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GROWTH RATE AND BEHAVIOR OVER 20 YEARS IN THE CRUSTOSE LICHEN *Haematomma erythromma* AT ELEPHANT ISLAND, ANTARCTICA

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Abstract: Antarctica is one of the most extreme environments on the planet considering the climatic conditions. This greatly limits the development of plants, and is reflected in slow growth, especially in the lichens present in this environment. *Haematomma erythromma* is a nitrophile lichen easily identifiable by its color and was the species chosen to evaluate growth in Antarctica. Using a plastic sheet, squares of 20 x 20 cm were placed on eight different rocks with crustose lichen communities and the species found were drawn in 1992 and in 2012. The location chosen for the survey was Stinker Point, on Elephant Island, north of the South Shetland Archipelago. After 20 years and evaluating 178 thalli, *H. erythromma* grew 0.2 to 0.7 mm/year, one of the slowest among Antarctic lichens. The thallus growth is mainly oriented West/Northwest, against prevailing wind direction, probably due to nutrient carried form a penguin rockery nearby. New thalli formed during this evaluation and the old ones also grew to connect each other, resulting in a confluent larger thallus. The new thalli grew mostly over *Xanthoria elegans* (Link.) Th. Fr., *Rhizoplaca aspidophora* (Vain.) Redón and *Buellia* spp. demonstrating that *H. erythromma* is capable of colonize areas with other lichen species coverage. The growth to be confluent with other thalli and the wind orientation are novelties to this species of lichen.

Keywords: competition; ice-free areas; lichen growth; lichenometry; long-term evaluation.

INTRODUCTION

The Antarctic vegetation is dominated by cryptogamic communities, being composed by approximately 350 lichenized fungi or lichens (mostly Ascomycota fungi), 112 mosses (Bryophyta), and 22 liverworts (Marchantiophyta) species (Øvstedal & Smith 2001, Ochyra *et al.* 2008, Putzke 2020). The knowledge on the life history of these species in such an extreme environment still needs to be improved. For example, variation in species growth rates during periods of many years was rarely investigated in Antarctica (Sancho *et al.* 2019). Furthermore, in the last 50 years the Antarctic Peninsula has warmed more than four times faster than the average rate of Earth's overall warming (Turner *et al.* 2005). To understand how the impact of local human activities (more than 80 research bases and tourism) and the global climatic change interfere in the Antarctic ecosystems, it is fundamental to know the growth and development behaviors of these species in this harsh but pristine environment.

Lichen growth rates are frequently evaluated through lichenometry, with the rock being dated relative to the presence and size of lichens inhabiting it (Valladares & Sancho 1995). Some lichen thalli found in Antarctica are larger than those found in other parts of the world, probably due to gigantism, being the age of these lichens dated from *ca.* 500 to 5,000 years (Øvstedal & Smith 2001). Additionally, some of the lichen species found in the Antarctica are growing at a faster rate than those found on the continent due to temperature changing, exhibiting a size gradient between the two regions (Sancho *et al.* 2007). This size gradient could be used as a proxy to monitor climate change. The growth rates of fruticose lichens are always higher (usually >2 mm year^{-1}), than those of crustose ones (usually < 1 mm year^{-1}) in polar areas (Li *et al.* 2014).

Rhyzocarpon geographicum Körb is an example of a fast-growing rate crustose lichen found in the Antarctic Peninsula, growing up much faster than earlier growth rate estimates, reaching more than 100 % of increased coverage of a single thalli in 11 years (Sancho & Pintado 2004). This fast-growing rate of *R. geographicum* has significant implications not only for lichenometry studies in Antarctica, but also may allow comparisons with the growth rates of other Antarctic crustose lichens (Lindsay 1973, Little 2009).

The focus of the present study is the crustose lichen genus *Haematomma* A. Massal. (Ascomycota, Lecanoraceae), which includes *ca.* 35 species, distributed mostly in warm-temperate and tropical regions of the world (Øvstedal & Smith 2001, Messuti & De la Rosa 2009). In Antarctica, the only known species of this genus is *Haematomma erythromma* (Nyl.) Zhlbr., being considered as a nitrophilous one (Redon 1985, Øvstedal & Smith 2001), locally abundant on rock surfaces especially close to the shore, but also at inland sites used as skuas (*Stercorarius* spp. – Charadriiformes, Stercorariidae) perches (Øvstedal & Smith 2001). *Haematomma* formation was reported as a lichen community, often composed by some common species like *Acarospora macrocyclos* Vain. and *Usnea antarctica* Du Rietz, and species of the genera *Xanthoria* and *Buellia* (Olech 1990).

In 1980 were published the first results of five years of observations on the growth of 15 crustose lichens species on Signy Island, Antarctica (Hooker 1980a,b,c, Lewis-Smith 1995, Johansson 2008). These results were obtained by photograph comparisons and the *H. erythromma* growth was pointed out (together with that of *R. geographicum*, *Lecidea* spp., and *Buellia* spp.) as not measurable after two years period (1972 – 1974) (Hooker 1980a,b,c, Lewis-Smith 1995, Johansson & Thor 2008). Monitoring the growth rates of Antarctic lichens could help to create protected areas in this continent, since the slowest rate taxa could be identified and preserved from human presence (Protocol on Environmental Protection to the Antarctic Treaty 1980). Additionally, lichen growth rates might be used as an indicator of climate changes in this continent (Sancho & Pintado 2004). Therefore, this study aims to describe the growth rate and behavior of *H. erythromma* associations after a 20 years period (1992 and 2012) in the Elephant Island, Antarctica. Additionally, the development of *H. erythromma* was compared according to its community composition and to the effects of wind direction.

MATERIAL AND METHODS

Study area

Elephant Island is located 61º 07' S; 55º 03' W, and has 37 km in the E-W direction and 16 Km in the N-S direction (Figure 1). The central area is totally ice-covered. The ice-free areas are on the coast, but the access is difficult because there are steep cliffs and the wind and waves are often very strong. Samplings were carried out in the locality of Stinker Point, which is the largest coastal ice-free area and has the richest flora of the island. This area is limited to the northwest near the beach by the Sultan Glacier and south by the Endurance Glacier. The distances between the two glaciers is 4,500 m, and from the beach to glacier is 800 m in a straight line. The work was carried out in the surroundings of the Wiltgen Refuge (61°13′34.1″S; 55°21′58″W), two containers building installed by the Brazilian Antarctic Program in 1986 and removed in 1998 (Putzke *et al.* 2019).

