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Minimum area assessment and different sampling approaches for the study of vegetation communities in Antarctica

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Abstract: Antarctic vegetation offers excellent opportunities for the study of dynamics and biodiversity of natural systems with high environmental sensitivity. This paper addresses the methodological and technical aspects for the minimum area (MA) assessment (the smallest area which adequately represents community composition) and compares three different sampling approaches for vegetation at Jubany, King George Island. Five target communities, among the most widespread and representative of a wide range of floristic richness and dynamism, were selected through the phytosociological study. The minimum area, determined from four methods, ranged between 2 and 24 m^2. Similar values have been obtained for the polar desert vegetation of the Northern Hemisphere. Three sampling approaches were tested in the five communities: the phytosociological survey with 100 cm grid, the phytosociological survey with 5 cm grid, the point intercept with 10 cm grid. To achieve comparable data a standard plot, satisfying the MA requirements of all the communities, has been adopted for all the study sites. The results indicate that the integration of the three methods provides the highest level of information, especially in respect of limitations on field sampling and logistics.

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Key words: Maritime Antarctica, phytosociological survey, point intercept, species/area curve

Introduction

Antarctic vegetation is mainly composed of scattered communities dominated by cryptogams, with only two vascular plant species, *Deschampsia antarctica* Desv. and *Colobanthus quitensis* Bartl. occurring in Maritime Antarctica (Smith 1996).

The harsh environmental conditions and the geographical isolation (Kennedy 1999) have selected for ecosystems of limited ecological complexity, lacking efficient buffering systems (Wookey & Robinson 1997), with high sensitivity to environmental and human perturbations and limited resistance to even small fluctuations (Smith 1990a).

Minor variations in microclimate may produce significant changes in plant communities (Melick & Seppelt 1997), affecting plant colonization, growth and community development (Smith 1990a).

The Polar Regions are sensitive areas offering excellent opportunities for detecting the initial effects of perturbations produced by climate change and/or by human impact both on the abiotic (Weller 1998) and on the biotic components (Smith 1990a, 1994, Hodkinson *et al.* 1998) of ecosystems.

Descriptions of the main characteristics and patterns of vegetation communities are available for a range of different sites throughout Antarctica (Longton 1967, Gimingham & Smith 1970, Lindsay 1971, Smith 1972, 1988, 1990a, 1999, Allison & Smith 1973, Walton 1990, Gremmen *et al*. 1994, Melick *et al*. 1994, Melick & Seppelt 1997, Frenot *et al*. 1998). The lack of a common methodological approach, particularly for the minimum area (MA), the plot size and location, the coverage indices, does not allow a full comparison of most of the available data.

The minimum area, the smallest area within which the species composition of a community is adequately represented (Mueller-Dombois & Ellenberg 1974), has been rarely considered for the community descriptions provided for Antarctic vegetation (Smith 1972, 1988, Melick & Seppelt 1997).

The plot size has been fixed, ranging from 400 cm^2 (Gimingham & Smith 1970, Allison & Smith 1973) to 2500 cm^2 (Gremmen *et al* 1994, Melick *et al*. 1994), or variable following community and/or environmental gradients (Heilbronn & Walton 1984a), and their location has been selected randomly (Gimingham & Smith 1970, Allison & Smith 1973, Melick *et al*. 1994) or in contiguous areas along transects (Smith 1990b).

The percentage cover of each species has been measured using different methods, including qualitative estimations (Melick *et al*. 1994), subjective scales (Schwartz *et al*. 1992), Braun-Blanquet scale (Nakanishi 1977, Smith 1988), the ordinal scale modified by van der Maarel (Gremmen *et al*. 1994), and a discrete scale with 5% intervals (Heilbronn & Walton 1984b).

