Chapter 1
The Ecosystem of Kongsfjorden, Svalbard

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Abstract This book summarizes physical and biological aspects from Kongsfjorden (78° 59' N, 11–12° E), Svalbard. The contributions to this volume cover atmospheric conditions above Ny-Ålesund, as well as physical conditions in Kongsfjorden. The chapters about oceanographic dynamics and sea ice conditions are based on time-series observations of interannual variability, whereas the chapter about the underwater light regime focuses on seasonal dynamics. The pelagic system is covered by reviews of pelagic production, phytoplankton and zooplankton communities. Benthic flora studies address microphytobenthos and macroalgal biodiversity, as well as the physiology of kelp related to stress perception and responses. Benthic fauna communities are described with associated environmental drivers of change. An outline of an Arctic fjord ecosystem model for Kongsfjorden-Krossfjorden is presented. Data that go into models come from sampling at different stations in the marine environment, with an important contribution from long-term data series at stations. Some of the long-term data are based on recordings from autonomous underwater observatories. Finally, one summary presents Kongsfjorden as harbinger of the future Arctic.

Keywords Arctic marine ecosystem · Environmental drivers · Biodiversity · Advection · Climate change · Kongsfjorden · Arctic

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1.1 Introduction

Kongsfjorden is a glacial fjord located in the European Arctic on the west Spitsbergen coast in Svalbard at 78° 59′ N, 11–12° E. Scenic mountains and calving glaciers surround the fjord (Figs. 1.1 and 1.2). It is an established reference site for marine ecological studies and monitoring, together with the atmospheric monitoring station at the Zeppelin Mountain. The establishment of the Marine Laboratory in Ny-Ålesund in 2005 allows for combining field research with controlled experiments in the laboratory (Fig. 1.3). Since 2007, the fjord has been protected against commercial trawling (Fig. 1.4), which has facilitated the establishment of automated marine observatories in this fjord (Hop et al., Chap. 13).

As Kongsfjorden is an open fjord, without a sill, it is strongly influenced by the inflow of warm Atlantic water from the West Spitsbergen Current, mixed with Arctic Water on the shelf (Cottier et al. 2005; Hop et al. 2006; Walczowski et al. 2012). The fjord is connected to Fram Strait, a gateway to the Arctic Ocean (Wassmann et al. 2015), through the trough Kongsfjordrenna, which extends from the fjord to the shelf break. Climate-driven physical and biological changes have been recorded in Fram Strait at the deep-sea long-term observatory HAUSGARTEN (Soltwedel et al. 2016). Advection of Transformed Atlantic Water (TAW) into the fjord is important for its seasonal oceanographic dynamics, as well as for its biological communities (Cottier et al. 2005, 2007; Hop et al. 2006; Willis et al. 2006, 2008; Dalpadado et al. 2016). Even though the Atlantic signal extends throughout the fjord, the inner fjord is considered mostly Arctic with regard to physical and biological characteristics (Hop et al. 2002; Lydersen et al. 2014). The inner fjord basin is largely influenced by run-off from tidal glaciers, which create gradients in freshwater influence and sediment load towards the middle of the fjord (Calleja et al. 2017; D'Angelo et al. 2018).

Because of the dual Atlantic and Arctic inputs, the fjord houses pelagic and benthic communities that comprise a mixture of boreal and Arctic flora and fauna (Hop et al. 2002, 2016; Walkusz et al. 2009; Voronkov et al. 2013). The spring bloom during April–May kick-starts the biological production (Hegseth et al., Chap. 6), which is utilized by zooplankton during the summer and autumn to build up lipid stores (Falk-Petersen et al. 2009; Walkusz et al. 2009). The biological communities in the fjord remain active during the dark winter season, although with changed composition and reduced abundance of zooplankton in the water column (Berge et al. 2015a, b; Grenvald et al. 2016; Geoffroy et al. 2018). Warming during wintertime and declining sea ice may influence seasonal ecosystem dynamics (Hop et al., Chap. 13; Pavlova et al., Chap. 4). Benthic fauna are relatively stable throughout the year (Wlodarska-Kowalczuk et al. 2016), with carnivores and opportunistic species increasing in numbers in shallow waters during winter (Kedra et al. 2011).

