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Natural variability or anthropogenically-induced variation? Insights from 15 years of multidisciplinary observations at the arctic marine LTER site HAUSGARTEN

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A B S T R A C T

Time-series studies of arctic marine ecosystems are rare. This is not surprising since polar regions are largely only accessible by means of expensive modern infrastructure and instrumentation. In 1999, the Alfred Wegener Institute, Helmholtz-Centre for Polar and Marine Research (AWI) established the LTER (Long-Term Ecological Research) observatory HAUSGARTEN crossing the Fram Strait at about 79° N. Multidisciplinary investigations covering all parts of the open-ocean ecosystem are carried out at a total of 21 permanent sampling sites in water depths ranging between 250 and 5500 m. From the outset, repeated sampling in the water column and at the deep seafloor during regular expeditions in summer months was complemented by continuous year-round sampling and sensing using autonomous instruments in anchored devices (i.e., moorings and free-falling systems). The central HAUSGARTEN station at 2500 m water depth in the eastern Fram Strait serves as an experimental area for unique biological in situ experiments at the seafloor, simulating various scenarios in changing environmental settings. Long-term ecological research at the HAUSGARTEN observatory revealed a number of interesting temporal trends in numerous biological variables from the pelagic system to the deep seafloor. Contrary to common intuition, the entire ecosystem responded exceptionally fast to environmental changes in the upper water column. Major variations were associated with a Warm-Water-Anomaly evident in surface waters in eastern parts of the Fram Strait between 2005 and 2008. However, even after 15 years of intense time-series work at HAUSGARTEN, we cannot yet predict with complete certainty whether these trends indicate lasting alterations due to anthropologically-induced global environmental changes of the system, or whether they reflect natural variability on multiyear time-scales, for example, in relation to decadal oscillatory atmospheric processes.

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1. Introduction

While always fluctuating, the global climate is presently experiencing a period of constantly increasing temperatures, with a warming trend amplified in the Arctic (Hassol, 2004). Results of large-scale simulations of the Earth's future climate by several global climate models predict a continuous increase in air and water temperatures, also leading to further reduction in ice-cover (IPCC, 2013). Since the 1950s, sea-ice retreat in the Arctic Ocean has been relatively modest at rates of 3–4% per decade (Parkinson et al., 1999). However, since the late 1990s, annual-averaged shrinking rates accelerated to 10.7% per decade (Comiso et al., 2008), whilst the summer sea-ice extent has shrunk even more rapidly. According to the US National Snow and Ice Data Center (NSIDC), arctic sea-ice during the 2012 melt season has reached its lowest extent since satellites began measuring sea-ice in 1979, with 44% ice coverage below the 1981–2010 average, and 16% ice coverage below the previous minimum extent in 2007.

Moreover, according to the results from large-scale surveys carried out by US submarines equipped with upward looking sonar and ICESat satellite observations, there has been a significant thinning of the sea-ice by approximately 50% since the late 1950s (Kwok and Rothrock, 2009). Laxon et al. (2013) compared satellite and model-derived sea-ice volume data between the years 2003–2008 and 2010–2012, and found that sea-ice volume declined by 36.2% at the end of summer, and by 9.1% at the end of winter. In its recent report, the Intergovernmental Panel on Climate Change (IPCC) prophesied that the Arctic could become ice-free in the second half of this century, while Wang and Overland (2012) argued that this scenario might even take place much earlier, with predictions as early as the end of the arctic summer 2040. Greenhouse gases emitted through human activities and the resulting increase in global mean temperatures are most likely the underlying causes of the sea-ice decline, although it is recognized that the current sea-ice decline most likely resulted from a complex interaction between natural and anthropogenic causes and variations in climate change, acting on different time scales (Drinkwater et al., 2014).

The shift from an ice-covered and cold ocean to an ice-free and warmer ocean will have severe impacts on the polar marine ecosystem and its functioning (e.g., Wassmann et al., 2011). Thinner ice may permit better growth of ice algae, but earlier and faster spring melting may reduce their growing season (Arrigo, 2013). Locally, thinner ice floes with a multitude of melt ponds allow enhanced light transmission and may increase phytoplankton growth beneath the ice (Arrigo et al., 2012; Nicolaus et al., 2012). The timing and location of pelagic primary production will generally be altered (Kahru et al., 2010). Ice-edge phytoplankton blooms will be displaced progressively northwards (Engelsen et al., 2002). Whether sea-ice retreat generally leads to an increase in primary productivity is under debate (Arrigo et al., 2008; Tremblay and Gagnon, 2009; Wassmann et al., 2010). In fact, biogeochemical models predict no or even negative changes in productivity and export flux in the Barents Sea and the Fram Strait (Forest et al., 2010; Slagstad et al., 2011).

