Total biomass and annual yield of *Drosera* on cultivated *Sphagnum* in north-west Germany

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SUMMARY

Sphagnum paludiculture farms, where *Drosera* species grow spontaneously under semi-natural conditions, may provide fresh *Drosera* raw material for the pharmaceutical industry as a sustainable alternative to collecting *Drosera* from natural peatlands. We collected and measured the fresh mass of all plants of *Drosera rotundifolia* and *Drosera intermedia* growing in 1 m^2 plots located in fields of cultivated *Sphagnum palustre* and *Sphagnum papillosum*, and thus calculated plant density, total biomass and harvestable yield (flowering plants only). We found significantly higher total biomass (433 ± 368 kg ha^{-1}) and yield (292 ± 227 kg ha^{-1} yr^{-1}) for *D. rotundifolia* compared to *D. intermedia* (68 ± 67 kg ha^{-1} and 56 ± 55 kg ha^{-1} yr^{-1}) in July/August. The highest recorded total biomass for *D. rotundifolia* growing on *S. palustre* was 590 ± 342 kg ha^{-1}. Total biomass and yield for *D. rotundifolia* were, respectively, 5–54 times and 3–29 times literature values reported for natural habitats in central and northern Europe. The effect of *Sphagnum* species was significant for *D. rotundifolia*, which achieved higher total biomass and yield in the *S. palustre* field than in the *S. papillosum* field. *D. intermedia* grew only in the *S. papillosum* field because the *S. palustre* field lacked suitable microhabitats. Highly productive populations of *D. rotundifolia* developed in both *Sphagnum* paludiculture fields two years after their establishment, but there was only a small population of *D. intermedia* at that stage. For commercial farming and sustainable production of *D. rotundifolia* we recommend its cultivation on *S. palustre* lawns, harvesting in July/August, and harvesting only plants that are more than 12 months old.

KEY WORDS: sundew, sustainable production, paludiculture, pharmaceutical industry, medicinal plant

INTRODUCTION

The herbaceous insectivorous genus *Drosera* L. (Droseraceae; the sundews) is present, with 218 species, throughout the world (Carow 2005). In central Europe, *Drosera rotundifolia* L., *Drosera intermedia* Hayne, *Drosera anglica* Hudson and their natural hybrids occur in nutrient-poor, strongly acidic to base-rich wetlands, often as pioneers (Crowder *et al*. 1990). *D. rotundifolia* and *D. intermedia* usually grow in different microhabitats owing to different water level preferences that lead to a horizontal segregation (Thum 1986). Compared to other European *Drosera* species, *D. rotundifolia* is well-adapted to living on *Sphagnum* carpets without being overgrown (Hegi 1961). Every year, each rosette forms a winter bud just below the *Sphagnum* surface so that stem elongation can keep pace with (even rapid) *Sphagnum* growth (Svensson 1995). Old rosettes from previous years can be seen at different heights on the plants (see Figure A3 in the Appendix). Both *D. rotundifolia* and *D. intermedia* are small in size and their natural population densities vary greatly. For example, *D. rotundifolia* plants are 5–20 cm tall with a fresh mass per plant of 0.01–0.6 g (Galambosi *et al*. 2000a, 2000b; Király *et al*. 2011), and they grow at densities ranging from zero to 434 m^{-2} in natural peatlands (Thum 1986, Redbo-Torstensson 1994, Kallio 2020).

There have been only a few studies of *Drosera* biomass and/or yield (biomass of flowering plants) in natural peatlands. For *D. rotundifolia*, dry biomass production of 1–5 kg ha^{-1} yr^{-1} in southern Finland (Vasander 1981, Liedenpohja 1981) and 6–11 kg ha^{-1} yr^{-1} in central Sweden (Backéus 1985) have been reported. In south-east Germany, Thum (1986) recorded dry mass production of 12 kg ha^{-1} yr^{-1} for *D. rotundifolia* and 14 kg ha^{-1} yr^{-1} for *D. intermedia*. Galambosi *et al*. (2000a) estimated fresh yields, for *D. rotundifolia* growing on nine mires in south-east and north Finland, of 10–111 kg ha^{-1} yr^{-1} which, with a dry : fresh mass ratio of 1:8 (see below), correspond well with the other values.

Drosera plants have been used for centuries in the treatment of pulmonary diseases (Šamaj *et al*. 1999, Babula *et al*. 2009) and the current annual demand for *Drosera* dry biomass on the central European pharmacological market is 6–20 tons (Galambosi & Jokela 2002). *D. rotundifolia* was originally the main constituent of the pharmaceutical drug ′Droserae herba′ (Baranyai *et al*. 2016) and is still preferred by the pharmaceutical industry, but the declining occurrence of this species has led to increasing substitution of others (*D. intermedia*, *D. anglica*, *Drosera madagascariensis*, *Drosera peltata*) (Melzig *et al*. 2001, Hiller & Loew 2009, Baranyai & Joosten 2016). All European *Drosera* species are nowadays included in the European Red List of Threatened Plant Species (Khela 2012) and continuing collection from the wild may lead to further population reduction of both these and non-European *Drosera* species (Baranyai & Joosten 2016). Propagation and cultivation of *Drosera* have been tested, but the methods applied hitherto are time-consuming and costly (Baranyai *et al*. 2016). Therefore, large scale *Drosera* cultivation is still not practised and unsustainable collection from the wild continues. Overall, the long-term supply situation for sundew must be regarded as critical, which increases the need for sustainable regional cultivation.

Over the last decade, the cultivation of *Sphagnum* has emerged as a climate-friendly land use alternative for drained and degraded bog land (Gaudig *et al*. 2014, Wichtmann *et al*. 2016, Günther *et al*. 2017, Gaudig *et al*. 2018). Such ‘*Sphagnum* paludiculture’ aims to produce raw material for horticultural growing media (Krebs *et al*. 2012, Kumar 2017) but also provides new habitats for bog-typical vascular plant species (Muster *et al*. 2015, Gaudig & Krebs 2016, Muster *et al*. 2020). On the *Sphagnum* farm at Rastede (Lower Saxony, Germany), *D. rotundifolia* and *D. intermedia* apppeared spontaneously, probably from seeds of both species introduced with the *Sphagnum* founder material in the spring of 2011. These *Drosera* species formed dense populations after 2–3 years, enabling study of the potential and options for commercial cultivation of sundew in *Sphagnum* paludicultures (Baranyai 2016, Baranyai & Joosten 2016). The quality of *D. rotundifolia* and *D. intermedia* grown on *Sphagnum* paludiculture lawns was shown to meet the pharmaceutical requirements (Baranyai *et al*. 2016), and different methods for establishing *D. rotundifolia* were tested successfully (Baranyai *et al*. 2021). However, for commercial cultivation, it is also essential to have knowledge of the potential yield.

This study aims - for the first time - to quantify total biomass and harvestable yield of *D. rotundifolia* and *D. intermedia* growing spontaneously on *Sphagnum* paludiculture lawns and to determine whether:

1. total biomass and annual yield (flowering plants) differ between (a) *Sphagnum* species, (b) harvest month and (c) years;
2. plant density differs between (a) *Sphagnum* species, (b) years and (c) flowering and non-flowering plants;
3. individual plant mass differs between (a) *Sphagnum* species, (b) harvest month and (c) years, as well as with (d) plant age; and
4. the proportions of flowering *Drosera* plants change with harvest month.

METHODS

Site description

The study was carried out at the Rastede *Sphagnum* farm, north-west Germany (53° 15′ 80″ N, 08° 16′ 05″ E, 0.5 m below sea level; Gaudig *et al*. 2014, Temmink *et al*. 2017, Gaudig *et al*. 2018), where mean annual precipitation is 849 mm and mean annual temperature is 9.8 °C (Brust *et al*. 2018). The *Sphagnum* farm was established on 4 ha of bog grassland in May 2011 (Wichmann *et al*. 2017). Our study took place on a *Sphagnum palustre* field and a *Sphagnum papillosum* field (both 10 × 200 m). The *S. palustre* field was characterised by a dense lawn of *S. palustre* and *Sphagnum fallax* (Figure 1), and the *S. papillosum* field by a dominance of *S. papillosum* accompanied by *S. fallax* and small amounts of *Sphagnum cuspidatum* and *Sphagnum fimbriatum*. Other moss species occurred sporadically in both fields; in addition to other *Sphagnum* species these included *Polytrichum strictum* and *Aulacomnium palustre*. The fields were equipped with an automatic irrigation system that maintained the water table around 5 cm below the *Sphagnum* surface over the entire year (Brust *et al*. 2018, Vroom *et al*. 2020). The *S. papillosum* field had small areas of bare peat which were periodically shallowly inundated (Figure 2). In 2013, at the start of the experiment, the mean *Sphagnum* cover (98 %) and the lawn thickness (9 cm) in the *S. palustre* field were greater than in the *S. papillosum* field (90 % *Sphagnum* cover, 6 cm lawn thickness) (Gaudig *et al*. 2014, Krebs *et al*. 2015). In both fields the total cover of vascular plants was < 25 %, dominated by *Juncus effusus* L. and *D. rotundifolia*, with *Juncus bulbosus* L., *Carex canescens* L., *Rhynchospora alba* (L.) Vahl, *Eriophorum angustifolium* Honck., *Erica tetralix* L. and various Poaceae as additional species (Gaudig & Krebs 2016). As a weed control measure, vascular plants were mown to a height of 5–10 cm above the *Sphagnum* surface, at monthly intervals from May to September, in 2013 and 2014. *D. intermedia* grew only in the *S. papillosum* field. No *Sphagnum* harvest took place at the site before or during the experiment.

