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Bewertungsansätze und Degradationsanalysen von Küstengewässern der deutschen Ostseeküste

Heft 28

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Coastal studies at the Southern Baltic Sea

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HERAUSGEBER DIESES HEFTES: Rhena Schumann

REDAKTION: Rhena Schumann
Hendrik Schubert

HERSTELLUNG DER DRUCKVORLAGE: Christian Porsche

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REDAKTIONSADRESSE: Universität Rostock
Institut für Biowissenschaften
18051 Rostock
E-mail: dagmar.heinrich@uni-rostock.de
Tel. 0381 / 498-6071
Fax. 0381 / 498-6072

BEZUGSMÖGLICHKEITEN: Universität Rostock
Universitätsbibliothek, Schriftentausch
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Vorwort

Als junge Doktorandin lernte ich die Rostocker Meeresbiologischen Beiträge als ein wesentliches Publikationsorgan kennen. So manche meiner Ergebnisse erschienen hier als oder in Gemeinschaftspublikationen über all das, was wir über unser Untersuchungsgebiet, die Darß-Zingster Boddenkette, seine Flora und Fauna, die Stoffkreisläufe herausfanden. Ganz wichtig erwies sich später der Band 2 (1994), der unseren Erkenntnisstand bis ca. 1992 zusammenfasste. Zunächst mag sich dieser Band 2 – wie auch alle anderen Publikationen zu inneren Küstengewässern - als „nur von lokalem Interesse" darstellen, aber das ist nicht wahr.

Die Darß-Zingster Boddenkette ist zwar global verglichen eine kleine Brackwasser-Lagune, aber dennoch ist sie typisch für solche Gewässer, die alle ähnlichen Stressoren ausgeliefert sind: Brackwasser und schlechtes Unterwasserlichtklima (geringe Sichttiefe). Aufgrund ihrer Morphologie erlaubt die Darß-Zingster Boddenkette, einen Salz- und Trophiegradienten auf kleinstem geographischen Raster zu untersuchen - ein ideales Untersuchungsgebiet, um Eutrophierungsprozesse zu studieren. Damit hat sie das Potential, zu einem wissenschaftlich bedeutenden Brackwasserästuar, einem Modellsystem, aufzusteigen.

So war die Anfang der 1970er Jahre gefasste Entscheidung, genau an diesem Ökosystem eine Biologische Station aufzubauen und dauerhaft zu unterhalten, sehr weise. Die nun verfügbare bzw. installierte Infrastruktur umfasst Schiffe, Labor und online-Messungen hydrologischer Parameter, stellt eine umfangreiche Datenbasis für weitere Experimente und Probennahmen bereit. Die Boddenkette ist seit Jahren offizielle Study Site der LTER Gemeinschaft (Long Term Ecological Research). In dieser Gemeinschaft sollen unsere Messungen in ein „größeres" Datennetz eingehen. Dem stelle ich mich gern als Stationsleiterin.

Nun feierten wir im September 2017 den 40jährigen Gründungstag der Biologischen Station mit einer wissenschaftlichen Tagung. Es war eine unglaubliche Rückbesinnung und Wieder-Vernetzung, mit neu geknüpften Kontakten und vielen Plänen. Das war eine wichtige Bestätigung und ein Auftrag, an unserer Mission festzuhalten: Langzeitmonitoring ökologischer Parameter und gleichzeitig die nächste Generation an Umweltforschern auszubilden. Dem soll dieser Band der Rostocker Meeresbiologischen Beiträge gewidmet sein. Deshalb gibt es zwei Beiträge zur Geschichte der Station, ihren Protagonisten und den Forschungsschwerpunkten.

Das soll auch im Fokus der gesamten Universitätsgeschichte stehen. Wir feiern gerade ein großes Jubiläum. Das ist toll. Es gibt eine „große" Geschichte – Universitäts-, aber auch eine „kleinere" – Institut / Fakultät / wieder Institut… Ich hoffe sehr, dass die Materialien nach 1968 bald verfügbar sind. Wer außerhalb meiner Generation sollte diese Informationen, diese Schätze heben? Bis dahin, machen wir unsere eigene Geschichte und nehmen ein „Loch" in Kauf.

Gruppenfoto der Teilnehmerinnen an der Jubiläumveranstaltung im September 2017 – bereit zur Party auf unserem weitläufigen Gelände. Foto: K.-U. Schumann

Vor Beginn der Feier im Max-Hünten-Haus in Zingst. Foto: Universität Rostock. ITMZ

Unsere Spezialistinnen zur Historie. Sabine Fulda aus unserem Bereich und Mitglied des Arbeitskreises Geschichte der MNF (l) mit Angela Hartwig (r, Universitätsarchiv). Foto: Heike Lippert

Eigentlich sollte sich dann eine Übersicht über weitere Mesokosmosexperimente nach 1994 anschließen. Das würde dann nahtlos an den Beitrag von Reinhard Heerkloß anschließen (HEERKLOß 2008), der in seinem Nachruf für Ulrich Schiewer dessen Leidenschaft insbesondere für solche Experimente würdigte. Diese Übersicht sollte die lange Liste an Experimenten fortsetzen und die jeweiligen Ziele der Experimente benennen. Dann sollten alle bisher unveröffentlichten Experimente mit einem Beitrag versehen werden, der das Experiment-Setup, die Methoden, die Ziele und die wesentlichen Ergebnisse benennt. Ein solcher Beitrag existiert bereits und wurde im letzten Band der Rostocker Meeresbiologischen Beiträge (SCHUBERT et al. 2017) veröffentlicht. Ein zweiter mit unseren jüngsten Mesokosmen erscheint jetzt hier. Alle Mesokosmen der letzten 20 Jahre zusammen sollten ein sogenannter Mesokosmos-Band werden. Damit wollten wir zeigen, dass diese Tradition an Mesokosmen und Enclosures (manche Forscherinnen trennen zwischen Experimenten an Land, aber outside, und Experimenten *in situ* aber eingeschlossen) auch nach wie vor von uns weitergeführt wird.

Nun stellte sich bei all meiner Suche nach Autoren heraus, dass es nur sehr wenige Kolleginnen gibt, die ab 1995 an solchen Experimenten beteiligt waren und jetzt auch noch Zeit und Spaß haben, eine solche Veröffentlichung zu schreiben. Damit steht mir eine recht große Aufgabe bevor, das alles selbst zu initiieren, den sogenannten „Lead“ zu nehmen und meine Kolleginnen so zu nerven, dass und bis sie beitragen. Dafür brauche ich etwas mehr Zeit, hoffe aber, dass ich es demnächst doch noch schaffen kann. Das Projekt liegt mir wirklich am Herzen. Aufgeschoben soll nicht aufgehoben sein! Und liebe Kolleginnen, ich bin nicht der Wolf, der immer wieder verliert so à la „Ну заяц, ну погоди!“ (Nun Hase, na warte!). Das nächste Mal schaffen wir die Publikationen! Gemeinsam.

Und wie so oft beherbergen wir im RMB wieder weitere Publikationen. Herzlich willkommen den Makrophytenforscherinnen!

Rostock, Dezember 2018

Rhena Schumann

Universität Rostock, Institut für Biowissenschaften, Biologische Station Zingst, 18374 Zingst
rhena.schumann@uni-rostock.de

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Rhena SCHUMANN*

* University of Rostock, Institute of Biological Sciences, Biological Station Zingst, Mühlenstraße 27, 18374 Zingst
rhena.schumann@uni-rostock.de

Research at the Biological Station Zingst

Abstract

The Biological Station Zingst was founded in September 1977. Research in the Darß-Zingst Bodden Chain started in the late 1960ies in cooperation with the Maritime Observatory of the Leipzig University. Data recording began with hydrological parameters and meteorology. Nutrients in the water column were added in the early 1980ies. The (at least) monthly cruises along the salinity and trophy gradient are one central component of the monitoring in this lagoon system. The other major activity is the daily sampling of the Zingster Strom as a site of moderate conditions in this lagoon system. Nutrients and abiotic parameters were monitored from 1980 in an equidistant series. Phytoplankton biomass (chlorophyll a) and seston were added in the late 1990ies. Total nitrogen and phosphorus, bacterio-, phyto- and zooplankton are monitored weekly in summer and biweekly in winter at least since the 1990ies. Microbial activities and food web interactions were investigated experimentally – mostly in enclosure experiments. This article summarises the scientific objectives and main results of research based or supported by the Biological Station.

Keywords: inner coastal waters, Southern Baltic, long term ecological research (LTER), mesocosm experiments, eutrophication

1 Introduction

The collectivisation of agricultural production was finished in 1960 in the German Democratic Republic (GDR). The objective of this process was to guarantee the populace' provision with foodstuff in a good quality (EWALD 1968). However, the taken measures involved an intensive industrialisation of agricultural production, i.e. the formation and cultivation of large fields as well as the routine application of mineral fertilisers and crop pesticides (KUHRT et al. 1999). Very late, these measures were re-evaluated and partly cancelled or revoked (HEINZ 2011).

As in all other countries, the intensive use of natural resources led to many problems, which were addressed also in the GDR by the Landeskulturgesetz (1970). Even before that, there was a resolution by the ministerial council to set up a network of measuring stations along the Baltic coast. The objectives were to collect data on primarily hydrological data (ice cover, navigability, water levels), but also on eutrophication indicators (CORRENS & ZÄNGER 1967). Measuring programs by state's agencies as well as research institutions incl. universities were established.

The idea of a field station for teaching came up already in the 1950ies (SCHUMANN et al. 2019). In the early 1970ies, it was decided to build a research and teaching station in Zingst (SCHUMANN 2018). The Darß-Zingst Bodden Chain has a connection to the open Baltic. Zingst is situated in "the middle" of a salinity and eutrophication gradient of this bodden chain (Fig. 1). The station was opened in 1977 and is staffed by 3 persons. Thus, a daily monitoring program could be established. The monthly ship cruises started in the late 1960ies in cooperation with the Maritime Observatory of the University of Leipzig. Measuring campaigns in the field and mesocosm experiments included many more scientists from the institute as well as students.

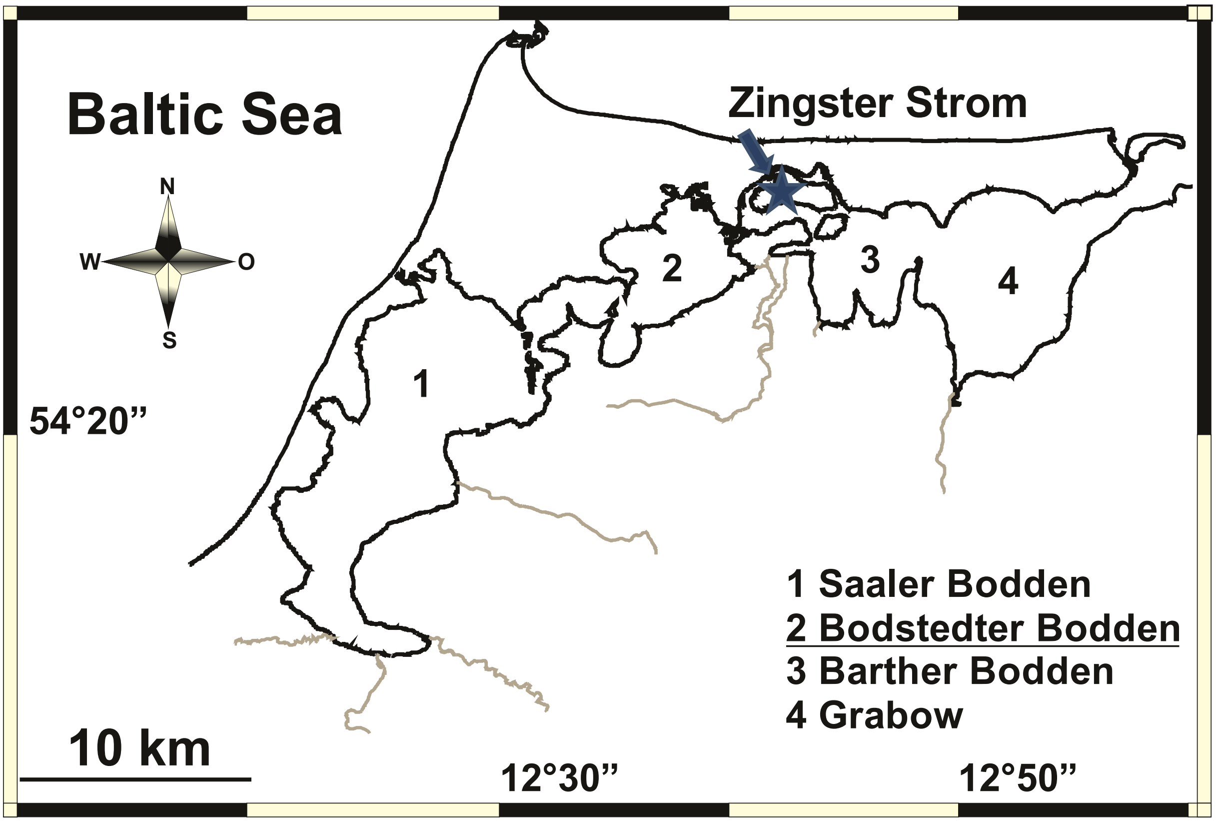

Fig. 1 Map of the Lagoon system: Darß-Zingst Bodden Chain with the site Zingster Strom near the Biological Station Zingst (arrow). Many experiments were conducted in the Kirr Bight formed by the island Kirr (Star).

The general research topics and measures will be described and listed here accompanied by the resulting publications. There will be another publication in a later issue laying out the mesocosm experiments, especially those having taken place after 1990. The technical setup of the latest mesocosm series (ZOOM) is also published in this issue (BERTHOLD 2018).

2 Research topics

Already in the early 1970ies, research topics of coastal lagoon ecology were agreed upon in a structured fashion. All partners were lined up to produce data on biota, element budgets and control factors as well as to quantify matter flows, growth functions, regulation loops etc. The collaborating institutions were the Water management directorate Coast-Warnow-Peene (WWD, today part of the State Agencies for Environment, Nature Conservation and Geology – LUNG – as well as State Agency for Environment and Agriculture – StALU in Mecklenburg-Western Pomerania), the Maritime Observatory Zingst of the University Leipzig, several working groups of the University of Rostock and the Institute for Marine Research (today Institute of Baltic Sea Research). The overarching goal was to establish a biocybernetic model of the Darß-Zingst Bodden Chain (Schnese et al. 1973). Biocybernetics describe the controlling and regulating mechanisms in organisms and ecosystems. Some smaller models were developed, as a biochemical ecosystem model, matter flows and balances, hydrodynamic model and organism's functions (Vietinghoff et al. 1979, Vietinghoff et al. 1981, Vietinghoff et al. 1982 a and b, Brinckmann et al. 1981, Brinckmann 1982). Later, some balances of matter flows were calculated without modelling (e.g. Schumann 1993, Schiewer et al. 1991, Schiewer 1994). However, this great goal inspired many experiments and the long-term monitoring. The Biological Station Zingst with its team of 5 permanent co-workers (back then) formed the basis for the complex investigations of the ecology and matter cycles in the Darß-Zingst Bodden Chain (Schlungbaum 1988 a).

First plans may have been to build a more or less automatically working measuring platform, as it was planned for the WWD (Landesarchiv Greifswald 1966). Data cables and water pipes were laid below the dike between the Zingster Strom (Fig. 1) and the station. For more than 10 years, physical parameters were measured online in the pumped water flow. In the late 1980ies, this so-called "automat-lab" was disassembled. The daily measurements of meteorological, physical and chemical parameters resulted already in a 40 years long equidistant data series (365 days per year, e.g. Schumann et al. 2006, Selig et al. 2006, Fig. 2A, Fig. 5). A decade later in 2002, *in situ* probes were installed in the Zingster Strom to obtain again physical online data (see above). They were funded by the LUNG and so meteorological and hydrophysical data are available every 10-15 min. Additionally, there are also weekly to biweekly long-term data on plankton organisms available. Zooplankton observations began in 1969. Phytoplankton biomass and composition was investigated from the 1970 with regular monitoring starting in the early 1980ies. In the 1990ies, weekly measurements of total phosphorus and nitrogen began as well as daily chlorophyll *a* and seston determinations.

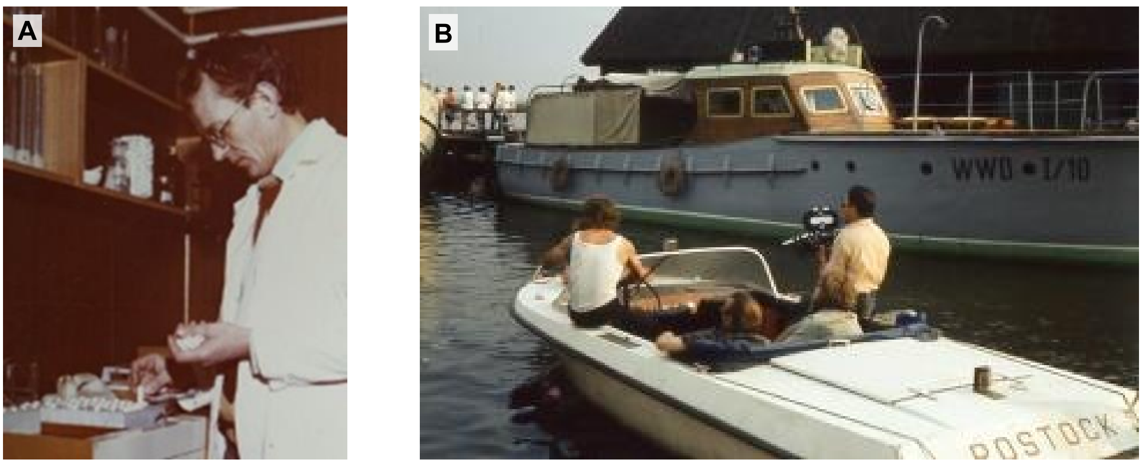

Fig. 2 **A:** Henning Baudler is busy at the first nutrient autoanalyser (Foto: DEWAG). **B:** A film team records the research vessels, which assisted one of the SYNOPTA field campaigns (Foto: provided by H. Baudler).

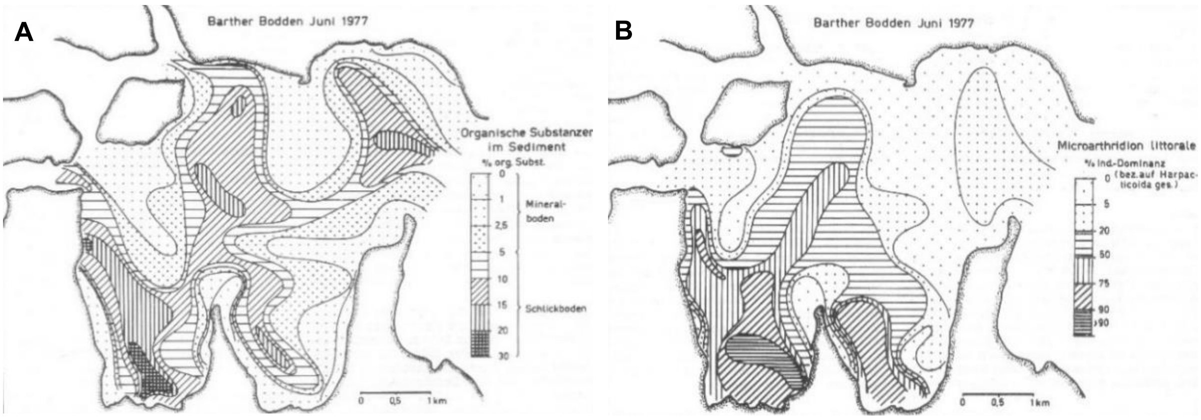

Fig. 3 **A:** Map of the organic contents in sediments of the Barther Bodden (SCHLUNGBAUM et al. 1979). **B:** Map of the benthic harpacticoid copepod *Microarthridion littorale* (same area as in Fig. 3A, ARLT & SCHLUNGBAUM 1979)

1972 and 1979, two extraordinary field campaigns took place: SYNOPTA, which were synoptic sampling events in all bodden basins for water and sediment parameters (e.g. JOST & NAUSCH 1980, Fig. 3A). Many ships of the Maritime Obersvatory and from the WWD supported these campaigns (Atair, Ikarus, Adler, WWD I/10 and 4, Fig. 2B, BAUDLER & HUPFER 2011). The results of these campaigns as well as further sampling events were maps of sediment properties and benthos organisms, which were compiled to sediment atlases (e.g. Figs. 3A and 3B). Many working groups were involved: marine biology, ecology, applied ecology, botany and zoology. The WWD funded also in the following years research on matter and nutrient cycles in respect to eutrophication effects (see below). The related questions were primarily investigated by so called mesocosm or enclosure experiments (e.g. SCHIEWER & JOST 1986, SCHIEWER 1997). From these results, a concept for a coastal waters TGL (Technische Normen, Gütevorschriften und Lieferbedingungen der DDR = technical standards, quality regulations and delivery conditions of the GDR) was compiled, which corresponded to the Western German DIN (SCHLUNGBAUM 1988 b). Both anticipated many aspects of the European Water Framework Directive, which was set in force in 2000.

In the 1990ies, several projects, all initiated by Hendrik Schubert (Ecology), investigated (also) the Darß-Zingst Bodden Chain. The impact of UV radiation on plankton organisms was addressed by UV-MAOR. Main results were data on the underwater light climate and its dynamics and light adaptation of phytoplankton (e.g. SCHUBERT et al. 2003, FORSTER & SCHUBERT 2001). The mechanism of state transition (quick and short term adaptation of the photosynthesis apparatus to changing light) was proven for the first time under natural conditions with phytoplankton of the Darß-Zingst Bodden Chain (SCHUBERT et al. 1997). In the EU-project CHARM, phytoplankton biomass and composition was evaluated as an eutrophication indicator (e.g. SAGERT et al. 2008, RIELING et al. 2003). A whole project series (e.g. ELBO and MAKMO) developed comprehensive bioindication systems for coastal waters (e.g. SCHUBERT et al. 2007, SCHORIES et al. 2005).

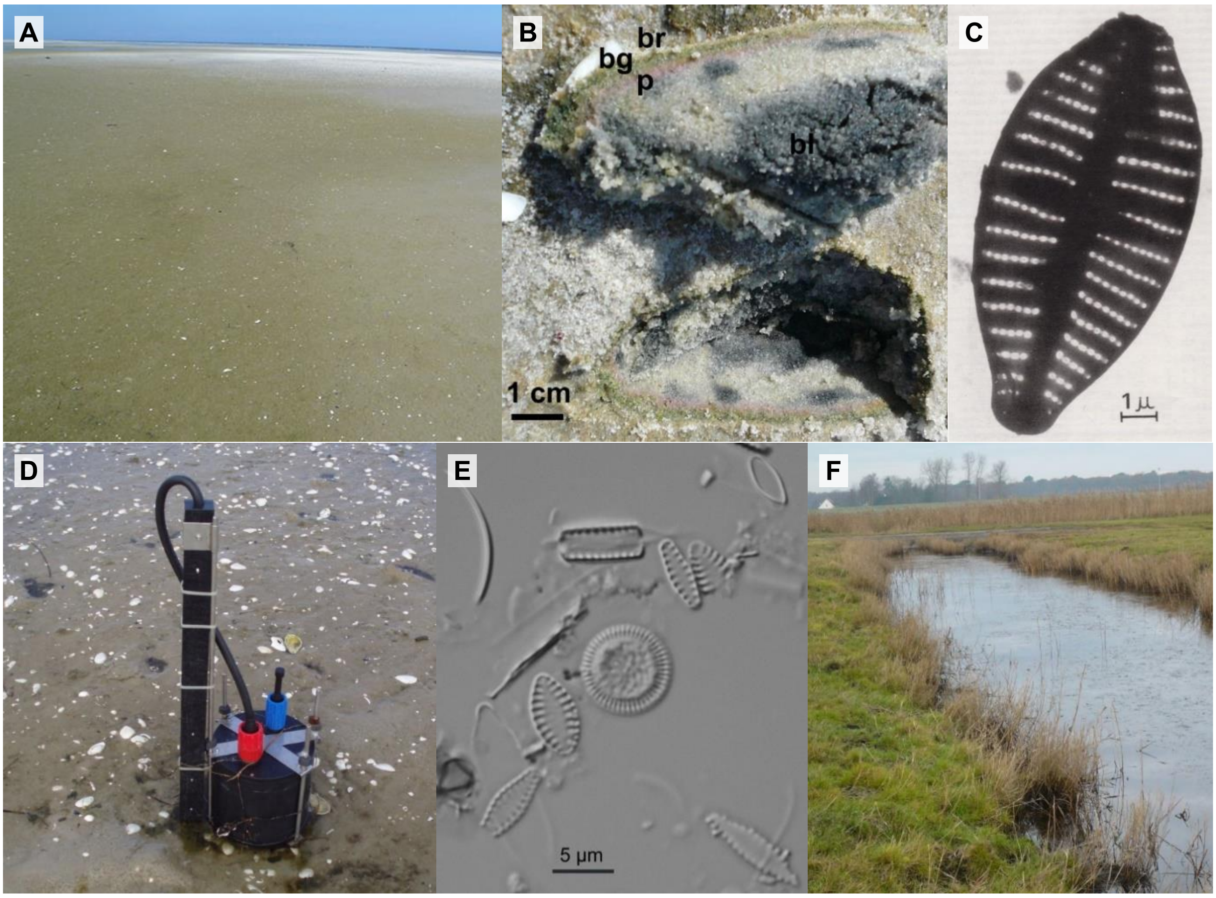

Fig. 4 **A:** Wind flat at the tip of the Zingst peninsula. The darker sediment areas are infested by diatoms as microphytobenthos and most likely by cyanobacteria beneath as well. **B:** Microbial mats forming a vertically structured sediment in the wind flat. br (brown) = diatoms, bg (blue green) = cyanobacteria, p (pink) = purple sulphur bacteria, bl (black) = sulphate reducing bacteria. **C:** *Gomphonema parvulum* (Kütz.) Grun. Diatom from microphytobenthic communities described early in the 1970ies (PODELLECK 1980). **D:** Autonomous water level probe constructed by the working group of "Technical electronics and sensorics". Foto: H. Baudler modified from KARSTEN et al. 2012. **E:** Diatoms inhabiting sand grains are rather small. Foto: K. Kuriyama. **F:** Polder in the Sundische Wiese at the Eastern part of the Zingst peninsula, which will be restructured from 2019 on.

One major joint project with the University of Greifswald investigating matter cycling was ÖKOBOD (funded by the Federal Ministry for Education and Research, 1996-1998). Objectives were to quantify carbon turnover in the water column and sediments, to balance matter exchange between water and sediment and to evaluate the role of the top fluffy sediment layer in this context. Several analytical methods were established in the ecology working groups and at the Biological Station: dissolved and particulate carbon and nitrogen, total protein and free amino acids, total carbohydrates, particle sizes and composition (e.g. SCHUMANN et al. 1998 and 2001, GÖRS et al. 2007). Other more applied projects were: Efficiency of sediment traps, assessment of the Barth harbour modification, several lagoon studies. A more recent study was KEI (short term variability of eutrophication indicators, 2000-2010). The Darß-Zingst Bodden Chain is, moreover, an official study site of the LTER community (Long term ecological research) and the Biological Station serves as its management and provides data for projects and publications. The good data basis of the station made another joint project possible – BACOSA (Baltic Coastal Sea System Analysis), which joins the Universities of Rostock (and here the Institute of Biosciences and the Agricultural Faculty), Greifswald and Kiel. Main objectives are the estimation of processes in the phosphorus cycle, the impact of submerse macrophytes and reed belts on phosphorus availability to phytoplankton, the structure of food webs and the quantification of ecosystem services.

