

1 **Plants in aquatic ecosystems: current trends and future directions**

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34 *Key words:* Angiosperms; Botany; Herbivory; Limnology; Macrophytes; Submerged aquatic
35 vegetation; Trends in research

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37 *Running title:* Plants in aquatic ecosystems

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39 **Accepted for publication in *Hydrobiologia* published by Springer. The final publication is available**
40 **at Springer via <https://doi.org/10.1007/s10750-017-3190-7>**

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43 **Abstract**

44 Aquatic plants fulfil a wide range of ecological roles, and make a substantial contribution to the
45 structure, function and service provision of aquatic ecosystems. Given their well-documented
46 importance in aquatic ecosystems, research into aquatic plants continues to blossom. The 14th
47 International Symposium on Aquatic Plants, held in Edinburgh in September 2015, brought together
48 120 delegates from 28 countries and six continents. This special issue of *Hydrobiologia* includes a
49 select number of papers on aspects of aquatic plants, covering a wide range of species, systems and
50 issues. In this paper we present an overview of current trends and future directions in aquatic plant
51 research in the early 21st century. Our understanding of aquatic plant biology, the range of scientific
52 issues being addressed and the range of techniques available to researchers have all arguably never
53 been greater; however, substantial challenges exist to the conservation and management of both
54 aquatic plants and the ecosystems in which they are found. The range of countries and continents
55 represented by conference delegates and authors of papers in the special issue illustrate the global
56 relevance of aquatic plant research in the early 21st century but also the many challenges that this
57 burgeoning scientific discipline must address.

58

59 **Introduction**

60 In the early 21st century, researchers recognize the fundamental importance of plants that grow in
61 and around water to the structure, functioning and service provision of aquatic ecosystems
62 (Chambers et al., 2008). Aquatic plants interact with and influence the hydrological,
63 geomorphological and physico-chemical environments, and interact with a wide range of other
64 organisms, from microbes to vertebrates, for example, by providing habitat and food (Brix, 1997;
65 Engelhardt & Ritchie, 2001; Wood et al., 2017a). The current interest contrasts with the views of
66 earlier limnologists a century ago who considered aquatic plants to be largely unimportant in aquatic
67 ecosystems; for example, Shelford (1918) argued that "*One could probably remove all the larger*
68 *plants and substitute glass structures of the same form and surface texture without greatly affecting*
69 *the immediate food relations*". Over the past century the study of aquatic plants has expanded
70 considerably, because of the increased recognition of their importance in fundamental system
71 processes. Specialist journals have been established, such as Aquatic Botany (Den Hartog, 1975) and
72 Journal of Aquatic Plant Management, as well as conferences devoted to aquatic plant research.

73 As a consequence of the growth of aquatic plant research over recent decades, our views on many
74 key topics in aquatic botany have shifted (Vermaat & Gross, 2016; Phillips et al., 2016), and so this
75 introduction to the special issue on plants in aquatic systems presents an overview of current trends
76 and future directions in aquatic plant research in the early 21st century. It is a time of newly emerging
77 fields and the advancement of long-established research areas. The research is set against a
78 background of rapid environmental change that has been on-going for at least the last two centuries.
79 The pace of change is unremitting with demands on water resources set to increase globally
80 (Dudgeon et al., 2006; Vörösmarty et al., 2010). In the future the response of aquatic plant
81 dominated systems (e.g., shallow lakes and seagrass beds) to global temperature increases and
82 climatic extremes may well become a focus of research efforts. The in-depth understanding aquatic
83 botanists possess can only contribute positively to our understanding of how climate change will

84 perturb aquatic systems. Trends in aquatic plant research reflect the environmental pressures on
85 freshwater systems, legislative drivers, technical advances and developments in the wider fields of
86 ecology and environmental management.

87 Both national and international legislative drivers have had a clear impact on the direction of aquatic
88 plant research. In Europe, the implementation of the European Union (EU) Water Framework
89 Directive (WFD) (European Commission, 2000) led to a massive surge in research on monitoring
90 methods, their inter-calibration and the analysis of the resulting large multi-site datasets (Hering et
91 al., 2010). As the WFD implementation moves into its second phase, we now see a shift in focus to
92 restoration projects. We have learnt much during the implementation of this directive and it is likely
93 that we will see knowledge transfer from European scientists to colleagues in countries across the
94 globe. We see many countries in Asia and Africa now adopting reference based systems for
95 freshwater assessment (e.g., Kennedy et al., 2016).

