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SHORT COMMUNICATION

First record of two invasive aquatic weeds *Ludwigia repens* (*Onagraceae*) and *Myriophyllum aquaticum* (*Haloragaceae*) in Poland

Artur Pliszko[1]

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Abstract
The aquarium trade has contributed to the introduction of many invasive alien plant species that threaten the structure and functioning of aquatic ecosystems around the world. In this study, I present the first Polish record of *Ludwigia repens* (*Onagraceae*) and *Myriophyllum aquaticum* (*Haloragaceae*), two invasive alien aquatic plants cultivated in aquaria. The plants were found on the shores and in the waters of an artificial pond in Kraków, southern Poland, in 2024. The location and abundance of both species are documented, and their introduction pathway and naturalization potential are discussed. Moreover, since *M. aquaticum* belongs to the invasive alien species of European Union concern and requires rapid eradication, its occurrence was reported to the Kraków City Office, following Polish law.

Keywords Aquarium plant trade · Biological records · Central Europe · Invasive alien species

Introduction

The aquarium trade is considered one of the main sources of invasive alien plant species in aquatic ecosystems in the world (Padilla and Williams 2004; Strecker et al. 2011; Nunes et al. 2015; Hill et al. 2020). Interestingly, the development of e-commerce over the past two decades has significantly accelerated the introduction of alien aquarium plants, contributing to their invasion in new areas (Mazza et al. 2015; Peres et al. 2018). Although many countries have taken legal action to regulate the trade of invasive alien plants or have developed special codes of conduct for them, public awareness of the threats posed by biological invasions is still low (June-Wells et al. 2012; Heywood and Sharrock 2013; Verbrugge et al. 2014; Peres et al. 2018; Oliva-Paterna et al. 2022).

The invasion of ornamental aquarium plants can be very devastating for both ecosystems and economies (Gallardo et al. 2016; Hill et al. 2020; Macêdo et al. 2024). For instance, the formation of dense, monospecific mats on the water surface by floating invaders such as *Pistia stratiotes* L., *Pontederia crassipes* Mart., and *Salvinia molesta* D. Mitch. causes several negative changes in the physicochemical properties of the water environment leading to disruption of the food web and loss of native biodiversity. Moreover, mass infestations of these plants can impede water transport and negatively affect tourism and recreation (Hill and Coetzee 2017; Zahari and Seswoya 2021; Macêdo et al. 2024). For these reasons, owners of invasive or potentially invasive aquarium plants should be aware of the risks when cultivating them, to ensure that they do not escape spontaneously or are not released into the natural environment with aquarium or garden waste.

Ludwigia repens J.R. Forst. (*Onagraceae*) is an amphibious, monoecious perennial plant native to North and Central America (Peng et al. 2005). It is one of the most popular *Ludwigia* species in the aquarium trade and ornamental gardening (Cirujano Bracamonte et al. 2014; Leśniak 2019). It was introduced to Europe, Asia, Africa, and Australia (Randall 2017; POWO 2024). In Europe, it is naturalized in Austria, Czechia, Slovakia, Hungary, and Spain (Peng et al. 2005; Randall 2017; Nobis et al. 2019). In addition, it is considered invasive in Spain (Sanz Elorza et al. 2011; Randall 2017). *Ludwigia repens* prefers warm temperatures and is mainly restricted to tropical and subtropical regions. It usually occurs on muddy and sandy shores of lakes and

✉ Artur Pliszko
artur.pliszko@uj.edu.pl

[1] Department of Taxonomy, Phytogeography and Palaebotany, Institute of Botany, Faculty of Biology, Jagiellonian University, Gronostajowa 3, 30-387 Kraków, Poland

ponds, along riverbanks and roadside ditches, as well as in shallow, slightly acidic to alkaline freshwaters, thriving in sunny and partly shaded places (Peng et al. 2005; Cirujano Bracamonte et al. 2014). The impact of *L. repens* on wildlife and ecosystems is insufficiently recognized (U.S. Fish & Wildlife Service 2021). Nevertheless, it is suggested that through rapid growth and the formation of dense patches, it can outcompete native plants, reduce light, food, and habitat for fish and other aquatic animals, as well as limit water flow and recreational use of waterways (WeedWise 2021).