Since 2000, the wind flat "Bock" at the end of the Zingst Peninsula is also intensively investigated (Fig. 4A). Several diploma and dissertation theses were written about cyanobacterial mats and diatom microphytobenthos (e.g. WITTE 2005, HEYL 2015, Fig. 4B) as well as the hydrological situation of the flat (KARSTEN et al. 2012, Fig. 4D). Investigations on microphytobenthos there and older results (Fig. 4C) are expanded / re-evaluated for the whole Bodden Chain (Fig. 4E). The cooperation with the national park's authority was intensified, so that new research topics were agreed upon. One project is the observation of nutrient releases after renaturation measures of former grasslands, which is very interesting in the case of the East Zingst area (Sundische Wiese, Fig. 4F), because data from the status before restauration can be recorded.

3 Important Results

Meteorology, hydrography and hydrology: The Darß Zingst Bodden Chain is characterised by a strong and stable gradient of salinity and trophy, which allows studying eutrophication impacts on matter cycles within the same climate zone and even under the same weather conditions. In addition to our own data, we can use meteorological data as well as data on air pollution of the atmosphere measuring station Müggenburg (Federal Environmental Agency) and water balance (inflow, water exchange with the Baltic) by the Federal Maritime and Hydrographic Agency. These data can be combined with our own current data and may serve as the basis for a hydrological model.

Eutrophication: The long term data series and the monthly samplings along the trophy gradient describe the eutrophication until the late years of the 1980ies. Signs of remesotrophication were expected and searched for after certain management measures, like manure storage, treatment and controlled application as well as a general waste water treatment. Changes in the management of liquid manure from the mid 1980ies on (VOIGT 1988) improved at least the phosphate concentrations in the water column strongly (Fig. 5). Nitrogen import into the lagoon system seems to depend more on hydrological parameters (water runoff as river input and as diffuse sources). Further measures since the 1990ies (waste water treatment plants, decreased agricultural land use, national park) did not decrease phytoplankton biomass yet. This very high biomass causes the very low Secchi depth of 30 cm on average (SCHUMANN et al. 2012) and is the most obvious sign of the ecosystem degradation.

Element cycles: The ecosystem understanding was improved and partly changed by various mesocosm experiments and caused an extension of the monitoring program. The flux of phosphates from sediments or the amounts of phosphate as readily available from the sediments seems to be lower than thought before. The before assumed high diffusive release rates from the sediment (e.g. SCHLUNGBAUM 1982, BERGHOFF et al. 2000) may be not as high as thought before (BITSCHOFSKY 2016). However, resuspended sediment particles may even adsorb more phosphate than was released due to their high adsorption capacity

(SCHLUNGBAUM 1982, KARSTENS et al. 2015) also in the oxic water (SELIG et al. 2005). Moreover, an oxic sediment surface layer may hinder phosphate release from the sediments at calm conditions. The water column is almost permanently oxic in this water body and other along the southern Baltic Sea coast (LUNG 2013). The high phytoplankton biomass still has a high nutrient demand (BERTHOLD & SCHUMANN in revision). We base that opinion on the seasonal different phosphate uptake behavior of phytoplankton, i.e. changing supply. Furthermore, apparent growth rates and primary production were low without additional fertilization, at simultaneously high phosphatase activities, low growth rates and primary production without phosphate fertilisation as well as a high phosphatase activity (SCHUMANN et al. 2009). Additionally, zooplankton seems unable to control phytoplankton standing stocks most of the year. If this is caused by the food web structure (top down control) or if potent filter feeders cannot develop due to the brackish conditions (FEIKE & HEERKLOß 2008), is subject of the recent project BACOSA (see above). All in all, the food webs and element cycles seem to be in such a stable state that the ecosystem cannot be easily manipulated to a reduce phytoplankton.

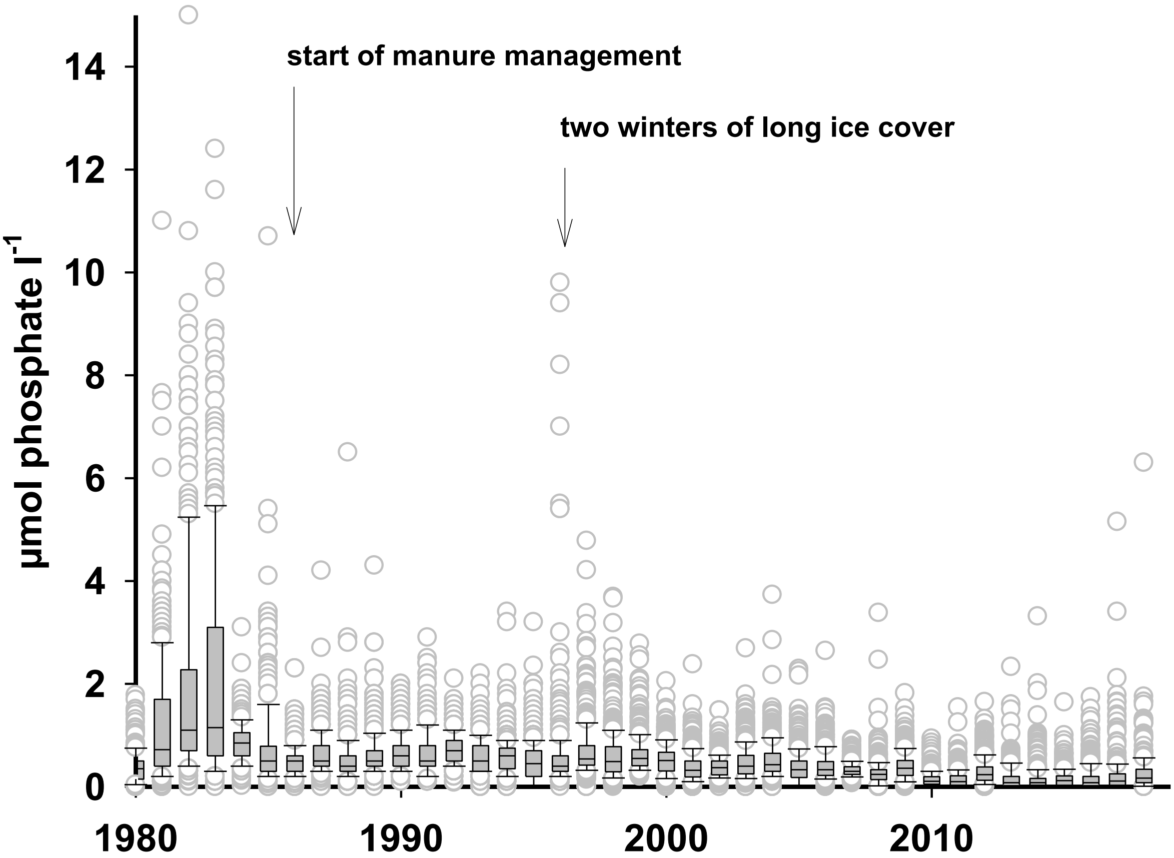

Fig. 5 Box whisker plots of phosphate concentrations (µmol phosphate-P l^{-1}) in the Zingster Strom since 1980 based on daily measurements. Line in box: annual median, box: interquartile distance, whisker: 10 and 90 % percentile. n_{total} = 13890

4 Future plans

In the next future, we plan to provide online retrieved hydrological parameters (water temperature, oxygen saturation, conductivity and pH in the internet. This helps other researchers to plan samplings on an event basis.

Other aims are to unravel matter fluxes from land to sea as well as matter cycling within this eutrohicated lagoon. Additionally, more key players of matter cycling shall be identified: bacteria, protists and larger consumers.

Acknowledgements

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Projects and initiatives

BACOSA (2013-2019) Baltic Coastal System Analysis and Status Evaluation. Funded by the Federal Ministry of Education and Research

CHARM (2002-2005) Characterisation of the Baltic Sea Ecosystem: Dynamics and Function of Coastal Types. Workpackage 2 and 3: Key indicators and response in relation to typology for phytoplankton and macrophytes, Workpackage 7: Dissemination. European Community

ELBO (2000-2003) Entwicklung von leitbildorientierten Bewertungsgrundlagen für die Übergangsgewässer nach der EU-Wasserrahmenrichtlinie – Übergangsgewässer der deutschen Ostseeküste. Funded by the Federal Ministry of Education and Research

KEI (2000-2010) Untersuchungen zur Kurzzeitvariabilität ausgewählter Eutrophierungsindikatoren im Zingster Strom. Funded by the State Agency for Environment, Nature Conservation and Geology Mecklenburg-Western Pomerania

LTER (ongoing membership in this society) Long-term Ecological Research

MAKMO (2003-2004) Entwicklung eines Monitoringschemas für die Außenbereiche der deutschen Ostseeküste – Makrophytobenthos. Funded by the respective State Agencies of Mecklenburg-Western Pomerania and Schleswig-Holstein.

ÖKOBOD (1996-1998) Ökosystem Boddengewässer - Organismen und Stoffhaushalt. Teilprojekt: Charakterisierung und Klassifizierung von Aggregaten Funded by the Federal Ministry of Education and Research

SYNOPTA (1972 and 1979) Synoptische Aufnahmen von Ökosystemparametern. University of Rostock.

UV-MAOR (1993-1998) UV-Wirkung auf Marine Organismen. Teilprojekt: UV-Wirkung auf Planktonmikroorganismen in eutrophen Flachwassergebieten. Funded by the Federal Ministry of Education and Research

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Rhena SCHUMANN*

* University of Rostock, Institute of Biological Sciences, Biological Station Zingst, Mühlenstraße 27, 18374 Zingst
rhena.schumann@uni-rostock.de

Team of the Biological Station Zingst

Abstract

The Biological Station Zingst was founded in 1977 as a part of the Institute of Biological Sciences. Long-term monitoring in the Darß-Zingst Bodden Chain started in the late 1960ies with hydrological parameters and meteorology. Nutrients and plankton were added later to the long-term monitoring. Other tasks of the Biological Station are teaching of analytical methods, supporting sampling of water and sediments as well as hosting mesocosm experiments. This article presents the main contributors to the founding of the Biological Station, their research and teaching.

Keywords: Biological Station Zingst, Southern Baltic, Darß-Zingst lagoon, scientists

1 Introduction

A detailed description of biological research at the Rostock University was given in ARNDT (2006) covering predominantly the years before 1968, when the third university reform was applied. The foundation of the Biological Station Zingst took place later. All important documents upon estate's acquisition, construction treaties[1], personnel assignment and interactions with the Institute of Biological Science (Sektion Biologie) in Rostock are not available yet in the university's archives. The missing times have to be reconstructed so far and preliminarily by witnesses as was done in SCHUMANN et al. (2019). This paper wants to honour all researchers having devoted time, ideas and effort in coastal ecosystems research at the Biological Station Zingst.

In the early 1970ies, the Institute of Biological Sciences decided to build a research and teaching station in Zingst. It is situated in at the Zingster Strom, a part of the eutrohic, brackish Darß-Zingst Bodden Chain (lagoon system). The vicinity to the Maritime Observatory of the Leipzig University, the facilities of the Water management directorate Coast-Warnow-Peene, the atmosphere measuring station Müggenburg (see below) and the possibility to use construction expertise from the Children's holiday camp in Pruchten (managed by the University of Rostock) supported this decision. Many of these neighbours added and some still contribute continuously to the value of the joint data sets.

[1] Only a copy of the electrician's quote is in the station's documents.

This work focusses on scientists and colleagues conducting the monitoring, participating in the joint mesocosm experiments and sampling events. General research topics with important results valid for Baltic and other lagoon systems are outlined in this issue (SCHUMANN 2018). The long term data set has still to be compiled in respect to the respective starting points, frequency and sampling sites. However, technical information and metadata are given in the data repository of the LTER (long term ecological research) community in the DEIMS repository (https://data.lter-europe.net/deims/).

2 Directors of the Biological Station and working groups using it

The first director of the Biological Station Zingst was Günter Schlungbaum from 1977 on (Fig. 1 A). He was a senior scientific assistant from 1969 until 1980, became an associate professor in 1980 and full professor for applied ecology in 1993. He retired in 2000 (*cpr: catalogus professorum rostochiensum*). Especially in the 1980ies and 1990ies, research and teaching at the Biological Station was dominated by topics and requirements of the working group "Applied Ecology". This is very interesting, since two other professors are always mentioned in relation to founding and establishing the station: Ernst-Albert Arndt (Marine Biology, Fig. 1 B) and Werner Schnese (Hydrobiology, Fig. 1 C). The working group of Werner Schnese was, however, called "Production Biology" as can be read in some protocols, when these papers will be accessible in the archives. These two groups investigated also intensively the Darß-Zingst Bodden Chain and used the station's infrastructure.

Starting at the 1st of March 1978, Henning Baudler (Fig. 1 D) managed and leaded the station until his retirement at the 31st of July in 2012. He studied physics at the University of Rostock and graduated in oceanology at the Maritime Observatory of the University of Leipzig. Henning Baudler held seminars and practical courses in meteorology and oceanology also for biology students of the Rostock University as he still was a research assistant at the Maritime Observatory. This program for different students was expanded for distance learners of ecological environmental protection. He gave also practical courses for students from Russia (Immanuel Kant University Kaliningrad) and Lithuania (University of Klaipeda), which was embedded in respective bilateral exchange programs. Students of various disciplines participated annually in excursions visiting the areas of the Vistula and Curonian lagoons were taught in oceanology, geology, and ornithology. These partnerships allowed a tight cooperation with scientists from these Eastern Baltic countries resulting in several joint publications. Henning Baudler developed and installed together with colleagues of the University of Rostock working on electrical engineering and informatics an online measuring system logging physical parameters of the atmosphere, the water column and in the wind flat at the Eastern tip of the peninsula Zingst.

I am (Rhena Schumann Fig. 1 E), the third head of the Biological Station. As a pupil, I worked in a study group, which investigated phytoplankton in rivers of Berlin. This group was led by Lothar Täuscher (TÄUSCHER 2012). I enjoyed our excursions every spring to the Biological Station Boiensdorf. Consequently, I studied from 1984 to 1989 Marine Ecology at the University of Rostock and came to Zingst in 1986 for the first time. 1988, I joined one of the mesocosm experiments of the working group "Experimental Ecology" (Prof. Schiewer). As a PhD student, I worked in many enclosure and mesocosm experiments, as ROKI 1990, AGVER 1992 and CIROT 1993. The ecosystem research was fascinating, the housing within the station, however, was very not hospitable. I further investigated phytoplankton and the microbial loop also in the Darß-Zingst Bodden also in the field and started my own long-term data series on phyto- and bacterioplankton in 1991 (SCHUMANN 1994). However, I investigated these field samples only as a hobby for many years after my graduation. Many years later in 2007, I got the opportunity returning to coastal systems research and matter cycling in brackish lagoons. Since 2002, I supervised practical courses in Zingst (aquatic system status evaluation for bachelor undergraduates in Biosciences, later also in water quality for master undergraduates of Aquaculture. Since 2012, I gave also on-site lectures for distance learners in water conservation.

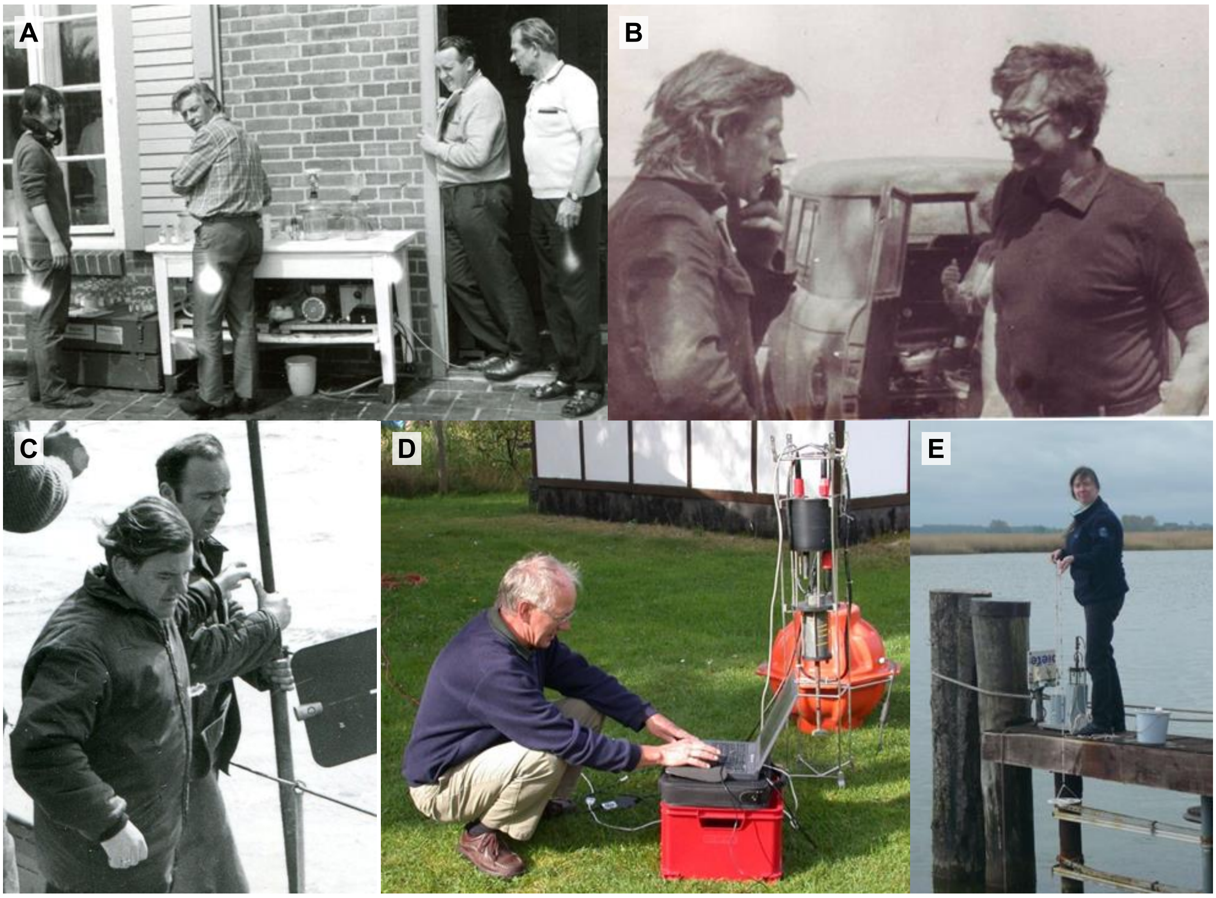

Fig. 1 **A:** Ferdinand Brzezinski (middle) is filtering water samples in front of the Maritime Observatory during the synoptic sampling campaign in 1972. Günter Schlungbaum is observing (3rd from left). Foto: H. Baudler. **B:** Ferdinand Brzezinski (left) and Ernst-Albert Arndt in the mid-1980ies at an excursion in front of the legendary Barkas. Foto: R. Heerkloß. **C:** Werner Schnese (front) and Peter Hupfer (back) expose a flow probe. Foto: P. Hupfer. **D:** Henning Baudler is initialising another flow probe, which was developed in cooperation with the working group of technical electronics and sensorics (2009). Foto: F. Schmacka. **E:** Me as a "pier"biologist upon sampling and measuring in our daily routine program. Foto: L. Felgentreu

Apart from the professors Werner Schnese (Fig. 1 C) and Ernst-Albert Arndt (Fig. 1 B), several other scientists contributed much to develop the research at the Biological Station. One of them was Ulrich Schiewer (Fig. 2 A), who planned and installed many enclosure experiments in the 1980ies and early 1990ies. He published several papers on these experiments and, thus, brought the station to international attention (e.g. SCHIEWER et al. 1984, SCHIEWER et al. 1991, SCHIEWER et al. 1993, SCHUMANN & SCHIEWER 1994). Hendrik Schubert (Fig. 2 B), who followed him as a full professor of ecology, has a strong focus on ecology of inner coastal waters. Ulf Karsten became full professor in applied ecology (now applied ecology & phycology) and followed Günter Schlungbaum in 2000. He always supported the improvement of the station's infrastructure and the long-term monitoring in the Darß-Zingst Bodden Chain.

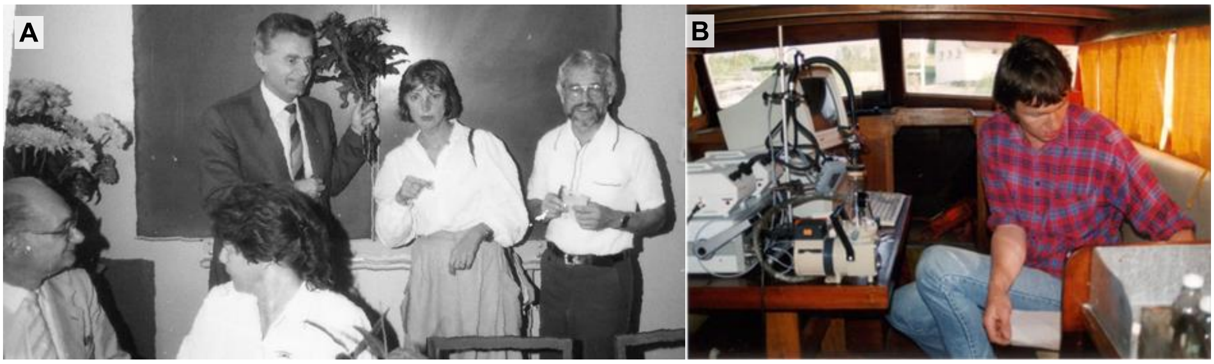

Fig. 2 **A:** Ulrich Schiewer receiving congratulations upon his appointment as an extraordinary professor from Sibylle Abarzua and Norbert Erdmann in 1988. Sitting in front: Eike Libbert and Waltraut Schiewer. Foto: R. Heerkloß. **B:** Hendrik Schubert on board of the Gammarus in the mid 1990ies measuring primary production. Foto: R. M. Forster.

3 Staff and Guest Researchers

The first ship for sampling the lagoon system was built and put into service to sample water. Klaus Fütterer was the first ship's master of the *Gammarus* and Bernd Kriesten helped on board and worked as a house manager. Since 1989, Volker Reiff (Fig. 3 A) took over all these tasks, after he worked for a short time at the *Gadus*, the former research vessel stationed in Rostock (BAUDLER & HUPFER 2011). Nowadays, Volker Reiff is involved not only in sampling, but also in the maintenance of the measuring equipment, construction of mesocosms and participates fully in the daily measuring program. The technician does all analytical work in the lab, especially nutrient determination. The first technician at the station was Gerda Krüger (Fig. 3 B), who was followed by Rita Wulff (Fig. 3 C).

There were several senior scientists responsible also for chemical analytics and its quality management, the implementation of new methods and teaching: the first was Günther Nausch (nutrient analyses, Fig. 3 D), who worked later at the Leibniz Institute for Baltic Sea Research (IOW) and is now retired, followed by Uwe Selig (phosphorus cycle, now project execution office) and Christine Neumann (many years in various working groups of the University and at the IOW).

Especially in the late 1970ies and in the 1980ies, many other biologists of our university participated in mesocosm experiments and field campaigns: Monika Nausch (matter cycling, Fig. 3 D), Günter Jost (aquatic microbiology, Fig. 3 E), Norbert Wasmund (phytoplankton and microphytobenthos) (all senior scientists at the IOW now), Hartmut Arndt (protistology, was PhD candidate then, is now full professor of ecology at the university in Cologne, Fig. 3 E), Sabine Fulda (senior scientist in plant physiology, later plant genetics, now retired), Reinhard Heerkloß (zooplankton, Fig. 3 D), Peter Spittler (protistology) (all at our university, some are retired now) and Thomas Walter. Zoologists and marine biologists worked also at the Darß-Zingst Bodden Chain and used the ships, sampling devices and hands on help provided by the Biological Station: Helmut Winkler (fish biology), Günter Arlt (meiozoobenthos) (senior scientist and professor at our university, retired), as well as the macrozoobenthologists Detlef Franek and Roger Burckhardt, Regine Bönsch (Institute for Applied Ecosystem Research, Broderstorf), Michael Zettler (IOW) and Ralf Bochert (State Agency for agriculture and fisheries Mecklenburg-Pomerania). Other working groups of the Institute of Biological Sciences, like biophysics, animal and plant physiology, dedicated also resources to the investigation of coastal ecosystems. Ulrich Vietinghoff and his senior scientist Marie-Luise Hubert promoted statistical methods and ecosystem modelling. However, these colleagues turned their focus to the Greifswalder Bodden in the 1980ies.

The working group of Hartmut Ewald provided much to the technology of measuring environmental parameters: Rainer Jaskulke and Bernd Himmel. They did not only construct probes, but also algae incubators and coupled our sensors to the computer network.

Fig. 3 **A:** Volker Reiff as the shipsmaster inspects his new research vessel, the *Nauplius*, at the Barther ships yard in summer 2011. We had just handed over the old ship, the *Gammarus*, to its new owners after having a last fare well trip. Petra Nowak was the first on board and served as a weight in a heeling test. **B:** Gerda Krüger at our first nutrient autoanalyser from mlw (Volkseigenes Kombinat Medizin-, Labor- und Wägetechnik Freital). Foto: H. Baudler. **C:** In 2011, we got our third autoanalyser. Rita Wulff observes carefully how the measuring manifolds are set up. **D:** Günther and Monika Nausch (sitting at the desk) as well as Reinhard Heerkloß (2nd row, right) at a scientific meeting. Foto: provided by R. Heerkloß. **E:** Hartmut Arndt (left) und Günter Jost taking samples at an enclosure construction. Foto: provided by H. Arndt.

Additionally, the Biological Station hosts many other guests, which use the infrastructure for workshops, field trips and their own experiments (Fig. 4 A and B). Ecological excursions are often combined with a trial day as a marine biologist. We gladly support such events by boat trips and sampling in the lagoons, microscopy or lab shows. The informal atmosphere turns all activities and scientific vocabulary into fun, which results in such creative and entertaining drawings as well to some remarkably comical quotes as “Blaukorn (mineral fertiliser) is blue and rain water also” following a famous tongue twister. This reflects that rain water is rich in phosphate, what turns blue upon the molybdenum blue reaction for measurement. The result was compared to one grain of fertiliser dissolved in one litre of water with a similar result. The students should get a visual impression of very small concentrations and could handle all samples on their own. Usually, this experience triggers long debates about fertilisation in gardens, flower pots, agriculture and environmental protection.

