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Variability of individual biomass and leaf size of *Saxifraga nivalis* L. along a transect between seabirds colony and seashore in Hornsund, Spitsbergen

Katarzyna Zmudczyńska, Adrian Zwolicki, Mateusz Barcikowski, Lech Iliszko, Lech Stempniewicz

Department of Vertebrate Ecology and Zoology
University of Gdańsk, Legionów 9, 80–441 Gdańsk, Poland
e-mail: kzmud@op.pl

Abstract. Many plants could respond to different nutrient content in soil in a change of their appearance and/or size. One of these sensitive species is *Saxifraga nivalis* L. which biomass and leaf width change in specific conditions found between the cliff with seabirds colony and seashore in Hornsund, Spitsbergen. The area is strongly influenced by birds, mainly because of guano deposition. Both leaf width and body biomass are self-correlated and increase along the transect marked out between the colony and seashore with declining distance from the colony. These individual parameters positively correlate with soil physicochemical features studied in this area. There is also negative relationship between nutrients content in soil and distance from the colony. Thus, the main reason of the stated variability among individuals seems to be nutrients availability in soil and some of its physical and chemical properties which are differential in the gradient of manuring by birds.

Key words: individual variability, nutrient gradient, *Saxifraga nivalis*, seabirds impact.

1. Introduction

Seabirds in Arctic foraging at sea and breeding on land, introduce large amounts of marine-derived organic matter from resourceful sea to poor land and thus, enrich the coastal ecosystem in nutrients (e.g. Tatur & Myrcha 1984; Wainright et al. 1998; Vidal et al. 2000; Ellis 2005; Stempniewicz 2005; Ellis et al. 2006). The impact of the birds is mainly through guano deposition in the colony and its vicinity (Tatur 1989; Vidal et al. 1998; Zelenskaya & Khoreva 2006) and also along the route from sea to land and from land to sea (Stempniewicz 1990, 1992). The other phenomens causing ornithogenic fertilization are: leaving prey remains, carcasses, feathers, eggshells (Polis et al. 1997; Anderson & Polis 1999; Ellis 2005) and even volatilization of ammonia produced during degradation of terrestrially deposited guano (Wainright et al. 1998). The greatest impact of these factors is observed near colony (Ryan & Watkins 1989; Wainright et al. 1998) where the concentration and activity of birds are in the highest level. Of less importance is the direct coastal region where birds disperse on bigger space.

The availability of nutrients caused by seabirds changes along the gradient of the birds colony influence (Ryan & Watkins 1989; García et al. 2002). On the community level, plants may response to these changes by variability of cover, species richness or diversity (Theodose & Bosman 1997; Vidal et al. 2003; Pennings et al. 2005; Wait et al. 2005; Zelenskaya & Khoreva 2006). On the individuals level, different biomass (Anderson & Polis 1999), morphology (Zelenskaya & Khoreva 2006), biometric features (Madan 2006), content of nutrients, like nitrogen or phosphorus (Wainright et al. 1998) and thus physiological properties i.e. photosynthetic abilities or productivity, may characterize plant specimens of one species depending on the quantity of guano deposition.

The aim of this study was to describe the variability of individuals of alpine saxifrage *Saxifraga nivalis* L. along the transect from the common breeding colony of Brunnich's guillemots and kittiwakes and to the seashore with respect to some physical and chemical properties of the soil.

2. Study area

This research was conducted in the influence area of common breeding colony of Brunnich's Guillemots *Uria lomvia* and kittiwakes *Rissa tridactyla* at the foot of Gnålberget Mountain (77°01'N 15°52'E), on the north coast of Hornsund fjord (South-West Spitsbergen, Svalbard). The area of the study ranged between the cliff where the colony nested and about 500 m distant seashore. The land slope decreased alongside with the distance from the colony ($r_s = -0.76$; $p<0.05$; $n = 10$) beginning with 40–50° directly under the cliff side and ending with the flat plain on the seaside.

Plant communities occurring in this area are described as fertilized (bird-cliff) vegetation (Rønning 1996), exceptionally rich and lush. It is a luxuriant mixture of herbs, grasses and mosses that form continuous and very thick mats.