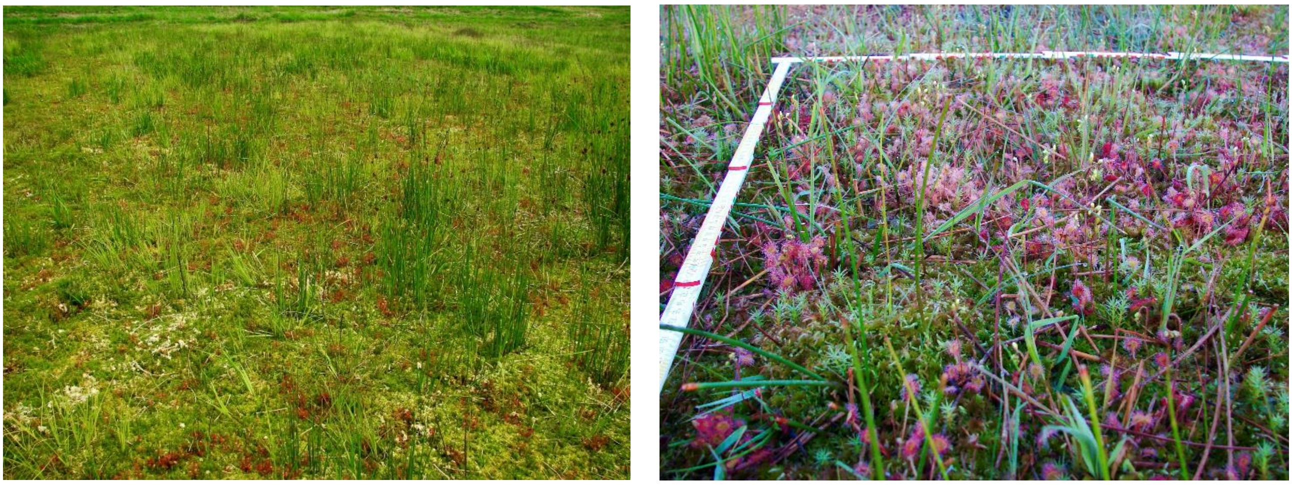

Figure 1. Closed *Sphagnum palustre* lawn (left) and a random plot with high density of *Drosera rotundifolia* plants (right) on the *Sphagnum palustre* field of the *Sphagnum* farm in Rastede (north-west Germany). Photos: Balázs Baranyai, 16 July 2013.

Figure 2. Open mud (left) and small open and water-covered sites with *Drosera intermedia* (right) on the *Sphagnum papillosum* field of the *Sphagnum* farm in Rastede (north-west Germany). Photos: Balázs Baranyai, 16 July 2013.

Study design and data collection

To study total biomass, yield, plant density, individual plant mass and morphology, 23 plots (size 1 × 1 m, in total $n = 46$) were randomly located across each of the *Sphagnum* fields. All individuals of *D. rotundifolia* and *D. intermedia* with a rosette on the *Sphagnum* surface (whole plants including roots) were collected between the 14th and 18th of each month, from two plots in each *Sphagnum* field in June–September 2013 ($n = 8$ per field, $n = 16$ in total) and from three plots in each *Sphagnum* field in May–September 2014 ($n = 15$ per field, $n = 30$ in total). Collected plants were stored in closed plastic bags (500 ml) at 8 °C (± 4 °C) for a maximum of one week before further processing.

On the day of collection we immediately measured the fresh mass of each individual plant, including all above-ground and below-ground parts, using a Kern EMB 600-2 precision balance (KERN & SOHN GmbH, Balingen, Germany). To determine water content, 38 *D. rotundifolia* and 42 *D. intermedia* plants with flowers were randomly collected on 21 July 2021 and dried in batches of 5–7 plants for 72 hours at 40 °C in a Memmert Cleanroom drying oven. Water content was calculated as the mass lost during drying and this value was used to convert from fresh mass to dry mass where appropriate.

We assigned all plants to age classes (0–3, 3–6, 6–12, 12–24, >24 months) using the descriptions and images of Nitschke (1860), Drude (1891), Diels

(1906) and Bertsch (1912), see Figures A1–A3. For each plant we recorded the numbers of active/non-active leaves and flowering stems, the length of the roots, and petiole length from axil to margin of the lamina. We distinguished between active leaves (healthy and able to catch insects, or currently with insects) and non-active leaves (too young - not opened, or too old - dying off and brown, to catch insects). We also distinguished between flowering and non-flowering specimens, as flowering plants have higher concentrations of pharmaceutically active ingredients (Baranyai *et al*. 2016, 2021). Some *Drosera* flowers had been cut off by the mowing for weed control, which led to an estimated biomass loss of ≤ 5 %. Therefore, we treated plants with (mature) stalks but without flowers as flowering plants. We defined plant density as the number of *Drosera* plants, and yield as the total fresh biomass of flowering plants, collected from each (1 m^2) plot. The size of the area needed to harvest 1 kg of fresh *Drosera* biomass (flowering plants only) was calculated from the mean yield per plot.

Data analysis

Data exploration and statistical tests were performed using R version 3.1.3 (R Development Core Team 2009). Figures were made with Microsoft Excel (version Professional Plus 2010), except those resulting from the BRT (see below). All results are presented as means ± standard deviation (SD).

We applied a detailed data exploration including outliers, collinearity, normality and heterogeneity. We analysed differences in the effect of *Sphagnum* field variants, harvest years and harvest months on total fresh biomass, yield and plant density for both *Drosera* species using the non-parametric Kruskal-Wallis test and a post-hoc test after Dunn (R package PMCMRplus; Pohlert 2021), as this typical ‘rank’ test does not make assumptions about homogeneity of variances or normal distribution and accommodates unequal sample sizes (Dytham 2010). A Pearson correlation test was used to explore the relationship between total biomass and plant density.

To test the dependence of fresh biomass of individual *Drosera* plants on plant age, month of collection and number of leaves, per individual plant and *Sphagnum* species, we used boosted regression trees (BRT; Friedman 2001, Elith *et al*. 2008; library gbm (version 1.6-3; Ridgeway 2007) implemented in the software R). BRT can fit complex nonlinear relationships, reduces the problem of ‘overfitting’ (Elith *et al*. 2008), and highly correlated explanatory variables do not cause numerical aberrations (Friedman & Meulman 2003). Since the two *Drosera* species differ greatly in morphology, the larger dataset of *D. rotundifolia* was used for BRT analysis. We used 10-fold cross validation for model development and validation. Within the BRT model, three terms (bag fraction, learning rate and tree complexity) were used to optimise predictive performance (Elith *et al*. 2008). Explanatory variables that did not improve the performance of the model were removed.

RESULTS

We collected data for 5907 *Drosera rotundifolia* and 301 *Drosera intermedia* plants, from 46 random plots, between June 2013 and September 2014.