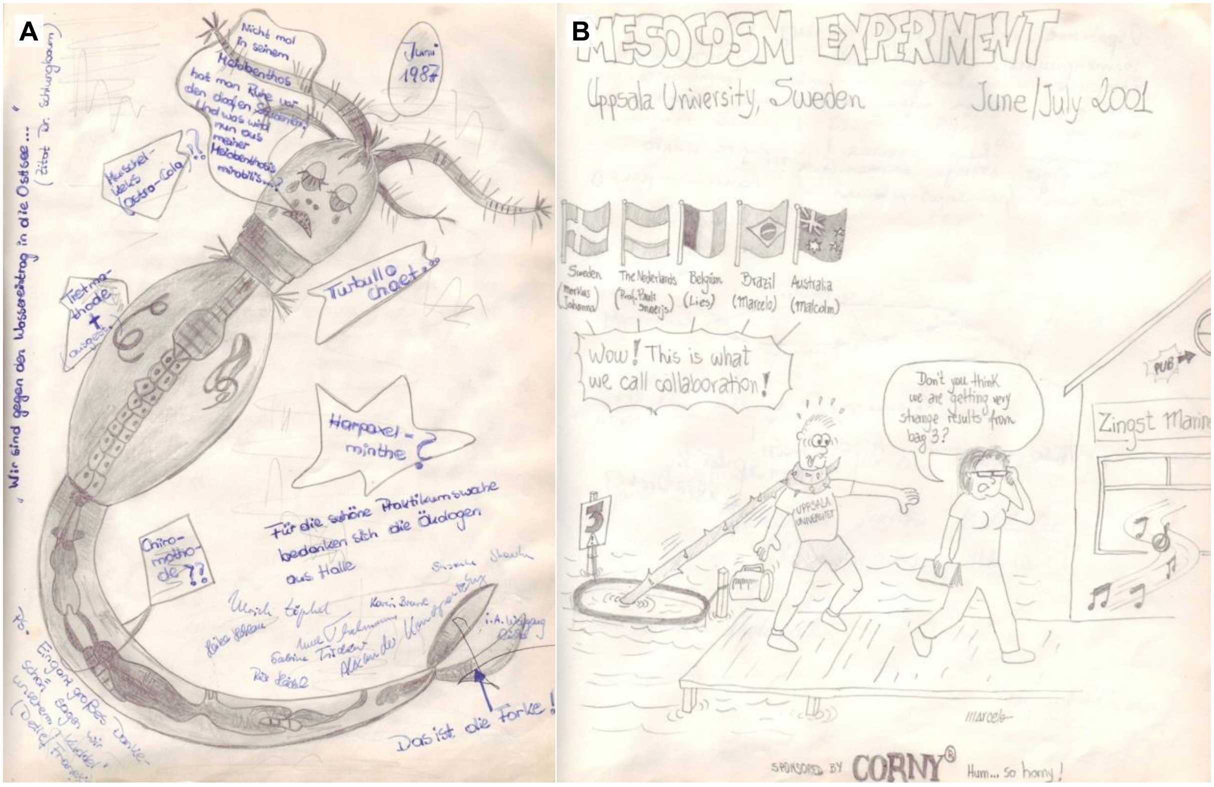

Fig. 4 **A:** This is a very funny guest book entry of students from the University of Halle. The research object is clearly and lovingly painted: a benthic harpacticoid copepod. **B:** The Biological Station supported a Swedish enclosure experiment, in which a very international crew collaborated.

4 Future plans

For some years now, we improved the connection between the working groups in Rostock and Zingst. Thus, more and more colleagues from Rostock share in the daily monitoring program and support practical courses. On the other hand, the personnel of Zingst helps analysing nutrient samples and teaches water chemistry for Research Training Groups or any individual scientist.

The university plans to build a new house for accommodating larger groups of students in the near future. This will improve especially the sleeping rooms, the kitchen and the lecture room.

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Maximilian BERTHOLD[*]

[*] University of Rostock, Institute of Biological Sciences, Biological Station Zingst, Mühlenstraße 27, 18374 Zingst
maximilian.berthold@uni-rostock.de

Take a ZOOM into eutrophication of coastal water bodies – The Zingster Outdoor Benthocosms

Abstract

Many coastal waters are still affected by eutrophication. Not always have remediation measures led to an improved ecosystem condition. The resilience of the ecosystem status to all measures raises new research questions. Why does the ecosystem not respond to the reduction of nutrient input, or only very slowly, or in any other way that was expected? Experiments are an approach when such processes are too slow to respond within expected response times or the desire for improvement. However, *in situ* enclosures can be very resource-intensive. This study presents a cost-efficient and stable *ex situ* mesocosm approach to gain insight into a non-tidal, shallow lagoon system at a shorter time scale. A major question regarding such experiments is, if they reproduce the natural conditions well. This question was assessed by comparing temperature and oxygen saturation in the mesocosms and in the ecosystem. Water temperature differed only within ±1.5 K between mesocosm and Zingster Strom, which is comparable to other mesocosm or enclosure approaches. Oxygen saturation during the day was slightly higher, but night time saturation was at the same level as in the adjacent lagoon system. Hypoxia was not observed. Overall, the mesocosm approach appears to be suitable for biomanipulative studies.

Keywords: Mesocosms, eutrophication, lagoon

1 Introduction

Anthropogenically induced eutrophication is one of the greatest impacts on coastal water bodies. Waters worldwide have been affected by elevated nutrient inputs, leading to a change of a macrophyte dominated system to a phytoplankton dominated one in most systems (e.g. CAPON et al. 2015; SCHEFFER & CARPENTER 2003; WEISNER et al. 1997). For decades, one of the main objectives has been to reverse the effect of human impact on aquatic ecosystems. Consequently, the EU-water framework directive aims at the "good ecological state" for each water body (EUROPEAN COMMUNITY 2000). The reduction of nutrient inputs from point sources may not be sufficient to achieve visible improvements of water quality, i.e. mostly expressed as Secchi depth or water transparency.

A well-studied ecosystem is the eutrophic Darß-Zingst Bodden chain (DZBC), a shallow lagoon system at the southern Baltic Sea. It is a typical lagoon system of the Baltic Sea and has been monitored for decades with accompanying experiments (SCHIEWER 2006, SCHIEWER 2007). First descriptions of lost underwater vegetation and phytoplankton dominance were described to be from the 1930s (GESSNER 1957, SCHLUNGBAUM et al. 2000). Interestingly, the total phosphorus concentrations in the inner lagoon parts in the 1930s were as high as they are today (long-term median 4 µmol TP l^{-1}, BERTHOLD et al. 2018, GESSNER 1957). In the meantime, total P loads, mainly due to point sources, increased to more than 80 t P a^{-1} and dropped again to 20 t P a^{-1} (BACHOR et al. 2013).

However, there is still no improvement in turbidity or a lower phytoplankton biomass after all measures in the catchment area and the registered reduced inflows (BACHOR et al. 2013). Recurring hypotheses are that either the sediment loads the water column with nutrients during suboxic events (e.g. NAUSCH & SCHLUNGBAUM 1991) or that the food web remineralization within the water column occurs very quickly (e.g. SCHIEWER 1997). The hypotheses of bottom-up control can be tested in experimental approaches. Perhaps, there is also some influence of food webs on the matter cycling (top-down control).

These questions should be investigated, e.g. in whole lakes, in enclosures, mesocosms or minicosms. However, it is not always possible to carry out holistic ecosystem approaches (e.g. due to their protection status). Therefore, experimental approaches are necessary and well established on a smaller scale, i.e. mesocosms or enclosures. There are several different definitions. Therefore, it is defined here as follows: a whole system experiment is the term for an experiment in which the ecosystem is divided into several parts that are treated differently (e.g. BUCK et al. 2008). Enclosures are set up as an area or volume, which is separated and analysed without the impact of e.g. changing currents affecting it. Different treatments are possible. Actually, most of the Zingster "mesocosms" were enclosures (ARNDT et al. 1990, FORSTER & SCHUBERT 2000, SCHIEWER et al. 1993). Mesocosms are installed completely out of the system, but with a large volume (>100 l water, e.g. Benincá et al. 2008, WOHLERS-ZÖLLNER et al. 2012). They may be easier to be powered and more accessible. Mesocosm approaches can be short- or long-term incubations, manipulating nutrients or other abiotic factors and studying species composition. Minicosms are defined here as very small volume and rather short term incubations, e.g. plankton volume of 10 ml to 3 l (e.g. SCHUMANN et al. 2009) or sediment cores (GEBHARDT & FORSTER 2018), which are incubated for 24 h up to 10 d.

If mesocosms contain benthos, they can also be called benthocosms. The Kiel Outdoor Benthocosms analysed the effect of rising CO_2 levels on the marine environment (WAHL et al. 2015). The Sylter Benthocosms are used for food web experiments and impacts on seagrass development (PANSCH et al. 2016). The Marine Ecosystem Research Laboratory (MERL) is used for experiments with nutrient driven impact, like eutrophication, in the Narragansett Bay (USA) (OCZKOWSKI et al. 2014). The Sylter benthocosms and the MERL are constructed on land and are true mesocosms.

Among the abiotic factors recorded are water temperature, air exchange, light climate, nutrient fluxes and salinity. However, temperature control in mesocosms and enclosures is one of the most important abiotic factors, especially when the compartments are incubated on land or in a laboratory. Temperature can be controlled by water exchange (PANSCH et al. 2016) or artificial cooling systems (WAHL et al. 2015). The Zingster outdoor mesocosms (ZOOM), which share the properties of benthocosms, are buried in the soil and cannot be cooled further. Atmospheric exchange cannot be controlled in all outdoor-installations (enclosures), e.g. by wind-induced mixing, gas exchange and external nutrient supply by precipitation. Salinity, nutrient concentrations and currents depend on the system, but can be artificially manipulated.

The problem is that any *ex situ* mesocosm experiment can be highly artificial, which limits the extrapolation of results and concepts to the real ecosystem (PERCEVAL et al. 2009). The distinction between the conditions in mesocosms compared to the enclosures or more so to the original ecosystem can be quite large compared to enclosures. Therefore, long-term experiments were conducted with mesocosms in a narrower sense, i.e. land based, to assess the stability of the experiment and the plankton community and to minimize possible handling problems for subsequent manipulations. A stable, cost-efficient mesocosm approach is presented here for the simulation of a non-stratified shallow lagoon system. The ZOOM were constructed as an alternative for enclosure experiments, which can be considerably more expensive in construction and maintenance if they should last longer than a few days. The feasibility of this approach was tested by comparing the temperature and oxygen evolution within a mesocosm to the adjacent lagoon system for the growth period of June to August 2015.

2 Material and Methods

2.1 Experimental design

The mesocosms were built on the grounds of the Biological Station Zingst, University of Rostock and contained about 1750 l of water and almost 100 l of sediment (Fig. 1). The basin material was fiberglass reinforced plastic, is chemically and biologically inert, stable against UV, temperature changes and high tear forces by changing groundwater (Cemo). The mesocosms had a surface area of 2 m^2 at the surface, and 1.9 m^2 at the bottom. The control of abiotic parameters i.e. temperature, radiation, had to be cost-efficient and comparable to the observed ecosystem. A partly buried outdoor mesocosm should be cooled by the surrounding soil and be less prone to overheating compared to mesocosms standing above ground. The total area exposed to sunlight would be minimized to the actual water surface. This terrestrial-cooling approach allows a similar light climate as in the real system, because the water surface is at the same level as the lagoon system. The buried mesocosms were free of surrounding structures that would interfere with diurnal cycles of sunrise and sunset.

Internal water pumps (pump capacity: 300 l h^{-1}, Neptun) were used to prevent stratification of the water body and allow a permanent circulation similar to that in shallow coastal water bodies. At least three of those pumps were used per mesocosm to let the whole water column circulate within two hours. The wind fetch area was 2 m^2 and would at least allow minor additional circulation by wind induced mixing.

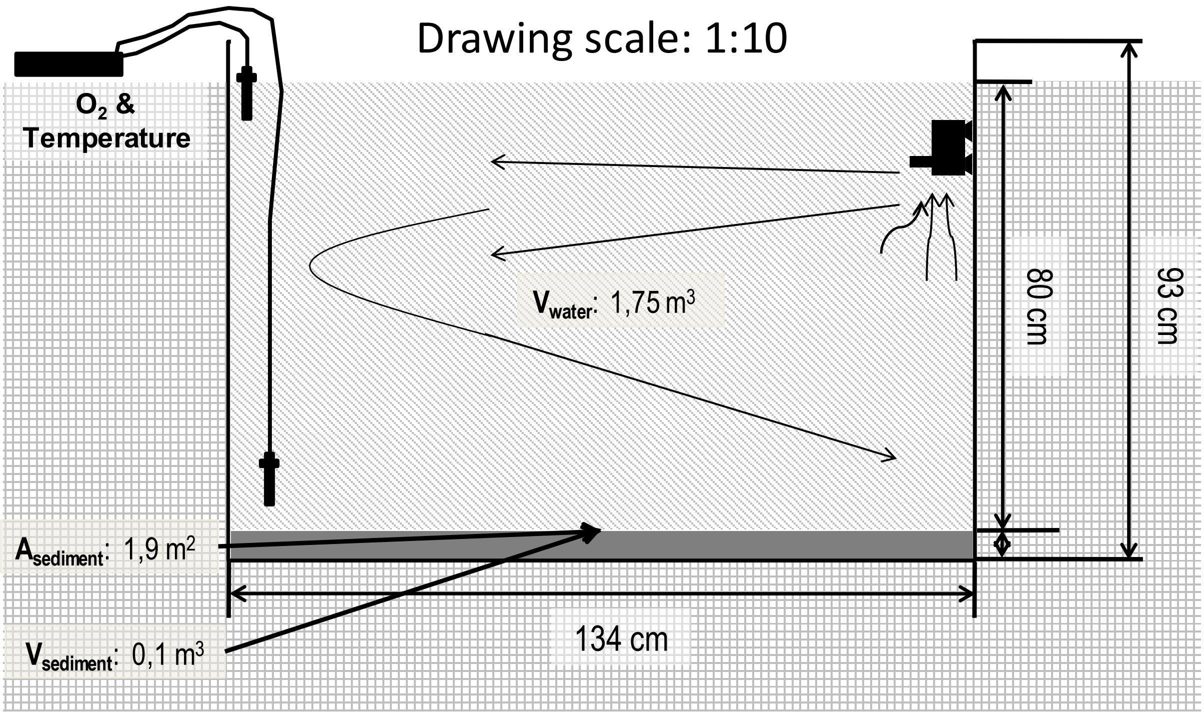

Fig. 1 Scheme of the Zingster Outdoor Mesocosms (ZOOM).

Sediment from the DZBC was filled in the mesocosm with a height of 4 – 5 cm (Fig. 2A). The sediment was sampled in the shallow areas (20 – 50 cm) of the lagoon to include diaspore banks of submerged macrophytes. Sampling locations were Michaelsdorf (Bodstedter Bodden) and Dabitz (Grabow, Tab. 1) with the dominating macrophyte species of *Stuckenia pectinata*, *Ruppia* sp., *Chara* spp.

Water for all mesocosms was taken from the Zingster Strom, the middle part of the adjacent lagoon system 90 m away from the experimental setup. Water was pumped into the mesocosms by an electrical water pump at the beginning of the experiment. Water loss by evaporation was not compensated by addition of Zingster Strom water to prevent increasing salinity and changing water parameters. Rain was the only natural water inflow during the time of the experiment.

Fig. 2 **A:** Filling of the 2000 l mesocosms with sediment. **B:** Zooplankton is sampled in the ZOOM mesocosms.

Tab. 1 Overview of Zingster Outdoor Mesocosms (ZOOM)

Year	Number	Treatments	Starting date	Sediment source	Aim
2015 2016 2017	2 4 4	With and without goby (*Pomatoschistus microps/minutus*) and shrimps (*Palaemon elegans*)	07.05.2015 24.06.2016 16.05.2017	mixture from Bodstedter Bodden (54°22,306'N 12°34,136'E) and Grabow (54°22,017'N 12°48,358'E)	Food web structure & production

The concept of ZOOM was to test the effects of the food web composition on a possible “top-down” control. One set of mesocosms were with fish and shrimp, to include as many trophic levels as possible. In the other set of mesocosms, zooplankton and gammarids were liberated from grazing, by excluding fish and shrimp. Zooplankton was sampled regularly in both sets of mesocosms (Fig. 2B). The later approach was tested to compare the real ecosystem to the mesocosm approach. Therefore, only oxygen increase by primary productivity and temperature were analysed and will be presented here. In total, there were three series of ZOOM mesocosms from 2015 through 2017 (Tab. 1). The water came always directly from the Zingster Strom.

2.2 Measurement of abiotic parameters

The main parameters oxygen and temperature were measured automatically in a 5-min interval to be directly compared with the automatic measuring unit in the Zingster Strom (15-min interval) of the Biological Station Zingst. Temperature and oxygen were measured with a coupled sensor by an LDO (Hq-40d, Hach). Two of those sensors were installed into each mesocosm. One sensor was hung right below the water surface, the second one above the sediment in 80 cm water depth. The sensor in the Zingster Strom measures at a water depth of 100 cm. The sensors were calibrated before the start. It was assumed that the salinity was more or less stable so that the automatic salinity correction of the Hach-device was used to read out device-calculated oxygen concentrations. Additionally, water parameters, like salinity (salinity probe, WTW) and pH (pH probe, Hach), were measured in a biweekly interval and compared to the monitoring of the Biological Station Zingst.

Oxygen concentrations of the mesocosm sensors were averaged, as production in both water depths was most likely different. Furthermore, daily medians of oxygen concentration were calculated to improve visibility of long-term trends instead of diurnal cycles.

2.3 Statistical analysis

All measured oxygen and temperature values of the mesocosms were compared with values of the automatically measuring unit in the Zingster Strom by a frequency distribution analysis (Excel). Only simultaneously measured values were compared, so that the data set of the more frequently measured mesocosms (5 min) was reduced to the 15 min intervals in the Zingster Strom.

3 Results

3.1 Temperature development

In 2015, there were only two compartments of large ZOOM mesocosms. The one without fish and shrimp is compared here to the *in situ* conditions in the Zingster Strom over the summer season. This compartment is called “the mesocosm” further on.

The absolute and strong variations of about 10 K over some days are normal and reflect the meteorological forcing onto a shallow brackish lagoon and more so on the true mesocosm (Fig. 3A). There was no temperature stratification within the mesocosm throughout the observation period. The majority of temperature values (~85 %) were within a ±0.5 K range between surface and bottom sensor (Fig. 3B). Highest differences (> 1.0 K) were measured during the beginning of the experiment in June during the longest and first warming period, but not afterwards. This result indicates a well-mixed water column.

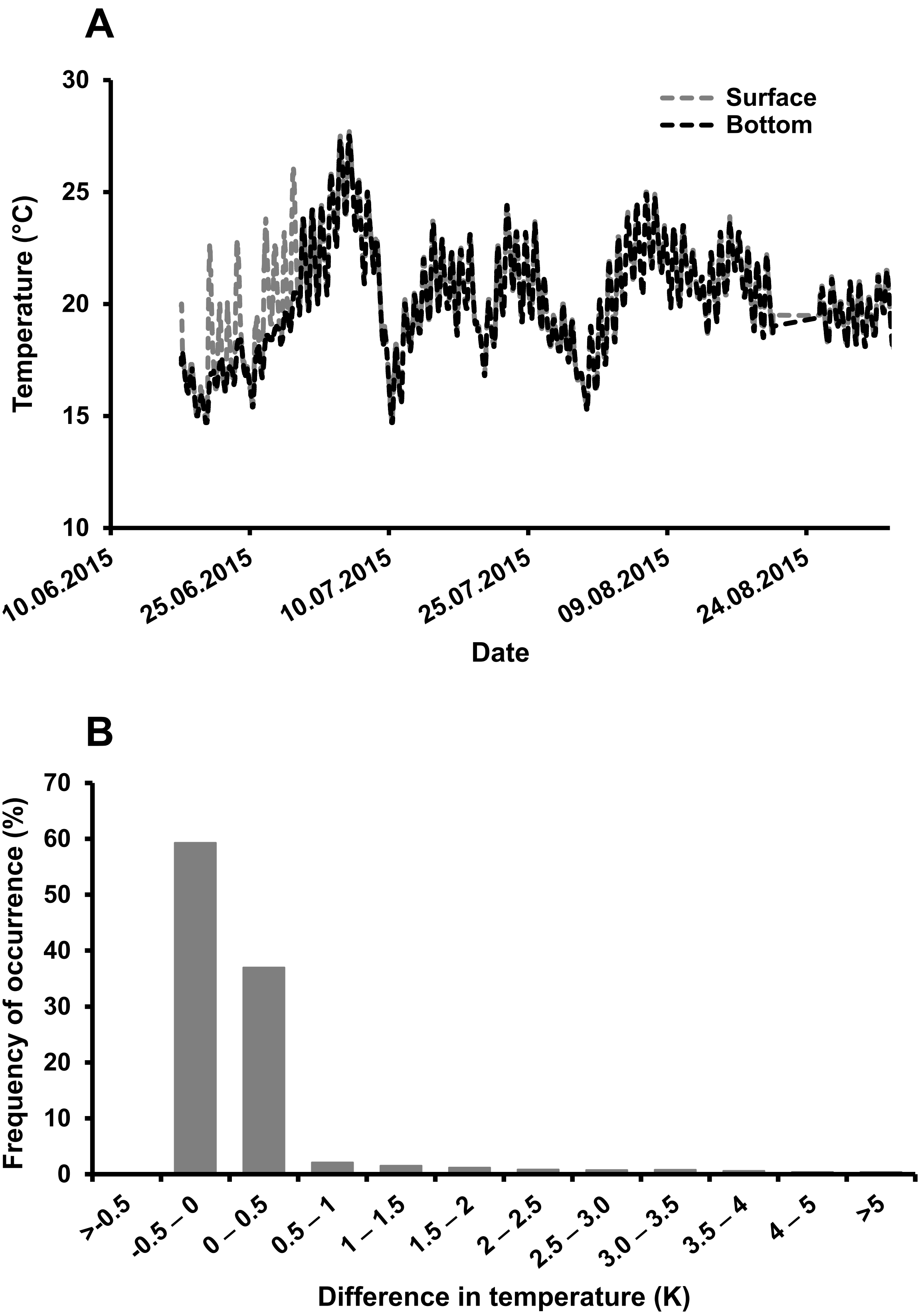

Fig. 3 **A:** Total temperature development inside the mesocosm at the surface (20 cm) and bottom (80 cm). **B:** Temperature difference (K) as percentage frequency of occurrence of surface and bottom water inside the mesocosm between June and August 2015. Temperature was measured every 5 minutes simultaneously at surface and bottom (n = 20588).

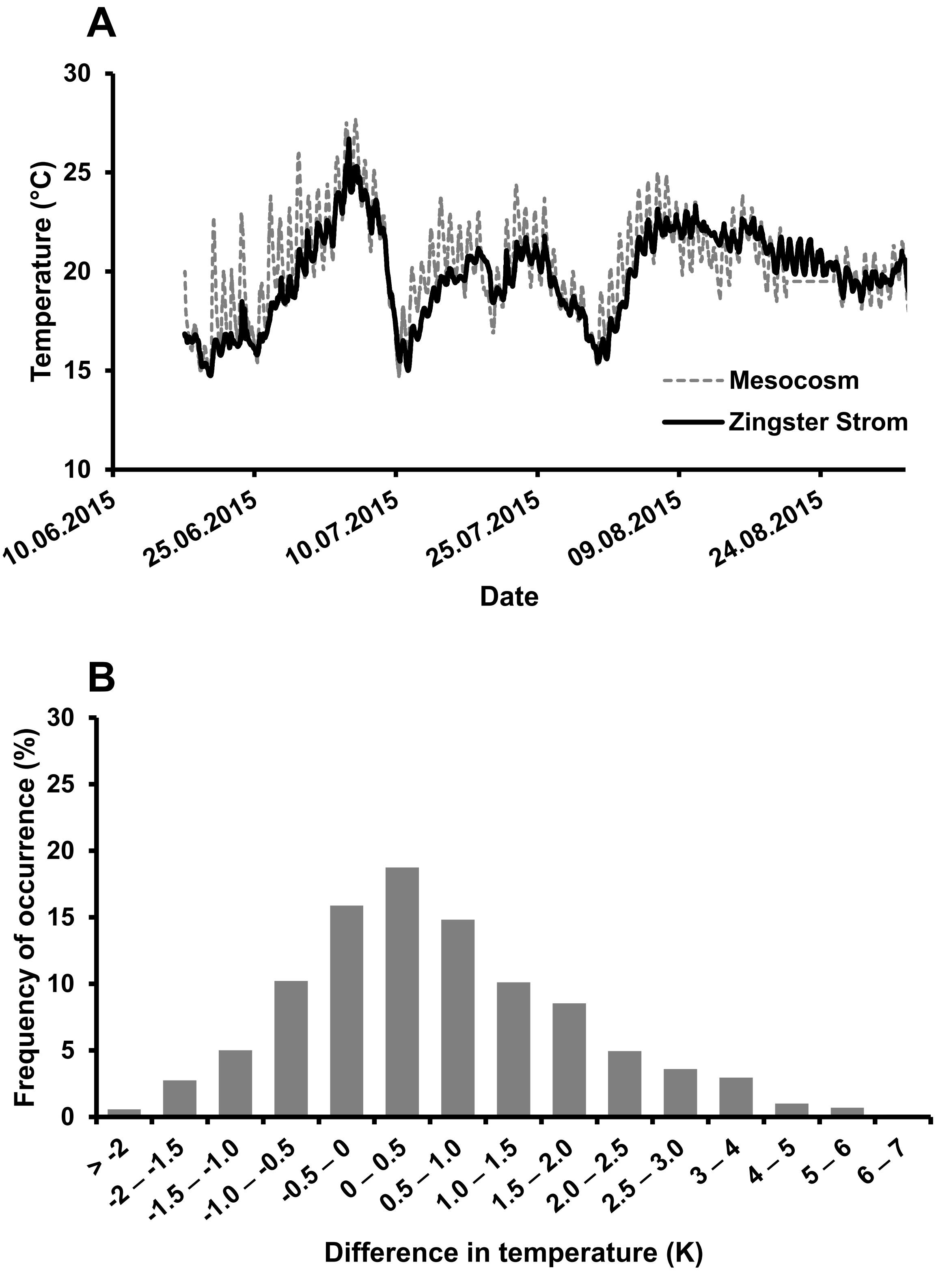

Fig. 4 **A:** Temperature development inside the Zingster Strom (actual ecosystem) and the experimental mesocosm. Temperature was measured every 15 minutes inside the Zingster Strom (n = 9209) and every 5 minutes in the mesocosms (n = 20588). **B:** Temperature difference (K) as percentage frequency of occurrence between surface mesocosm water and the Zingster Strom during June and September 2015. Compared were only simultaneously measured values (n = 6921).

The mesocosm showed the same temperature development like the Zingster Strom (Fig. 4A). However, the daily amplitude, especially the maximum values, reached up to 5 K higher in the mesocosm compared to the Zingster Strom. Only very rare (< 5 %) lower temperatures were measured in the mesocosm. Temperatures got more similar to the ecosystem during night times. Obviously, solar radiation was better absorbed in the mesocosms and less well dissipated. Perhaps, the vessel material absorbed energy itself. Three-quarters of all temperature differences between the Zingster Strom and the mesocosm were within ±1.5 K (Fig. 4B). Additionally, the highest differences were measured only during periods of fair weather, i.e. intense solar radiation, what again hints to different energy uptake behaviour of the mesocosms (material).

3.2 Oxygen development

The mesocosm was almost never severely undersaturated, i.e. < 50 %. The bottom layer was only rarely < 70 % oxygen saturation and only one third of the time below 100 % saturation. The upper layer was only 20 % of the time < 100 % saturation, but also 20 % of the time > 150 % (n = 20226). The oxygen concentration (daily median) was never below 7 mg l^{-1} in the water column (Fig. 5A).

The oxygen saturation and concentration at the bottom showed a time lag during the day, i.e. it increased as expected later compared to the surface. Phytoplankton at the bottom may have produced less oxygen there, but that would also indicate that the water current in the mesocosm did not completely mix the water column. In contrast to the stable temperature values inside the mesocosm, 65 % of all oxygen saturations were at least 10 % higher at the surface compared to the bottom of the mesocosm. The oxygen concentration at the surface was 70 % of the time at least 1 mg O_2 l^{-1} higher compared to the bottom (Fig. 5B). This observation brings another factor into the mesocosm function: sediment respiration. This respiration is present day and night and may explain the above mentioned time lag of oxygen increase over day at the bottom layer as well as the frequently lower oxygen saturations at any time.

The mesocosm had always much higher oxygen saturations at the surface during the day, but only slightly less saturations during the night (data not shown). However, the sensor at the bottom measured at the same water depth, as the sensor in the Zingster Strom. Therefore, the mean oxygen concentration in the water mesocosm water column was used to compare it to the Zingster Strom.