In the current era of climate change, documented and projected alterations in the physico-chemical environment in the Kongsfjorden system include: atmosphere and ocean warming (Maturilli et al., Chap. 2; Tverberg et al., Chap. 3), decrease of

Fig. 1.1 Kongsfjorden, in the background three prominent mountains (Tre Kroner): Svea (1225 m), Nora (1226 m), Dana (1175 m)

Fig. 1.2 Kronebreen tidal glacier in inner Kongsfjorden

Fig. 1.3 Kings Bay Marine Laboratory, Ny-Ålesund

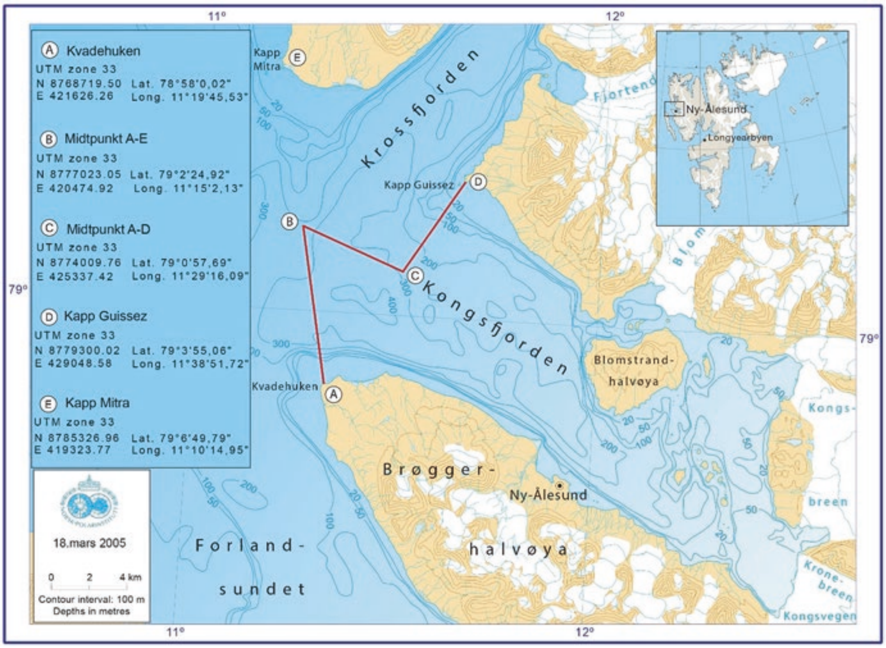

Fig. 1.4 Trawl protection zone in Kongsfjorden, 2005

winter sea-ice cover (Pavlova et al., Chap. 4), ocean acidification (Fransson et al. 2016), glacier retreat (Kohler et al. 2007; Blaszczyk et al. 2009), higher terrestrial run-off resulting in increasing nutrient, sediment and soil-associated contaminant loads (Granberg et al. 2017), and changes in light climate, particularly ultraviolet B exposure (due to stratospheric ozone depletion; Hanelt et al. 2001).

The marine communities in Kongsfjorden respond to the variability and changes in environmental conditions, as documented in seasonal and long-term studies. Long-term changes involve alterations of pelagic primary production and algal community composition (Hegseth and Tverberg 2013; Hegseth et al., Chap. 6), of benthic macroalgal biomass and production (Bartsch et al. 2016), and of community composition and production of benthic fauna (Beuchel et al. 2006; Kedra et al. 2010; Paar et al. 2016). Macro zooplankton is responding quite rapidly to changes in Arctic and Atlantic water masses (Kwasniewski et al. 2003; Willis et al. 2006, 2008; Ormanczyk et al. 2017), for instance in case of krill and amphipods in less than a decade (Buchholz et al. 2010; Dalpadado et al. 2016). Long-term changes in mesozooplankton were more difficult to detect over 20 years of monitoring in Kongsfjorden because of pronounced inter-annual variation and longer-term variability. However, the biomass of the boreal copepod *Calanus finmarchicus* has clearly increased, as well as the total biomass of zooplankton (Hop et al., Chap. 7). Moreover, strong changes in seaweed biomass and depth distribution have been detected over a time span of 20 years (Bartsch et al. 2016). In parallel, a drastic change in depth distribution of macrozoobenthic biomass and secondary production has been reported (Paar et al. 2016). Changes in the lower marine food web in Kongsfjorden have affected the middle and upper trophic levels, represented by fishes, seabirds and seals (Lydersen et al. 2014; Vihtakari et al. 2018). Such changes may involve abrupt regime shifts, rather than linear trends. Species-specific responses may result in new inter-specific interactions, such as competitive or trophic changes, and affect ecosystem functions (e.g. Russell et al. 2012; Pörtner 2014). Alternatively, because compartmentalized food webs tend to be resilient, marine ecosystems can adapt to ongoing climate change (Stouffer and Bascompte 2011).