Individual plant biomass

For 2013/14, the mean fresh mass of single plants of *D. rotundifolia* did not differ between the *S. palustre* (0.21 ± 0.17 g) and *S.papillosum* (0.20 ± 0.16 g) fields ($\chi^2 = 0.173$, d.f. = 1, $P = 0.676$; Kruskal-Wallis test; Figure 3, Table 1). The mean mass of flowering *D. rotundifolia* plants was 0.32 ± 0.18 g in the *S. palustre* field and 0.30 ± 0.16 g in the *S. papillosum* field (Table 1), and double that of non-flowering plants in both fields (0.13 ± 0.11 g on *S. palustre* and 0.13 ± 0.12 g on *S. papillosum* for both years; Table 1). The mean mass of individual *D. rotundifolia* plants in the *S. palustre* field was significantly (27 %) higher in 2013 than in 2014 (Table 1), while in the *S. papillosum* field it was similar in both years ($\chi^2 = 1.608$, d.f. = 1, $P = 0.204$; Kruskal-Wallis test; Table 1). In the *S. papillosum* field, mean plant mass was lower (0.20 ± 0.16 g) for *D. rotundifolia* than for *D. intermedia* (0.33 ± 0.26 g, $\chi^2 = 21.843$, d.f. = 1, $P \leq 0.001$; Kruskal-Wallis test; Tables 1 and 2).

The mean mass of flowering plants was double that of non-flowering plants for both *D. intermedia* and *D. rotundifolia* in both years ($\chi^2 = 57.174$, d.f. = 1, $P \leq 0.001$; Kruskal-Wallis test). The mean mass of *D. intermedia* plants in flower was 0.47 ± 0.29 g against 0.25 ± 0.21 g for non-flowering plants. The mean mass of *D. intermedia* plants was similar in 2013 and 2014 ($\chi^2 = 2.734$, d.f. = 1, $P = 0.0982$; Kruskal-Wallis test; Table 2).

The fresh mass of *D. rotundifolia* plants increased proportionally with plant age (Figure 3). Morphological data showed that mature plants had more leaves, longer roots and petioles, and most had flowering stems (Figure 3, Tables A1 and A2 in the Appendix). For *D. intermedia*, individual plant mass also increased with age (Table A3). The mass of individual older plants (age class >24 months) was significantly higher for *D. intermedia* than for

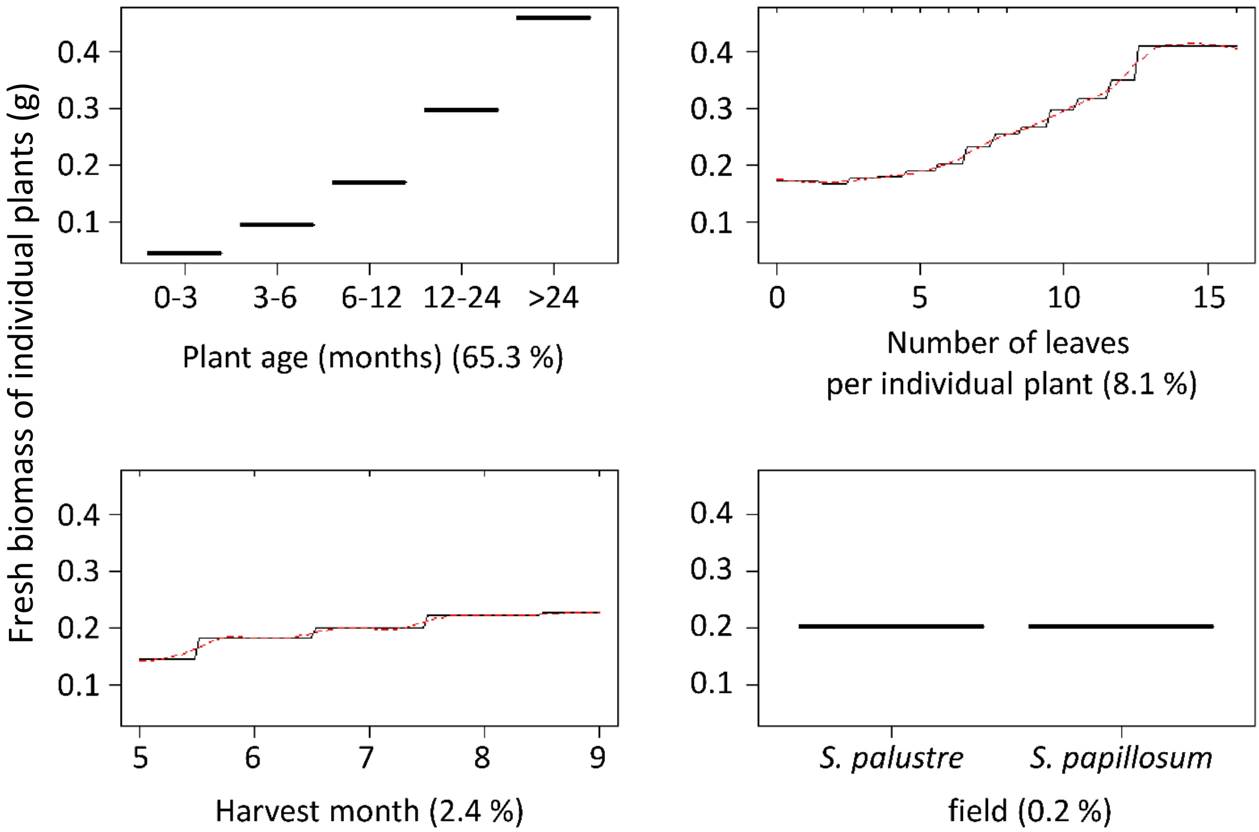

Figure 3. Boosted regression tree model of *Drosera rotundifolia* biomass (response variable) and predictor/explanatory variables plant age, number of leaves per individual plant, harvest month and *Sphagnum* species. Percentages indicate the absolute contribution of the variable to the total biomass. The boosted regression tree model was performed with 5907 observations and four predictors, using Gaussian distribution, with tree complexity = 5 (sets the complexity of individual trees, interaction order), learning rate = 0.01 (sets the weighting applied to individual trees, shrinkage factor), bag fraction = 0.75 (sets the proportion of observations used in selecting variables). The final model was fitted with 1200 trees with explained deviance = 0.7654.

Table 1. Mean fresh mass (FM) of individual *Drosera rotundifolia* plants growing on *Sphagnum palustre* and *Sphagnum papillosum* fields. Flowering = plants with stalk(s); Non-flowering = plants without stalk(s); Total = flowering + non-flowering plants. Harvest dates: June–September 2013 and May–September 2014 (*n* = 23 per *Sphagnum* species; 2013: 2 plots × 4 months; 2014: 3 plots × 5 months).

	Year	*Sphagnum palustre*			*Sphagnum papillosum*		
		Number of plants	FM ± SD (g)	FM ± SD 2013/14 (g)	Number of plants	FM ± SD (g)	FM ± SD 2013/14 (g)
Flowering	2013	622	0.35 ± 0.17	0.32 ± 0.18	88	0.28 ± 0.13	0.30 ± 0.16
	2014	1128	0.31 ± 0.18		537	0.30 ± 0.16	
Non-flowering	2013	725	0.18 ± 0.11	0.13 ± 0.11	100	0.12 ± 0.07	0.13 ± 0.12
	2014	1895	0.11 ± 0.11		812	0.13 ± 0.13	
Total	2013	1347	0.26 ± 0.17	0.21 ± 0.17	188	0.19 ± 0.13	0.20 ± 0.16
	2014	3023	0.19 ± 0.19		1349	0.20 ± 0.17	

D. rotundifolia (Table A4). For the age class 3–24 months, no differences in plant biomass were found between the two *Drosera* species (Table A4).

The mean mass of individual (flowering and non-flowering) *D. rotundifolia* plants increased from May to June, especially for plants older than 24 months, reached a maximum in June to August, and decreased during September (Figure A4). The same trend was found when only flowering *D. rotundifolia* plants were analysed, except that no flowering plants occurred in May (Figure A5). We found no flowering plants younger than three months old (Figure A5). *Drosera intermedia* plant biomass also increased from May to June, but remained constant from June to September (Table A3).

Plant density

The density of all (flowering and non-flowering) plants was 141 ± 124 m^{-2} (mean value ± SD) for *D. rotundifolia* and 17 ± 24 m^{-2} for *D. intermedia* in 2013 and 2014 (Table 3). The range of plant density was 9–479 m^{-2} (n = 46, both *Sphagnum* fields) for *D. rotundifolia* and 0–92 m^{-2} (n = 23, *S. papillosum* field only) for *D. intermedia*. The density of *D. rotundifolia* plants was higher in the *S. palustre* field (190 ± 133 m^{-2}) than in the *S. papillosum* field (81 ± 82 m^{-2}; χ^2 = 9.197, d.f. = 1, $P \leq 0.01$; Kruskal-Wallis test). In the *S. papillosum* field we recorded a lower (compared to *D. rotundifolia*) mean density of *Drosera intermedia* (17 ± 24 m^{-2}; χ^2 = 28.309, d.f. = 1, $P \leq 0.001$; Kruskal-Wallis test; Table 3).