The oxygen concentration in the mesocosm showed the same reaction to weather forcing (not shown) but at the beginning and in the end of the experiment considerably different amplitude than the Zingster Strom (both daily median, Fig. 6A). These results indicate that both systems are equal stable during night, i.e. that the sediment respiration impact onto the water column was representative for the ecosystem. In contrast, the production of mostly phytoplankton had a much higher impact on the oxygen saturation of the much smaller water column during day. Macrophytes were not very abundant in the mesocosm. Oxygen saturation of both systems were within a range of ±10 % difference at only one third of all sampling points, and oxygen concentration of ±1 mg O_2 l^{-1} almost half of the time (Fig. 6B).

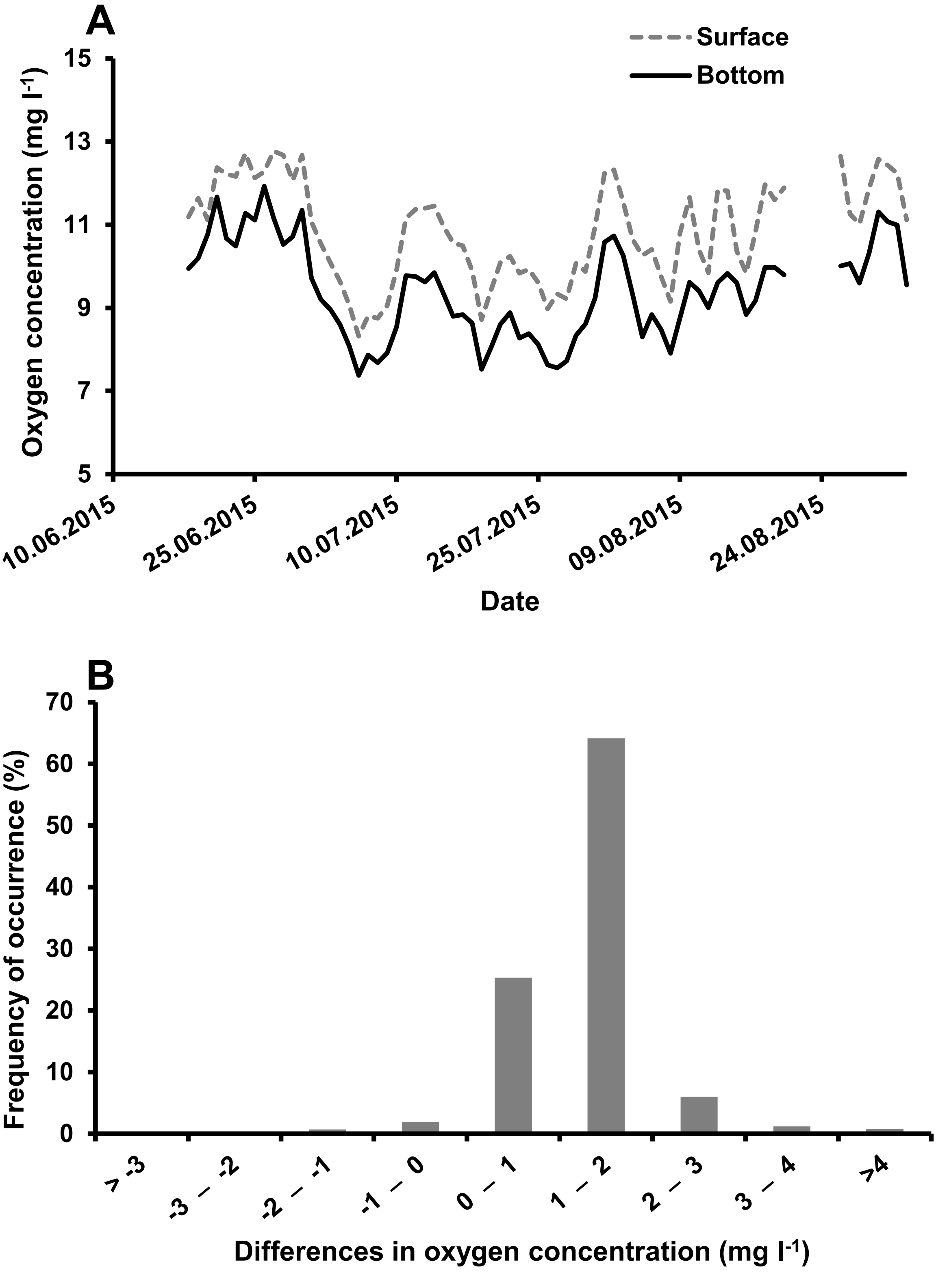

Fig. 5 **A:** Oxygen saturation concentration (daily median) at the surface and the bottom of the mesocosm. **B:** Oxygen concentration difference (mg l^{-1}) as percentage frequency of occurrence of surface (20 cm) and bottom (80 cm) water inside the mesocosm between June and August 2015. Oxygen was measured every 5 minutes at surface and bottom and only simultaneously available values were compared (n = 19597).

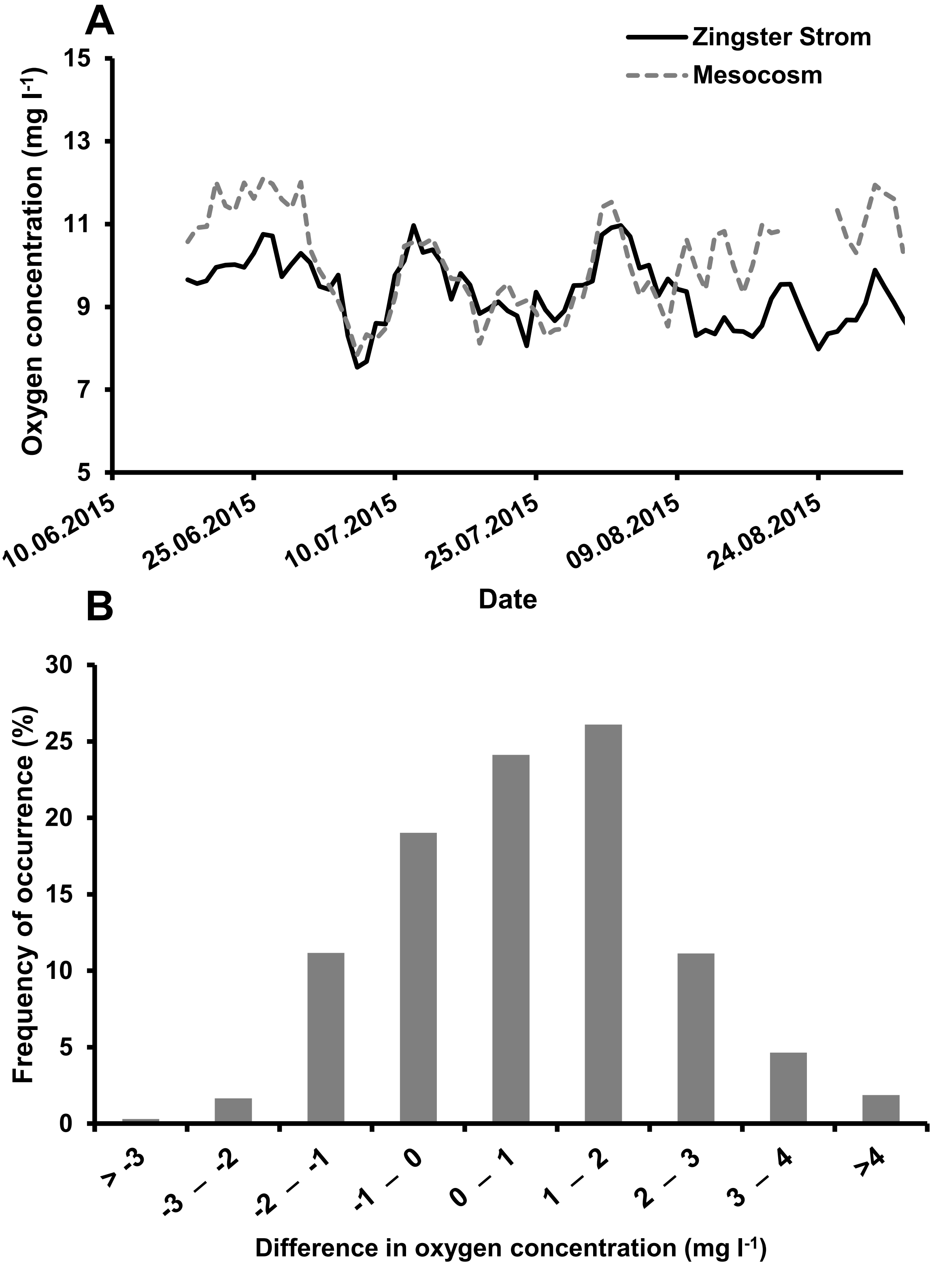

Fig. 6 **A:** Oxygen concentration (daily median) inside the Zingster Strom and the experimental mesocosm. Oxygen was measured every 15 min inside the Zingster Strom (n = 9209) and every 5 min in the mesocosms (n = 19597). **B:** Difference in oxygen concentration (mg l^{-1}) as percentage frequency of occurrence between mesocosm water (mean concentration surface & bottom) and the Zingster Strom during June and September 2015. Compared were only simultaneously measured values (n = 6869).

4 Discussion

4.1 Technical considerations

The construction costs, technical equipment and maintenance of the here presented ZOOM mesocosms are rather low compared to the large mesocosms mentioned in the introduction. The sediment should be either stored cool or taken fresh from the system, depending on the inclusion of macrozoobenthos. All automatic logging devices and the tank walls are prone to biofouling. Therefore, the easy accessibility also several times per day for maintenance and sampling profited from the near vicinity to the lab. Moreover, boats were not needed like for lake-site enclosures and, power supply was easy.

However, terrestrial invertebrates were a problem. The tanks had to be checked for snails, insects and worms very often. HARGRAVE (2006) used a 1.0 mm mesh to prevent invertebrates to enter the mesocosms. However, a mesh negatively affects the light climate by reducing the available light. It is possible to use translucent high-density polyethylene lids, which allows up to 90% of the PAR to pass (PANSCH et al. 2016). This construction would prevent evaporation and contamination by invertebrates, but may increase the temperature if installed on land.

Additionally, atmospheric dry deposition would be partly prevented. However, atmospheric dry and wet deposition can be an important source for nutrients into the water column (TIPPING et al. 2014). In total, 156 mm precipitation or 312 l rain water were transported into the mesocosm (18 % of total volume) during the experiment (data Biological Station Zingst). The very near vicinity to land may have increased dry nutrient deposits on the other hand, what could not be evaluated well enough so far. Salinity was on median 6.6 ± 0.5 (n = 10) and was not diluted much due to precipitation. An addition of brackish water was not necessary.

4.2 Comparability of coastal waters with the Zingster Outdoor Mesocosms

The temperature development between the lagoon system and the mesocosm was comparable. The temperature difference of 75 % at ±1.5 K was at the same range as described in the KOB (WAHL et al. 2015). The KOB benthocosms had 78 % of the time an off-set of ±1.5 K between fjord and benthocosm (WAHL & BUCHHOLZ 2015). The approach burying the ZOOM into the ground showed the same cooling efficiency, as enclosures or systems, which are cooled by adjacent water flow. Another way was to insulate heavily, like the SBC, which were constructed with double walls and filled with Styrofoam (PANSCH et al. 2016). The cooling effect was probably influenced by the high groundwater level in the surrounding area. Therefore, ZOOM was not only cooled by the ground, but also indirectly by water.

4.3 Dimensions of planktonic and benthic oxygen budgets

Although the temperature of the mesocosm was comparable to the Zingster Strom, the diurnal oxygen development differed strongly. This unbalance was observed, even though the water column was mixed permanently. There was also a slight oxygen gradient from top to bottom layer in the ZOOM. Causes for this difference (Zingster Strom *versus* mesocosm) and gradient (within the mesocosm) can be:

1. The gradient resulted from lowered primary production at the bottom due to light limitation. However, the attenuation in the mesocosms were not higher than in the Zingster Strom.
2. The measurable gradient can be attributed to an insufficient water mixing in the mesocosm. Such a gradient was not observed in the Zingster Strom, which is a site of high water current velocities.
3. The sediment oxygen demand was higher in the mesocosms compared to the Zingster Strom. However, oxygen saturation in both systems were more comparable during night, so that this can only be a minor cause for differences and gradients.
4. The production in the mesocosm was much higher than in the Zingster Strom, what caused high oversaturations. Perhaps, there was a higher nutrient influx, a better light climate due to higher phytoplankton sedimentation and a lower gas exchange with the atmosphere by a weaker wind fetch.

MEYERCORDT & MEYER-REIL (1999) described a sediment oxygen demand of 0.7 – 1.1 mmol O_2 m^{-2} h^{-1} (17 – 26 mmol m^{-2} d^{-1}) in an embayment of the DZBC with sediment characteristics comparable to the ones used in this study. The difference of oxygen concentration between surface and bottom is 40 – 47 mmol O_2 m^2 d^{-1}, if the water column is separated into two equal halves. Therefore, it can be assumed half of the difference between surface and bottom can be explained by sediment respiration. The remaining gradient has to be accounted to a high attenuation in these turbid waters (SCHUBERT et al. 2001). SCHUMANN & KARSTEN (2006) described a strong cyano-bacterial dominance for the DZBC. It was described for shallow lakes that cyano-bacteria can lower light climate over-proportionally (SCHEFFER et al. 1997) and the DZBC shows the lowest Secchi depth and highest cyanobacterial biovolume across coastal water bodies of the southern Baltic Sea (BERTHOLD et al. 2018). Hence, the bottom parts of the mesocosms were probably less productive due to light limitation, than the surface even with constant water mixing. The remaining difference between the oxygen balances of the ecosystem and the mesocosm results from the much higher oversaturation during the day and a slightly lower undersaturation at night. However, this difference had no influence on the general similarity of the mesocosm with the Zingster Strom, since the oxygen concentrations were > 6 mg O_2 l^{-1} in 95 % of the cases. Oxygen concentrations above this level were also continuously described by monitoring in the lowest part of the DZBC (BACHOR et al. 2013).

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Heiko KORSCH*

* Schillbachstraße 19, 07743 Jena
heiko.korsch@t-online.de

The worldwide range of the Charophyte species native to Germany

Abstract

Based on extensive evaluations, the worldwide distributions of the 36 Charophyte species native to Germany are presented. Some of these species are distributed almost worldwide (e.g. *Chara braunii*, *C. vulgaris*, *Nitella hyalina*), while others have much smaller ranges. *Chara filiformis* for example is restricted to a small part of continental Europe. For many species comments are made to explain the species concept used or to give hints about doubtful data.

Keywords: Plant geography, Characeae, Charophytes, range-maps, *Chara*, *Lamprothamnium*, *Lychnothamnus*, *Nitella*, *Nitellopsis*, *Tolypella*

Zusammenfassung: Areale der in Deutschland heimischen Characeen-Arten.

Auf der Grundlage umfangreicher Recherchen werden die weltweiten Areale der in Deutschland vorkommenden 36 Characeen-Arten dargestellt. Von diesen Arten sind einige (z. B. *Chara braunii*, *C. vulgaris*, *Nitella hyalina*) fast weltweit verbreitet, andere haben deutlich kleinere Areale. So ist z. B. *Chara filiformis* auf kleine Teile Europas beschränkt. Zu einer ganzen Reihe von Arten werden Kommentare geben. Diese erläutern die verwendeten Artumgrenzungen oder geben Hinweise zu fraglichen Angaben.

1 Introduction

In recent decades and after a phase of stagnation in Germany, interest in the Characeae has markedly increased. The Habitats Directive 92/43/EC (EC1992) and the Water Framework Directive 2000/60/EC (EC 2000) of the European Union have intensified this process.

Because of their size and their complex structure, the Charophytes are morphologically clearly distinguished from most other groups of Algae. The results of genetic investigations show that they are more closely related to the Mosses and higher plants rather than to the other algae (QUI 2008). For that reason, most of the people who are studying these plants are higher plant-botanists rather than phycologists. A consequence of this is that the editors of one of the most important vascular plant floras of Germany, the Rothmaler series (JÄGER 2011, JÄGER et al. 2013) have suggested the inclusion of the Characeae into this flora.

The worldwide distribution range of each species is traditionally described by range formulae in the Rothmaler series. The distribution limits of all German Charophyte species were investigated to support the global distribution limits. A revision of the literature (overview in VAN RAAM 2004) has shown that range-maps are published for only a few species. Furthermore, the existing range-maps are mostly some decades old and, therefore, do not consider the current knowledge and new records.

2 Material and methods

The nomenclatural and taxonomic base used follows the Arbeitsgruppe Characeen Deutschlands (2016). The aim was to identify the worldwide range of all 36 species of Characeae recorded in Germany as exactly as possible. This was done by extensive literature studies (see literature). Where there were existing modern overview works for single countries these were preferred. However, such overviews are only available for some European and very few other countries. From many other parts of the world there are only, if any, scarce publications. Only a few reviews of herbarium material were made. However, in many of the publications used such reviews are one of the basic sources. In addition, scans of the herbarium sheets from many North American herbaria available in the internet over the “Macroalgal Herbarium Portal” were used to confirm and complete literature data. Broad, inaccurate information like “Siberia”, records only for a whole country or dots without sources in published maps like that of CORILLION (1957) were ignored intentionally.

The extremely wide species concept of WOOD (1965) brings big problems with usage of names in published distribution data. Often, but not in every case, it is obvious in the publications in which sense/extent the names of the species are used. The assignment of records to the species names in the way used by the German authors (Arbeitsgruppe Characeen Deutschlands 2016) was only done if it was certain or very likely. But it was not possible in all cases to clarify which species concept laid behind the names used, whether the usage applied here or that of WOOD (1965). So, some uncertain records still remain unresolved.

Based on this information, it was possible to get a fairly complete picture of the existing records for the distribution of the Charophyte species. But it is important to be aware of the gaps in this knowledge in many regions. The lowest level of knowledge is in many parts of Africa except for the Mediterranean coast. But many of the German species do not extend here and the impact on the range-maps should be minor. Another problematic area is the northern part of Siberia and also of Canada where there are only a few published records. The activities of R. ROMANOV and others has markedly increased the knowledge in recent years but the range borders here are still rough approximations.

All of the identified distribution points or information were brought into a world map in a geographic information system (Quantum-GIS). From this, the resulting shapes of the distribution area of each species were generated. Temporal differentiation of the records could not be made because actual information from many parts of the world are lacking.

3 Results

The range areas are shown with stripes and without surrounding shape-lines to reflect the uncertainty of the borders.