Comparative studies of Svalbard fjords typically have involved Kongsfjorden, Isfjorden and Hornsund. These are all open fjords on the western coast of Spitsbergen that are influenced by Arctic and Atlantic water masses and tidal glaciers. They have their specific characteristics, however, since Isfjorden is much larger than Kongsfjorden, while Hornsund is shorter. Interestingly, Hornsund is colder than Kongsfjorden because of the inflow of Arctic Water of the South Cape Current, and future warming may result in Hornsund becoming more similar to Kongsfjorden with regard to hydrography and primary production (Piwosz et al. 2009). Comparative studies of Kongsfjorden and Hornsund have involved mostly physical and ecological aspects, which were published in a dedicated volume of *Oceanologia* (Weslawski 2017), adding further evidence to previously published comparative studies (e.g. Wlodarska-Kowalczuk et al. 1998; Gluchowska et al. 2016). Rijpfjorden on Nordaustlandet has become an Arctic comparison to Atlantic-influenced Kongsfjorden, particularly with regard to studies during the polar night on diurnal vertical migration (Berge et al. 2009, 2014, 2015a, b). According to modelling studies, the largest increase in temperature and primary production will occur on the north coast of Svalbard (Slagstad et al. 2011, 2015), which may cause Rijpfjorden to become more influenced by Atlantic Water and the ecosystem changes may project those that have already occurred in Kongsfjorden. Comparisons that are more distant can be done with glacial fjords in Greenland, such as Young Sound, although these fjords are much larger systems and influenced by cold water in the East Greenland Current (Rysgaard and Nielsen 2006).

The Kongsfjorden area has a rich history of research and monitoring activities, much of which are associated with the currently 11 research stations from 10 countries at Ny-Ålesund. Physical and ecological aspects of Kongsfjorden have been summarized in review papers (Hop et al. 2002, 2006; Svendsen et al. 2002), and research from the Kongsfjorden area have been collated in several special journal issues (Wiencke 2004; Weslawski 2017; Cappelletti et al. 2016). The 13 review chapters published in this volume of *Advances in Polar Ecology* complement the 34 research papers that were published in two issues of *Polar Biology* (Wiencke and Hop 2016). Both the book and the special issue were initiated during the Second Kongsfjorden Ecosystem Workshop held on 10–17 March 2014 at the conference facility *Hamn i Senja*, Skaland, Norway (Figs. 1.4, 1.5, 1.6, 1.7 and 1.8). The workshop involved 60 researchers from nine countries (Austria, France, Germany, Netherlands, Norway, Poland, Russia, Spain, and Sweden) (Fig. 1.9).

1.1.1 Reviews in this Volume

The contributions to this volume cover atmospheric conditions above Ny-Ålesund (Maturilli et al., Chap. 2), as well as physical conditions in Kongsfjorden. The chapters about oceanographic dynamics (Tverberg et al., Chap. 3) and sea ice conditions (Pavlova et al., Chap. 4) are based on time-series observations of interannual variability, whereas the chapter about the underwater light regime focuses on seasonal dynamics (Pavlov et al., Chap. 5). The pelagic system is covered by reviews of pelagic production, phytoplankton and zooplankton communities (Hegseth et al., Chap. 6; Hop et al., Chap. 7). Benthic flora studies address microphytobenthos (Karsten et al., Chap. 8) and macroalgal biodiversity (Fredriksen et al., Chap. 9), as well as the physiology of kelp related to stress perception and responses (Bischof et al., Chap. 10). Benthic fauna communities are described with associated environmental drivers of change (Molis et al., Chap. 11). Duarte et al. (Chap. 12) present an outline of an Arctic fjord ecosystem model for Kongsfjorden-Krossfjorden. Data that go into models come from sampling at different stations in the marine environment, with an important contribution from long-term data series at stations. Some of the long-term data are based on recordings from autonomous underwater observatories (Hop et al., Chap. 13). Finally, one summary presents Kongsfjorden as harbinger of the future Arctic (Bischof et al., Chap. 14). The main content and conclusions from these reviews and with novel presentations of long-term data are detailed below.