The objectives of this paper are:

a) the minimum area assessment of vegetation communities applying different methods both for the

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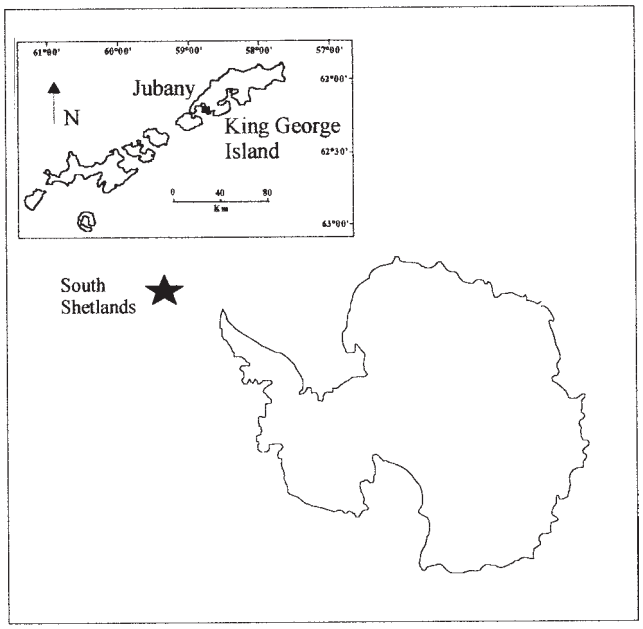


Fig. 1. Geographical location of King George Island, South Shetland Islands, Antarctica.

sampling regime and for the species/area curve (S/A) interpretation,

b) the comparison of the minimum area determined for the vegetation communities at Jubany (as indicative of the biogeographical region of Maritime Antarctica) with the MA assessed by Lévesque (1996) for the polar desert vegetation of the Northern Hemisphere;

c) to test the suitability of different sampling approaches for the description of vegetation communities.

The results achieved here should contribute to the development of a common methodological approach for the study of biodiversity and vegetation monitoring, both at species and community levels, within the framework of the SCAR Project "Regional Sensitivity to Climate Change in Antarctic terrestrial and limnetic ecosystems" (RiSCC). Within the RiSCC Project, the use of a common methodological approach will allow data comparisons between different study sites along the Antarctic Ecological Transects. These transects are established to assess climate change effects on the sensitive polar ecosystems and their biodiversity.

Study area

The study area was located at Jubany, King George Island, South Shetland Islands (62°14'15"S, 58°40'00"W) (Fig. 1), in the biogeographical region of Maritime Antarctica (Longton 1979). Jubany is a core site for long-term monitoring, due to its representative location within a transect from the Antarctic Peninsula to Maritime Antarctica, in a key region characterized by several climatic and biological gradients (Smith 1996).

King George Island is almost entirely composed of igneous rocks, mainly basalts, with the subsidiary occurrence of metamorphic rock types.

The climate is cold moist maritime, with an average annual air temperature of -2°C (Olech 1994), and a mean air temperature above 0°C for at least one to four months in summer. Precipitation is mainly concentrated in summer and ranges between 350 and 500 mm per year (Øvstedal & Smith 2001).

Vegetation is mainly composed of cryptogamic species, dominated by mosses and lichens, with *Deschampsia antarctica* and *Colobanthus quitensis*. The vegetation of the South Shetland Islands has been studied by different authors, focusing both on the taxonomy of lichens and bryophytes (Redón 1985, Jacobsen & Kappen 1988, Ochyra 1998, Aptroot & Knaap 1993, Olech 1994, Sancho *et al*. 1999), and on the recognition and description of the main vegetation communities (Gimingham & Smith 1970, Lindsay 1971, Allison & Smith 1973, Longton 1979, Smith 1996)

Materials and methods

Vegetation survey and minimum area assessment

The vegetation communities in the study area were investigated using the phytosociological method of Braun-Blanquet (1964), with surveys throughout the Potter Peninsula, as well as along three main transects.

Species nomenclature follows Øvstedal & Smith (2001) and Redón (1985) for lichens, Ochyra (1998) for bryophytes.

The data provided by these surveys allowed the identification of the main vegetation communities and recognition of both their distribution patterns in relation to environmental gradients and their dynamism. The main characteristics of the vegetation communities investigated are shown in Cannone & Guglielmin (2003). Five communities were selected as targets for the minimum area assessment and the comparison of different sampling approaches. These communities were representative of a wide range of floristic richness, dynamism and ecological requirements, from pioneer communities poor in species to the more evolved and complex established ones.

