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# Advances in Ecosystem Research: Saildrone Surveys of Oceanography, Fish, and Marine Mammals in the Bering Sea

By Calvin W. Mordy, Edward D. Cokelet, Alex De Robertis, Richard Jenkins, Carey E. Kuhn, Noah Lawrence-Slavas, Catherine L. Berchok, Jessica L. Crance, Jeremy T. Sterling, Jessica N. Cross, Phyllis J. Stabeno, Christian Meinig, Heather M. Tabisola, William Burgess, and Ivar Wangen

**ABSTRACT.** Saildrones are unmanned surface vehicles engineered for oceanographic research and powered by wind and solar energy. In the summer of 2016, two Saildrones surveyed the southeastern Bering Sea using passive acoustics to listen for vocalizations of marine mammals and active acoustics to quantify the spatial distribution of small and large fishes. Fish distributions were examined during foraging trips of northern fur seals (*Callorhinus ursinus*), and initial results suggest these prey distributions may influence the diving behavior of fur seals. The Saildrone is faster, has greater instrument capacity, and requires less support services than its counterparts. This innovative platform performed well in stormy conditions, and it demonstrated the potential to augment fishery surveys and advance ecosystem research.

## BACKGROUND

The Bering Sea, a large high-latitude sea that extends ~1,200 km between the Aleutian archipelago and Bering Strait, is characterized by a broad (~500 km) eastern shelf that is approximately the combined size of California, Oregon, and Washington. This region supports a rich ecosystem that includes large populations of zooplankton and numerous species of fish, shellfish, birds, and marine mammals (Iverson et al., 1979). Approximately 40% of all US fish and shellfish landings come from these waters, including walleye pollock (*Gadus chalcogrammus*), which are the dominant midwater fish on the outer shelf, and represent one of the largest commercial fisheries in the world (National Marine Fisheries Service, 2016). The abundant prey field supports a variety of marine mammals, including ~50% of the worldwide population of northern fur seals (*Callorhinus ursinus*; hereafter fur seals), which breed in the Pribilof Islands (Testa, 2016), and the extremely rare North Pacific right whale (*Eubalaena japonica*), which feeds over the broad eastern Bering Sea shelf in summer (Shelden et al., 2005).

To untangle the impacts of climate variability and other environmental drivers on demography, behavior, and trophic links between these species, Bering Sea researchers have relied on traditional platforms that have limited spatial (e.g., moorings) or temporal (e.g., research ships) coverage. New autonomous platforms can increase spatiotemporal and adaptive sampling in this remote environment, and provide new research perspectives at a time when changing climate is transforming Arctic and sub-Arctic ecosystems (Hunt et al., 2011; Wassmann et al., 2011).

## SAILDRONE

The Saildrone is a wind- and solar-powered autonomous vehicle that can be launched from shore and remain at sea for extended periods. The Saildrone's origin was a fixed-wing vehicle called Greenbird (http://www.greenbird.co.uk) that was used by Richard Jenkins to set speed records for a wind-powered vehicle on land and ice. Subsequent modifications to convert this vehicle into the Saildrone include: solar power for communication, controls, and instrumentation; automated tacking between waypoints; real-time navigation and data return; and large payload capacity and payload power. Thrust and heel are controlled by a tail-mounted trim-tab that manipulates the wing, and direction is controlled by a conventional rudder. Navigational commands from shore automatically trigger actuators that operate these components (Meinig et al., 2015).