The mean density of flowering *D. rotundifolia* plants for all months in both years (2013 and 2014) was 66 ± 59 m^{-2} on both *Sphagnum* fields (88 ± 64 m^{-2} on *S. palustre* and 39 ± 36 m^{-2} on *S. papillosum*; Table 3). The highest density of flowering *D. rotundifolia* plants (for both years) was recorded on the *S. palustre* field in July (122 ± 63 m^{-2}), and the lowest on the *S papillosum* field in August (19 ± 15 m^{-2}). We recorded four times fewer flowering plants for *D. intermedia* compared to *D. rotundifolia* (7 ± 10 m^{-2} against 39 ± 36 m^{-2}; χ^2 = 23.921, d.f. = 1, $P \leq 0.001$; Kruskal-Wallis test; Table 3). In May 2014, no flowering *Drosera* plants were registered on either *Sphagnum* field.

The *D. rotundifolia* plant density increased moderately, but not significantly, from 2013 (128 ± 138 m^{-2}, n = 16) to 2014 (146 ± 121 m^{-2}, n = 30) (χ^2 = 0.310, d.f. = 1, P = 0.577; Kruskal-Wallis test), whereas the *D. intermedia* plant density decreased (34 ± 17 m^{-2} in 2013, 12 ± 24 m^{-2} in 2014; χ^2 = 4.935, d.f. = 1, $P \leq 0.0$; Kruskal-Wallis test).

For *D. rotundifolia* the highest proportion of flowering plants was recorded in July (53 %) and August (47 %) on both *Sphagnum* fields. The same observation was made for *D. intermedia*, with the highest proportion in July (57 %) and August (64 %) on the *S. papillosum* field (Table 4).

Plant density was not correlated with the fresh biomass of individual plants (*D. rotundifolia*: d.f. = 40, t = -0.751, P = 0.4565; *D. intermedia*: d.f. = 17; t = 0.349, P = 0.7312; Pearson correlation test).

Total biomass and yield

Considering 2013 and 2014 together, the total biomass of *D. rotundifolia* was higher on the *S. palustre* field than on the *S. papillosum* field (39.4 ± 30.3 g m^{-2} and 16.6 ± 15.5 g m^{-2}, respectively; χ^2 = 7.609, d.f. = 1, $P \leq 0.01$; Kruskal-Wallis test; Table 3). The result for both fields across both years

Table 2. Fresh mass (FM) of individual *Drosera intermedia* plants growing on the *Sphagnum papillosum* field. Flowering = plants with stalk(s); Non-flowering = plants without stalk(s); Total = flowering + non-flowering plants. Harvest dates: June–September 2013 and May–September 2014 (n = 23; 2013: 2 plots × 4 months; 2014: 3 plots × 5 months). We registered no *D. intermedia* plants growing on *Sphagnum palustre*.

	Year	Number of plants	FM ± SD (g)	FM ± SD 2013/14 (g)
Flowering	2013	68	0.46 ± 0.24	0.47 ± 0.29
	2014	40	0.48 ± 0.35	
Non-flowering	2013	66	0.22 ± 0.17	0.25 ± 0.21
	2014	127	0.27 ± 0.23	
Total	2013	134	0.34 ± 0.24	0.33 ± 0.26
	2014	167	0.32 ± 0.28	

Table 3. Total biomass of *Drosera rotundifolia* and *Drosera intermedia* on *Sphagnum palustre* and *S. papillosum* fields. Flowering = plants with stalk(s); Non-flowering = plants without stalk(s); Total = flowering + non-flowering plants. Harvest dates: June–September 2013 and May–September 2014 (n = 23 per *Sphagnum* species; 2013: 2 plots × 4 months; 2014: 3 plots × 5 months). N = plant density (number of plants per square metre). No flowering plants were found in May 2014.

Drosera species	*Sphagnum* field		N ± SD (m^{-2})	Fresh biomass per plant ± SD (g)	Fresh biomass per plot ± SD ($g\ m^{-2}$)	Number of plants per kg ± SD
D. rotundifolia	*S. palustre*	Flowering	88 ± 64	0.31 ± 0.18	29.6 ± 21.8	3,183 ± 665
		Non-flowering	114 ± 77	0.13 ± 0.11	15.0 ± 9.9	7,614 ± 1,967
		Total	190 ± 133	0.21 ± 0.17	39.4 ± 30.3	5,425 ± 1,934
	S. papillosum	Flowering	39 ± 36	0.30 ± 0.16	11.7 ± 9.7	3,189 ± 523
		Non-flowering	48 ± 57	0.13 ± 0.12	5.2 ± 3.7	7,665 ± 2,153
		Total	81 ± 82	0.19 ± 0.16	16.6 ± 15.5	5,121 ± 1,148
	S. palustre + *S. papillosum*	Flowering	66 ± 59	0.31 ± 0.17	21.4 ± 19.3	3,186 ± 598
		Non-flowering	84 ± 76	0.13 ± 0.11	11.1 ± 9.3	7,738 ± 2,151
		Total	141 ± 124	0.20 ± 0.17	29.4 ± 26.7	5,228 ± 1,679
D. intermedia	*S. papillosum*	Flowering	7 ± 10	0.47 ± 0.29	3.2 ± 4.8	2,260 ± 924
		Non-flowering	10 ± 18	0.25 ± 0.21	3.8 ± 4.7	3,610 ± 1,252
		Total	17 ± 24	0.33 ± 0.26	5.2 ± 7.4	3,077 ± 1,115

Table 4. Percentage of flowering plants amongst all (flowering and non-flowering) *Drosera* plants collected from all plots in different months. Harvest dates: June–September 2013 and May–September 2014 (n = 23; 2013: 2 plots × 4 months; 2014: 3 plots × 5 months).

Month	*D. rotundifolia*			*D. intermedia*		
	Total number of plants	Number of flowering plants	%	Total number of plants	Number of flowering plants	%
May	411	0	**0**	9	0	**0**
June	1165	371	**32**	45	4	**9**
July	1759	934	**53**	87	50	**57**
August	1378	652	**47**	53	34	**64**
September	1194	420	**35**	107	20	**18**

was similar ($\chi^2 = 0.003$, d.f. = 1, $P = 0.95$; Kruskal-Wallis test) and significantly higher in July (45.0 ± 25.1 g m^{-2}) compared to May and June ($\chi^2 = 11.471$, d.f. = 4, $P \leq 0.05$; Kruskal-Wallis test). For both fields, the highest total biomass was recorded in July and August, at 43.3 ± 36.8 g m^{-2}. The highest biomass totals on the *S. palustre* field were observed in July (58.5 ± 28.7 g m^{-2}) and August (59.5 ± 39.7 g m^{-2}) (Figure 4).

The total biomass of *D. intermedia* (5.2 ± 7.4 g m^{-2}) was much lower than that of *D. rotundifolia* ($\chi^2 = 22.816$, d.f. = 1, $P \leq 0.001$; Kruskal-Wallis test; Table 3) and was higher in 2013 than in 2014 (11.5 ± 6.7 g m^{-2} versus 3.5 ± 6.9 g m^{-2}; $\chi^2 = 5.863$, d.f. = 1, $P \leq 0.05$; Kruskal-Wallis test). This species had already reached high values in July and August (6.8 ± 6.7 g m^{-2}), but the maximum occurred in September (8.5 ± 12.5 g m^{-2}). We found no *D. intermedia* on the *S. palustre* field.

Yields of *D. rotundifolia* were substantially higher than those of *D. intermedia* (21.4 ± 19.3 g m^{-2} against 3.2 ± 4.8 g m^{-2}; $\chi^2 = 21.081$, d.f. = 1, $P \leq 0.001$; Kruskal-Wallis test), and this was found for both years ($\chi^2 = 0.611$, d.f. = 1, $P = 0.434$; Kruskal-Wallis test; Table 3). Yields of *D. rotundifolia* were significantly higher on the *S. palustre* field than on the *S. papillosum* field (29.6 ± 21.8 g m^{-2} against 11.7 ± 9.7 g m^{-2}; $\chi^2 = 7.372$, d.f. = 1, $P \leq 0.01$; Kruskal-Wallis test; Table 3). The highest yields were recorded in July and August with a mean of 29.2 ± 22.7 g m^{-2} for both fields. Yields of *D. rotundifolia* on the *S. palustre* field in July (42.1 ± 22.8 g m^{-2}) and August (39.5 ± 26.1 g m^{-2}) were not significantly different ($\chi^2 = 7.629$, d.f. = 3, $P = 0.054$; Kruskal-Wallis test; Figure 4).

