# A comparative study of the mosses Ptychostomum pseudotriquetrum and P. bimum 

Investigating morphological characters, habitat, and distribution across northern Sweden

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#### Abstract

The mosses Ptychostomum pseudotriquetrum and P. bimum (syn: Bryum, Bryophyta) are difficult to distinguish from each other, as they appear morphologically identical besides their difference in sexual condition. Because of their similarities, some researchers treat both as $P$. pseudotriquetrum, while others treat them as two distinct species. Previous studies have described differences in characters besides sexual condition. However, there are few such studies, and none has been conducted in northern Sweden. The purpose of this study was to investigate if $P$. pseudotriquetrum and $P$. bimum could be distinguished by characters other than the sexual condition and study the environmental preferences and distributions of the species in northern Sweden. Thirty-three specimens were used in the study. Ten different characters were examined, and morphological data were collected and analyzed for differences. Information regarding habitat and distribution were gathered and analyzed. The statistical analyses showed a significant difference in the leaf decurrency between the species, and an almost significant difference regarding stem length and shape of median leaf lamina cells. No other differences were found. The results correspond with previous research claiming $P$. pseudotriquetrum and $P$. bimum should be considered two distinct taxa. The difference in leaf decurrency suggests that this character might be useful in future research to distinguish the two species, especially when the study samples are sterile, or when there is a lack of molecular data to confirm the species identification. At present the two species are best regarded as semicryptic, pending further detailed investigations of potentially distinguishing characters.


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## 1 Introduction

The classification of Bryophyta is ever changing with constant revisions, especially regarding phylogenetic inferences (Goffinet and Shaw 2009). Because of intensifying disturbance and exploitation of natural ecosystems worldwide increasing the risk of species extinction (Brook et al. 2006), it is important to register and clarify the components of biodiversity, especially considering that most species remain undescribed (Bickford et al. 2007). Crypsis is a great challenge to biodiversity research ( Yu et al. 2013) and is considered to be very common in bryophytes (Bischler and Boisselier-DuBayle 1997; Shaw 2001). The phenomenon refers to species that are at least superficially morphologically indistinguishable but are reproductively isolated from one another (Bickford et al. 2007; Myszczynski et al. 2017). Cryptic species means that two, or more, distinct species risk being inaccurately classified, and hidden, under one species name (Bickford et al. 2007). The number of cryptic species globally, therefore, remains uncertain (Renner 2020). Species that are almost indistinguishable by morphology can be called semi-cryptic (e.g., Hedenäs 2020).

As a result of the increasing availability of DNA sequences, research on cryptic species has progressed over the past two decades (Bickford et al. 2007). Despite this, cryptic species that are uncovered using modern methods may remain taxonomically cryptic (Schlick-Steiner et al. 2007). An interaction between molecular and traditional taxonomy is needed, i.e., morphological studies where supposedly cryptic species are later identified by means of external physical characters (Schlick-Steiner et al. 2007). Knowledge of cryptic species is important since they could hide the plasticity of taxonomically important character systems, and thus bias researchers' reconstruction of the historical evolution of characters (Heinrichs et al. 2011; Ho et al. 2012; Pons et al. 2011; Vanderpoorten et al. 2001, 2002; Yu et al. 2010). Identification of cryptic species also provides an understanding of species diversity, and the conservation needs for the species aggregates (Hedenäs 2020; Yu et al. 2013). Studies combining molecular evidence and morphology show that there is hidden diversity among the mosses of northern Scandinavia, and that the numbers of both morphologically recognizable and cryptic species in these areas are underestimated (e.g., Hedenäs 2020). This underlines that the species diversity of northern Sweden deserves to be further studied.

Ptychostomum pseudotriquetrum (syn: Bryum. (Hedw.) G.Gaertn., B.Mey. and Scherb.), and its species complex, has great classification difficulties. The species complex is highly variable, and different taxa including varieties and subspecies have been described (Hallingbäck et al. 2008; Nyholm 1993). Ptychostomum pseudotriquetrum is challenging, since seemingly distinct morphological entities have been hidden under this name and were, in some cases, only later recognized as distinct species (Holyoak 2021; Hedenäs et al. 2021). An example of such a distinct species, i.e., formerly hidden under the name P. pseudotriquetrum, is Ptychostomum bimum (syn: Bryum. (Schreb.) Lilj.). The classification of $P$. bimum is challenging as its taxonomic treatment relative to $P$. pseudotriquetrum varies depending on the researcher. It is probable that $P$. bimum evolved from $P$. pseudotriquetrum by a chromosome doubling of the latter (Holyoak 2021). Holyoak and Hedenäs (2006) reported a distinct difference in the sexual condition, as $P$. bimum differs most notably from $P$. pseudotriquetrum in being synoicous instead of dioicous. Crum and Anderson (1981) and Dirkse et al. (1989) treated synoicous forms as insignificant synonyms of $P$. pseudotriquetrum. Smith (1978) treated $P$. bimum instead as a variety. Subsequent research has reported differences in shape and mean size of the mid-leaf cells (Demaret and Empain 1985), differences in leaf cell-wall thickness (Zolotov 2000) and the leaves of P. bimum as less decurrent and more crowded (Nyholm 1993). The finds of
supposed differences in characters other than the sexual condition between the two led Nyholm (1993), Smith (2004) and Zolotov (2000) to treat $P$. bimum as a distinct species.

The habitat preferences of $P$. pseudotriquetrum and $P$. bimum appear to be very similar (Holyoak and Hedenäs 2006). Unfortunately, the two are indistinguishable while collected in the field, as evidenced by the occurrence of both taxa under the name $P$. pseudotriquetrum in herbarium UME (Sjölander, own observations). Given that $P$. bimum has had little recognition in the past, its distribution is not well understood (Nyholm 1993; Spence 2014). The environmental preferences and distributions of these two bryophytes have never been studied in the north of Sweden.

The purpose of this study is to investigate if the two species $P$. pseudotriquetrum and $P$. bimum, at present best described as semi-cryptic, can be distinguished by characters other than the sexual condition, and if so, how well those character differences correspond with current literature. The study will also investigate whether there are differences in environmental preferences and distribution between the two species in northern Sweden. To attempt to answer these questions the following hypotheses will be investigated:
$H 1$ : There are differences in character states between $P$. pseudotriquetrum and $P$. bimum other than sexual condition (and number of chromosomes; see above).