Myriophyllum aquaticum (Vell.) Verdc. (*Haloragaceae*) is a submerged or emergent, dioecious, perennial plant native to South America (Orchard 1981). It is commonly cultivated as an ornamental plant in aquaria and garden ponds (Rojas-Sandoval 2024). It was introduced to North America, Europe, Asia, Africa, and Australia, and is widely considered invasive (Randall 2017; Becker and Wong 2023; Rojas-Sandoval 2024). It occurs in tropical and warm temperate regions, preferring shallow and nutrient-rich freshwater habitats such as lakes, ponds, slow-flowing rivers, irrigation channels, and roadside ditches, as well as muddy water banks (Aiken 1981; Orchard 1981; Wersal and Madsen 2011; IUCN 2018; Rojas-Sandoval 2024). *Myriophyllum aquaticum* rapidly colonizes aquatic habitats, creating dense patches, thereby displacing native plant species, changing conditions for water animals and algae, and blocking the flow of water (Wersal and Madsen 2011; Rojas-Sandoval 2024). Besides, it enhances the abundance of mosquitos, increasing the risk of transmitting mosquito-borne diseases to humans (Becker and Wong 2023). In Europe, *M. aquaticum* is treated as an invasive alien species of Union concern for which prevention, early detection, and rapid eradication of new invasions are required (EU 2022).

In Poland, no alien species of the genera *Ludwigia* L. and *Myriophyllum* Ponted. ex L. have been found in the wild so far (Tokarska-Guzik et al. 2012; Mirek et al. 2020; Tokarska-Guzik et al. 2021). Nevertheless, *L. repens* and *M. aquaticum* are cultivated as ornamental plants in aquaria and water gardens (Leśniak 2019; Tokarska-Guzik et al. 2021). In this study, I present the first Polish record of alien *L. repens* and *M. aquaticum* growing outside cultivation.

Materials and methods

Plant identification

The plants were identified based on morphological descriptions and illustrations presented by Aiken (1981), Clement (2000), Peng et al. (2005), IUCN (2018), and Scribailo and Alix (2022). *Ludwigia repens* is morphologically variable, especially in shape and size of leaves, flower and capsule size, bracteole and pedicel length, and tightness of pollen tetrads. The stems are prostrate to suberect, sparsely branched, glabrous, up to 80 cm long. The leaves are opposite, petiolate, narrowly elliptic to broadly lanceolate-elliptic to suborbiculate, with blades of 8–45 × 4–27 mm (Peng et al. 2005; Hoch 2022). In general appearance, it resembles *L. palustris*, but differs from it mainly in the opposite leaves, presence of petals, longer sepals, and longer anthers (Peng et al. 2005). Additionally, in the aquarium trade, *L. repens* can be confused with *L.* × *kentiana* E.J. Clement, an artificial hybrid between *L. palustris* and *L. repens*. However, the petals in the hybrid are cream and tiny (0.5 mm long), whereas in *L. repens*, they are yellow and bigger, up to 3–5 mm long (Clement 2000).

Myriophyllum aquaticum produces branched or unbranched stems up to 5 m long, with feather-like leaves gathered in whorls of 4–6. It is characterized by the blue-green coloration of the emergent leaves. Furthermore, the emergent leaves are narrowly oblanceolate in outline, 1.5–3.5 cm long, and 0.4–0.8 cm wide, usually with 18–36 pinnae per leaf (IUCN 2018; Scribailo and Alix 2022). Interestingly, only female plants (with white flowers) have been found outside its native range (Aiken 1981; IUCN 2018; Rojas-Sandoval 2024). When growing in pots or unfavorable conditions, it has a red stem and therefore it can be confused with *M. rubricaule* Valk. & Duist. However, *M. rubricaule* has a purplish red stem, green leaves in whorls of 4 or 5, and pink flowers (van Valkenburg et al. 2022).