3. Materials and methods

Individuals variability

The study was conducted at the turn of July and August 2006. On the study area, there was a transect beginning underneath the cliff with the colony and ending on the coast. Along the transect 19 zones were ranged in ascending distances from the colony. Thus, there were more zones in the in vicinity of the colony (region where the greatest variation in vegetation was observed), than in the coastal area, more distant from the cliff. The basis to designate these zones were 10 squares (160 cm x 160 cm) marked out earlier for physicochemical analysis of the soil. Moreover, for better representation of the individual variability one square (=one zone) was added halfway between the ones designed earlier (tab. 1).

Individuals of *Saxifraga nivalis* were found and collected only in zones 8–18. In total N=334 non-flowering individuals (without flowers or even flowering stems) were picked up. About 30 specimens were taken from each zone (tab. 1). At the beginning the plants were collected from the square and if there were not enough also from its vicinity within the zone.

Two parameters were used to characterize the individual variability in the population. Those were: width of a leaf and biomass of the whole individual because of its high sensitivity to environmental factors (Traiser et al. 2005). The width of a leaf, as it is a photosynthetically active part of a plant, is recognized as a measure of its complete size (Fonseca et al. 2000; Bragg & Westoby 2002) and thus of the condition of the whole specimen. Similarly, biomass shows the productivity of a particular species in changing environmental conditions (Anderson & Polis 1999).

For each individual, there were measured the broadest width of the three biggest leaves [mm] and wet mass of the whole body [g]. Afterwards, the plants were dried up in 80°C until the weight remained constant and weighed again.

Physicochemical analysis of the soil

Soil was prepared for analysis immediately after bringing from the field. It was divided into 3 samples, each of 80 cm^3, weighed with an electronic scales exact to 0.1 g and subjected to further procedures in order to assess:

1) proportion of soil dry mass
   Soil samples were ground and put in open vessels into a drier with a temperature of 40–60°C for at least 24 hours. After that, they were weighed again.
2) salinity and pH of soil solution
   Soil samples were filled with 160 cm^3 of distilled water. The solution was mixed and shaken out for about 20 minutes and then filtered through a sieve with 0.5 mm diameter mesh. The salinity and pH were quantified in this filtrate with pH/conductance/salinity meter CPC-401 (Elmetron).
3) content of nitrogen (NO_3^- i NH_4^+), potassium (K^+) and phosphorus (PO_4^{3+}) in soil
   Soil samples were filled with 200 cm^3 0.03 N acetic acid. Closed vessels were left for about 60 minutes shaken out the from time to time. Afterwards the solution was filtered through a sieve and next through a paper filter. The filtrate, diluted with distilled water alternatively, was analysed with photometer LF205 (Slandi) after conducting standard procedure.

Physicochemical analysis of the soil was done in 10 squares but there were only 4: No. 9, 11, 13 and 17 in the range of *Saxifraga nivalis* occurence.

4. Results

There was a decline in both: the leaf width and the body mass of individuals observed as the distance from the colony increased (fig. 1).

A significant difference in the leaf width occurred (with some exceptions) between individuals of the upper and the lower part of the transect (tab. 2). The leaf width in zones 8–14 was significantly higher compared with zones 16–18, and zones 8–10 even with the zone 14. However,

Table 1. Location of the squares in relation to the colony and the number of individuals of *Saxifraga nivalis* in every zone (+ individuals occured but the material was losted during treatment); Hornsund, S-W Spitsbergen. Squares with the physicochemical analysis of the soil made are bolded.

Square number	Distance from the colony [m]	Number of individuals
1	0.0	
2	3.0	
3	6.0	
4	10.5	
5	15.0	
6	21.4	
7	28.5	
8	38.6	35
9	48.8	36
10	63.9	31
11	79.1	34
12	101.9	34
13	124.7	35
14	158.9	32
15	193.0	+
16	244.3	35
17	295.5	35
18	372.4	27
19	449.3	

there were no significant differences founded between neighbouring zones except the two last ones.