H2: There are differences in habitat and distribution between $P$. pseudotriquetrum and $P$. bimum in northern Sweden.

## 2 Methods

### 2.1 Study species

Ptychostomum pseudotriquetrum is a red-green, green or yellow-green plant, whereas older shoots turn red-brown (Spence 2014). The height of the stem is $2-6 \mathrm{~cm}$ (Spence 2014) but can be equal to or higher than 10 cm (Nyholm 1993). The stem is strongly radiculose, i.e., has many rhizoids (Nyholm 1993; Spence 2014), and at the apex of the shoot there are either female- or male sexual organs (dioicous). The stem leaves are equidistantly arranged, $1-4 \mathrm{~mm}$ long, ovate and concave (Spence 2014) or ovate-lanceolate (Nyholm 1993), with a short-excurrent costa (Nyholm 1993; Spence 2014). The leaf base is longly and narrowly decurrent (Nyholm 1993; Spence 2014), and the leaf apex is acute (Spence 2014) or shortly acuminate (Nyholm 1993). The cells in the middle of the leaf are between 14-22 $\mu \mathrm{m}$ wide (Spence 2014) or 16-20 $\mu \mathrm{m}$ (Nyholm 1993), and rhomboid (Nyholm 1993; Spence 2014) or hexagonal (Nyholm 1993), whereas the basal cells are rectangular and widened (Nyholm 1993).

Ptychostomum bimum is a green, yellow-green plant (Spence 2014), which becomes brownish or dark red in exposed habitats (Nyholm 1993). The height of the stem is 1-4 cm (Nyholm 1993), or between 1.5-4 cm (Spence 2014). The stem is also densely covered with rhizoids (Spence 2014; Nyholm 1993), and at the apex of the shoot are both female and male sexual organs (synoicous). The stem leaves are equidistantly arranged, 1-3.5 mm in length, their shape ovate (Spence 2014) or ovate-lanceolate (Nyholm 1993), the base shortly decurrent (Nyholm 1993; Spence 2014). The leaf apex is acute (Spence 2014) or shortly acuminate (Nyholm 1993). The leaf costa is very strong (Nyholm 1993) and short-excurrent (Nyholm 1993; Spence 2014). The cells in the middle of the leaf are 12-17 $\mu \mathrm{m}$ wide (Nyholm 1993), or up to $18 \mu \mathrm{~m}$ (Nyholm
1993) and either rhomboidal (Nyholm 1993; Spence 2014) or hexagonal, and the basal cells are rectangular and widened (Nyholm 1993).

Both species are widely distributed in Europe, North America and New Zealand, while $P$. pseudotriquetrum occurs also in South America, Macaronesia, northern- and southern Africa, North-, East- and Central Asia, Greenland, and the Antarctic (Nyholm 1993). They are found from the lowland up to the low alpine belt of mountains (Spence 2014; Nyholm 1993) and grow in damp or wet habitats, often near water, such as on soil and soil covered rocks (Spence 2014; Fife 2015), even if the latter occurs less frequently for $P$. pseudotriquetrum in forest streams (Fife 2015). In addition to shallow water at streams and lake edges, $P$. pseudotriquetrum can be found in habitats like marshes (Glime 2020) and swamps (Fife 2015).

### 2.2 Data collection

### 2.2.1 Habitat and distribution

The specimens of the present study were chosen from collections named " $P$. pseudotriquetrum" in the herbarium of Umeå (UME). Only collections from the northern counties of Sweden were examined. The collections with the most complete information regarding the specimens' habitats were primarily selected (Figure 1). The collections were chosen with the goal of having an even distribution across the north Swedish counties. With such criterias accounted for, 27 collections were selected, and from those a total of 33 specimens were studied (see 2.2.2 for details). The collections were categorized into one of three categories: "shore", "mire" or "spring" in accordance with avaliable information regarding the specimens' habitats.


Figure 1. Examples of collections with the most complete information regarding the specimens' habitats.

### 2.2.2 Species affiliation and study character approach

The species affiliation was assigned by sexual organs using a dissecting scope (Nikon SMZ645), i.e., I identified if the specimen was either $P$. pseudotriquetrum (dioicous) or $P$. bimum (synoicous). Since female and male organs mature during July-August (Arnell 1875) the selected collections from that period were prioritized to improve the chances of finding young or recently mature sexual organs at the apex of the bryophyte's shoot (Figure 2). I examined countless of specimens (which were predominantly declared sterile and, in this case, useless) from all the 27 collections, until I had identified an adequate number of sexually mature samples of both species to be able to conduct the statistical analyses regarding potential differences between the species. A total of 33 specimens were identified and studied: 21 of $P$. pseudotriquetrum and 12 of $P$. bimum.


Figure 2. Female and male organs at the apex of the bryophyte's shoot (identification of $P$. bimum).
Once the species identification was complete, ten gametophytic characters were examined: leaf cell width, leaf lamina length, costa length, length of leaf decurrency, stem length, stem rhizoidcoverage, and the shape of the leaf, leaf apex, and median- and basal leaf cells. Five main stem leaves were picked from each specimen and used as the basis for the study of the characters (Figure 3A; Figure 3B). To ensure I attained reliability of the values, the stem leaves were taken at an equivalent position ( $5-10 \mathrm{~mm}$ below the stem apex) on each individual gametophyte, avoiding the leaves close to the shoot tip since these were not yet properly mature (Figure 3A). Using tweezers, the leaf base was picked as close to the stem as possible. In special cases where sexual organs were present at the apex of the stem branches but not the main stem, the stem branch leaves were examined. In these cases, it was still the length of the main stem that was measured and used. The cell width, the length of the leaf lamina, the costa, the leaf decurrency, and the shape of the median- and basal cells were examined under a compound microscope (Leica ATC 2000). The shape of the leaf and leaf apex were examined under a dissecting scope (Nikon SMZ645).


Figure 3. A) P. pseudotriquetrum where five stem leaves have been picked approximately $5-10 \mathrm{~mm}$ below the stem apex, leaving the main stem bare in this area; B) Five stem leaves picked from $P$. pseudotriquetrum, which were examined and used as the basis for the study of the morphological characters: leaf cell width, leaf lamina length, costa length, length of leaf decurrency, and the shape of the leaf, leaf apex, and median- and basal leaf cells.

