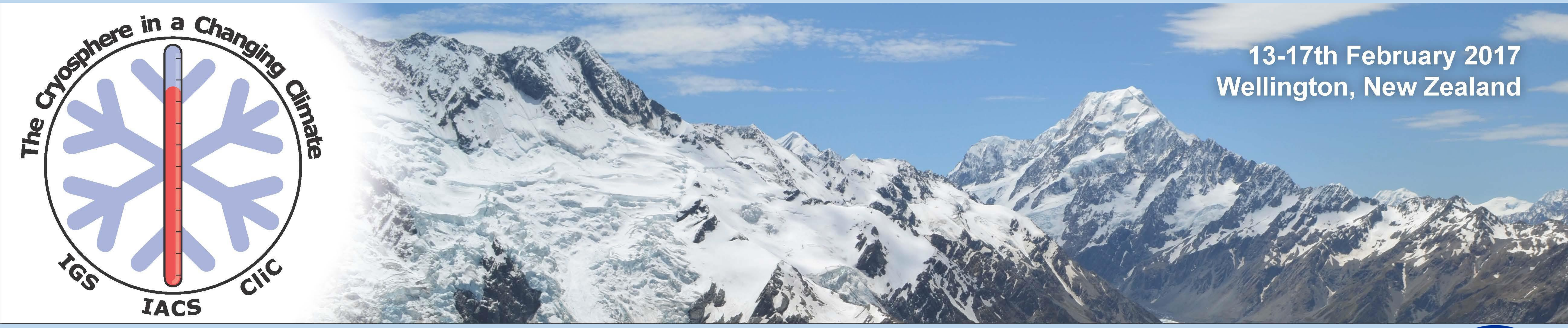


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# Rapid glacier receding changes foraging habitats of marine birds and mammals in the Arctic fjord

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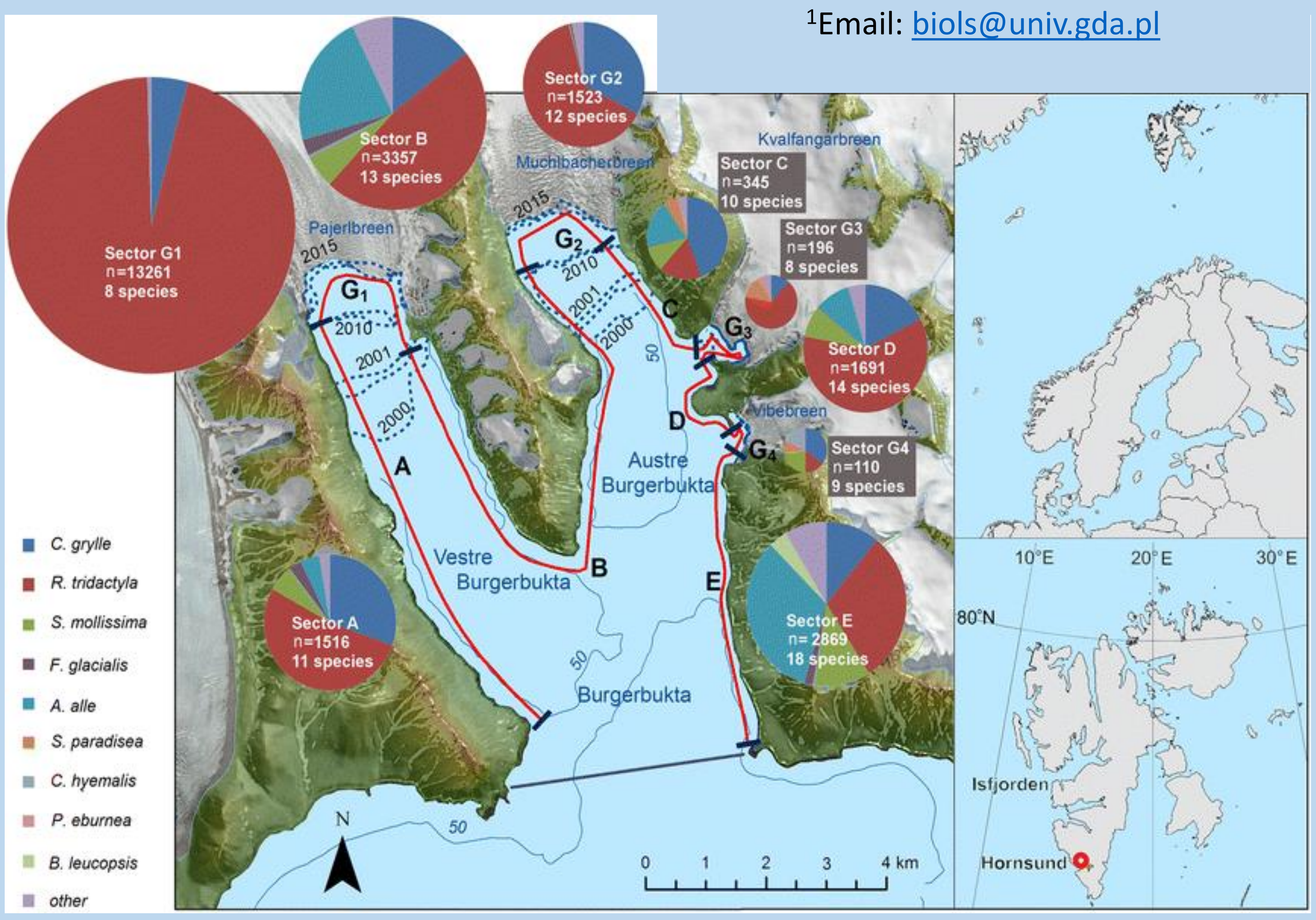