96 The global financial crash in 2008 has exacerbated the difficulty in obtaining research funding in
97 many countries, and immediate output in terms of results reigns over the long-term understanding
98 of complex interactions and processes (Krugmann, 2012). In Europe we have also seen a reduction in
99 core funding for national research organizations and university researchers who work on aquatic
100 plant management issues and there are concerns that there will be a slow erosion of the research
101 base. The United Kingdom's decision in 2016 to leave the EU will likely have implications for site-level
102 conservation of aquatic plants under the EU Habitats Directive (Council of the European
103 Communities, 1992), although it is not yet clear what will replace the EU Directives in UK law. In the
104 USA, the Department of Energy has been planning to increase hydropower output by retro-fitting
105 turbines to pre-existing dams that are currently only used for flood control or water supply. While
106 the election in the USA of President Trump in 2016, who is a climate change sceptic and pro-fossil
107 fuel advocate, makes the implementation of this policy much less certain, it is worth noting that it did
108 have substantial cross-party support. If this work is undertaken it could reduce the USA's carbon

109 production and reduce its requirement to buy in fossil fuels from abroad, but careful assessment of
110 downstream impacts on aquatic plants and other taxa will need to be undertaken. In China the
111 current five-year plan, which has significant green policies, has energized the environmental sector
112 and led to substantial efforts to exchange knowledge with western countries. We hope this exchange
113 will lead to greater international collaboration between aquatic botanists in the future. In developing
114 countries there is a need too for the services of aquatic botanists where rapid population expansion
115 and the intensification of resource use have increased demands on water supplies and other natural
116 resources. A striking example is the numerous hydropower plants constructed in South America that
117 have caused profound changes in aquatic ecosystems, including macrophyte community composition
118 and patterns of colonization (e.g., Martins et al., 2013). Yet at the same time as these enormous
119 ecological changes, many developing countries also face reduced research funding and weakened
120 environmental legislation, which limits conservation efforts (Azevedo-Santos et al., 2017). The
121 conference attracted delegates from many developing countries and we would strongly encourage
122 their future participation.

123 While global financial trends and legislative drivers have affected the direction of research, technical
124 advances in survey and analytical methodologies have also been influential. Some established
125 techniques have become increasingly used in aquatic botany, for example, molecular biology and
126 stable isotope analysis. Recent reductions in the cost of stable isotope analysis have facilitated their
127 use. Developments in ecological modelling and computational biology have allowed aquatic plants to
128 be incorporated into models that can predict interactions between macrophytes and other
129 organisms (e.g., Wood et al., 2014; Stillman et al., 2015). The continued development of remote
130 sensing, drone technology and the software to interpret aerial photography, now allows new types
131 of spatial analysis. Moreover, the potential for drones to carry Light Detection and Ranging (LIDAR)
132 equipment could facilitate aquatic plant-sediment interaction studies. The rise of 'citizen science'
133 represents greater public participation in scientific research and has the potential to aid data
134 collection (McKinley et al., 2017). Similarly, the emergence of R (the free statistical software

135 environment) has encouraged the development and sharing of new analytical techniques (R Core
136 Development Team, 2016).

137 Aquatic botanists work from an especially strong position where the physiology of the plants is well
138 described and there is a deep knowledge of the plants' roles in system function. Aquatic plants have
139 many advantages over other aquatic biota as study organisms: they are sessile, they can be
140 accurately mapped, rapidly surveyed and cultured easily in the laboratory, and they are increasingly
141 being used by a wide variety of researchers. Although, historically, there was an assumption that
142 publishing aquatic botany studies in high impact journals was challenging, there is anecdotal
143 evidence that this is no longer the case.