Similar situation was observed regarding the whole body biomass of an individual (tab. 3). There were significantly higher values of this parameter (with some exceptions) in the area located closer to the colony (represented by zones 8–14) than in zones located closer to the sea (zones 16–18). There were no significant differences detected between neighbouring zones.

Strong significant positive correlation was found between the leaf width and the biomass of an individual (r_S= 0.8; p<0.05) (fig. 2).

Furthermore, there was a significant negative correlation with the distance from the colony both for the leaf width (r_s = –0.78; p<0.05; fig. 3) and the biomass (r_s = –0.48; p<0.05; fig. 4) of individuals.

There was a significant correlation in this area between both the leaf width and the biomass and physicochemical

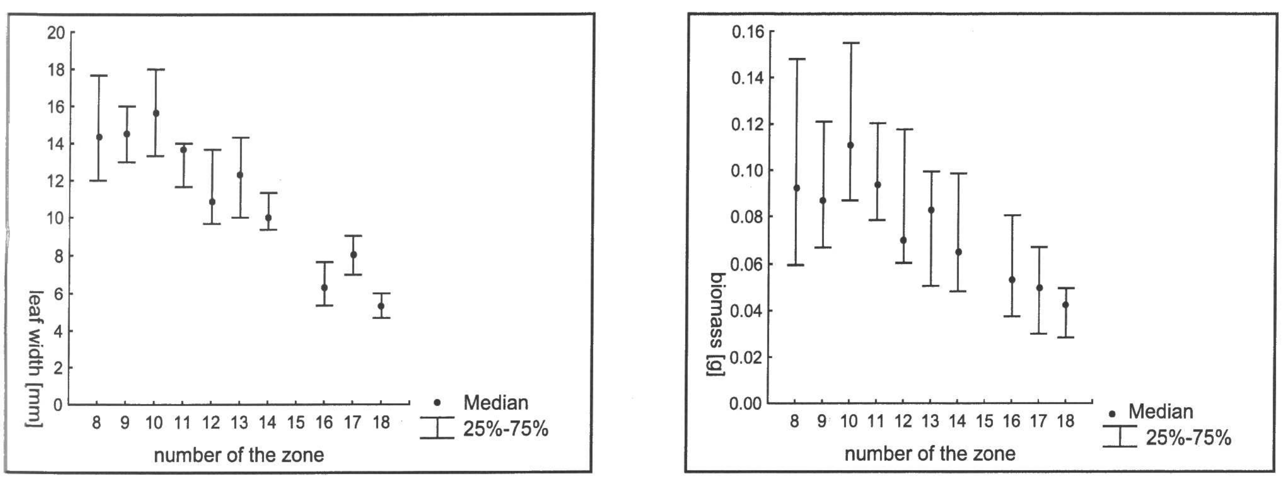

Figure 1. Leaf width [mm] and body biomass [g] of *Saxifraga nivalis* in each zone of the seabird colony impact gradient; Hornsund, S-W Spitsbergen.

Table 2. Differences in individual leaf width [mm] of *Saxifraga nivalis* among zones (Kruskal-Wallis' test $H_{9,334}$=230.49; p<0.001; *post-hoc* Dunn's test – bolded the significance p<0.05, additionally underlined the significance p<0.001); Hornsund, S-W Spitsbergen

	8	9	10	11	12	13	14	16	17
9	0.85								
10	0.08	1.00							
11	1.47	2.35	1.40						
12	3.01	**3.89**	2.94	1.54					
13	1.86	2.73	1.79	0.41	1.10				
14	<u>**4.62**</u>	<u>**5.53**</u>	<u>**4.54**</u>	3.10	1.52	2.67			
16	<u>**8.29**</u>	<u>**9.15**</u>	<u>**8.21**</u>	<u>**6.84**</u>	<u>**5.32**</u>	<u>**6.42**</u>	**3.87**		
17	<u>**6.64**</u>	<u>**7.50**</u>	<u>**6.56**</u>	<u>**5.18**</u>	**3.67**	<u>**4.77**</u>	2.22	1.65	
18	<u>**10.89**</u>	<u>**11.87**</u>	<u>**10.80**</u>	<u>**9.24**</u>	<u>**7.51**</u>	<u>**8.76**</u>	<u>**5.85**</u>	1.45	**3.33**