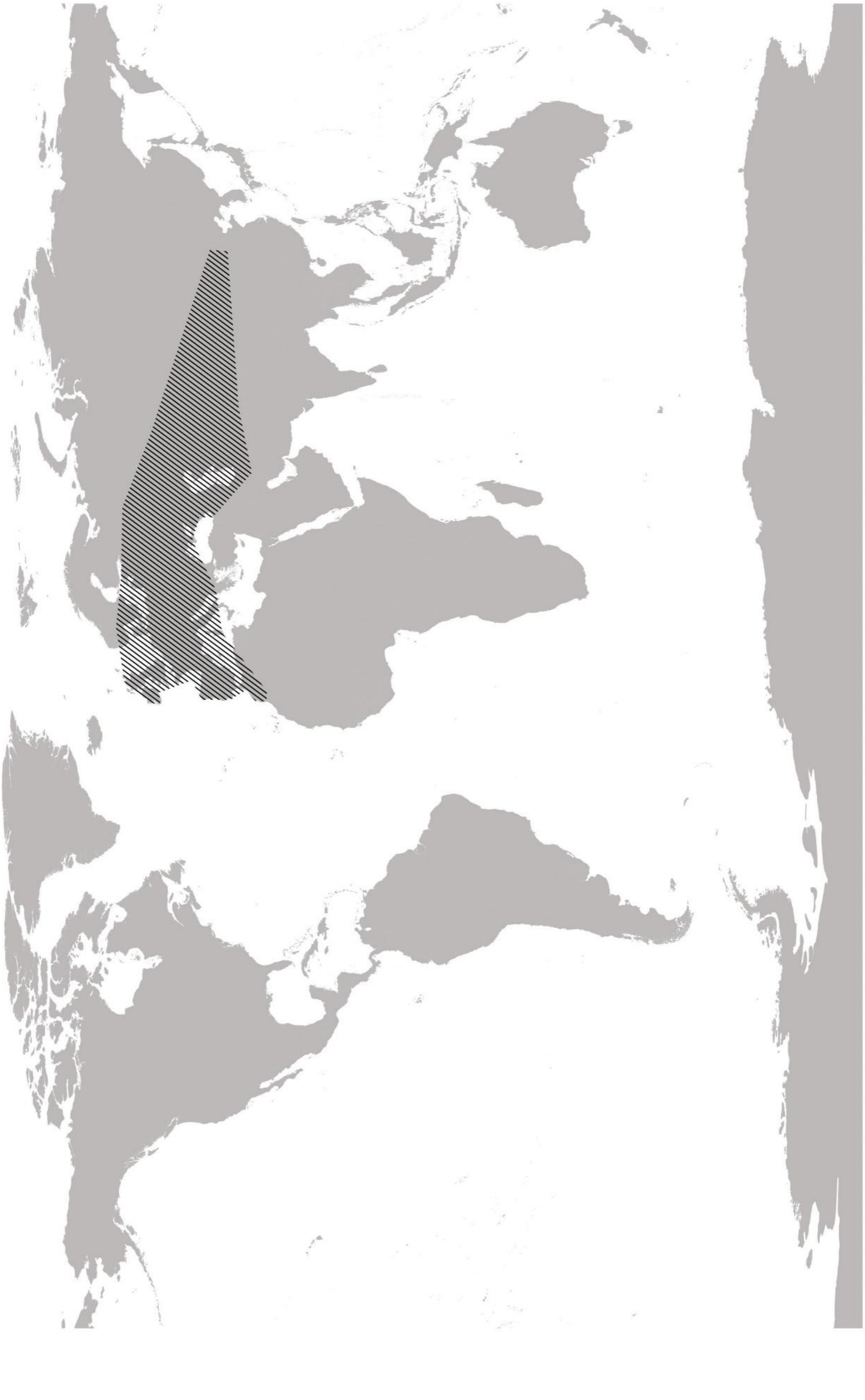

Fig. 1 *Chara aculeolata*

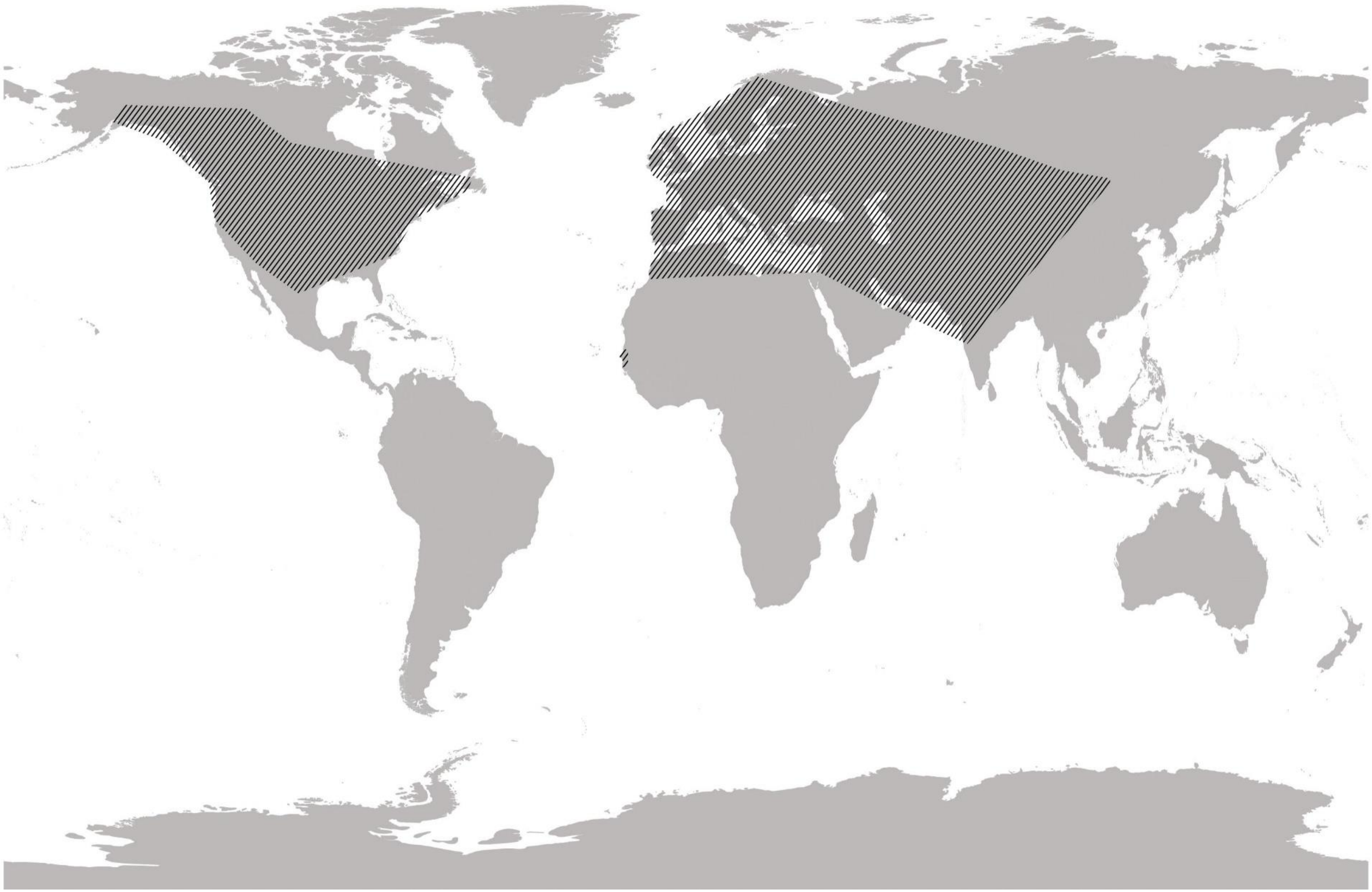

Fig. 2 *Chara aspera*

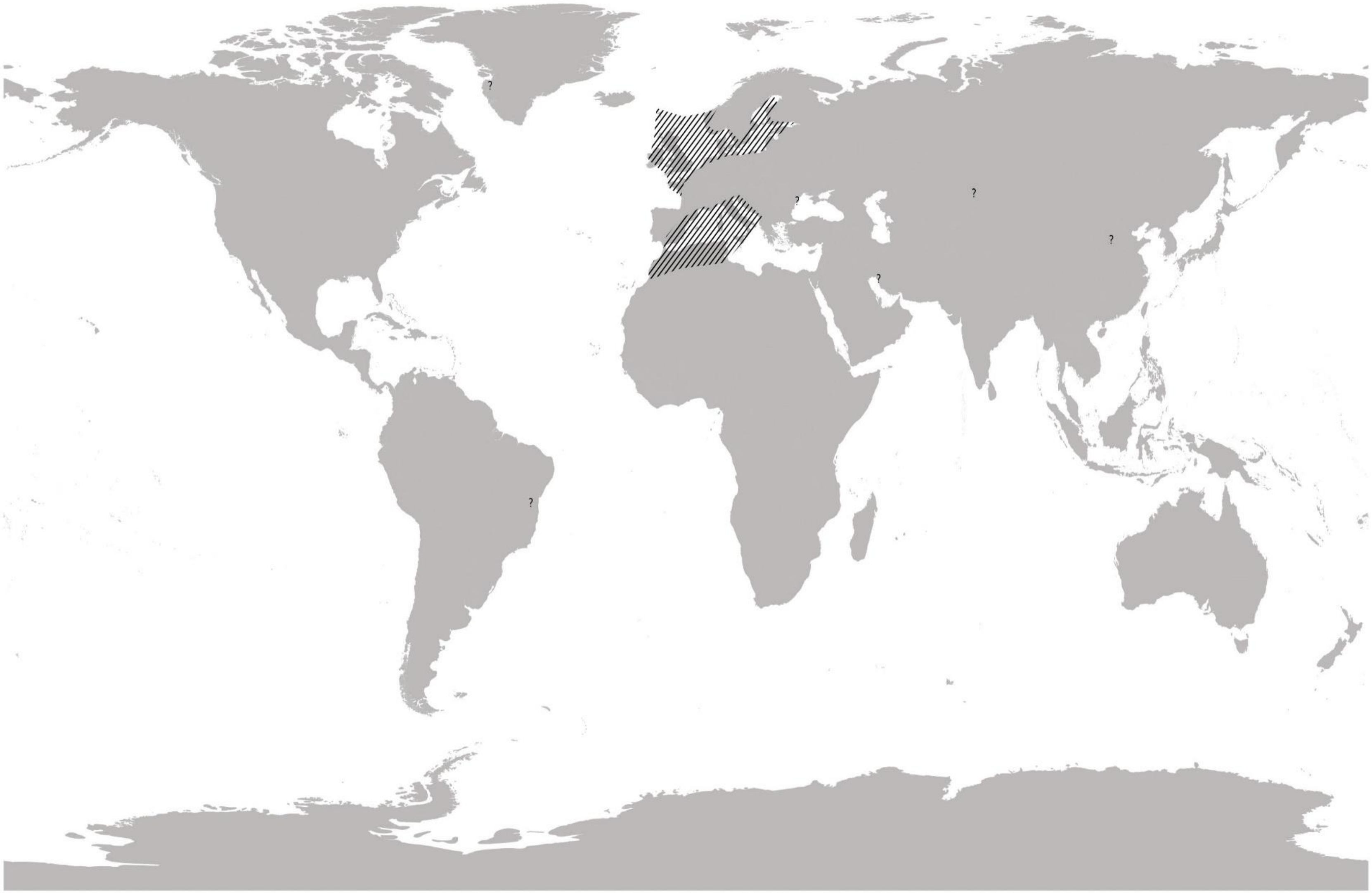

Fig. 3 *Chara baltica*

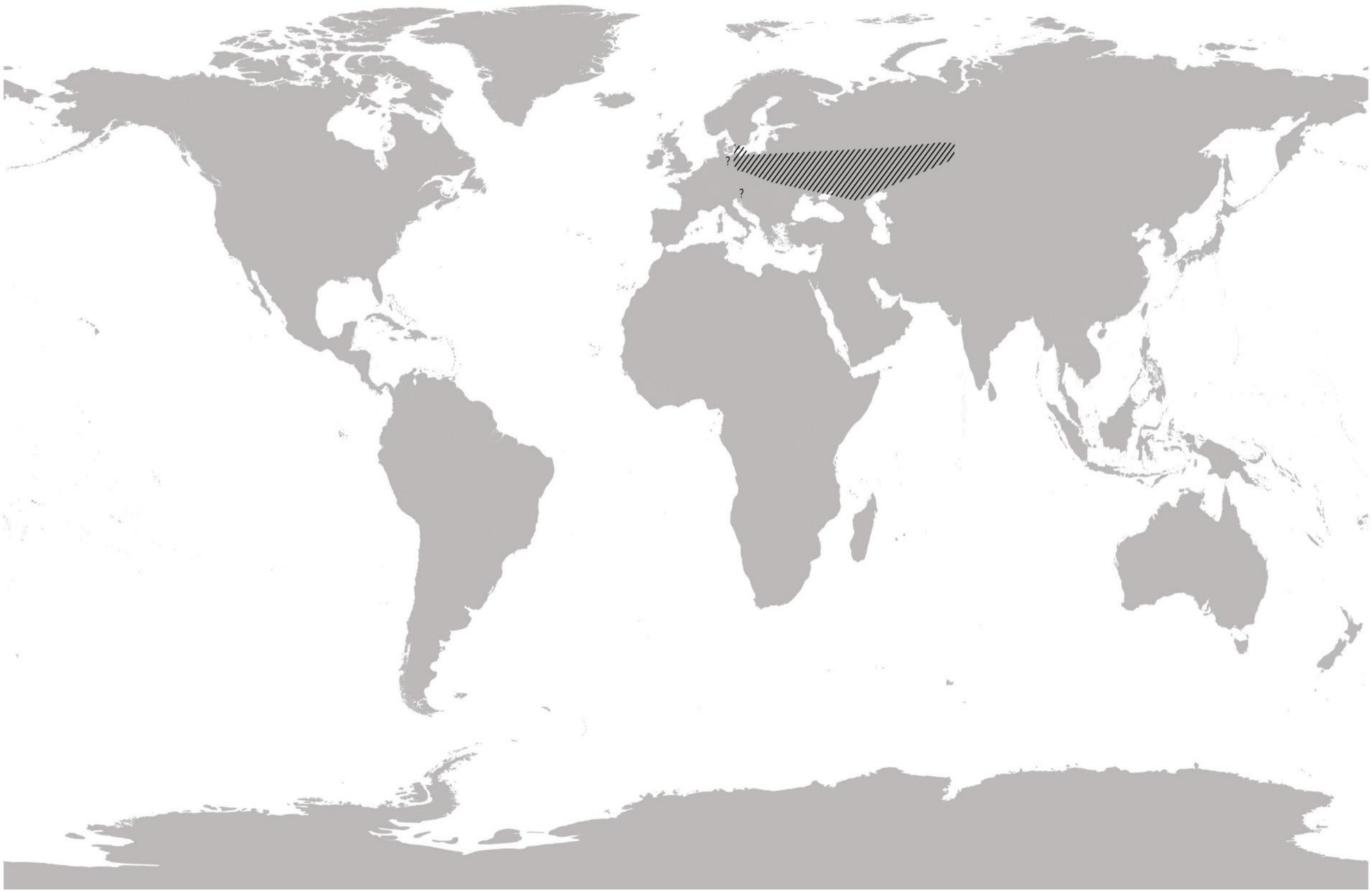

Fig. 4 *Chara baueri*

Fig. 5 *Chara braunii*

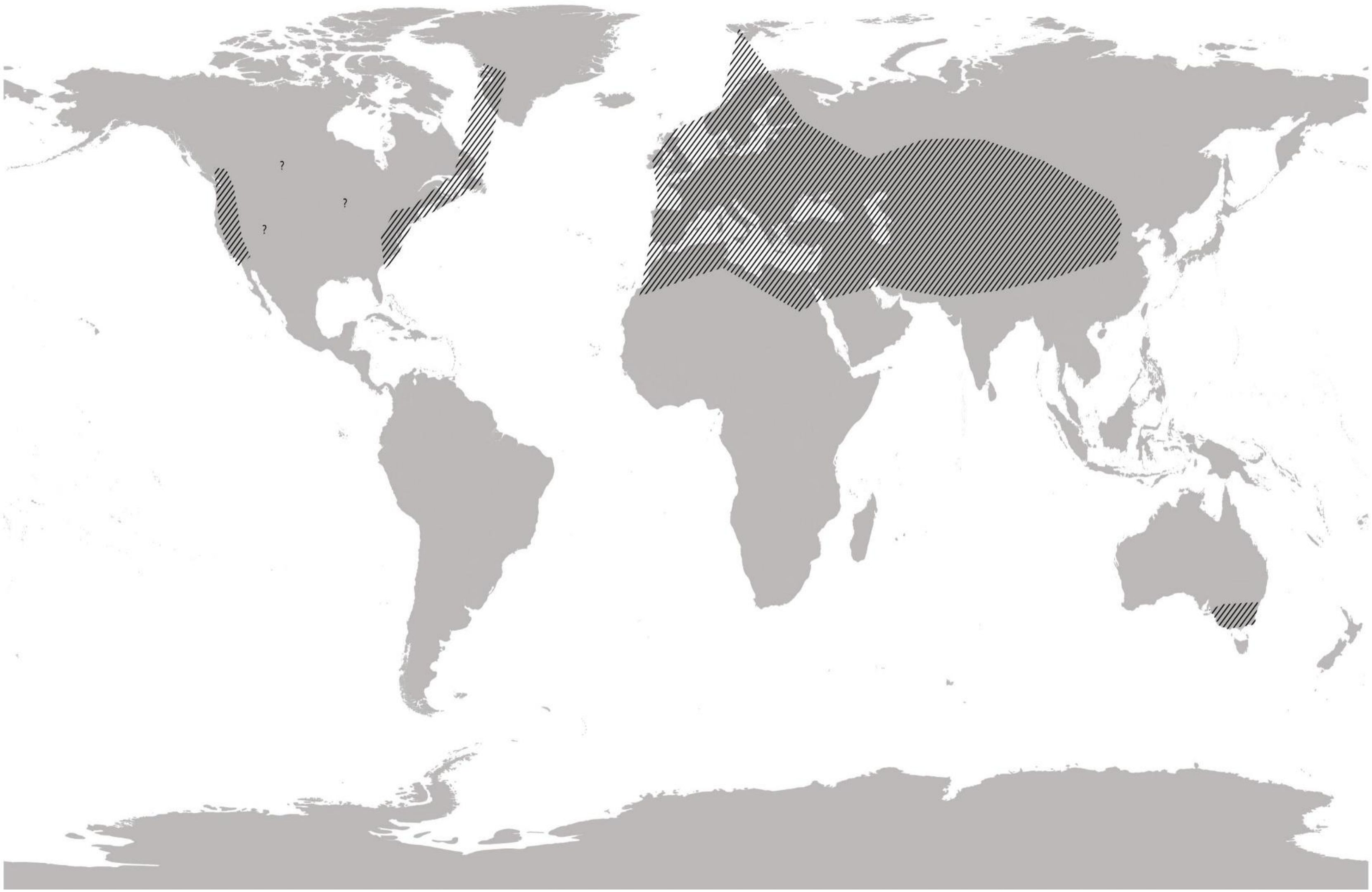

Fig. 6 *Chara canescens*

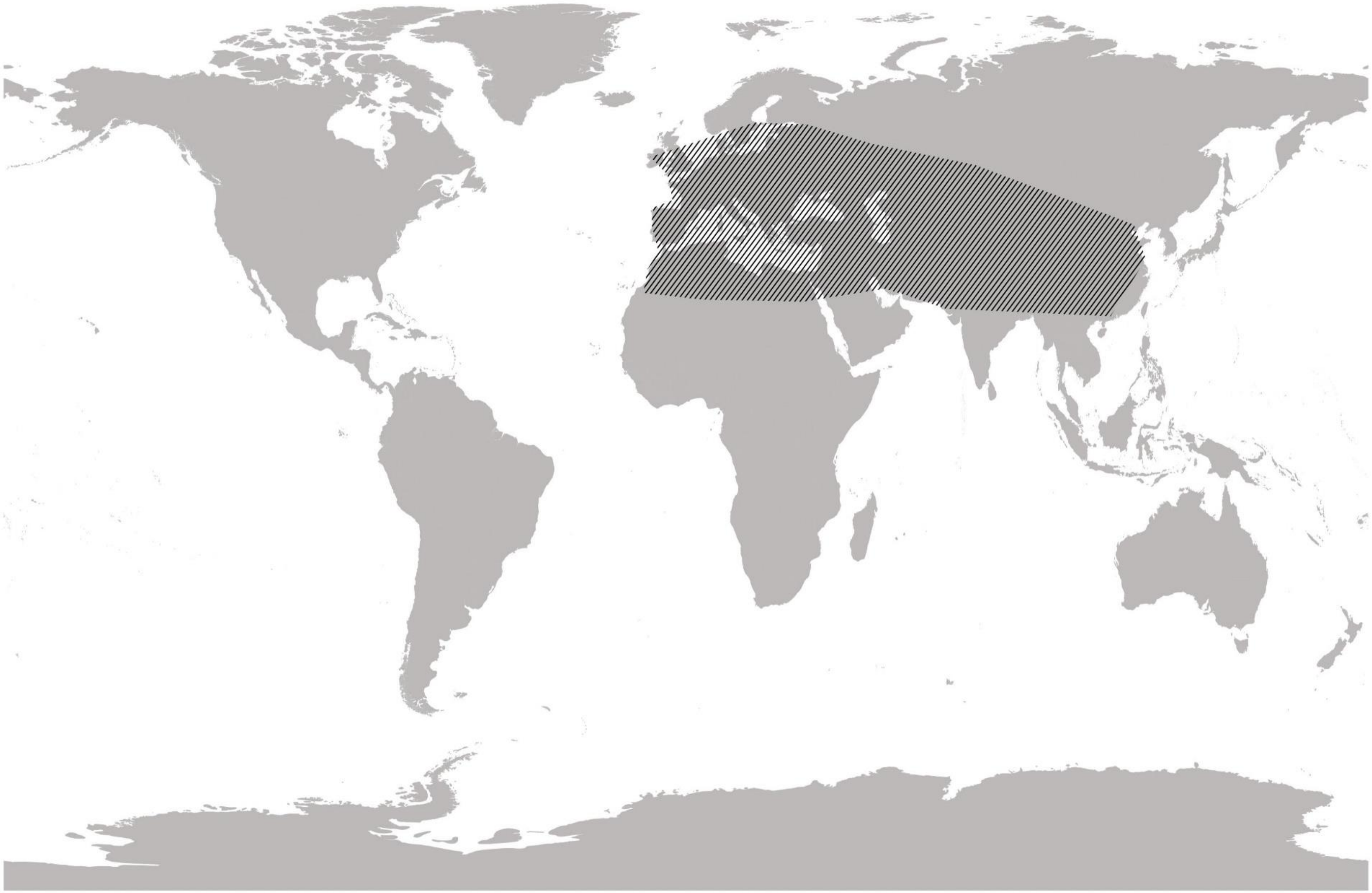

Fig. 7 *Chara connivens*

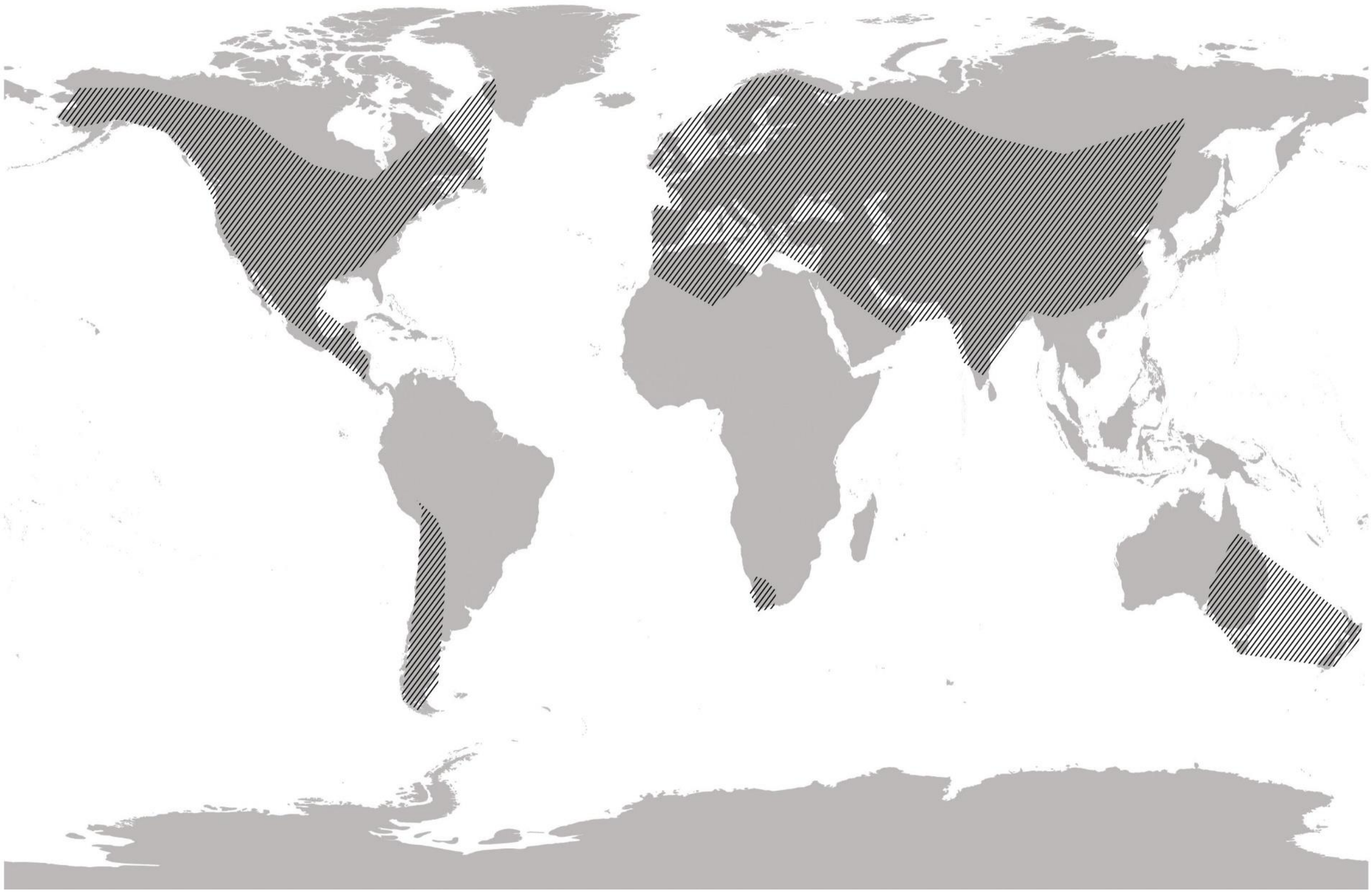

Fig. 8 *Chara contraria*

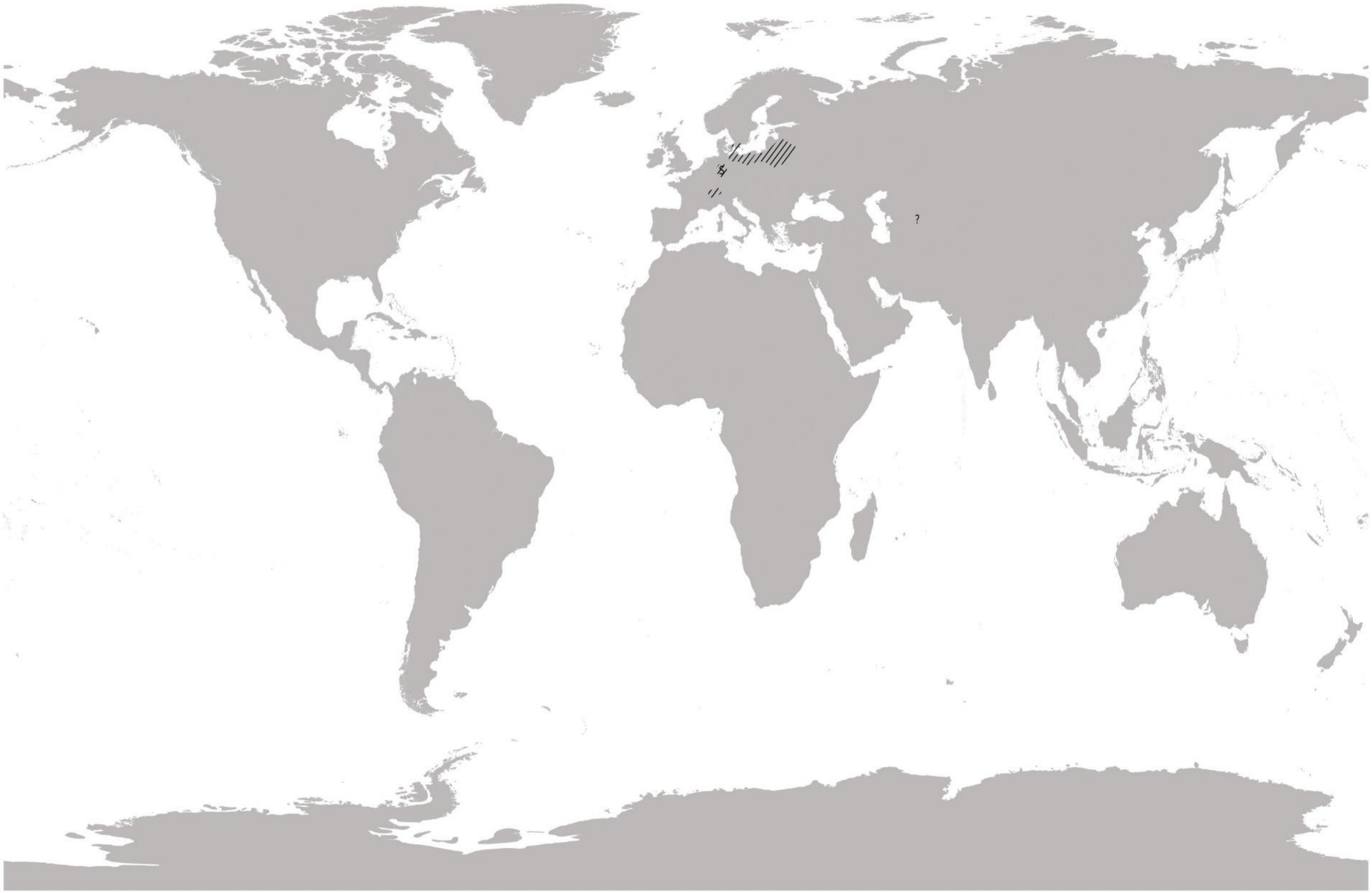

Fig. 9 *Chara filiformis*

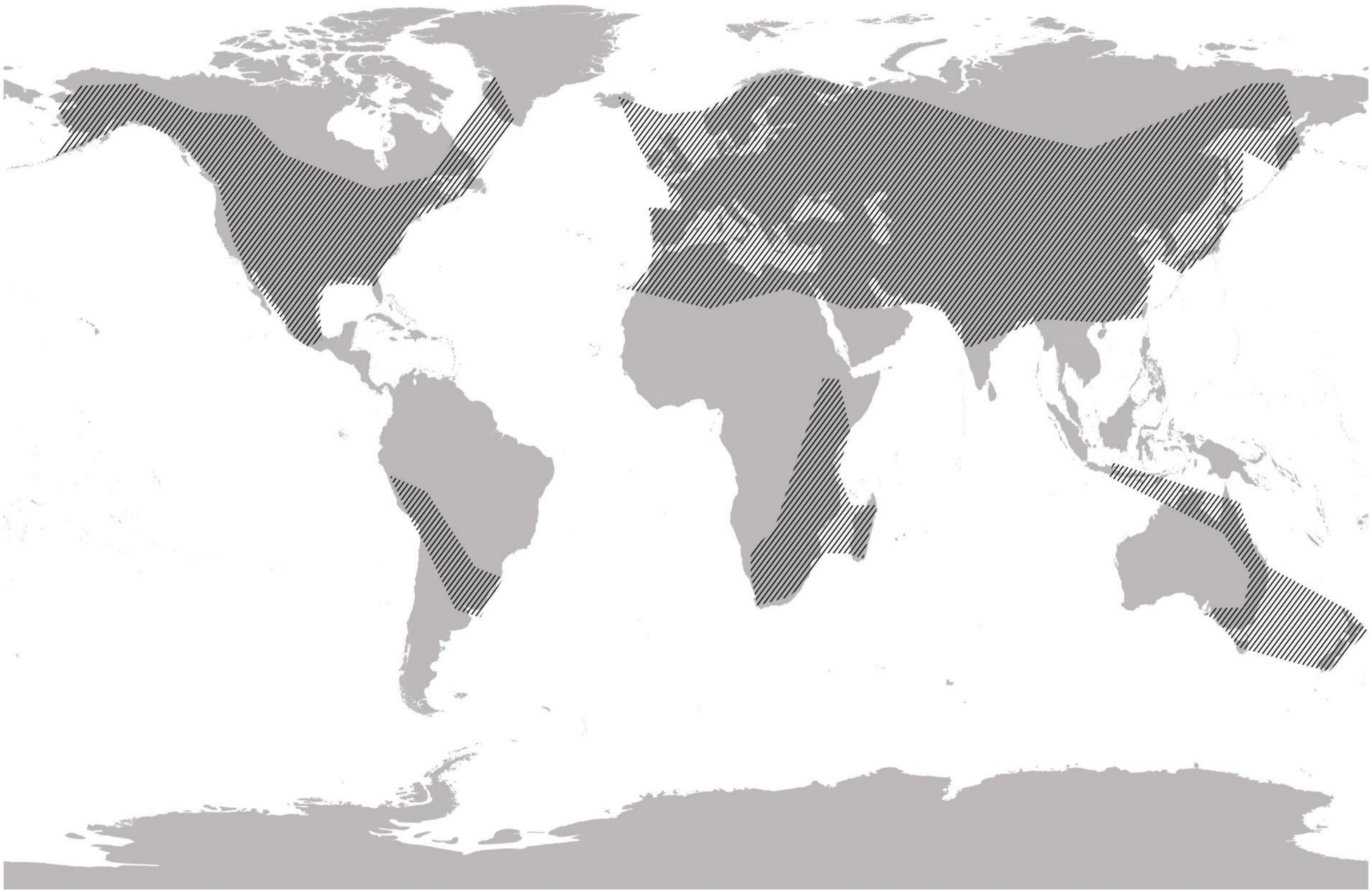

Fig. 10 *Chara globularis*

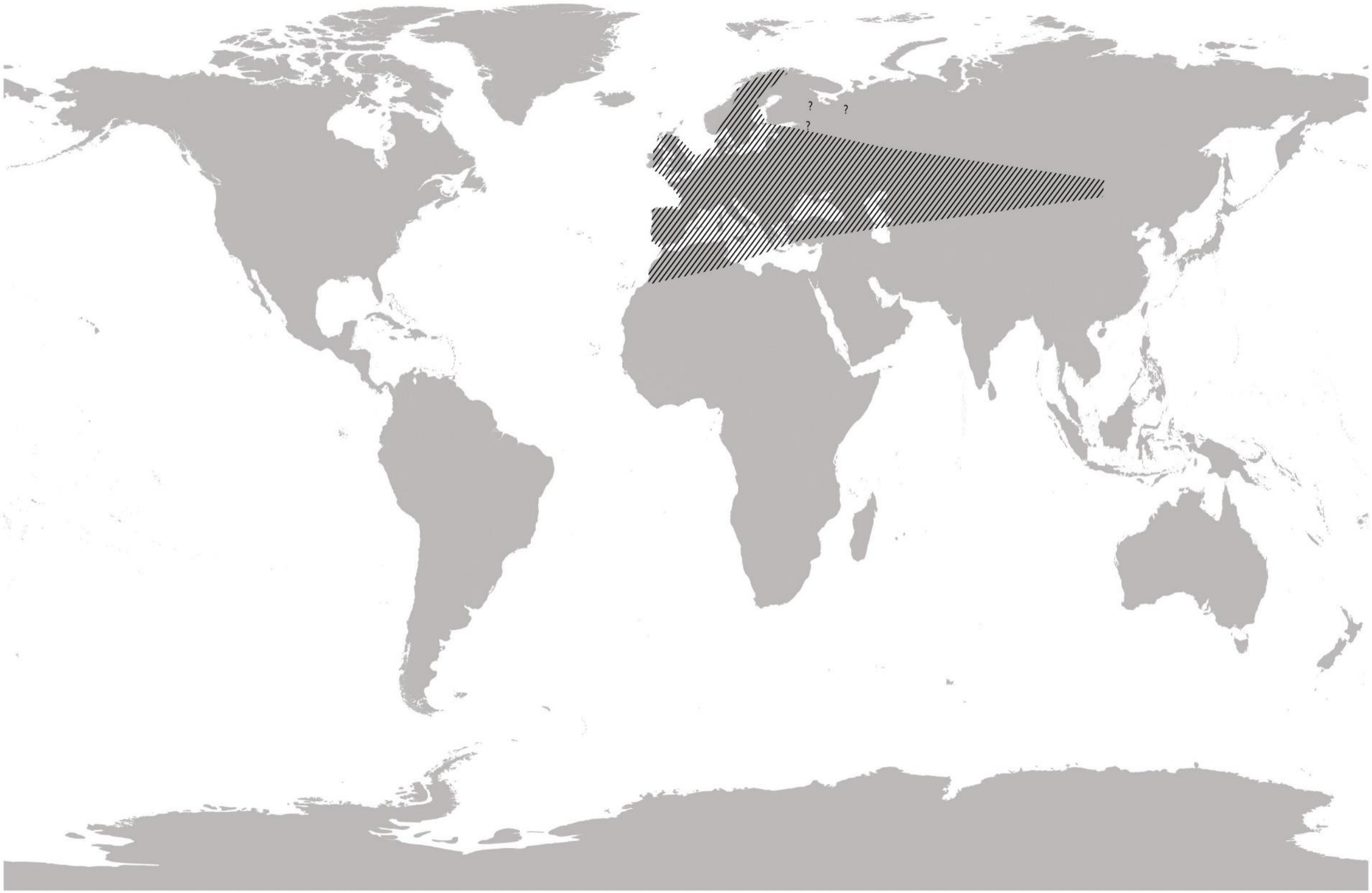

Fig. 11 *Chara hispida*

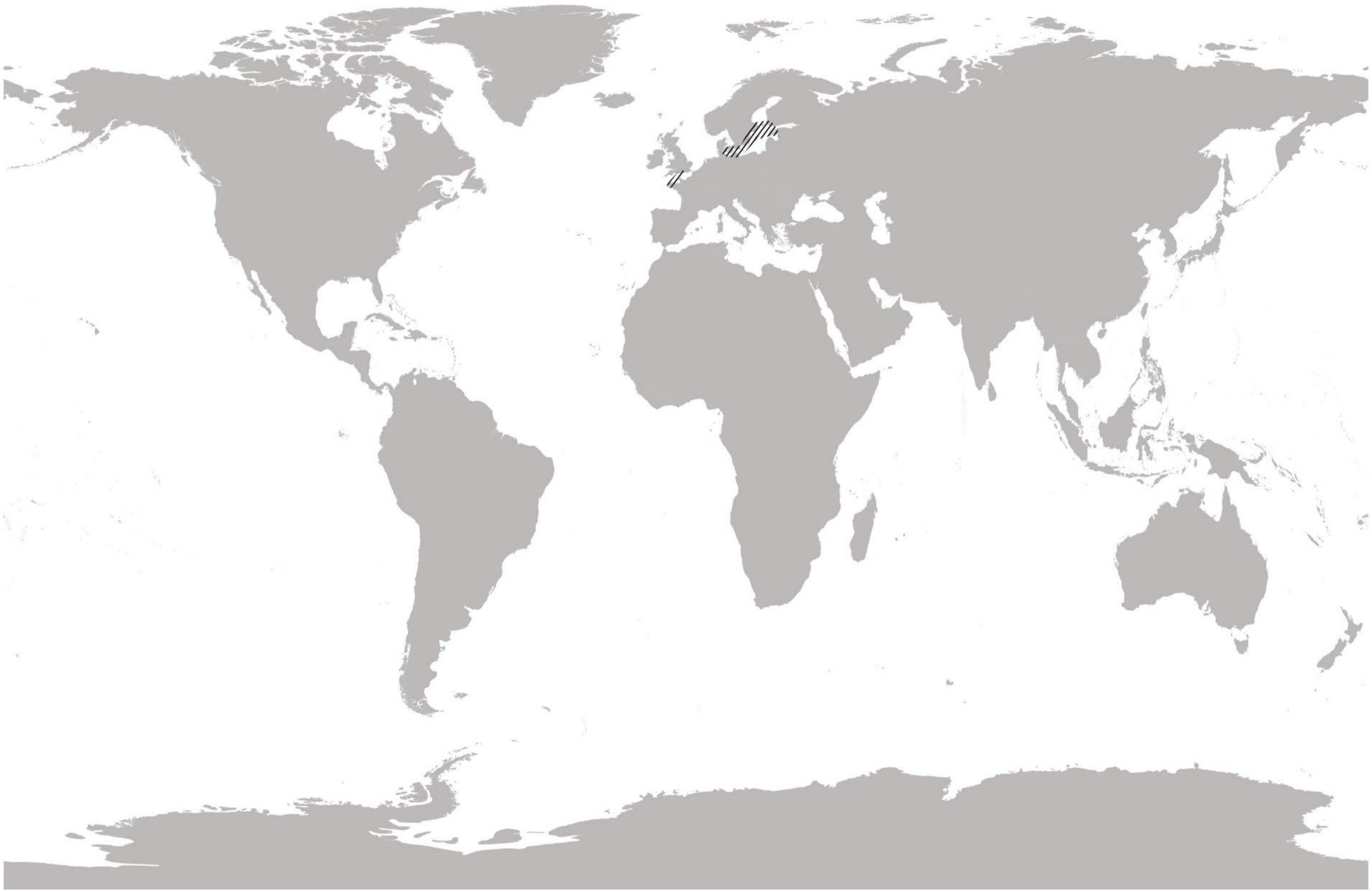