Fig. 1.5 Hamn i Senja hosted the Second Kongsfjorden Ecosystem Workshop, March 2014

Fig. 1.6 The Second Kongsfjorden Ecosystem Workshop in progress

Fig. 1.7 Michael Greenacre always ready to entertain with music or statistics

Fig. 1.8 Kongsfjord workshop organizers and Guest Editors: Christian Wiencke and Haakon Hop

1.1.1.1 Atmosphere

The Arctic region is considered as most sensitive to climate change, with warming occurring considerably faster than the global average due to several positive feedback mechanisms contributing to the "Arctic amplification" (Pithan and Mauritsen 2014). The study by Maturilli et al. (Chap. 2) focuses on the changes in atmospheric boundary conditions in the Kongsfjorden area and relates the long-term climate observations (1993–2017) from this area to a larger regional and hemispheric context. Temperatures have increased during the last century, primarily during winter (3.1 ± 2.2 K per decade). This winter warming is related to changes in the net longwave radiation, whereas changes in the net shortwave radiation during the summer period are attributed to the decrease in reflected radiation caused by less snow cover. Variability in synoptic cloud cover is the cause of the inter-annual variability in incoming solar radiation in summer, observed in the monthly mean global shortwave radiation, as well as in photosynthetically active radiation (PAR) and UV radiation. The marine system in Kongsfjorden is influenced by air temperature and atmospheric humidity. The hydrological cycle with seasonal run-off to Kongsfjorden is affected by atmospheric variability, and cloud formation determines incoming radiation at the surface.

1.1.1.2 Ocean Dynamics

Ocean dynamics have been monitored each year in Kongsfjorden since 1994. The transect covers the full length of the fjord, as well as the adjacent shelf and upper continental slope outside Kongsfjorden. Oceanographic data are also supplied from moorings in Kongsfjorden (Hop et al., Chap. 7). Tverberg et al. (Chap. 3) have shown that Atlantic Water (AW) from the West Spitsbergen Current enters Kongsfjorden every summer, although to a varying extent. The focus of their paper is on this variable content of AW in Kongsfjorden, the forcing mechanisms that may govern the inflow of this water mass, and its distribution in the fjord. In earlier years, the winter convection inside the fjord, combined with sea-ice formation, produced dense water that prevented AW from entering Kongsfjorden until the summer. However, since 2006, advection of AW occurred also during winter, either as water flowing along the bottom of Kongsfjordrenna or via advection near the surface. Some of the variation in advection is caused by the natural variability of wind and currents. However, the advection at the surface, which happens when open-water convection produces very dense shelf water, seems to be a consequence of the general trend of atmospheric and oceanic warming, and the decreasing sea-ice cover in the Arctic.

1.1.1.3 Sea Ice

Seasonal sea ice is an important feature of Svalbard fjords, with pronounced impact on both the physical environment and the ecosystem. Pavlova et al. (Chap. 4) present the results of systematic sea-ice monitoring in Kongsfjorden from 2003 to 2016.

Fig. 1.9 Group photo of the participants of the Second Kongsfjorden Ecosystem Workshop in March 2014. Registered participants were (in alphabetical order): Ragnhild Asmus, Philipp Assmy, Agnès Baltzer, Sebastien Barrault, Inka Bartsch, Jørgen Berge, Frank Beuchel, Kai Bischof, Markus Brand, Cornelia Buchholz, Friedrich Buchholz, Christian Buschbaum, Malin Daase, Sebastien Descamps, Pedro Duarte, Stig Falk-Petersen, Philipp Fischer, Stein Fredriksen, Geir Wing Gabrielsen, Marta Gluchowska, Francisco Gordillo, Martin Graeve, Michael John Greenacre, Svein Are Hanssen, Else Nøst Hegseth, Haakon Hop, Kim Huenerlage, Carlos Jiménez, Marianne Johansen, Ulf Karsten, Jack Kohler, Kit M. Kovacs, Svein Kristiansen, Slawek Kwasniewski, Jürgen Laudien, Benoit Lebreton, Eva Leu, Silke Lischka, Maarten J.J. Loonen, Cornelius Lütz, Christian Lydersen, Børge Moe, Markus Molis, Roland Neuber, Martin Paar, Alexey Pavlov, Vladimir Pavlov, Olga Pavlova, Paul E. Renaud, Marcus Rex, Joëlle Richard, Michael Y. Roleda, Vigidis Tverberg, Martine van den Heuvel-Greve, Jan Marcin Weslawski, Christian Wiencke, Józef M. Wiktor, Maria Wlodarska-Kowalczuk, Anette Wold and Angela Wulff

