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Hanna Shoal: An integrative study of a High Arctic marine ecosystem in the Chukchi Sea

This second special issue on the ecosystem under the COMIDA (Chukchi Sea Offshore Monitoring in the Drilling Area) Project focuses on the productive region around Hanna Shoal, the northernmost shoal on the Chukchi shelf. Our first issue (Dunton et al., 2014) emphasized the chemical and biological characteristics of the northeastern Chukchi Sea benthos. This effort expands our studies on the unique physical oceanography of Hanna Shoal, which lies at the interface between northward flowing Pacific Water and the Arctic Ocean, to include its influence on zooplankton dynamics and higher trophic level biota. Between both studies, conducted over a 5-year period (2009-2013) and four summer cruises, COMIDA scientists from seven institutions occupied some 85 stations (Fig. 1).

Hanna Shoal is a distinct feature of the northern Chukchi Sea, with water depths shoaling to just 20 m, compared with 55 to 60 m on the surrounding seabed. The shallow areas of Hanna Shoal are heavily ice-gouged and scoured, resulting in a seabed that is generally characterized by unsorted course materials, including sand, gravel, and small pebbles. As a result, the fauna on the top of the Shoal is relatively depauperate compared to its protected deeper flanks, especially on the eastern and southern sides (Ravelo et al, 2014; Schonberg et al., 2014). Despite the heavy scouring by ice that effectively removes most long-lived biota, the grounded ice provides a platform for high concentrations of walruses in summer that actively forage on the abundance of molluscs, polychaete worms, and other benthic fauna on the deeper flanks (Schonberg et al., 2014). But even following final ice retreat by late-summer, walruses are known to make the 500-km round-trip from haul-outs on the northwestern Arctic coast to feed around Hanna Shoal (Jay et al., 2012).

The high biomass and diversity of the Chukchi Sea has attracted the attention of the scientific community for decades owing to the role of the unique physics that steer highly productive water masses into the region, its relatively shallow average depth (42 m on the northeastern Chukchi Shelf), and weak grazing pressure on phytoplankton from low zooplankton abundance during spring (Grebmeier et al., 2006). These combined factors facilitate the deposition of a large proportion of pelagic primary production to the seafloor, thus providing a major carbon subsidy to the benthic food web. This has triggered considerable research on food webs (Iken et al., 2009; McTigue and Dunton 2014), benthic-pelagic coupling (Dunton et al., 2005), and localized benthic "hotspots" first noted nearly three decades ago by Grebmeier et al. (1988).

1. Water circulation around Hanna Shoal and implications for zooplankton

Our current understanding of the flow around Hanna Shoal and its corresponding water mass properties are the product of both models and in situ measurements made by a number of physical oceanographers over the past decade (see Weingartner et al. (2017). Thanks to their cooperative and coordinated efforts, a much clearer picture of the complex interplay of bathymetry, water mass contributions, and formation of dense winter water has emerged (Spall, 2007; Weingartner et al., 2013; Brugler et al., 2014) as reflected in a circulation model that depicts a general clockwise flow around the north and east sides of the Shoal as well as on the west flank (Fig. 2). Weingartner et al. (2017) provides a more focused analysis of the summer hydrography of the region, with an emphasis on the interannual differences in ice concentration and its effects based on shipboard and towed CTDs, satellite-tracked drifters and remotely sensed sea ice data. They found evidence for clockwise flow that transports water from the western side of the shoal eastward plus counterclockwise northwestward baroclinic flow on the northeast side. The opposing flows result in a convergence on the northern flanks of Hanna Shoal that may contribute to enhanced cross-shelf transport.

Current flows and water mass types around Hanna Shoal have profound impacts on water column chlorophyll *a* biomass as well as zooplankton distribution, abundance, and composition in shelf waters (see Ashjian et al., 2005 and Grebmeier et al., 2006). Earlier work showed high chlorophyll-*a* levels on the western, northern, and eastern sections of Hanna Shoal, which is consistent with the cold and dense nutrient-rich Bering Sea waters flowing clockwise around the flanks of Hanna Shoal (Grebmeier et al., 2006). This finding is supported by the observations of Weingartner et al. (2017) and Pickart et al. (2016). Ashjian et al. (2017) noted that zooplankton composition on the northeast region of Hanna Shoal was most distinct from the remainder of the Shoal, suggesting that these populations originated in the Arctic Ocean (rather than the Bering Sea), consistent with the flow regime noted by Weingartner for the northern region of the Shoal. In addition, using individual-based Lagrangian model experiments, Elliott et al. (2017) concluded that Hanna Shoal supplies diapause competent *Calanus glacialis* from the Bering and southern Chukchi northward to the Chukchi Cap and northeastward to the Beaufort Slope, in agreement with the cross-shelf transport mechanism suggested by Weingartner et al. (2017).