144 Against this background of environmental and societal change, aquatic botanists met recently to take
145 stock of their discipline at the 14th International Symposium on Aquatic Plants, held in Edinburgh in
146 September 2015. The symposium series originally began as an aquatic weeds meeting but over time
147 the focus of the symposia changed as research and management interests altered. As our
148 understanding and appreciation of the different roles that macrophytes play has increased, so too
149 have the breadth of topics addressed at the symposia. The conference continues to attract delegates
150 involved in the practical management of aquatic systems and those working directly in research. The
151 synopsis which follows is based primarily on the conference output. The 14th International
152 Symposium was attended by 120 delegates from 28 countries and six continents, and featured 79
153 oral presentations in addition to over 30 poster presentations. Although the 2015 symposium and
154 the 13 preceding symposia were held in Europe, henceforth, every second symposium will be held
155 outside Europe to reflect the global nature of the subject and the attendees. Global regions often
156 diverge in approaches and attitudes towards macrophytes, for instance, weed management with
157 herbicides is well accepted in the United States yet largely prohibited in Europe. Therefore, truly
158 international conferences are vital in order to provide opportunities for global debates on such key
159 issues. The next conference will take place in February 2018 in New Zealand and it will be jointly held

160 with the Aquatic Plant Management Society of North America. The conference will also be supported
161 by our colleagues from China, where there has been an upsurge in research interest in aquatic plants
162 in recent years.

163 Traditionally, authors of conference presentations elaborated their contributions as full papers
164 published in a special issue of *Hydrobiologia* (e.g., Caffrey et al., 1996; Caffrey et al., 1999; Caffrey et
165 al., 2006; Pieterse et al., 2010; Ferreira et al., 2014). Thus, in this special issue of *Hydrobiologia*, we
166 present a number of studies of aquatic plants that comprise the peer-reviewed proceedings of the
167 14th International Symposium on Aquatic Plants. In the remainder of this paper, we present an
168 overview of current trends and future directions in aquatic plant research in the early 21st century.
169 We focus on the following key areas of study, each of which represented a key session during the
170 conference: (i) physical habitat interactions, (ii) riparian processes, (iii) ecological stoichiometry and
171 nutrient cycling, (iv) trophic interactions – focused on plant herbivore interactions, (v) community
172 responses to environmental change in space and time, (vi) aquatic plant monitoring, (vii)
173 ecotoxicology, (viii) restoration, (ix) the future of invasive species management and (x) fundamental
174 science.

175

176 **Overview of current trends and future directions in aquatic plant research**

177 *Physical habitat interactions and riparian processes*

178 The interactions between plants and water flow and sediments has been championed sporadically
179 for over forty years, but in the last decade work has accelerated as the importance of the
180 interactions for ecology, hydrology and fluvial geomorphology were fully realized. Plants influence
181 physical processes: transport of solutes, sediment deposition/resuspension, hydraulic conditions and
182 light transmittance (O'Hare, 2015; Klančnik et al., 2017). In turn the physical environment affects
183 macrophytes. Its effects are induced by mean velocity, turbulence and water level (O'Hare, 2015).

184 Macrophytes can be affected at scales, from individual plants to populations and communities. This is
185 exemplified by plant growth which is known to be influenced from the microscale, for example, cell
186 ultrastructure (Atapaththu et al., 2015), to macroscale, for example, biomechanical traits (Puijalón et
187 al., 2011; Schoelynck et al., 2014). Current developments in our understanding of these complex two-
188 way interactions between aquatic vegetation and physical factors are tightly linked to fluid dynamics
189 modelling (Marjoribanks et al., 2014; Verschoren et al., 2016).

190 While aquatic botanists have tended to focus on aquatic macrophytes, geographers have been
191 examining both instream and riparian vegetation. An especially exciting development is the
192 realization that vegetation fringing a river's edge has a substantial influence on fluvial
193 geomorphological processes. In effect, nearshore plants (emergent and submerged) help engineer
194 river form (Gurnell, 2014; Gurnell et al., 2016). This has significant practical implications as
195 alterations to hydrology and fluvial geomorphology are as widespread as nutrient pollution in
196 Europe, effecting approximately half of all water bodies (Kristensen, 2012). We speculate that this
197 reflects an unmeasured but global trend as evidenced by the contributions from Africa and Asia to
198 this session on impacts of flow disturbance and regulation. Regulation by hydropower dams
199 influences the colonization rates of aquatic and riparian vegetation, with synergic impacts when
200 rivers are subjected to sediment removal or impaired by storage reservoirs (Aguiar et al., 2016). Such
201 disturbances create ecosystems prone to alien plant invasions, and regulation alters the growth
202 trajectories, composition and complexity of native communities (Bunn & Arthington, 2002). During
203 the conference the concerning case of Podostemaceae in West-Africa (strictly aquatic angiosperms)
204 was highlighted, where six species are critically endangered and four species have become extinct
205 due to altered flows (personal communication). Such issues can be overcome: for example,
206 implementing environmental flows that inundate geomorphological structures and create slack
207 waters helped with the restoration of regulated rivers by enhancing recruitment and colonization
208 (Rivaes et al., 2015; Souter et al., 2014). While most research in this field focuses on rivers, data from
209 the UK and Denmark indicate artificial water-level fluctuations in lakes affects macrophytes (e.g.,