The inner Kongsfjorden is usually covered by seasonal fast ice, initially forming between December and March and persisting until April–June. Before 2006, sea ice typically extended into the central part of the fjord, but during the last decade, it has often been confined to the northern inner fjord, with a minimum extent in 2012. Only in 2009 and 2011, sea-ice extent was similar to earlier years. Maximum seasonal thickness of fast ice was around 0.6 m or more until 2006, since when it declined to about 0.2 m in recent years. The snow thickness on fjord fast ice declined from around 0.2 m in spring prior to 2006 to <0.05 m in recent years, which reflected the shorter duration of ice cover. Advection of warm Atlantic Water into Kongsfjorden, particularly during the winters of 2006 and 2007, contributed to reduced fast-ice formation. This inflow, in combination with relatively mild winters, can be regarded as the main factors for changing fast-ice conditions in Kongsfjorden during the last 10 years. The changes of the seasonal dynamics of sea-ice extent have important implications for the marine ecosystem in Kongsfjorden with regard to pelagic and benthic production, as well as for seabirds and marine mammals.

1.1.1.4 Underwater Light-Regime

Kongsfjorden at the high latitude of 79°N experiences a strong seasonality in light climate, changing from polar night in winter to midnight sun in summer. Sea ice conditions and the optical properties of seawater further modify the amount and the spectral composition of solar radiation penetrating into the water column, thus defining the underwater light climate in Kongsfjorden. Light represents one of the major drivers of the entire marine ecosystem. Pavlov et al. (Chap. 5) synthesize the fragmentary information available from the literature, as well as presenting some unpublished data, and discuss the underwater light regime and its main controlling factors in Kongsfjorden. They also provide a short synopsis about the relevance of light for different components of an Arctic marine ecosystem with regard to primary production, behavioural aspects and synchronization of growth and reproduction.

1.1.1.5 Phytoplankton

Phytoplankton phenology is a key driver of chemical and biological processes in marine ecosystems because it directly affects the cycling of nutrients, strength of the biological carbon pump, and energy transfer to higher trophic levels. However, phytoplankton time-series from the European Arctic are scant, thus limiting our ability to link phytoplankton phenology to environmental variability. Hegseth et al. (Chap. 6) compile previously published phytoplankton investigations, chlorophyll fluorescence time-series data and unpublished phytoplankton data covering the years 2002–2014 from Kongsfjorden and the shelf outside the fjord, to elaborate the most pertinent environmental factors responsible for the seasonal and inter-annual variability in phytoplankton bloom dynamics, biomass and species composition.

Phytoplankton dynamics in Kongsfjorden generally follow the classic spring-bloom paradigm, with the main biomass peak in April–May dominated by spore-forming diatom species and the colony-forming haptophyte *Phaeocystis pouchetii*, followed by a diverse but low-biomass community characterised by dinoflagellates, small flagellates and their protozoan grazers during summer. The long-term trend in phytoplankton phenology is not clear, as it is generally characterised by large inter-annual variability, which can be mainly attributed to variability in the magnitude of Atlantic Water inflow, sea-ice cover and glacier melt-water discharge.