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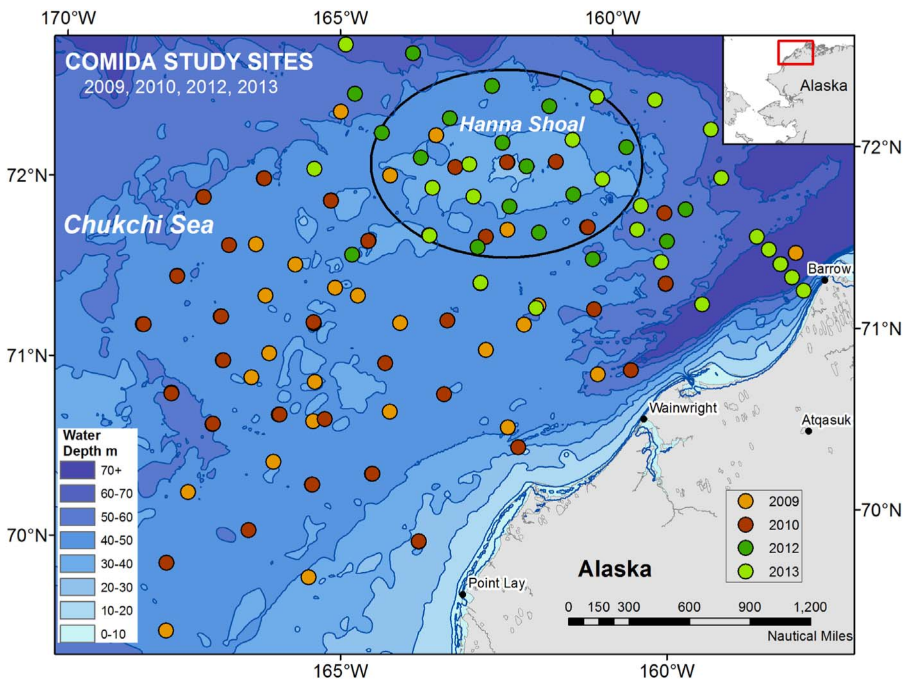

Fig. 1. The location of Hanna Shoal and stations occupied in the northeast Chukchi Sea during summers 2009, 2010, 2012, and 2013 for the COMIDA program in relation to the bathymetry (m) of the region.

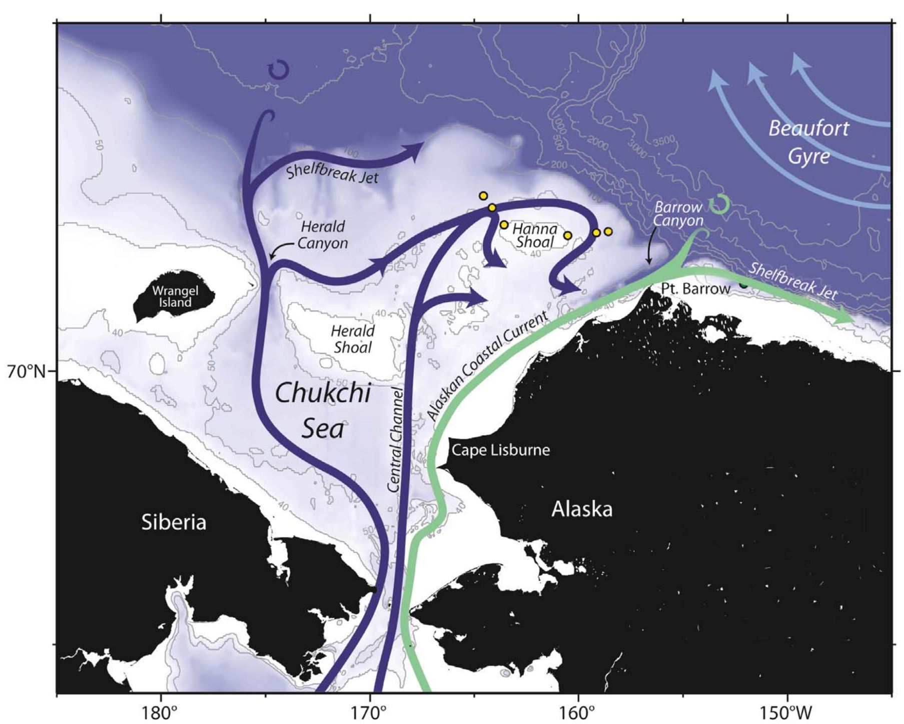

Fig. 2. A synopsis of major water circulation patterns in the northern Chukchi Sea. The model shows nutrient-rich Bering Sea water flowing north through the Central Channel before turning east along the Chukchi Sea shelf break, circumventing Hanna Shoal and exiting through Barrow Canyon to the Beaufort Sea. The northward flowing Alaskan Coastal Current is shown in green. COMIDA hydrographic and current moorings (in yellow ellipses) deployed on Hanna Shoal by Weingartner et al. (2017) are denoted yellow. Graphic adapted from Brugler et al. (2014) and Pickart et al., (2016).

2. Sediment and water column chemistry

Sediment samples were collected using a variety of equipment (grabs, box corers, gravity cores, etc.) from the USCGC *Healy*. Earlier work showed that total organic carbon was highest in fine-grained sediments from stations on the flanks of the Shoal and that, interestingly, up to 35% of the organic matter was from terrigenous sources, likely from coastal erosion and inputs from Arctic rivers (e.g. the Yukon; Trefry et al., 2014). None of our Hanna Shoal stations exhibited trace metal contamination, and evidence from gravity cores (which record decades to centuries of deposition) indicate there has been no detectable anthropogenic contributions (Trefry et al., 2014).

Similarly, Harvey and Taylor (2017) studied a suite of organic contaminants, including polycyclic aromatic hydrocarbons (PAHs), and found PAHs generally very low and present at background levels in surface sediments surrounding Hanna Shoal with few exceptions. Their chemical analysis of muscle tissues in the whelk *Neptunea* revealed that this omnivorous species is a valuable indicator of anthropogenic inputs