210 Baastrup-Spohr et al., 2015; May & Spears, 2012; Smith et al., 1987), and that shoreweed (*Littorella*
211 *uniflora* (L.) Asch.) has potential as a model species in ecological studies of both lake productivity and
212 morphometry (e.g., Baastrup-Spohr et al., 2016; Robe & Griffiths, 2000).

213 In due course, this field of research has the potential to produce novel tools for management,
214 especially nature-based solutions to flooding, and fresh insights into the ecology of aquatic plants. A
215 research effort equivalent to that which elucidated the basic mechanisms of lake eutrophication
216 (Vollenweider, 1968) will likely be required to resolve these major research questions. With this
217 realization will come a far greater appreciation of the role of both instream and riparian vegetation in
218 engineering physical habitats. Further collaborative research between geographers and ecologists
219 will emerge.

220

221 *Ecological stoichiometry and nutrient cycling*

222 Ecological stoichiometry bridges ecology and ecosystem functions or processes at various levels,
223 from individuals to communities. Despite clear theories (Elser et al., 2000), elemental requirements
224 and the influence of environmental factors on nutrient uptake seem more complex for aquatic plant
225 systems. At a global scale, silica is a nutrient which is in surprisingly short supply in marine
226 environments requiring frequent inputs from freshwater systems. The role of macrophytes and other
227 primary producers in influencing silica delivery is gaining increasing interest and its accumulation in
228 macrophytes may be a functional trait that enables them to adapt to environmental conditions
229 (Schoelnyck & Struyf, 2016). At local scales, macrophytes strongly influence their physico-chemical
230 environment. Aquatic weed mats may constitute important hotspots for greenhouse gas emissions in
231 temperate shallow lakes, but wetland vegetation can also assist in nitrogen assimilation (Ribaudó et
232 al., 2017; Volkman et al., 2016). Yet, the relation between environmental nutrient availability and
233 macrophyte nutrient content is often less clear. For example, research, presented during the
234 conference, showed that upland streams with proliferations of pond water-crowfoot (*Ranunculus*

235 *peltatus* L.) tend to have a low N:P ratio at overall very high nitrogen and phosphorus concentrations
236 (personal communication). Although intra-specific C:N:P stoichiometry of submerged macrophytes
237 correlates to sediment and water nutrient availability, inorganic carbon availability may also play a
238 strong role in their nitrogen-based metabolism (Hussner et al., 2016). Further research, presented
239 during the conference, found that macrophyte tissue nutrient concentrations appear more closely
240 related to plant growth form than to phylogeny (personal communication).

241

242 *Trophic interactions – focused on plant herbivore interactions*

243 Since the seminal paper by Lodge (1991) on herbivory of aquatic plants, researchers have been
244 devoting considerable attention to plant-herbivore interactions in aquatic ecosystems. Now, in the
245 early 21st century, it has now been demonstrated, unequivocally, that herbivores can provide strong
246 top-down regulation of macrophyte beds (Bakker et al., 2016; Wood et al., 2017a). These top-down
247 mechanisms can interact with recovery from stress; for example, recovery of macrophyte beds after
248 eutrophication attracts herbivorous water birds, but the colonization process can be hampered by
249 strong vertebrate herbivory. In contrast, smaller invertebrate grazers may assist recovery of
250 eutrophic systems. They stimulate submerged macrophyte growth and establishment by consuming
251 periphyton (instead of the tougher macrophytes) that would otherwise reduce light availability for
252 macrophytes (Bakker et al., 2016; Wood et al., 2017a).