1.1.1.6 Zooplankton

The zooplankton in Kongsfjorden is shaped by the irregular advection of water from the West Spitsbergen Current, as well as the input of freshwater of glacial and riverine origin. The zooplankton community reflects the varying contributions of Arctic and Atlantic water masses in the fjord, and changes with increasing temperature and declining sea ice. Hop et al. (Chap. 7) review zooplankton studies from Kongsfjorden and present new data from a 20-year time series (1996–2016) of zooplankton abundance/biomass in the fjord based on annual surveys during summer. During the last decade, the marine environment of the West Spitsbergen Shelf and adjacent fjords, including Kongsfjorden, has undergone changes in response to increasing temperatures and volumes of inflowing Atlantic Water, as well as to declining sea ice. Annual monitoring of mesozooplankton in the fjord since 1996 has shown high seasonal, spatial, and inter-annual variation in species abundance and biomass, as well as in the proportion of Atlantic and Arctic species. Inter-annual variations in species composition and abundance demonstrate fluctuating patterns related to changes in ocean dynamics. Long-term zooplankton data demonstrate that some Atlantic species have become more abundant in Kongsfjorden, suggesting that they may actually benefit from increasing temperatures. Moreover, the total biomass of zooplankton has increased in the fjord, implying potentially higher secondary production. There was no clear impact of changes in environmental factors on the abundance or biomass of the Arctic species *Calanus glacialis*, however, suggesting that these changes have not reached critical levels for this species.

1.1.1.7 Microphytobenthos

The seafloor of shallow waters is typically inhabited by microphytobenthic (MPB) communities, composed mainly of diatoms. Only sparse information is available on the MPB ecophysiology and acclimation processes from Arctic regions. Karsten et al. (Chap. 8) review the knowledge about the physico-chemical environment, ecology and ecophysiology of MPB diatoms in Kongsfjorden. They have high rates of primary production, stabilise sediment surfaces against erosion under hydrodynamic forces, and affect the exchange of oxygen and nutrients across the sediment-water interface. Additionally, this phototrophic community represents a key component in the functioning of the Kongsfjorden food web, particularly as a major food source for benthic suspension- or deposit-feeders. Microphytobenthos in Kongsfjorden is well adapted to pronounced seasonal variations in solar radiation, low temperatures, and hyposaline (meltwater) conditions in summer, as well as to long periods of ice and snow cover in winter. Enhanced knowledge of the molecular mechanisms involved in bioenergetics, resource allocation, metabolic fluxes and community composition are expected to improve our ability to understand the influence of polar benthic diatoms on biogeochemical processes and the responses to global-change scenarios.

1.1.1.8 Benthic Macro- and Microalgae

Several floristic studies on macroalgae of Svalbard have been published. Kongsfjorden, Isfjorden and Hornsund are the three best investigated Spitsbergen fjords, and most of the species information comes from these three fjords. However, quantitative sublittoral sampling along depth transects and along the fjord axis has been undertaken only in Kongsfjorden. Clear differences were found from the outer to the inner parts of the fjord. Fredriksen et al. (Chap. 9) present macroalgal biodiversity data from Kongsfjorden compared to data for the whole Svalbard archipelago. In total, 197 species of macroalgae have been recorded for Svalbard, and 84 of these occur in Kongsfjorden. The taxonomic status of some species is discussed. Changes in the macroalgal flora during the last decades in Svalbard in general and in Kongsfjorden in particular are related to increased temperature in combination with reduction in sea ice. Simultaneous changes in the sublittoral are due to an altered underwater light regime with both positive and negative consequences for the vertical species' distribution and productivity. Introductions of new species to Svalbard are expected from more temperate regions, especially from the North Atlantic. Although biodiversity of microbenthic diatoms is quite low, they colonise large parts of Kongsfjorden in high abundances and, in addition to macroalgae, are important as primary producers and therefore also for trophic relationships in the harsh Arctic environment.

1.1.1.9 Kelp and Environmental Changes

On rocky substrata along shallow-water cold-temperate and Arctic coastlines, large brown seaweeds ("kelps") form physically heterogeneous and biologically diverse habitats of high ecological significance. The distribution of these ecosystem engineers is largely controlled by the prevailing temperature, light regime (including UVB radiation) and substrate availability, but can also be influenced by biotic interactions within the kelp communities. Additional environmental factors in Kongsfjorden are alterations of current and wind patterns, resulting in the increased inflow of Atlantic Water into the fjord ('Atlantification'). Moreover, increased precipitation and higher terrestrial and glacial runoff have led to altered salinity regime and increased sediment discharge into the fjord, with the potential impact of reducing light availability to marine plants. Bischof et al. (Chap. 10) provide an overview on ecologically relevant abiotic and biotic factors influencing kelp distribution, and their potential to act as environmental stressors. They assess responses on different organisational levels of kelp by following the effects cascading from the initial sensing of the environment, signal transduction to gene expression, physiological reactions, to changes in cellular ultrastructure, and their consequences for growth, reproduction and population biology for the different kelp species in Kongsfjorden. Results synthesized from more than 20 years of seaweed research in Kongsfjorden suggest a generally high adaptability of most kelp species. An important exception is the Arctic-endemic species *Laminaria solidungula*, which will largely suffer from changing environmental conditions, primarily increase in temperature. Thus, changes in kelp community composition, but also overall system productivity, are to be expected.

