

**SPECIAL ISSUE ARTICLE**

WILEY

# The ecology of the endemic quillwort *Isoëtes malinverniana*: From basic research to legal and in situ conservation

Thomas Abeli<sup>1</sup> | Cecilio F. Caldeira<sup>2</sup> | Elena Barni<sup>3</sup> | Consolata Siniscalco<sup>3</sup> |  
Valentina Parco<sup>4</sup> | Graziano Rossi<sup>5</sup><sup>1</sup>Department of Sciences, University of Roma Tre, Rome, Italy<sup>2</sup>Instituto Tecnológico Vale (ITV), Belém, Brazil<sup>3</sup>Department of Life Science and Systems Biology, University of Torino, Torino, Italy<sup>4</sup>Parco Lombardo della Valle del Ticino, Pontevecchio di Magenta, Italy<sup>5</sup>Department of Earth and Environmental Sciences, University of Pavia, Pavia, Italy**Correspondence**Prof. Thomas Abeli, Department of Sciences, University of Roma Tre, Viale Guglielmo Marconi 446, 00146, Rome, Italy.  
Email: thomas.abeli@uniroma3.it**Funding information**

Excellence Departments, MIUR-Italy

**Abstract**

1. Scientific publications on the conservation of threatened species can drive practical conservation solutions for endangered species. Yet, a posteriori assessment of the impact of such publications is rarely seen in the scientific literature.
2. The impact of two articles published in *Aquatic Conservation: Marine and Freshwater Ecosystems* (AQC) on the conservation of the endangered quillwort *Isoëtes malinverniana* is assessed. The articles were the result of a 10-year study on the focal species that eventually led to the first reintroduction of *I. malinverniana*. The first article described the development of a cost-effective model for the selection of suitable reintroduction sites for the species. The second article provided a summary of the techniques used to reintroduce the species and included techniques of ex situ propagation, recipient site preparation, planting methods, and monitoring.
3. This article reviews the practical conservation actions for *I. malinverniana* that followed the publication of two AQC papers and how they may affect research and conservation for other quillworts and aquatic macrophytes.
4. The results were surprising and went well beyond the initial expectations of the authors. Both AQC publications stimulated the conservation of *I. malinverniana* from different points of view. They contributed by informing scientists and policymakers of the risk of extinction of this species, leading to the establishment of a new protected area in Piedmont (northern Italy).
5. Our published data represent a sound starting point for funding opportunities in the context of the European Union LIFE programme. Further impacts include an expansion of knowledge on oligotrophic habitat management, the assessment of conservation status, and the education of the general public, with the last of these greatly enhanced by the two ex situ collections created in the botanic gardens of Tourin and Pavia. Interestingly, other authors are now using our approach in research and conservation on other endemic and endangered quillworts worldwide.

**KEYWORDS**

agriculture, conservation evaluation, habitats directive, macrophytes, nutrient enrichment, stream

## 1 | INTRODUCTION

*Isoëtes malinverniana* Ces. & De Not. is a critically endangered quillwort endemic of Lombardy and Piedmont (northern Italy). Its range in the plain of the River Po overlaps with one of the most densely populated areas of Europe, characterized by intensive agriculture. In this area it occupies the artificial and semi-natural channels used to supply water to rice paddies and corn fields. Originally, these channels contained oligotrophic waters deriving from springs and rivers. The use of chemicals (herbicides and fertilizers) in the conventional cultivation of rice and the mechanical removal of vegetation from the bottom of the channels represent the main threats for the species (Barni et al., 2013). *Isoëtes malinverniana* is currently listed as Critically Endangered according to the International Union for Conservation of Nature (IUCN) Red List (Orsenigo et al., 2018), and is legally protected at the local level (Piedmont and Lombardy) and also by the European Habitats Directive (Council of the European Communities, 1992). Its occurrence in the heart of the rice district of Europe presents difficulties in undertaking practical conservation measures that conflict with the high economic interests of the area.