The minimum area of each community was determined by recording the species that occurred during successive increases in the plot size, until the total number of species stabilized (Mueller-Dombois & Ellenberg 1974). Different sampling regimes are possible, including:

a) the use of single quadrats randomly placed (Smith 1972, Allison & Smith 1973, Lévesque 1996),

b) the use of quadrats contiguously placed within a bigger plot (Goodall 1952, Kilburn 1966, Inouye 1998),

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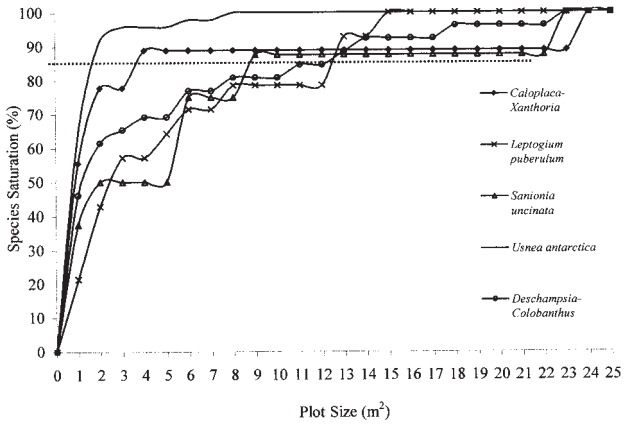


Fig. 2. Species/area curve of the five communities investigated representing the % of species saturation vs plot size (m^2).

c) the nested plot (Mueller-Dombois & Ellenberg 1974).

From the data recorded using the contiguous quadrats it is possible to reconstruct the nested plot. For this reason, the sampling regime has been selected to compare the results obtained by the random quadrats with those from the contiguous quadrats. This test has been carried out on the *Usnea antarctica* community, one of the richest in species in the study area. The contiguous quadrats detected a higher species number than the random ones, but both methods provided similar values of MA. The contiguous quadrats were therefore adopted as sampling regime for all the MA measurements. This system also allowed information on the spatial distribution of the species within the communities to be collected and is also suitable for monitoring permanent plots to determine long term changes in vegetation.

Two different species/area curves can be derived providing the percentage of species saturation vs the plot size (Fig. 2) and the cumulative species number vs the plot size (Fig. 3).

Four different criteria have been used for the determination of the minimum area from the species/area curves:

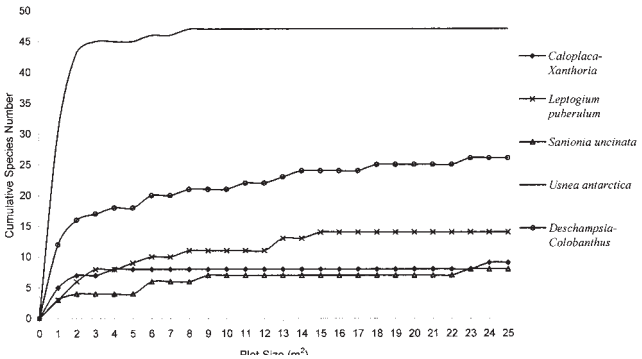


Fig. 3. Species/area curve of the five communities investigated representing the cumulative species number vs plot size (m^2).

a) the point of maximum curvature of cumulative species number (Barkman 1989),

b) 10% ratio, given by "the point along the S/A curve at which a 10% increase of the total sampling area yields only 10% more species of the total number recorded" (Cain 1938, Mueller-Dombois & Ellenberg 1974),

c) the 80% of species saturation (Lévesque 1996)

d) the 90% of species saturation. This last criterion has been used to check if there were significant differences with respect to the indications of the other criteria.

The results of these different methods have been compared and discussed in order to select the most suitable plot size for biodiversity investigations and vegetation monitoring, both at species and community level.

These data have been compared with the available information from Antarctica and from the polar desert vegetation in the Northern Hemisphere (Lévesque 1996).