Taxonomic treatment and plant nomenclature followed POWO (2024). Geographical-historical status in the Polish flora was assessed using criteria proposed by Pyšek et al. (2004). Herbarium specimens of *L. repens* and *M. aquaticum* are deposited in the Herbarium of the Institute of Botany of the Jagiellonian University in Kraków (KRA).

Study area

The study was conducted in the Płaszów Pond in Kraków (Fig. 1), southern Poland, Central Europe, where *Ludwigia repens* and *Myriophyllum aquaticum* were recorded for the first time, on July 21, 2024. The Płaszów Pond was created in a former clay extraction site in the 1950s and covers about 9 ha, with a maximum depth of 2.83 m (Gawałkiewicz 2018; Szarek-Gwiazda et al. 2018). It is characterized by low floristic richness and reed vegetation, dominated by *Phragmites australis* (Cav.) Trin. ex Steud. and *Typha angustifolia* L. (Żurek et al. 2019). It serves as a small retention reservoir and is stocked and used by anglers. Moreover, the areas around the pond are used by citizens for recreation (Gawałkiewicz 2018).

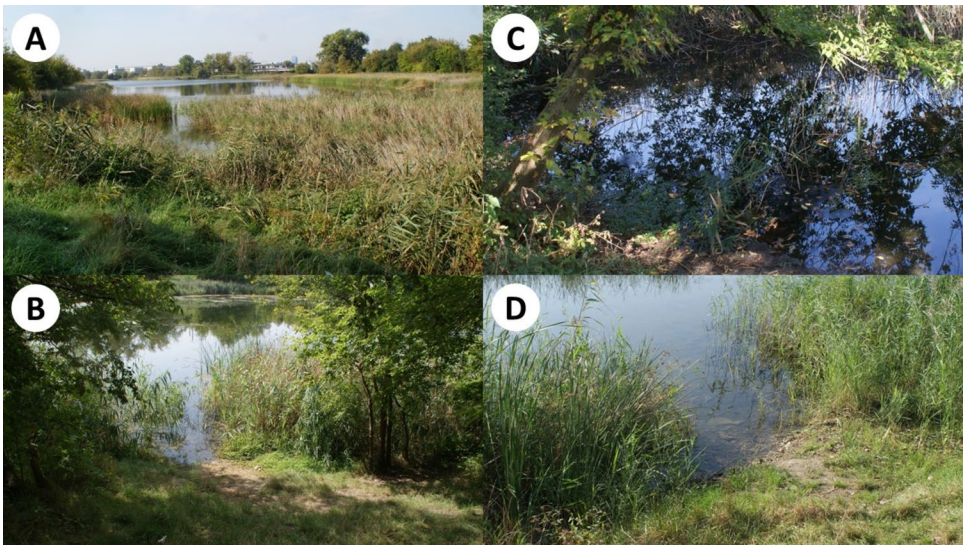

Fig. 1 Vegetation of the Płaszów Pond in Kraków, southern Poland: A – eastern part of the pond, B – locality 1 with *Ludwigia repens* and *Myriophyllum aquaticum*, C – locality 2 with *L. repens* and *M. aquaticum*, D – locality 3 with *L. repens* (photographed by A. Pliszko)

In August and September 2024, field surveys were taken to estimate the distribution and abundance of *L. repens* and *M. aquaticum* along the shores of the Płaszów Pond. GPS coordinates and altitude of the sites were measured using a Garmin GPSMAP 62st. In addition, the pH and temperature of the water were measured in triplicate at the sites using a PH-3508 m on September 05, 2024. The locality of *L. repens* and *M. aquaticum* in Poland was mapped using the ATPOL (Atlas of distribution of vascular plants in Poland) cartogram method (Zając 1978).