Two articles published in *Aquatic Conservation: Marine and Freshwater Ecosystems* (AQC) on the conservation of *I. malinverniana* are discussed here because of their past and present impacts on the conservation of the focal species that go well beyond the original scope of the research that produced them. Important outcomes of this research are further publications on the species arising from a multidisciplinary approach carried out in the last 10 years (Barni et al., 2013; Gentili et al., 2010).

## 2 | SUMMARY OF THE AQC PUBLICATIONS

The first article (Abeli, Barni, Siniscalco, Amosso, & Rossi, 2012) used data from an ecological study to identify cost-effective and rapidly measurable water quality indicators for selecting suitable sites for the reintroduction of *I. malinverniana*. The study of the ecology of *I. malinverniana* showed that this species is typical of oligotrophic water, characterized by low values of electrical conductivity and slightly basic pH levels (Barni et al., 2013). These two ecological parameters were introduced in a logistic model that could be used for screening several potential reintroduction sites and for indicating which sites should be disregarded and which should be analysed more thoroughly. The model was shown, a posteriori, to have been overly restrictive in the choice of suitable release sites, probably because of the small sample size, although the approach is still applicable to quillworts other than *I. malinverniana*.

The second article (Abeli, Cauzzi, Rossi, Pistoja, & Mucciarelli, 2018) reported on the outcome of the first reintroduction attempt of *I. malinverniana* (the second reintroduction of a quillwort worldwide) 1 year after the release of plants in the recipient site. The

article provided a summary of the techniques used to propagate the species ex situ, to select and prepare the recipient site, and to solve the problem of the uprooting of individuals by the water current. Abeli et al. (2018) also suggested how the information gathered during a 10-year multidisciplinary study (involving genetics, ecology, and reproductive biology) on the focal species could be applied to practical conservation actions.

These two publications together with a third article published in a different journal (Barni et al., 2013) represent key milestones in the conservation of *I. malinverniana* and are stepping stones for the conservation of other endangered quillworts (e.g. *Isoëtes sabatina*, Troia & Azzella, 2013; *Isoëtes cangae*, Caldeira et al., 2019). The impacts of these articles on the focal species, and on other threatened species within the genus *Isoëtes* and beyond, include assessments of the conservation status of species at the global level, fundraising, policy, species and habitat management, and the application of scientific methods, and is likely to inform the future conservation of the species, as discussed below.

## 3 | IMPACTS OF THE AQC PUBLICATIONS

The main impact of Abeli et al. (2012) together with Barni et al. (2013) was the understanding that *I. malinverniana* was near to becoming extinct. Based on the model developed by Abeli et al. (2012), a later study revealed that none out of nine potential sites for the reintroduction was suitable for the species (Piceni, 2015). This, along with a further contraction of the species range recorded in 2011–2013, stimulated conservation initiatives at different political and administrative levels. The species was included in the first phase of red listing of the Italian flora by the red listing committee appointed by the Italian Botanical Society and the Ministry of Environment (Rossi et al., 2013). The species was then adopted as a case study for developing a unified field monitoring form for Italian policy species (i.e. those included in the Habitats Directive 92/43/EEC; Ercole, Giacanelli, Bacchetta, Fenu, & Genovesi, 2016). The Lombardy Region included *I. malinverniana* among the target species of an important LIFE project (GESTIRE 2020; <http://www.naturachevale.it/il-progetto/life-gestire-2020>), partially funded by the European Union, which also promoted important links with other funding schemes dedicated to sustainable agriculture (e.g. the Rural Development Plan). Moreover, two important ex situ collections were created and are currently maintained at the Botanic Garden of the University of Turin and at the Botanic Garden of the University of Pavia. These two ex situ collections provide the opportunity to enhance the knowledge of citizens about the loss and conservation of biodiversity. The article also increased the awareness of key stakeholders about the need for in situ conservation of *I. malinverniana*. Thanks to the field-based research, resulting in the papers quoted herein, the current range of the species was accurately mapped. Although the species was designated as a 'plant species of community interest' in need of strict