Survey design

The survey was carried out during three expeditions to the Elephant Island in 1992, 1994 and 2012. In each expedition, eight 25 x 25 cm squares were evaluated in large flat rocks with crustose nitrophilous lichen communities, seven in an area near the old and removed Wiltgen refuge (called rocks A, B, C, D, E, F, G, and H) with respective coordinates below (Figure 2): A = 61°13′21.33″S. 55°22′08.19″W; B = 61°13′21.51″S.

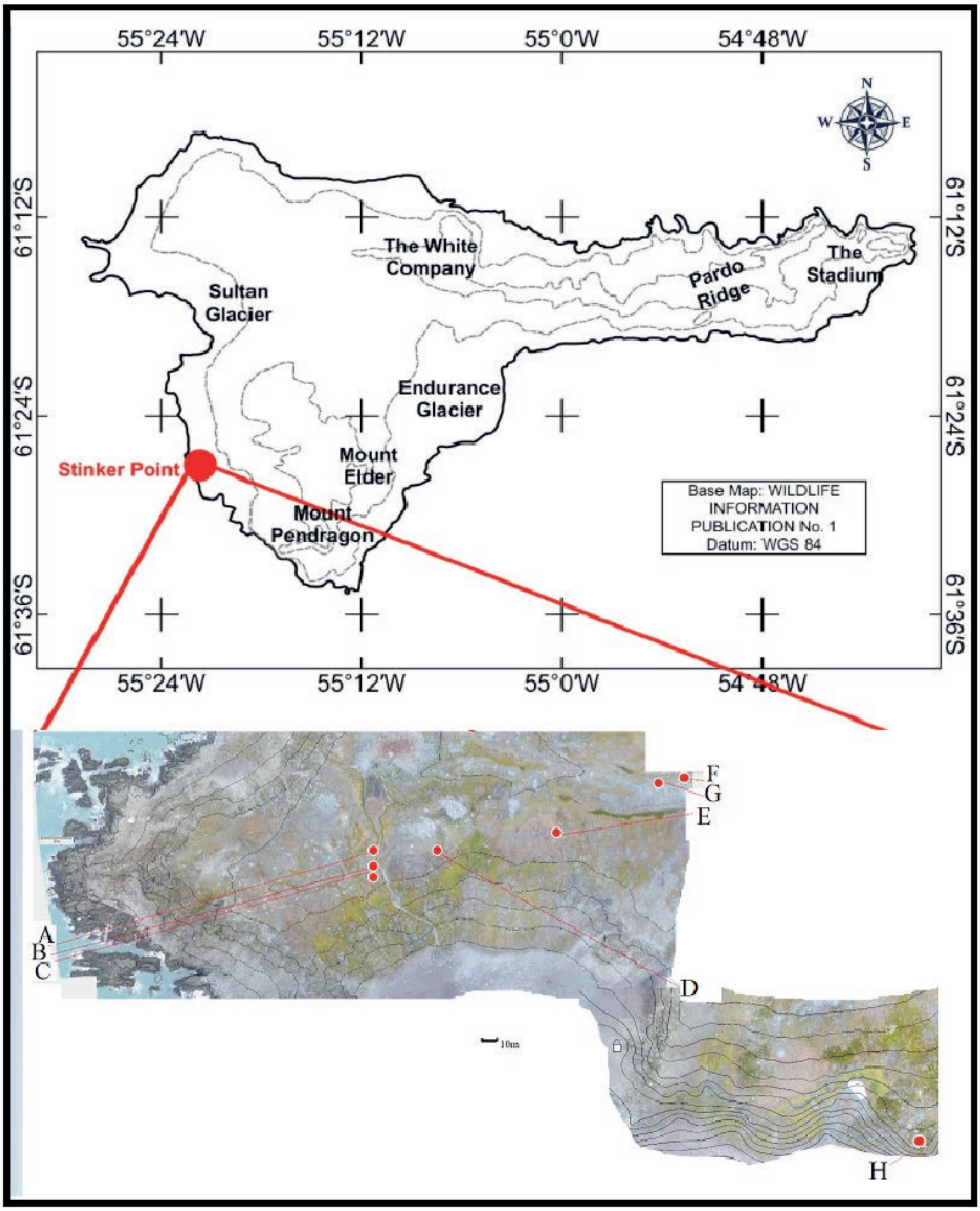

Figure 1. Map of Elephant Island, with the sample areas (A to H; red dots) in Stinker Point, Antarctica.

55°22′08.40″W; C = 61°13′21.73″S. 55°22′08.17″W; D = 61°13′21.38″S. 55°22′05.02″W; E = 61°13′20.96″S. 55°21′59.82″W; F = 61°13′26.26″S. 55°21′46.38″W; G = 61°13′19.86″S. 55°21′55.28″W; and H = 61°13′19,69″S, 55°21′54,32″W.

To measure lichen growth in each expedition, a transparent plastic sheet was laid over each of the eight communities and each lichen area was drawn on it by transparency. The four corners of the square were marked on the rock with a nail and hammer so that each plastic slide was placed in the exact position after each new annual assessment. In addition, natural cracks in the rocks, encrustations of quartz or other materials were also drawn on the blades, to arrange the square always in the same position. Each species name was written directly on the plastic sheet (after identification in the laboratory), allowing to