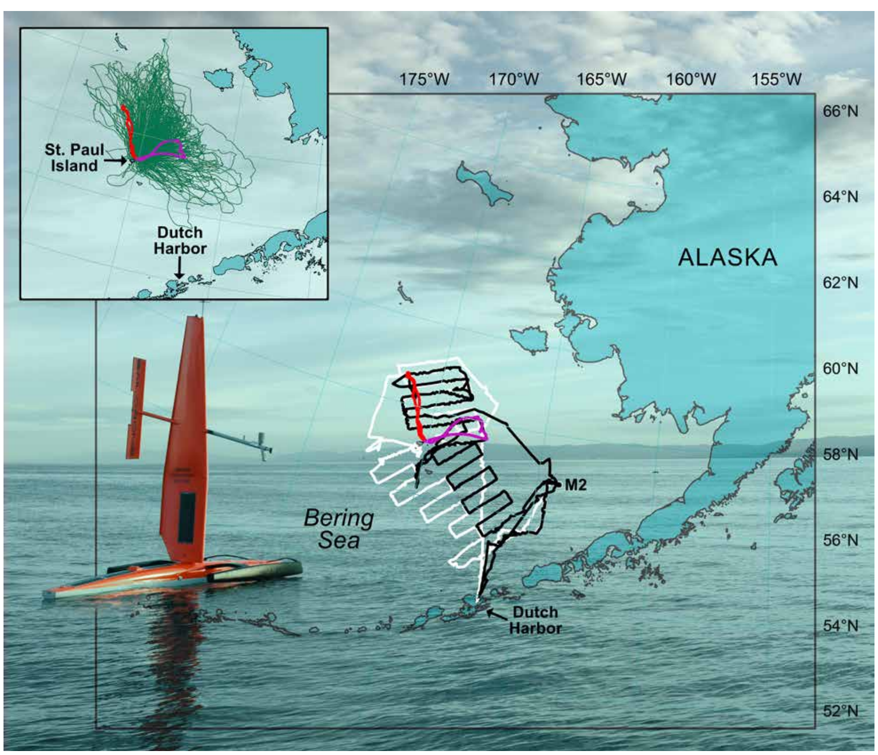


FIGURE 1. Saildrone photo and maps showing track lines from two Saildrones that were deployed during the 2016 Bering Sea mission (black, white) along with tracks of 29 satellite-tagged northern fur seals (inset), including two fur seals targeted for focal follows (purple and red).

In partnership with Saildrone Inc. (http://saildrone.com) through a Cooperative Research and Development Agreement, researchers and engineers at the University of Washington and the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory (PMEL) equipped the Saildrone with meteorological and oceanographic sensors as part of the Innovative Technology for Arctic Exploration (ITAE) program (https://www.pmel.noaa.gov/itae).

In April 2015, the inaugural science mission commenced when two Saildrones were launched from Dutch Harbor, Alaska, into the Bering Sea. For 97 days, they sailed a total of 15,525 km while following ice retreat and surveying the Yukon River plume in Norton Sound, at times operating in just a few meters of water (Cokelet et al., 2015).

Following this successful demonstration, researchers at NOAA's Alaska Fisheries Science Center (AFSC) worked with engineers at Saildrone Inc., PMEL, Kongsberg Maritime AS, and Greeneridge Sciences Inc. to install active and passive acoustic sensors customized for the Saildrone. To estimate fish distributions, a new-generation Wide-Band Autonomous Transceiver (WBAT) from Simrad (Kongsberg Maritime AS) was installed with a keel-mounted gimbaled 70 kHz model ES70-18 CD Simrad transducer. To capture vocalizations from marine mammals, an Acousonde™ (Model B003A) passive acoustic recorder from Greeneridge Sciences Inc. was installed on the side of the keel.