### 2.2.3 Morphological characters

## Cell width ( $\mu \mathrm{m}$ )

Cell width was measured in the central portions of two leaves using the microscope at a magnification of 40 x . Two cells were measured in the first leaf, and three in the second (see appendix for details). Cell width included one cell wall and the adjacent cell lumen (Figure 4). Leaf cells were arbitrarily selected, i.e., the cell that I first saw in the microscope was measured, followed by the cell directly to the right of the first and so forth.


Figure 4. Cell width in the central portions of the leaf at a magnification of 40 x was measured with a scale. One scale bar equals $2.5 \mu \mathrm{~m}$.

## Leaf lamina length (mm)

Five leaves were measured using the microscope at a magnification of 4 x . The measurement was taken from the leaf apex to the leaf base. Leaf lamina length was also used to calculate the relative length of the costa and the relative leaf decurrency (see below).

## Costa/lamina ratio (\%)

Costa length ( mm ) was measured in five leaves using the microscope at a magnification of 4 x . The length was measured from the apex of the costa to its base. The ratio costa length and lamina length, expressed as percent, was calculated by dividing the costa length with the lamina length. Costa/lamina ratio was used as a character to analyze instead of measured costa length $(\mathrm{mm})$ since the latter to a greater extent is affected by the size of the bryophyte's shoot.

## Leaf decurrency/lamina ratio (\%)

Leaf decurrency ( mm ) was measured in five leaves using the microscope at a magnification of 4 x . The extent of the decurrency was measured from the base of the leaf to the end of the decurrency. The ratio decurrent length and lamina length, expressed as percent, was calculated by dividing the decurrent length with the lamina length. Leaf decurrency/lamina ratio was used as a character to analyze instead of measured leaf decurrency ( mm ) since the latter to a greater extent is affected by the size of the bryophyte's shoot. Leaf decurrency was only measured for the last studied 22 samples because while working with the first samples, I realised the character would be useful to examine. The first 11 samples could not be re-examined as the studied shoots were discarded after being examined.

## Stem length (cm)

The stem length was measured from the apex to the base of the shoot. A standard ruler was used.

## The rhizoid-coverage

To rank the stem's coverage of rhizoids for each specimen three categories were used: "low cover", "average cover" and "dense cover".

## Shape of leaf and leaf apex

The shape of the leaf and the leaf apex were classified using the dissecting scope. To categorize the shape of the leaf the character states "ovate" and "lanceolate" were used, whereas "acute" and "acuminate" were used for the leaf apex. If three or more (maximum five) leaves had a character state, that state was taken to represent the specimen.

## Shape of median- and basal leaf lamina cells

The general shapes of the median- and basal leaf lamina cells were classified using the microscope at a magnification of 40 x . To categorize the shape of the median cells the character states "hexagonal" and "rhomboid" were used, whereas "hexagonal" and "rectangular" were used for the basal cells. If three or more (maximum five) leaves had a character state, that state was taken to represent the specimen.

### 2.3 Statistical analyses

The cell width, length of lamina, length of costa and length of decurrent all consisted of five separate measurements per specimen. Because the five measurements came from the same specimen, they were not independent measurements. Therefore, an average value for each character was calculated to represent the specimen (the calculations were made from the data included in the Appendix). The average value was used when conducting statistical analyses. A Shapiro-Wilks test was performed on all the datasets of the mentioned characters, including stem length, to determine if they were normally distributed, using JASP (version 0.16.3, JASP Team).

The statistical analyses tested the hypotheses' underlying null hypotheses, i.e., that there exist no differences between the taxa in the studied variables. When conducting multiple statistical tests there is an increased chance of making a type 1 error (Armstrong 2014). To counteract this, Bonferroni's correction was used. The preferred significance level ( $p=0.05$ ) was divided with the number of tests $(n=11)$ to calculate the appropriate significance level ( $p=0.0045$ ), which was used during testing.

To compare cell width, length of lamina, costa/lamina ratio and leaf decurrency/lamina ratio between the species, multiple independent T-tests were used, which is an appropriate test when comparing normally distributed continuous variables between two independent groups. These tests were conducted in Excel Data Analysis (Version 2210, Microsoft Corp. 2018).

To compare the stem length between the species a Mann-Whitney U-test was performed, which is an appropriate test when comparing a non-normally distributed continuous variable between two groups. This test was carried out in JASP.

To investigate potential differences in rhizoid-coverage, habitat, and in the shape of the leaf, the leaf apex, and the median- and basal cells, multiple chi-squared tests were used. The test is appropriate when comparing categorical variables between two groups. The chi-squared tests were carried out in JASP. Six samples were excluded from the analysis regarding the habitat, due to insufficient label information.

A Principal Component Analysis (PCA) was performed based on cell width, length of leaf lamina, costa/lamina ratio and leaf decurrency/lamina ratio and stem length. The PCA was used to summarize the total variation in the dataset in a few dimensions. While the method sacrifices some accuracy it allows to explore the position of the samples in relation to the major trends in the data (Powers 2022). The PCA was carried out in STATISTICA (version 13.3, TIBCO Software Inc. 2017).

## 3 Results

All 33 samples were used in all analyses except for habitat ( $n=27$ ) and leaf decurrency/lamina ratio $(n=22)$. No data points were lost.

### 3.1 Morphological characters

Of the studied characters cell width, lamina length, costa/lamina ratio and leaf decurrency/lamina ratio, only the latter differed between $P$. pseudotriquetrum and $P$. bimum. The length of leaf decurrency differed highly significantly between the species ( $p<0.001$; Table 1). The leaf decurrency in $P$. pseudotriquetrum was $11.42 \% \pm 0.61$ (mean $\pm$ standard error, Table 1). The leaf decurrency in $P$. bimum was $6.84 \% \pm 0.52$ (mean $\pm$ standard error, Table 1).