Yields of fresh *D. intermedia* were 7.8 ± 7.3 g m^{-2} in 2013 (when various high values were measured) and 2.7 ± 2.8 g m^{-2} in 2014. The highest yields for both years were measured in July (5.1 ± 4.9 g m^{-2}) and August (6.0 ± 6.1 g m^{-2}; Figure 5).

The number of flowering plants needed for 1 kg of fresh *Drosera* biomass was lower for *D. intermedia* (2,260 ± 924 kg^{-1} on *S. papillosum*) than for *D. rotundifolia* (3,186 ± 598 kg^{-1} for both *Sphagnum* species; Table 3), requiring an area of 217 m^2 for *D. intermedia* and of 47 m^2 for *D. rotundifolia* (34 m^2 on the *S. palustre* field and 80 m^2 on the *S. papillosum* field).

The determination of water content showed that fresh *D. rotundifolia* contained 86.9 ± 0.4 % and fresh *D. intermedia* contained 94.9 ± 1.1 % of water, resulting in a dry : fresh biomass ratio of approximately 1 : 8 for the former and 1 : 20 for the latter species.

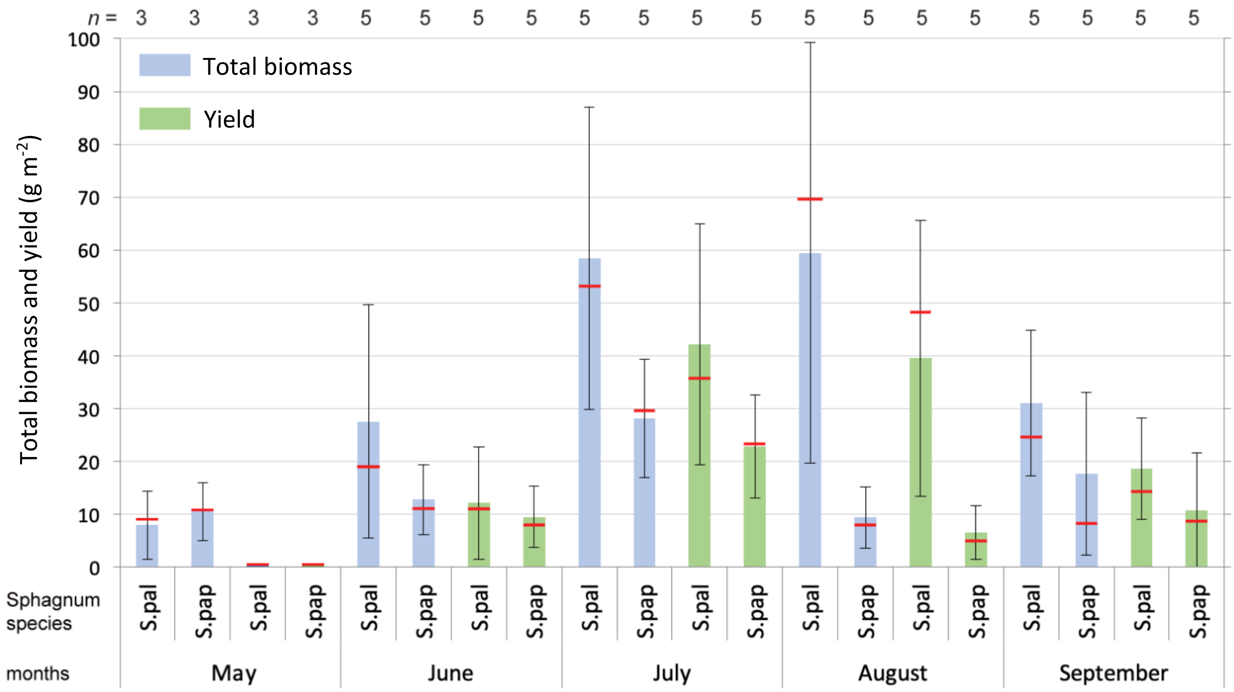

Figure 4. Total biomass (all flowering/non-flowering plants in the plots) and yield (all flowering plants) of *Drosera rotundifolia* growing on *Sphagnum palustre* (S.pal) and *S. papillosum* (S.pap) fields between May/June and September in 2013 and 2014. The vertical bars show the means, the whiskers the standard deviations, and the red lines the medians. Number of replicates (*n*) is written above each bar.

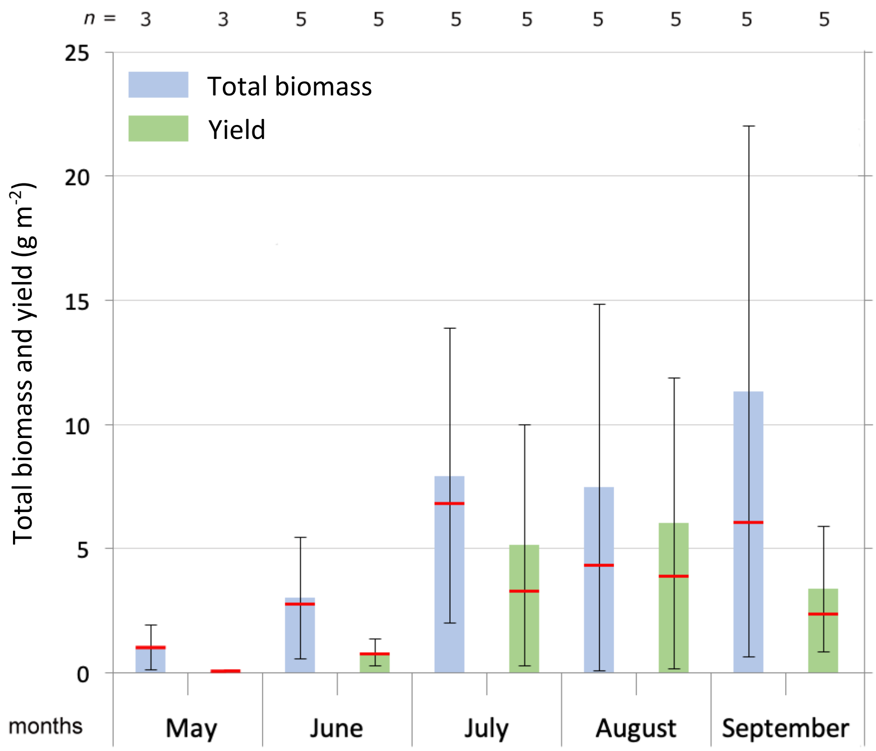

Figure 5. Total biomass (all flowering/non-flowering plants in the plots) and yield (all flowering plants) of *Drosera intermedia* on the *Sphagnum papillosum* field between May/June and September in 2013 and 2014. Vertical bars show the means, the whiskers the standard deviations, the red lines the medians. Number of replicates (*n*) is written above each bar.

DISCUSSION

This is the first study to assess total biomass and yield of *D. rotundifolia* and *D. intermedia* from the perspective of producing *Drosera* raw material for medicinal purposes on a *Sphagnum* farm in Germany. The study shows that *D. rotundifolia* generally occurs much more frequently and shows higher plant density, total biomass and yield than *D. intermedia*. Approximately 90 % of the studied area had well-developed populations of *D. rotundifolia* and no *D. intermedia*. These sites were characterised by closed *Sphagnum* lawns without level differences or hummock-hollow structures (Figure 1). We observed only *D. intermedia* on the remaining < 10 % of the area, which consisted of lower-lying open and water-covered surfaces distributed very irregularly over the *S. papillosum* field (Figure 2). Such patches were not present in the *S. palustre* field. The difference in occurrence reflects the natural habitats of the two species: *D. rotundifolia* occurs mostly in higher and drier parts of the bog surface, often on hummocks of *Sphagnum* (Tutin *et al.* 1968, Baranyai & Joosten 2016), whereas *D. intermedia* prefers lower, wetter habitats such as exposed and water-covered mud (Tutin *et al.* 1968, Thum 1986). The two species often co-occur in the same bog but in different microhabitats (Paul & Lutz 1941, Thum 1986), in a manner similar to their presentation in the *Sphagnum* paludiculture fields.

The total biomass of *D. rotundifolia* in the *Sphagnum* paludiculture fields was 5–54 times higher than in natural boreal and nemoral mires (Liedenpohja 1981, Vasander 1981, Backéus 1985, Thum 1986), whereas yield was 3–29 times higher than in Finnish peatlands (Galambosi *et al*. 2000a). The *Sphagnum* paludiculture fields with their continuous openness (created by regular mowing of vascular plants), constant wetness (resulting from sophisticated water management) and *Sphagnum* dominated vegetation (Gaudig *et al*. 2018) apparently provided a particularly attractive environment for *D. rotundifolia* (Baranyai & Joosten 2016). The presence of other vascular plants may result in growth limitation by shading and litterfall (Baranyai *et al*. 2021) and reduced insect availability (nutrient supply) (Thum 1986).

