Attractions around 6th ICDRA 2022
Quedlinburg, Germany
The 6th ICDRA 2022 is soon going to be held at IPK, Gatersleben, Germany. The closest town where most of the accommodation facilities are, Quedlinburg, is an attraction worth a visit and a stay. Quedlinburg is known for its old architecture and also for the castle which is a UNESCO world heritage site. The pictures on the cover depict a view of the town from the castle (left) and the church inside the castle (right). We wish that you enjoy the conference as well as the surroundings during your upcoming visit to Germany. Photos by Dr. K. Sowjanya Sree, Central University of Kerala, India.

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Upcoming Article Alert for the next issue of DF: "Overview on active Duckweed applications' development" by Tsipi Shoham.

Disclaimer: Articles in the Duckweed Forum are published in the form sent in by the authors, except for some minor language editing. The authors are responsible and are liable for any legal issues concerning plagiarism and/or use of copyrighted material in any form.
The 4th International Steering Committee on Duckweed Research and Applications Members

- **Chair:** Prof. Eric Lam, Rutgers, The state University of NJ, New Brunswick, USA; ericL89@hotmail.com
- **PD Dr. Klaus-J. Appenroth**, Friedrich Schiller University of Jena, Germany; Klaus.Appenroth@uni-jena.de
- **Dr. K. Sowjanya Sree**, Central University of Kerala, Periye, India; ksowsree9@cukerala.ac.in
- **Dr. Yubin Ma**, Ocean University of China, Qingdao, China; mayubin@ouc.edu.cn
- **Dr. Tsipi Shoham**, GreenOnyx Ltd., Tel Aviv, Israel; tsipi@greenonyx.biz

April 29th, 2022

Dear readers of our Duckweed Forum,

Greetings and welcome to the issue of our Newsletter in which we herald the next International Conference on Duckweed Research and Applications (ICDRA), and publish its preliminary program. This year, the ICDRA will be held in Gatersleben, Germany, and it will be the sixth time for which duckweed researchers and application specialists from around the world will gather in one place and spend several days exchanging ideas and results from their work. During this meeting, which is normally held once every two years, the results of the election for members of the next Steering Committee will be announced. In addition, the site for the next ICDRA will be voted on by the participants. In this issue, we have one entry to apply for hosting the 7th ICDRA in Bangkok, Thailand. We have not received additional applications before the publication of this Duckweed Forum issue but new entry is still possible, so please do contact the current steering committee members if you desire to bid for hosting this event in two years’ time.

In addition to applying for hosting the 7th ICDRA, researchers from Thailand are also involved with a team of researchers from Japan to build a duckweed holobiont research consortium based in Thailand. The description of the interdisciplinary research thrust areas for this consortium is very comprehensive and should present many opportunities for synergy between basic and applied research. I encourage all our readers to check it out in this issue of the DF.

For this issue, one of our committee members, Klaus Appenroth, has curated 21 Reviews and Review-like publications related to duckweeds. He made this contribution in addition to his usual curation of duckweed-related publications since the last Duckweed Forum issue. Thanks to Klaus for his diligent contribution to this Newsletter!

Finally, our Spotlight section this time is a piece on young students from Israel who has won a contest to come up with a viable solution for a target of societal importance. Their project on deploying *Lemna minor* as an economical source of nutrition for rural communities in Kenya is a very inspiring read. I hope all of our readers will enjoy it as well to follow these young students’ journey of discovery that helped them to learn intimately about sustainable agriculture.

Looking forward to seeing most of you at Gatersleben.

Sincerely,

*Eric Lam*  
Chair, ISCDRA
6th ICDRA- 2022: Preliminary Program

Sunday May 29

16:00 Registration, poster hanging
18:00 Opening address
18:30 Plenary talk Eric Lam, Rutgers U, NJ, USA
  Duckweed hibernation: unravelling the molecular basis of the unique induction switch
  in Spirodela polyrhiza
19:30 Welcome reception

Monday May 30

8:30 Invited talk Rob Martienssen, Cold Spring Harbor Laboratory, NY, USA
  Genomic and epigenomic consequences of crown growth habit in the lamiaceae

9:00 Invited talk Shuqing Xu, Muenster U, DE
  The Giant duckweed, a model system for studying plant evolution in a multitrophic community

9:30 Laura Morello, IBBA CNR, Milano, IT
  TRF fingerprinting unveiled interspecific hybridization in the genus Lemna

9:50 tba
10:10 tba
10:30 Coffee break

Differentiation & stress

11:00 Invited talk K. Sowjanya Sree, Kerala Central U, IN
  Nutrient stress on duckweeds

11:30 Invited talk Alexandra Chavez, Muenster U, DE
  Non-genetic inheritance alters stress resistance across generations in the Giant duckweed

12:00 Gnaat Gillor, BGU Navev, IL
  All in one: the microbiome of a rootless plant

12:20 Minako Isoda, Kyoto U, JP
  Analysis on floral induction of Wolffia liliacea

12:40 Alexander Ware, Nottingham U, UK
  To root or not to root: evolution of rootlessness in duckweed

13:00 Lunch
### Monday May 30

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tr>
<td>12:00</td>
<td><strong>Ecology, microbiome &amp; stress</strong></td>
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<tr>
<td>14:00</td>
<td>Invited talk Marcel Jansen, Cork U, IE</td>
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<tr>
<td></td>
<td>Lemnaceae as a key player in the circular economy; examples of wastewater valorization in Ireland</td>
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<tr>
<td>14:30</td>
<td>Invited talk Quinten Bafort, Ghent U, BE</td>
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<td></td>
<td>Stress tolerance in tetraploid <em>Spirodela polyrhiza</em></td>
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<td>15:00</td>
<td>Simona Paolacci, UCC/BMRS, West Cork, IE</td>
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<td>Wastewater valorization in an integrated multitrophic aquaculture system; assessing nutrient removal and biomass production by duckweeds</td>
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<td>15:20</td>
<td>Masaaki Morikawa, Hokkaido U, JP</td>
</tr>
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<td></td>
<td>Dual function of environmental bacteria that enable duckweed prosperity</td>
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<td>16:00</td>
<td>tba</td>
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<tr>
<td>16:00</td>
<td><strong>Coffee, fruits &amp; cake</strong></td>
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<tr>
<td>16:30</td>
<td><strong>Poster presentation &amp; viewing I</strong></td>
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<th>Time</th>
<th>Session</th>
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<tr>
<td>18:30</td>
<td>Public lecture Klaus-J. Appenroth, FSU Jena, DE</td>
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<tr>
<td></td>
<td>Eine neue Kulturpflanze mit großem Potential für Ernährung, Wasserreinigung und Energie</td>
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<tr>
<td>19:30</td>
<td><strong>General Assembly</strong></td>
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<tr>
<td></td>
<td>News from Steering Committee; Suggestions for 7thICDRA, Round-table discussion: &quot;Duckweed futures&quot;, Joint projects etc.</td>
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<td>20:30</td>
<td><strong>BBQ &amp; beer</strong></td>
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### Tuesday May 31

<table>
<thead>
<tr>
<th>Time</th>
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<tbody>
<tr>
<td>08:30</td>
<td><strong>Ecology, microbiome &amp; stress</strong></td>
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<tr>
<td>08:30</td>
<td>Invited talk Asaph Aharoni, WIS, Rehovot, IL</td>
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<tr>
<td></td>
<td>The underwater chemical world of duckweed</td>
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<tr>
<td>09:00</td>
<td>Invited talk Tokitaka Oyama, Kyoto U, JP</td>
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<td></td>
<td>Variability of chronobiological characteristics in duckweed</td>
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<tr>
<td>09:30</td>
<td>Cristian Mateo-Elizalde, Cold Spring Harbor Laboratory, NY, USA</td>
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<td>Unraveling genetic mechanisms of sexual reproduction in duckweed</td>
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<tr>
<td>09:50</td>
<td>Moshe T. Halpern, ARO, Volcani Institute, IL</td>
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<tr>
<td></td>
<td>Using rootless duckweed <em>Wolfia globosa</em> as a model to clarify the effect of e[CO2] on NO3 photo-assimilation in C3 plants</td>
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<tr>
<td>10:10</td>
<td>Philippe Juneau, Quebec U, Montreal, CA</td>
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<td>How aminomethylphosphonic acid (AMPA), the main glyphosate metabolite, affects <em>Lemma minor</em> photosynthesis?</td>
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<th>Time</th>
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<tr>
<td>10:30</td>
<td><strong>Coffee break</strong></td>
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Tuesday May 31

Physiology & metabolism II

23  11:00  Invited talk Paul Ziegler, Bayreuth U, DE
The life cycle of Spirodela polyrhiza: a model for aquatic plant overwintering?

24  11:30  Daríleiva do Rosario Freitas, UFV, BR
Different sources of iron modulate responses in the antioxidant system in plants

25  11:50  Olena Kishchenko, Huaiyin Normal U, CN
The dynamics of NO3 and NH4+ uptake in duckweed are coordinated with the expression of major nitrogen assimilation genes

26  12:10  Shogo Ito, Kyoto U, JP
Development of a cryopreservation protocol for a variety of duckweed meristems by the vitrification-cryo-plate method

27  12:30  Manuela Nagel, IPK Gatersleben, DE
Advances in droplet-vitrification and -freezing of Lemna fronds for long-term preservation of duckweeds

13:00  🍽️ Lunch

Genome organization, diversity & imaging

26  14:00  Invited talk Nikolai Borisjuk, Huaiyin Normal U, CN
Organization and evolution of duckweeds ribosomal RNA genes

29  14:30  Invited talk Todd Michael, Salk Institute, La Jolla, CA, USA
Duckweed genome architecture

30  15:00  Phuong Hoang, Dalat U, VN & IPK Gatersleben, DE
Chromosome numbers, genome sizes and evolutionary implication for genome evolution and diversity of Lemnaceae

31  15:20  Anton Stepanenko, Huaiyin Normal U, CN
Biodiversity of Lemnaceae in water reservoirs of Ukraine and China assessed by double chloroplast DNA barcoding

32  15:40  Viktor Olah, Debrecen U, H
Family portrait of a duckweed colony: What can imaging-based phenotyping tell us about stress

16:00  🍃 Coffee, fruits & cake

16:30  Poster presentation & viewing II

18:30  Guided tour in Quedlinburg

20:00  🍽️ Conference dinner (Schlossmühle, Quedlinburg)

https://icdra2022.ipk-gatersleben.de/
# Preliminary Program ICDRA 2022

**6th INTERNATIONAL CONFERENCE ON DUCKWEED RESEARCH AND APPLICATIONS**

29 May to 01 June 2022

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## Wednesday June 01

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>08:30</td>
<td>Invited talk Britt Schumacher, DBFZ GmbH, Leipzig, DE</td>
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<td>Duckweed - Conservation and conversion into biogas</td>
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<tr>
<td>09:00</td>
<td>Invited talk Ingrid van der Meer, WUR, Wageningen, NL</td>
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<td>Water lentils and derived products thereof for human consumption: overview of the current status of NF approval in Europe</td>
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<tr>
<td>09:30</td>
<td>Jurriaan Mes, WUR, Wageningen, NL</td>
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<td></td>
<td>Water lentils protein for human nutrition</td>
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<tr>
<td>09:50</td>
<td>Anton Peterson, Huaiyin Normal U, CN</td>
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<td><em>Lemna turionifera</em> demonstrates good potential as an alternative system for transient expression of recombinant proteins</td>
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<td>10:10</td>
<td>Johannes Demann, Osnbrück U, DE</td>
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<td>Insights into the nutritional value of duckweed as protein feed for broiler chicken</td>
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<td>10:30</td>
<td>Coffee break</td>
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## Large scale cultivation & social aspects

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<tr>
<th>Time</th>
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<tr>
<td>11:00</td>
<td>Invited talk Paul Skillcorn, Skillcorn Technologies, Austin, TX, USA</td>
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<td></td>
<td>Duckweeds, the engine of the New Circular Economy</td>
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<tr>
<td>11:30</td>
<td>Invited talk Tsipi Shoham, GreenOnyx, IL</td>
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<td>Securing fresh nutrition via a breakthrough technology for growing duckweeds</td>
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<td>12:00</td>
<td>Finn Petersen, UAS Osnabrück, DE</td>
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<td>Development and scale-up process from a small duckweed culture to a large in-door vertical farm for duckweed biomass production</td>
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<td>12:20</td>
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<td>12:40</td>
<td>Wisuwat Songnuan, Mahidol U, Bangkok, TH</td>
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<td>Carbon dioxide sequestration potential of two Thai duckweed species, <em>Wolffia globosa</em> and <em>Lemna aequinoctialis</em>, under open-air greenhouse condition</td>
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<tr>
<td>13:30</td>
<td>Best Poster Award (founded by CLF PlantClimatics GmbH) and Closing remarks</td>
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<tr>
<td>14:00</td>
<td>End of conference</td>
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[https://icdra2022.jpk-gatersleben.de/](https://icdra2022.jpk-gatersleben.de/)
## Preliminary Program ICDRA 2022