Table 1. The independent t -tests comparing $P$. pseudotriquetrum and $P$. bimum. The analysis compared the parameters: cell width, lamina length, costa/lamina ratio and leaf decurrency/lamina ratio. n: number of samples; M: mean; SE: standard error; df: degrees of freedom.

|  | P. pseudotriquetrum |  |  |  |  |  | P. bimum |  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :---: | :---: |
| Character | Unit | $n$ | $M$ | $S E$ | $n$ | $M$ | $S E$ | $d f$ | $t$ | $p$ |  |  |
| Cell width | $\mu \mathrm{m}$ | 21 | 20.79 | 0.79 | 12 | 18.79 | 1.13 | 31 | -1.48 | 0.149 |  |  |
| Lamina length | mm | 21 | 2.91 | 0.17 | 12 | 2.70 | 0.19 | 31 | -0.805 | 0.427 |  |  |
| Costa/lamina ratio | $\%$ | 21 | 99.84 | 0.46 | 12 | 99.75 | 0.62 | 31 | -0.114 | 0.910 |  |  |
| Leaf decurrency/lamina ratio | $\%$ | 12 | 11.42 | 0.61 | 10 | 6.84 | 0.52 | 20 | -5.593 | $<0.001$ |  |  |

The difference in stem length between the species was almost significant before Bonferroni correction ( $p=0.056$; Table 2).

Table 2. Mann-Whitney U-test comparing stem length between P. pseudotriquetrum and P. bimum. n: number of samples; M: mean; SE: standard error.

|  |  | P. pseudotriquetrum |  | P. bimum |  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Character | Unit | $n$ | $M$ | $S E$ | $n$ | $M$ | $S E$ | $U$ | $p$ |
| Stem length | cm | 21 | 2.82 | 0.26 | 12 | 2.01 | 0.23 | 74.50 | 0.056 |

There was no significant difference in rhizoid-coverage between the species $(p=0.483$; Table $3)$.

Table 3. Chi-squared test comparing rhizoid-coverage between $P$. pseudotriquetrum and $P$. bimum. n: number of samples; df: degrees of freedom.

| Character | $\boldsymbol{P}$. pseudotriquetrum (21) | P. bimum (12) |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Rhizoid-coverage | $n$ | $n$ | $d f$ | $X^{2}$ | $p$ |
| Low | 4 | 1 | 2 | 1.454 | 0.483 |
| Average | 5 | 5 |  |  |  |
| Dense | 12 | 6 |  |  |  |

The shape of the median cells showed a tendency to differ before Bonferroni correction ( $p=$ 0.021 ; Table 4), but the difference was not significant after the correction. The shape of the median cells of $P$. pseudotriquetrum were mainly hexagonal, whereas the shape of the median cells of $P$. bimum were mainly rhomboid (Figure 5).

Table 4. Chi-squared tests to assess the relationship between $P$. pseudotriquetrum and $P$. bimum. The analyzed characters: the shape of the leaf, leaf apex, and median- and basal leaf cells. n: number of samples; df: degrees of freedom.

|  |  | P. pseudotriquetrum (21) | P. bimum (12) |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Character | Shape | $n$ | $n$ | $d f$ | $X^{2}$ | $p$ |
| Lamina leaf | Ovate | 14 | 7 | 1 | 0.229 | 0.632 |
|  | Lanceolate | 7 | 5 |  |  |  |
| Leaf apex | Acute | 10 | 7 | 1 | 0.351 | 0.554 |
|  | Acuminate | 11 | 5 |  |  |  |
| Median cells | Hexagonal | 17 | 5 | 1 | 5.304 | 0.021 |
|  | Rhomboid | 4 | 7 |  |  |  |
| Basal cells | Hexagonal | 8 | 2 | 1 | 1.660 | 0.198 |
|  | Rectangular | 13 | 10 |  |  |  |



Figure 5. The distribution of the shape of the median cells for $P$. pseudotriquetrum and $P$. bimum. The blue color represents the rhomboid shape, whereas the orange color represents the hexagonal shape.

### 3.1.1 Principal Component Analysis

In the PCA, Factors 1 and 2 explained $56.9 \%$ of the variation in the characters: cell width, leaf lamina length, costa/lamina ratio, leaf decurrency/lamina ratio and stem length. The first two factors distinguish $73 \%$ of the $P$. bimum and $P$. pseudotriquetrum samples from each other (Figure 6A). The distribution of samples along Factor 1 is primarily explained by leaf cell width, costa/lamina ratio, and leaf lamina length, whereas the distribution along Factor 2 is explained by stem length and leaf decurrency/lamina ratio (Figure 6B).


Figure 6. The PCA is based on cell width (cell, $\mu \mathrm{m}$ ), lamina length (length, mm ), costa/lamina ratio (costa, \%), leaf decurrency/lamina ratio (decurrency, \%) and stem length (stem length, cm ). A) The distribution of samples based on the variation in the mentioned characters along factors 1 and 2; B) explanatory characters along factors 1 and 2 .

### 3.2 Habitat and distribution

There was no difference in habitat preferences between the species ( $p=0.683$; Table 5). The distribution of the samples was mostly similar between the species, the one noticeable difference being that $P$. pseudotriquetrum was found near mountain areas more often than $P$. bimum (Figure 7).

Table 5. Chi-square test comparing the distribution of samples from different habitats, between $P$. pseudotriquetrum and $P$. bimum. n: number of samples; df: degrees of freedom.

|  | P. pseudotriquetrum (18) | P. bimum (9) |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Habitat | $n$ | $n$ | $d f$ | $X^{2}$ | $p$ |
| Shore | 7 | 2 | 2 | 0.762 | 0.683 |
| Mire | 6 | 4 |  |  |  |
| Spring | 5 | 3 |  |  |  |



Figure 7. The distributions of $P$. pseudotriquetrum and $P$. bimum in northern Sweden. ©Lapplänning.

## 4 Discussion

This study shows that $P$. pseudotriquetrum and $P$. bimum in northern Sweden differ not only in their sexual conditions, but also in how longly decurrent the leaves are. Other characters that have been used to distinguish the two turned out to be unreliable, although especially the median leaf lamina cells may be worth further studies. Even if the two cannot be reliably distinguished in the field, i.e., often hidden under the same name " $P$. pseudotriquetrum", the differences found here motivate their recognition as semi-cryptic species.

### 4.1 Morphological characters

The results of the PCA show that $P$. pseudotriquetrum and $P$. bimum differ from each other, but with a relatively significant overlap in their overall morphology (Figure 6A). However, it was shown that they can be distinguished not only by their sexual condition but also by the length of the leaf decurrency and possibly by the plant size and shape of the median leaf lamina cells.