Fig. 1. Study area in Hornsund (SW Spitsbergen) with coastal transect (*red line*) consisting of nine shoreline sectors and one pelagic (*indigo line*) surveyed in July/August 2014–15. Five sectors (*A-E*) ran along non-glaciated coastline (NGCL), glaciated sectors (*G1-G4*) were situated along glacier fronts, two (*G1-G2*) belonged to sea-terminating tidewater glaciers (STTG) and two (*G3-G4*) to coastline-terminating glaciers (CLTG). *Pie charts* show total number of individuals, number and proportions of species observed in particular sectors (2 years combined). *Thin blue line* denotes 50 m isobath and *dotted lines* denote ranges of glacier fronts during 2000–2015

**Table 1**. Study area (STTG: sea-terminating tidewater glaciers, CLTG: coastline-terminating glaciers, NGCS: non-glaciated coastline sectors).

| sector | habitat type | length (km) | area[1] (km²) | exposition | littoral zone | coast type |
|---|---|---|---|---|---|---|
| A | NGCS | 8.50 | 2.55 | NE | narrow, steep, deep | low skjerra, steep rocky backshore, rocky cliffs |
| G1 | STTG | 1.40 | 0.42 | S | no littoral, deep glacier bay | tidal glacier cliff, dead ice aside, large glacier river debouching deep underwater surfacing in the lagoon |
| B | NGCS | 9.00 | 2.70 | WE | narrow, steep, shallow at Luciapynten | cliff with abrasive shelf, dead ice cliff, moraine beach, low gravel beach |
| G2 | STTG | 1.60 | 0.48 | SE | no littoral, deep glacier bay | tidal glacier cliff, dead ice on the sides, large glacier river reaching fjord superficially aside from the glacier front |
| C | NGCS | 2.30 | 0.69 | WS | narrow, steep | cliff with abrasive shelf, dead ice cliff, low gravel beach |
| G3 | CLTG | 0.52 | 0.16 | WS | shallow glacier bay | coastal terminating glacier, dead ice cliff, superficial glacier river in the lagoon |
| D | NGCS | 2.00 | 0.60 | W | broad, shallow | moraine low gravel beach |
| G4 | CLTG | 0.30 | 0.09 | W | shallow glacier bay | coastal terminating glacier, dead ice cliff, superficial glacier river in the lagoon |
| E | NGCS | 3.90 | 1.17 | W | broad, shallow | moraine low gravel beach, several rivulets from melting glaciers receded far inland |
| sum | | **29.52** | **8.86** | | | |