The total biomass of *D. intermedia* that we measured was lower than found by Thum (1986) in south-east Germany, which can also be explained by the habitat structure of our *Sphagnum* paludiculture fields. Thum’s observations originated from a natural bog with typical hummock-hollow structures, where he found nearly the same total biomass for both *Drosera* species and almost double the biomass for *D. intermedia* compared to our study. No other data for total biomass and yield of *D. intermedia* in Europe were found.

The largest individual plant mass of *D. rotundifolia* was reached by plants > 24 months old, followed closely by plants aged 12–24 months. Plants of age 6–12 months reached the 2–3 times greater maximum mass one year later (Figures A4–A5). Our study implies that, in order to ensure a long-term stable population and a sustainable harvest, only plants that are at least 12 months old should be collected. These findings are in harmony with the results of Baranyai *et al*. (2016), who found that flowering *Drosera* plants older than 12 months reach the required concentrations of bioactive compounds for medicinal purposes in July and August.

Regarding the optimal harvest date, we recorded the highest proportion of flowering plants (≥ 47 % of total plants), and thus the highest yield, in July and August for both *Drosera* species. Therefore, we recommend harvesting *D. rotundifolia* and *D. intermedia* during these months to meet the demand of the pharmaceutical industry for flowering plants (Baranyai *et al*. 2021).

An advantage of the *Sphagnum* paludiculture fields is that fewer flowering plants must be collected to produce one kg of fresh *D. rotundifolia* (3,186 ± 598 plants kg^{-1}; Table 3), compared to collection from wild populations (2,500–16,000 flowering plants in Spain (Lange 1998); 5,000–10,000 flowering plants in Finland (Galambosi *et al*. 2000a).

All studies (e.g. Galambosi *et al*. 2000a, Kallio 2020), including ours, have shown great variability in total biomass, yield and plant density of *Drosera*, with high standard deviations. Currently, such data are extremely rare and include various peatland types and habitats, which are difficult to compare. Further studies on *Drosera* should in any case include an exact description of the environmental conditions.

The demand for dry *Drosera* biomass in central Europe is 6–20 tons per year (Galambosi & Jokela 2002), which corresponds to ~50–160 tons of fresh *Drosera rotundifolia*. The results of our study imply that a cultivation area of 300–750 hectares is required to meet this demand.

It is important to note that the *Sphagnum* paludiculture farm at Rastede was established and is managed for the production of *Sphagnum* as a raw material for horticultural growing media. For this purpose, a 10 cm layer of the *Sphagnum* is removed every third to fifth year, which leads to local destruction of the *Drosera* populations. Since *Drosera* species can be found on the site today (in 2022), the populations can obviously recover or re-establish after the *Sphagnum* harvest. We assume that this happens either from the seed bank of the remaining *Sphagnum* moss layer and/or from neighbouring *Sphagnum* paludiculture fields, but we do not know how fast these populations recover or whether they reach the same biomass as before. We assume that, with appropriate management (water, maintenance, establishment), *Drosera* cultivation on *Sphagnum* could achieve even better results, but further investigation will be needed to confirm this assumption.

To achieve long-term sustainable production of *Drosera* biomass on *Sphagnum* with constantly high yields of flowering plants, this study recommends the cultivation of *D. rotundifolia* on *S. palustre* lawn, harvest in July and August, and the collection of plants older than 12 months.

In Europe, large areas of drained raised bog need to be rewetted to reduce their enormous greenhouse gas emissions, and this requires the establishment of paludicultures in cases where agricultural use has to be maintained. *Drosera* paludiculture on *Sphagnum* can combine the sustainable use of wet peatlands with the provision of high-quality biomass for the pharmaceutical industry, and could totally or partially replace the collection of *Drosera* from the wild. Such cultivation may also be possible in other regions, e.g. in the boreal zone, but this would require further research. Additionally, cost-benefit analysis is required to demonstrate that the cultivation of *D. rotundifolia* on *Sphagnum* is economically feasible.

ACKNOWLEDGEMENTS

We thank the Scholarship Programme of the German Federal Environmental Foundation (DBU) for funding the first author. We also thank the company Torfwerk Moorkultur Ramsloh Werner Koch GmbH & Co. KG for in-kind support and for allowing access to their *Sphagnum* paludiculture farm.

AUTHOR CONTRIBUTIONS

BB, MK and HJ planned the study. BB designed and prepared the experimental setup and recorded the data. Data management and statistical analysis were carried out jointly by BB and MK. The manuscript was written by BB with considerable contributions from HJ, CO and MK. All authors contributed to the final version of the manuscript.

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Submitted 25 Mar 2020, final revision 07 Aug 2022
Editors: Ab Grootjans and Olivia Bragg

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Appendix

Figure A1. *Drosera intermedia* plants by age class, collected on the *Sphagnum papillosum* field of the *Sphagnum* farm in Rastede (north-west Germany). Collected and determined by Balázs Baranyai, 17 August 2014.

Figure A2. *Drosera rotundifolia* plants by age class, collected on the *Sphagnum palustre* field of the *Sphagnum* farm in Rastede (north-west Germany). Collected and determined by Balázs Baranyai, 17 August 2014.

Figure A3. *Drosera rotundifolia* plants of ages 12–24 and >24 months, the latter with rosettes from the previous year (2013) and the year of collection (2014). Collected on the *Sphagnum palustre* field of the *Sphagnum* farm in Rastede (north-west Germany). Collected and determined by Balázs Baranyai, 17 August 2014.

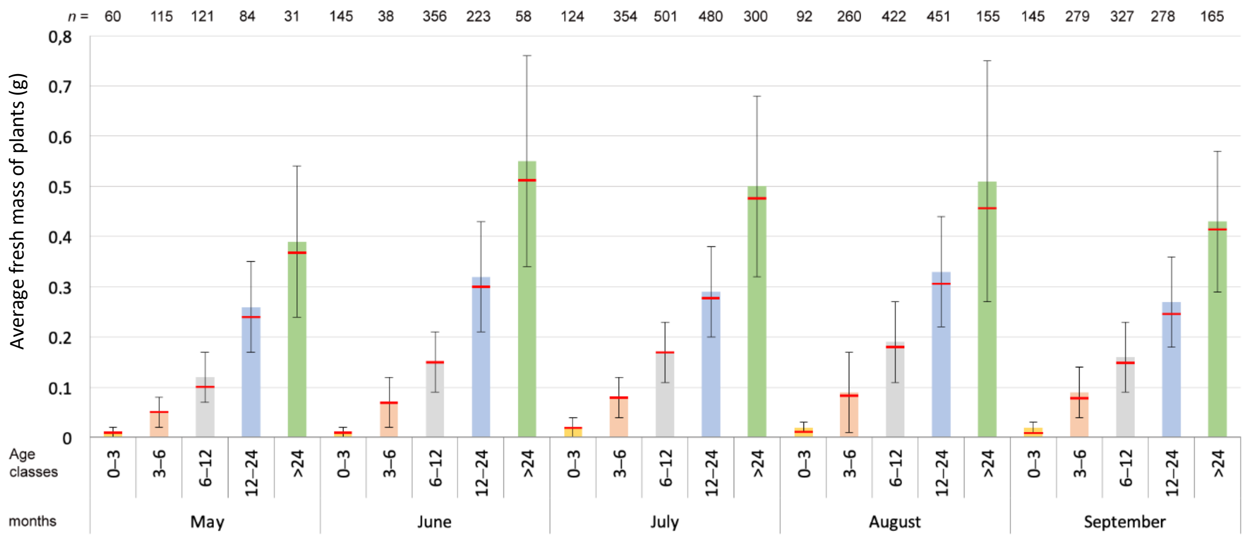

Figure A4. Fresh biomass of individual *Drosera rotundifolia* plants (flowering and non-flowering) collected between May/June and September in 2013 and 2014 on the *Sphagnum palustre* and *Sphagnum papillosum* fields, ordered by age class (0–3, 3–6, 6–12, 12–24, >24 months). Vertical bars show the means, the red lines medians and the whiskers standard deviation. Number of replicates (*n*) is written above each bar.