## 2016 SAILDRONE SURVEY

In May 2016, two Saildrones departed Dutch Harbor, Alaska, to conduct oceanographic, fisheries, and marine mammal studies (Figure 1). Mission goals were to assess the use of the Saildrone for acoustic fish surveys, survey for the presence of the critically endangered North Pacific right whale, and examine the foraging behavior of fur seals in relation to the prey field. Saildrones first sailed to a NOAA long-term mooring (M2) for a data-quality check of meteorological and oceanographic sensors, and then began a survey over the outer shelf to listen for right whales and examine pollock distributions (which constitute the primary acoustic target in this region; De Robertis et al., 2010). Upon reaching the Pribilof Islands (St. Paul Island and St. George Island), the vehicles rendezvoused with NOAA Ship *Oscar Dyson* to cross-compare vehicle and ship sensors. Thereafter, the Saildrones headed north to examine the distribution of pollock in the traditional foraging area used by fur seals (Figure 1 inset; Kuhn et al., 2014). After 105 days and a total of 12,075 km, the two Saildrones returned to Dutch Harbor. The average speed of the vehicles was ~1 m $s^{-1}$, with peak speeds up to 3.6 m $s^{-1}$ obtained during high wind conditions (15 m $s^{-1}$ winds gusting to 23 m $s^{-1}$).

The two Acousondes yielded ~5,150 hours of acoustic recordings. Despite complications from ubiquitous hull-slapping noise, analysis revealed acoustic signatures of killer whales and humpbacks, with possible detections of a right whale and fin whale.

On two occasions, *Oscar Dyson* trailed 500 m behind a Saildrone to compare active acoustic systems under varying weather conditions. Net sampling with *Oscar Dyson* confirmed that as in previous years (De Robertis et al., 2010; Benoit-Bird et al., 2013), fish backscatter on the outer shelf in 2016 was almost entirely attributable to walleye pollock, with older fish distributed closer to bottom. Relative to data collected on *Oscar Dyson* (and other reference platforms), generally the Saildrone data were of high quality and demonstrated the potential use of this platform to augment acoustic fishery surveys (Figure 2a). However, in winds >8–10 m $s^{-1}$ (<22% of data), echosounder transmissions exhibited evidence of attenuation from bubbles swept under the transducer. This effect was not observed on *Oscar Dyson*, which has much deeper transducers (9.1 m). Analysis of the strength of the bottom echo (Shabangu et al., 2014) and comparisons with *Oscar Dyson* records indicate that at lower wind speeds, Saildrone echosounder observations were largely free of this bias.

Fur seals that forage on the Bering Sea shelf rely on pollock as their primary prey (Zeppelin and Ream, 2006). Until now, only limited surveys of prey availability have been available to complement foraging studies and to thereby assess the consequences of variations in foraging efficiency on population parameters (Benoit-Bird et al., 2013; Kuhn et al., 2015). In mid-July, researchers from AFSC attached satellite tags (depth and temperature recorders) to 29 fur seals on St. Paul Island to obtain foraging locations and dive profiles. While the fur seals were foraging, the Saildrones continuously collected prey data for 65 days, covering the vast majority of the foraging range of the tracked animals. In addition, several focal follows were conducted where Saildrones followed tagged animals for more than 80 hours and 210 km. Initial results suggest that differences in prey distributions spatially and in the water column may influence the foraging behavior of fur seals, and demonstrate that fur seals forage on both small and large pollock (Figure 2). These types of studies will help fill significant gaps in our understanding of how fur seals respond to variation in prey resources, which is particularly valuable for developing conservation strategies for this declining population.

During this highly successful mission, the Saildrones performed well in the harsh conditions of the Bering Sea (e.g., stormy, low light, biofouling) and demonstrated the potential of this innovative platform to advance ecosystem research.

## FUTURE

Following the 2016 mission, the Saildrone was redesigned to improve speed and to integrate new sensors (Figure 3). Field trials showed that the next-generation Saildrone was approximately one knot faster than earlier Saildrones in most conditions. Removal of the outriggers significantly reduced hull noise in the Acousonde recordings. Simrad has upgraded the echosounder to a 38 kHz WBT-mini that provides real-time data return, and attenuation from bubbles is less sensitive at this lower frequency (Novarini and Bruno, 1982). To accommodate additional sensors, power capacity on the Saildrone was increased to 30 W. Newly integrated sensors include a surface ocean $pCO_2$ system, a 300 kHz acoustic Doppler current profiler, and a radiometer suite for measuring heat exchange. While future deployments in the Bering and Chukchi Seas are narrowly