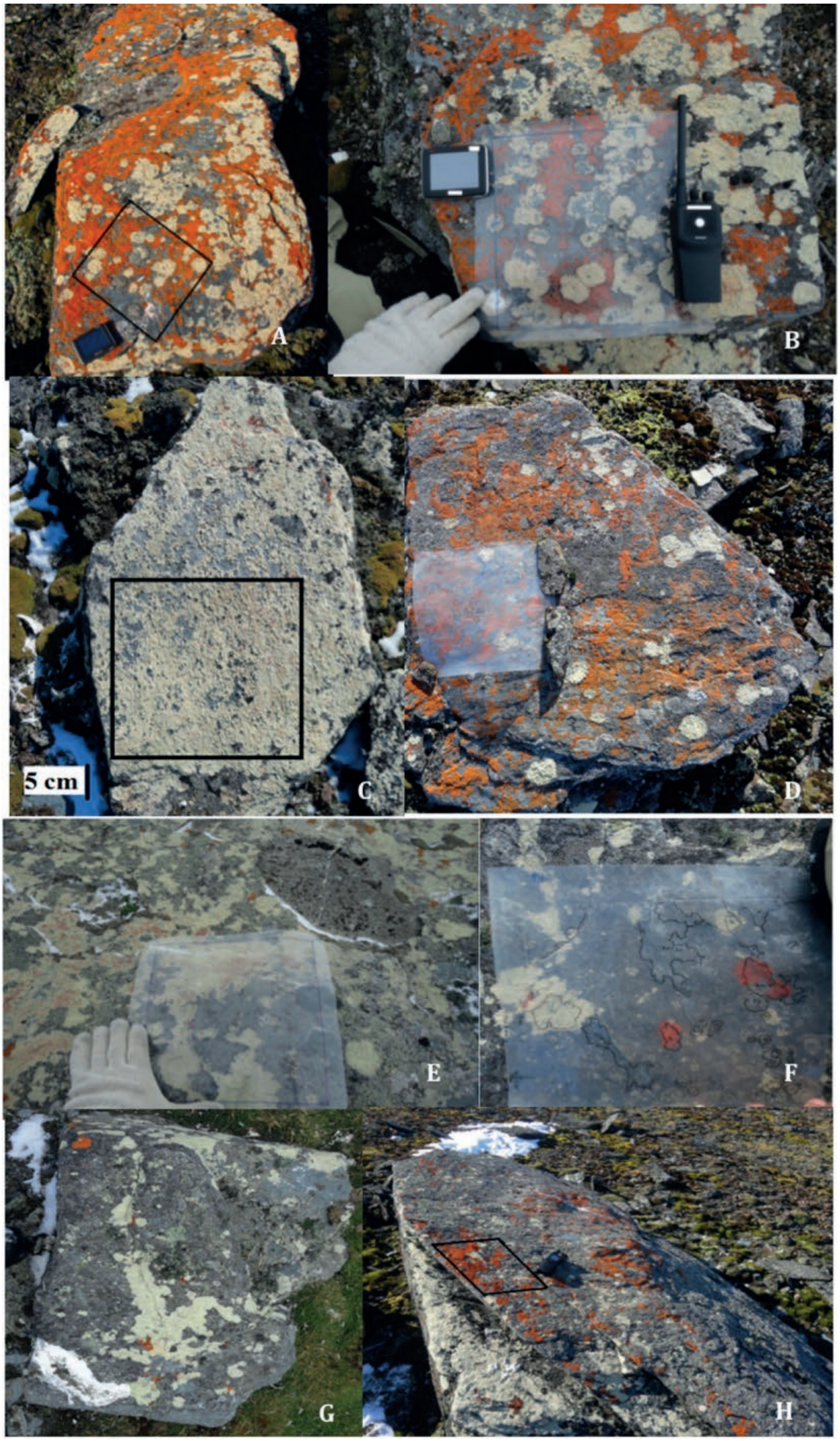

Figure 2. Evaluated sites (A to H) at Elephant Island, South Shetland Islands, Antarctica, with location of the square on each rock to sample crustose lichen communities.

evaluate community diversity (species richness and composition) and coverage area data for each species. We used this technique because digital photography was not available for the project at the start of the study in 1992, thus the same technique was used in 2012 for consistency.

Small fragments of the lichens found on the same rock, but not inside the square, were collected and taken to the field laboratory set up at the Stinker Point camp for identification. The samples were deposited at the HCB herbarium of the Universidade de Santa Cruz do Sul, state of Rio Grande do Sul, Brazil. Macroscopical, microscopic and biochemical data were used according to Øvstedal & Smith (2001) and their references for identification at the specific level. *Haemathoma erythromma* is easily recognized by its pallid yellow crustose thallus with small red apothecia, and it ornithocoprophic habit (Redon 1985).

The growth of each species over a 20-year period was evaluated using the software AutoCAD (2015) to determine (i) the area of coverage for each lichen drawn on the plastic sheet; and (ii) diameter of the coverage area. Preferential growth direction was determined qualitatively by the overlap of each annual drawing.

The wind direction was collected from the weather station installed in the Goeldi refuge and the plastic sheet was orientated using a compass. There were selected four thalli (that were not confluent in 2012) to estimate growth in relation to cardinal points. This was done measuring the largest extension of the thallus and relating it to the geographical position. The main wind direction was then overlapped. The confluence of the lichen thalli was evaluated by overlapping both images and checking their growth oriented towards another thallus, as established by Booth (1971).

RESULTS

During the entire study, *H. erythromma* was found growing in association with other 13 species, namely: *A. macrocyclos*, *Buellia anisomera*, *Amandinea augusta*, *Buellia coniposis*, *Buellia granulosa*, *Buellia latemarginata*, *Buellia russa*, *Mastodia tesselata*, *Pannaria hoockerii*, *Rhizoplaca aspidophora*, *Usnea antarctica*, *Xanthoria*

Table 1. Lichen coverage (area and percentual growth) in *Haematomma erythromma* (Ascomycota, Lecanoraceae) communities in 1992 and 2012 at Elephant Island, South Shetland Islands, Antarctica. Negative values correspond to a reduction in thallus area for the species.