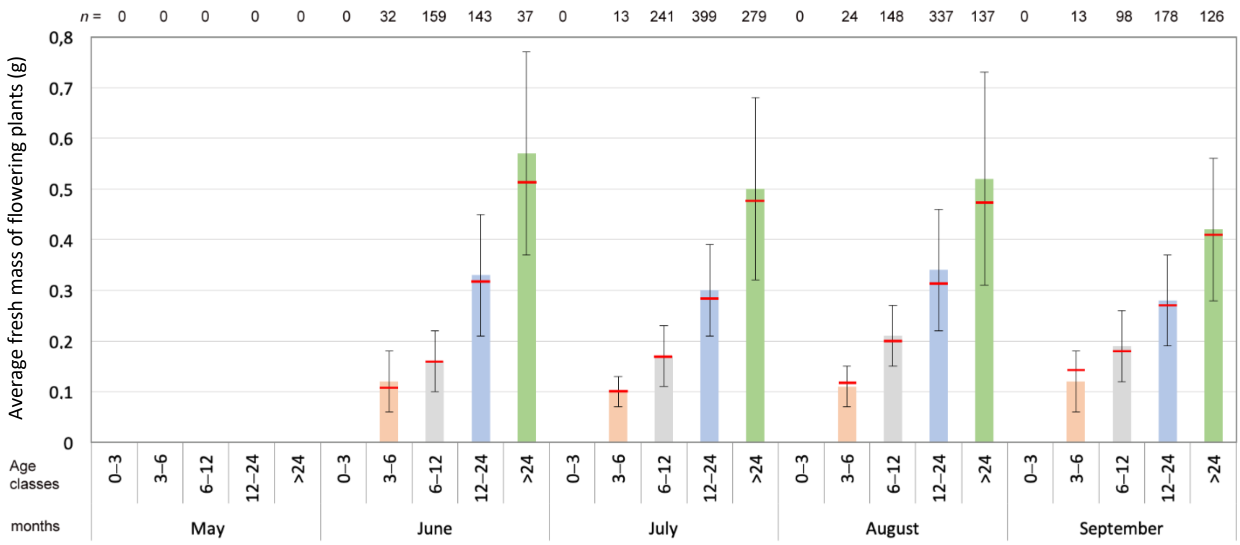

Figure A5. Fresh biomass of individual flowering *Drosera rotundifolia* plants collected between May/June and September in 2013 and 2014 on the *Sphagnum palustre* and *Sphagnum papillosum* fields, ordered by age class (0–3, 3–6, 6–12, 12–24, >24 months). Vertical bars show the means, the red lines medians and the whiskers standard deviation. Number of replicates (*n*) is written above each bar.

Table A1. Morphological features of *Drosera rotundifolia* growing in 2013 and 2014 on the *Sphagnum palustre* field; mean values ± SD (standard deviation). *n* = number of individual plants.

Month	Age class (months)	*n*	Fresh mass (g)	Total number of leaves	Number of active leaves	Number of non-active leaves	Petiole length (mm)	Number of flower stems	Length of roots (mm)
May	0–3	28	0.02 ± 0.03	3.46 ± 0.74	2.36 ± 0.62	1.11 ± 0.50	9.39 ± 2.90	0.0 ± 0.0	12.53 ± 7.13
	3–6	79	0.05 ± 0.03	4.59 ± 0.91	3.09 ± 0.82	1.51 ± 0.73	14.51 ± 2.92	0.0 ± 0.0	18.02 ± 5.84
	6–12	61	0.10 ± 0.04	5.26 ± 0.96	3.57 ± 0.81	1.69 ± 0.72	16.81 ± 2.94	0.0 ± 0.0	27.51 ± 12.33
	12–24	37	0.25 ± 0.09	7.08 ± 1.52	4.69 ± 1.09	2.39 ± 0.90	20.77 ± 3.15	0.0 ± 0.0	23.35 ± 11.35
	>24	10	0.39 ± 0.20	7.70 ± 2.00	5.60 ± 1.65	2.10 ± 0.74	22.10 ± 3.88	0.0 ± 0.0	30.93 ± 19.56
June	0–3	128	0.01 ± 0.01	3.62 ± 0.84	2.24 ± 0.70	1.39 ± 0.66	11.75 ± 4.66	0.0 ± 0.0	17.25 ± 8.23
	3–6	330	0.07 ± 0.05	4.96 ± 1.15	3.30 ± 0.95	1.66 ± 0.79	19.10 ± 5.70	0.08 ± 0.28	22.02 ± 9.64
	6–12	284	0.15 ± 0.06	6.12 ± 1.26	4.25 ± 1.15	1.87 ± 0.91	26.03 ± 5.86	0.45 ± 0.51	27.97 ± 12.26
	12–24	153	0.30 ± 0.11	7.29 ± 1.69	5.10 ± 1.43	2.20 ± 1.11	31.73 ± 6.24	0.61 ± 0.61	28.79 ± 13.84
	>24	43	0.51 ± 0.19	8.58 ± 2.14	5.88 ± 1.66	2.70 ± 1.57	31.68 ± 5.38	0.70 ± 0.77	33.04 ± 16.01
July	0–3	70	0.03 ± 0.02	3.46 ± 0.76	1.94 ± 0.63	1.51 ± 0.76	11.07 ± 4.05	0.00 ± 0.00	20.05 ± 11.35
	3–6	254	0.08 ± 0.04	4.59 ± 1.06	2.76 ± 0.81	1.83 ± 0.84	17.17 ± 5.40	0.03 ± 0.17	24.26 ± 10.40
	6–12	338	0.17 ± 0.05	5.43 ± 1.24	3.34 ± 0.95	2.09 ± 0.92	22.59 ± 5.87	0.39 ± 0.51	28.23 ± 11.74
	12–24	335	0.29 ± 0.09	6.11 ± 1.44	3.87 ± 1.14	2.25 ± 1.08	28.82 ± 5.09	0.87 ± 0.50	31.14 ± 12.63
	>24	221	0.51 ± 0.19	7.67 ± 1.93	4.92 ± 1.72	2.74 ± 1.36	35.31 ± 5.99	1.35 ± 0.67	37.99 ± 15.96
August	0–3	81	0.02 ± 0.01	3.46 ± 0.57	1.90 ± 0.68	1.56 ± 0.59	9.99 ± 3.76	0.0 ± 0.0	23.52 ± 12.62
	3–6	231	0.10 ± 0.04	4.36 ± 0.89	2.81 ± 0.77	1.55 ± 0.78	17.07 ± 5.33	0.10 ± 0.33	31.59 ± 14.15
	6–12	385	0.20 ± 0.08	5.12 ± 1.13	3.41 ± 0.84	1.71 ± 0.84	21.59 ± 6.12	0.40 ± 0.57	33.96 ± 13.00
	12–24	389	0.32 ± 0.12	5.87 ± 1.39	4.04 ± 1.26	1.83 ± 0.95	27.73 ± 6.15	1.11 ± 0.86	37.50 ± 14.58
	>24	142	0.51 ± 0.25	7.53 ± 1.87	5.18 ± 1.64	2.35 ± 1.00	34.51 ± 7.12	1.50 ± 0.91	35.55 ± 13.14
September	0–3	66	0.02 ± 0.01	2.97 ± 0.93	1.95 ± 0.79	1.03 ± 0.65	8.47 ± 3.76	0.0 ± 0.0	17.82 ± 7.66
	3–6	186	0.09 ± 0.05	2.74 ± 1.29	1.91 ± 1.04	0.87 ± 0.85	15.37 ± 4.59	0.06 ± 0.24	32.67 ± 14.16
	6–12	210	0.16 ± 0.07	4.06 ± 2.29	2.96 ± 1.67	1.16 ± 1.15	19.45 ± 4.85	0.33 ± 0.52	37.31 ± 17.10
	12–24	187	0.27 ± 0.09	3.82 ± 2.25	2.92 ± 1.84	0.96 ± 1.05	23.31 ± 5.78	0.87 ± 0.75	42.44 ± 15.67
	>24	124	0.43 ± 0.13	5.21 ± 3.04	3.96 ± 2.50	1.28 ± 1.50	27.82 ± 6.50	1.49 ± 1.09	48.27 ± 16.16

Table A2. Morphological features of *Drosera rotundifolia* growing in 2013 and 2014 on the *Sphagnum papillosum* field; mean values ± SD. *n* = number of individual plants.