**Table 2**. Changes in the ice-free area of Burgerbukta related with glacier retreating 2000-2015.

| dates [yyyy.mm] | Vestre Burgerbukta total area [km²] | change [km²] | Austre Burgerbukta total area [km²] | change [km²] | Burgerbukta total area [km²] | change [km²] |
|---|---|---|---|---|---|---|
| 2000.06 | 9.407 | | 7.979 | | 17.386 | |
| 2001.06 | 10.454 | 1.047 | 8.475 | 0.496 | 18.929 | 1,543 |
| 2002.07 | 10.702 | 0.248 | 8.651 | 0.176 | 19.353 | 0,424 |
| 2010.08 | 11.934 | 1.232 | 9.840 | 1.189 | 21.774 | 2,421 |
| 2010.09 | 12.400 | 0.106 | 9.988 | 0.148 | 22.388 | 0,254 |
| 2014.08 | 13.201 | 1.161 | 11.279 | 1.291 | 24.480 | 2,452 |
| 2015.07 | 13.143 | -0.058 | 11.343 | 0.063 | 24.486 | 0,005 |
| Change 2000-2015 | | **+3.736** | | **+3.364** | | **+7.100** |

**Table 3**. Changes in length of retreating glacier fronts in Burgerbukta during 2000-2015.

| dates [yyyy.mm] | Pajerlbreen front length [m] | Muchlbacherbreen front length [m] | Kvalfangarbreen front length [m] | Wibebren front length [m] | all glaciers in total [m] |
|---|---|---|---|---|---|
| 2000.06 | 2650 | 1551 | 541 | 550 | 5292 |
| 2001.06 | 1657 | 1472 | 466 | 554 | 4149 |
| 2002.07 | 1511 | 1534 | - | - | 3045 |
| 2010.08 | 1910 | 1804 | 614 | 516 | 4844 |
| 2014.08 | 2840 | 2200 | 1447 | 529 | 7016 |
| 2015.07 | 3396 | 2115 | 1455 | 522 | 7488 |
| Change 2000-2015 | **+746** | **+564** | **+914** | **-28** | **+2196** |

**Abstract**. Climate-induced glacier retreat is considered in the context of its reducing the sea-ice contact zone used by marine birds and mammals as important foraging grounds and may cause declines in their numbers. To test this hypothesis, a survey was conducted in diversified habitats of a rapidly deglaciating Arctic fjord in Svalbard. Of the 15 seabird and four mammal species found, coastal surface-feeders prevailed over benthic-feeders and pelagic pursuit-divers. Deep tidewater glacier bays were used by the most numerous but least heterogeneous foraging community, in contrast to the shallow lagoons of coastline-terminating glaciers and deglaciated shorelines. After the 15 years of glaciers retreat documented in Hornsund, the sea-ice contact zone used by birds and mammals has not declined. On the contrary, the increasing freshwater supply from underwater glacial rivers raising zooplankton up to the surface, thus making it available to seabirds, enhances the attractiveness of tidewater glacier bays. Along with the stage of retreat, the importance of glacier bays as feeding grounds changes. Foraging conditions deteriorate when the glacier terminus reaches the coastline and the glacier bay becomes shallower. However, glacier retreat enlarges the area of littoral habitats accessible to benthophages. Glacier-related habitats situated close to colony are used as alternative/emergency feeding grounds by seabirds that normally forage outside the fjord. This is especially important during the chick-rearing period and also during bad weather conditions in the open sea. Our study demonstrates that, so far, the abundance and species diversity of seabirds foraging in the rapidly deglaciating Hornsund are both high, suggesting that they benefit from the current intensive glacier melt. However, with further climate change an apparent biodiversity paradox may occur. Here, overall biodiversity will increase but local diversity of pagophilic species will decline. Such nonlinear responses complicate the prediction of future polar ecosystem dynamics.

**Field methods.** 17 boat-based surveys (July-August 2014-15) following the whole coastline. Pelagic seabirds counted on transect crossing the bay. Observations covered 300 m wide strip (8.86 km²) of the transect area. All foraging individuals were included and assigned to a particular transect sector. Changes in glacier ranges (2000–2015) obtained by screen digitizing (Landsat satellite images, http://glovis.usgs.gov). Lengths of glacier fronts and deglaciated area in Burgerbukta were calculated with ArcGIS (Fig. 1, Tab. 2,3). Seabirds and mammals grouped into three foraging guilds: surface feeding [SF], pursuit diving [PD] and benthic feeding [BF], and into: coastal feeders [CF] and pelagic feeders [PF] with regard to spatial foraging preferences.