Species	Overall size in 1992 (cm²)	Overall size in 2012 (cm²)	Growth %*
Haematomma erythromma (Nyl.) Zahlbr.	615.55	1051.87	70.88
Usnea antarctica Du Rietz	6.73	58.64	771.32
Pannaria hoockerii (Borrer ex Sm.) Nyl.	17.78	92.76	421.71
Buellia coniposis (Wahlenb. ex Ach.) Th. Fr.	31.76	60.53	90.59
Rhizoplaca aspidophora (Vain.) Redón	35.37	47.5	34.30
Xanthoria elegans (Link.) Th. Fr.	1288.37	1081.2	- 16.08
Acarospora macrocyclos Vain.	22.02	15.8	- 28.25
Buellia anisomera Vain.	48.33	31.13	- 35.59
Buellia granulosa (Darb.) Dodge	117.95	8.87	- 92.48
Mastodia tesselata (Hook.f. & Harv.) Hook.f. & Harvey	2.59	0.1	- 96.14
Buellia russa (Hue) Darb.	0	8.13	n/a
Xanthoria candelaria (L.) Th. Fr.	0	0.14	n/a
Buellia latemarginata Darb.	0	46.08	n/a
Amandinea augusta Vain.	0	7.86	n/a

candelaria, and *Xanthoria elegans* (Table 1). The highest overall growth, based in the coverage incremental for each species, was registered for U. antarctica (771.3 %), followed by *P. hoockerii* (421.7 %), *B. coniopsis* (90.6 %), *H. erythromma* (70.9 %), and *R. aspidophora* (34.3 %) (Table 1). The other eight species had a reduction in the area originally measured in 1992 or disappeared (Table 1). The growth rate of *H. erythromma* was evaluated originally for 70 thalli in 1992 but in 2012 there were found 178 thalli (more 254 % of new thalli formed) and confluence was observed for 29 thalli (41.4 % from the original ones; Table 2).

Species growth rate

Comparing the thalli of *H. erythromma* in two years of observation (1992 to 1994) no growth was observed, as already mentioned by other authors (Hooker 1980a) with differences noted only after 20 years. *Haematomma erythromma* grew from a minimum of 0.2 mm to 0.7 mm/year (Figure 3) with main direction orientated to West/Northwest (against wind predominant direction) and in order to unite the nearest thalli in one unique confluent larger thallus (Figures 4 and 5). In all sites *H. erythromma* was growing over other lichens species (including *X. elegans* and *Buellia* spp., but except *P. hookeri*), and can overgrowth them with great success despite its low growth rate. In each site, development of *H. erythromma* varied according to its community composition as follow:

Site A: In 2012, coverage of lichens was mainly composed by *X. elegans* (295.88 cm², 47.34 %) and *H. erythromma* (118.65 cm², 19.98 %). *Haematomma erythromma* gained ground over other lichens species even growing very slowly from 1992 to 2012. Comparing the three images of the site A, it is evident that thalli of *H. erythromma* try to grow to connect nearby thalli (Figure 3). There were located seven points of intention of confluence between different thallus in 1992: four already fused in 2012, two still interrupted by *X. elegans*, and a third separate by a *Buellia* spp. thallus. *Haematomma erythromma* appears to be able to launch new thalli along the new area between different isolated thalli. In 2012, a total of nine new thalli of *H. erythromma* were growing in this site, all disposed between two older thalli.

Site B: There were evident seven main *H.*

Table 2. Numbers of thalli, coverage and area of *Haematomma erythromma* (Ascomycota, Lecanoraceae) in 1992 and 2012, in each studied site (A to H), at Elephant Island, South Shetland Islands, Antarctica.

	A		**B**		**C**		**D**		**E**		**F**		**G**		**H**	
Year	1992	2012	1992	2012	1992	2012	1992	2012	1992	2012	1992	2012	1992	2012	1992	2012
Number of thalli	16	33	31	49	1	1	2	3	2	46	2	19	5	13	11	14
Coverage (%)	8.46	19.61	21.98	37.84	96.53	100	1.69	2.71	0.38	11.03	2.24	9.6	12.78	27.17	34.88	53.37
Area (cm²)	33.8	78.4	87.9	151.3	386.1	400	6.76	10.8	1.5	44.1	8.96	38.4	51.1	108.6	139.5	213.5
Number of confluent thalli to 2012	4		10										5		10	

