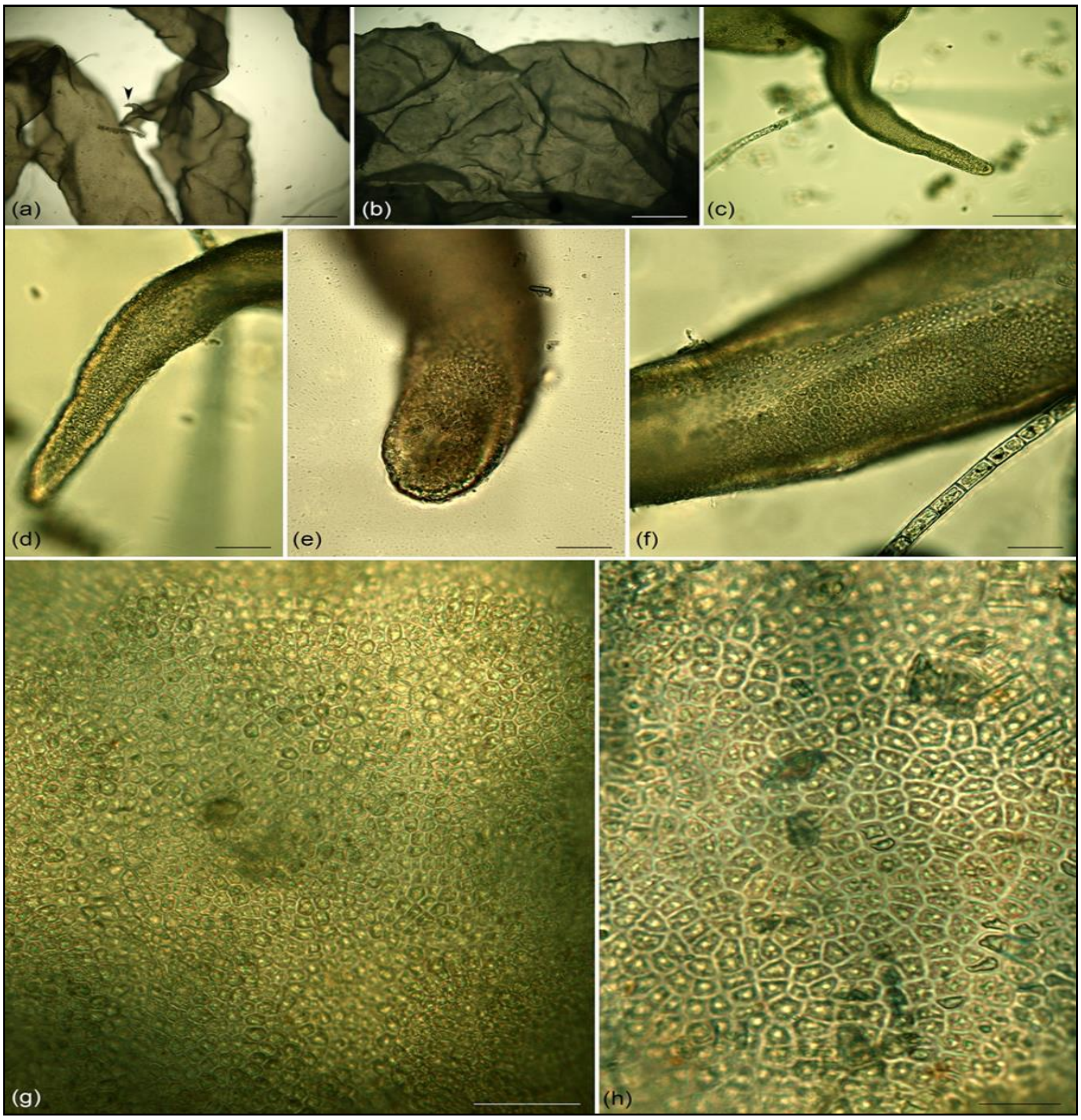

Figure 2: Key morphological traits of *Ulva intestinalis* from a stream flowing from the basin collecting water from the drilled thermal springs in Esso village, Kamchatka in May 2017 (LE): a, b – wrinkled tubular thalli with short robust primary branches (arrowhead), c – short robust primary branch, d – cells at primary branch illustrated at c, e – view of tangential irregular cross section at basal part of plant, f – lateral view of basal part of plant with narrow strip of cells having different general appearance, i.e., more narrow, elongated and with degraded chloroplasts, a filament of *Tribonema viride* Pascher (Ochrophyta, Xanthophyceae, Tribonemataceae) is visible at low right corner, g, h – irregular placement of cells with solitary pyrenoids in wide parts of plant, view from above. Scale bars: a, b – 400 µm, c – 200 µm, d-g – 40 µm, h – 20 µm.

It is unclear if *U. intestinalis* can sustain reproduction in study locality. This species could be occasionally colonize the site, in agreement with the *r*-strategy of opportunistic *Ulva* species (Burkholder and Glibert, 2013; Fort et al., 2020). Such species are widely known benefit from excessive anthropogenic nitrogen (Fort et al., 2020), making them useful ecological indicators of eutrophic waters (e.g., Areco et al., 2021; Rybak, 2021). Considering rare and unstable occurrence of *U. intestinalis* in inland Kamchatka, it could be there as a rare aquatic weed unable to maintain a stable population. Aquatic birds, known to transport and disperse a wide spectrum of plants, may be their main dispersal vectors (Lovas-Kiss et al., 2018).

Whereas seacoasts and estuaries are typical habitats for *Ulva* species worldwide (see references in Rybak, 2018; Bartolo et al., 2022), species with tubular thalli (former genus *Enteromorpha*) are also known from inland localities (Bliding, 1963; Moshkova and Hollerbach, 1986; Li and Bi, 1998; Ichihara et al., 2009; Messyasz, 2009; Mareš et al., 2011; iNaturalist, 2024). *Ulva intestinalis* has not been reported from new sites in marine habitats of Kamchatka and neighboring areas after its first records by Ruprecht and Woronichin from southern coasts of this peninsula (Ruprecht, 1850; Woronichin, 1914; Vinogradova, 1974, 1979; Klochkova and Berezovskaya, 1997, 2001; Klochkova et al., 2009a, b; Selivanova and Zhigadlova, 1997a, b, 2009a, b). According to Vinogradova (1979), *U. intestinalis* is not typical for Far East seas. The same can be suggested for continental water bodies of Primorye Territory (Kukharenko, 1989; Medvedeva and Nikulina, 2014). Close marine localities are known from the Okhotsk Sea and the Sea of Japan in Sakhalin Region, Khabarovsk Territory and Primorye Territory (Ruprecht, 1850; Sinova, 1928; Nagai, 1940; as *E. intestinalis* f. *saprobia*; Vinogradova, 1974; Kudrjaschov et al., 1976; Levenets, 2011; Kozhenkova, 2020).

CONCLUSIONS

A population of *Ulva intestinalis* living more than 200 km from the ocean in central Kamchatka, a region with a largely unsuitable climate and water chemistry, seems to be possible in only waters originating from thermal springs and experiencing eutrophication. Sporadic records of this species from Kamchatka suggest it may be unable to maintain stable populations in this region, and experience repeated local extinctions and recolonizations.

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