Of the ten studied characters which were analyzed and compared, only the ratio of leaf decurrency differed significantly between $P$. pseudotriquetrum and $P$. bimum (Table 1). This shows that there are differences in character states between the species other than the sexual condition. Because of this, the first null hypothesis was rejected. The found differences in leaf decurrency correspond well with literature stating that the leaves of $P$. bimum as less longly decurrent compared to P. pseudotriquetrum (Nyholm 1993). Schlick-Steiner et al. (2007) states that it is needed to combine molecular and traditional taxonomy to identify cryptic species, and the present study lacks the molecular component. However, assuming that the difference in sexual condition is consistent with molecular entities, the difference in the length of decurrency between the species motivates their recognition as semi-cryptic species, as they are mostly indistinguishable in the field and only with some difficulty in the laboratory. The lack of molecular data might be a problem, since crypsis often is a matter of perspective when studying external physical characters, which can be prone to individual perception over accurate definition (Cargill et al. 2016). If molecular data confirm the two entities that were here based on the sexual condition and leaf decurrency, this would also confirm their recognition as semicryptic species.

The stem length showed almost a significant difference between the species before Bonferroni correction (Table 2). Stem length was suggested to differ between the species, i.e., P. bimum being smaller in size than P. pseudotriquetrum (Nyholm 1993; Spence 2014). Regarding the rhizoid-coverage, the lack of significant difference in this character (Table 3) corresponds with literature stating that the stem is often densely covered with rhizoids for both species (Nyholm 1993; Spence 2014). Finally, the shape of the median cells showed a tendency to differ (Table 4; Figure 5), but the difference was not significant after Bonferroni correction of the P -value. The results of the present study suggest a difference in this character between the species, which corresponds with findings by Demaret and Empain (1985) as they reported differences in shape of the mid-leaf cells. However, some of the literature claims that the shape of the median cells is either hexagonal or rhomboid for both species (Nyholm 1993; Spence 2014). These discrepancies in results, including my own, indicate the need for more research investigating the character. The lack of significance of the difference in stem length and in the shape of the median cells in this study could possibly be a result of too few samples to reveal existing differences between the species. Therefore, it would be desirable to analyze a bigger sample size in future research to increase the statistical power of the study.

The present findings of morphological differences, besides the sexual condition, support the claims of previous researchers that the two bryophytes should be treated as distinct species (Hedenäs et al. 2021; Nyholm 1993; Smith 2004, 2006; Zolotov 2000). As Hedenäs (2020) explains, species that are almost indistinguishable by morphology can be called semi-cryptic. Because P. pseudotriquetrum and P. bimum differ in subtle morphological features (i.e., sexual condition, leaf decurrency) and can be distinguished, although with some difficulties, without molecular analysis, I argue that $P$. pseudotriquetrum and $P$. bimum should be considered as semi-cryptic species.

Studies like the present are important to provide greater understanding of species complexity and biodiversity, and in this way, they will help guide conservation decisions for species aggregates (Hedenäs 2020; Yu et al. 2013). In addition, to acknowledge semi-cryptic species helps researchers construct characters' historical evolution (Heinrichs et al. 2011; Ho et al. 2012; Pons et al. 2011; Vanderpoorten et al. 2001, 2002; Yu et al. 2010). Considering species as semi-cryptic rather than treating them as synonyms helps guide future research, both regarding the species studied here and in other similar cases.

### 4.2 Habitat and distribution in northern Sweden

The comparison of habitat preferences between $P$. pseudotriquetrum and $P$. bimum showed no significant difference between the species (Table 5). Because of this, the second null hypothesis could not be rejected. This is in line with previous research indicating that the species' habitat preferences are similar (Holyoak and Hedenäs 2006).

When visually inspecting the distribution of $P$. Pseudotriquetrum and $P$. bimum across the map there were no noticeable differences between the species, except the occurrence of more samples of $P$. pseudotriquetrum in the mountain regions compared to $P$. bimum (Figure 7). The overall pattern of distribution is consistent with previous studies indicating that the species occur from the lowland up to the low alpine belt of mountains (Spence 2014; Nyholm 1993). I was unable to find any previous research that points to differences in habitat between the species. A likely explanation for the lack of $P$. bimum samples found near mountain areas in this study is the low sample size. To investigate potential differences in geographic patterns additional research with bigger sample sizes is required.

### 4.3 Future studies

It would be of interest for future research to explore the differences and similarities between $P$. pseudotriquetrum and $P$. bimum further. A greater understanding of the species might be gained by studying leaf decurrency more in depth, since this should provide a valuable character to distinguish the two species in the numerous cases when the samples are sterile and there is a lack of molecular data. The leaf decurrency builds on previous research indicating $P$. pseudotriquetrum and P. bimum are best considered as semi-cryptic, and suggests the possibility of future methods of identifying these species. Because of the difficulties telling the species apart in the field, people who previously have collected samples of $P$. bimum have often erroneously classified them as $P$. pseudotriquetrum. Such a case, where both taxa misleadingly occur under the name $P$. pseudotriquetrum, was evidenced by this study as I identified 12 specimens of $P$. bimum from collections named " $P$. pseudotriquetrum" in hebarium UME (Sjölander, own observations). Future herbarium studies will therefore re-classify many specimens named " $P$. pseudotriquetrum", using similar approaches as in this study (Hedenäs, personal communication). It would also be of interest to study the geographic pattern of $P$. pseudotriquetrum and P. bimum more in depth.

Furthermore, as the statistical analyses of this study showed near-significant differences in stem length and median cell shape between the species, future studies should investigate these characters further, which might provide additional useful information for identifying the species. If it can be shown that there exist differences in addition to the sexual condition and leaf decurrency this could be an argument to treat the two taxa as 'normal' species rather than semi-cryptic ones.

### 4.4 Conclusions

The purpose of this study was to investigate if $P$. pseudotriquetrum and $P$. bimum could be distinguished by characters other than the sexual condition, and how well those character differences correspond with current literature. The study is the first of its kind to investigate $P$. pseudotriquetrum and P. bimum collected in northern Sweden. It also provides detailed morphological data, which is important when examining potentially cryptic and semi-cryptic species. The study also investigated if there was a difference in habitat and distribution between the species. No such differences were found.

The main finding of this study is that the leaf decurrency is a character that can potentially be used to distinguish the two species. This is useful especially in cases when the samples are sterile, or when there is a lack of molecular data to confirm species identification. This result provided by the present study adds to the view that $P$. pseudotriquetrum and $P$. bimum are two distinct species, and I argue they should be treated as semi-cryptic. The study also indicates that the stem length and the shape of the median cells might be characters that differ between the species, and therefore worthy of future examination.