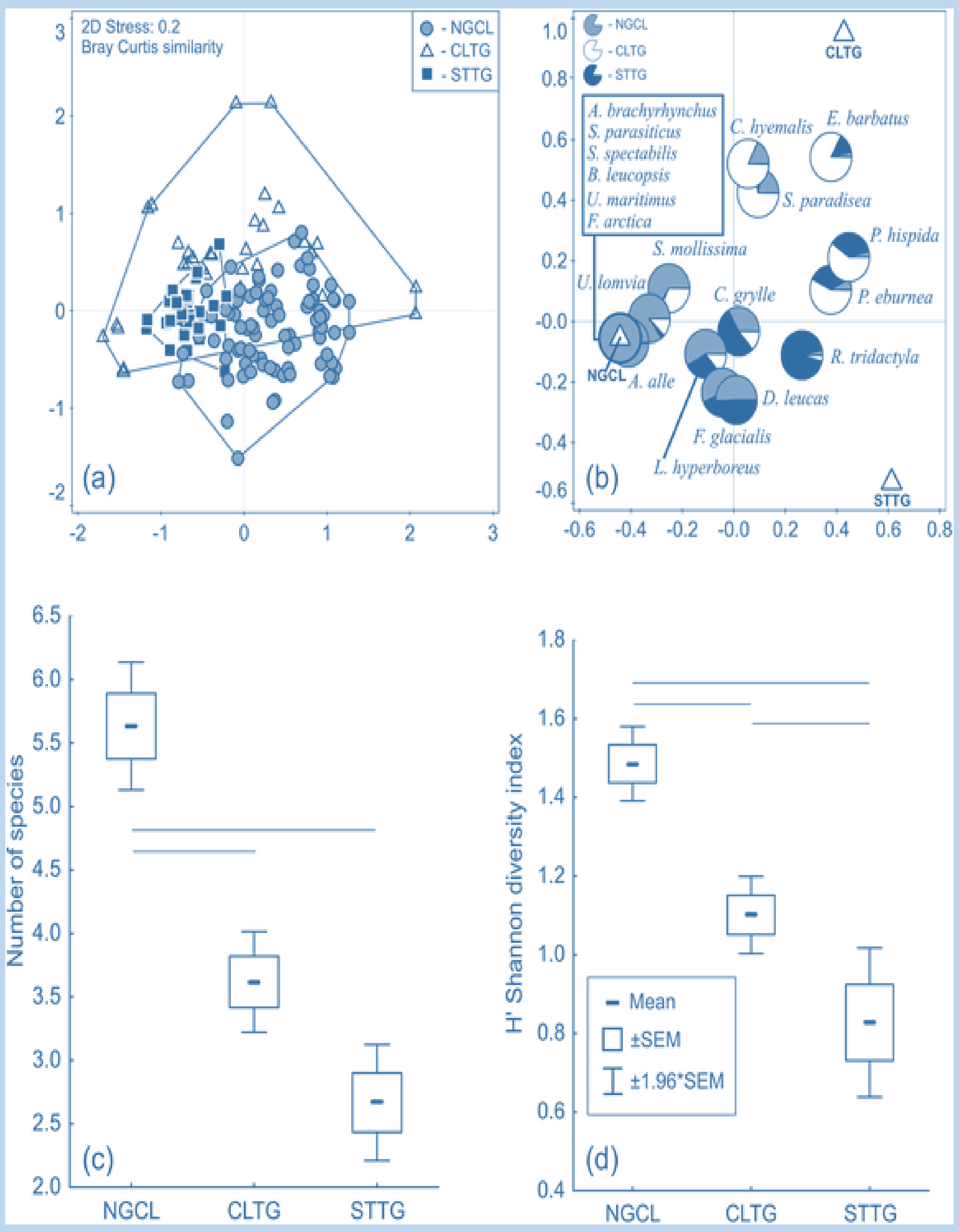


Fig. 2. Comparison of the three distinguished habitat types (*NGCL*: non-glaciated coastline, *STTG*: sea-terminating tidewater glaciers, *CLTG*: coastline-terminating glaciers). **a**: NMDS ordination diagram based on similarity of species composition within the three habitat types, plotted with envelopes; **b**: CCA ordination diagram with pie charts describing species participation in density within the three habitat types. *Triangles* present ordination of the environmental factor; **c**: number of marine bird and mammal species; **d**: Shannon diversity index. Significant differences ($p < 0.01$) between the habitats are indicated by *horizontal lines*

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