253 Recognizing the importance of herbivory opens new research avenues by scaling up from
254 macrophyte beds to aquatic ecosystem functioning, as herbivores affect methane emission, carbon
255 cycling and regime shifts (Hidding et al., 2016). Furthermore, there is an urgent need to predict how
256 global change will alter trophic interactions as a result of exotic species invasions (Redekop et al.,
257 2017), temperature rises (Zhang et al., 2017) or changes in hydrological patterns (Wood et al.,
258 2017b). Finally, current and future conservation challenges lay in predicting and managing the
259 consequences of recovery of larger vertebrate herbivores, through re-introductions such as the

260 Eurasian beaver (*Castor fiber* L.) in Europe (e.g., re-wilding), as well as by strong local herbivore
261 population increases in species such as mute swans (*Cygnus olor* Gmelin).

262

263 *Community responses to environmental change in space and time*

264 The study of the responses of aquatic plant communities to environmental change in space and time
265 is both a mature field of research and one with critical new questions being asked. Current research
266 effort has seen a continued focus on the role of bottom-up regulation through environmental drivers
267 (e.g., Fernández-Aláez et al., 2017) and competitive processes between macrophyte species (e.g.,
268 Gérard & Triest, 2017; Nunes & Camargo, 2017) in shaping aquatic plant community composition.
269 Our understanding of how connectivity can influence floodplain macrophyte populations has now
270 matured to the point where scenario modelling is feasible, for example, on the Murray-Darling
271 system in Australia where species richness of floodplain plant communities can be predicted as a
272 function of channel connectivity in the watershed (Campbell et al., 2014). Furthermore, recent
273 studies of aquatic plant responses to floods in large floodplains have offered support for the flood
274 homogenization hypothesis (Thomaz et al., 2007). Floodplain inundation has received less attention
275 on smaller systems; however, comparative assessments of the importance of different aquatic
276 habitats to a Scottish regional flora confirmed the importance of riverine backwaters (Keruzoure et
277 al., 2013), a habitat that had been previously neglected. That study illustrated an increasing
278 awareness of spatial processes operating beyond individual sites, and the associated issue of scale-
279 dependent responses. Thus, for example, the effects of land use on macrophyte richness in lakes are
280 scale-dependent and are of greater importance at small spatial scales relative to the influence of
281 hydrological connectivity (O'Hare et al., 2012). Looking beyond the immediate is one of the most
282 powerful approaches of space and time analyses, and frequently produces insightful findings. Not
283 only do we see this in relation to hydrological connectivity but also in legacy signals, for example, the
284 lakes of northwest Europe are geologically young due to their glacial origins, with the signal of
285 glaciation still evident in the composition of their flora (Alahuhta et al., 2017).

286

287 *Aquatic plant monitoring*

288 Changes in the abundance or composition of an aquatic plant community are often obvious signals of
289 alteration in the ecological condition of a lake or stream. In fact, a recent review of assessment
290 methods used to implement the EU Water Framework Directive showed that the majority of
291 methods are based on macroscopic plants (28% of all methods), followed by benthic invertebrates
292 (26%) (Birk et al., 2012). Moreover, unlike many other biological indicators, macrophytes are equally
293 good at detecting eutrophication/organic pollution and hydrological/morphological changes (Birk et
294 al., 2012). Historically, surveys of abundance and composition were challenging in terms of both field
295 effort and taxonomic ability. As identified at this symposium, improved methods for mapping
296 abundance and composition of aquatic vegetation are now becoming available: high-resolution aerial
297 images of lake and rivers taken with unmanned aircraft systems permit identification, mapping and
298 abundance estimates of non-submerged species while near-infrared-sensitive DSLR cameras can be
299 used to map spatial distribution and depth of submerged species (e.g., Visser et al., 2015).