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## Appendix

| \#Specimen | $\begin{aligned} & \text { UMU- } \\ & \text { ref. } \end{aligned}$ | Species | \#Leaf | \#Cell width | Cell width ( $\mu \mathrm{m}$ ) | Leaf lamina length (mm) | Costa/lamina ratio (\%) | Leaf decurrency /lamina ratio (\%) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 115119 | P. bimum | 1 | 1 | 12,5 | 2,575 | 102,913 | 10,680 |
|  |  |  | 1 | 2 | 15 |  |  |  |
|  |  |  | 2 | 3 | 15 | 3,95 | 101,266 | 3,165 |
|  |  |  | 2 | 4 | 12,5 |  |  |  |
|  |  |  | 2 | 5 | 10 |  |  |  |
|  |  |  | 3 |  |  | 3,3 | 102,273 | 9,848 |
|  |  |  | 4 |  |  | 3,625 | 101,379 | 4,828 |
|  |  |  | 5 |  |  | 4,15 | 101,807 | 3,614 |
| 2 | 114522 | P. pseudotriquetrum | 1 | 1 | 22,5 | 2,85 | 101,754 | 15,789 |
|  |  |  | 1 | 2 | 22,5 |  |  |  |
|  |  |  | 2 | 3 | 20 | 2,8 | 101,786 | 6,250 |
|  |  |  | 2 | 4 | 17,5 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 3,175 | 101,575 | 7,874 |
|  |  |  | 4 |  |  | 3,2 | 103,906 | 10,938 |
|  |  |  | 5 |  |  | 2,7 | 102,778 | 8,333 |
| 3 | 107125 | P. pseudotriquetrum | 1 | 1 | 25 | 4,525 | 102,210 | 11,050 |
|  |  |  | 1 | 2 | 27,5 |  |  |  |
|  |  |  | 2 | 3 | 27,5 | 4,6 | 102,717 | 8,152 |
|  |  |  | 2 | 4 | 25 |  |  |  |
|  |  |  | 2 | 5 | 30 |  |  |  |
|  |  |  | 3 |  |  | 4,5 | 101,667 | 8,889 |
|  |  |  | 4 |  |  | 4,5 | 101,667 | 5,556 |
|  |  |  | 5 |  |  | 4,575 | 101,639 | 12,568 |
| 4 | 82726 | P. pseudotriquetrum | 1 | 1 | 20 | 2,025 | 93,827 | 20,988 |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 20 | 2,725 | 101,835 | 12,844 |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 20 |  |  |  |
|  |  |  | 3 |  |  | 2,625 | 100,952 | 10,476 |
|  |  |  | 4 |  |  | 2,725 | 100,917 | 12,844 |
|  |  |  | 5 |  |  | 2,175 | 101,149 | 14,943 |
| 5 | 179129 | P. pseudotriquetrum | 1 | 1 | 22,5 | 3,15 | 97,619 |  |
|  |  |  | 1 | 2 | 25 |  |  |  |
|  |  |  | 2 | 3 | 25 | 3,05 | 104,918 |  |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 25 |  |  |  |


|  |  |  | 3 |  |  | 3,3 | 96,970 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 4 |  |  | 3,125 | 99,200 |  |
|  |  |  | 5 |  |  | 3,4 | 96,324 |  |
| 6 | 73649 | P. bimum | 1 | 1 | 20 | 2,725 | 99,083 |  |
|  |  |  | 1 | 2 | 20 |  |  |  |
|  |  |  | 2 | 3 | 22,5 | 3,35 | 100,746 |  |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 22,5 |  |  |  |
|  |  |  | 3 |  |  | 3,025 | 100,826 |  |
|  |  |  | 4 |  |  | 1,775 | 100,000 |  |
|  |  |  | 5 |  |  | 2,75 | 100,909 |  |
| 7 | 73649 | P. pseudotriquetrum | 1 | 1 | 17,5 | 3,3 | 97,727 |  |
|  |  |  | 1 | 2 | 12,5 |  |  |  |
|  |  |  | 2 | 3 | 17,5 | 3 | 100,000 |  |
|  |  |  | 2 | 4 | 17,5 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 3,375 | 98,519 |  |
|  |  |  | 4 |  |  | 2,925 | 98,291 |  |
|  |  |  | 5 |  |  | 3,5 | 97,857 |  |
| 8 | 114590 | P. pseudotriquetrum | 1 | 1 | 15 | 2,7 | 102,778 |  |
|  |  |  | 1 | 2 | 15 |  |  |  |
|  |  |  | 2 | 3 | 10 | 2,65 | 101,887 |  |
|  |  |  | 2 | 4 | 12,5 |  |  |  |
|  |  |  | 2 | 5 | 12,5 |  |  |  |
|  |  |  | 3 |  |  | 2,8 | 106,250 |  |
|  |  |  | 4 |  |  | 2,725 | 102,752 |  |
|  |  |  | 5 |  |  | 2,15 | 108,140 |  |
| 9 | 107117 | P. bimum | 1 | 1 | 17,5 | 2,275 | 96,703 |  |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 17,5 | 2,65 | 99,057 |  |
|  |  |  | 2 | 4 | 20 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 2,225 | 101,124 |  |
|  |  |  | 4 |  |  | 2,175 | 101,149 |  |
|  |  |  | 5 |  |  | 2,125 | 97,647 |  |
| 10 | 107115 | P. pseudotriquetrum | 1 | 1 | 20 | 2,425 | 102,062 | 12,371 |
|  |  |  | 1 | 2 | 22,5 |  |  |  |
|  |  |  | 2 | 3 | 17,5 | 2,45 | 103,061 | 10,204 |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 2,6 | 102,885 | 10,577 |
|  |  |  | 4 |  |  | 2,875 | 102,609 | 11,304 |
|  |  |  | 5 |  |  | 2,55 | 95,098 | 6,863 |