Table 3. Differences in individual body mass [g] of *Saxifraga nivalis* among zones (Kruskal-Wallis' test; $H_{9,334}$=100.16; p<0.001; *post-hoc* Dunn's test – bolded the significance p<0.05, additionally underlined the significance p<0.001); Hornsund, S-W Spitsbergen

	8	9	10	11	12	13	14	16	17
9	0.10								
10	0.64	0.54							
11	0.25	0.15	0.37						
12	1.59	1.69	2.20	1.83					
13	1.43	1.53	2.03	1.67	0.13				
14	2.64	2.75	**3.28**	2.90	1.01	1.15			
16	**3.74**	**3.84**	<u>**4.34**</u>	**3.98**	2.18	2.31	1.21		
17	<u>**4.88**</u>	<u>**4.98**</u>	<u>**5.48**</u>	<u>**5.12**</u>	**3.32**	**3.45**	2.35	1.14	
18	<u>**7.61**</u>	<u>**7.72**</u>	<u>**8.30**</u>	<u>**7.89**</u>	<u>**5.83**</u>	<u>**5.98**</u>	<u>**4.73**</u>	**3.35**	2.05

Table 4. Spearman's correlation coefficient (p<0.05; underlined values p>0.05) among leaf width [mm], biomass [g] of *Saxifraga nivalis*, distance from the colony [m] and physicochemical properties of the soil; Hornsund, S-W Spitsbergen. Ion content shown as mg/1000 g of soil dry mass.

	n	dry mass [%]	salinity [mg NaCl/l]	pH	NO_3^-	NH_4^+	K^+	PO_4^{3-}
Leaf width [mm]	4	0.71	0.39	0.62	0.58	–0.68	0.35	0.57
Biomass [g]	4	0.45	0.41	0.30	0.48	–0.35	0.31	0.46
Distance [m]	10	–0.80	–0.70	0.63	–0.88	<u>–0.23</u>	<u>0.13</u>	–0.95

features of the soil which were: proportion of soil dry mass, pH, salinity and contents of ions: NO_3^-, NH_4^+, K^+ and PO_4^{3+} (tab. 4). Both individual parameters were positively correlated with all the soil characteristics except from the ammonium ion content which was negatively correlated with those parameters. Stronger relationship was always found for the leaf width than for the biomass with exception of soil salinity which correlated with both biomerical features of almost the same strength.

Soil parameters were negatively correlated with the distance from the colony along the whole transect, except from the soil reaction which was positively correlated. The ammonium and potassium ion contents were not significantly correlated with the distance from the colony (p>0.05) (tab. 4).

5. Discussion

Many studies confirm the impact of various environmental factors, such as nutrients availability (e.g. Fonseca et al. 2000, Trubat et al. 2006, Rubio et al. 2003), altitude

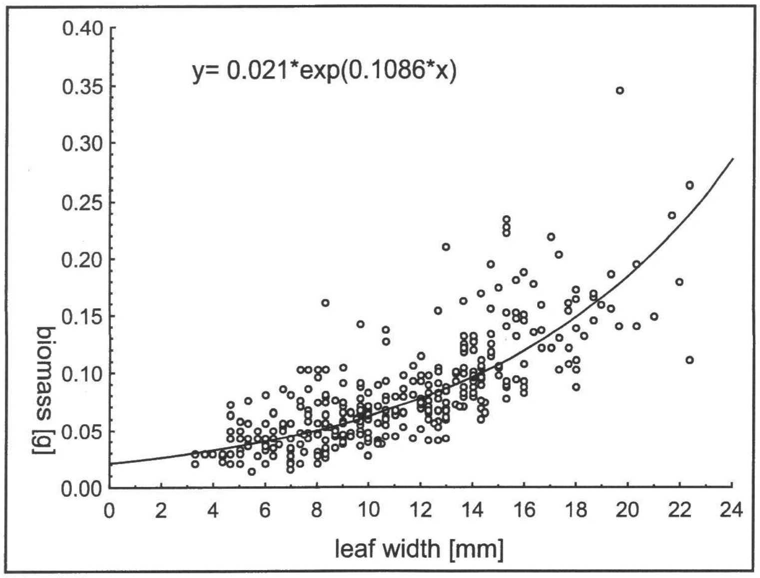

Figure 2. Relationship between leaf width [mm] and body biomass [g] of *Saxifraga nivalis*; Hornsund, S-W Spitsbergen