Altered algal abundance and composition will affect zooplankton community structure (Caron and Hutchins, 2013) and subsequently the flux of particulate organic matter to the seafloor (Wohlers et al., 2009), where the changing quantity and quality of this matter will impact benthic communities (Kortsch et al., 2012; Jones et al., 2013). Changes in the predominance of certain trophic pathways will have cascading effects propagating through the entire marine community.

Generally, arctic marine organisms will be compromised by temperature regimes approaching the limits of their thermal capacity (Burrows et al., 2011, 2014). As a consequence, warmer waters in the Arctic will allow a northward expansion of sub-arctic and boreal species (Hirche and Kosobokova, 2007; Poloczanska et al., 2013). Besides water temperature increase, expanding ocean acidification will pose another threat to pelagic and benthic life in the Arctic Ocean (e.g., Bates et al., 2009; Lischka and Riebesell, 2012; AMAP, 2013).

To detect and track the impact of large-scale environmental changes on the marine ecosystem in the transition zone between the northern North Atlantic and the central Arctic Ocean, the Alfred Wegener Institute, Helmholtz-Centre for Polar and Marine Research (AWI) established the LTER (Long-Term Ecological Research) observatory HAUSGARTEN in the Fram Strait between NE Greenland and the Svalbard archipelago (Soltwedel et al., 2005). Since 1999, repeated sampling in the water column and at the seafloor during yearly expeditions in summer months was complemented by continuous year-round sampling and sensing using autonomous instruments on anchored devices. The central HAUSGARTEN station at about 79° N, 04° E in the eastern Fram Strait (~2500 m water depth) serves as an experimental area for unique biological experiments at the deep seafloor, simulating various scenarios in changing environmental settings (Premke et al., 2006; Gallucci et al., 2008; Kanzog et al., 2009; Guilini et al., 2011; Soltwedel et al., 2013).

Time-series studies at the HAUSGARTEN observatory provide insights into processes and dynamics within an arctic marine ecosystem and act as a baseline for further investigations of ongoing changes in the Fram Strait. Long-term observations at HAUSGARTEN significantly contribute to the global community's efforts to understand variations in ecosystem structure and functioning on seasonal to decadal time-scales in an overall warming Arctic and will allow for improved future predictions under different climate scenarios.

2. Site description

The LTER observatory HAUSGARTEN is located in a region which is influenced by the highly productive Marginal Ice Zone (MIZ) in the Fram Strait. Currently, HAUSGARTEN constitutes a network of 21 permanent sampling sites, the majority of which are located along a bathymetric transect between ~250 m and ~5500 m water depth at about 79° N from the Kongsfjorden (Svalbard) in the east, along the Vestnesa Ridge toward the Molloy Hole (i.e., the deepest known depression in the Arctic Ocean) and across the Greenland continental margin (stations in the western Fram Strait were newly established in 2014). Three sampling sites close to the ice edge between 79°30′ N and 80°00′ N in the north-eastern Fram Strait and a supplementary site in a permanently ice-free area at 78°30′ N in the eastern part of the strait complete the network (Fig. 1).

The Fram Strait is the only deep water connection between the Nordic Seas and the central Arctic Ocean with a sill depth of ca. 2600 m. The hydrography in the eastern part of the strait is characterized by the inflow of relatively warm and nutrient-rich Atlantic Water (AW) into the central Arctic Ocean (Beszczynska-Möller et al., 2012). Cooler and less-saline Polar Water exits the central Arctic Ocean as the Eastern Greenland Current (EGC) in the western part of the Fram Strait (de Steur et al., 2009), separated by a frontal system (East Greenland Polar Front) from the water masses in the eastern part of the Fram Strait (Paquette et al., 2012). Hydrographic patterns in the strait result in a variable sea-ice cover, with predominantly ice-covered areas in the west, permanently ice-free areas in the south-east, and seasonally-varying ice conditions in the central and north-eastern parts. Anomalies in summer sea-ice coverage from a 30-year reference period (1981–2000) in the greater Fram Strait since the establishment of HAUSGARTEN observatory in 1999 are shown in Fig. 2. Strong positive values (more sea-ice compared to the long-term mean) were found in 2003, 2008, and 2009,