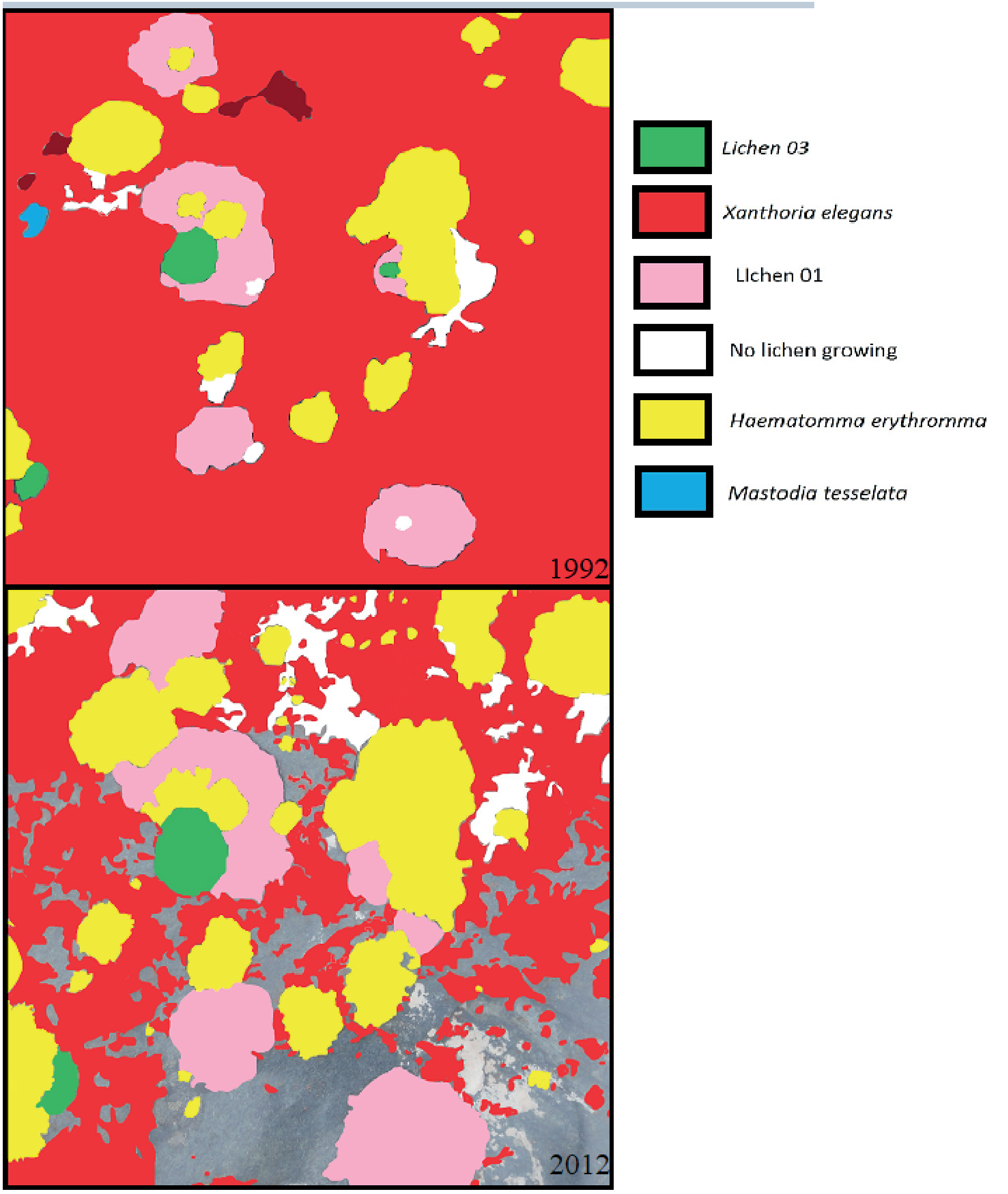

Figure 3. Images of site A generated by drawing the lichen thalli directly from the rock to a plastic sheet in the same area in 1992 (above) and 2012 (below), at Elephant Island, South Shetland Islands, Antarctica.

erythromma growing areas, with 26 isolated thalli in 1992. In 2012, all of them were connected, forming seven irregular units and a total of 21 new isolated thalli

Site C: In this site, dominance of *H. erythromma* was complete after 20 years. Five different thalli of *Buellia* spp. were evident in 1992, but were overgrowth by *H. erythromma* and disappeared completely in 2012, remaining a giant thallus of *H. erythromma*. Despite this, the giant thallus was disrupting, resulting in openings in its structure but without other species colonization. This is the case of almost all the remaining rock outside the demarked square, which has 60 cm in diameter, but with some *X. elegans* appearing on some places outside the evaluated square. The growth of individual thalli of *H. erythromma* in this site was not estimate since most thallus were confluent. In four thalli only it was possible to observe some independent growth. The maximum growth ranges 5.0 mm to 9.0 mm, which represents 0.25 to 0.45 mm/year, with thalli growing more West/Northwest - Northeast/East position. Analyzing the growth through the distances between thalli isolated in 1992 and connected in 2012 it was possible to confirm a growth of 0.27 to 0.7 mm/year, overgrowing thalli of *X. legans* and *B. granulosa* (Tables 2 and 3).

Site D: This community was dominated by *X. elegans* (covering 81.51 % and 92.27 % of the area respectively in 1992 and 2012), being found only one thallus of *H. erythromma*, with a small lateral growing area of another thallus entering the area at the top of the square. In 20 years of growth, this was the slowest individual thallus of *H. erythromma* of all studied (10.47 cm^2 to 15.37 cm ^{2}), what was also the case with the other species in this square. It appears that all stopped growing with the *X. elegans* very fragmentary, resulting in areas of free rock surfaces. Despite this, no other lichen species colonize these newly exposed areas. On the contrary, some thalli disappear, what was the case of *Buellia* spp. in the left half of the site evaluated, some of them very fragmented.

Site E: Site E had mainly *X. elegans* coverage in 1992 (75 %), with the remaining area divided by *Buellia* spp. and *R. aspidophora*. Only three thalli of *H. erythromma* were evident, occupying 4.88 cm^2 (0.8 %). In 2012 all *R. aspidophora* disappeared, overcrowded mostly by *X. elegans*.

Site F: This site was covered mainly by *H. erythromma* (47.82 %), *Buellia* spp. (33.35 %), and *P. hoockerii* (11.79 %) thalli. In 20 years, *H. erythromma* grew from 228.97 to 321.45 cm^2 (11.8 %). *Xanthoria elegans* and *B. russa* were overgrowth and disappear in the square, and *A. macrocyclos* (8 small thalli) and *M. tesselata* (one thallus) were found only in 2012. Three large *H. erythromma* thalli penetrate the square area, one from Northwest and two form Southeast of the square delimitations. The thalli grew up in the direction of small new colonies of the same species, being confluent with them. New growing edges of the thalli are redirected to connect with new colonies in the surroundings. The Northwest side of the *H. erythromma* area practically stopped its growth in contact with *B. augusta*, extending the thallus only to contact others. The Southeast side was conducting growth also to the nearest thalli. Isolated thalli inside *B. augusta* grew only from 0.93 (11 x 11 cm) to 3.03 cm^2 (20 x 21cm) in 20 years. Some *H. erythromma* thalli were close to the *B. russa* thallus, but the *B. russa* thallus not allowed it to contact others, resulting in a small growth for both.

Site G: In 1992, two prominent *X. elegans* and two *H. erythromma* colonies were found and they were still easily observable in 2012. In 2012, a total of 15 new growing colonies of *H. erythromma* were observed, six growing to be confluent with the biggest colony and the other irregularly distributed over the square area.

Site H: In this site was noted a large *H. erythromma* thallus growing from Northwest to Southeast mainly, but with branches to other positions. The remaining area was covered by a miscellaneous of lichens (*Buellia* spp., *A. macrocyclos*, *R. aspidofora*, and *X. elegans*) and the fruticose *U.*

Patterns of growth of the different species in relation to H. erythromma

Xanthoria elegans: This species is reducing its coverage in four of the sites where it was observed up to 2012. The reduction of the overall coverage of this species was noted particularly in sites A (79.2 to 32.91), B (42.03 to 18.43), and D (81.34 to 60.04), especially due fragmentation under the interference of *H. erythromma*.

Pannaria hookerii: In 1992 on site A, one thallus of *P. hookerii* was growing connected to a *B.*

Table 3. Growth of thalli of *Haematomma erythromma* (Ascomycota, Lecanoraceae) in 1992 and 2012, in site C, at Elephant Island, South Shetland Islands, Antarctica. The number of thalli presented together were confluent in one thallus in 2012.

