Advances in Ecosystem Research:

Saildrone Surveys of Oceanography, Fish and Marine Mammals in the Bering Sea

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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 demonstrated the potential to augment fishery surveys and advance ecosystem research.

BACKGROUND

The Bering Sea is a large high-latitude sea that extends ~1200 km between the Aleutian archipelago and Bering Strait, and 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 impact of climate variability and other environmental drivers on demography, behavior, and trophic links between these species, researchers in the Bering Sea 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 the arctic and sub-arctic ecosystems (Hunt et al., 2011; Wassmann et al., 2011).

SAILDRONE

The Saildrone is a wind- and solar-powered high-speed 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/) 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 way-points; real-time navigation and data return; and a large payload capacity and payload power. Thrust and heel are controlled by a trim-tab mounted in a tail, which 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).

In partnership with Saildrone Inc. (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 (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, the Saildrones sailed a total of 15,525 km following ice retreat, and surveying the Yukon River plume in Norton Sound, at times sailing 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 sailed from 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 sailed 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} that were 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, the *Oscar Dyson* trailed 500 m behind a Saildrone to compare active acoustic systems under varying weather conditions. Net sampling with the *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 the *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 the *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 the *Oscar Dyson* indicate that at lower wind speeds, 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), but until now only limited surveys of prey availability have been available to complement these studies, and 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 d 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 > 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, bio-fouling), 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 found that the next-generation Saildrone was approximately 1 knot faster than earlier Saildrones in most conditions. The outriggers were removed, and this 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 30W. 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 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.

ACKNOWLEDGMENTS

Thanks to the many machinists, engineers, and staff who worked on this project, to Rebecca White and Karen Birchfield for graphics, and the Captain and crew of NOAA Ship *Oscar Dyson*. Northern fur seal research was conducted under MMPA permit #782-1708. This research was generously supported by NOAA’s Office of Oceanic and Atmospheric Research, PMEL, and Schmidt Marine Technology Partners, and partially funded by JISAO under NOAA Cooperative Agreement NA15OAR4320063. This is contribution EcoFOCI-0892-RPPO to the Ecosystems and Fisheries-Oceanography Coordinated Investigations; 2017-086 to JISAO; and 4670 to PMEL.

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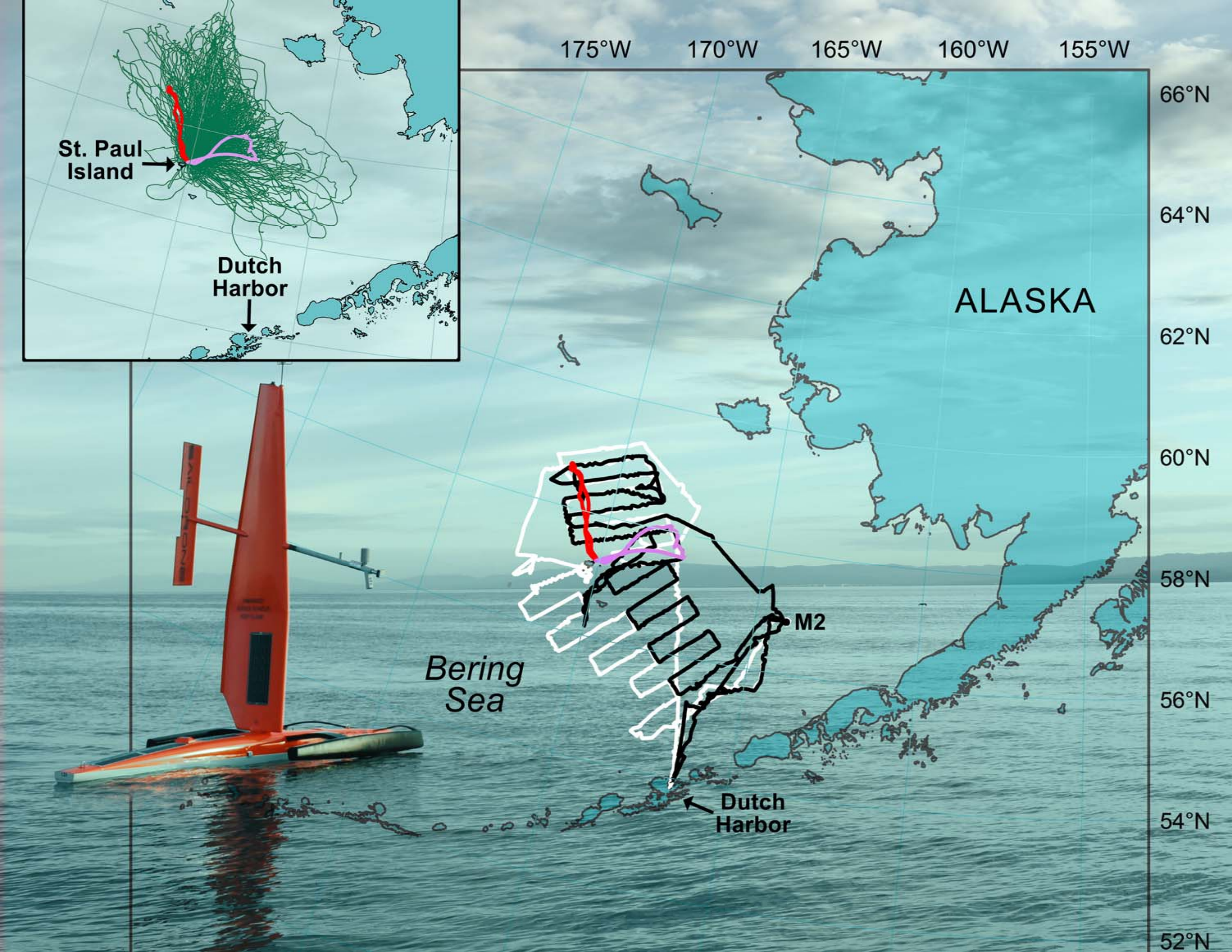
FIGURE 1. Map showing Saildrone track lines from the 2016 Bering Sea mission (black, white) and tracks of 29 satellite-tagged northern fur seals (inset) including two fur seals targeted for focal follows (lavender and red).