6th INTERNATIONAL CONFERENCE ON
DUCKWEED RESEARCH AND APPLICATIONS
29 May to 01 June 2022

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<tr>
<th>Monday May 30 16:30</th>
<th>Poster presentation &amp; viewing I</th>
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<tr>
<td>1</td>
<td>Alexej Sonnenfeld</td>
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<td>2</td>
<td>Leone E. Romano</td>
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<td>3</td>
<td>Dylan Jones</td>
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<td>4</td>
<td>Anton Stepanenko</td>
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<td>5</td>
<td>Tram Tran</td>
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<td>6</td>
<td>Kellie E. Smith</td>
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<td>7</td>
<td>Olena Kishchenko</td>
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<td>Olena Kishchenko</td>
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<td>Metha Meetam</td>
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<td>Avital F. Yosef</td>
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<td>11</td>
<td>Ljudmilla Borisjuk</td>
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<td>12</td>
<td>Manuela Nagel</td>
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<tr>
<th>Tuesday May 31 16:30</th>
<th>Poster presentation &amp; viewing II</th>
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<tbody>
<tr>
<td>13</td>
<td>Isabelle van Dyck</td>
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<tr>
<td>14</td>
<td>Martin Höfer</td>
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<td>15</td>
<td>Rachel O'Mahoney</td>
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<td>16</td>
<td>Claire Smith</td>
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<td>17</td>
<td>Adelaide Iannelli</td>
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<td>18</td>
<td>Timo Stadtlander</td>
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<td>19</td>
<td>Martin Schäfer</td>
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<td>20</td>
<td>Fernanda V. da Silva Cruz</td>
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<td>21</td>
<td>Sajjad Kamal Shuvro</td>
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<td>22</td>
<td>Johan A. Pasos-Panqueva</td>
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<td>23</td>
<td>Pimsiri Danphitsanuparn</td>
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<td>24</td>
<td>Linda Klamann</td>
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<tr>
<td>25</td>
<td>Jannis von Salzen</td>
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<tr>
<td>26</td>
<td>Reindert Devlamynck</td>
</tr>
<tr>
<td>27</td>
<td>Hassana Ghanem</td>
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[https://icdra2022.ipk-gatersleben.de/](https://icdra2022.ipk-gatersleben.de/)
Duckweeds are commonly found in wind-sheltered or slow-moving freshwater reservoirs such as canals, ditches, marshes, ponds, and swamps around Thailand. *Lemna aequinoctialis* is one of the most predominant species, while *Spirodela polyrhiza*, *Landoltia punctata*, and *Wolffia globosa* are frequently found in more selective water habitats (Fig. 1). *Wolffia globosa*, locally called ‘Phum’ or ‘Khai-nam’ (meaning ‘water egg’ in Thai) or ‘Khai-phum’, has been consumed for centuries as an ingredient in Thai traditional cuisine such as curry, spicy salad, and stir-fried dishes, particularly in the Northern and Northeastern regions of Thailand. Other duckweeds have been normally used as high protein poultry-feeds to increase egg yolk color by local farmers. Moreover, duckweeds, especially *Lemna* and *Spirodela*, are employed to treat wastewater from municipalities and industrial sources.

**Fig. 1** Combination of duckweeds growing in small waterways around Kasetsart University. The panel on the right shows duckweed clones, *Spirodela polyrhiza*, *Landoltia punctata*, *Lemna aequinoctialis*, and *Wolffia globosa* (from top to bottom), as cultures grown in the lab.
With tropical climate and richness of biodiversity, Thailand is an attractive country to explore duckweed diversity and their exquisitely beneficial biomass. Due to their fast growth and rapid reproduction, the use of natural duckweed biomass or cultivation of duckweeds to harvest high nutrient biomass used for human food and animal feed is possible. However, duckweeds have not yet been extensively utilized as much as their great potential. Their diversity and biomass components have not yet been fully utilized. Thai farmers still favor commercial animal feed even though they realize that duckweeds are rich source of nutrition. The consumption of Khai-nam in traditional food by many Thai ethnic groups has substantially decreased in popularity. The under-utilization of duckweeds is largely attributed to the lack of scientific evidence and support from academic and government sectors.

Towards the Bio-Circular-Green (BCG)-based social and economic policies recently launched by the Thai government, duckweeds are regarded as a key national bioresource that is ideally aligned with the BCG goals. The joint research initiatives between Thailand and Japan have been established since 2021 under a multi-disciplinary project entitled “Development of the Duckweed Holobiont Resource Values towards Thailand BCG Economy” implemented under the “Science and Technology Research Partnership for Sustainable Development (SATREPS)” of Kasetsart University, Thailand (Fig. 2). The project is supported by Japan International Cooperation Agency (JICA) in collaboration with Japan Science and Technology Agency (JST). The ¥300M project has been awarded to Prof. Masaaki Morikawa, Hokkaido University, and Prof. Arinthip Thamchaipenet, Kasetsart University, in collaboration with other Thai and Japanese partners (Mahidol University, Khon Kaen University, Chulalongkorn University, Nakhon Pathom Rajabhat University, BIOTEC, NANOTEC, NBT, NSTDA, Osaka University, Kyoto University, Tohoku University, University of Yamanashi, and NIES) to support equipment, bilateral exchange, conference, and other facilities for 5 years (2021-2026) under the sub-topics as follows:

**Group 1** Duckweed Holobiont Resource & Research Center (DHbRC)
*Group 2* Biodiversity of duckweeds and associated microbes
*Group 3-1* Duckweed-microbe interaction: biomass, nutrition, stress
*Group 3-2* Duckweed active substances
*Group 4-1* Biofuel from duckweed: methane
*Group 4-2* Bioplastic from duckweed
*Group 4-3* Duckweed for animal feed: laying hen
*Group 4-4* Duckweed for functional food
*Group 5* Duckweed for wastewater treatment
*Group 6* Social implementation

Under the project, the duckweed specimens in Thailand will be collected and investigated for their biodiversity, ecological and physiological interactions, genomics, and genetic makeup. Since duckweeds are known to closely associate with microbes as ‘holobiont’ in nature and potentially benefit from the associations, the research will employ multi-omics technology to examine the genome, microbiome, and transcriptome profiles that underlie the duckweed-microbe interactions. The basic knowledge and unlocked secrets gained from the studies will lead to efficient and novel utilization of the duckweed-microbe bioresources to enhance biomass production, protein/starch composition, nutrition, active compounds, and stress tolerance of the duckweeds. The applications of duckweed holobionts may include production of high-value active substances, high-nutrition chicken feed and functional foods. Furthermore, duckweeds will be applied for treatment of wastewater from animal farms and food industries to improve water quality and the biomass thus produced will be circularly used for biofuel and bioplastic production. Under this research consortium, the Duckweed Holobiont Resource & Research Center (DHbRC) will be established at Faculty of Science, Kasetsart University, to host duckweed and associated microbe collections, a pilot duckweed indoor factory, and various research facilities. The project also aims to contribute knowledge and know-how to local farmers and SMEs in Thailand and communities around the world who are interested to utilize duckweed. Our mission conforms with the
Thailand BCG model and the UN Sustainable Development Goals (SDGs) and is geared toward the transformation from value-based to innovation-driven and sustainable economy.

Fig. 2 Research plan for the “Development of the Duckweed Holobiont Resource Values towards Thailand BCG Economy” project supported under SATREPS, JICA (2021-2026).
Twenty-one Reviews and Review-like papers about Lemnaceae: an update

Klaus-J. Appenroth
Matthias Schleiden Institute – Plant Physiology, University of Jena, Jena, Germany

Reviews help newcomers to get quickly informed about a topic. In the Duckweed Forum 4(4), 305-308 (2016) we compiled 20 reviews or review-like publications. Since that time, duckweeds became much more popular as a model system for research and applications (Acosta et al., 2021). The following 21 reviews or review-like papers were compiled as an update for the DF reader to cover the time since our former collection of reviews was published.

#1 Return of the Lemnaceae: duckweed as a model plant system in the genomics and postgenomics era
The Plant Cell 33: 3207-3234 (2021)

#2 Duckweed (Lemnaceae) for potentially nutritious human food: A review
Xu, J.; Shen, Y.; Zheng, Y.; Smith, G.; Sun, X.S.; Wang, D.; Zhao, Y.; Zhang, W.; Li, Y.

#3 Growth and nutritional quality of Lemnaceae viewed comparatively in an ecological and evolutionary context
Plants 11: 145, 2021. DOI 0.3390/plants11020145

#4 Duckweeds: their utilization, metabolites and cultivation
Baek, G.Y.; Saeed, M.; Choi, H.-K.
Applied Biological Chemistry 64: 73. DOI 10.1186/s13765-021-00644-z

#5 Accumulation of starch in duckweeds (Lemnaceae), potential energy plants
Appenroth, K.J.; Ziegler, P.; Sree, K.S.
#6 Wolffia, a minimalist plant and synthetic biology chassis
Lam, E.; T.P. Michael

#7 Lemnaceae and Orontiaceae are phylogenetically and morphologically distinct from Araceae
Tippery, N.P.; Les, D.H.; Appenroth, K.J.; Sree, K.S.; Crawford, D.J.; Bog, M.
Plants 10: 2639 (2021)

#8 Progress in thermochemical conversion of duckweed and upgrading of the bio-oil: A critical review
Djandja, O.S.; Yin, L.X.; Wang, Z.C.; Guo, Y.; Zhang, X.X.; Duan, P.G.
Science of the Total Environment 769: 144660 (2021)

#9 Research and application in duckweeds: A review

#10 Research progress of a potential bioreactor: duckweed
Biomolecules 11: 93 (2021)

#11 Multifaceted roles of duckweed in aquatic phytoremediation and bioproducts synthesis
Liu, Y.; Xu, H.; Yu, C.J.; Zhou, G.K.

#12 Key to the determination of taxa of Lemnaceae: an update
Bog, M.; Appenroth, K.J.; Sree, K.S.
Nordic Journal of Botany 38: e02658 (2020)

#13 Duckweed (Lemnaceae): Its molecular taxonomy
Bog, M.; Appenroth, K.J.; Sree, K.S.

#14 Application of common duckweed (Lemna minor) in phytoremediation of chemicals in the environment: State and future perspective
Ekperusi, A.O.; Sikoki, F.D.; Nwachukwu, E.O.
#15 Use of duckweed (*Lemna* L.) in sustainable Livestock production and Aquaculture – A Review
Sonta, M.; Rekiel, A.; Batorska. M.

#16 Duckweed biomarkers for identifying toxic water contaminants?
Ziegler, P.; Sree, K.S.; Appenroth, K.J.
Environmental Science and Pollution Research 26: 14797-14822 (2019)

#17 Using agro-industrial wastes for the cultivation of microalgae and duckweeds: Contamination risks and biomass safety concerns
Markou, G.; Wang, L.; Ye, J.F.; Unc, A.
Biotechnology Advances 36: 1238-1254 (2018)

#18 Genomes and transcriptomes of duckweeds

#19 Monitoring circadian rhythms of individual cells in plants
Muranaka, T.; Oyama, T.

#20 Nutritional value of duckweeds (*Lemnaceae*) as human food
Appenroth, K.J.; Sree, K.S.; Bohm, V.; Hammann, S.; Vetter, W.; Leiterer, M.; Jahreis, G.

#21 Nutritional value of the duckweed species of the genus *Wolffia* (*Lemnaceae*) as human food
Duckweed special issue in MDPI Plants

Deadline for manuscript submission extended: 10 October, 2022

Guest Editors:

Dr. Viktor Olah
University of Debrecen, Hungary

Dr. Klaus-J. Appenroth
University of Jena, Germany

Dr. K. Sowjanya Sree
Central University of Kerala, India

Duckweed: Research Meets Applications

Special Issue Information

Duckweeds are the smallest angiosperms belonging to the family Lemnaceae, normally occupying the surface of lentic habitats. As minute and simple organisms, they seem to fascinate generations of scientists with the many secrets they possess. Besides their basic role in aquatic ecosystems, they offer a suitable model for ecologists, physiologists, geneticists, and researchers of many other fields.