1.1.1.10 Benthic Communities

Knowledge on the causes and consequences of benthic community change is essential to understand and conserve Arctic marine ecosystems. Molis et al. (Chap. 11) summarize the current knowledge about the effects of abiotic and biotic factors on benthic species interactions and community traits (diversity, structure, and functioning of Arctic coastal hard- and soft-bottom habitats), with emphasis on Kongsfjorden. Arctic hard- and soft-bottom communities show some fundamental differences in their ecology. For instance, the recovery in hard-bottom communities after disturbances takes exceptionally long (decades) due to slow growth and/or sporadic recruitment, while it is considerably shorter in soft-bottom communities. Arctic hard-bottom communities display strong competitive hierarchies that appear negligible in sediment communities. The authors suggest shifting the focus in Arctic benthos research from pattern to processes in future studies.

1.1.1.11 Arctic Fjord Ecosystem Model

Duarte et al. (Chap. 12) present a detailed outline of an Arctic fjord ecosystem model using Kongsfjorden-Krossfjorden as a case study. Marine ecosystem models are compared, with emphasis on fjord models, towards defining best available modelling technologies, based on an analysis of the differences in the variables and processes simulated by different models. The authors argue about the importance of (i) coupling Arctic fjord models with land and glacier drainage models, (ii) including thermodynamic, hydrodynamic and ice dynamic sub-models, and (iii) simulating biogeochemical processes in the water, ice and benthic environments for, at least, the macro-elements carbon, nitrogen and phosphorus. With regard to higher trophic levels, their energetic importance, predation and migration need to be considered in fjord ecosystem models, when developing these in direction of end-to-end models.

1.1.1.12 Autonomous Marine Observatories

Several moored autonomous marine observatories, with a variety of sensors and scientific instruments, have been installed in Kongsfjorden since 2002. They provide seasonal and inter-annual data on a number of physical, chemical and biological variables, which serve as important baselines for the gauging of seasonal variability vs. climate-induced changes in this fjord system. Environmental and ecological changes observed in Kongsfjorden are, to some extent, related to larger-scale changes in Fram Strait because of the advection of Atlantic Water into the open fjord. Hop et al. (Chap. 13) provide an account of the location of moored observatories in Kongsfjorden, with a list of parameters measured at the different moorings, and review the scientific advances that have been made through data collection from these marine observatories.

1.1.1.13 Kongsfjorden as Harbinger of the Future Arctic

Due to its year-round accessibility and excellent on-site infrastructure, Kongsfjorden and the Ny-Ålesund Research and Monitoring Facility have become a primary location to study the impact of environmental change on Arctic coastal ecosystems. As a result, Kongsfjorden is one of the best-studied Arctic fjord systems. Located at the interface of Arctic and Atlantic oceanic regimes, it is already experiencing large amplitudes of variability in physical and chemical conditions. Thus, Kongsfjorden may be considered as an early warning indicator of future changes, which can then be extrapolated to a pan-Arctic scale. Bischof et al. (Chap. 14) identify current knowledge gaps and research priorities, with respect to ecological and adaptive responses to Arctic ecosystem changes, and provide a stimulus for developing new international and interdisciplinary research initiatives.

1.1.1.14 Review Gaps

To further extend our understanding of the Kongsfjorden ecosystem, more physical and biological compartments need to be considered. Several of these were covered in presentations at the Second Kongsfjorden Ecosystem Workshop in 2014, but reviews are currently lacking on marine geology and palaeoceanography, hydrology and sedimentation processes, tidal glaciers, bacteria and the microbial loop, shrimps, fishes, seabirds, marine mammals, food-web aspects and pelagic-benthic coupling, environmental contaminants as well as other human impacts. Many of these topics have been dealt with in scientific publications of research conducted in the Kongsfjorden region. Since this extensive knowledge should also be summarized in reviews, there is certainly scope for a second Kongsfjord book, if somebody wishes to kick-start it.

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