| 11 | 107124 | P. pseudotriquetrum | 1 | 1 | 20 | 1,925 | 96,104 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 17,5 | 1,825 | 98,630 |  |
|  |  |  | 2 | 4 | 12,5 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 1,85 | 97,297 |  |
|  |  |  | 4 |  |  | 1,225 | 95,918 |  |
|  |  |  | 5 |  |  | 1,55 | 95,161 |  |
| 12 | 179136 | P. bimum | 1 | 1 | 20 | 2,7 | 100,926 | 9,259 |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 20 | 2,625 | 100,952 | 5,714 |
|  |  |  | 2 | 4 | 17,5 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 2,8 | 100,893 | 7,143 |
|  |  |  | 4 |  |  | 2,475 | 101,010 | 8,081 |
|  |  |  | 5 |  |  | 2,55 | 100,980 | 4,902 |
| 13 | 113560 | P. pseudotriquetrum | 1 | 1 | 22,5 | 2,875 | 95,652 |  |
|  |  |  | 1 | 2 | 25 |  |  |  |
|  |  |  | 2 | 3 | 27,5 | 3,975 | 104,403 |  |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 20 |  |  |  |
|  |  |  | 3 |  |  | 3,4 | 98,529 |  |
|  |  |  | 4 |  |  | 3,775 | 98,675 |  |
|  |  |  | 5 |  |  | 3,525 | 96,454 |  |
| 14 | 179133 | P. bimum | 1 | 1 | 15 | 2,675 | 98,131 | 9,346 |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 15 | 2,9 | 105,172 | 4,310 |
|  |  |  | 2 | 4 | 15 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 2,05 | 102,439 | 4,878 |
|  |  |  | 4 |  |  | 2,625 | 100,000 | 4,762 |
|  |  |  | 5 |  |  | 3,25 | 101,538 | 3,846 |
| 15 | 179372 | P. pseudotriquetrum | 1 | 1 | 17,5 | 3,9 | 98,718 |  |
|  |  |  | 1 | 2 | 20 |  |  |  |
|  |  |  | 2 | 3 | 35 | 4,25 | 98,824 |  |
|  |  |  | 2 | 4 | 35 |  |  |  |
|  |  |  | 2 | 5 | 25 |  |  |  |
|  |  |  | 3 |  |  | 3,775 | 94,040 |  |
|  |  |  | 4 |  |  | 4,275 | 97,661 |  |
|  |  |  | 5 |  |  | 2,9 | 96,552 |  |
| 16 | 179372 | P. bimum | 1 | 1 | 22,5 | 3,425 | 97,810 | 7,299 |
|  |  |  | 1 | 2 | 22,5 |  |  |  |
|  |  |  | 2 | 3 | 22,5 | 3,5 | 97,857 | 4,286 |


|  |  |  | 2 | 4 | 22,5 |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 2 | 5 | 20 |  |  |  |
|  |  |  | 3 |  |  | 3,75 | 99,333 | 4,667 |
|  |  |  | 4 |  |  | 4,45 | 101,124 | 2,247 |
|  |  |  | 5 |  |  | 4,35 | 100,000 | 2,299 |
| 17 | 104804 | P. pseudotriquetrum | 1 | 1 | 20 | 4,025 | 98,137 |  |
|  |  |  | 1 | 2 | 22,5 |  |  |  |
|  |  |  | 2 | 3 | 20 | 4,325 | 97,688 |  |
|  |  |  | 2 | 4 | 17,5 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 4,15 | 95,783 |  |
|  |  |  | 4 |  |  | 4,175 | 91,617 |  |
|  |  |  | 5 |  |  | 4,25 | 98,235 |  |
| 18 | 73908 | P. pseudotriquetrum | 1 | 1 | 17,5 | 4,525 | 95,028 |  |
|  |  |  | 1 | 2 | 15 |  |  |  |
|  |  |  | 2 | 3 | 22,5 | 3,975 | 97,484 |  |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 20 |  |  |  |
|  |  |  | 3 |  |  | 4,525 | 98,895 |  |
|  |  |  | 4 |  |  | 3,425 | 91,971 |  |
|  |  |  | 5 |  |  | 4,2 | 97,024 |  |
| 19 | 116725 | P. pseudotriquetrum | 1 | 1 | 25 | 2,775 | 100,901 |  |
|  |  |  | 1 | 2 | 22,5 |  |  |  |
|  |  |  | 2 | 3 | 22,5 | 3,125 | 101,600 |  |
|  |  |  | 2 | 4 | 20 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 2,8 | 100,893 |  |
|  |  |  | 4 |  |  | 2,9 | 100,862 |  |
|  |  |  | 5 |  |  | 2,975 | 100,000 |  |
| 20 | 179551 | P. bimum | 1 | 1 | 17,5 | 2,525 | 95,050 | 10,891 |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 17,5 | 2,725 | 94,495 | 11,009 |
|  |  |  | 2 | 4 | 12,5 |  |  |  |
|  |  |  | 2 | 5 | 20 |  |  |  |
|  |  |  | 3 |  |  | 2,05 | 101,220 | 8,537 |
|  |  |  | 4 |  |  | 3,15 | 97,619 | 4,762 |
|  |  |  | 5 |  |  | 2,75 | 96,364 | 11,818 |
| 21 | 179551 | P. pseudotriquetrum | 1 | 1 | 22,5 | 3,1 | 99,194 | 11,290 |
|  |  |  | 1 | 2 | 25 |  |  |  |
|  |  |  | 2 | 3 | 22,5 | 3 | 97,500 | 12,500 |
|  |  |  | 2 | 4 | 17,5 |  |  |  |
|  |  |  | 2 | 5 | 15 |  |  |  |
|  |  |  | 3 |  |  | 2,25 | 98,889 | 15,556 |