Month	Age class (months)	*n*	Fresh mass (g)	Total number of leaves	Number of active leaves	Number of non-active leaves	Petiole length (mm)	Number of flower stems	Length of roots (mm)
May	0–3	32	0.01 ± 0.00	3.47 ± 0.76	2.34 ± 0.60	1.13 ± 0.49	8.65 ± 2.29	0.0 ± 0.0	13.83 ± 7.25
	3–6	36	0.06 ± 0.04	4.77 ± 1.11	3.09 ± 0.85	1.69 ± 0.83	13.01 ± 2.55	0.0 ± 0.0	17.91 ± 11.08
	6–12	60	0.13 ± 0.05	5.92 ± 1.42	3.93 ± 1.16	1.98 ± 0.85	14.76 ± 2.95	0.0 ± 0.0	28.90 ± 10.91
	12–24	47	0.27 ± 0.09	7.26 ± 2.07	4.68 ± 1.55	2.57 ± 1.21	18.98 ± 3.74	0.0 ± 0.0	37.17 ± 14.32
	>24	21	0.40 ± 0.13	9.05 ± 2.18	5.48 ± 1.78	3.57 ± 1.57	20.44 ± 3.14	0.0 ± 0.0	29.78 ± 18.06
June	0–3	17	0.02 ± 0.01	4.12 ± 0.93	2.53 ± 0.80	1.59 ± 0.62	10.15 ± 2.73	0.0 ± 0.0	12.99 ± 6.85
	3–6	53	0.08 ± 0.05	5.08 ± 1.40	3.30 ± 1.17	1.77 ± 0.82	16.39 ± 4.41	0.08 ± 0.27	22.22 ± 9.91
	6–12	72	0.16 ± 0.07	6.15 ± 1.46	4.00 ± 1.16	2.15 ± 0.93	20.47 ± 4.98	0.46 ± 0.56	27.76 ± 15.36
	12–24	70	0.37 ± 0.12	7.40 ± 1.30	5.24 ± 1.45	2.16 ± 1.09	26.54 ± 5.51	0.96 ± 0.52	37.09 ± 17.54
	>24	15	0.65 ± 0.22	8.20 ± 1.47	6.47 ± 1.73	1.73 ± 1.16	28.30 ± 6.22	1.60 ± 0.63	38.49 ± 15.26
July	0–3	54	0.02 ± 0.01	3.31 ± 0.79	2.06 ± 0.83	1.25 ± 0.52	7.70 ± 2.96	0.0 ± 0.0	17.55 ± 8.24
	3–6	100	0.08 ± 0.03	4.77 ± 1.10	3.17 ± 0.90	1.61 ± 0.79	14.15 ± 4.39	0.05 ± 0.22	23.87 ± 9.49
	6–12	163	0.16 ± 0.06	4.99 ± 1.31	3.15 ± 1.16	1.83 ± 0.88	19.69 ± 5.41	0.71 ± 0.50	23.76 ± 9.88
	12–24	145	0.29 ± 0.09	5.82 ± 1.56	3.81 ± 1.33	2.01 ± 1.08	25.20 ± 6.07	1.25 ± 0.64	29.94 ± 12.74
	>24	79	0.46 ± 0.14	6.56 ± 2.09	4.35 ± 1.64	2.21 ± 1.06	29.34 ± 6.89	1.62 ± 0.70	37.92 ± 14.94
August	0–3	11	0.01 ± 0.01	3.18 ± 0.60	2.18 ± 0.75	1.00 ± 0.63	7.35 ± 2.15	0.0 ± 0.0	15.99 ± 5.11
	3–6	29	0.09 ± 0.05	4.69 ± 0.81	3.24 ± 0.95	1.45 ± 0.78	13.68 ± 3.05	0.07 ± 0.26	25.49 ± 11.77
	6–12	37	0.18 ± 0.06	5.68 ± 1.38	3.92 ± 1.01	1.76 ± 0.76	17.22 ± 4.50	0.30 ± 0.46	31.89 ± 14.48
	12–24	62	0.33 ± 0.10	6.48 ± 1.26	4.65 ± 1.01	1.84 ± 0.98	22.96 ± 4.08	1.08 ± 0.71	38.88 ± 16.91
	>24	13	0.56 ± 0.11	7.08 ± 1.26	5.00 ± 0.82	2.08 ± 0.76	27.16 ± 3.22	2.23 ± 0.73	55.75 ± 17.85
September	0–3	79	0.02 ± 0.01	3.03 ± 0.75	2.22 ± 0.65	0.81 ± 0.60	8.31 ± 4.44	0.00 ± 0.00	16.62 ± 8.90
	3–6	93	0.08 ± 0.04	3.28 ± 1.12	2.59 ± 0.95	0.70 ± 0.79	12.18 ± 2.99	0.02 ± 0.15	24.50 ± 10.48
	6–12	117	0.17 ± 0.07	3.24 ± 1.28	2.49 ± 0.97	0.76 ± 0.85	16.30 ± 5.33	0.30 ± 0.50	34.86 ± 15.63
	12–24	91	0.27 ± 0.11	3.42 ± 1.64	2.75 ± 1.09	0.66 ± 0.93	18.28 ± 4.31	0.96 ± 0.95	36.30 ± 12.57
	>24	41	0.42 ± 0.19	6.10 ± 3.22	4.34 ± 2.25	1.76 ± 1.45	22.16 ± 7.01	1.07 ± 0.88	38.94 ± 16.71

Table A3. Morphological features of *Drosera intermedia* growing on the *Sphagnum papillosum* field in 2013 and 2014; mean values ± SD. In September (2013 and 2014) the length of roots was not measured. *n* = number of individual plants.

Month	Age class (months)	*n*	Fresh mass (g)	Number of flower stems	Length of roots (mm)
May	3–6	1	0.06 ± 0.00	0.0 ± 0.0	15.7 ± 0.00
	6–12	4	0.11 ± 0.05	0.0 ± 0.0	37.03 ± 11.99
	12–24	4	0.39 ± 0.11	0.0 ± 0.0	44.98 ± 19.73
	>24	0	-	-	-
June	3–6	24	0.10 ± 0.06	0.04 ± 0.20	18.88 ± 7.74
	6–12	2	0.17 ± 0.05	0.0 ± 0.0	26.05 ± 3.32
	12–24	14	0.28 ± 0.20	0.0 ± 0.0	21.96 ± 9.59
	>24	5	0.50 ± 0.11	0.80 ± 0.84	20.50 ± 6.03
July	3–6	8	0.07 ± 0.04	0.0 ± 0.0	19.20 ± 6.96
	6–12	29	0.20 ± 0.10	0.43 ± 0.50	18.32 ± 8.73
	12–24	26	0.35 ± 0.14	0.85 ± 0.55	19.94 ± 8.03
	>24	23	0.70 ± 0.24	1.09 ± 0.83	33.74 ± 17.11
August	3–6	2	0.13 ± 0.01	0.0 ± 0.0	28.70 ± 8.20
	6–12	8	0.18 ± 0.05	0.13 ± 0.35	49.22 ± 19.79
	12–24	24	0.33 ± 0.16	0.67 ± 0.56	50.59 ± 14.19
	>24	19	0.68 ± 0.25	1.68 ± 0.89	70.81 ± 9.37
September	3–6	12	0.06 ± 0.03	0.0 ± 0.0	-
	6–12	34	0.14 ± 0.07	0.12 ± 0.41	-
	12–24	44	0.36 ± 0.19	0.18 ± 0.50	-
	>24	19	0.66 ± 0.32	0.63 ± 0.60	-

Table A4. Comparison of the mean plant mass (± SD) per age class of *Drosera rotundifolia* and *Drosera intermedia* collected in the *Sphagnum papillosum* field during 2013 and 2014. Test of difference within the age classes using the Kruskal Wallis test, χ^2: Kruskal Wallis chi-squared statistic; d.f.: degrees of freedom; P: level of significance. The test was not performed for age class 0–3 months because there were insufficient data for *D. intermedia*.

Age class (months)	*Drosera* species	Number of plants	Fresh mass (g)	χ^2	d.f.	P
0–3	*D. rotundifolia*	193	0.02 ± 0.01	-	-	-
	D. intermedia	1	0.01 ± 0.00			
3–6	*D. rotundifolia*	311	0.08 ± 0.04	0.281	1	0.595
	D. intermedia	46	0.08 ± 0.05			
6–12	*D. rotundifolia*	449	0.16 ± 0.06	0.044	1	0.832
	D. intermedia	77	0.17 ± 0.08			
12–24	*D. rotundifolia*	414	0.30 ± 0.11	3.462	1	0.062
	D. intermedia	112	0.34 ± 0.17			
>24	*D. rotundifolia*	169	0.46 ± 0.17	37.778	1	$\leq$0.001
	D. intermedia	66	0.67 ± 0.26			