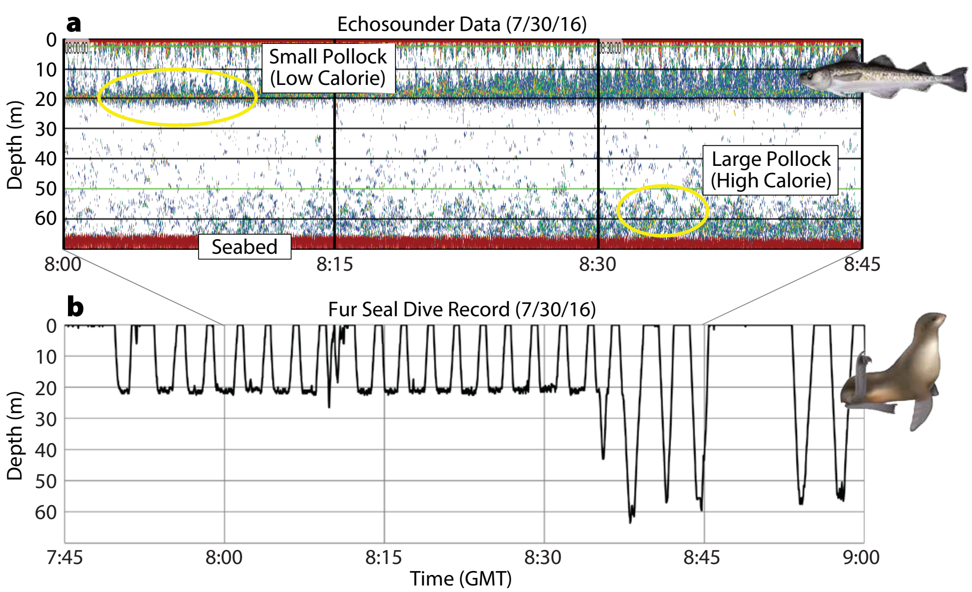


**FIGURE 2.** Saildrone echosounder (70 kHz) data showing (a) backscatter from small pollock at ~10–20 m depth and larger pollock near the bottom, and (b) a dive profile from a northern fur seal. The fur seal and Saildrone crossed paths within <1 hr of each other, and the maximum separation for this data example was approximately 7 km at 9:00 GMT. This separation was smaller than the typical prey patch size, as layers of pollock can extend for ~100 km (Walline, 2007). This fur seal spent some time diving to ~20 m depth and then switched to deeper dives. Based on the prey sampling data throughout the fur seal foraging area, this dive pattern suggests the fur seal was initially foraging on smaller pollock and then switched to targeting the larger pollock near the bottom.