Number of thalli	1992			2012			
	North/ South (mm)	East/ West (mm)	Area (cm^2)	North/ South (mm)	East/ West (mm)	Area (cm^2)	Growth (20 years) (cm^2)
01/02	29/21	23/23	3.62/2.49	41/35	41/40	12.25/11.09	8.63/8.6
14	11	16	1.35	24	31	5.54	4.19
03	9	14	1.45	19	25	3.22	1.77

anisomera. but the last one was colonized by two growing points of *H. erythromma*. In 2012 both thalli were confluent surrounding the *P. hookerii* thallus on the northern side. *Pannaria hookeri* grew occupying 1/3 of the *Buellia* sp. thallus. In 2012, a third *H. erythromma* thallus was noted in the square, and will probably contact the greater *Buelia* sp. thallus in some years, dividing the thallus in two independent ones. The only *P. hookerii* thallus in site A doubled its area in 20 years (4.03 in 1992 to 8.1 cm^2 in 2012), overgrowing the thallus of a *Buellia* sp. and a *X. elegans*, but stopped its growth when contacted to two *H. erythromma* thalli.

<u>*Rhizoplaca aspidophora*</u>: During 20 years the only new species entering the site A was *R. aspidophora* (two thalli), which occupied an area of 2.87 cm^2 in 2012 (0.46 %), directly installed on *X. elegans*. In site E in 2012, all *R. aspidophora* registered in 1992 disappeared, overcrowded mostly by *X. elegans* and 32 thalli of *H. erythromma*. Thirteen thalli of *H. erythromma* are in the same position of *R. aspidophora* (from a total of 18 *H. erythromma* thalli found in 1992). In site H, *R. aspidophora* was generally strongly affected by *H. erythromma* who occupied in one rock 1/3 of its original area in 20 years. These thalli were confluent and are growing together. The largest area covered by *R. aspidophora* was that of a single specimen, whose growth rate has been retarded by the occurrence of a new *U. antarctica* thallus.

<u>*Mastodia tesselata:*</u> This species was found in 1992 in site A covering 0.52 cm^2 and in site B (nine small thalli), but disappeared in both sites in 2012. In site F, a new thallus of this species (0.1 cm^2) was found in 2012.

<u>*Acarospora macrocyclos*</u>: Despite reducing its overall area from 4.42 in 1992 to 1.15 cm^2 in 2012 in site A, *A. macrocyclos* remained with three very small thalli, one of them with the same area after 20 years and isolated inside or besides a *Buellia* sp. thallus. In site B, a thallus with 17.6 cm^2 in 1992 disappeared completely in 2012. In site F, a group of eight new thalli of this species appeared in 2012. In site H, two new *A. macrocyclos* thalli were formed after 20 years, being one totally surrounded and the other half surrounded by *H. erythromma*.

<u>*Usnea antarctica*</u>: This species was found only in 2012 on sites B (3.99 %), D (0.52 %), F (27.96 %), and G (2.99 %). This species was found in 1992 only in site H, occupying an area of 23.18 cm^2 in 2012. The number of thalli of *U. antarctica* increased from four individuals (6.73 cm^2) in 1992 to nine in 2012 (23.18 cm^2), all at the Northwest half of the marked square showing the possibility to change the rock surface form crustose dominant to fruticose.

<u>*Buellia* spp.:</u> In general, local occurrences of *Buellia* species has increased from 1992 to 2012, since many species were found only in the last observation, such as *B. russa* (sites H and D), *B. latemarginata* (site H), and *Amandinea augusta* (formelly a *Buellia*) (site H). In the other sites, the different species reduced their coverage from 1992 to 2012, like *A. augusta* (site F: from 373.15 to 224.15 cm^2), *B. anisomera* (site D: from 48.33 to 31.13 cm^2), and *B. granulosa* (site B: from 117.95 to 8.87 cm^2). Only in site A another species (*Buellia coniopsis*) increased its coverage from 31.76 to 60.53 cm^2 and one *H. erythromma* thallus growing inside this species was overgrown by it, disappearing completely in 2012 (Table 4).

Table 4. Observed growth rates for some Antarctic lichen species from published literature in comparison to our results obtained at Elephant Island, South Shetland Islands, Antarctica.

Lichen species	Species growth type	Growth in mm/year in references	Specific locality	Growth in mm/year in this study	References
Usnea antarctica	Fruticose	2.0	Livingston Island	2.5	Sancho & Pintado (2004)
Xanthoria elegans	Placodioid crustose	0.2 - 0.5	Signy Island	decrease	Hooker (1980b), Lindsay (1973)
Acarospora macrocyclos	Placodioid crustose	1.0 - 1.2	Signy Island Livingston Island	decrease	Hooker (1980c), Lewis-Smith (1995), Sancho& Pintado (2004)
Haematomma erythromma	Crustose	n/a	Elephant Island	0.2-0.7	Hooker (1980a)

Growth pattern of H. erythromma *with respect to wind direction*

In the six thalli that were not confluent selected to estimate growth in relation to cardinal points (Figure 4), it was found that in general all thalli grown preferentially to West, Northwest and Southwest, always against prevailing wind direction (West).

DISCUSSION

We counted and monitored 178 *H. erythromma* thalli in eight sampled areas over a period of 20 years, from which the growth rate measured reached a maximum of 7.0 mm and growth was detected mostly against the prevailing wind direction. The thalli in general also grew towards adjacent thalli, becoming confluent and often over other lichen species.

Species growth rate

The lichen growth in Antarctic environments can be classified as impressive, since it has the coldest and driest conditions on Earth (Convey 2006, Sancho *et al.* 2019). However, these conditions are usual for lichen growth and their use as bioindicators could become more prominent in