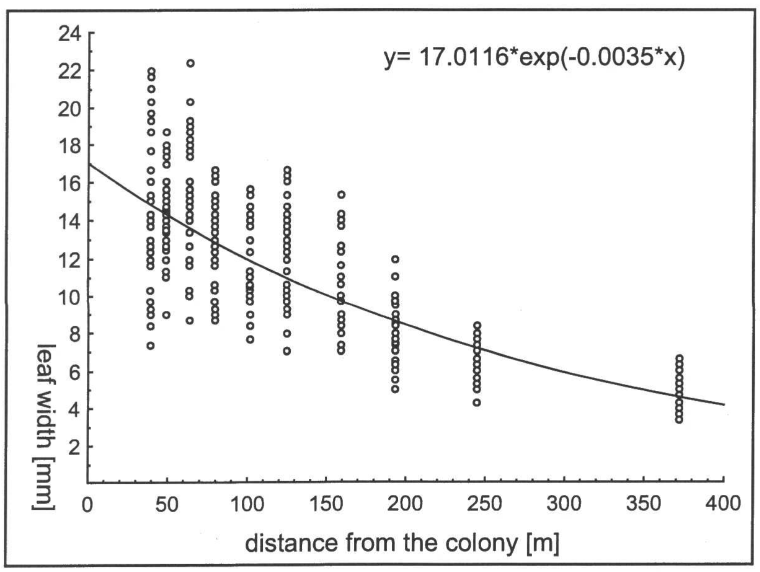

Figure 3. Relationship between leaf width [mm] of *Saxifraga nivalis* and distance from the colony [m]; Hornsund, S-W Spitsbergen

(Taguchi & Wada 2001), light (Bragg & Westoby 2002), wind (Niklas 1996), hydrological regime (Meškauskaitė & Naujalis 2006; Trubat et al. 2006) or grazing (Semmartin & Ghersa 2006) on morphology and biomass of a particular plant species. The main source causing the variability of *Saxifraga nivalis* individuals in the transect marked out between seabirds colony and the seashore seems to be nutrient content in soil and associated soil features (Gillham 1956). Presence of mineral compounds could be explained in two ways: either as an effect of direct guano deposition by flying birds depending on their density in a particular part of the transect or as a consequence of fertilizer flow from under the colony (where it is most concentrated) down the slope, where it is gradually absorbed by plants (Harding et al. 2004; Stempniewicz 2005). However, irrespective of the possible way of supplying with nutrients, there are higher values of soil physicochemical parameters observed near the colony and they decrease with the distance what means with the slope inclination.

The another possible factor of individual changes of alpine saxifrage could be diverse soil moisture in the area. It has been shown that proportion of dry mass significantly decreases with the distance from the colony. However, together with increasing soil moisture there was a decrease