The aim of this Special issue is to provide a comprehensive update of the current progress in duckweed research and applications. Contributions in forms of both original research papers and reviews from a broad scope of disciplines related to duckweed research and applications (e.g., morphology, taxonomy, and ecology including ecological interactions, ecotoxicology, environmental monitoring and remediation, physiology, biochemistry, genetics, omics, biotechnology, biomass production and its uses, etc.) are welcome.
Application to host ICDRA-2024: Bangkok, Thailand

The Duckweed Holobiont Resource & Research Center (DHbRC), Kasetsart University, Thailand, and the Science and Technology Research Partnership for Sustainable Development (SATREPS) program, Japan, would like to host

**The 7th ICDRA, 2024, at Bangkok, Thailand**

**HOST:** Kasetsart University, Thailand

**CO-HOST:** Science and Technology Research Partnership for Sustainable Development (SATREPS), JICA, Japan

Kasetsart University is the first and the largest agricultural university in Thailand (Kaset = ‘agriculture’ in Thai). The main campus is in Bangkhen, north of Bangkok with several other campuses throughout Thailand. The establishment of Kasetsart University was part of the evolution of agricultural education in the country. The research quality of Kasetsart University is affirmed by the prominent position of 53rd in Agriculture & Forestry ranked by the QS World University Rankings 2022. The university commits to teaching, research, and innovation leading to the sustainable development of society based on the knowledge of the land. In the year 2023, Kasetsart University will celebrate its long and successful 80th year since its establishment.

The Duckweed Holobiont Resource & Research Center (DHbRC) is being established under the 5-year (2021-2026) joint research initiative between Kasetsart University, Thailand, and SATREPS, Japan. More than 40 Thai and Japanese researchers from various institutions and disciplines are working together to explore the diversity of duckweeds and their associated microbial holobionts for basic knowledge as well as applications toward the Thai government’s model of Bio-Circular-Green (BCG) economy and sustainable development. Ongoing research areas at DHbRC include biodiversity of duckweeds and associated microbes, duckweed-microbe interactions, bioactive substances from duckweed, biofuel, bioplastic, animal feed, functional food, wastewater treatment, and social implementation of various duckweed applications.
CONFERECE VENUE: Bangkok, Thailand

Bangkok was voted the ‘Best City’ for tourists in the DestinAsian Readers’ Choice Awards 2022. There is no secret that Bangkok, the capital city of Thailand and home to more than 10 million multi-cultural residents, boasts a wide range of exciting activities, attractions, and some of the world’s best cuisines. The Bangkok metropolitan area is safe, affordable, and English-friendly with many hotels and public transportations to offer. Bangkok is situated at the heart of Southeast Asia and served by two international airports that connect to major cities around the world. The mass transit system, a.k.a. the Airport Rail Link, will conveniently shuttle you from the airports to the conference venue within one hour. In addition, other tourist destinations that include relaxing beaches, natural rainforests, and historical cities are located just a few hours away from Bangkok waiting for you to enjoy.

The conference will be hosted at Kasetsart University, Bangken campus, which is adjacent to two major Bangkok skytrain lines and has many affordable accommodations for the participants to choose from. Depending on the number of participants, the conference may also be hosted at a suitable hotel or convention hall nearby.

TRANSPORTATION:

Suvarnabhumi International Airport (BKK), one-hour by car or Airport Rail Link
Don Mueang International Airport (DMK), 30-min by car or Airport Rail Link

CONFERENCE HIGHLIGHTS:

When one comes to Thailand, expect to see a lot of duckweeds!! Not to be missed is Khai-nam (*Wolffia globosa*), our traditional Thai food that has recently made its way back to popularity in modern cuisines and healthy-eating lifestyle. Other conference highlights are as follows:

- A special joint-session with the Thai-Japan DHbRC/SATREPS consortium research conference.
- Tour of the Duckweed Holobiont Resource & Research Center (DHbRC), Kasetsart University.
- Excursion trip for nature & cultural heritage sightseeing, including visits at local Khai-nam (*Wolffia globosa*) cultivation farms.
- Taste of duckweed' event: Try out traditional and modern Khai-nam food dishes created by renown Thai chefs, plus a cooking station open for conference participants to show off their own duckweed cooking skills.

- Industrial-Academic partnership: A special event dedicated to meetings between the participants and Thai and global industrial leaders in Agritech & Food/Beverage industry who are eager to partner for collaborations in various duckweed applications such as food, feed, cosmetics, medicine, and environmental clean-up.

FINANCIAL ASSISTANCE:
The SATREPS program will provide partial assistantship to a limited number of conference participants who are in need.

CONTACT:

Prof. Arinthip Thamchaipenet  
Department of Genetics, Faculty of Science, Kasetsart University  
Bangkok, Thailand  
Email arinthip.t@ku.ac.th

Asst. Prof. Metha Meetam  
Department of Biology, Faculty of Science, Mahidol University  
Bangkok, Thailand  
Email metha.mee@mahidol.ac.th
Students Spotlight: Students from Ein Shemer Ecological Greenhouse, Israel

The water lentils GREEN CARPET project wins the Israeli competition for sustainable development (ISDG) contest

The Green Carpet project, led by a team of students from the Ein-Shemer Ecological Greenhouse, for the development of a system to grow water lentils in rural areas in Kenya, won first place in the Israeli competition for sustainable development (ISDG). The 10th and 11th grade students from the Mevo’ot Eron and Gvanim schools in the Menashe Regional Council are going to represent Israel at the FAO (The Food and Agriculture Organization of the United Nations) in Rome in June 2022. The agricultural farm and the two schools are part of the Ministry for rural education and participate in it’s unique educational program for advanced agriculture, which combines farming, science, technology and environment, and the Menashe regional council program for global environmental challenges.

The contest was organized by the Israeli Foreign Ministry, the Israeli Education Ministry and the JNF (Jewish National Fund), a non-profit organization for national land and forest development in Israel, and included 70 schools from throughout the country.

Naama Aizen, 16 years old: “The main idea of the contest is to raise awareness of the UN sustainable development goals. Each team was required to combine three different elements: the goal they wished to tackle, a developing country as the geographical target for implementation, and the proposed solution - an idea conceived by the team members. We chose the goal of Zero Hunger (#2) in target country Kenya, and our development idea is based on water lentils. That is why we called our project LiberEat, because we wanted to develop a solution of nutrition security for the rural populations in developing countries.”

The students’ work process began in three parallel areas: studying the UN SDG’s, mapping the ideas implemented by the Greenhouse as a basis for the project, and meetings with a range of experts, including Ambassador Oded Joseph, Dr. Sinaia Netanyahu, European Centre for Environment and Health, WHO European Regional Office, Dr. Mark Polikovsky of the Weizmann Institute, who studies duckweed, Itai Ivri, an expert on seaweed cultivation, Oded Rahav, entrepreneur and environmental activist Zvi Herman, International Agro Development Advisor, Greenhouse founder Avital Geva, Michal Dolev Hashimshony, CEO of Engineers Without Borders - Israel, Sigal Lutzky, Scientific director of the Ecological Greenhouse, Noam Geva, the Greenhouse Director and Noga Astrachan, nutritionist at Ambar feed mills.

Ella Nawy, 17 years old: “We concluded that the most suitable organism for this purpose is the duckweed Lemna minor for a number of reasons: first of all, according to an article by the FAQ, Lemna minor is very protein rich (can reach 40% protein in dry weight). In addition, it is one of the fastest growing plants in the world. In optimal conditions, Lemna minor plants can double its biomass within 16-48 hours. Third, the lentil grows in stagnant water so that its cultivation does not require electricity. It also grows both in fresh and brackish water so that it does not require drinking water. Fourth, it has very mild taste, which makes it easily integrated in different foods and can be consumed in a variety of ways. And lastly, duckweed is widespread worldwide so that numerous countries can grow it without introducing invasive species.”
Ultimately, the students chose Kenya because as a target country for cooperation it meets the requirements for communication, the existence of a local species of duckweed, and the need for new food sources.

Yuval Gofer, 15 years old: "In the process of thinking about the problem, we contacted the Israeli embassy in Kenya, which connected us to the CESP organization, local entrepreneurs. We talked to the heads of the organization a number of times and learned from them about the needs of the rural areas in Kenya. We understood that in order to manufacture food for a large population in those areas there needs to be a solution that is not based on expensive electricity or drinking water. Added to that was our requirement not to introduce invasive species."

In the next stage, the students planned the solution: a system to grow *Lemna minor* using minimal resources (electricity, fertilizer, drinking water) on the basis of the “zero waste” principle, with household food leftovers serving to manufacture liquid fertilizer for growing the lentil. The main product of the system, the *Lemna minor* plant, can be used in two main ways: to nourish livestock (mainly chickens), or after the required processing as “protein powder” that can be added to food. The additional byproduct of the system, created in the process of manufacturing the liquid fertilizer, is biogas. Accordingly, the students called the system PBF (protein, biogas, fertilizer).

Tal Lerner, 16 years old: "Under the supervision of Etay Ivri we planned and built a two-part system: an anaerobic fermenter comprised of a barrel in which organic matter breaks down into organic fertilizer, which is used to fertilize the pool and the growing pool. Experiments we did showed that a square meter of the duckweed pool can produce a kilogram wet weight of plant material, and after straining in a fishing net and dried under a fly net in the sun, this can produce 42 g dry weight of plant matter ready for use. The system uses waste from the village where it will be placed to fertilize the duckweed after anaerobic fermentation, and thereby to produce more protein."

Naama Aizen: "Throughout the project our team encountered different challenges in implementing and building the project. The first challenge was to find an effective way to build the growing pool. We examined two different ways: a clay-lined pool and a polyethylene-lined pool. Clay allows sealing the floor and preventing seepage of water into the soil. The advantage of this method is that you can find clay in nearby water sources and thereby build the pool free of cost and without using non-degradable plastic. The disadvantage is that clay requires maintenance, without which it might crack. Conversely, polyethylene is very easy to maintain, but is made of plastic and costs money. Another challenge is to manufacture at a high pace. To that end we do experiments to develop a best growth protocol."
The students are guided by Greenhouse instructors: Noam Geva, Oded Rahav, Itai Ivry, and Dr. Mark Polikovsky.

Noam Geva, the director of the Greenhouse and member of the group’s mentoring team: “The subjects of sustainable development and global food challenge are the central issues we must confront as educators. This is the challenge of our generation and of course for the students – the future generation. The research and development process the students engage in here exposed them to the challenges of the environment, agriculture and health, and to global social and cultural aspects. As far as I’m concerned, the goal is to pique their curiosity and enthusiasm, and educate them about cooperation and environmental responsibility. The project is supported by the Ministry for Rural Education, the Menashe Regional Council, the Ecological Greenhouse Association, Granot factories and the Menashe Economic Corporation.”

Dr. Mark Polikovsky: “As a plant scientist I chose to focus my research on Lemna minor, because I realized that water plants in general and the Lemna minor species in particular can be an important source of nutrition and fulfill the growing demand for protein. All of the forecasts are that in the near future the combination of alternative sources of protein such as water lentils will become a substantial part of our diet. In addition to the need to increase the supply of protein sources, there is an increasing appreciation that we must not ignore the environmental processes and degradation created by current sources of protein. Most of the protein we consume comes from land-plant and animal agriculture, which as we know causes severe environmental damage and impacts climate change. We understand that our choice of food does not consist merely of taste and price but there is also a close relationship between human health and environmental health. No doubt that understanding must impact our choice of the foods we consume. This kind of understanding always begins with education. That is why I am very moved to be part of a project that transmits the relevant knowledge for understanding the processes of growing and the composition of water lentils as part of an educational project, while creating an actual solution for manufacturing a source of protein in a creative way.”

The students note the impact their participation in the program had on them:

Tal Lerner: “The contest enabled me to rediscover the world. The encounter with people from different countries and cultures like India and Kenya greatly enriched my knowledge. Talking to people taught me that there are different ways to approach a challenge, especially the food challenge.”

Yuval Gofer: “Thanks to the contest I learned a lot about how to deal with ambassadors and CEOs and in general how to make cooperation work. I learned about a lot of important subjects and the many challenges the world must deal with. I also learned a lot about the amazing plant called Lemna minor and realized that I can make a real change in the world for hundreds of teenagers my age. I met, befriended and made contacts with many scientists and professionals who can help me in the future.”

Ella Nawy: “The project opened my eyes to the challenges facing numerous people in the world and especially the hunger that afflicts more than one tenth of the earth’s population. It disturbs me that children my age and even younger are not properly nourished. The project forced me to leave my comfort zone, that was expressed by ignorance, and gave me an opportunity to make the incredible idea of creating change on a global level into a reality. I met a group and by working and thinking together we advanced an idea that proves that even at a young age and from a small place in a small country you can take small steps towards a better world. As far as I’m concerned there should be no hunger in the world.”

Naama Aizen: “Participation in the project and in the SDG contest contributed to me in numerous ways. Primarily thanks to the project I got to know scientists and researchers from all over the world, to have contact with them and to share knowledge with them about my project, as well as learning from them about projects they developed and in which they participated as well. I learned how to interact seriously and make contact with people in different countries over Zoom, email and letters, and I got the opportunity to present my team’s work to CEOs, members of organizations and professors from Israel. Participation in the project gave me the desire and
courage to be part of something bigger than myself and my close circle and enabled me to think about ways and solutions for challenges faced by many people in the world.”