Results and discussion

Ludwigia repens was found in three localities, two of which were shared with *M. aquaticum*, in the eastern part of the Płaszów Pond (Table 1, Figs. 1, 2, and 3). All three localities are situated in the unit DF69 of the ATPOL cartogram grid (Fig. 4). Both species occupied sandy and muddy shores, as well as shallow waters up to 40 cm depth, mainly in the accompany of *Phragmites australis*. The water in the pond was slightly alkaline (Table 1) which is consistent with the previous measurements made by Szarek-Gwiazda et al. (2018). *Ludwigia repens* formed loose clusters of shoots in the water and dense ones on the shores of the pond (especially at locality 1), while the shoots of *M. aquaticum* were sparse or singular (Table 1). Also, *L. repens* produced flowers (Fig. 2A), but poorly set fruit, and *M. aquaticum* was only vegetative (Fig. 3). Nevertheless, the lack or limited production of seeds does not prevent the spread of these species because they show a high capacity for vegetative propagation through fragmentation of stems and rhizomes, and whole plants or their fragments can be easily transported by water or boats (Aiken 1981; IUCN 2018; WeedWise 2021; Rojas-Sandoval 2024).

It is difficult to determine when exactly *L. repens* and *M. aquaticum* appeared in the Płaszów Pond. Considering the low abundance and sparse distribution as well as the high thermal requirements their occurrence seems rather recent. During the natural resource inventory carried out in the Płaszów Pond in 2017, they were not found (Żurek et al. 2019). Moreover, since both species do not have a native range in Poland and are kept mainly in aquariums and water gardens (Leśniak 2019; Tokarska-Guzik et al. 2021), their co-occurence in Kraków seems to be due to human activity not to natural migration. Most likely, they were introduced together in spring 2024 as aquarium waste by some aquarist living in a nearby housing estate and presumably, locality 1 was the place of their dumping (because of the highest abundance of both species). During the season, some of the shoots were carried away by the rippling water and rooted on new shores of the pond (localities 2 and 3, Table 1). The release or escape of alien aquarium plants into the natural environment has been confirmed in European countries, but climatic conditions do not always enable their naturalization or invasion in new areas (Nunes et al. 2015). The optimal temperatures for growth of *L. repens* and *M. aquaticum* are 19–28 °C and 20–25 °C, respectively (Rataj and Horeman 1977; Wang et al. 2024). Therefore, their survival in Kraków in winter when air temperature drops below 0 °C (Climate Data 2024; Statistics Poland 2024) seems unlikely, especially since the Płaszów Pond is not supplied with natural or artificial thermal waters. For comparison, three tropical and subtropical alien aquarium plants, i.e. *Hydrocharis laevigata* (Humb. & Bonpl. ex Willd.) Byng & Christenh., *Pistia stratiotes* and *Pontederia crassipes*,

Table 1 Characteristics of the *Ludwigia repens* (LR) and *Myriophyllum aquaticum* (MA) localities in the Płaszów Pond, Kraków, southern Poland

Locality	GPS coordinates	Altitude [m a.s.l.]	Mean water pH (± SD)	Mean water temperature (± SD) [°C]	Cover of shoots of LR [m^2]	Number of shoots of MA	Accompanied plant species on the shore (s) and in the waters (w)
1	50.03935°N, 19.97411°E	199	8.04 (±0.32)	26.06 (±0.42)	20	50	*Acer negundo* (s), *Calamagrostis epigejos* (s), *Carex hirta* (s), *Ceratophyllum demersum* (w), *Elodea canadensis* (w), *Lemna minor* (w), *Lolium perenne* (s), *Phragmites australis* (s, w), *Plantago major* (s), *Salix caprea* (s), *Spirodela polyrhiza* (w), *Utricularia australis* (w)
2	50.03870°N, 19.97308°E	199	8.00 (±0.32)	21.63 (±0.94)	4	1	*Acer negundo* (s), *Calystegia sepium* (s), *Lemna minor* (w), *Phragmites australis* (s, w), *Rubus caesius* (s), *Solanum dulcamara* (s, w), *Utricularia australis* (w)
3	50.04086°N, 19.97276°E	199	7.57 (±0.07)	25.76 (±0.36)	<0.25	0	*Bidens frondosa* (s), *Echinochloa crus-galli* (s), *Epilobium hirsutum* (s), *Juncus articulatus* (s), *Lolium perenne* (s), *Phragmites australis* (s, w), *Schoenoplectus lacustris* (w)