Fig. 12 *Chara horrida*

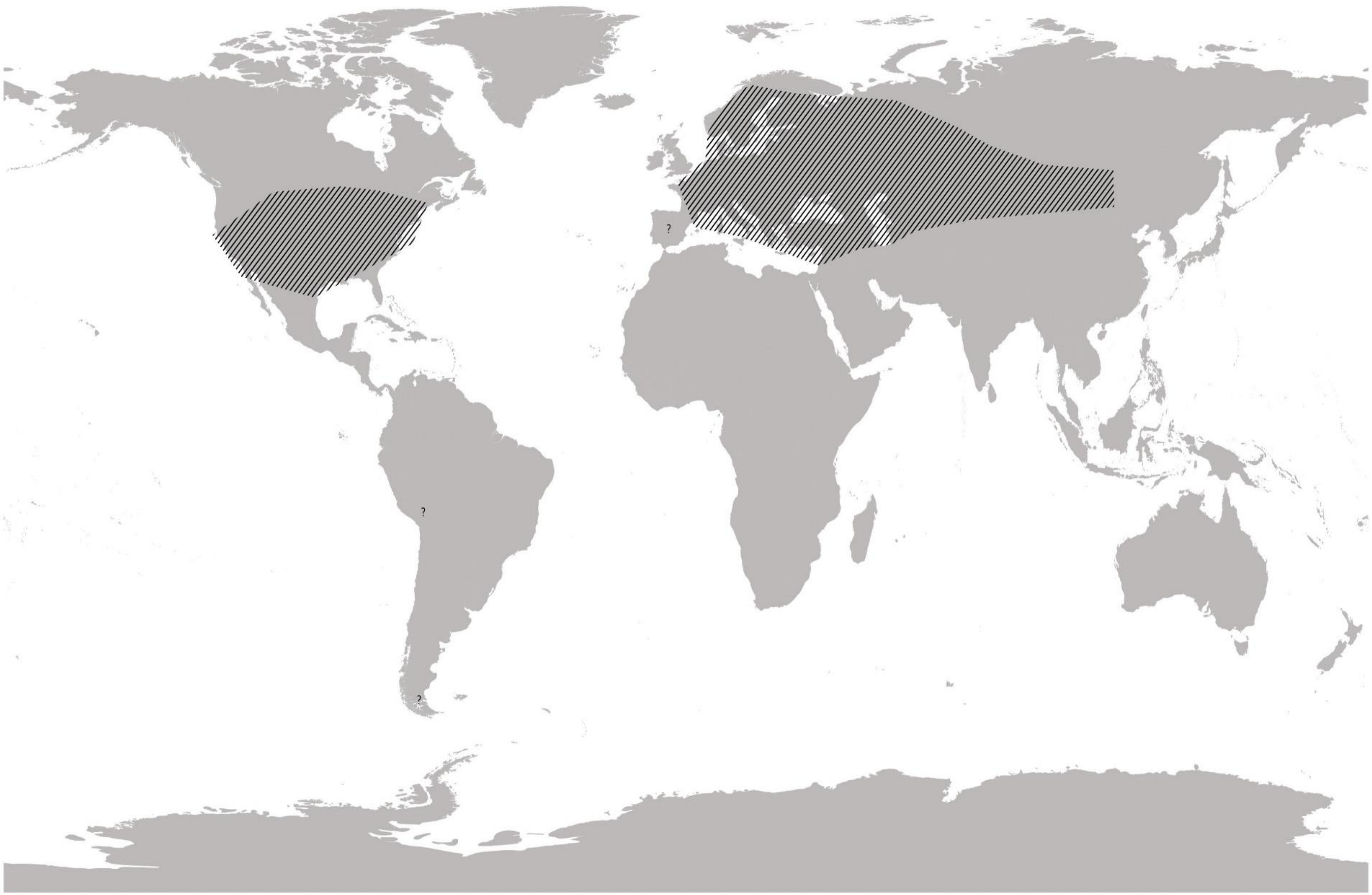

Fig. 13 *Chara papillosa*

Fig. 14 *Chara strigosa*

Fig. 15 *Chara subspinosa*

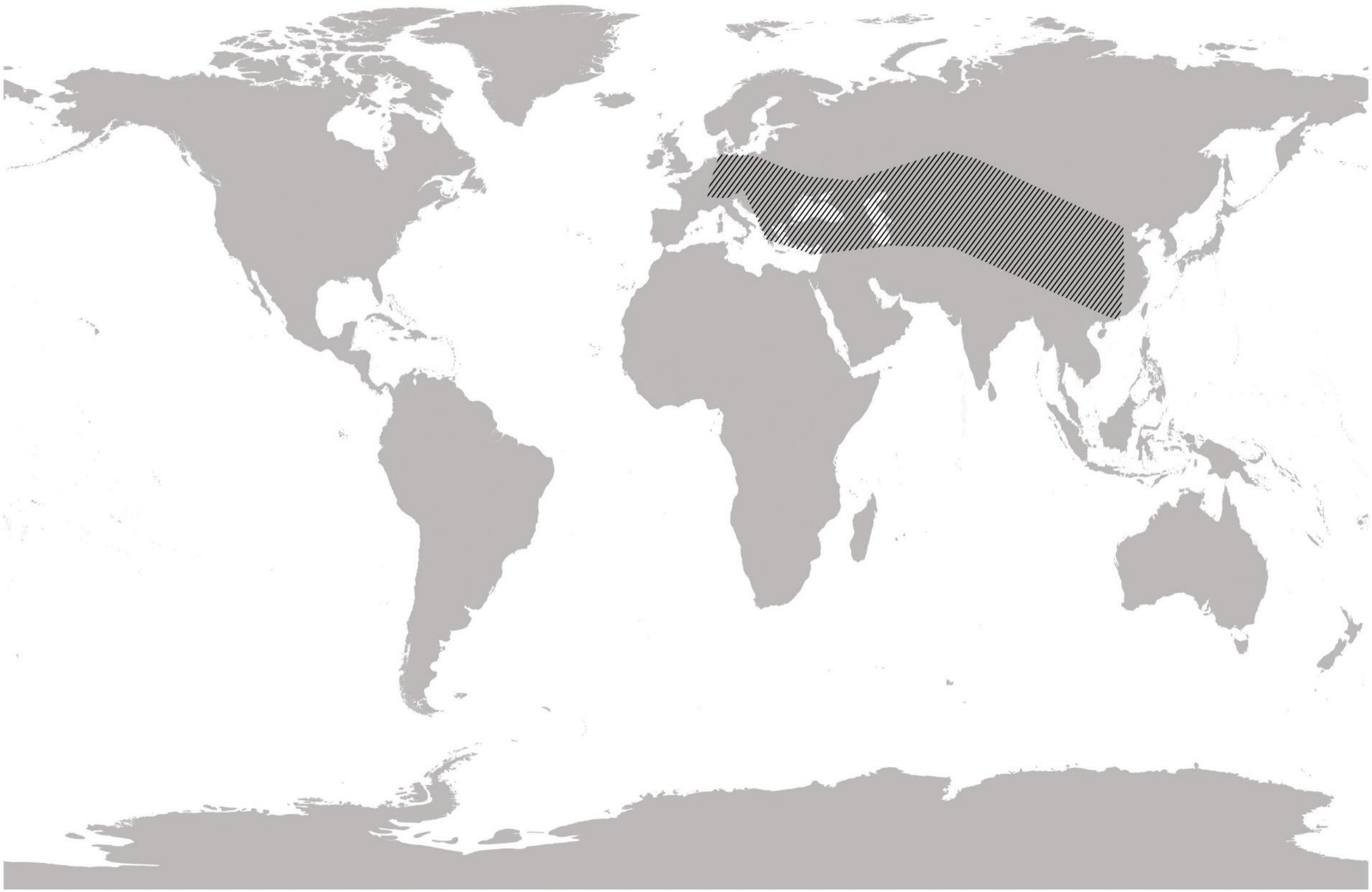

Fig. 16 *Chara tenuispina*

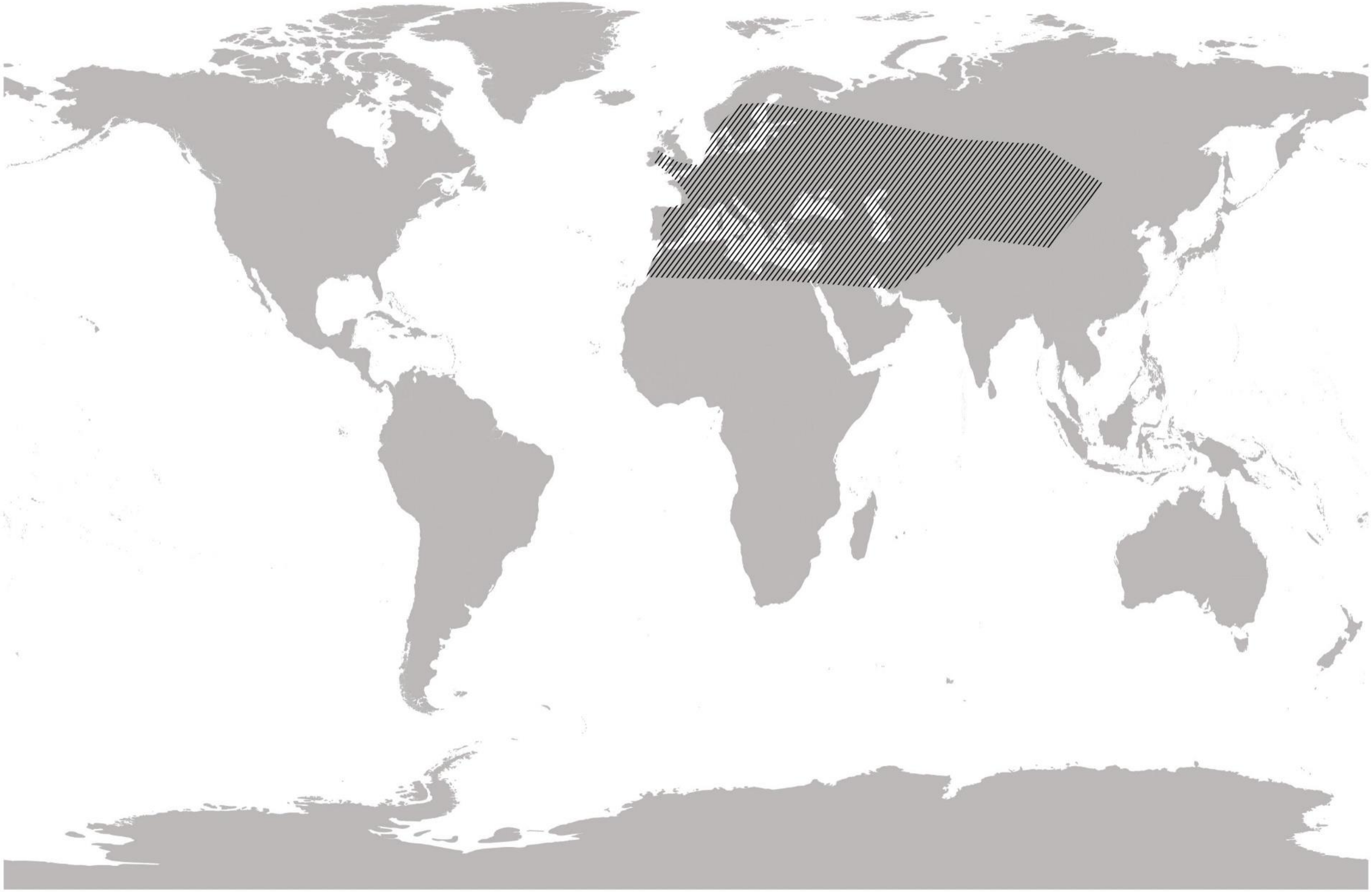

Fig. 17 *Chara tomentosa*

Fig. 18 *Chara virgata*

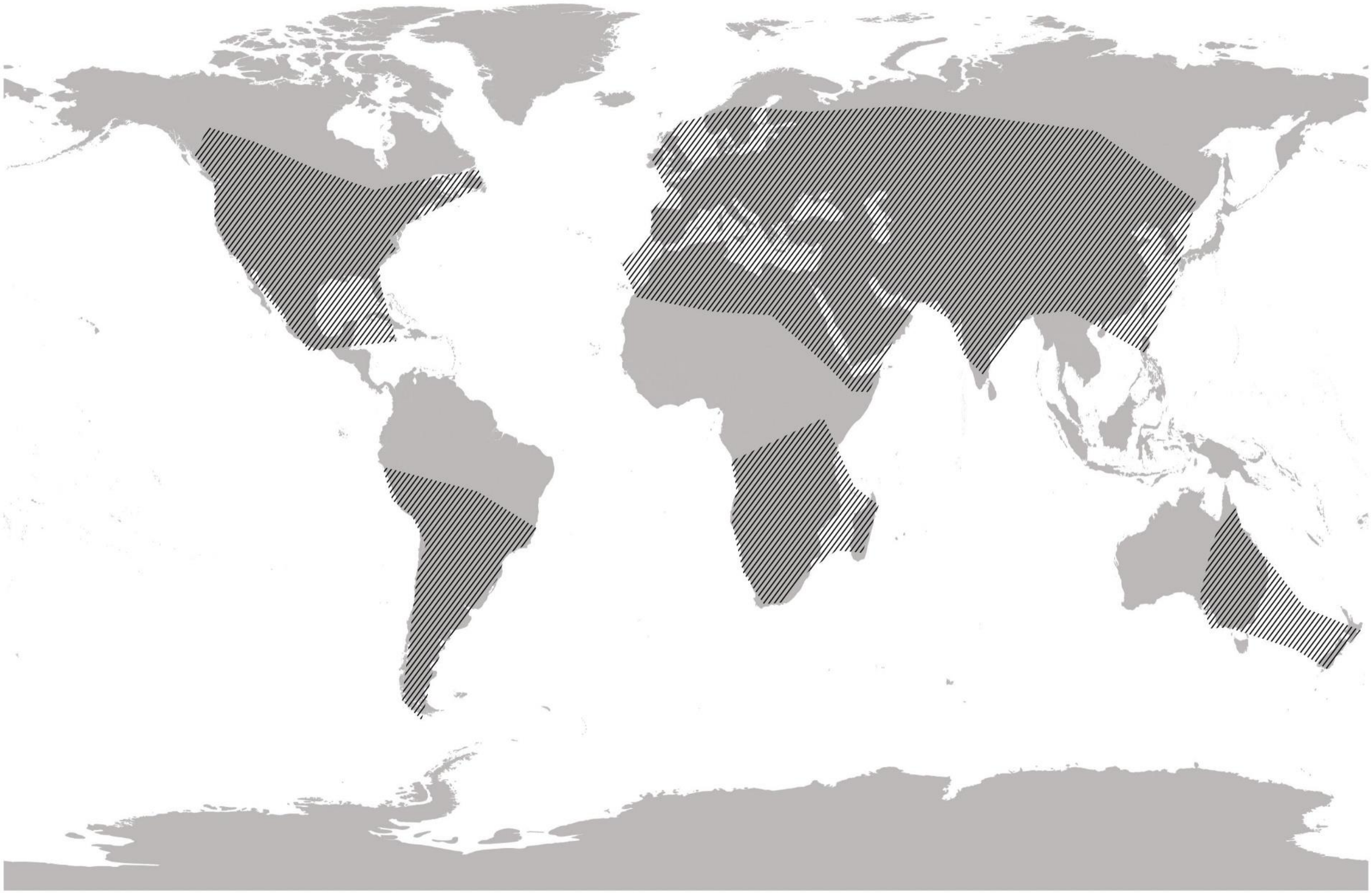

Fig. 19 *Chara vulgaris*

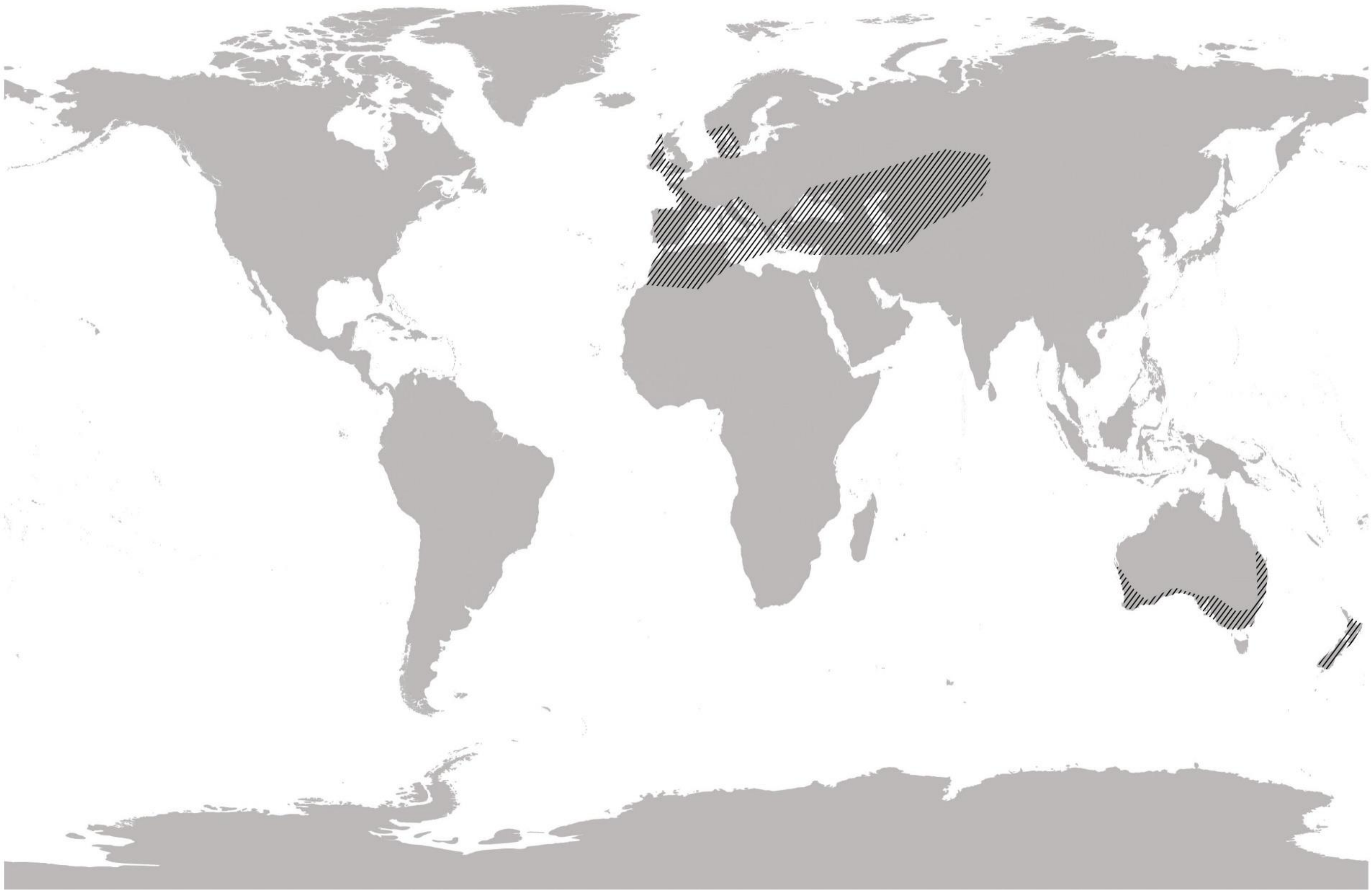

Fig. 20 *Lamprothamnium papulosum*

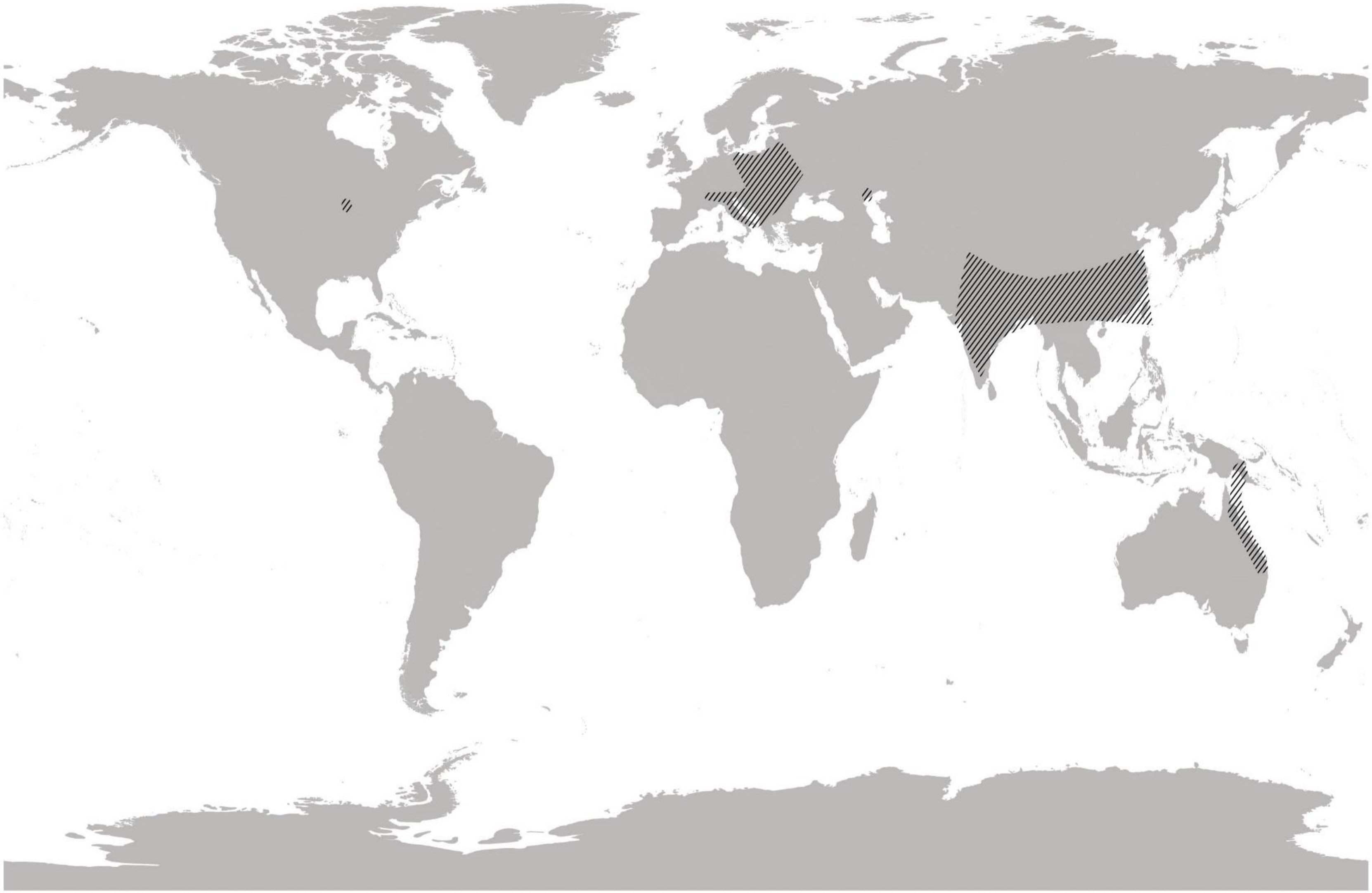

Fig. 21 *Lychnothamnus barbatus*

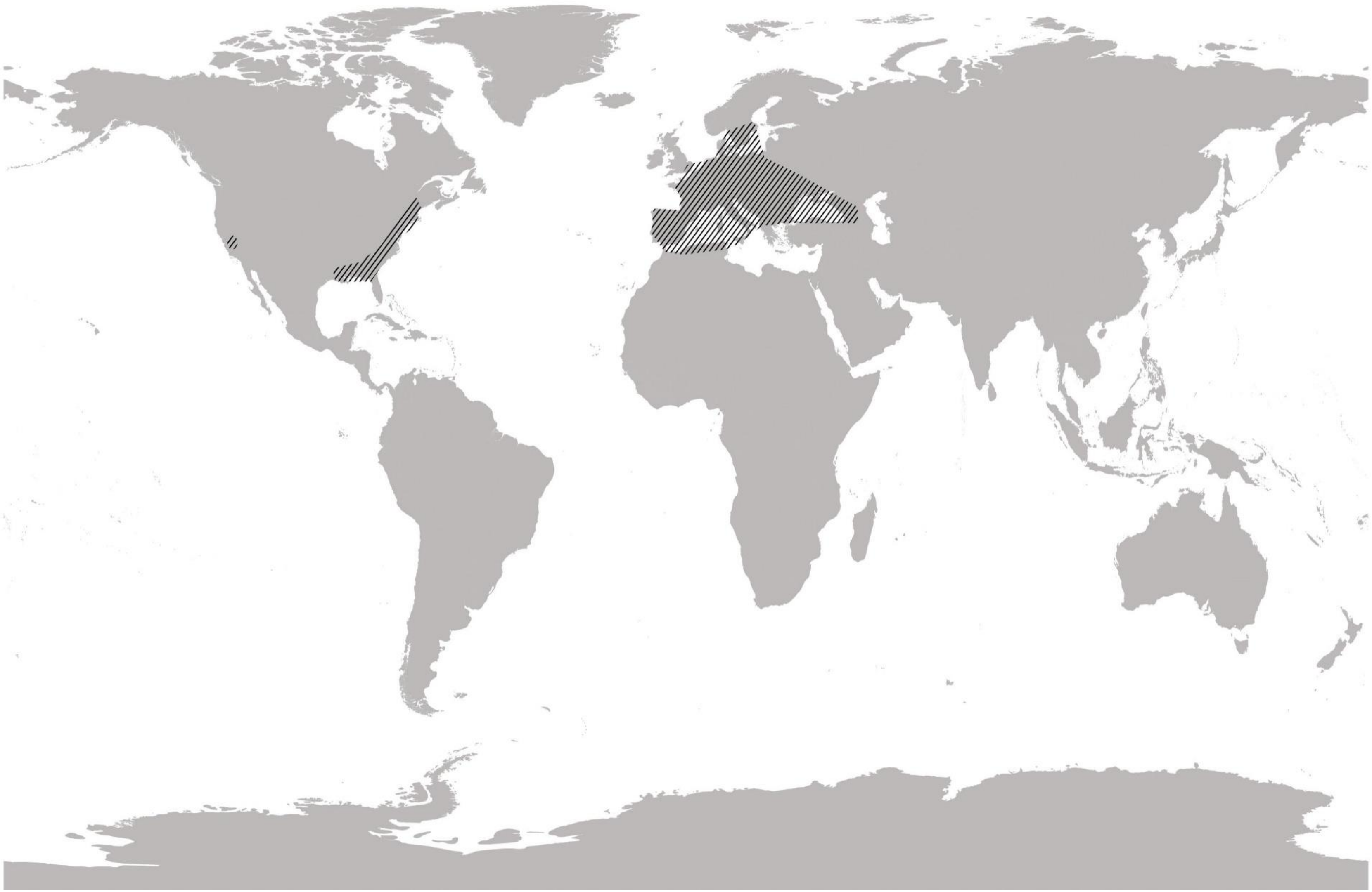

Fig. 22 *Nitella capillaris*

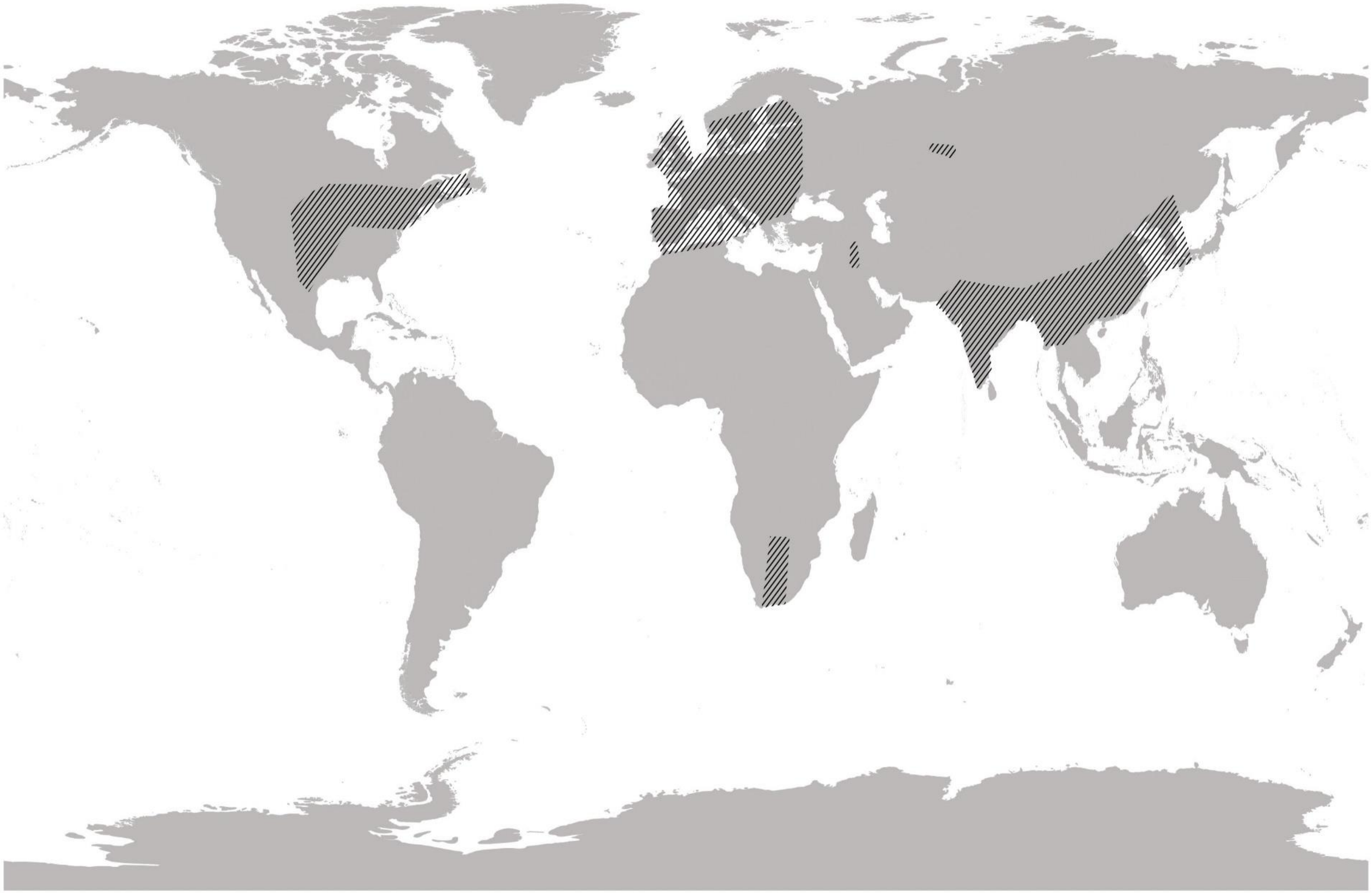

Fig. 23 *Nitella confervacea*

Fig. 24 *Nitella flexilis*