protection, it was soon realized that only one of the sites with an extant population was designated as a Site of Community Importance (Council of the European Communities, 1992; European Commission, 2019). As a consequence and as most sites are located in Piedmont, the local Government of Regione Piemonte (D.G.R. 20/04/2017, n. 33–4,914) proposed the creation of a Site of Community Importance, named pSCI IT1120026 'Stazioni di *Isoëtes malinverniana*', which was recently adopted by the Commission Implementing Decision (EU) 2019/18 of 14 December 2018. Information about the ecological requirements of the species and the management of sites gathered in the AQC papers will constitute a suitable base to establish the mandatory conservation measures.

In parallel, the Ticino Natural Park started a project for the reintroduction of the species in which the data derived from the ecological study published by Abeli et al. (2012) were essential for the feasibility and reliability of such a project. Both articles are cited in the recent action plan drawn up by the Regional Administration of Lombardy for species of European Interest, including *I. malinverniana*, that integrated the published data into local management policy for the species (Regione Lombardia, 2019a,b).

The multidisciplinary conservation approach adopted for *I. malinverniana*, and described in Abeli et al. (2018), is of paramount importance to drive conservation programmes for further isoëtoid species. Therefore, similar strategies have been employed after the recent description of the narrow endemic *I. cangae* from eastern Amazonia (de Pereira, Salino, Arruda, & Stutzel, 2016). A single population of *I. cangae* was found in an upland lake of the Carajás mountain range (Brazil). Following the approach used for *I. malinverniana*, extensive morphological and genetic characterization of the species were conducted (Nunes, Oliveira, Guimarães, Giuliotti, & Caldeira, 2018). Propagation techniques to obtain a large number of sporelings from very few (four) adult plants were also developed (Caldeira et al., 2019). In addition, limnological investigations involving physical, chemical, and biological conditions in the site of occurrence, and in four other similar lakes nearby were undertaken (Sahoo et al., 2017).

## 4 | CONCLUSIONS

The conservation status of *I. malinverniana* remains critical, despite research that has contributed to our understanding of various aspects of the life history and ecology of this species. The two articles discussed here are evidence of the ability of research to inform and improve different conservation techniques for the species (both ex situ and in situ), but demonstrable effects on the conservation status of *I. malinverniana* are poor. The reasons for this include the lack of pristine areas within the historical range of the species and very slow changes towards sustainable agricultural practices at a regional scale. Nevertheless, Abeli et al. (2012) have provided habitat quality targets for the conservation of *I. malinverniana*, and both AQC papers may have broader impacts on future conservation actions for other quillworts. The genus *Isoëtes* includes more than 200 taxa, most of which are endemic and highly threatened (with 25 assigned to an

IUCN threat category out of the 60 assessed, with 12 species listed as Critically Endangered in the IUCN Red List; <https://www.iucnredlist.org>; see also Brunton & Troia, 2018).

In particular, *I. malinverniana* is a species of European importance, being listed in Annex II of the Habitats Directive (Council of the European Communities, 1992). Species listed in the Directive can benefit from funds from the European Union for their conservation, under the LIFE Programme (<https://ec.europa.eu/easme/en/life>). LIFE projects tend to be ambitious and involve large teams of representatives from a range of organizations, but the research activity is very limited, and the funds are dedicated to practical conservation actions, such as habitat management and reintroduction. Consequently, the science underpinning the conservation actions of LIFE projects must already be available in order to make a LIFE proposal sound and to gain funding. The two AQC articles discussed here constitute a solid knowledge base for any future LIFE application dedicated to the conservation of *I. malinverniana* and other organisms in oligotrophic fresh waters in the European Union.