Fig. 2 *Ludwigia repens* in the Płaszów Pond in Kraków, southern Poland: A – middle part of the shoot with flowers, B – shoots growing out of water, C – dense patch of shoots occupying a water-land habitat, D – creeping shoots rooted on the shore of the pond (photographed by A. Pliszko)

which were found in a small pond at Agatowa Street in Kraków in 2020, did not survive the winter (Pliszko and Górecki 2021). On the other hand, *M. aquaticum* can survive in low temperatures, between 0 °C and 5 °C (Wang et al. 2024), and *L. repens* also tolerates cold waters, up to 10 °C or less (Aquasabi 2022), therefore, mild winters may increase the probability of their establishment. Interestingly, with the ongoing climate change, it is predicted that some regions in Poland may be suitable for the *M. aquaticum* establishment in the 2030s (Xian et al. 2023). In addition, *L. repens* can be established in thermal waters, as observed in Slovakia and Hungary (Nobis et al. 2019).

Currently, *L. repens* and *M. aquaticum* should be treated as casual alien species in the flora of Poland. However, their persistence and spread need to be monitored. Since *M. aquaticum* is an invasive alien species of Union concern and requires rapid eradication (EU 2022; Regulation of the Council of Ministers 2022), I reported its presence to the Department of Environmental Management of the Kraków City Office, following Polish law (Act of 11 August 2021 on alien species). Furthermore, each time I visited the Płaszów Pond, I manually removed all the shoots of *M. aquaticum* that I noticed (Fig. 3D), using them as herbarium specimens for the KRA collection. Nevertheless, some of the

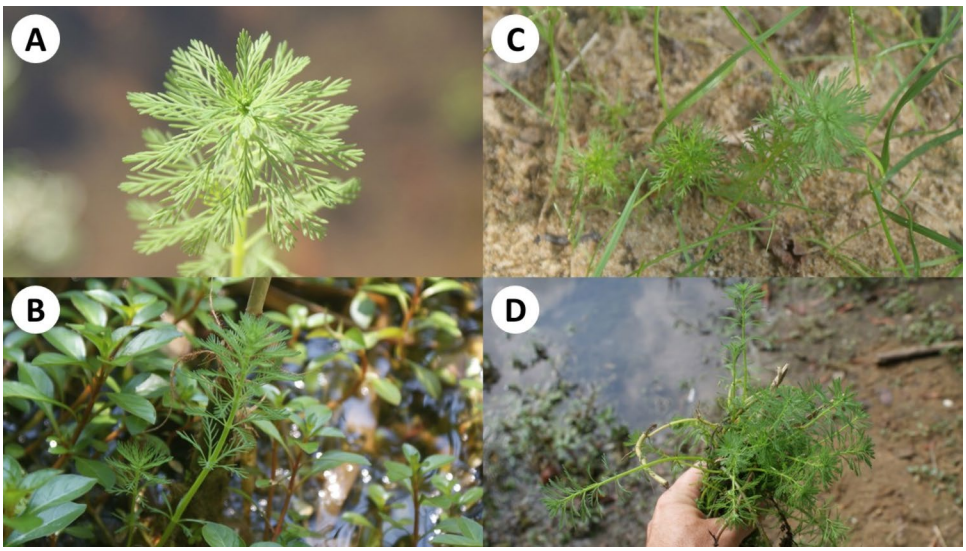

Fig. 3 *Myriophyllum aquaticum* in the Płaszów Pond in Kraków, southern Poland: A – upper part of the emerging shoot, B – two emerging shoots within the patch of *Ludwigia repens*, C – shoots growing on the shore of the pond, D – shoots removed manually (photographed by A. Pliszko)