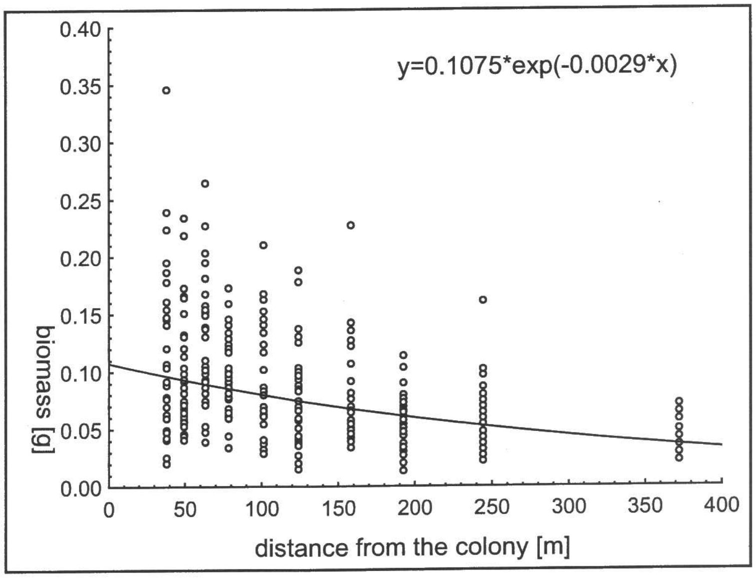

Figure 4. Relationship between body biomass [g] of *Saxifraga nivalis* and distance from the colony [m]; Hornsund, S-W Spitsbergen

in values of individual parameters of the plant. Thus, we could expect the optimal water conditions for *Saxifraga nivalis* (recognized as a mesophyte, McJannet et al. 2000) occurring near the upper border of distribution where the plants were the highest. It is also known that higher content of nitrogen and phosphorus improves species root hydraulic conductance (Radin & Matthews 1989; Trubat et al. 2006) and too low content of the nutrients restricts efficient water transport inside a plant and consequently its normal growth. This situation could take place in the lower part of the transect that is well watered but poor in nutrients. Both the leaf width and the biomass of individuals were significantly lower in comparison with specimens from the upper zones. On the other hand, ecological stress caused by too high moisture of soil can be sufficient in limiting body size (Meškauskaitė & Naujalis 2006) regardless of too less content of nutrients. This diversity in moisture conditions along the transect should not strongly change during the growing season. Summer rainfall in the Arctic regions is usually low and organisms normally rely throughout most of the vegetative period on the available water released at snow melt (Hodkinson et al. 1999).

Saxifraga nivalis was observed not far from the seashore (about 100 m away) and its size was increasing with declining distance from the colony. The highest values of the studied parameters of the plant were noted in zone 8, located 38.6 m away from the cliff. No specimens were found in the following zones up to the slope. It is possible that range of tolerance to increasing content of one or more nutrients in soil for this plant had its boundary there. Dominant vascular plant species observed above this place were *Cochlearia groenlandica* and *Poa alpina* (unpubl. data) which could be more resistant to guano impact than the saxifrage. As a result, the said plant species were more abundant there. (Vidal et al. 1998; Wait et al. 2005). Another factor potentially ousting *Saxifraga nivalis* from the part of the transect situated under the colony could be mechanical disturbances caused by stones tearing off the cliff and rolling down the slope. These rocky debris, very often of a great size, can destroy a relatively thin vegetation layer. To regenerate lost shoots alpine saxifrage may need stable ground for longer time than that intervals between sequential damaging. Contrary to the remaining two species, there also could be a soil humidity effect in the upper part of the transect, which is drier than the lower one (see above). In this competition the winner-species is the acido- and nitrophilous plant, *Cochlearia groenlandica* (Aiken et al. 1999), not as sensitive to high level of nutrients content as *S. nivalis*. It colonizes the uncovered places as a first plant (unpubl. data, Ziaja 2006) and may occupy the habitat almost completely. It inhibits the growth of potentially more sensitive species like alpine saxifrage.

Furthermore, *Saxifraga nivalis* was not observed in the lowest, coastal zone where the dominant vascular plant was *Saxifraga oppositifolia* (unpubl. data). The reason could be too low content of nutrients in soil or sea salt spray occuring periodically. However, salinity in this area was not higher than in regions where the plant individual occured (unpubl. data). On the other hand, a probable factor of this absence seemed to be duration of snow cover which was observed still in the beginning of June in zone 10 (unpubl. data). It could be that snow cover shortened growing season preventing the saxifrage from flowering and normal growth (Sonesson & Callaghan 1991; Scott & Rouse 1995; Hodkinson et al. 1999).

This phenomenon should not impact the rest of the transect. There was no snow cover in the area above the zone 10 in the mentioned time of observation. The snow conditions were probably similar there and the growing period lasted enough time for *S. nivalis* in the region where it occurred because there were flowering individuals found in every zone (unpubl. data).