Comparison of three sampling approaches for the description of vegetation communities

Three different sampling approaches have been tested in each of the five communities in order to assess which one or which combination provided the best level of information for the vegetation description. To achieve comparable data from all the communities a standard plot size was used. To be significant for the description at community level, this plot size should reflect the minimum area requirements, thus providing information both at species and community level (Mueller-Dombois & Ellenberg 1974, Lévesque 1996). As the largest MA measured is 24 m^2 the size selected for all the sites is 25 m^2, given by a 5 x 5 m square.

Each plot was protected by a buffer zone to avoid any trampling or disturbance. The description of each site has been completed by the measurement of the following topographic and edaphic parameters: elevation, slope, aspect, substrate, surface texture.

Within each plot of the communities investigated, the three sampling approaches have been compared in terms of their accuracy, time of execution, logistical requirements and the avoidance of trampling effects and/or disturbance.

The phytosociological survey (PS) has been chosen because it describes accurately the floristic composition of the community and is suitable for investigations focused on community description and monitoring, and on biodiversity assessments. It may show some shortcomings in the possible over and/or under-estimation of the percentage coverage of each species.

The point intercept method (PI) provides accurate quantitative data concerning species dominance (Lévesque 1996), with the advantage of requiring little field time to collect. This method can also provide biomass estimations without destructive impacts on vegetation (Jonasson 1988).

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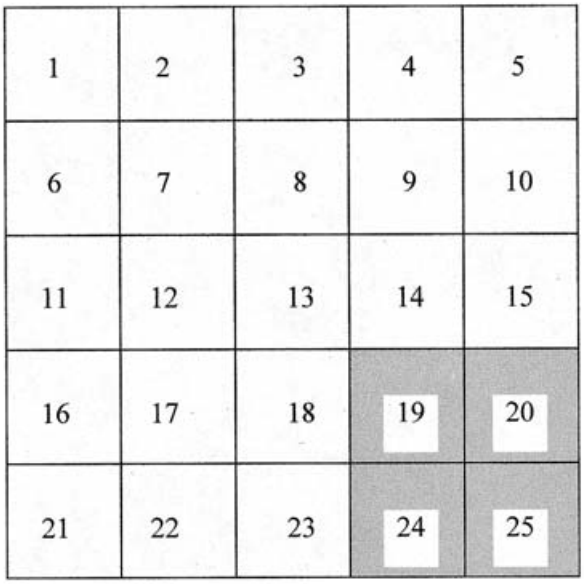


Fig. 4. Sampling regime applied in each of the five sites for the phytosociological method. Numbers from 1 to 25 indicate the PS100, the areas in grey are those investigated by the PS5 with a similar regime.

In addition, the estimation of the percentage coverage given by the PI is objective and independent of the investigator (Mueller Dombois & Ellenberg 1974) and the point intercept data may be used as a reference to check on the values measured by the visual estimations in the phytosociological survey.

Each standard plot was divided into 25 squares of 1 m^2 (Fig. 4). Within each quadrat each species has been recorded and its percentage coverage visually estimated. This method has been applied using two different grids: 100 cm grid (PS100) and 5 cm grid (PS5) (Lévesque 1996). The adoption of two different grids within each quadrat allows the detection of major or minor variations in vegetation. In addition, the smaller grid is useful to describe the spatial micropatterns within the community. The 5 cm grid has been applied only on 4 m^2 surfaces because this size is small enough to avoid any trampling effects and to limit the time required for its application.

The sampling design adopted for the PS100 and the PS5 is shown in Fig. 4. The PI was carried out in all the 25 m^2 squares at each site, using 1 m^2 subplots and along a grid of orthogonal lines, with noda located 10 cm apart.

Results and discussion

General vegetation survey

The vegetation survey shows that throughout the Potter Peninsula and along three transects the vegetation is dominated mainly by the fruticose and foliose lichen sub formations, while, in the wet areas, the tall moss-cushion sub formation occurs. The observed distribution patterns of vegetation and their relationships with the main environmental gradients confirm previous studies (Longton 1967, Lindsay 1971, Allison & Smith 1973, Smith 1996). The main characteristics of the five target communities are shown in Table I.

Minimum area

The comparison of the random vs contiguous quadrats provided similar results in terms of MA. The stabilization of

Table I. Main topographic and vegetation characteristics of the five permanent sites.