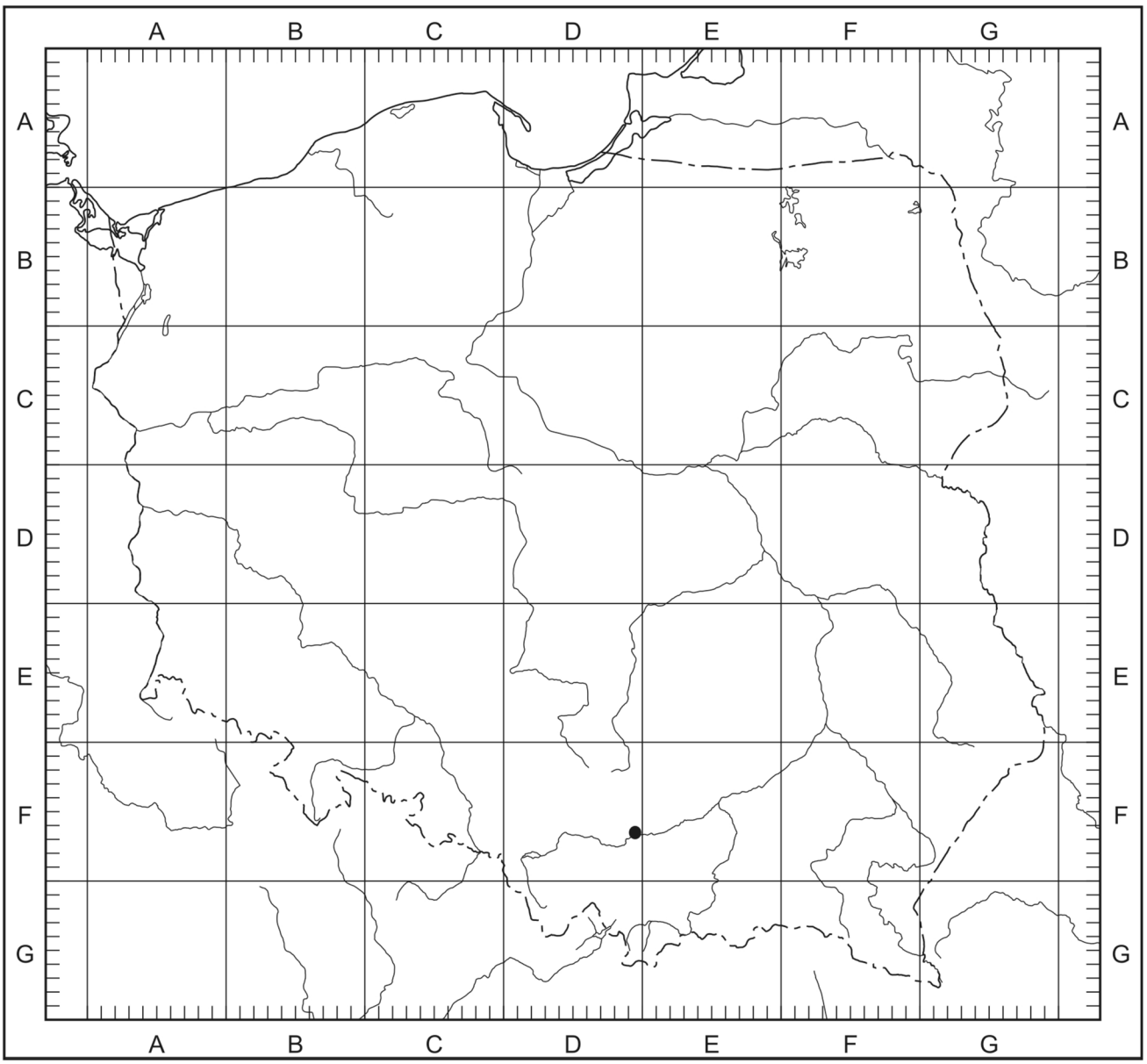

Fig. 4 Locality (black dot) of *Ludwigia repens* and *Myriophyllum aquaticum* in Poland within the ATPOL cartogram grid

specimens, which were not suitable for the herbarium, were thrown into the trash bin.

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Author contribution Conceptualization; methodology; investigation; resources; original draft preparation.

Declarations

Conflict of interests There is no conflict of interest as there is a single author.

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