Top left picture: From the top left to bottom right: the students Tal Lerner, Ella Nawy, and Naama Aizen, the instructors Noam Geva, the Greenhouse director, and Oded Rahav, and the student Yuval Gofer

Top right picture: Experimental cultivation modules for growing Water Lentils

Bottom left and middle picture: The process of building the project pond for growing Water Lentil in the rural area in Kenya. The pond was designed and built by the students using clay to seal and defined the cultivation area.

Bottom right picture: Naama Aizen studying Lemna plants that grew in the experimental pools
Genome-wide identification of bacterial colonization and fitness determinants on the floating macrophyte, duckweed

Ishizawa, H; Kuroda, M; Inoue, D; Ike, M. (2022) Communication Biology 1: 68

Genome-wide transposon sequencing reveals the genes driving bacterial colonization of duckweed. These genes indicate a trade-off between the colonization and proliferation abilities on the host plant. Bacterial communities associated with aquatic macrophytes largely influence host primary production and nutrient cycling in freshwater environments; however, little is known about how specific bacteria migrate to and proliferate at this unique habitat. Here, we separately identified bacterial genes involved in the initial colonization and overall fitness on plant surface, using the genome-wide transposon sequencing (Tn-seq) of *Aquitalea magnusonii* H3, a plant growth-promoting bacterium of the floating macrophyte, duckweed. Functional annotation of identified genes indicated that initial colonization efficiency might be simply explained by motility and cell surface structure, while overall fitness was associated with diverse metabolic and regulatory functions. Genes involved in lipopolysaccharides and type-IV pili biosynthesis showed different contributions to colonization and fitness, reflecting their metabolic cost and profound roles in host association. These results provide a comprehensive genetic perspective on aquatic-plant-bacterial interactions, and highlight the potential trade-off between bacterial colonization and proliferation abilities on plant surface.

Characterization of various subunit combinations of ADP-glucose pyrophosphorylase in Duckweed (*Landoltia punctata*)

Wang, M; Dai, Y; Li, X; Ma, X; Li, C; Tao, X. (2022) BioMed Research International No. 5455593. DOI:10.1155/2022/5455593

*Landoltia punctata* can be used as renewable and sustainable biofuel feedstock because it can quickly accumulate high starch levels. ADP-glucose pyrophosphorylase (AGPase) catalyzes the first committed step during starch biosynthesis in higher plants. The heterotetrameric structure of plant AGPases comprises pairs of large subunits (LSs) and small subunits (SSs). Although several studies have reported on the high starch accumulation capacity of duckweed, no study has explored the underlying molecular accumulation mechanisms and their linkage with AGPase. Therefore, this study focused on characterizing the roles of different *L. punctata* AGPases. Expression patterns of LpAGPs were determined through comparative transcriptome analyses, followed by coexpressing their coding sequences in *Escherichia coli*, *Saccharomyces cerevisiae*, *Arabidopsis thaliana*, and *Nicotiana tabacum*. Comparative transcriptome analyses showed that there are five AGPase subunits encoding cDNAs in *L. punctata* (LpAGPS1, LpAGPS2, LpAGPL1, LpAGPL2, and LpAGPL3). Nutrient starvation (distilled water treatment) significantly upregulated the expression of LpAGPS1, LpAGPL2, and LpAGPL3. Coexpression of LpAGPSs and LpAGPLs in *E. coli* generated six heterotetramers, but only four (LpAGPS1/LpAGPL3, LpAGPS2/LpAGPL1, LpAGPS2/LpAGPL2, and LpAGPS2/LpAGPL3) exhibited AGPase activities and displayed a brownish coloration upon exposure to iodine staining. Yeast two-hybrid and bimolecular fluorescence complementation (BIFC) assays validated the interactions between LpAGPS1/LpAGPL2, LpAGPS1/LpAGPL3, LpAGPS2/LpAGPL1, LpAGPS2/LpAGPL2, and LpAGPS2/LpAGPL3. All the five LpAGPs were fusion-expressed with hGFP in *Arabidopsis* protoplasts, and their green fluorescence signals were uniformly localized in the chloroplast, indicating that they are plastid proteins. This study uncovered the cDNA sequences, structures, subunit interactions, expression patterns, and subcellular localization of AGPase. Collectively, these findings provide new insights into the molecular mechanism of fast starch accumulation in *L. punctata*. 
Aquaculture/ Agriculture

Comparative evaluation of natural water conditioners for their potential use in freshwater aquaculture


In this study, the use of natural adsorbents, such as zeolite (clinoptilolite), leonardite, and duckweed (*Lemna minor*, L. 1753) was investigated for the regulation of optimum water qualities in freshwater aquaculture. The study was carried out in 3 experiments in triplicate. In the first experiment, aquarium fish feed (35% protein) was used as the ammonia source at 3 different rates (0.2, 0.4, and 0.6 g feed per 500 mL of tap water). In the second experiment, clinoptilolite (C) and leonardite (L) mixture (C:L = 1:2) were added to balance excessive ammonia. In the third experiment, duckweed (1.5 g/500 mL) was added to aquaria (10 cm in diameter) in a way to cover the surface area, and the ammonium adsorption of duckweed at low NH$_4^+$-N concentrations was determined with 9 measurements. In this study, NH$_3$ values reached their peaks (0.19 mg/L) at the end of 1st experiment, in which ammonia values originating from the unconsumed feed were determined. In the 2nd experiment, NH$_3$ values began to decline (0.06 mg/L) with the addition of natural adsorbents (zeolite + leonardite) and were decreased to 0.003 mg/L with the addition of duckweed in experiment III, where natural adsorbents started to reach saturation. When the data obtained at the end of this study were evaluated, it was determined that all 3 natural materials had a positive effect on water parameters in aquaculture systems. As a result, it was determined that in high concentrations of zeolite + leonardite mixture and in low concentration of duckweed there had been a good removal efficiency.

Biotechnology

Effects of various spectral compositions on micro-polluted water purification and biofuel feedstock production using duckweed

Li, Q; Yi, ZL; Yang, GL; Xu, YL; Jin, YL; Tan, L; Du, AP; He, KZ; Zhao, H; Fang, Y. (2022) Environmental Science and Pollution Research DOI10.1007/s11356-022-19488-1

The purification of micro-polluted water for drinking water can play an important role in solving water crisis. To investigate the effects of spectral composition on nutrient removal and biofuel feedstock production using duckweed, *Landoltia punctata* was cultivated in different spectral compositions in micro-polluted water. Results showed that the nitrogen and phosphorus removal efficiency were 99.4% and 93.5% at a recommended red and blue light photon intensity mixture ratio of 2:1. Meanwhile, maximum growth rate of duckweed (11.37 g/m$^2$/day) was observed at red/blue =2:1. In addition, maximum starch accumulation rate of duckweed was found to be 6.12 g/m$^2$/day, with starch content of 36.63% at red/blue =4:1, which was three times higher when compared to that of white light. Moreover, the recommended ratio of red and blue light was validated by economic efficiency analysis of energy consumptions. These findings provide a sustainable environmental restoration method to transform water micro-pollutants to available substances.

*Lemna minor* aqueous extract as a natural ingredient incorporated in poly (vinyl alcohol)-based films for active food packaging systems

Luzi, F; Del Buono, D; Orfei, B; Moretti, C; Bounaurio, R; Torre, L; Puglia, D. (2022) Food Packaging and Shelf Life 32: 100822

An aqueous extract of *Lemna minor* (LE - 0.5%, dry weight/volume), a wild spontaneous aquatic species, was used as an active agent in poly (vinyl alcohol) (PVA) films at the concentrations of 1, 5, 10, 20 wt%, realized through the solvent casting process. This species was selected after determining a high total phenol content (TPC - 6.7 mg g$^{-1}$ DW) and antioxidant of its aqueous extract. Transparency, color and morphological studies were considered to define the effect of the LE component on the optical properties of the matrix obtained. In addition, antioxidant, antifungal and antibacterial studies were performed to shed light on the LE effect on the active functional properties of the realized films for multifunctional packaging. The optical characterization of the obtained films revealed that the extract of *Lemna minor* in PVA films induced some alterations, although its presence determined positive radical scavenging and antimicrobial activity. These results demonstrate the possibility of using these polymeric systems in the food packaging sector.
Utilizing waste duckweed from phytoremediation to synthesize highly efficient FeNxC catalysts for oxygen reduction reaction electrocatalysis
Li, K; Li, JT; Yu, HD; Lin, FW; Feng, GQ; Jiang, MH; Yuan, DK; Yan, BB; Chen, GY. (2022) Science of the Total Environment 819: 153115

Duckweed is a universal aquatic plant to remove nitrogen source pollutants in the field of phytoremediation. Due to the naturally abundant nitrogen, synthesis of carbon materials from duckweed would be a high-value approach. In oxygen reduction reaction (ORR) of metal-air batteries and fuel cells, non-noble metals and heteroatoms co-doped electrocatalysts with excellent catalytic activity and remarkable stability are promising substitutes for Pt-based catalysts. The first-class ORR performance is determined by appropriate pore structure and active sites, which are strongly associated with the feasible synthesis methods. Herein, a facile one-step synthesis strategy for the transition metals and nitrogen-codoped carbon (MNxC) based catalysts with hierarchically porous structure was developed. The MNxC (M = Fe, Co, Ni, and Mn) active sites were constructed and FeNxC (D-ZB-Fe) was the best electrocatalyst with excellent ORR performance. Results showed that D-ZB-Fe exhibited an obvious honeycomb porous structure with specific surface area of 1342.91 m².g⁻¹ and total pore volume of 1.085 cm³.g⁻¹. It also possessed considerable active atoms and sites, where the proportion of pyridine N and graphite N was up to 72.9%. The above feature made for a superior ORR electrocatalytic activity. In specific, the onset and half-wave potential were 0.974 V and 0.857 V vs. RHE (Reversible Hydrogen Electrode), respectively. When compared with performances of commercial Pt/C, the four-electron pathway and relatively low peroxide yield, ca. 5%, were almost equivalent. Furthermore, D-ZB-Fe showed an excellent stability and remarkably methanol tolerance by the durability test. In conclusion, this research provides a new synthesis strategy of electrocatalysts with porous structures and active sites.

Poly(lactic acid)/thermoplastic cassava starch blends filled with duckweed biomass

Duckweed (DW) is a highly small, free-floating aquatic plant. It grows and reproduces rapidly, comprises mainly protein and carbohydrate, and has substantial potential as a feedstock to produce bioplastics due to its renewability and having very little impact on the food chain. The aim of this work was to analyze the effect of DW biomass on the characteristics and properties of bio-based and biodegradable plastics based on a poly(lactic acid)/thermoplastic cassava starch (PLA/TPS) blend. Various amounts of DW biomass were compounded with PLA and TPS in a twin-screw extruder and then converted into dumbbell-shaped specimens using an injection molding machine. The obtained PLA/TPS blends filled with DW biomass exhibited a lower melt flow ability, higher moisture content, and increased surface hydrophilicity than the neat PLA/TPS blend. Incorporation of DW with low concentrations of 2.3 and 4.6 wt% increased the tensile strength, Young's modulus, and hardness of the PLA/TPS blend. Moisture and glycerol from DW and TPS played important roles in reducing the Tg, Tcc, Tm, and Td of PLA in the blends. The current work demonstrated that DW could be used as a biofiller for PLA/TPS blends, and the resulting PLA/TPS blends filled with DW biomass have potential in manufacturing injection-molded articles for sustainable, biodegradable, and short-term use.

Biogas potential assessment of the composite mixture from duckweed biomass
Chusov, A; Maslikov, V; Badenko, V; Zhazhkov, V; Molodtsov, D; Pavlushkina, Y. (2022) Sustainability 14: 351

The article presents the research results of anaerobic digestion processes in bioreactors of composite mixtures based on initial and residual biomass of Lemna minor duckweed and additives: inoculum (manure), food waste, and spent sorbents to determine biogas potential (biogas volume, methane content). Duckweed L. minor, which is widespread in freshwater reservoirs, is one of the promising aquatic vegetation species for energy use. Residual biomass is obtained by chemically extracting valuable components from the primary product. The purpose of the research was to evaluate the possibility of the energy potential of residual biomass of L. minor to reduce the consumption of fossil fuels and reduce greenhouse gas emissions. This is in line with the International Energy Agency (IEA) scenarios for the reduction of environmental impact. The obtained results confirm the feasibility of using this type of waste for biogas/biomethane production. The recommendations on the optimal composition of the mixture based on the residual biomass of L. minor, which
will allow for an increase in biogas production, are given. The obtained data can be used in the design of bioreactors.