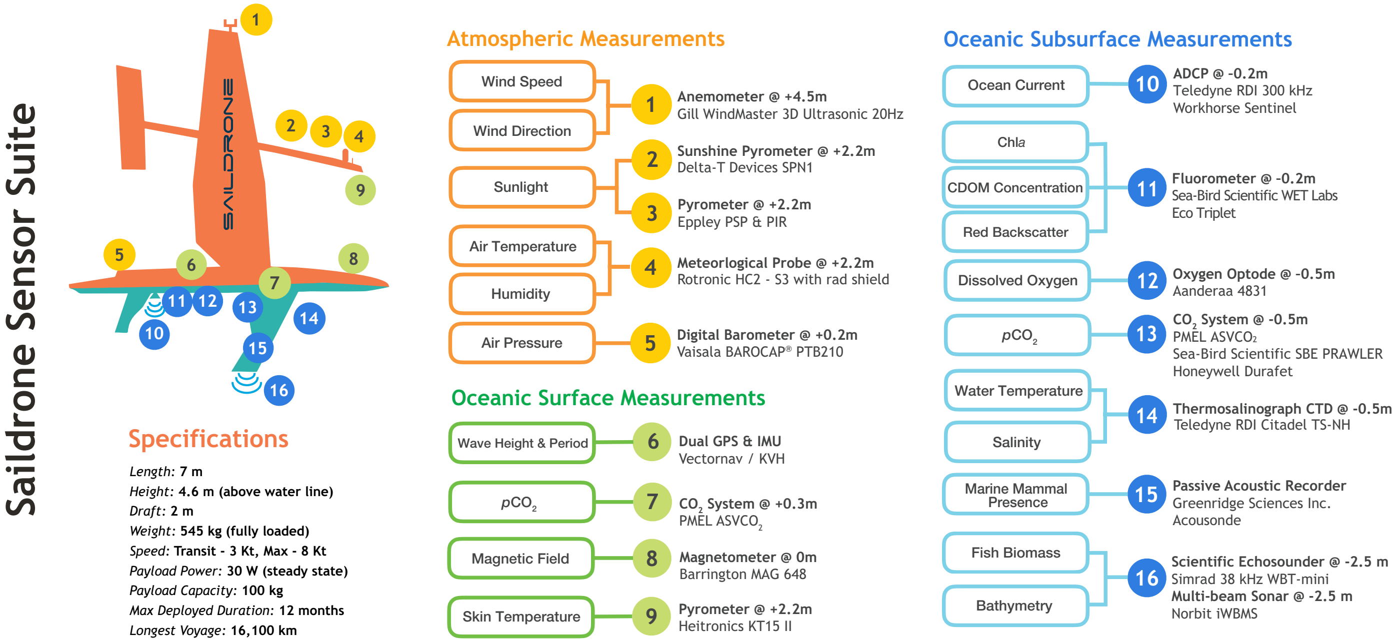


**FIGURE 3.** Sensor suite and specifications on the new generation (Gen 4) Saildrone. During the 2016 mission, a Gen 3 Saildrone was used and did not include sensors 7, 8, 10, 13, or the multibeam sonar. Other upgrades on the Gen 4 include replacement of the Simrad WBAT with a Simrad WBT-mini, and the use of pyrometer suite in place of a photosynthetically active radiation (PAR) sensor.

focused on acoustic, marine mammal, and $pCO_2$ surveys, this platform has proven robust with broad capabilities, and has the potential to address research across regions and disciplines.

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## AUTHORS

**Calvin W. Mordy** (mordy@uw.edu) is Oceanographer, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington (JISAO-UW), and National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory (NOAA-PMEL), Seattle, WA, USA. **Edward D. Cokelet** is Oceanographer, NOAA-PMEL, Seattle, WA, USA. **Alex De Robertis** is Fisheries Biologist, NOAA-Alaska Fisheries Science Center (NOAA-AFSC), Seattle, WA, USA. **Richard Jenkins** is Chief Executive Officer, Saildrone Inc., Alameda, CA, USA. **Carey E. Kuhn** is Ecologist, NOAA-AFSC, Seattle, WA, USA. **Noah Lawrence-Slavas** is Engineer, NOAA-PMEL, Seattle, WA, USA. **Catherine L. Berchok**, **Jessica L. Crance**, and **Jeremy T. Sterling** are all Research Biologists, NOAA-AFSC, Seattle, WA, USA. **Jessica N. Cross** and **Phyllis J. Stabeno** are Oceanographers, and **Christian Meinig** is Director of Engineering, all at NOAA-PMEL, Seattle, WA, USA. **Heather M. Tabisola** is Research Staff, JISAO-UW and NOAA-PMEL, Seattle, WA, USA. **William Burgess** is Senior Research Engineer, Greeneridge Sciences Inc., Santa Barbara, CA, USA. **Ivar Wangen** is Engineer, Kongsberg Maritime AS, Horten, Norway.



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