300 Research is continuing to show that community metrics (e.g., cover, diversity and richness) and
301 species frequency of occurrence are often related to water quality, lending support for the
302 development of macrophyte-based indices for classification of fresh waters and brackish water
303 ecosystems and seagrass beds (Spears et al., 2016). Although many macrophyte indices are based
304 only on hydrophytes due to their dependency on the quality of the aquatic environment, the
305 importance of helophytes has been demonstrated as indicators of the eutrophication process, for
306 example, in the bioassessment of lowland lakes (Kolada, 2016). Biochemical measurements may also
307 provide a new tool for bioassessment: for example, during the conference evidence was presented
308 that ^{15}N and C:N values from caged duck weed (*Spirodela* sp.) were found to relate to the proximity
309 and timing of sewage manure or fertilizer inputs into rivers in South Africa (personal
310 communication). Despite encouraging advances in both methods for mapping aquatic vegetation and

311 approaches for assessing water quality, physical factors such as hydrological modifications to water
312 courses or inter-annual variation in water levels can confound the relationship between macrophyte
313 occurrence and water quality, necessitating caution when deciding the status of a water body based
314 on limited (temporal or spatial) macrophyte data.

315

316 *Ecotoxicology*

317 The banning of herbicides for use in aquatic systems across the EU resulted in a shift in research
318 away from studies on the efficacious use and impacts of pesticides in controlling aquatic plants. A
319 strong research focus remains, however, on the effects of pesticides and other pollutants derived
320 from terrestrial systems on aquatic plants (Coutris et al., 2011; King et al., 2016).

321 This was the first time an ecotoxicology session was held at the conference and it focused on linking
322 ecological studies with chemical risk assessment, with the overarching aims to make assessment
323 methods more realistic and to identify emerging plant-contaminant issues. The work presented in
324 the session indicated a continuing shift toward the use of more realistic test species. To refine risk
325 assessments, laboratory studies used more realistic exposure conditions than standard techniques;
326 an example was presented at the conference in which pesticide exposure pulses, typical of running
327 water bodies, caused less harm to gibbous duckweed (*Lemna gibba* L.) than standard exposure
328 conditions (personal communication). A higher tier approach, using mesocosms, proved effective
329 when investigating indirect effects of chemicals on plant populations and communities. On plant-
330 contaminant issues, the interaction between chemical contaminants and other stressors was evident;
331 for example, evidence presented at the conference showed that the stoichiometry (C:N:P) of
332 Eurasian water milfoil (*Myriophyllum spicatum* L.) was not only influenced by light and nutrients, but
333 also by herbicides and the metalloid arsenic (personal communication). Field monitoring and
334 biomarker assays revealed a significant relationship between the decline of dwarf eelgrass (*Zostera*

335 *nottei* Hornem.) in the Vaccarès lagoon in France and its exposure to chemical contaminants
336 including metals and pesticides (personal communication).

337

338 *Restoration*

339 Management of aquatic macrophytes is an essential part of freshwater restoration projects (Phillips
340 et al., 2016). Macrophyte restoration can have multiple benefits, for example, supporting
341 endangered waterfowl and fish species or limiting the spread of invasive species, such as Nuttall's
342 waterweed (*Elodea nuttallii* (Planch.) H. St. John), in Europe. To successfully restore macrophytes,
343 consideration of the following factors can be helpful: the genetic background of macrophyte
344 population used, native seed bank viability, control of herbivores and, in the case of eutrophic lakes,
345 the use of geo-engineering tools which reduce internal P loading, (Combroux et al., 2001; Guittonny-
346 Philippe et al., 2015; Hussner et al., 2017). Restoration science is still under development and new
347 data are desirable; monitoring using macrophyte growth forms can provide a cost-effective tool for
348 evaluating the effect of individual restoration projects while long-term records of macrophyte
349 dynamics can provide valuable information for assessment of broader, global scale change (Ecke et
350 al., 2016).

351 Throughout the history of this symposium the loss of lake macrophytes due to eutrophication has
352 been a core issue. Now, in the 21st century, research on the mechanisms of eutrophication continues
353 but with a somewhat different emphasis; we now see more work presented on systems that are in
354 recovery. Research has turned to drivers that influence the recovery trajectory; for example, trophic
355 interactions involving herbivores, which have been somewhat neglected in the past, and issues
356 associated with the role of invasive species.