**Highly efficient fermentation of glycerol and 1,3-propanediol using a novel starch as feedstock**

Yang, Y; Chen, Y; Jin, YL; Liu, J; Qin, X; Liu, WJ; Guo, L. (2022) Food Bioscience 46: 101521

As a potential cost-effective feedstock for highly efficient fermentation of glycerol and its downstream product 1,3-propanediol (1,3-PD), duckweed starch was characterized and used for glycerol fermentation, for the first time, in this study. Genes involved in glycerol biosynthesis (gpd1 and gpp2) were overexpressed in *Escherichia coli*, and genes involved in glycerol catabolism (glpK and gldA) were disrupted, which led to significantly decreased residual sugar levels and dramatically increased glycerol production. The maximum glycerol concentration in fed-batch fermentation reached 102.72 g L\textsuperscript{-1} at 28 h, and the glycerol productivity was 3.67 g L\textsuperscript{-1} h\textsuperscript{-1}, which, to our knowledge, is the highest productivity thus far reported. Subsequently, glycerol broth was fermented into 1,3-PD by *Klebsiella pneumoniae*. The concentration, conversion rate and productivity of 1,3-PD reached 35.54 g L\textsuperscript{-1}, 40.28% and 0.89 g L\textsuperscript{-1} h\textsuperscript{-1}, respectively, without optimization. In summary, the duckweed starch-to-glycerol-to-1,3-PD process is feasible and shows potential for improving glycerol industry competitiveness.

**Ecology**

**Do polystyrene nanoplastics have similar effects on duckweed (Lemna minor L.) at environmentally relevant and observed-effect concentrations?**

Xiao, F; Feng, L-J; Sun, X-D; Wang, Y; Wang, Z-W; Zhu, F-P; Yuan, X-Z. (2022) Environmental Science and Technology 7: 4071-4079

Although the biological effects of nanoplastics (<100 nm in size) in aquatic environments have been increasingly investigated, almost all such studies have been performed at observed-effect concentrations (higher than 1 µg/mL). The use of observed-effect concentrations of nanoplastics can provide essential data for evaluating the potential risks, but how these results apply to the effects of concentrations of nanoplastics observed in the environment remains unclear. Here, we show that exposure to both positively and negatively charged nanoplastics at the observed-effect concentration (ranging from 0 to 50 µg/mL) can result in physiological changes of *Lemna minor* L., a typical flowering aquatic plant species, inducing H\textsubscript{2}O\textsubscript{2} and O\textsubscript{2}\textsuperscript{-} accumulation and even cell death. However, the nanoplastics at environmentally relevant concentrations (lower than 0.1 µg/mL) had no obvious effects on phenotype of *L. minor*. Moreover, nanoplastics at both observed-effect and environmentally relevant concentrations were adsorbed onto the roots and fronds of the plants, whereas uptake by the roots and fronds occurred only at the observed-effect concentration. Although no phenotypic changes across 30 generations of cultivation were observed when the plants were exposed to 0.015 µg/mL nanoplastics, the expression of genes related to the response to stimuli and to oxidative and osmotic stress was upregulated under both observed-effect and environmentally relevant concentrations. Our findings suggest that the long-term presence of nanoplastics at environmentally relevant concentrations might induce some variations in the transcription level and have potential threat to floating microphytes and aquatic ecosystems.

**Chloride toxicity to native freshwater species in natural and reconstituted Prairie Pothole waters**

Harper, DD; Puglis, HJ; Kunz, BK; Farag, AM. (2022) Archives of Environmental Contamination and Toxicology 82: 416-428

Oil and gas extraction in the Prairie Pothole Region (PPR) of the northern USA has resulted in elevated chloride concentrations in ground and surface water due to widespread contamination with highly saline produced water, or brine. The toxicity of chloride is poorly understood in the high hardness waters characteristic of the region. We evaluated the toxicity of chloride to two endemic species, *Daphnia magna* (water flea) and *Lemna*
**Duckweed Forum**

*gibba* (duckweed), exposed in field-collected waters (hardness similar to 3000 mg/L as CaCO$_3$) and reconstituted waters (hardness 370 mg/L as CaCO$_3$) intended to mimic PPR background waters. We also investigated the role of chloride in the toxicity of water reconstituted to mimic legacy brine-contaminated wetlands, using two populations of native *Pseudacris maculata* (Boreal Chorus Frog). Chloride toxicity was similar in field-collected and reconstituted waters for both *D. magna* (LC$_{50}$ 3070-3788 mg Cl$^{-1}$/L) and *L. gibba* (IC$_{50}$ 2441-2887). Although hardness can ameliorate chloride toxicity at low to high hardness, we did not observe additional protection as hardness increased from 370 to similar to 3000 mg/L. In *P. maculata* exposures, chloride did not fully explain toxicity. Chloride sensitivity also differed between populations, with mortality at 2000 mg Cl$^{-1}$/L in one population but not the other, and population-specific growth responses. Overall, these results (1) document toxicity to native species at chloride concentrations occurring in the PPR, (2) indicate that very high hardness in the region’s waters may not provide additional protection against chloride and (3) highlight challenges of brine investigations, including whether surrogate study populations are representative of local populations.

**Feed & Food**

**Diet-induced fasting ghrelin elevation reflects the recovery of insulin sensitivity and visceral adiposity regression**

Tsaban, G; Meir, AY; Zelicha, H; Rinott, E; Kaplan, A; Shalev, A; Katz, A; Brikner, D; Bluher, M; Ceglarek, U; Stumvoll, M; Stampfer, MJ; Shai, I. (2022) Journal of Clinical Endocrinology and Metabolism 107: 336-345

Lower fasting ghrelin levels (FGL) are associated with obesity and metabolic syndrome. We aimed to explore the dynamics of FGL during weight loss and its metabolic and adiposity-related manifestations beyond weight loss. This was a secondary analysis of a clinical trial that randomized participants with abdominal obesity/dyslipidemia to 1 of 3 diets: healthy dietary guidelines (HDG), Mediterranean diet (MED), or green-MED diet, all combined with physical activity (PA). Both MED diets were similarly hypocaloric and included 28 g/day walnuts. The green-MED group further consumed green tea (3-4 cups/day) and a *Wolffia globosa* (Mankai) plant green shake. We measured FGL and quantified body fat depots by magnetic resonance imaging at baseline and after 18 months. Among 294 participants (body mass index = 31.3 kg/m$^2$; FGL = 504 +/- 208 pg/mL; retention rate = 89.8%), lower FGL was associated with unfavorable cardiometabolic parameters such as higher visceral adipose tissue (VAT), intrahepatic fat, leptin, and blood pressure (P < 0.05 for all; multivariate models). The Delta FGL(18-month) differed between men (+7.3 ± 26.6%) and women (-9.2% ± 21.3%; P= 0.001). After 18 months of moderate and similar weight loss among the MED groups, FGL increased by 1.3%, 5.4%, and 10.5% in HDG, MED, and green-MED groups, respectively (P = 0.03 for green-MED vs HDG); sex-stratified analysis revealed similar changes in men only. Among men, FGL (18-month) elevation was associated with favorable changes in insulin resistance profile and VAT regression, after adjusting for relative weight loss (HbA1c: r=-0.216; homeostatic model of insulin resistance: r = -0.154; HDL-c: r = 0.147; VAT: r = -0.221; P < 0.05 for all). Insulin resistance and VAT remained inversely related with FGL elevation beyond that explained by weight loss (residual regression analyses; P< 0.05). Diet-induced FGL elevation may reflect insulin sensitivity recovery and VAT regression beyond weight loss, specifically among men. Green-MED diet is associated with greater FGL elevation.

**Can Lemna minor mitigate the effects of cadmium and nickel exposure in a Neotropical fish?**

Bezerra, V; Risso, WE; Bueno Dos Reis Martinez, C, Simonato, JD (2022) Environmental Toxicology and Pharmacology 103862. DOI10.1016/j.etap.2022.103862

We aimed to evaluate if *Lemna minor* can mitigate the observed effects of cadmium (Cd) and nickel (Ni) exposure in *Prochilodus lineatus*. Fish were exposed for 96h to 20g L$^{-1}$ of Cd, 1.5 mgl$^{-1}$ of Ni, or to a mixture of these two metals. In all tests, one group was exposed to the metals with duckweed on the water surface, and other group was exposed only to the metals, without plants. After each exposure, samples of *P. lineatus* tissues were collected to evaluate multiple biomarkers. Duckweed prevented bioaccumulation in some fish tissues and attenuated changes in acetylcholinesterase activity, increases in erythrocytic nuclear abnormality frequency, and hyperglycemia. However, the changes in plasma ion concentrations, reduction in activity of ion
transport enzymes, and histological damage were not mitigated. Therefore, we concluded that *L. minor* partially attenuates the effects caused by Cd and Ni exposure.

**Effect of *Lemna minor* supplemented diets on growth, digestive physiology and expression of fatty acids biosynthesis genes of *Cyprinus carpio***

Goswami, RK; Sharma, JG; Shrivastav, AK; Kumar, G; Glencross, BD; Tocher, DR; Chakrabarti, R. (2022) Scientific Reports 12: 3711

The potential nutritional value of duckweed *Lemna minor* (Lemnaceae) was evaluated for common carp *Cyprinus carpio* fry. Fish were fed diets containing five graded levels of duckweed: 0% (LM0, control), 5% (LM5), 10% (LM10), 15% (LM15) and 20% (LM20). The final weight and specific growth rate were significantly higher in LM15 and LM20 diets fed fish compared to others. Feed conversion ratio was minimum in fish fed diet LM20. Amylase activity was significantly higher in LM0 treatment. Total protease, trypsin and chymotrypsin activities showed linear relationships with the increased level of duckweed in the diet. Protein and essential amino acids contents were significantly higher in carp fed diets LM15 and LM20 compared to others. Lipid content was significantly higher in fish fed duckweed-based diets compared to control. A direct relationship was found between the inclusion level of duckweed in the diet and n-3 long-chain polyunsaturated fatty acid (LC-PUFA) content of carp. Contents of desaturated and elongated products of dietary linolenic acid (18:3n-3) including 20:4n-3, 20:5n-3, 22:5n-3 and 22:6n-3 increased in a graded manner with increasing dietary duckweed. The monounsaturated fatty acids and n-6 PUFA contents reduced significantly in fish fed duckweed. Expression of fads2d6, elovl2, elovl5 and fas were higher in carp fed diets LM10, LM15 and LM20 compared to control fish. The inclusion of *L. minor* in diet enhanced the nutritional value of carp by increasing protein, lipid, amino acids and n-3 PUFA contents.

**Growth and nutritional quality of Lemnaceae viewed comparatively in an ecological and evolutionary context***

Demmig-Adams, B; Lopez-Pozo, M; Polutchko, SK; Fourounjian, P; Stewart, JJ; Zenir, MC; Adams, WW. (2022) Plants 11: 145

This review focuses on recently characterized traits of the aquatic floating plant *Lemna* with an emphasis on its capacity to combine rapid growth with the accumulation of high levels of the essential human micronutrient zeaxanthin due to an unusual pigment composition not seen in other fast-growing plants. In addition, *Lemna*'s response to elevated CO$_2$ was evaluated in the context of the source-sink balance between plant sugar production and consumption. These and other traits of Lemnaceae are compared with those of other floating aquatic plants as well as terrestrial plants adapted to different environments. It was concluded that the unique features of aquatic plants reflect adaptations to the freshwater environment, including rapid growth, high productivity, and exceptionally strong accumulation of high-quality vegetative storage protein and human antioxidant micronutrients. It was further concluded that the insensitivity of growth rate to environmental conditions and plant source-sink imbalance may allow duckweeds to take advantage of elevated atmospheric CO$_2$ levels via particularly strong stimulation of biomass production and only minor declines in the growth of new tissue. It is proposed that declines in nutritional quality under elevated CO$_2$ (due to regulatory adjustments in photosynthetic metabolism) may be mitigated by plant-microbe interaction, for which duckweeds have a high propensity.

**Interaction with other organisms***

**Auxin-producing bacteria from duckweeds have different colonization patterns and effects on plant morphology***

Gilbert, S; Poulev, A; Chrisler, W; Acosta, K; Orr, G; Lebeis, S; Lam, E (2022) Plants 11: 721

The role of auxin in plant-microbe interaction has primarily been studied using indole-3-acetic acid (IAA)-producing pathogenic or plant-growth-promoting bacteria. However, the IAA biosynthesis pathway in bacteria involves indole-related compounds (IRCs) and intermediates with less known functions. Here, we seek to
understand changes in plant response to multiple plant-associated bacteria taxa and strains that differ in their ability to produce IRCs. We had previously studied 47 bacterial strains isolated from several duckweed species and determined that 79% of these strains produced IRCs in culture, such as IAA, indole lactic acid (ILA), and indole. Using *Arabidopsis thaliana* as our model plant with excellent genetic tools, we performed binary association assays on a subset of these strains to evaluate morphological responses in the plant host and the mode of bacterial colonization. Of the 21 tested strains, only four high-quantity IAA-producing Microbacterium strains caused an auxin root phenotype. Compared to the commonly used colorimetric Salkowski assay, auxin concentration determined by LC-MS was a superior indicator of a bacteria’s ability to cause an auxin root phenotype. Studies with the auxin response mutant axr1-3 provided further genetic support for the role of auxin signaling in mediating the root morphology response to IAA-producing bacteria strains. Interestingly, our microscopy results also revealed new evidence for the role of the conserved AXR1 gene in endophytic colonization of IAA-producing *Azospirillum baldaniorum* Sp245 via the guard cells.