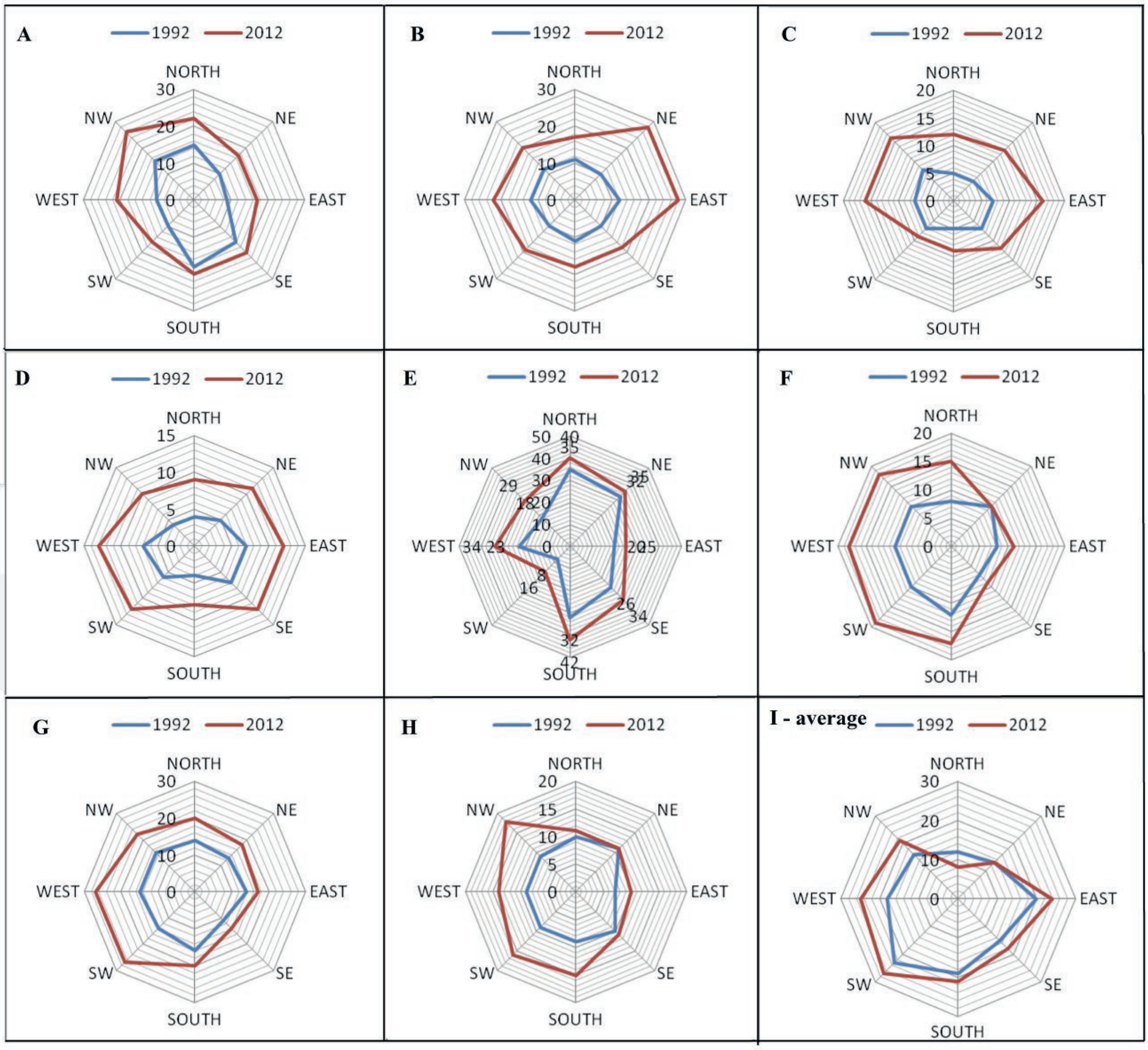

Figure 4. Preference of growth of *Haematomma erythromma* (Ascomycota, Lecanoraceae) thalli according to cardinal points in sites B (thalli A to D), C (E to H) and E (thallus I) at Elephant Island, South Shetland Islands, Antarctica.