A final comment concerns the difficulties to publish articles on narrow endemic species in high-impact scientific journals. Studies on narrow endemic species are often characterized by small datasets, which in turn affect the possibility of applying sound statistical methods for analysing the data. Moreover, studies on endemic species may be of local interest only, compared with wider studies reaching a broader audience. Nevertheless, as demonstrated in this and other papers in this special issue, scientific articles reporting on the ecology, biology, conservation, and management of endemic species may have direct positive impacts on their conservation. Initiatives to make ecological information available for conservation, undertaken by established journals, such as AQC, and new journals, such as *Ecological Solutions and Evidence* of the British Ecological Society (Cadotte, Jones, & Newton, 2019), are therefore welcome.

## ACKNOWLEDGEMENTS

The authors acknowledge the two editors, Philip Boon and John Baxter, for the invitation to contribute to this special issue. The Grant of Excellence Departments, MIUR-Italy (ARTICOLO 1, COMMI 314–337 LEGGE 232/2016), is gratefully acknowledged for support for one of the authors (Prof. Thomas Abeli). Moreover, thanks are due to Parco Regionale del Ticino (Magenta, Milano) for the financial support for our studies on *Isoëtes malinverniana*. The authors are also grateful to Dr Sarah E. Dalrymple (Liverpool John Moores University) for linguistic revision of the article.

## ORCID

Thomas Abeli  <https://orcid.org/0000-0003-3096-2035>

Cecilio F. Caldeira  <https://orcid.org/0000-0003-4762-3515>

## REFERENCES

- Abeli, T., Barni, E., Siniscalco, C., Amosso, C., & Rossi, G. (2012). A cost-effective model for preliminary site evaluation for the reintroduction of a threatened quillwort. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 22, 66–73. <https://doi.org/10.1002/aqc.1246>