**Allelopathic inhibition of the extracts of *Landoltia punctata* on *Microcystis aeruginosa***

Li, D; Li, P; Yan, ZQ; Li, N; Yao, LG; Cao, LL (2022) Plant Signaling & Behavior 17: 2058256

To study the allelopathic effect of the extracts of *Landoltia punctata*, the changes of cell density of *Microcystis aeruginosa* were measured. The anti-algae allelopathic effect of different organic solvent extracts of *L. punctata* was evaluated, and the physiological, biochemical indexes were determined to discuss the mechanism of algal inhibition. The results showed that the petroleum ether, dichloromethane and ethyl acetate extracts showed various inhibitory effects on *M. aeruginosa*. Among them, ethyl acetate extract was the most strongly allelopathic part with the semi-effect concentration (EC₅₀) of 59.6 mg L⁻¹, the central polarity part of inhibitory activity. The contents of chlorophyll a (Chl a) and phycobiliproteins (PBPs) of *M. aeruginosa* were decreased under the concentration of 200 mg L⁻¹ ethyl acetate extract, which indicated that the photosynthesis of *M. aeruginosa* was inhibited. The content of microcystins was lower compared to control under 200 mg L⁻¹. The contents of superoxide dismutase (SOD), malondialdehyde (MDA) and hydrogen peroxide (H₂O₂) of cell pellets were firstly increased and then decreased, which suggested that the algal cells were seriously damaged by oxidation. The results indicated that the extracts of *L. punctata* had inhibitory effect on *M. aeruginosa*, and the ethyl acetate extract was the central part of the inhibitory substances, which caused photosynthesis and oxidation damage to inhibit cell proliferation. These findings will be helpful for exploration and application of allelopathic effects of *L. punctata* in harmful algae control.

**The long-term exposure of cyanotoxin, cylindrospermopsin, on the macrophyte *Lemna trisulca***


The increase in frequency and prevalence of cylindrospermopsin (CYN)-producing cyanobacteria blooms have become a growing problem worldwide. Therefore, the long-term effects of CYN on the physiological processes of the macrophyte, *Lemna trisulca*, were examined. During a 5-day exposure to a range of CYN concentrations (0.5, 1 and 5 µg ml⁻¹), the low levels of stress experienced by *L. trisulca* stimulated its growth rate and photosynthesis and led to an increase in the synthesis of photosynthetic pigments. In turn, it was shown that a 3-week exposure to the highest tested CYN concentration (5 µg ml⁻¹) resulted in the inhibition of biomass accumulation (by 7.6%) compared with that of the control plants, but necrosis and chlorosis were not observed. A negative correlation with the concentration of carotenoids was also observed, which may suggest that the antioxidant mechanisms of *L. trisulca* are effective only up to a certain CYN concentration. An increase in protein content in the tissues of macrophytes treated with concentrations of CYN ranging from 0.5 to 5 µg ml⁻¹ indicates that the toxin did not inhibit protein synthesis but increased the metabolism of *L. trisulca*, potentially to provide energy for defence. The toxin also affects the homeostasis of mineral ions in cells. This is the first description of the physiological response of *L. trisulca* to the long-term effects of a wide range of CYN concentrations.
Molecular Biology

**Interspecific divergence of circadian properties in duckweed plants**

The circadian clock system is widely conserved in plants; however, divergence in circadian rhythm properties is poorly understood. We conducted a comparative analysis of the circadian properties of closely related duckweed species. Using a particle bombardment method, a circadian bioluminescent reporter was introduced into duckweed plants. We measured bioluminescence circadian rhythms of eight species of the genus *Lemna* and seven species of the genus *Wolffiella* at various temperatures (20, 25, and 30 °C) and light conditions (constant light or constant dark). *Wolffiella* species inhabit relatively warm areas and lack some tissues/organs found in *Lemna* species. *Lemna* species tended to show robust bioluminescence circadian rhythms under all conditions, while *Wolffiella* species showed lower rhythm stability, especially at higher temperatures. For *Lemna*, two species (*L. valdiviana* and *L. minuta*) forming a clade showed relatively lower circadian stability. For *Wolffiella*, two species (*W. hyalina* and *W. repanda*) forming a clade showed extremely long period lengths. These analyses reveal that the circadian properties of species primarily reflect their phylogenetic positions. The relationships between geographical and morphological factors and circadian properties are also suggested.

**Identification, structural, and expression analyses of SPX genes in Giant Duckweed (Spirodela polyrhiza) reveals its role in response to low phosphorus and nitrogen stresses**
Yang, J; Zhao, X; Chen, Y; Li, G; Li, X; Xia, M; Sun, Z; Chen, Y; Li, Y; Yao, L. (2022) MDPI Cells 11: DOI10.3390/cells11071167

SPX genes play important roles in the coordinated utilization of nitrogen (N) and phosphorus (P) in plants. However, a genome-wide analysis of the SPX family is still lacking. In this study, the gene structure and phylogenetic relationship of 160 SPX genes were systematically analyzed at the genome-wide level. Results revealed that SPX genes were highly conserved in plants. All SPX genes contained the conserved SPX domain containing motifs 2, 3, 4, and 8. The 160 SPX genes were divided into five clades and the SPX genes within the same clade shared a similar motif composition. P1BS cis-elements showed a high frequency in the promoter region of SPXs, indicating that SPX genes could interact with the P signal center regulatory gene Phosphate Starvation Response1 (*PHR1*) in response to low P stress. Other cis-elements were also involved in plant development and biotic/abiotic stress, suggesting the functional diversity of SPXs. Further studies were conducted on the interaction network of three *SpSPXs*, revealing that these genes could interact with important components of the P signaling network. The expression profiles showed that *SpSPXs* responded sensitively to N and P deficiency stresses, thus playing a key regulatory function in P and N metabolism. Furthermore, the expression of *SpSPXs* under P and N deficiency stresses could be affected by environmental factors such as ABA treatment, osmotic, and LT stresses. Our study suggested that *SpSPXs* could be good candidates for enhancing the uptake ability of *Spirodela polyrhiza* for P nutrients in wastewater. These findings could broaden the understanding of the evolution and biological function of the SPX family and offer a foundation to further investigate this family in plants.

Phytomedicine

**Pulmonary protein oxidation and oxidative stress modulation by Lemna minor L. in progressive bleomycin-induced idiopathic pulmonary fibrosis**
Karamalakova, Y; Stefanov, I; Georgieva, E; Nikolova, G. (2020) Antioxidants 11: 523

Bleomycin (BLM) administration is associated with multifunctional proteins inflammations and induction of idiopathic pulmonary fibrosis (IPF). *Lemna minor* L. extract, a free-floating monocot macrophyte possesses antioxidant and anti-inflammatory potential. The aim of the study was to examine the protective effect of *L. minor* extract on lung protein oxidation and oxidative stress modulation by BLM-induced pulmonary fibrosis in Balb/c mice. For this purpose, the protein carbonyl content, advanced glycation end product, nitrooxide protein oxidation (S-MSL), and lipid peroxidation (as MDA and ROS), in lung cells were examined. The histological
examinations, collagen deposition, and quantitative measurements of IL-1 beta, IL-6, and TNF in lung tissues and blood were investigated. Intrapерitoneal, BLM administration (0.069 U/mL; 0.29 U/kg b.w.) for 33 days, caused IPF induction in Balb/c mice. Pulmonary combining therapy was administered with \textit{L. minor} at dose 120 mg/ml (0.187 mg/kg b.w.). \textit{L. minor} histologically ameliorated BLM induced IPF in lung tissues. \textit{L. minor} significantly modulated (p < 0.05) BLM-alterations induced in lung hydroxyproline, carbonylated proteins, 5-MSL-protein oxidation. Oxidative stress decreased levels in antioxidant enzymatic and non-enzymatic systems in the lung were significantly regulated (p < 0.05) by \textit{L. minor}. \textit{L. minor} decreased the IL-1 beta, IL-6, and TNF-alpha expression in lung tissues and plasma. The \textit{L. minor} improves the preventive effect/defense response in specific pulmonary protein oxidation, lipid peroxidation, ROS identifications, and cytokine modulation by BLM-induced chronic inflammations, and could be a good antioxidant, anti-inflammatory, and anti-fibrotic alternative or IPF prevention involved in their pathogenesis.

**Phytoremediation**

**Wastewater valorisation in an integrated multitrophic aquaculture system; assessing nutrient removal and biomass production by duckweed species**

Paolacci, S; Stejskal, V; Toner, D; Jansen, MAK (2022) Environmental Pollution 302: 119059

The aquaculture industry is considered a key sector for the supply of high quality, nutritious food. However, growth of the aquaculture sector has been slow, particularly in Europe, and this is amongst others linked to concerns about environmental impacts of this industry. Integrated Multitrophic Aquaculture (IMTA) has been identified as an important technology to sustainably improve freshwater fish production. In IMTA, economically valuable extractive species feed on waste produced by other species, remediating wastewater, and minimising the environmental impact of aquaculture. This study presents quantitative information on the nitrogen and phosphorus removal efficiency of a duckweed-based, pilot, semi-commercial IMTA system. Duckweed species are free-floating freshwater species belonging to the family of Lemnaceae. The aim of this study was to test the potential of duckweed-based IMTA under realistic environmental conditions. Three different approaches were used to assess remediation capacity; 1) assessment of water quality pre and post treatment with duckweed showed that the system can remove 0.78 and 0.38 Ty⁻¹ of Total Nitrogen (TN) and Total Phosphorus (TP), respectively 2) based on nitrogen and phosphorus content of newly grown duckweed biomass, it was shown that 1.71 and 0.22 Ty⁻¹ of TN and TP can be removed, respectively 3) extrapolation based on laboratory established nitrogen and phosphorus uptake rates determined that 0.88 and 0.08 Ty⁻¹ of TN and TP can be removed by the system. There is substantive agreement between the three assessments, and the study confirms that duckweed can maintain good quality water in an IMTA system, while yielding high protein content (21.84±2.45%) biomass. The quantitative data on nitrogen and phosphorus removal inform the design of further IMTA systems, and especially create a scientific basis to determine the balance between aquaculture and extractive species.

**Species interactions in three Lemnaceae species growing along a gradient of zinc pollution**

Lanthemann, L; van Moorsel, SJ. (2022) Ecology and Evolution 12: 8646

Duckweeds (Lemnaceae) are increasingly studied for their potential for phytoremediation of heavy-metal polluted water bodies. A prerequisite for metal removal, however, is the tolerance of the organism to the pollutant, e.g., the metal zinc (Zn). Duckweeds have been shown to differ in their tolerances to Zn; however, despite them most commonly co-occurring with other species, there is a lack of research concerning the effect of species interactions on Zn tolerance. Here, we tested whether the presence of a second species influenced the growth rate of the three duckweed species \textit{Lemna minor}, \textit{Lemna gibba}, and \textit{Lemna turionifera}. We used four different Zn concentrations in a replicated microcosm experiment under sterile conditions, either growing the species in isolation or in a two-species mixture. The response to Zn differed between species, but all three species showed a high tolerance to Zn, with low levels of Zn even increasing the growth rates. The growth rates of the individual species were influenced by the identity of the competing species, but this was independent of the Zn concentration. Our results suggest that species interactions should be considered in...
future research with duckweeds and that several duckweed species have high tolerance to metal pollution, making them candidates for phytoremediation efforts.

Effects of sulfamethazine and cupric ion on treatment of anaerobically digested swine wastewater with growing duckweed

Xiao, Y; Yang, CP; Cheng, JYJ. (2022) International Journal of Environmental Research and Public Health 19: 1949

Duckweed (Spirodela polyrhiza) has the potential to treat anaerobically digested swine wastewater (ADSW), but the effects of antibiotics and heavy metals in ADSW on the treatment performance and mechanism of S. polyrhiza are not clear. Herein, an experiment was conducted to investigate the effects of sulfamethazine (SMZ) and cupric ion on NH$_4^+$-N and total phosphorus (TP) removal from synthetic ADSW. The activity of superoxide dismutase (SOD) and the contents of photosynthetic pigments, vitamin E, and proteins in duckweed were also evaluated. Under the stress of SMZ, duckweed showed excellent removal efficiency of nutrients, and the results of SOD activity and photosynthetic pigments content indicated that duckweed had good tolerance to SMZ. Interestingly, a combined application of SMZ and cupric ion would inhibit the nutrient removal by duckweed, but significantly increased the contents of photosynthetic pigments, proteins, and vitamin E. In addition, the consequence indicated that high value-added protein and vitamin E products could be produced and harvested by cultivating duckweed in ADSW. Furthermore, possible degradation pathways of SMZ in the duckweed system were proposed based on the analysis with LC-MS/MS. This research proposed a novel view for using duckweed system to remove nutrients from ADSW and produce value-added products under the stress of SMZ and cupric ion.