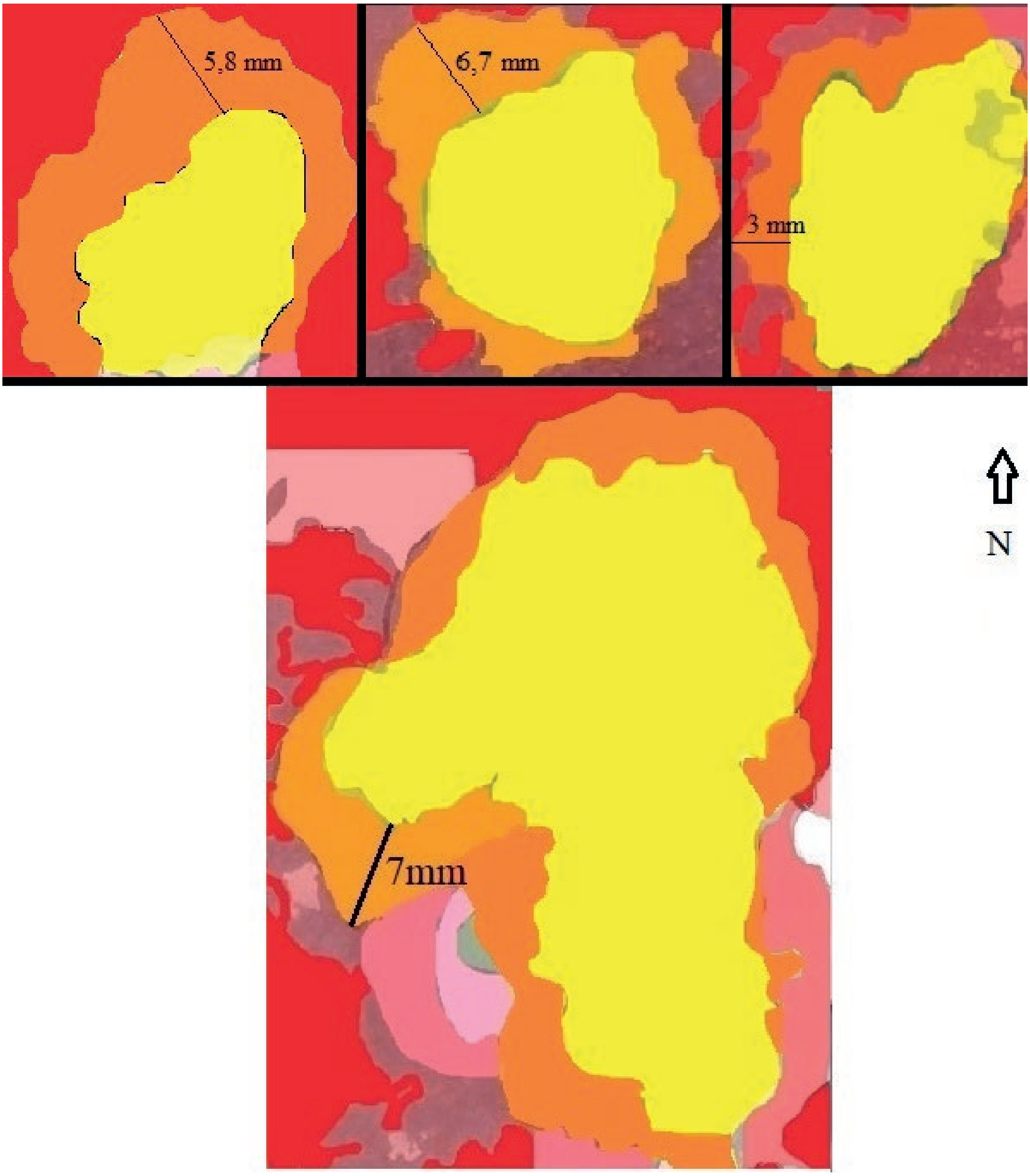

Figure 5. Overlapping of drawings of *Haematomma erythromma* (Ascomycota, Lecanoraceae) thalli evaluated in 1992 (yellow) and in 2012 (orange), at Elephant Island, South Shetland Islands, Antarctica.

the future by searching for their exact development pattern (Sancho *et al.* 2007). However, little is known about *H. erythromma*, but as this species has the lowest growth rate, it must be one of the species severely affected by climate change. Therefore, new studies should examine this relationship. Climatic changes can produce rapid and massive changes for lichens, with dramatic declines in apparent growth (Sancho *et al.* 2007).

The 178 thalli monitored in the present study grew 0.2 to 0.7 mm/year, a slower growth than that found for *R. geographicum* (Sancho & Pintado 2004). A previous study measured 0.21 mm of growth in *H. erythromma* in a two-year period (1974-1977), assessing 18 thalli marked in two sites (Hooker 1980a). Within the eight studied sites, only in site D was found 100% surface coverage of *H. erythromma* after 20 years, overgrowing eight thalli of *Buellia* spp. that were registered in 1992. The old thallus was also losing its structure in 2012, creating openings in the coverage and optimal conditions for new colonizers. This was also observed in site B.

One of the difficulties for Antarctic lichens is finding its algal partner. Acquiring this alga from another lichen already installed can facilitate the colonization of a surface (Cao *et al.* 2015), which may be one of the strategies of *H. erythromma* when it grows over other crustose species. *Haematomma erythromma* is capable to colonize areas with other lichen species coverage, and may use its algal associate to colonize these areas. Further investigation is needed to stablish this connection.

The success of a competitive interaction between lichens frequently depends on at least eight factors: colonization rate and density, radial growth rate, type of contact between species, thallus senescence rate (rate of fragmentation), chemical composition, thallus size, and palatability for herbivores (Pentecost 1980, Lawrey 1984). The herbivory for *H. erythromma* was not observed in Antarctica during our expeditions, and should be less important in this environment owing to the lack of herbivores. The radial growth rate is low for what has been demonstrated here and the type of contact between crustose species is similar. Senescence for this species seems to occur only when an entire rock is colonized (Sancho & Pintado 2004). In Antarctica, the rate of colonization and density along with the chemistry of the thallus remain the same as in other locations (Sancho *et al.* 2007).

Patterns of growth of the different species in relation to H. erythromma

The lichen community where *H. erythromma* was registered was found in the present study covering sloping surfaces up to 60 degrees or almost horizontal rock surfaces (often occurring in rocks with a flat surface) in places with a southern exposure. The community is associated with fruticose lichens such as *U. antarctica* and *Usnea acromelana* Stirton, accompanied by *A. macrocyclos*, *B. coniopsis*, *X. elegans*, *X. candelaria*, *R. aspidophora,* and a few other species (Olech 1990, 1994). All the species reported in association with *H. erythromma* were also found in this study, except *U. acromelana*.

For the crustose *Buellia* spp., Green *et al.* (2012) found radial growth rates from 0.01 to 0.43 mm/year, which was the slowest compared to the growth rates of other species in the community. A similar growth rate for *Buellia* spp. was found in this study (0.02 to 0.4 mm). *Buellia coniopsis* was the only species that overgrowth one *H. erythromma* thallus.

The new thalli of *H. erythromma* are also utilizing the surface of lichens such as *R. aspidophora* (a crustose species with very prominent apothecia) as starting points for colonization, eventually eliminating them completely by overgrowth. It is also noticeable that *H. erythromma* can overcome the occupation of the surface of the rocks by foliose species like *X. elegans*. Most of the studies have noticed a succession from the crustose species, the first to colonize a substrate, to the foliose ones (Armstrong & Welch 2007). In the present study, foliose species are still excluded by crustose, redesigning the succession in the Antarctic environment.

Finally, the *H. erythromma* community is ornithocoprophilous, as it occurs in the surroundings of bird nesting points (Redon 1985, Olech 1990). All species found in the squares studied fit this classification. Eventual excess or lack of nutrients may contribute to some of the results and need to be studied in more detail in the future. In Signy Island, an increase in area of 15–32% per year has been recorded in nitrophilous species of the genera *Acarospora*, *Buellia*, and *Caloplaca* (Smith 1995).

Growth pattern of H. erythromma *with respect to wind direction*

The water content of lichens depends on environmental conditions, specially wind intensity, but wind can also bring nutrients from surrounding bird nesting points, allowing a higher growth rate (Kranner *et al.* 2008). The growth direction observed for *H. erythromma* into wind prevailing direction was probably due to nutrient deposits on thallus on the side mostly impacted by the wind, as a penguin rockery is found at Northwest of the studied area. Wind can also cause abrasion, but lichens are known to tolerate abrasion (Nash 2008). This can also be the case of the species evaluated here, being the thallus resistant and growing faster on in the side better supplied by wind nutrients, but further investigations are needed.

After 20 years monitoring 178 thalli of *Haematomma erythromma* we conclude that the species grew 0.2 (minimum) to 0.7 (maximum) mm/year, one of the slowest among Antarctic lichens, mainly oriented West/Northwest, against prevailing wind direction and the new thalli grew to connect each other, resulting in a confluent larger thallus.

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