Supporting Information

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SI Materials and Methods

Study Area. The permanent monitoring stations in Kongsfjord (78° 58.6′N, 11°30.1′E) and in Smeerenburgfjord (79°41.3′N, 11°04.0′ E) are located along northwest Spitsbergen, the largest island of the Svalbard archipelago, (see Fig. 1). The fjords along the western coast of the Svalbard archipelago are influenced by a mixture of Atlantic water (AW), Arctic water, and glacial melt water (1). The AW influx brings relatively warm (T > 3 °C) and salty (S > 35 ppt) water into the fjords. The amount of heat influx via the AW is linked to bathymetry of the seafloor, large-scale climate variability (North Atlantic and Arctic Oscillations) and local wind patterns (1, 2). Kongsfjord is designated as an international research site for exploring the impacts of climate change (3).

The study sites differ with respect to angle of inclination and substrate heterogeneity. The Kongsfjord site is located on a horizontal surface characterized by bedrock with smaller and larger pebbles. In Kongsfjord, the community was initially dominated by red calcareous algae and sea anemones but after the regime shift by brown algae. The Smeerenburgfjord site, residing on a vertical rocky wall, is characterized by various sessile suspension feeders, red calcareous algae, and after the regime shift by bryozoans and several taxa of erect macroalgae. For a list of the taxa found at the study sites, see Table S1. The higher diversity of sessile filter feeders in Smeerenburgfjord may be attributed to the vertical orientation of the rock surface compared with the horizontal surface in Kongsfjord. Generally, because of differences in light availability and sedimentation, horizontal substrates tend to be more dominated by macroalgae, whereas vertical walls are more covered with epifauna (4). This seems also the case of our study sites, except that erect macroalgae did expand at the vertical study site in Smeerenburgfjord.

Photographic Data Processing and Sampling Design. The diver-operated camera setup was mounted on a (0.5 × 0.5 m) metal frame. Between 1980 and 2003, the photographs were taken using an analog Hasselblad Super Wide Camera with a Biogen 38 mm lens in a Hasselblad underwater casing fitted with a Zeiss corrective glass port. From 2003, the analog camera was replaced by a digital Nikon D 100 6 megapixels with a Nikkor 14-mm lens F/2.8 AF-D. The analog photographs were scanned in high resolution (3 megapixels). A detailed description of the sampling design and data processing methods can be found in Beuchel et al. (5–7).

Digital image analysis was carried out using the program Photoshop CS4 Extended (Adobe) which includes a scientific measurement tool allowing area and count estimations. The measurement tool enables calibration of the pixels in the photograph to the original frame size in meter (0.5 × 0.5 m). All of the images were processed by adjusting color and contrast gradients depending on the quality of the photographs. All selected areas (taxa) were measured in square centimeters and counted. The minimum sizes of macrobenthic organisms observed are 1–3 mm. Organisms were identified to the highest reliable taxonomic resolution. Identification to species levels was only possible for the very conspicuous taxa. The abundance estimates, number of individuals per square meter for solitary and percentage cover for colonial taxa, are calculated sample means of the five quadrates.

Macroalgae. The various macroalgal taxa were lumped into one category. In Kongsfjord only Phaeophyta (brown algae) were found, the majority belonging to the genus *Desmarestia* spp. Previous investigations in Kongsfjord have identified two *Desmarestia* species, *Desmarestia aculeata* and *Desmarestia viridis* (8). In Smeerenburgfjord several taxa belonging to both Phaeophyta and Rhodophyta (red algae) were registered. Apart from *Desmarestia* spp. and other filamentous brown algae and red algae, the conspicuous brown algae *Saccorhiza dermatodea* and conspicuous fleshy red algae, *Phycodrys rubens*, were identified.

Three groups were characterized as algal aggregations, consisting of erect macroalgae and/or hydrozoans and bryozoans. These taxa were lumped, because the physical association between these taxa makes it hard to distinguish them in the photographs.

To correct and compensate for the 2D top-down error, the photographs were divided into three community layers: (*i*) the first layer is composed of the erect macroalgae; (*ii*) the second layer of the large motile taxa; and (*iii*) the third layer of all sessile taxa. The first layer was subtracted from the second, and a new total area was calculated. Next, the first and second layers were subtracted from the third layer, and, again, a new total area was calculated. This top-down correction was performed because erect filamentous and leaf-like macroalgae may hide taxa below their thalli, or they may extend the substrate area upon which other taxa may settle.

Sea Surface Temperature. The yearly SST values are averages of monthly means obtained from NOAA databases. The processing of the SST data are described and discussed in the paper by Smith et al. (9) and in the NOAA websites http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html and http://www.ncdc.noaa.gov/ersst.