Aqueous selenium removal and distribution in cattail and duckweed in constructed wetland microcosms

Nattrass, MP; Morrison, JI; Baldwin, BS. (2022) Agrosystems geosciences and Environment 5: 20241

Selenium (Se)-affected stormwater runoff raises concerns about potential downstream impact of Se on aquatic ecosystems. Unplanted (UNP) detention ponds augmented with cattail (Typha angustifolia L.; CAT) and duckweed (Lemna minor L.; DWD) may provide a solution for continuous, rapid abatement of Se-affected runoff. This research was conducted to evaluate the efficacy of CAT or DWD and determining the distribution of Se within a continually flooded detain and drain system. Microcosms containing 3 kg of soil planted to either one CAT, 25 g fresh DWD, or left unplanted (UNP, control) were flooded with a 3-L solution at 40 µg Se L$^{-1}$, as sodium selenate (Na$_2$SeO$_4$), or a zero Se control. Over two 10-d flood-discharge cycles (FDCs), plants in microcosms were evaluated in growth chambers maintained at 30 $^\circ$C under a 12-h photoperiod with 400 µmol m$^{-2}$ s$^{-1}$ irradiance. Initial and final water, soil, plant, and granular activated charcoal (GAC) were analyzed for total [Se] with inductively coupled plasma-mass spectroscopy (ICP-MS). Data were analyzed with PROC GLM (SAS EG 7.1) at alpha = .05. Within 10 d after Se application, CAT and DWD decreased aqueous Se from 40 µg Se L$^{-1}$ to below the 11.8 µg Se L$^{-1}$ threshold. Selenium recovery ranged between 75 and 100% of the applied Se. In continually flooded systems, the primary elimination pathway appears to be associated with the soil solid phase. Cattail and DWD are suitable species for constructed wetland phytoremediation of Se-affected runoff. The microcosm design presented may be useful for future evaluations.

The role of H$_2$O$_2$-scavenging enzymes (ascorbate peroxidase and catalase) in the tolerance of Lemna minor to antibiotics: Implications for phytoremediation

Gomes, MP; Kitamura, RSA; Marques, RZ; Barbato, ML; Zamocky, M. (2022) Antioxidants 11: 151.

We investigated the individual and combined contributions of two distinct heme proteins namely, ascorbate peroxidase (APX) and catalase (CAT) on the tolerance of Lemna minor plants to antibiotics. For our investigation, we used specific inhibitors of these two H$_2$O$_2$-scavenging enzymes (p-aminophenol, 3-amino,1,2,4-triazole, and salicylic acid). APX activity was central for the tolerance of this aquatic plant to amoxicillin (AMX), whereas CAT activity was important for avoiding oxidative damage when exposed to ciprofloxacin (CIP). Both monitored enzymes had important roles in the tolerance of L. minor to erythromycin (ERY). The use of molecular kinetic approaches to detect and increase APX and/or CAT scavenging activities
could enhance tolerance, and, therefore, improve the use of L. minor plants to reclaim antibiotics from water bodies.

**Exponential decay: an approach to model nutrient uptake rates of macrophytes**

Nesan, D; Chan, DJC. (2022) International Journal of Phytoremediation 23: 1519-1524

One of the challenges of integrating phytoremediation into a waste treatment system is the sensitivity of plant species to fluctuations in environmental conditions and the difficulty in estimating subsequent changes to their rates of uptake. In this study, we examine a method using the exponential decay equation to approximate the median uptake rate (MUR) of nutrients for three aquatic macrophyte species, *Salvinia molesta*, *Spirodela polyrhiza*, and *Lemna minor*. These MUR values were then used to directly evaluate the phytoremediation performance between species and at varying levels of salinity stress. The results of this study indicate that an exponential decay relationship produced the most accurate models of the nutrient uptake profile for each species, with highest correlation values in 74.1% of tests for the three species at increasing salinity over a period of 14 d. *S. polyrhiza* and *L. minor* began to show significant reductions in nutrient uptake and growth at salinity concentration above 10g/L. Using MUR, direct comparisons can be made between species in a time and mass-independent manner, allowing for the rapid assessment of phytoremediation performance under conditions of increasing salinity stress.

**Performance of pilot-scale constructed floating wetlands in the removal of nutrients and pesticides**


Aiming to evaluate the efficacy of constructed floating wetlands (CFW) in removing agrochemicals (nutrients and pesticides), a series of experiments were run continuously for a 16-week period in pilot-scale CFW systems to study the effect of two aquatic plant species (duckweed and water hyacinth) and climatic parameters. The CFW systems were loaded daily with agricultural polluted water containing a fertilizer and five pesticides, whose concentrations and removal efficiencies were measured in the experiments. Average nutrient and pesticide reductions varied from 27.4% to 83.6% and from 12.4% to 42.7%, respectively. The two plants performed almost equally well. High temperatures and increased solar radiation significantly contributed to increased removal performance. The results suggest the use of CFW systems as effective and low-cost agricultural pollution control technologies.

**Phytotoxicity**

**Interlaboratory validation of toxicity testing using the duckweed *Lemna minor* root-regrowth test**

Park, J; Yoo, EJ; Shin, K; Depuydt, S; Li, W; Appenroth, KJ; Lillicrap, AD; Xie, L; Lee, H; Kim, G; De Saeger, J; Choi, S; Kim, G; Brown, MT; Han, T. (2022) Biology 11: 37

Duckweed (*Lemna minor*) is commonly used as a phytotoxicity test organism, adopted by the main international standardization organizations (ISO, OECD, USEPA, ASTM). For duckweed tests, measurements of fronds or biomass are usually preferred with a standard exposure period of at least 7 days. The proposed root-regrowth test differs from other internationally standardized methods in several important aspects: (a) the test can be performed within 72 h; (b) the test vessel was a 24-well cell plate; (c) the required volume of test water samples was 3 mL; (d) roots were excised before exposure and newly developed roots then measured. The validation of the new test method by interlaboratory comparison tests confirmed that the *Lemna* root bioassay is valid and reliable. The root growth test is therefore a valuable tool for rapid toxicity screening of wastewater effluents and hazardous pollutants in natural waters because it is simple to perform, quick to conduct, cost-effective to operate, and can have operational benefits for testing time, since management decisions need to be made promptly in the event of unpredictable pollution events. The common duckweed (*L. minor*), a freshwater monocot that floats on the surfaces of slow-moving streams and ponds, is commonly used in
toxicity testing. The novel *Lemna* root-regrowth test is a toxicity test performed in replicate test vessels (24-well plates), each containing 3 mL test solution and a 2-3 frond colony. Prior to exposure, roots are excised from the plant, and newly developed roots are measured after 3 days of regrowth. Compared to the three internationally standardized methods, this bioassay is faster (72 h), simpler, more convenient (requiring only a 3-mL) and cheaper. The sensitivity of root regrowth to 3,5-dichlorophenol was statistically the same as using the conventional ISO test method. The results of interlaboratory comparison tests conducted by 10 international institutes showed 21.3% repeatability and 27.2% reproducibility for CuSO$_4$ and 21.28% repeatability and 18.6% reproducibility for wastewater. These validity criteria are well within the generally accepted levels of <30% to 40%, confirming that this test method is acceptable as a standardized biological test and can be used as a regulatory tool. The *Lemna* root regrowth test complements the lengthier conventional protocols and is suitable for rapid screening of wastewater and priority substances spikes in natural waters.

**Single and mixture toxicity of selected pharmaceuticals to the aquatic macrophyte *Lemna minor***

Ramirez-Morales, D; Fajardo-Romero, D; Rodriguez-Rodriguez, CE; Cedergreen, N. (2022) Ecotoxicology DOI10.1007/s10646-022-02537-3

Plants represent uncommon targets to evaluate pharmaceuticals toxicity. In this work, *Lemna minor* was employed as a plant model to determine the toxicity of selected pharmaceuticals, and to assay if such toxicity could be predicted by QSAR models based on green algae. Among eight compounds, measurable toxicity was determined for ketoprofen (EC$_{50}$ = 11.8 ± 1.9 mg/L), fluoxetine (EC$_{50}$ = 27.0 ± 8.7 mg/L) and clindamycin 2-phosphate (EC$_{50}$ = 57.7 ± 1.7 mg/L). Even though a correlation of r$^2$ = 0.87 was observed between experimental toxicity towards algae and *L. minor*, QSAR estimations based on algae data poorly predicted the toxicity of pharmaceuticals on the plant. More experimental data for *L. minor* are necessary to determine the applicability of these predictions; nonetheless, these results remark the importance of measuring experimental ecotoxicological parameters for individual taxa. The toxicity of pharmaceutical binary mixtures (ketoprofen, fluoxetine and clindamycin) revealed in some cases deviations from the concentration addition model; nonetheless these deviations were small, thus the interactions are unlikely to be of severe biological significance. Moreover, the EC$_{50}$ concentrations determined for these pharmaceuticals are significantly higher than those detected in the environment, suggesting that acute effects on *L. minor* would not take place at ecosystem level.

**Long-term interactions between microplastics and floating macrophyte *Lemna minor*: The potential for phytoremediation of microplastics in the aquatic environment**

Rozman, U; Jemec Kokalj, A; Dolar, A; Drobne, D; Kalcikova, G. (2022) The Science of the Total Environment 831: 154866

The presence of microplastics (MPs) in the environment has raised many concerns, and therefore approaches and technologies to remove them in situ are of high interest. In this context, we investigated the interactions between polyethylene MPs (fragments with a mean size of 149 ± 75 µm) and an aquatic floating macrophyte *Lemna minor* in order to assess its potential use for in situ phytoremediation. We first investigated the long-term effects of a high (100 mg/L = 9600 MPs/L), but still environmentally relevant concentration of MPs on *L. minor*. Subsequently bioadhesion of MPs was studied and the number and strength of MPs adhering to plant biomass were assessed. MPs did not adversely affect various parameters of plants (e.g., specific growth rate, chlorophyll contents, total antioxidant capacity, electron transport system activity, and contents of energy-rich molecules) throughout the duration of the experiment (12 weeks), except for the first week of the experiment, when protein content and total antioxidant capacity were affected. On the other hand, MPs affected the root length of *L. minor* during the first eight weeks of the experiment, while further exposure resulted in a decrease in the effects, indicating the ability of *L. minor* to tolerate the presence of MPs for a long period of time. MPs adhered rapidly to the plant biomass and the average percentages of strongly and weakly adhered particles were 6.5% and 20.0%, respectively, of the total MPs applied. In summary, results of this study suggest that *L. minor* can tolerate hotspot concentrations of MPs and can collect MPs from the water surface. Therefore, phytoremediation using floating plants could be considered as a potential method for in situ removal of MPs from the aquatic environment.
Combined effects of temperature and nutrients on the toxicity of cadmium in duckweed (*Lemna aequinoctialis*)

Yang, J; Li, G; Xia, M; Chen, Y; Chen, Y; Kumar, S; Sun, Z; Li, X; Zhao, X; Hou, H (2022) Journal of Hazardous Materials 432: 128646

Global anthropogenic changes are altering the temperature and nutrients of the ecosystem, which might also affect the extent of cadmium (Cd) toxicity in organisms. This study aimed to investigate the combined effects of temperature and nutrient availability (here, nitrogen [N] and phosphorus [P]) on Cd toxicity in duckweed (*Lemna aequinoctialis*). The growth parameters, nutrient uptake, and Cd tolerance of plantlets reached their highest values for duckweed grown in medium with 28mg/L N and 2.4mg/L P (N:P=11.67) at 25°C under 1mg/L CdCl$_2$ exposure. Raising the temperature (from 18°C to 25°C) and levels of N and P (from 0.01N/P to 2N/P) enhanced photosynthetic capacity and nutrient uptake, thus promoting plant growth and diluting the toxic effects of Cd. Although Cd uptake increased with increasing temperature, duckweed with relatively high biomass exhibited a lower accumulation of the toxic metal because their growth rate exceeded Cd uptake rate. Increasing N and P supply also enhanced the tolerance of duckweed to Cd by limiting Cd bioavailability. Our study therefore suggests the importance of combined effects from temperature and nutrients for Cd toxicity and provides novel insights for a comprehensive analysis of Cd toxicity associated with the environmental factors of a particular ecosystem.