Sociation	*Deschampsia-Colobanthus*	*Usnea antarctica*	*Sanionia uncinata*	*Leptogium puberulum*	*Caloplaca-Xanthoria*
Total vegetation % coverage	67.4	76.7	94.5	3.9	3.6
Dominant species	*Deschampsia antarctica*	*Usnea antarctica*	*Sanionia uncinata*	*Leptogium puberulum*	epilithic lichens
% coverage of dominant species	40	54	90.4	1.7	1.9
Co-dominant species	*Usnea antarctica* *Sanionia uncinata*	*Sanionia uncinata* *Usnea antarctica*	*Syntrichia princeps*	*Sanionia uncinata*	*Leptogium puberulum*
Dynamic stage	evolved	evolved	evolved	pioneer	pioneer
Ecology	mesic	xeric chionophobous	hydric-inundated chionophilous	hydric chionophilous	xeric chionophobous
Maximum species number	26	47	8	14	9
Stratification	1 vascular and 2 cryptogamic strata	1 vascular and 2 cryptogamic strata	2 cryptogamic strata	2 cryptogamic strata	1 cryptogamic stratum
Height of vegetation (cm)	1-8	2-4	2	1-4	1-4
Organic layer (cm)	0	0	6	0	0
Elevation (m a.s.l.)	12.3	30.7	19.9	28.6	26.6
Slope (°)	3	3	2	6	3
Aspect (°)	320	350	340	50	350
Surface texture					
% Blocks	30	15	0	10	10
% Pebbles	10	20	80	25	10
% Gravel	20	20	10	25	5
% Sand	40	45	10	40	75

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Table II. Minimum Area (m^2) by different methods.

Sociation	Last point of maximum curvature	10% increase (Cain 1938, Mueller-Dombois & Ellenberg 1974)	80% species saturation	90% species saturation
Caloplaca-Xanthoria	24	4	4	24
Leptogium puberulum	15	6	13	13
Sanionia uncinata	23	9	9	23
Usnea antarctica	3	3	2	2
Deschampsia-Colobanthus	23	6	8	14

the species number (100% saturation) was reached by the random quadrats after 11 replications (11 m^2) and the species richness did not increase further. With the contiguous quadrats, the stabilization of the species number was reached at 9 m^2.

The random quadrats detected a maximum of 33 species with 80% of species saturation in 5 m^2. The contiguous quadrats gave similar values (3 m^2 for the 80% of species saturation), but the total species number at 47 was significantly higher possibly because of more limited dispersion of the community with respect to the random quadrats. The contiguous quadrats were therefore selected for the assessment of the MA for all the communities.

The data have been evaluated using four different criteria (Table II) which give a wide range of results both within and between communities, ranging between 2 and 24 m^2.

The lowest values of MA, between 3 and 9 m^2, are produced by the application of the 10% ratio (Mueller-Dombois & Ellenberg 1974). Considering the 80% of species saturation (Fig. 2), the MA increases significantly (more than 50%) only for the *Leptogium puberulum* sociation. Analysing the point of maximum curvature of the species/area curve (Fig. 3) or, in case of more than one maximum, the highest value (Lévesque 1996), the MA increases much more, showing the highest values. The highest similarities were between the values for the last point of maximum curvature and the 90% species saturation. Only for the *Usnea antarctica* sociation was there significant convergence of the MA values obtained with the different methods.

The relationship between the minimum area and the total number of species is not clear. Nevertheless, some distribution patterns of the species and some structural characteristics of the communities may explain similar MA observed in highly diverse communities. This is particularly evident in comparing the discontinuous low coverage *Caloplaca-Xanthoria* and the continuous high coverage *Sanionia uncinata*.

Caloplaca-Xanthoria is characterized by the scattered and random distribution of the microcrustose lichens, without any tendency to clusters. The *Sanionia uncinata* community is composed of two main strata. The basal one is continuous, with coverage of more than 95% of *Sanionia uncinata*, whilst above it there is a second stratum of secondary and tertiary colonizers (Smith 1990a), mainly epiphitic lichens, with a scattered random distribution above the underlying *Sanionia uncinata*. The MA of these two communities may depend on the similarities of the distribution patterns of the species.