Length of the Ice-Free Season. The number of ice-free days is calculated by making use of sea ice concentration data obtained from passive microwave satellite imagery processed with the Bootstrap algorithm (10, 11) for the SMMR (January 1, 1980–August 10, 1987) and SSM/I (August 12, 1987–December 31, 2002) periods and processed with the Enhanced NASA Team algorithm (12) for the AMSR-E period (January 1, 2003–December 31, 2010). The concentrations thus calculated are projected onto polar stereographic grids whose equal-area cells have dimensions 25×25 km^2 for the SMMR and SSM/I data and 12.5×12.5 km^2 for the AMSR-E data. The final sea ice concentration datasets used here are for the SMMR and SSM/I periods (13) and for the AMSR-E period (14), both archived and distributed by the National Snow and Ice Data Center (http://nsidc.org/data). We derive the LIFS in each grid cell for each year between 1979 and 2010 from the daily sea ice concentrations [C (y, d; i)] for cell i on day (y, d) (year, day). To minimize possible isolated errors in the recording of the concentrations by the sensors, we work with smooth ice concentration time series instead of the original ones. In each grid cell i, the former are obtained from the latter by replacing the value of the ice concentration for day d in the original time series for year y by the average of the concentrations over a 5-d period centered on d. We define the LIFS L(y; i) at a certain point i in year y as the number of days between the clearance of the ice and the formation (more exactly, the appearance) of the ice in that point in that year. If the number of clearances and formations is larger than one, the LIFS is defined as the sum of the lengths of all periods between an ice clearance and the following ice formation. The criteria to identify dates of ice clearance and ice formation are as follows: We assume that there is clearance on day d if the ice concentration is 15% or higher in days d-4, d-3, d-2, and d-1 and below

15% in days d, $d+1$, $d+2$, $d+3$, and $d+4$. We consider that there is formation on day d if the ice concentration is below 15% in days d-4, d-3, d-2, and d-1 and 15% or higher in days d, $d+1$, $d+2$, $d+3$, and $d+4$. Because ice has occurred in all points at least once in the 1980–2010 period (not necessarily at the same time) in the region studied, the LIFS L(y) is, by definition, the spatially averaged LIFS over all points within that region. For more details on the calculations, see ref. 15.

List of Taxa Included in the nmMDS. Taxa included in the nmMDS (Fig. 4 *A* and *C*) are listed below.

Smeerenburgfjord:

i) *Dendrodoa aggregata*
ii) *Balanus* spp.
iii) Calcareous algae
iv) *Styela rustica*
v) *Spirorbis spirorbis*
vi) *Hiatella arctica*
vii) *Lebbeus polaris*
viii) Porifera indet.
ix) *Tonicella* spp.
x) *Halocynthia pyriformis*
xi) *Botryllus* spp.
xii) Hydrozoa indet.
xiii) Bryozoa indet.
xiv) Polycheate indet.
xv) *Boltenia echinata*
xvi) Aggregations algae-hydrozoa
xvii) *Ophiopholis aculeata*
xviii) *Strongylocentrotus droebachiensis*
xix) *Henricia* sp.
xx) Aggregations of algae-bryozoans
xxi) *Hyas* sp.
xxii) Aggregations of algae-hydrozoans-bryozoans

Kongsfjord:

i) *Urticina eques* or *Hormathia nodosa*
ii) Calcareous algae
iii) *Tonicella* spp.
iv) *Balanus* spp.
v) *Stronglycentrotus droebachiensis*
vi) Gastropoda indet.
vii) *Halocynthia pyriformis*
viii) Bivalvia indet.
ix) Natantia indet.
x) *Hiatella arctica*
xi) *Styela rustica*
xii) *Chlamys islandica*
xiii) *Pagurus* spp.
xiv) Polycheate indet.
xv) *Dendrodoa aggregata*

Smeerenburgfjord Manipulated Transect. In Smeerenburgfjord, a short-term increase in macroalgal abundance was observed in the manipulated plots (cleared of interactions), but not in the control plots, during the short-lasting peaks in SST and in the length of ice-free season in the start of the 1980s. The establishment and further growth of erect macroalgae took place only in patches that were cleared of the dominant calcareous algae (Fig. S1). The short-term establishment of erect macroalgae in the manipulated plots indicates that: (*i*) competition between the two macroalgal taxa (red calcareous algae and erect brown algae) took place; and (*ii*) removal of interactions facilitated erect macroalgae expansion in Smeerenburgfjord in the early 1980s. The return in 1986 of the Smeerenburgfjord community to its equilibrium state without erect macroalgae indicates that the environmental conditions did not yet favor the erect macroalgae takeover.