Large-scale screening and characterization of Cd accumulation and ultrastructural deformation in duckweed

Wang, X; Hu, L; Wu, D; Huang, T; Zhang, B; Cai, G; Gao, G; Liu, Z; Huang, X; Zhong, Z. (2022) The Science of the Total Environment 832: 154948

Cadmium (Cd) pollution in soil, rivers and lakes is a serious problem due to the current industrialization and urbanization in China. Duckweeds are recognized as promising species for Cd phytoremediation. However, intraspecific variations in Cd accumulation in duckweeds remain largely unknown. In this study, 16 accessions selected from 39 geographically isolated duckweed strains were chosen to investigate their Cd remediation abilities. The optimal accession *Landoltia punctata* named 07SGZP01 (*L. punctata* 0701) was identified and shown to accumulate maximal Cd in the body while maintaining the highest biomass. The dominant variety treated with different Cd concentrations showed that the biomass of *L. punctata* 0701 was significantly lower than that of the control group (CK). Cd contents in *L. punctata* 0701 were substantially increased from 2511.1 to 30,641.01 mg kg$^{-1}$ with an increase in Cd treatment levels from 0.3 to 20 mg L$^{-1}$. The transport coefficient (TF) increased as Cd levels increased from 0.3 to 2 mg L$^{-1}$. In addition, the Cd content in leaves was greater than that in roots (TF > 1) within this Cd concentration range, whereas the Cd content in roots was greater than that in leaves (TF < 1) when the concentration of the Cd treatment was greater than 5 mg L$^{-1}$. The bioaccumulation factor (BCF) decreased significantly with increasing Cd levels (P < 0.05). The rate of Cd removal in the solution gradually decreased with increasing Cd concentrations, and the removal rate achieved the highest value (75%) when the Cd concentration was 0.5 mg L$^{-1}$. In addition, Cd treatment (2 mg L$^{-1}$) not only damaged the ultrastructure of *L. punctata* 0701, as characterized by chloroplast deformation and cell vacuolation but also caused most of the stomata to close, and the leaf epidermal cells were damaged and ruptured.

A study of the effects of sodium alginate and sodium carboxymethyl cellulose on the growth of common duckweed (*Lemna minor* L.)

Boros, B; Grau, N; Isvoran, A; Datcu, A; Iovanci, N; Ostafo, V (2022) Journal of the Serbian Chemical Society DOI10.2298/JSC210805082B

Sodium alginate (ALG) and sodium carboxymethyl cellulose (CMC) are two polysaccharides that have a wide range of applications, which could lead to accidental pollution of the environment, making the assessment of their potential ecotoxicity imperative. The present study assesses the effects of ALG and CMC on the growth response of common duckweed (*Lemna minor* L.). The results emphasize that both polysaccharides can be classified as practically nontoxic based on their EC$_{50}$ values, with ALG having a relatively higher toxicity compared to CMC. It was also observed that high doses of 1, 5 and 10 mg mL$^{-1}$ of the two polysaccharides produced growth inhibitory effects against common duckweed. The toxicity of biopolymers against common duckweed, measured as EC$_{50}$ values, seems to be correlated to the hydrophobicity of the monomers building
The effect of chitosan-modified gold nanoparticles in *Lemna valdiviana* and *Daphnia pulex*

Abrica-Gonzalez, P; Zumelzu, E; Nimptsch, J; Balderas-Lopez, JA; Munoz-Diosdado, A; Moreno-Villoslada, I; Flores, ME. (2022) Gold Bulletin 55: 77-91

Gold nanoparticles (AuNPs) are nowadays used in many areas of science, particularly in medicine as drug release and gene carriers. The extensive use of these materials makes imperative the study of their effects on the environment after their disposal that mostly affects the aquatic media. The present work explores the bioaccumulation and toxicity of chitosan-functionalized and non-functionalized gold nanoparticles, with primary producers (*Lemna valdiviana*) and primary consumers (*Daphnia pulex*) aquatic organisms. Bioaccumulation of 27.4 nm AuNPs and 43.1 nm chitosan-gold nanoparticles (CO-AuNPs) was evaluated in both microorganisms, finding accumulation of AuNPs and inhomogeneous aggregation of CO-AuNPs in *D. pulex* gut, and internalization of both types of nanoparticles in *L. valdiviana* cell walls. The effective concentration of nanomaterial for 50% survival (LC$_{50}$) of *D. pulex* organisms was 1.13 mg/L for AuNPs and 0.96 mg/L for CO-AuNPs in the acute test. In *L. valdiviana* 7-day test, the EC$_{50}$ for area and frond number were 1.19 mg/L and 1.26 mg/L, respectively, for AuNPs, 1.53 mg/L and 1.44 mg/L, respectively, for CO-AuNPs, finding higher toxicity of CO-AuNPs to *D. pulex*, and AuNPs to *L. valdiviana*. The obtained results suggest that the effects of nanomaterials on the growth and survival of key organisms deserve further study, as this may lead to the development of appropriate environmental regulations.

Taxonomy & Geobotany

Intraspecific diversity in aquatic ecosystems: Comparison between *Spirodela polyrhiza* and *Lemna minor* in natural populations of duckweed

Bog, M; Appenroth, KJ; Schneider, P; Sree, KS. (2022) Plants 7: 968

Samples of two duckweed species, *Spirodela polyrhiza* and *Lemna minor*, were collected around small ponds and investigated concerning the question of whether natural populations of duckweeds constitute a single clone, or whether clonal diversity exists. Amplified fragment length polymorphism was used as a molecular method to distinguish clones of the same species. Possible intraspecific diversity was evaluated by average-linkage clustering. The main criterion to distinguish one clone from another was the 95% significance level of the Jaccard dissimilarity index for replicated samples. Within natural populations of *L. minor*, significant intraspecific genetic differences were detected. In each of the three small ponds harbouring populations of *L. minor*, based on twelve samples, between four and nine distinct clones were detected. Natural populations of *L. minor* consist of a mixture of several clones representing intraspecific biodiversity in an aquatic ecosystem. Moreover, identical distinct clones were discovered in more than one pond, located at a distance of 1 km and 2.4 km from each other. Evidently, fronds of *L. minor* were transported between these different ponds. The genetic differences for *S. polyrhiza*, however, were below the error-threshold of the method within a pond to detect distinct clones, but were pronounced between samples of two different ponds.

Alien aquatic plant species in European Russia

CHУЖЕЗЕМНЫЕ ВОДНЫЕ РАСТЕНИЯ ЕВРОПЕЙСКОЙ РОССИИ


The intense hydrobotanical investigations and high activity of international ornamental trade contributed to the list of the alien aquatic plant species in European Russia during several last decades (late 20th - early 21st centuries). However, the records from the Herbaria were not included in these reports. Our study aimed to complete this inventory by using multiple herbarium sources, our own field observations, and all publicly
available references. In this region we identified 26 species of alien aquatic plants species by reporting multiple new localities and status of their invasiveness. Two species from Eastern Asia (Wolffia globosa, Monochoria korsakowii) have not been observed previously in Western, Central or Southern Europe. Ten species (53%) were originated from North and Central America, four species (21%) - from South America, three species (16%) - from tropics and subtropics of the Old World, one species (5%) - from the Far East, and one species (5%) - from Southeast Asia. We found that the aliens grow predominantly in the rivers with thermal inputs and artificial water bodies. Invasive species occasionally can be found in the non-disturbed aquatic communities, although most of these species have been established in the surroundings of the cities with dense population where they were introduced from aquarium and ornamental culture. According to the classification of invasive plants (Pysek et al., 2004), twelve species (46%) are the outside cultivation casual plants, and eleven species (42%) are the alien outside cultivation naturalized non-invasive plants. Elodea canadensis Michx. and Lemna minuta Kunth are characterized by high invasiveness. Elodea nuttallii (Planch.) H. St. John most recently also showed more signs of being invasive.

Phragmites altissimus and Lemna turionifera, new species to the flora of the European North-East of Russia

РФРАГМИТЫС АЛТИСИМИСИ ЛЕМНА ТУРИОНИФЕРА - НОВЫЕ ВИДЫ ДЛЯ ФЛОРЫ ЕВРОПЕЙСКОГО СЕВЕРО-ВОСТОКА РОССИИ

The information on the first record of two synanthropic species (Lemna turionifera Landolt and Phragmites altissimus (Benth.) Mabille) in the European North-East of Russia is presented. Both species were recorded in anthropogenic habitats.
Instructions to Contributors for the Duckweed Forum

The Duckweed Forum (DF) is an electronic publication that is dedicated to serve the Duckweed Research and Applications community by disseminating pertinent information related to community standards, current and future events, as well as other commentaries that could benefit this field. As such, involvement of the community is essential and the DF can provide a convenient platform for members in the field to exchange ideas and observations. While we would invite everyone to contribute, we do have to establish clear guidelines for interested contributors to follow in order to standardize the workflow for their review and publication by the Duckweed Steering Committee members.

Contributions to DF must be written in English, although they may be submitted by authors from any country. Authors who are not native English speakers may appreciate assistance with grammar, vocabulary, and style when submitting papers to the DF.

DF is currently arranged in sections, which may be chosen by a prospective author(s) to contribute to: Main text, Opinion paper, Discussion corner, Useful methods, Student experiments, Student spotlight, Science meets art, and Cover photo(s). 1,000 words are suggested as the upper limit for each contribution, but can be extended on request to the Steering Committee if the reason for the waiver request is warranted.

Presubmissions

In addition to invitees by a Duckweed Steering Committee member, if you are considering submitting a contribution to DF but are unsure about the fit of your idea, please feel free to contact one of the members in the Duckweed Steering Committee in order to obtain feedback as to the appropriateness of the subject for DF. Please include a few sentences describing the overall topic that you are interested to present on, and why you think it is of interest to the general duckweed community. If you have the abstract or draft text prepared, please include it. The Duckweed Steering Committee will discuss the material in one of its meetings and the decision to formally invite submission will be given shortly afterwards.

Copyright and co-author consent

All listed authors must concur in the submission and the final version must be seen and approved by all authors of the contribution. As a public forum, we do not carry out any Copyright application. If you need to copyright your material, please do so beforehand.

Formatting requirements:

- A commonly used word processing program, such as Word, is highly recommended.
• Formatting requirements: 8.5-by-11-inch (or 22 cm-by-28 cm) paper size (standard US letter).

• Single-spaced text throughout.

• One-inch (or 2.5 cm) left and right, as well as top and bottom margins.

• 11-point Times New Roman font.

• Number all pages, including those with figures on the bottom and center of each page.

**Title:**

• Should be intelligible to DF readers who are not specialists in the field and should convey your essential points clearly.

• Should be short (no more than 150 characters including spaces) and informative.

• Should avoid acronyms or abbreviations aside from the most common biochemical abbreviations (e.g., ATP). Other acronyms or abbreviations should either:
  
  o be introduced in their full form (e.g., Visualization of Polarized Membrane Type 1 Matrix Metalloproteinase (MT1-MMP) Activity in Live Cells by Fluorescence Resonance Energy Transfer (FRET) Imaging); or
  
  o be clarified by use as a modifier of the appropriate noun (e.g., FOX1 transcription factor, ACC dopamine receptor).

**Authors:**

• All authors are responsible for the content of the manuscript.

• Provide the complete names of all authors.

• Identify which author will receive correspondence regarding the contribution.

• Provide the corresponding author’s name, telephone number, and current e-mail address.

**Image resolution and submission:**

It is extremely important that figures be prepared with the proper resolution for publication in order to avoid inaccurate presentation of the data. The minimum acceptable resolution for all figures is 300 dpi. Excessive file compression can distort images, so files should be carefully checked after compression. Note that figures that contain both line art (such as graphs) and RGB/grayscale areas (such as photographs) are best prepared as EPS (vector) files with embedded TIFF images for the RGB/grayscale portions. The resolution of those embedded TIFF images should be at least 300 dpi. Original images should be submitted as a separate file to the text file. It would be helpful to insert the intended into the Word file as well, if desired, to indicate the location for it. The legend to the image/figure should be added at the end of the text file and labeled as "Legend to Figures".
Links for Further Reading

http://www.ruduckweed.org/ Rutgers Duckweed Stock Cooperative, New Brunswick, New Jersey State University. Prof. Dr. Eric Lam

http://www.InternationalLemnaAssociation.org/ Working to develop commercial applications for duckweed globally, Exec. Director, Tamra Fakhoorian

http://thecharmsofduckweed.org Comprehensive site on all things duckweed-related, By Dr. John Cross, maintained by Paul Fourounjian.

http://plants.ifas.ufl.edu/ University of Florida’s Center for Aquatic & Invasive Plants.

Community Resources - Updated Table for Duckweed Collections in the Community

For information related to the location, collection size and contact email for duckweed collections in our community, please access the website of the RDSC (Rutgers Duckweed Stock Cooperative) under the heading "List of Worldwide Duckweed Collections". This Table will be updated as new entries for duckweed collections are being supplied to members of the International Steering Committee for Duckweed Research and Applications (ISCDRA). We also plan to publish the updated table in the first issue of each Duckweed Forum newsletter volume starting in 2021.

Note to the Reader

Know of someone who would like to receive their own copy of this newsletter? Would you like to offer ideas for future articles or have comments about this newsletter? Need to be added or removed from our contact list?

Please let us know via email to the Chair of ISCDRA, Prof. Eric Lam: ericL89@hotmail.com