357

358 *The future of invasive species management*

359 The spread of invasive species and decline in biodiversity is associated with accelerating
360 globalisation, human migration and increasing pressures on freshwater supplies; however, whilst
361 challenging, successful invasive species management has been demonstrated using combinations of
362 lake and aquatic plant-based approaches matched with appropriate management tools (Havel et al.,
363 2015). In some cases, regime shifts amongst aquatic flora, such as floating to submerged vegetation,
364 may follow from the use of classical biological control (Cuda et al., 2008; Bakker et al., 2016). Yet in
365 other cases invasive aquatic plants may not be considered the primary drivers of change, adding to
366 debate surrounding the anthropocentric interpretation of benefits (vs detriments) for many non-
367 native species in impacted habitats. Increasingly, there is a focus towards, arguably, bigger more
368 'threatening' issues such as climate change in the management of invasive species that could result
369 in greater impacts from existing nuisance aquatic plants at a global level. For example, alien aquatic
370 species can reduce the diversity of native seedbanks, thereby, jeopardising future restoration.
371 Targeted experimental work in both field and laboratory conditions is allowing researchers to
372 understand competitive interactions between native and invasive species (Gérard & Triest, 2017).
373 Continued research investment is required to manage the spread of invasive species. The
374 development of new knowledge and techniques will likely provide new opportunities in the future
375 for more effective invasive species management and aquatic restoration (e.g., Lozano & Brundu,
376 2017).

377

378 *Fundamental science*

379 Applied aspects dominate much of current aquatic plant research, such as aquatic plant populations'
380 restoration, monitoring and ecological quality assessment, and different forms of response of aquatic
381 plants to human disturbance or novel ways to control plant overgrowth. Nonetheless, fundamental
382 science is often the basis for management actions, and indeed many failures relate to the lack of
383 taxonomic resolution, the misunderstanding of species autecology and role in the ecosystem, or

384 undefined tolerance responses over the disturbance gradient. Fundamental science, thus, provides,
385 in large part, the key to successful plant management.

386 In spite of the development of genetic and cytoplasmic tools, morphological traits are still relevant as
387 well as the role of population traits, for example, for dispersal and survival. Many ecosystem
388 processes are also driven by vegetation, shaping succession of both plant and animal communities, in
389 the short- and long-terms, in which interspecific competition and environmental constraints
390 determine the end point. Understanding such processes is fundamental for biomanipulation,
391 ecosystem restoration and the proper management of both constructed and natural wetlands.

392

393 **Conclusions**

394 Both the conference presentations and this resulting special issue of *Hydrobiologia* reflect the broad
395 discipline that aquatic botany has become over the last century. Research interest in aquatic plants
396 range from the use of aquatic plants as model organisms, to the roles of aquatic plants within
397 ecosystems and to the conservation of aquatic plants themselves. Furthermore, the range of
398 countries and continents represented by conference delegates and authors of papers in this special
399 issue illustrate the global relevance of aquatic plant research in the early 21st century.

400 Currently, the International Symposia on Aquatic Plants are dominated by research on freshwater
401 taxa, and in particular those found in shallow lakes. However, greater integration of freshwater
402 macrophyte and marine seagrass research efforts, and their associated literatures, would benefit our
403 overall understanding of aquatic plant biology, management and conservation. Whilst aquatic plant
404 species may differ across ecotones, the processes that shape aquatic plant assemblages, such as
405 bottom-up and top-down control and competitive processes, will share common elements. For
406 example, recent research into herbivory on aquatic plants has synthesized information from
407 freshwater, brackish and marine ecosystems (e.g., Bakker et al., 2016; Wood et al., 2017a).

408 Our understanding of aquatic plants, the range of scientific issues being addressed and the range of
409 techniques available to researchers, have all arguably never been greater. This is to be welcomed, as
410 the challenges facing researchers and practitioners have also never been more pressing. Climate
411 change, rising human demand for resources including water, pollution of freshwater resources, the
412 spread of invasive non-native species, land-use changes and intensification, together with the
413 degradation, fragmentation and loss of aquatic habitats, all present huge challenges to the
414 conservation and management of both aquatic plants and the ecosystems in which they are found
415 (Dudgeon et al., 2006; Vörösmarty et al., 2010; Short et al., 2016). The 15th International Symposium
416 on Aquatic Plants, to be held in New Zealand in February 2018, will be an excellent opportunity to
417 assess our progress in meeting these challenges and to identify the areas in which we need to do
418 more.

419

420 **Acknowledgements**

421 We are grateful to André Padial, Baz Hughes, and two anonymous reviewers for their helpful
422 comments on earlier drafts of this manuscript.

423

424 **References**

425

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