Summary

The Arctic is among the regions where climate change is expected to be most pronounced and rapid. The arctic climate is characterized by significant spatial and temporal variability. Clear separation between natural climate fluctuations and anthropogenic-induced change is hampered by low spatial and temporal availability of instrumental climate data. To enhance understanding of the drivers of ongoing climate change and increase the reliability of climate projections, observational gaps need to be filled with proxy-based data. Tree-ring records have proven to be a valuable source for such palaeoclimatic information. However, trees are absent in such cold environments as the Arctic. Here, annually resolved (growth) parameters of Cassiope tetragona (white arctic bell heather) are considered as a tree-ring like climate proxy. The evergreen dwarf shrub C. tetragona is long-lived (> 100 years) and has a circumarctic distribution. The species’ leaves grow in pairs which alternate in angles of ninety degrees, thereby forming four rows of leaves (hence the name tetragona). Annual growth parameters can be measured on this species as leaves formed at the start and end of the growing season are smaller than those formed in between, which results in wave-like patterns of leaf lengths visible along its stems. Each wave represents one year of growth. Annual stem length growth can consequently be measured by summing leaf scar distances between two ‘lows’ in leaf scar distances. Leaf scars become, however, more difficult and finally impossible to distinguish with increasing age of the stems, as the outer bark layer loosens and drops off. Recently an alternative method to measure annual stem length growth based on the presence of wintermarksepta (WMS) in C. tetragona stems has been reported by which this problem is overcome. WMS consist of dark bands visible in lateral cross-sections of C. tetragona stems, which coincide with lows in leaf lengths and leaf scar distances thereby delimiting annual stem length growth. As temperature limits growth in the Arctic, growth chronologies developed for this species can likely serve as a temperature proxy, provided they precede local instrumental measurements. As carbon isotope discrimination in C3-plants is indirectly driven by soil water availability, carbon isotope ratios in annual growth fragments of Cassiope might contain additional information on past precipitation.

In this thesis the relationships between climate on the one hand and annual growth parameters of and carbon isotope discrimination in C. tetragona on the other are tested with the goal to use these relationships for the reconstruction of past arctic climate. To provide the required scientific framework for the use of C. tetragona as a climate proxy several field experiments were carried out in the high arctic archipelago of Svalbard in which three climate parameters were manipulated. In a long-term (seven years) experiment daily mean summer temperatures over the tundra vegetation were enhanced with 1.23 °C on average through placement of Open Top Chambers (OTCs). In a four-year experiment ambient summer precipitation was doubled by the manual addition of water and in a two-year experiment increased cloudiness was simulated by decreasing the amount of Photosynthetically Active Radiation (PAR) reaching the surface with 43%, through the placement of cubic tents constructed of gauze over the vegetation. The growth response of C. tetragona to these
manipulations was determined through measurement of annual growth as the number of leaves, total leaf length, average leaf length and stem length in both control and manipulated plots. The response of carbon isotope discrimination (Δ) to summer precipitation was assessed by measuring carbon isotope ratios in annual stem fragments and leaf cohorts in plants from control and extra watered plots.

Climate-growth relationships were furthermore validated through the construction of growth chronologies for three populations along a biogeographical gradient: near *C. tetragona*’s cold tolerance limit (Ny-Ålesund, Svalbard), at its assumed climatic optimum (Endalen, Svalbard), and near its European southern limit (Abisko, Sweden), which together represent the entire temperature gradient of this species. The stem length chronologies for Ny-Ålesund and Endalen of 154 and 169 years, respectively, are the longest developed for this species so far. Monthly mean climate data are predominantly used for climate-growth analyses. Monthly means are, however, rather coarse units in marginal regions with only a short growing season such as the Arctic. Therefore, the use of a measure for growing season intensity known as Growing Degree-Days (GDD) is tested here, besides monthly means, as predictor of growth. GDD is defined as the temperature sum above a given threshold, which is commonly set at 5 °C at higher latitudes (GDD5).

*C. tetragona* responded with increased growth to artificial warming with OTCs. In contrast, there was no growth response to the doubling of summer precipitation and only a very limited response to the severe reduction of PAR. Carbon isotope ratios did change, as had been expected, to an increase in precipitation with increased discrimination against the heavier C-13 isotope in shrubs from double precipitation plots.

Of the mean monthly climate parameters mean July temperature turned out to be the best predictor of annual growth measured over a biogeographical gradient. All growth parameters, with the exception of average leaf length, showed a strong, continuous, linear response to mean July temperature. Based on this relationship, Svalbard Airport mean July temperature was successfully reconstructed back to 1876, using the Endalen stem length chronology. Reconstructed mean July temperatures share 43% of the variance present in the instrumental record over the period 1912-2008.

The relationship between stem length growth and GDD5 was stronger than that between stem length growth and any monthly climate parameter at all research sites. This GDD5-growth association is linear in Svalbard, but not over the full assessed gradient, including Abisko. Still Svalbard Airport GDD5 could be reconstructed back to 1885, based on standardized growth at Ny-Ålesund and Endalen. This reconstruction has 61% common variance with the local instrumental record.

The Svalbard Airport GDD5 and mean July temperature reconstructions reveal that growing season intensity and temperatures showed both up- and downward trends up to the early 1960s. From that time onward there has been a consistent positive trend in both: temperatures have increased and growing seasons have become more intense.

Although carbon isotope discrimination (Δ) in annual leaf cohorts and stem fragments responded positively to experimentally enhanced precipitation, no convincing relationships
were found between a Δ-chronology and the instrumental record. The annual climate signal in changes of carbon isotope discrimination in *C. tetragona* stem length fragments is probably obscured through multiannual ring formation (radial growth). New sampling techniques are therefore required for further development of carbon isotope discrimination in this species as climate proxy.

Nonetheless, the strong climate-growth relationships in *C. tetragona*, its circumarctic distribution, its longevity, and the availability of (sub)fossil fragments in tundra soil cores and from beneath (retreating) glaciers, makes this species a very valuable relatively unexplored source for arctic climate reconstructions beyond the instrumental record and in areas lacking any meteorological data.