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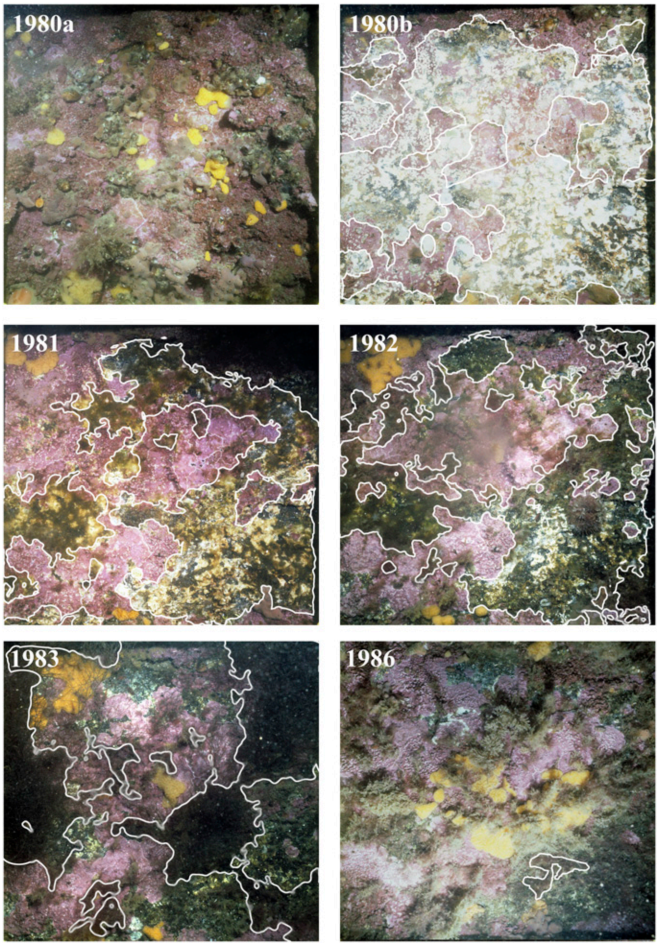

Fig. S1. Photographs of the manipulated transect (all from quadrat 2) in Smeerenburgfjord for the period 1980–1986. (*1980a*) Photograph of the quadrat 2 before the clearance in 1980. (*1980b*) Photograph of the same quadrat after the removal of organisms in 1980. (*1981* and *1982*) The dominant red calcareous algae have recovered (dark pink areas), but note the colonization of brown algae on the white spots where calcareous algae did not recover. (*1983*) Filamentous brown algae have established in the areas where calcareous algae did not recover, indicating competition for space between the taxa. (*1986*) Brown algae have retreated and do not expand again until the macroalgal regime shift in 2000. Cleared areas without calcareous algae and areas with macroalgal growth are encircled with a white line.

Table S1. Taxa identified (presence/absence) in the two fjords, Kongsfjord and Smeerenburgfjord

		Fjord	
	Taxonomic groups	Kongsfjord	Smeerenburgfjord
Macroalgae			
Rhodophyta			
	Red calcareous algae (*Lithothamnion* sp.)	+	+
Class	Rhodophyta indet.		+
Species	*Phycodrys rubens*		+
Phaeophyta			
Class	Phaeophyta indet.	+	+
Species	*Sacchoriza dermatodea*		+
Porifera			
	Porifera indet.	+	+
Genus	*Haliclona* spp.		+
Genus	*Grantia* sp.		+
Cnidiaria			
Class	Hydrozoa	+	+
Order	*Urticina eques/Hormathia nodosa*	+	
Annelida			
Species	*Spirorbis spirorbis*		+
Class	Polychaete indet.	+	+
	Polynoid polychaete		+
Arthropoda			
Crustacea			
Genus	*Balanus* sp.	+	+
Species	*Lebbeus polaris*		+
Suborder	Natantia indet.	+	
Genus	*Hyas* sp.	+	+
Genus	*Pagurus* sp.	+	+
Cheliceriformes			
Genus	*Nymphon* sp.		+
Mollusca			
Species	*Hiatella arctica*	+	+
Genus	*Tonicella* spp.	+	+
Class	Gastropoda indet.	+	+
Genus	*Margarites* spp.	+	+
Species	*Chlamys islandica*	+	
	Bivalvia indet.	+	
Bryozoa			+
Echinodermata			
Genus	*Henricia* sp.	+	+
Species	*Ophiopholis aculeata*	+	+
Species	*Strongylocentrotus droebachiensis*	+	+
Genus	*Ophiura* spp.		+
Genus	*Pteraster* spp.		+
Species	*Crossaster papposus*	+	
Chordata			
Ascidiacea			
Species	*Dendrodoa aggregata*	+	+
Species	*Styela rustica*	+	+
Species	*Halocynthia pyriformis*	+	+
Genus	*Botryllus* spp.		+
Species	*Boltenia echinata*		+
Species	*Didemnum albidum*		+
Algal aggregation			
Algae/Hydrozoa			+
Algae/Bryozoa			+
Algae/Hyd/Bry			+

Taxa were identified to the highest reliable taxonomic resolution.