- Abeli, T., Cauzzi, P., Rossi, G., Pistoja, F., & Mucciarelli, M. (2018). A gleam of hope for the critically endangered *Isoëtes malinverniana*: Use of small-scale translocations to guide conservation planning. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 28, 501–505. <https://doi.org/10.1002/aqc.2848>
- Barni, E., Minuzzo, C., Gatto, F., Lonati, M., Abeli, T., Amosso, C., ... Siniscalco, C. (2013). Estimating influence of environmental quality and management of channels on survival of a threatened endemic quillwort. *Aquatic Botany*, 107, 39–46. <https://doi.org/10.1016/j.aquabot.2013.01.009>
- Brunton, D. F., & Troia, A. (2018). Global review of recent taxonomic research into *Isoëtes* (Isoëtaceae), with implications for biogeography and conservation. *Fern Gazette*, 20, 309–333.
- Cadotte, M. W., Jones, H. P., & Newton, E. L. (2019). Making the applied research that practitioners need and want accessible. *Ecological Solutions and Evidence*, 1, e12000. <https://doi.org/10.1002/2688-8319.12000>
- Caldeira, C. F., Abranches, C. B., Gastauer, M., Ramos, S. J., Guimarães, J. T. F., Pereira, J. B. S., & Siqueira, J. O. (2019). Sporeling regeneration and ex situ growth of *Isoëtes cangae* (Isoëtaceae): Initial steps towards the conservation of a rare Amazonian quillwort. *Aquatic Botany*, 152, 51–58. <https://doi.org/10.1016/j.aquabot.2018.10.001>
- Council of the European Communities. (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Official Journal of the European Communities*, L206, 7–50.
- de S. Pereira, J. B., Salino, A., Arruda, A., & Stutzel, T. (2016). Two new species of *Isoëtes* (Isoëtaceae) from northern Brazil. *Phytotaxa*, 272, 141–148. <https://doi.org/10.11646/phytotaxa.272.2.5>
- Ercole, S., Giacanelli, V., Bacchetta, G., Fenu, G., & Genovesi, P. (2016). *Manuali per il monitoraggio di specie e habitat di interesse comunitario (Direttiva 92/43/CEE) in Italia: specie vegetali*. Roma: ISPRA, Serie Manuali e linee guida, 140/2016.
- European Commission. (2019). Commission Implementing Decision (EU) 2019/18 of 14 December 2018 adopting the twelfth update of the list of sites of Community importance for the Continental biogeographical region (notified under document C(2018) 8528). *Official Journal of the European Communities*, L7, 77–286. Available at: <https://eur-lex.europa.eu/oj/2019/direct-access.html?ojYear=2020>
- Gentili, R., Abeli, T., Rossi, G., Li, M., Varotto, C., & Sgorbati, S. (2010). Population structure and genetic diversity of the threatened quillwort *Isoëtes malinverniana* and implication for conservation. *Aquatic Botany*, 93, 147–152. <https://doi.org/10.1016/j.aquabot.2010.05.003>
- Nunes, G. L., Oliveira, R., Guimarães, J. T. F., Giulietti, A. M., Caldeira, C. F., Vasconcelos, S., ... Oliveira, G. (2018). Quillworts from the Amazon: A multidisciplinary populational study on *Isoëtes serracarajensis* and *Isoëtes cangae*. *PLoS ONE*, 13, E0201417. <https://doi.org/10.1371/journal.pone.0201417>
- Orsenigo, S., Montagnani, C., Fenu, G., Gargano, D., Peruzzi, L., Abeli, T., ... Rossi, G. (2018). Red Listing plants under full national responsibility: Extinction risks and threats in the vascular flora endemic to Italy. *Biological Conservation*, 224, 213–222. <https://doi.org/10.1016/j.biocon.2018.05.030>
- Piceni, G. (2015). Individuazione di siti potenzialmente idonei alla reintroduzione di *Isoetes malinverniana* Ces. et De Not. (BSc Thesis). University of Pavia, Italy.
- Regione Lombardia. (2019a). Piano d'azione per la flora in direttiva Habitat (allegati II e IV). Available at: <https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/Enti-e-Operatori/ambiente-ed-energia/Parchi-e-aree-protette/biodiversita-e-reti-ecologiche/piani-azione-delle-specie-di-interesse-comunitario/piani-azione-delle-specie-di-interesse-comunitario>. (Accessed July 2019).
- Regione Lombardia. (2019b). Piano d'azione per la flora in direttiva Habitat: misure e interventi di conservazione. Available at: <https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/Enti-e-Operatori/ambiente-ed-energia/Parchi-e-aree-protette/biodiversita-e-reti-ecologiche/piani-azione-delle-specie-di-interesse-comunitario/piani-azione-delle-specie-di-interesse-comunitario> (Accessed July 2019).
- Rossi, G., Montagnani, C., Gargano, D., Peruzzi, L., Abeli, T., Ravera, S., ... Orsenigo, S. (Eds.) (2013). *Lista Rossa della Flora Italiana. 1. Policy species e altre specie minacciate*. Roma, Italy: Comitato Italiano IUCN e Ministero dell'Ambiente e Della Tutela del Territorio e del Mare.
- Sahoo, P. K., Guimarães, J. T. F., Souza-Filho, P. W. M., Bozelli, R. L., Araujo, L. R., de Souza Menezes, R., ... Dall'Agnol, R. (2017). Limnological characteristics and planktonic diversity of five tropical upland lakes from Brazilian Amazon. *Annales de Limnologie - International Journal of Limnology*, 53, 467–483. <https://doi.org/10.1051/limn/2017026>
- Troia, A., & Azzella, M. M. (2013). *Isoëtes sabatina* (Isoëtaceae Lycopodiophyta), a new aquatic species from central Italy. *Plant Biosystems*, 147, 1052–1058. <https://doi.org/10.1080/11263504.2013.782902>

**How to cite this article:** Abeli T, Caldeira CF, Barni E, Siniscalco C, Parco V, Rossi G. The ecology of the endemic quillwort *Isoëtes malinverniana*: From basic research to legal and in situ conservation. *Aquatic Conserv: Mar Freshw Ecosyst*. 2020;30:1719–1722. <https://doi.org/10.1002/aqc.3351>