There are more researches needed to precisely describe the variability of *Saxifraga nivalis* size influenced by seabird guano in the area. One of additional parameters which is planned to study is foliar chlorophyll content as a measure of effective photosynthesis and productivity.

References

Aiken S. G., Dallwitz M. J., Consaul L. L., McJannet C. L., Gillespie L. J., Boles R. L., Argus G. W., Gillett J. M., Scott P. J., Elven R., LeBlanc M. C., Brysting A. K. & Solstad H., 2003, Flora of the Canadian Arctic Archipelago: Descriptions, Illustrations, Identification, and Information Retrieval [http://www.mun.ca/biology/delta/arcticf/].

Anderson W. B. & Polis G. A., 1999, Nutrient fluxes from water to land: seabirds affect plant nutrient status on Gulf of California islands, Oecologia 118: 324–332.

Bragg J. G. & Westoby M., 2002, Leaf size and foraging for light in a sclerophyll woodland, Functional Ecology 16: 633–639.

Ellis C. J., 2005, Marine birds on land: a review of plant biomass, species richness, and community composition in seabirds colonies, Plant Ecology 181: 227–241.

Ellis J. C., Farina J. M. & Witman J. D., 2006, Nutrient transfer from sea to land: the case of gulls and cormorants in the Gulf of Maine, Journal of Animal Ecology 75: 565–574.

Fonseca C. R., Overton J. McC., Collins B. & Westoby M., 2000, Journal of Ecology 88: 964–977.

García L. V., Marañón T., Ojeda F., Clemente L. & Redondo R., 2002, Seagull influence on soil properties, chenopod shrub distribution, and leaf nutrient status in semi-arid Mediterranean islands, Oikos 98: 75–86.

Gillham M. E., 1956, Ecology of the Pembrokeshire Island. V. Manuring by the colonial seabirds and mammals, with a note on seed distribution by gulls, Journal of Ecology 44: 429–454.

Harding J. S., Hawke D. J., Holdaway R. N. & Winterbourn M. J., 2004, Incorporating of marine-derived nutrients from petrel breeding colonies into stream food webs, Freshwater Biology 49: 576–586.

Hodkinson I. D., Webb N. R., Bale J. S. & Block W., 1999, Hydrology, water availability and tundra ecosystem function in a changing climate: the need for a closer integration of ideas?, Global Change Biology 5: 359–369.

Madan N. J., Deacon L. J. & Robinson C. H., 2006, Greater nitrogen and/or phosphorus availability increase plant species' cover and diversity at a High Arctic polar semidesert, Polar Biology, DOI: 10.1007/s00300-006-0213-7 [http://www.springerlink.com/content/jx74tnn48472m414/].

McJannet C. L., Aiken S. G., Dallwitz M. J., Gillespie L. J. & Consaul L. L., 2000, Saxifragaceae of the Canadian Arctic Archipelago: Descriptions, Illustrations, Identification, and Information Retrieval [http://www.mun.ca/biology/delta/arcticf/].

Meškauskaitė E. & Naujalis J. R., 2006, Structure and dynamics of *Saxifraga hirculus* L. Populations, Ekologija 1: 53–60.

Niklas K., 1996, Differences between *Acer saccharum* leaves from open and wind-protected sites, Annals of Botany 78: 61–66.

Pennings S. C, Clark C. M., Cleland E. E., Collins S. L., Gough L., Gross K. L., Milchunas D. G. & Suding K. N., 2005, Do individual plant species show predictable responses to nitrogen addition across multiple experiments?, Oikos 110: 547–555.

Polis G. A., Anderson W. B. & Holt R. D., 1997, Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs, Annual Review of Ecology and Systematics 28: 289–316.

Radin J. W. & Matthews M. A., 1989, Water transport properties of cortical cells in roots of nitrogen- and phosphorus-deficient cotton seedlings, Plant Physiology 89: 264–268.

Rønning O. S., 1996, The flora of Svalbard, Norsk Polarinstitut, Oslo: 176–177.