|  |  |  | 4 |  |  | 2,975 | 100,840 | 10,924 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 5 |  |  | 2,65 | 101,887 | 12,264 |
| 22 | 79994 | P. bimum | 1 | 1 | 12,5 | 1,325 | 86,792 | 5,660 |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 12,5 | 1,45 | 93,103 | 6,897 |
|  |  |  | 2 | 4 | 12,5 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 1,725 | 95,652 | 4,348 |
|  |  |  | 4 |  |  | 2,275 | 96,703 | 6,593 |
|  |  |  | 5 |  |  | 1,825 | 101,370 | 6,849 |
| 23 | 173469 | P. pseudotriquetrum | 1 | 1 | 17,5 | 2,125 | 97,647 | 16,471 |
|  |  |  | 1 | 2 | 22,5 |  |  |  |
|  |  |  | 2 | 3 | 25 | 1,9 | 98,684 | 14,474 |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 20 |  |  |  |
|  |  |  | 3 |  |  | 2,75 | 100,909 | 8,182 |
|  |  |  | 4 |  |  | 2,35 | 101,064 | 19,149 |
|  |  |  | 5 |  |  | 3,45 | 100,725 | 9,420 |
| 24 | 179110 | P. bimum | 1 | 1 | 20 | 3,45 | 101,449 | 5,072 |
|  |  |  | 1 | 2 | 27,5 |  |  |  |
|  |  |  | 2 | 3 | 22,5 | 3,55 | 94,366 | 6,338 |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 25 |  |  |  |
|  |  |  | 3 |  |  | 3,475 | 99,281 | 5,036 |
|  |  |  | 4 |  |  | 3,3 | 99,242 | 7,576 |
|  |  |  | 5 |  |  | 3,5 | 100,714 | 7,857 |
| 25 | 179110 | P. pseudotriquetrum | 1 | 1 | 17,5 | 2,425 | 101,031 | 13,402 |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 17,5 | 2,25 | 101,111 | 14,444 |
|  |  |  | 2 | 4 | 15 |  |  |  |
|  |  |  | 2 | 5 | 17,5 |  |  |  |
|  |  |  | 3 |  |  | 2,575 | 101,942 | 8,738 |
|  |  |  | 4 |  |  | 2,525 | 101,980 | 12,871 |
|  |  |  | 5 |  |  | 2,55 | 100,980 | 9,804 |
| 26 | 179108 | P. pseudotriquetrum | 1 | 1 | 25 | 2,425 | 102,062 | 15,464 |
|  |  |  | 1 | 2 | 20 |  |  |  |
|  |  |  | 2 | 3 | 20 | 2,45 | 102,041 | 18,367 |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 25 |  |  |  |
|  |  |  | 3 |  |  | 2,625 | 101,905 | 14,286 |
|  |  |  | 4 |  |  | 2,4 | 102,083 | 13,542 |
|  |  |  | 5 |  |  | 2,375 | 97,895 | 11,579 |
| 27 | 179144 | P. pseudotriquetrum | 1 | 1 | 25 | 3,075 | 100,813 | 10,569 |


|  |  |  | 1 | 2 | 25 |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 2 | 3 | 22,5 | 2,85 | 100,000 | 12,281 |
|  |  |  | 2 | 4 | 22,5 |  |  |  |
|  |  |  | 2 | 5 | 25 |  |  |  |
|  |  |  | 3 |  |  | 2,8 | 100,893 | 12,500 |
|  |  |  | 4 |  |  | 3,025 | 100,826 | 7,438 |
|  |  |  | 5 |  |  | 2,775 | 100,901 | 8,108 |
| 28 | 179141 | P. bimum | 1 | 1 | 27,5 | 2,975 | 100,840 | 10,084 |
|  |  |  | 1 | 2 | 25 |  |  |  |
|  |  |  | 2 | 3 | 25 | 2,525 | 100,990 | 8,911 |
|  |  |  | 2 | 4 | 25 |  |  |  |
|  |  |  | 2 | 5 | 27,5 |  |  |  |
|  |  |  | 3 |  |  | 2,925 | 100,000 | 8,547 |
|  |  |  | 4 |  |  | 2,525 | 100,990 | 8,911 |
|  |  |  | 5 |  |  | 2,175 | 98,851 | 8,046 |
| 29 | 179146 | P. pseudotriquetrum | 1 | 1 | 25 | 2,05 | 101,220 | 9,756 |
|  |  |  | 1 | 2 | 27,5 |  |  |  |
|  |  |  | 2 | 3 | 25 | 1,625 | 101,538 | 9,231 |
|  |  |  | 2 | 4 | 30 |  |  |  |
|  |  |  | 2 | 5 | 25 |  |  |  |
|  |  |  | 3 |  |  | 1,975 | 96,203 | 7,595 |
|  |  |  | 4 |  |  | 2,025 | 100,000 | 6,173 |
|  |  |  | 5 |  |  | 2,1 | 101,190 | 5,952 |
| 30 | 179146 | P. bimum | 1 | 1 | 12,5 | 1,8 | 101,389 | 9,722 |
|  |  |  | 1 | 2 | 15 |  |  |  |
|  |  |  | 2 | 3 | 17,5 | 1,725 | 101,449 | 7,246 |
|  |  |  | 2 | 4 | 17,5 |  |  |  |
|  |  |  | 2 | 5 | 15 |  |  |  |
|  |  |  | 3 |  |  | 2,225 | 102,247 | 7,865 |
|  |  |  | 4 |  |  | 1,7 | 102,941 | 8,824 |
|  |  |  | 5 |  |  | 2,025 | 101,235 | 8,642 |
| 31 | 74565 | P. pseudotriquetrum | 1 | 1 | 20 | 2,2 | 97,727 | 13,636 |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 17,5 | 2,125 | 97,647 | 10,588 |
|  |  |  | 2 | 4 | 17,5 |  |  |  |
|  |  |  | 2 | 5 | 20 |  |  |  |
|  |  |  | 3 |  |  | 2,55 | 100,980 | 11,765 |
|  |  |  | 4 |  |  | 2,575 | 100,971 | 10,680 |
|  |  |  | 5 |  |  | 2,375 | 102,105 | 11,579 |
| 32 | 100979 | P. pseudotriquetrum | 1 | 1 | 17,5 | 1,75 | 101,429 | 8,571 |
|  |  |  | 1 | 2 | 17,5 |  |  |  |
|  |  |  | 2 | 3 | 20 | 1,475 | 101,695 | 13,559 |
|  |  |  | 2 | 4 | 17,5 |  |  |  |


|  |  |  | 2 | 5 | 17,5 |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 3 |  |  | 2,525 | 100,000 | 13,861 |
|  |  |  | 4 |  |  | 2,35 | 101,064 | 10,638 |
|  |  |  | 5 |  |  | 1,65 | 101,515 | 9,091 |
| 33 | 100979 | P. bimum | 1 | 1 | 20 | 1,675 | 102,985 | 8,955 |
|  |  |  | 1 | 2 | 20 |  |  |  |
|  |  |  | 2 | 3 | 22,5 | 2,25 | 98,889 | 4,444 |
|  |  |  | 2 | 4 | 17,5 |  |  |  |
|  |  |  | 2 | 5 | 20 |  |  |  |
|  |  |  | 3 |  |  | 1,925 | 101,299 | 7,792 |
|  |  |  | 4 |  |  | 2,75 | 100,909 | 4,545 |
|  |  |  | 5 |  |  | 3,05 | 101,639 | 4,918 |