FIGURE 2. Saildrone echosounder (70 kHz) data showing backscatter from small pollock at ~10-20 m and larger pollock near the bottom (A), and dive profile from a northern fur seal (B). 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 and then switched to deeper dives closer to the bottom. 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 Saildrone. During the 2016 mission, a Photosynthetically Active Radiation (PAR) sensor was used in place of the pyrometers, a Simrad WBAT echosounder was used in place of the Simrad WBT-mini, and sensors 7, 8, 10, 13, and the multi-beam sonar were not in use.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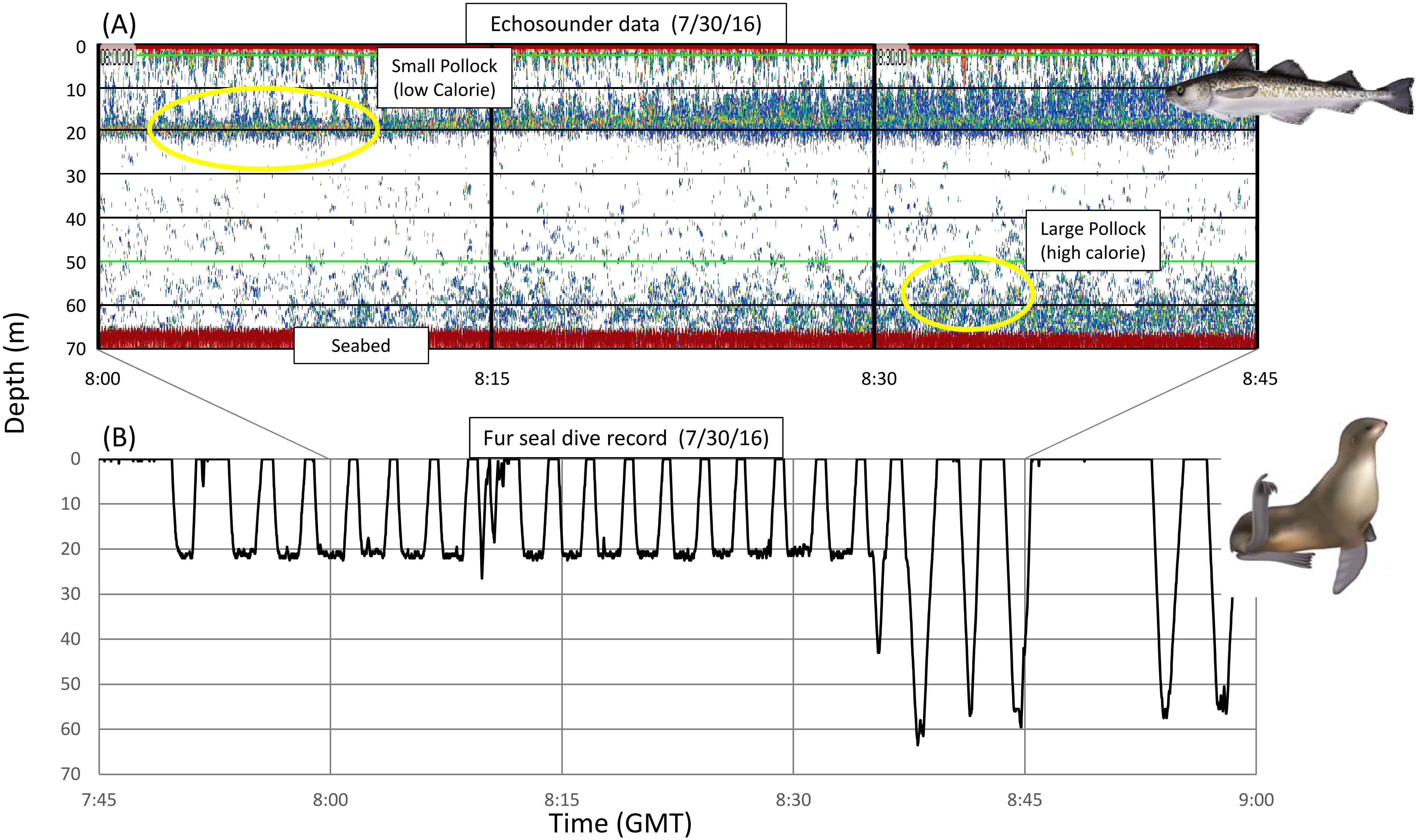
(A)
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Small Pollock
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Large Pollock
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10
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Depth (m)
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Fur seal dive record (7/30/16)
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7:45
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8:15
8:30
8:45
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Time (GMT)