Rubio G., Zhu J. & Lynch J. P., 2003, A critical test of the two prevailing theories of plant response to nutrient availability, American Journal of Botany 90: 143–152.

Ryan P. G. & Watkins B. P., 1989, The influence of physical factors and ornithogenic products on plant and arthropod abundance at an Inland Nunatak group in Antarctica, Journal Polar Biology 10: 151–160.

Scott P. A. & Rouse W. R., 1995, Impact of increased winter snow cover on upland tundra vegetation: a case example, Climate Research 5: 25–30.

Semmartin M. & Ghersa C. M., 2006, Intraspecific changes in plant morphology, associated with grazing, and effects on litter quality, carbon and nutrient dynamics during decomposition, Austral Ecology 31: 99–105.

Sonesson M. & Callaghan T. V., 1991, Strategies of survival in plants of the Fennoscandian Tundra, Arctic 44: 95–105.

Stempniewicz L., 1990, Biomass of Dovekie excrecta in the vicinity of breeding colony, Colonial Waterbirds 13: 62–66.

Stempniewicz L., 1992, Manuring of tundra near a large colony of seabirds on Svalbard, [in:] K.W. Opaliński

& R.Z. Klekowski (eds.), Landscape, Life World and Man in High Arctic, IE PAN, Warszawa: 255–269.

Stempniewicz L., 2005, Keystone species and ecosystem functioning. Seabirds in polar ecosystems, Ecological Questions 6: 111–115.

Taguchi Y. & Wada N., 2001, Variations of laf trait of an alpine shrub *Sieversia pentapetala* along an altitudinal gradient under a simulated environmental change, Polar Bioscience 14: 79–87.

Tatur A., 1989, Ornithogenic soils of the maritime Antarctic, Polish Polar Research 10: 481–532.

Tatur A. & Myrcha A., 1984, Ornithogenic soils on King George Island, South Shetland Islands (Maritime Antarctic Zone), Polish Polar Research 5: 31–60.

Theodose T. A. & Bowman W. D., 1997, Nutrient availability, plant abundance, and species diversity in two alpine tundra communities, Ecology 78: 1861–1872.

Traiser Ch., Klotz S., Uhl D. & Mosbrugger V., 2005, Environmental signals from leaves – a physiognomic analysis of European vegetation, New Phytologist 166: 465–484.

Trubat R., Cortina J. & Vilagrosa A., 2006, Plant morphology and root hydraulics are altered by nutrient deficiency in Pistacia lentiscus (L.), Trees 20: 334–339.

Vidal E., Medail F. & Tatoni T., 1998, Is the yellow-legged gull a superabundant bird species in the Mediterranean? Impact on fauna and flora, conservation measures and research priorities, Biodiversity and Conservation 7: 1013–1026.

Vidal E., Medail F., Tatoni T. & Bonnet V., 2000, Seabirds drive plant species turnover on small Mediterranean islands at the expense of native taxa, Oecologia 122: 427–434.

Vidal E., Jouventin P. & Frenot Y., 2003, Contribution of alien and indigenous species to plant-community assemblages near penguin reckeries at Crozet archipelago, Polar Biology 26: 432–437.

Wainright S. C., Haney J. C., Kerr C. A., Golovkin N. & Flint M. V., 1998, Utilization of nitrogen derived from seabird guano by terrestrial and marine plants at St. Paul, Pribilof Islands, Bering Sea, Alaska, Marine Biology 131: 63–71.

Wait D. A., Aubrey D. P. & Anderson W. B., 2005, Seabird guano influences on desert islands: soil chemistry and hernaceous species richness and productivity, Journal of Arid Environments 60: 681–695.

Zelenskaya L. A. & Khoreva M. G., 2006, Growth of the nesting colony of slaty-backed gulls (*Larus schistisagus*) and plant cover degradation on Shelikan Island (Taui Inlet, the Sea of Okhotsk), Russian Journal of Ecology 37: 126–134.

Ziaja W., 2006, Life expansion in Sørkapp Land, Spitsbergen, under the current climate warming, Reviews in Environmental Science and Biotechnology 5: 187–191.