This explanation is supported by the *Leptogium puberulum* sociation, characterized by 14 species in scattered patches of vegetation. Within each patch, the species showed a clustered distribution and this fact may be related to its lower values of MA.

Usnea antarctica community, which was continuous with a high coverage, showed an homogeneous distribution of the species, clustering together, as further confirmation.

The results obtained for this characteristic site of Maritime Antarctic vegetation are similar to those obtained by Lévesque (1996) when assessing the minimum area of the polar desert vegetation on Ellesmere Island, in the Canadian High Arctic. For the polar desert vegetation Wein & Rencz (1976) suggested using more than 100 quadrats (0.25 m^2) for the sampling area, while Matveyeva (1988) indicated 16 m^2 as minimum area for the Russian polar desert in the frost boil environment.

In Antarctica there are few data available on the minimum area and there are no reference studies assessing it systematically and referring to the three main biogeographical regions. Available data for some communities of Continental Antarctica indicate that an area of 2500 cm^2 would include more than 80% of the species occurring (Melick & Seppelt 1997). In the Maritime Antarctica the basic description of vegetation communities

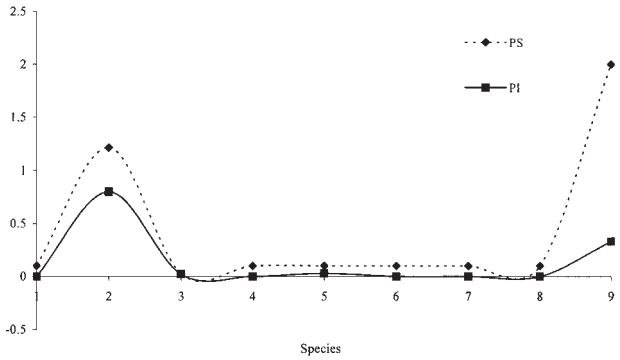


Fig. 5. Comparison of PS5 and PI in describing the floristic composition and species % coverage of the *Caloplaca-Xanthoria* sociation on 25 m^2.

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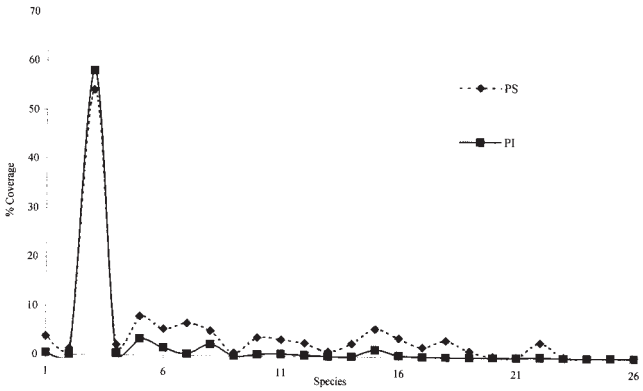


Fig. 6. Comparison of PS100 and PI in describing the floristic composition and species % coverage of the *Usnea antarctica* sociation on 25 m^2.

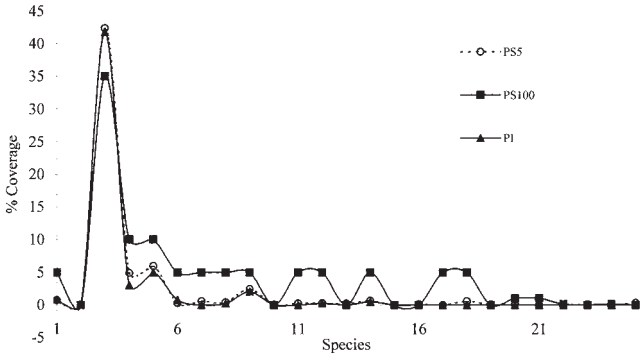


Fig. 7. Comparison of PS5, PS100 and PI in 1 m^2 of the *Usnea antarctica* sociation.

has been carried out on a total surface of 16 m^2, obtained by 20 randomly placed 20 x 20 cm quadrats (Allison & Smith 1973).

In most cases this size is not adequate and, therefore, when investigating a community lacking previous information on its MA, a bigger plot would be recommended (= 24 m^2) to describe its floristic richness and the associated biodiversity properly.