Saildrone Sensor Suite

Specifications

Length: **7 m**

Height: **4.6 m (above water line)**

Draft: **2 m**

Weight: **545 kg (fully loaded)**

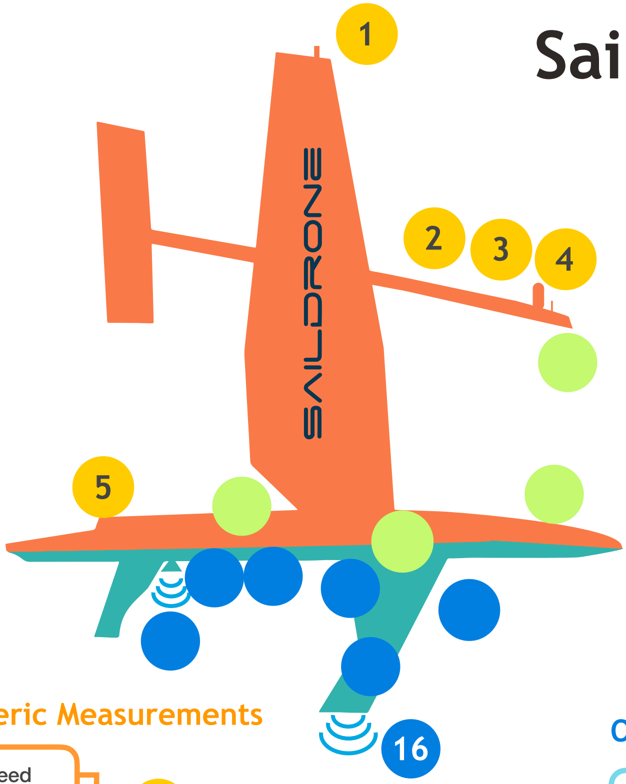
Speed: **Transit - 3 Kt, Max - 8 Kt**

Payload Power: **30 W (steady state)**

Payload Capacity: **100 kg**

Max Deployed Duration: **12 months**

Longest Voyage: **16,100 km**



Atmospheric Measurements

Wind Speed	1	**Anemometer @ +4.5m** Gill WindMaster 3D Ultrasonic 20Hz
Wind Direction		
Sunlight	2	**Sunshine Pyrometer @ +2.2m** Delta-T Devices SPN1
	3	**Pyrometer +2.2m** Eppley PSP & PIR
Air Temperature	4	**Meteorlogical Probe @+2.2m** Rotronic HC2 - S3 with rad shield
Humidity		
Air Pressure	5	**Digital Barometer @ +0.2m** Vaisala BAROCAP® PTB210

Oceanic Surface Measurements

Wave Height & Period	6	**Dual GPS & IMU** Vectornav / KVH
pCO_2	7	**CO_2 System @ +0.3m** PMEL ASVCO_2
Magnetic Field	8	**Magnetometer @ 0m** Barrington MAG 648
Skin Temperature	9	**Pyrometer @ +2.2m** Heitronics KT15 II

Oceanic Subsurface Measurements

Ocean Current	●	**ADCP @ -0.2m** Teledyne RDI 300 kHz Workhorse Sentinel
Chl*a*	●	**Fluorometer** Sea-Bird Scientific WET Labs Eco Triplet
CDOM Concentration		
Red Backscatter		
Dissolved Oxygen	12	**Oxygen Optode @ -0.5m** Aanderaa 4831
pCO_2	●	**CO_2 System @ -0.5m** PMEL ASVCO_2 Sea-Bird Scientific SBE PRAWLER Honeywell Durafet
Water Temperature	14	**Thermosalinograph CTD @ -0.5m** Teledyne RDI Citadel TS-NH
Salinity		
Marine Mammal Presence	15	**Passive Acoustic Recorder** Greenridge Sciences Inc. Acousonde
Fish Biomass	●	**Scientific Echosounder @ -2.5 m** Simrad 38 kHz WBT-mini **Multi-beam Sonar @ -2.5 m** Norbit iWBMS
Bathymetry		