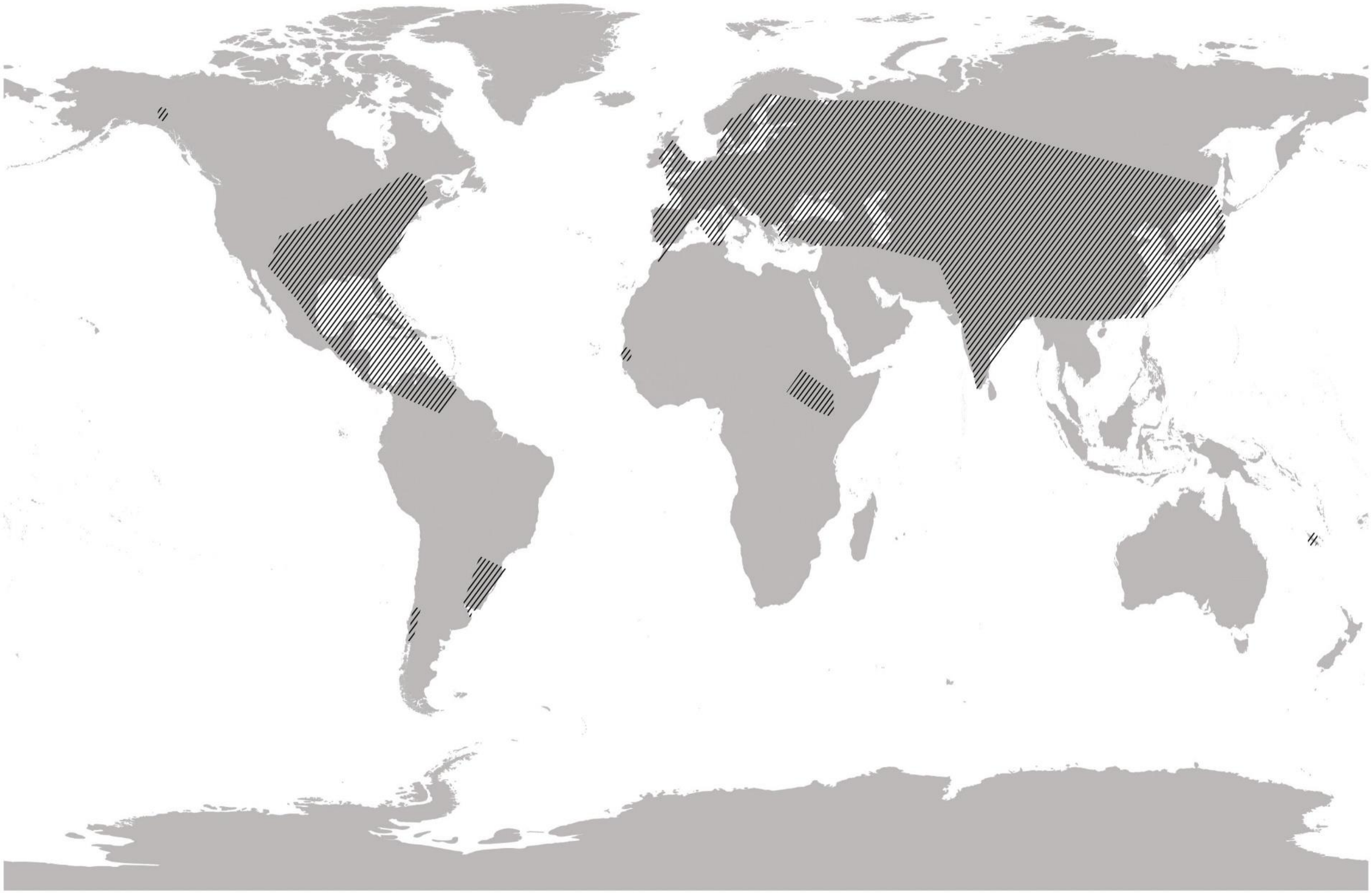

Fig. 25 *Nitella gracilis*

Fig. 26 *Nitella hyalina*

Fig. 27 *Nitella mucronata*

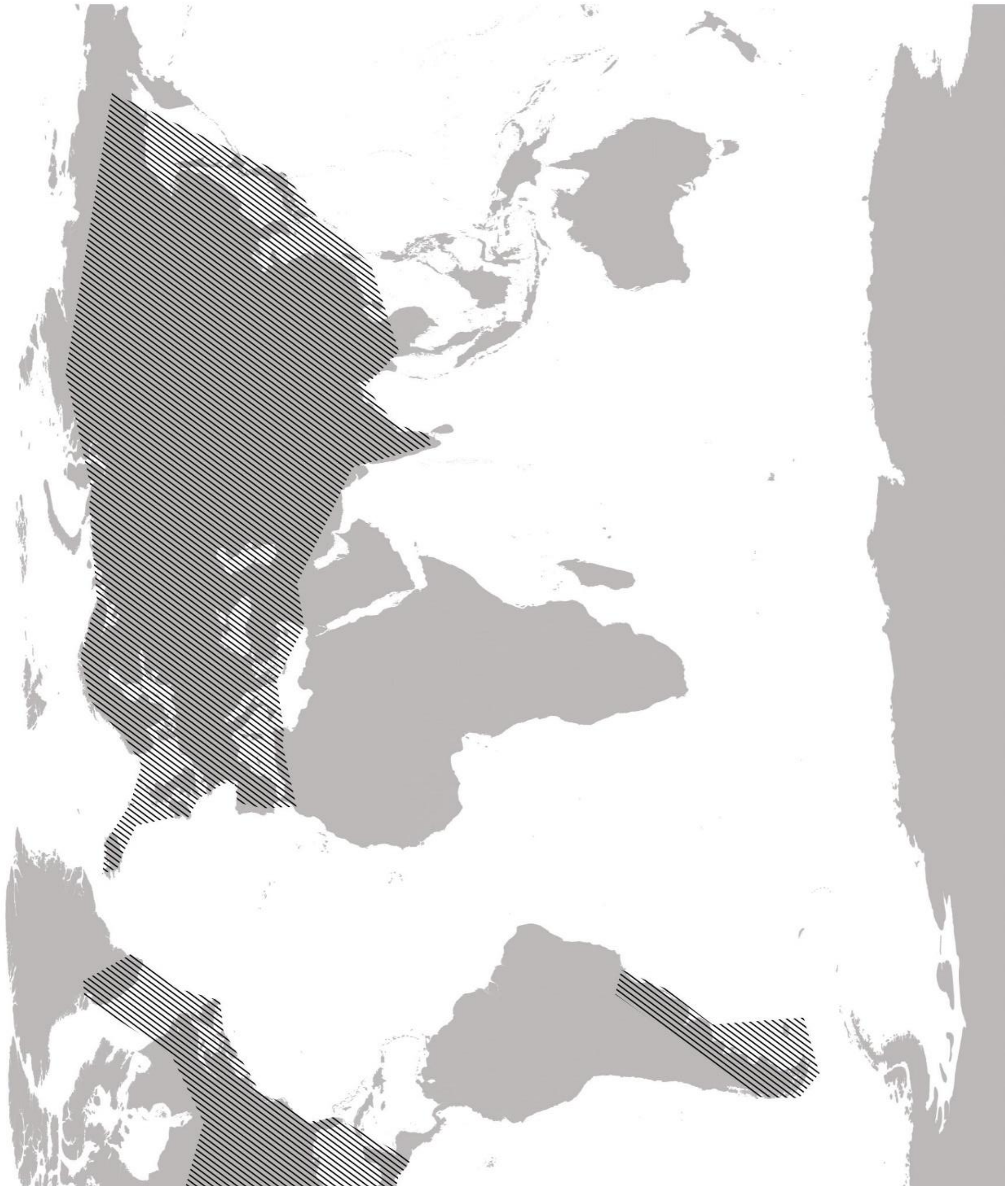

Fig. 28 *Nitella opaca*

Fig. 29 *Nitella syncarpa*

Fig. 30 *Nitella tenuissima*

Fig. 31 *Nitella translucens*

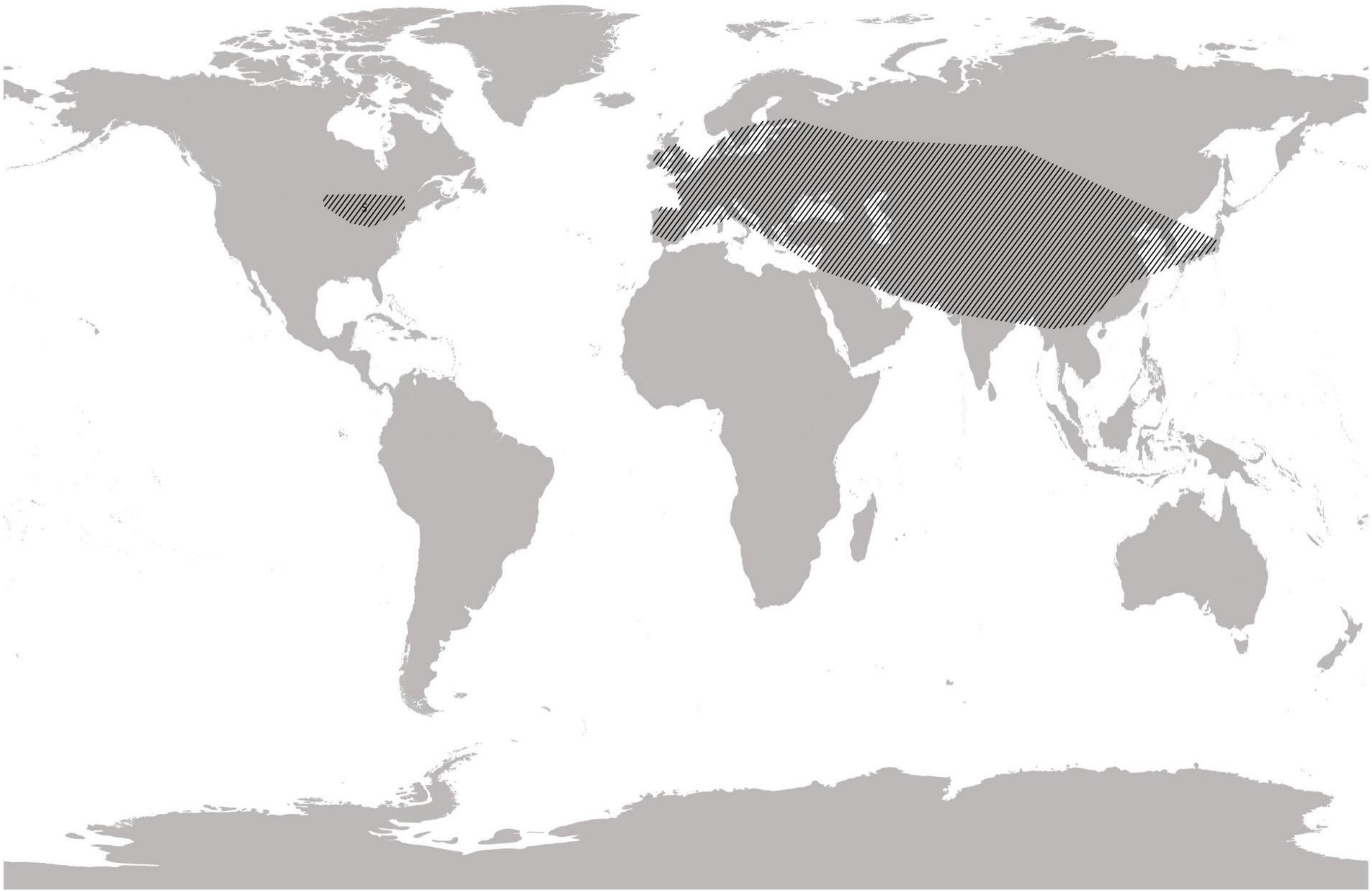

Fig. 32 *Nitellopsis obtusa*

Fig. 33 *Tolypella glomerata*

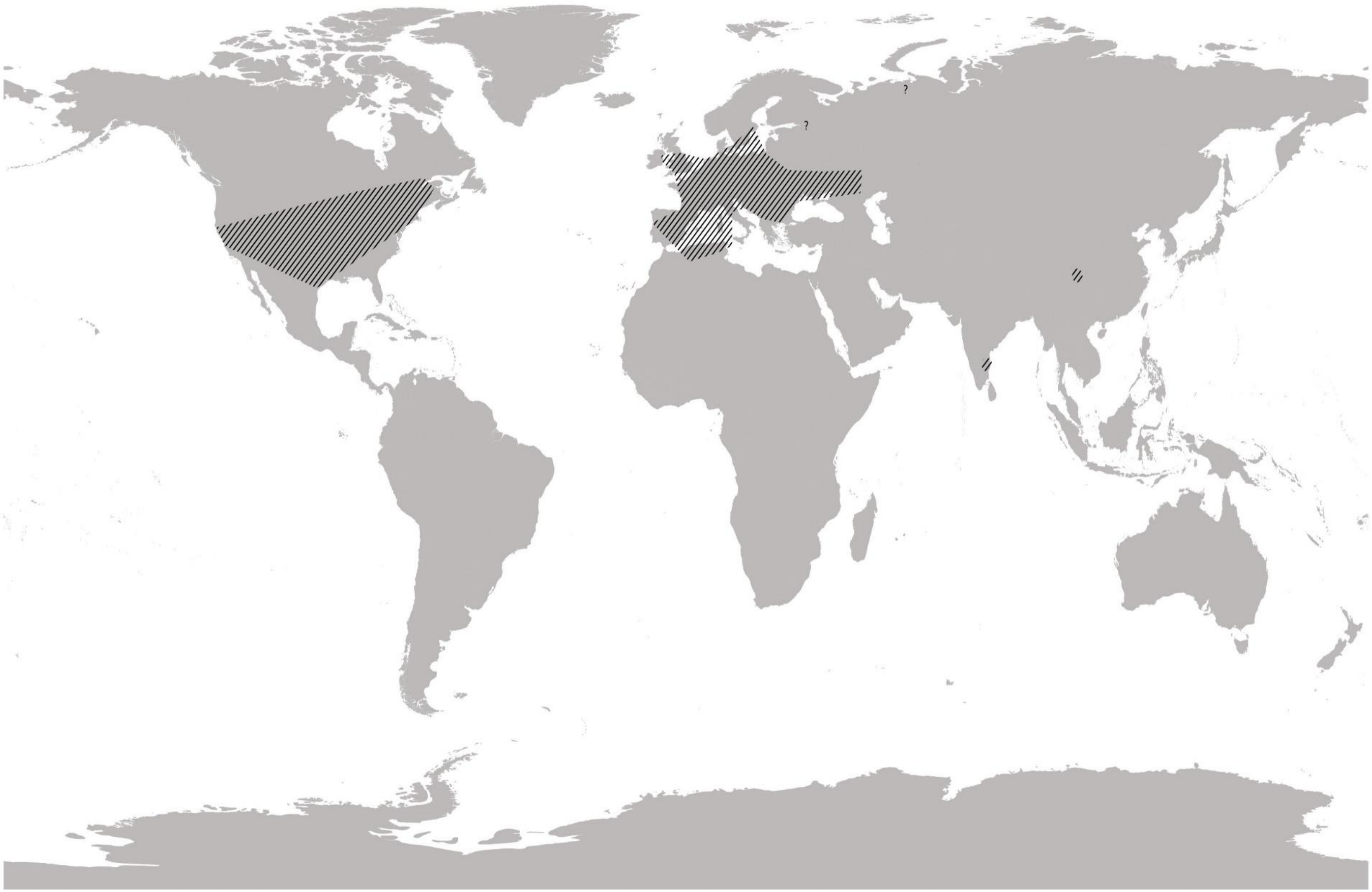

Fig. 34 *Tolypella intricata*

Fig. 35 *Tolypella nidifica*

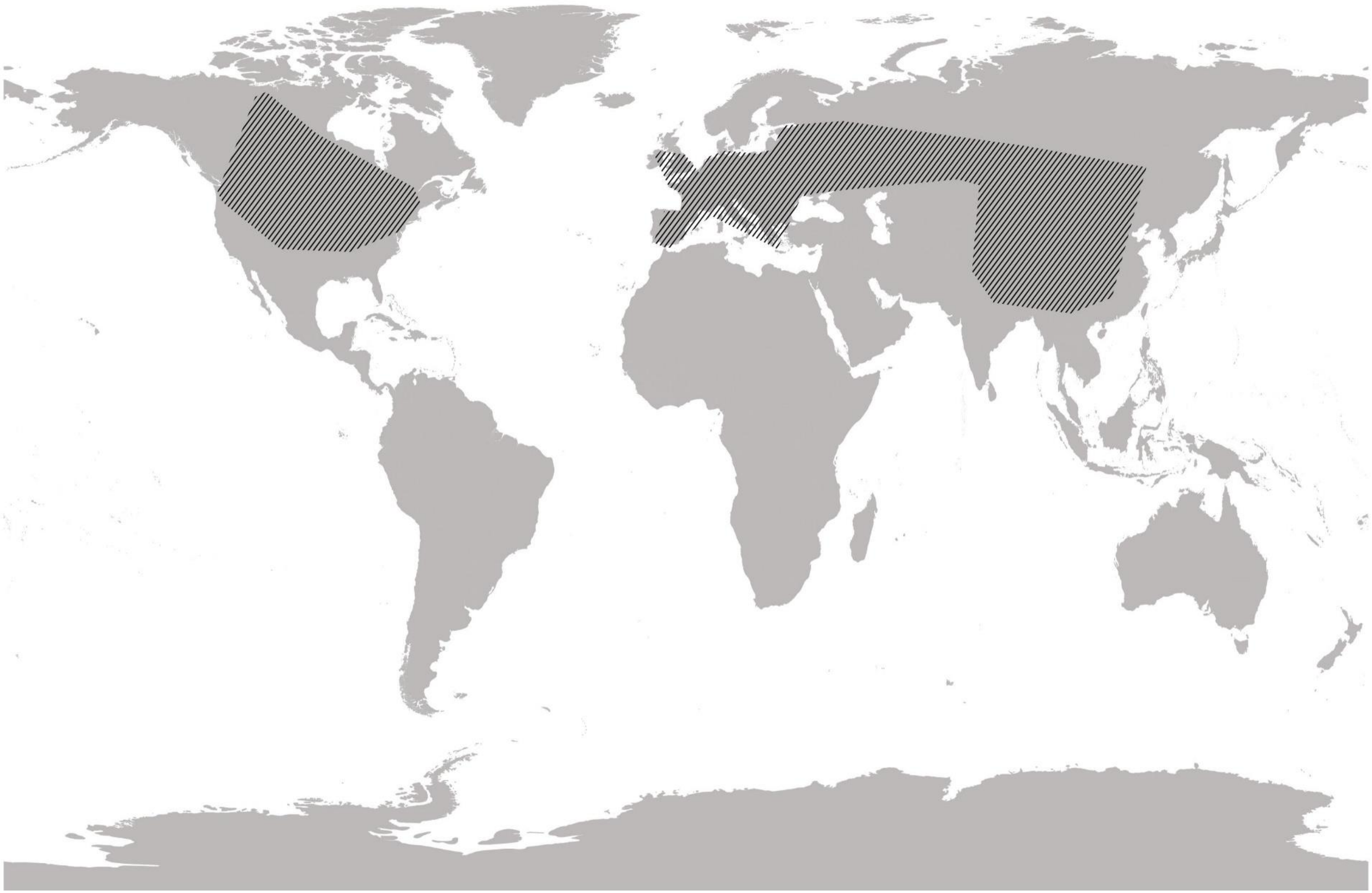

Fig. 36 *Tolypella prolifera*

4 Discussion

For some species some notes are necessary to aid the understanding of the maps or to explain the classification of records that are uncertain.