Comparison of three sampling approaches for the description of vegetation communities

The PS shows high efficiency in describing the floristic composition, almost independently from the community type, ranging from scattered vegetation poor in species (Fig. 5), to diverse continuous communities (Fig. 6). Both grids (5 cm, 100 cm) are suitable for this but the PS5 shows higher accuracy in detecting the microcrustose and microscopic species. The floristic composition obtained by the PI is always less precise with respect to that provided by the PS. Considering the whole size of each permanent plot, PI detects only 44% of the species recorded by PS5 in the scattered vegetation dominated by epilithic lichens (*Caloplaca-Xanthoria* sociation) (Fig. 5) and the 50% of the species in the high coverage *Sanionia uncinata* community. Similar results have been obtained comparing PI with PS100 (Fig. 6).

PS5, PS100 and PI have been tested directly for their accuracy and efficiency in describing the floristic composition.

In 1 m^2 of the *Usnea antarctica* sociation (Fig. 7), PS5 detects 100% of the 19 species occurring, while PS100 records 89% and PI only 47%. These differences are due to the lower efficiency of PS100 in detecting all the microcrustose species with respect to PS5, while for PI it depends both on the spatial distribution of the species and on their size. PI provides an objective estimate of the percentage cover independent of the investigator (Mueller-Dombois & Ellenberg 1974).

The effectiveness of the three methods in measuring properly the percentage coverage of species has been assessed by comparing the *Usnea* (continuous and rich in species) (Fig. 6) and the *Caloplaca-Xanthoria* community (scattered and poor in species) (Fig. 5).

There is a strong correlation (Fig. 7) between PI and PS5, both for the dominant and the companion species, while PS100 shows an underestimation of the dominant species and an overestimation of the species with coverage less than 10%.

The three methods tested show different accuracies both in describing the floristic composition and in measuring the % coverage. In addition, they require different times for execution, particularly the PS5, which is very time consuming and has a bigger trampling impact on vegetation.

The integration of the three methods, applying the PI and PS100 on the whole plot surface and PS5 only on a limited area, allows a higher level of information and accuracy, and detects different characteristics of the communities (structure, floristic composition, coverage, dominance, spatial micropattern).

PS100 is suitable for exhaustive vegetation descriptions requiring only a short time for execution. Its integration with the PS5 is recommended both for the floristic composition and the coverage estimates, as the PS100 shows limitations when applied to communities characterized by many microcrustose species and by secondary and tertiary colonizers difficult to detect.

The application of Point Intercept (PI) allows the rapid assessment of changes in dominance and provides reference data of the coverage useful for calibrating the PS estimations. PI shows higher accuracy and efficiency when applied on continuous high coverage vegetation, with one or few dominant species, and is not satisfactory for scattered discontinuous vegetation.

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Conclusion

The application of the concept of the minimum area and the testing of different sampling approaches to this has provided data useful for selecting which are the most suitable methods for accurate and efficient sampling and description of Antarctic vegetation.

The differences in the MA of the communities investigated confirm the need for its systematic assessment. For the vegetation communities of Maritime Antarctica, the MA does not depend only on the species number, but it reflects also the community structure, coverage, and growth forms. The MA of the polar desert in the Northern Hemisphere (Lévesque 1996) shows similar values to the MA of the Maritime Antarctic, although the former is mainly vascular species and the latter is mainly cryptogamic. The reasons for these similarities need further investigation.

In addition, the results obtained demonstrate the limits of a single sampling approach and the advantages of integrating different methods to fully describe vegetation patterns. In particular, the best results in terms of accuracy, efficiency, time to execute and avoidance of trampling effect may be achieved by applying PS100 and PI on all the 25 m^2 of the plot, integrated by PS5 on 4 m^2.

The integration of these methods show different vegetation characteristics and patterns of variation, concerning its structure, floristic composition (species type, number), dominance, percentage coverage, dynamics, and spatial distribution at microscale. Such investigations may contribute to the development of common methodologies and research protocols for the monitoring of Antarctic terrestrial ecosystems within the frame of the SCAR Project RiSCC.

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