Chara aculeolata KÜTZ. in RCHB. (= *C. polyacantha* A. BRAUN): Within the species group around *C. aculeolata* there is considerable confusion. There exist at least five names (*C. aculeolata, C. intermedia*, *C. papillosa*, *C. pedunculata* KÜTZ. and *C. polyacantha*) which are used in different or even contradictory ways. Often these species were not separated and also the delimitation from *C. hispida* is not clear in some cases. As a result, there is significant uncertainty with the distribution area.

Chara aspera WILLD.: The taxon *C. curta* NOLTE ex KÜTZ. is sometimes treated as a separate species but is here included in *C. aspera*. However this does not significantly affect the range of *C. aspera* because *C. aspera* s.str. is found in almost all regions with *C. curta*. A similar case is *Chara galioides* DC. It is not included in *C. aspera* here but its inclusion would have only very little impact on the range of *C. aspera* s.str.

Chara baltica (HARTMAN) BRUZELIUS: This name is applied without doubt only to the plants from the Baltic Sea and adjacent areas. Whether all of the so called plants from around the Mediterranean Sea, from Greenland (LANGANGEN 2007), the Black Sea (CARAUS 2012) and the Gulf of Persia (ARNAU 2014) belong to this species is not certain (SCHUBERT et al. 2016a). But there are genetically proved records at least from Sardinia (BECKER pers. comm.). Even more uncertain is the status of the records from central and eastern Asia and southern America.

Chara baueri A. BRAUN: This species is mainly known from a few populations in eastern Germany and western Poland. Beside these there are only single records recently discovered in the Volga-region (КЛИНКОВА & ЖАКОВА 2014) and from Kazakhstan (ROMANOV & KIPRIYANOVA 2010). Furthermore a herbarium sheet exists with plants from south Sweden. The records from Schwerin in Germany and from Austria are uncertain. The plants from Australia sometimes listed as a forma under *C. baueri* and sometimes as a forma under *C. braunii* C. C. GMELIN (e.g. WOOD 1965) are regarded here as a separate species, *C. muelleri* (A. BRAUN) F. MUELL. (see CASANOVA 2014).

Chara canescens LOISEL.: In this dioecous species, only the female plants are widespread. The records from central North America are of monoecious plants (WOOD 1965) and therefore probably belong to another species and not to *C. canescens* in our sense.

Chara filiformis A. BRAUN in HERTSCH: The appearance in the Borkener See in Germany lies in a former coal-mining area (KORTE et al. 2010) far away from the nearest natural populations and is therefore considered as a synanthrope. The record from central Asia (MIGULA 1904 as *C. jubata* A. Br.) should needs to be proofed.

Chara globularis THUILL.: Between *C. globularis* and *C. virgata* KÜTZ. there exist various intermediate forms. For that reason these two species are not differentiated in a few publications (e.g. CIRUJANO et al. 2008). However, *C. globularis* is widely distributed and in most regions it is much more frequent. Probably, there will be only a few areas where *C. virgata* is the only species present and the lack of differentiation will probably not markedly influence the range-map of *C. globularis*.

Chara hispida L.: The type of *C. hispida* in the LINNÉ-Herbaria belongs to *C. aspera* WILLD. In this sense, these names have been used for almost 200 years. In order to avoid ambiguity, VAN RAAM (1998) used the name *C. major* HY for this taxon.

However, there is a formally accepted proposal for preservation of the well-established meaning of the name *C. hispida* (GREGOR et al. 2014) and this is the name used here. The records from the northwest part of Russia need to be checked according to ROMANOV et al. (in print).

Chara horrida WAHLST.: The record from the Black Sea (BORISOVA & TKATSCHENKO 2008) belongs probably to *C. baltica* (N. STEWART and R. ROMANOV, pers. comm.). It is unlikely that the record from Hungary (FILARSZKY 1893) really belongs to this strictly marine species. For that reason, this record is ignored here.

Chara papillosa KÜTZ. (= *C. intermedia* A. BRAUN): In Germany, there are two taxa included under this name (SCHUBERT et al. 2016b), one, which prefers fresh and one which prefers brackish water. Also sometimes the differentiation of this species from *C. baltica* and *C. aculeolata* (see above) is very difficult (SCHUBERT et al. 2016a). Furthermore, the use of these names is full of confusions. For that reason, many published records are uncertain. In particular the records from South America (ALLEN 1940, HORN AF RANTZIEN 1949) need to be confirmed. CIRUJANO et al. (2007, 2008) give the name *Chara intermedia* A. BRAUN as a synonym under the name *Chara hispida* var. *major* (HARTMAN) R. D. WOOD. The picture on page 64 in CIRUJANO et al. (2008) shows plants that seems to belong to *C. hispida* L. So for the records from Spain, it is unclear to which species they belong in the sense of Arbeitsgruppe Characeen Deutschlands (2016). Also KRAUSE (1997), who visited the Iberian Peninsula several times, gives no record for *Chara papillosa* from there. The records of CIRUJANO et al. (2007, 2008) and ARNAU (2014) were, therefore, not included into the map of *C. papillosa* but it is possible that it does occur there.

Chara strigosa A. BRAUN: Sterile plants are sometimes difficult to differentiate from *C. aspera*. The ecological conditions of the Dnestr region (Moldova) (Anonymous 2014, ROMANOV et al. 2014a) are very different from the typical habitats of this species, which is otherwise restricted to higher mountains and boreal regions. This record of *C. strigosa* therefore needs confirmation.

Chara subspinosa RUPR. [= *C. rudis* (A. BRAUN) LEONH.]: One of the most famous Characeae phycologist of Germany W. KRAUSE had problems with differentiating the pair *C. subspinosa* and *C. hispida*. Many wrongly determined herbaria sheets show this clearly. Because of his authority many other people have accepted these erroneous determinations. For that reason, there exist a many wrong or doubtful data in Germany. The record in Czech south of the Erzgebirge (CAISOVA & GABKA 2009) lies also far away from the next confirmed appearances in the Donau valley or in north-east Germany and needs to be confirmed.

Chara virgata KÜTZ.: Between *C. globularis* and *C. virgata* there exist various intermediate forms. For this reason, these two species are not separated in a few publications and united under the name *C. globularis*. It is likely that there will be some additional regions where *C. virgata* grows and has not yet been recorded.

Lamprothamnium papulosum (WALLR.) J. GROVES: The records listed by GUERLESQUIN (1992) for China and Korea and by WOOD (1978) and GUERLESQUIN (1992) for South Africa probably do not belong to this species. These plants are most likely to be *Lamprothamnium macropogon* (A. BRAUN) I. L. OPHEL or *L. succintum* (A. BRAUN) R. D. WOOD (VAN RAAM 2012; R. ROMANOV, pers. comm.). The record from Bangladesh (NAZ & DIBA 2012) is more likely to be *Chara braunii* than *L. papulosum* according to the pictures given in this publication (R. ROMANOV, pers. comm.).

Nitella capillaris (KROCK.) J. GROVES & BULL.-WEBST.: Plants from North America were determined as *N. capillaris* by BRAUN (1883), and also by WOOD in his early years (e.g. 1947, revisions on sheets in the Herbaria of the University of California, Berkeley). About 20 years later, they were redetermined by WOOD (WOOD 1965, CHOUDHARY & WOOD 1973) as *N. flexilis*. CHOUDHARY (in CHOUDHARY & WOOD 1973) then described these plants as *Nitella flexilis* var. *americana.* Reviews of the plants available as scans in the Macroalgal Portal showed that the original determination as *N. capillaris* seems to be correct. The existence of slime around the gametangia and the dioecism makes the determination by CHOUDHARY & WOOD (1973), even in their very broad species concept, not really reproducible.

Nitella flexilis (L.) C. AGARDH: Some of the taxa treated here as species are included within WOOD's broad species concept of *N. flexilis*. Mainly in southern Europe, *Nitella flexilis* and *N. opaca* (C. AGARDH ex BRUZELIUS) C. AGARDH were sometimes united under the name *N. flexilis* sensu Wood (e.g. CIRUJANO et al. 2007). In Greece for example, KOUMPLI-SOVANTZI (1997) lists only *N. flexilis*. However, only *N. opaca* in the strict sense of Arbeitsgruppe Characeen Deutschlands (2016) is known to grow there (U. RAABE pers. comm.). The data of *N. flexilis* from KOUMPLI-SOVANTZI (1997) have, therefore, been transferred to the map of *N. opaca*. For the Iberian Peninsula CIRUJANO et al. (2007) also united *N. flexilis* and *N. opaca* under the name *N. flexilis* and only the data of ARNAU (2014) could be used in the maps of these two species.

Nitella translucens (PERS.) C. AGARDH: The record published by CARAUS (2012) from the Donau delta in Romania and the record from the Southeast Ukraine (BORISOVA 2014) are doubtful. These regions do not have the ecological conditions needed by this mainly oceanic or suboceanic species of soft water. In the past there were sometimes false determinations of *Nitellopsis obtusa* as *Nitella translucens* and this seem to be the most likely confusion. The records from Africa (BRAUN 1883) and from Bangladesh (PAL et al. 1962) are far away from the known range and it seems that nobody has confirmed it since that time. The plants from south India (pictures in SUBRAMANIAN 2002) look quite different to the European plants of these species. A re-examination of the material from these regions is needed. Under *N. translucens* in WOOD (1965) are *N. axillaris* A. BRAUN as a forma and *N. sublucens* T. F. ALLEN as a subspecies. Both are regarded here as separate species and are not included.

Nitellopsis obtusa (DESV.) J. GROVES: For several decades this has been an introduced and expanding species in North America (GEIS et al. 1981, ESCOBAR et al. 2016, ALIX et al. 2017).

Tolypella glomerata (DESV.) LEONH.: The records from south Australia which were based on collections and determinations of R. D. WOOD (WOOD 1965) do not belong to this species according to VAN RAAM (2012).

Tolypella intricata (TRENTEP. ex ROTH) LEONH.: The records from the Leningrad oblast and from the Nenets Autonomous Okrug need to be checked according to ROMANOV et al. (in print).

Tolypella nidifica O. F. MÜLL.: The differentiation of this species from *T. salina* CORILLION is very difficult and also, so far, no genetic differences have been found (P. NOWAK pers. comm.). For that reason it could be useful to include *T. salina* into *T. nidifica*. Although KRAUSE (1997) gives two records of *T. nidifica* from Spain, CIRUJANO et al. (2008) and CIRUJANO BRACAMONTE et al. (2013) list only *T. salina* for the Iberian Peninsula. The inclusion of *T. salina* would enlarge the range of *T. nidifica* onto the Iberian Peninsula.

Tolypella prolifera (ZIZ ex A. BRAUN) LEONH.: The records from South America as *T. prolifera* var. *montevideensis* (ALLEN & HERTER 1934, WOOD 1965) do not belong to this species according to VAN RAAM (2012).

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Anne DIETRICH[1] & Hendrik SCHUBERT[2]

[1] Institut für Angewandte Ökosystemforschung GmbH, Alte Dorfstraße 11, 18184 Neu Broderstorf, Germany
anna.dietrich@ifaoe.de

[2] Universität Rostock, Institut für Biowissenschaften, Albert-Einsteinstr. 3, 18051 Rostock, Germany

Arealerweiterung der Grünalge *Bryopsis plumosa* sowie der Rotalgen *Gracilaria vermiculophylla* und *Dasya baillouviana* in den Küstengewässern Mecklenburg-Vorpommerns

Abstract

Two non-indigenous species, *Dasya baillouviana* (Gmelin) Montagne, 1841 and *Gracilaria vermiculophylla* (Ohmi) Papenfuss, 1967 (Rhodophyta), and the indigenous species *Bryopsis plumosa* (Hudson) C. Agardh 1823 were found during the years 2016-2017 in the coastal area near Rostock (Bay of Mecklenburg). This represents a substantial extension of their distribution range in the Baltic Sea.

Keywords: *Bryopsis plumosa*, *Gracilaria vermiculophylla*, *Dasya baillouviana*, Baltic Sea

1 Einleitung

SCHORIES et al. (2009) stellten eine Übersicht über die Neophyten der deutschen Küstengewässer vor. Von den elf gelisteten Arten kamen zum Zeitpunkt der Veröffentlichung drei im Bereich der deutschen Ostseeküste vor: *Fucus evanescens* (C. AGARDH 1820), *Dasya baillouviana* (GMELIN) MONTAGNE 1841 und *Gracilaria vermiculophylla* (OHMI) PAPENFUSS 1967. Eine Übersicht von potentiellen Auswirkungen dieser Neophyten auf heimische Lebensgemeinschaften sind in LACKSCHEWITZ et al. (2014) für die Küstengewässer der Nord- und Ostsee beschrieben. Von den drei hier untersuchten Arten werden von LACKSCHEWITZ et al. (2014) nur im Fall von *G. vermiculophylla* starke Auswirkungen erwartet, die aber in dieser Form bislang in den deutschen Küstengewässern auch noch nicht aufgetreten sind.

Alle drei Arten wurden bislang nur in der westlichen Ostsee, d.h. dem Gebiet bis Höhe der Insel Fehmarn (siehe SCHORIES et al. 2009) angetroffen. Funde aus den Küstengewässern Mecklenburg-Vorpommerns waren nicht bekannt (SCHORIES et al. 2013). Seitdem hat der Klauentang *F. evanescens* sein Verbreitungsgebiet bis in die östliche Ostsee ausgedehnt und wurde mittlerweile sogar bei Stralsund gefunden (LACKSCHEWITZ et al. 2014).

Auch für die anderen Arten wird ein weiteres Vorrücken nach Osten erwartet. WEINBERGER (2006) schließt aus Untersuchungen zur Salinitätstoleranz von *G. vermiculophylla,* dass eine Ausdehnung des damaligen Verbreitungsgebietes in Richtung der niedrigsalinen östlichen Bereiche der Ostsee zu erwarten ist.

Die Verfügbarkeit von Hartsubstrat in geeigneten Tiefenbereichen ist, abgesehen von der Salinität, anscheinend der wichtigste Faktor für das Vorkommen von Makroalgen entlang der südlichen Ostseeküste. Ausgedehnte Weichsubstratgebiete, wie sie typisch für eine Ausgleichsküste sind, erschweren die Ansiedelung neuer Arten, da sie die Festlandskerne, die ausreichend Hartsubstart bieten würden, voneinander isolieren. Durch anthropogene Einflüsse wie Hafenanlagen oder Küstenschutzbauten, einschließlich Buhnenreihen, sind hier in den vergangenen 80 bis 100 Jahren zahlreiche sekundäre Besiedelungsflächen für Algen geschaffen worden, die die weitere Ausbreitung unterstützen können (SCHORIES et al. 2013). Der 2003 – 2004 errichtete Yachthafen „Hohe Düne“ ist ein solches Beispiel für sekundäres Hartsubstrat, das durch seine Lage dicht zu einer Hafeneinfahrt die Ansiedelung von Arten, die über Schiffsverkehr eingeschleppt werden, begünstigen kann (KUHLENKAMP & KIND 2017). Die Südmole bietet Schutz vor Welleneinwirkungen, die später errichtete küstenparallele Mole schützt zusätzlich den Flachwasserbereich und schuf damit ein Habitat, das die Ansiedlung des Neophyten *F. evanescens* ermöglichte (vgl. DIETRICH & SCHUBERT 2017).

F. evanescens ist allerdings, verglichen mit den beiden anderen Neophyten, eine recht auffällige Art, die auch als Strandanwurf lange Zeit erkennbar bleibt. Das ist bei den anderen beiden Neophyten nicht der Fall. Aus diesem Grund wurden, nach Entdeckung von *F. evanescens*, gezielte Untersuchungen im Bereich der Warnow-mündung durchgeführt um zu überprüfen ob weitere, im Gebiet bislang nicht nachgewiesene Arten sich im Bereich des sekundären Hartsubstrates angesiedelt haben.

2 Material und Methoden

In den Jahren 2016 und 2017 fanden regelmäßige Begehungen an der Stein-wand der Mole des Yachthafens „Hohe Düne“ statt (54°10’46"N 12°06’12"E; Gebiet A, Abb. 1). Zum Begehungsprogramm gehörte auch die Untersuchung eines ca. 100 m langen Bereiches an der Außenseite der Südmole durch Taucher.

Darüber hinaus wurden im Auftrag des Wasserstraßen- und Schifffahrtsamtes Stralsund im Juli 2017 Videoaufnahmen im Breitling durchgeführt, bei denen Makrophyten-Proben mittels Gartenharke gewonnen wurden. Weitere Taucheinsätze erfolgten im September 2017 östlich des Pagenwerders (54°09’59"N 12°06’30"E; Gebiet B, Abb. 1) in 0,5 – 2,0 m Tiefe sowie im Juli, September und Oktober 2017 vor dem Schnatermann (54°10’13"N 12°08’26"E; Gebiet C, Abb. 1) in 0,3 – 1,0 m Tiefe. Von allen gefundenen Arten wurden Herbarbelege und eine Fotodokumentation angefertigt.

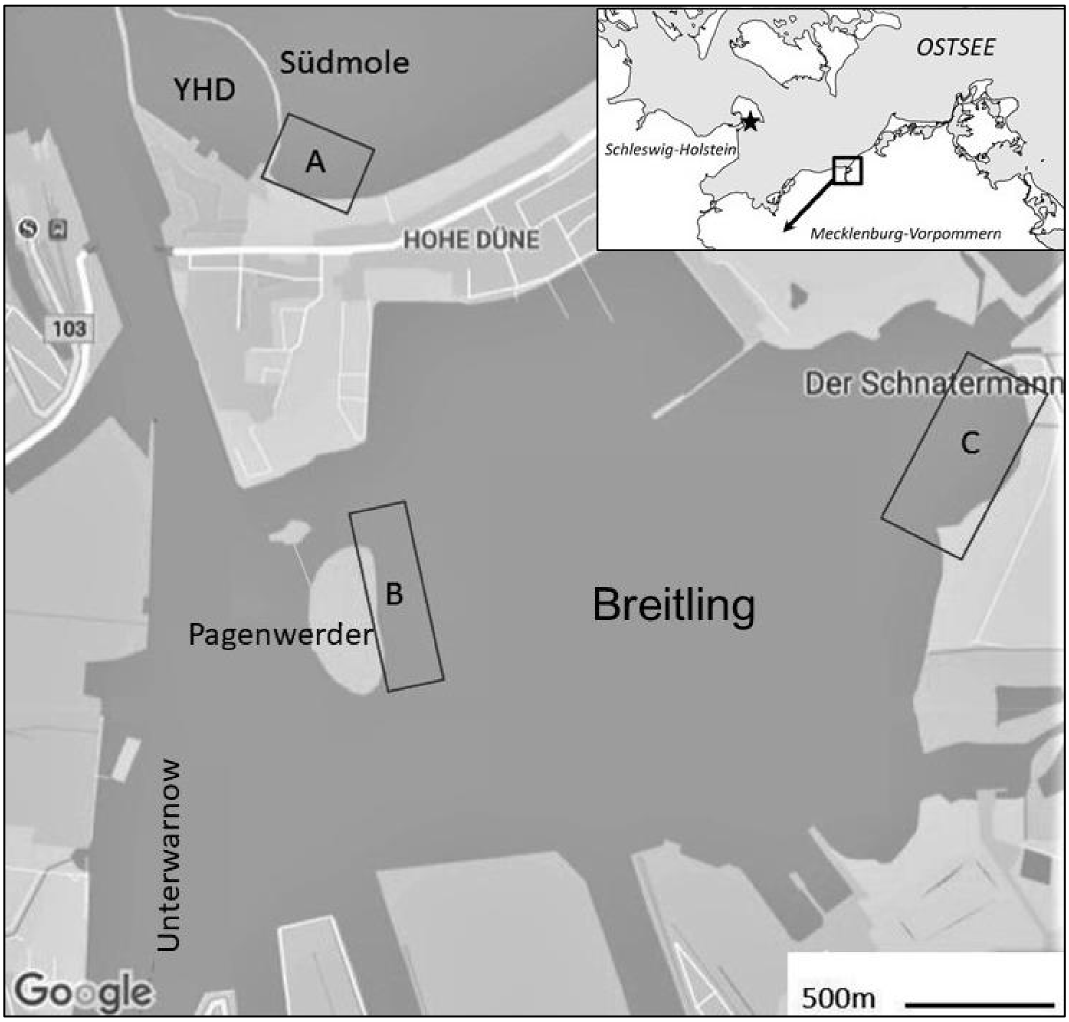

Abb. 1 Lage der Untersuchungsgebiete bei Rostock. Eingefügte Karte: bisherige Verbreitungsgrenze (★) von *Bryopsis plumosa, Dasya baillouviana* und *Gracilaria vermiculophylla* bei Insel Fehmarn. Rostock (□). Große Karte: YHD-Yachthafen „Hohe Düne“; A: Untersuchungsgebiet Südmole; B: Untersuchungsgebiet Pagenwerder; C: Untersuchungsgebiet Schnatermann. Kartenquelle: GoogleMaps.

3 Ergebnisse und Diskussion

Im Zuge der hier vorgestellten Untersuchungen wurden drei Arten, die bislang für die Ostseeküste Mecklenburg-Vorpommerns nicht nachgewiesen wurden, aufgefunden. Es handelt sich dabei um die in der Ostsee heimische Grünalge *Bryopsis plumosa* (HUDSON) C. AGARDH 1823 sowie die nicht-indigenen Rotalgen-Arten *G. vermiculophylla* und *D. baillouviana.* Bisher wurde angenommen, dass die Verbreitung dieser Arten auf die westliche Ostsee bis Höhe der Insel Fehmarn beschränkt ist (SCHORIES et al. 2009). Es gab bis 2009 keinerlei Nachweise für ein Vorkommen dieser Algen östlich der Kieler Bucht.

3.1 Bryopsis plumosa

Diese Art wurde erstmals im Juni 2016 im Bereich der Molen des Yachthafens „Hohe Düne“ (Gebiet A, Abb. 1) angetroffen. Sie kam auf jeglicher Form von Hartsubstraten vor und besiedelte sowohl die Stein- als auch die Holzmolen des Außenbereichs der Südmole. Darüber hinaus wurde sie auch auf Muschelschalen und auf kleineren Steinen im Flachwasserbereich östlich der Südmole bis zu 1,5 m Tiefe angetroffen. Seit der ersten Beobachtung breitet sich der Bestand langsam nach Osten aus. Im Bereich des Breitlings wurden im September 2017 einzelne kleine Exemplare auf Seepocken in ca. 2,0 m Tiefe vorgefunden.

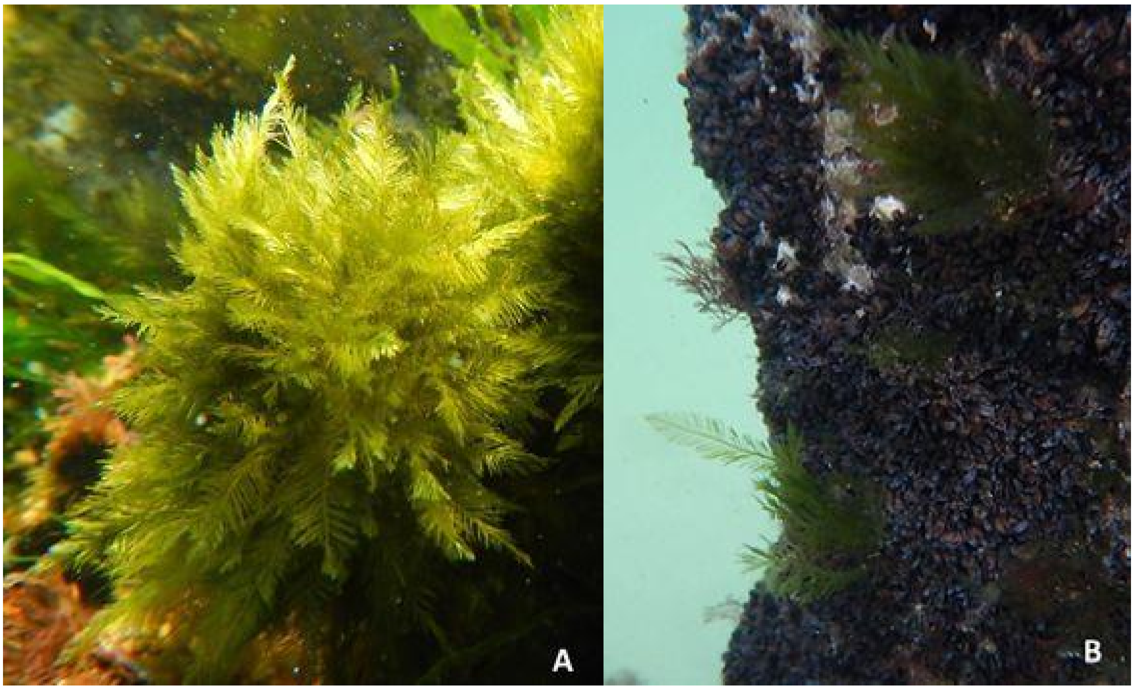

Abb. 2 *Bryopsis plumosa* an der Südmole vom Yachthafen „Hohe Düne“: **A** – auf Stein und **B** – auf einer Holzbuhne.

3.2 Dasya baillouviana

Diese Art wurde im September 2017 zunächst als Driftmaterial und im Oktober 2017 auch in Form einzelner festsitzender Individuen in 0,5 – 2,5 m Tiefe östlich der Südmole (Gebiet A, Abb. 1) angetroffen. In der westlichen Ostsee gilt die Art bereits seit 2002 als etabliert (SCHORIES & SELIG 2006), das Salinitätsoptimum für vegetatives Wachstum wird von LACKSCHEWITZ et al. (2014) mit 15 – 25 angegeben. Da die Salinität am neuen Standort lediglich bei 12 – 18 liegt, könnte die Art hier ihre östliche Verbreitungsgrenze erreicht haben.

Abb. 3 *Dasya baillouviana* bei Südmole des Yachthafens „Hohe Düne“: festwachsende (**A**) und freitreibende Individuen (**B**).

3.3 Gracilaria vermiculophylla

Abb. 4 *Gracilaria vermiculophylla* bei Pagenwerder (Breitling)

Im Zuge der Videountersuchungen im Juli 2017 wurde ein ausgedehnter Bestand dieser Art bei der Insel Pagenwerder (Gebiet B, Abb. 1) angetroffen. Der Bestand erstreckt sich entlang der ganzen östlichen Seite der Insel in einem Tiefenbereich von 1,3 – 2,3 m Tiefe. An der Schutzsteinmole der Insel ist die Alge bereits ab 0,5 m Tiefe in einzelnen Exemplaren zu finden; größere Matten von 1,0 – 2,0 m Durchmesser treten aber erst ab ca. 1,5 m Tiefe auf.

Der Bestand östlich Pagenwerder ist bislang noch auffallend isoliert. Weder im Bereich des nahegelegenen Schnatermanns (Abb. 1C) noch im Bereich Hohe Düne konnten bislang Individuen nachgewiesen werden. Der Fund von *G. vermiculophylla* ist der erste Nachweis dieser Art östlich der Insel Fehmarn. Die Art ist nach WEINBERGER (2006) gut an niedrige Salinitäten angepasst und es kann erwartet werden, dass sie sich zumindest bis Rügen weiter ausbreiten wir.

Aufgrund der Ausdehnung des Bestandes bei Pagenwerder und unter Berücksichtigung des im Breitling vorliegenden Salinitätsregimes muss *G. vermiculophylla* als im Gebiet etabliert betrachtet werden.

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