EMERGING TECHNOLOGIES FOR NOAA OCEAN RESEARCH, OPERATIONS AND MANAGEMENT IN AN ECOSYSTEM CONTEXT

Response from NOAA to a Report from the NOAA Science Advisory Board

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Introduction

The National Oceanic and Atmospheric Administration (NOAA) thanks the Science Advisory Board (SAB) for its thoughtful review and forward looking recommendations[1] for NOAA's incorporation of robotics, 'omics (encompassing genomics, transcriptomics, and proteomics), advanced and miniaturized sensors, and informatics as technologies for use in the study, characterization and assessment of our marine environment.

The SAB's report concluded with the five recommendations, all of which we agree and support. The uppercase terms "ADOPT NOW", "WATCH FOR FUTURE APPLICATIONS", etc., are as they appeared in the SAB's report. The report's recommendations are summarized next (in italics) and we also indicate where, in our response, we offer specific examples of the state NOAA's activities.

1. *NOAA should continue to invest in these ['omics] technologies and their applications. […] NOAA should take advantage of commercial / private development of sensors, because this area is rapidly advancing and costs are decreasing and quality is increasing. […] NOAA should continue its investment and look to develop new applications for eDNA monitoring and analysis. ADOPT NOW.*

   Response: NOAA has continued to invest in 'omics technologies and is already adopting and implementing them in the field (for applications in fisheries, early warning systems for HABs, marine mammal and fisheries population structure, microbiome), and in aquaculture; please see Section 1 below (pp. 4-7). We have also held internal workshops (please see Appendix A, pp. 35ff, for the workshop report including collaborative efforts) to assess the state of our work and coordinate cross Line Office and external partner efforts

2. *The number of types and applications for unmanned robotic vehicles are exploding and include subsurface floats, gliders and propelled vehicles, as well as vehicles that make observations from the surface of the ocean and the air above it. […] Many believe the future of ocean measurements will rely heavily on robotic vehicles and new sensor technologies, including measurements related to living marine resources. ADOPT NOW.*

   Response: indeed, the applications are taking place at an explosive rate and NOAA is adopting them, thereby changing the way in which it conducts surveys and field efforts. It is important to stress that robotics, AUV and related technologies will not replace the need for NOAA ship and aircraft time. These technologies augment the use of ships and aircraft by measuring in places vessels/aircraft cannot access, where they may be safety concern, etc. Section 2 (pp. 8-18) offer examples of the use of: Saildrone technologies planned for a U.S. west coast (NMFS/OAR) survey to take plane this the summer (2018) off the U.S. west coast, a completed pilot Saildrone survey in the Bering Sea, a combined Slocum-glider and mooring-based survey planned for the western Antarctic Peninsula in 2018-2019, and the NOS IOOS' Glider Network. These gliders are equipped with the latest acoustic, optical, and meteorological & oceanographic sensors. Aerial surveys with quad- and hexacopter technologies for assessing the state of marine mammal populations are also highlighted.
3. *Sophisticated imaging systems … for the laboratory and for use on board oceanographic ships have been in use for many years. These same systems are now being deployed in*

[1] https://www.sab.noaa.gov/ReportLibrary.aspx#11337161-ecosystem-sciences-and-management-working-group

situ on moorings or towed behind oceanographic ships providing much more capability. They offer the potential to fill time and space measurement gaps of important species. IMPORTANT, WATCH FOR FUTURE APPLICATIONS.

Response: imaging systems are now used operationally and near-operationally, in several NOAA mission areas. These include the use of advanced imaging sensors (robotic and towed) as well as automated analysis algorithms, including an example of crowdsourcing. Section 3 (pp. 18-28) summarizes ongoing applications in the systems off the Pacific Islands, Alaska and the Northeast U.S. continental shelf. Some of this work has been supported by the Automated Image Analysis Strategic Initiative, AIASI[2]. We continue to look for additional developments, while continuing the implementing of these ongoing activities.

4. *Automated measurement systems are capable of collecting data at rates far greater than can be efficiently analyzed using traditional methods that depend heavily on human involvement. Sophisticated data analysis techniques and personnel trained to use them are required to effectively utilize the high data volume of new sensing systems ADOPT NOW.*

   Response: related to the above response, we have begun to adopt automated analysis approaches (see pp. 20-21). We also need to continue to extend our capabilities, and one example is collaboration with external partners (such as with the Center for Coastal and Ocean Mapping/Joint Hydrographic Center[3] and Woods Hole Oceanographic Institution; see pp. 24-25). We also agree that training of personnel will be required as the technologies advance the size of the data sets generated continues to grow.

5. *Passive acoustic sensors on moorings and mobile platforms, as well as new sensors for new orbital and suborbital platforms including ship-launched drones, aircraft and satellites are coming on line and are adding to our ocean observation capabilities. IMPORTANT, WATCH FOR FUTURE APPLICATIONS.*

   Response: Section 4 (pp. 29-32) summarizes the state of selected additional upcoming technologies that we are evaluating. Passive acoustics are in a relative advanced state and are in broad use in the assessment of marine mammal populations. The use of drones and sensors in orbital/suborbital platforms, e.g., Sentinel, and CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), are not yet quite at the same level of operationalization, but they are areas of which we are watchful in NOAA.

Summary: we thank the SAB for its thoughtful comments and advice. We support and concur with the SAB's report's recommendations. We add, as illustrated by the examples below, that NOAA is already making solid investments in the identified technologies, and in several instances, their implementations are in advanced, tangible stages of R2O (research-to-operations). It is also important to underscore the SAB's recommendations, that we need to invest in training the personnel required to extract the full extent of what these technologies offer. We look forward to continued collaboration with the SAB and their recommendations.

1. *'Omics*

This is a field that is developing rapidly and where several NOAA Line Offices (LOs; NMFS and OAR) have already invested in 'omics and are jointly coordinating activities. In November of

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[2] http://marineresearchpartners.com/nmfs_aiasi/Home.html

[3] https://marine.unh.edu/program/center-coastal-and-ocean-mappingjoint-hydrographic-center

2017 we held a cross-LO meeting and the Meeting Report is included in Appendix A. Some examples of specific ongoing activities follow. Contacts: Drs. Mark Strom, Kelly Goodwin, and Jeff Guyon.

Aquaculture. Sablefish (black cod) is a high valued deep-water fish found in the North Pacific Ocean. Sablefish catch limits are managed by NOAA Fisheries. Early research geared towards commercialization of sablefish aquaculture identified that female sablefish grew to market size much faster than males. Monosex production therefore would dramatically improve the economics of sablefish aquaculture. Drawing on research in other species, the (Northwest Fisheries Science Center) NWFSC used genomic sequencing and comparative analysis of reproductive pathways in order to identify genes involved in sexual differentiation during embryogenesis. In partnership with the University of Maryland, a technique called “RNA silencing” was used to create all female, reproductively sterile sablefish. RNA silencing is not a genetic modification, but instead is a treatment that results in temporary block in gene expression. The technology is well suited for marine aquaculture that is more environmentally sustainable, since production of reproductively sterile fish prevents potential genetic contamination of wild fish should farmed fish escape from ocean net pens. The goal is to develop a completely non-GMO method for sterilization of sablefish that can be broadly applied to marine finfishes, and potentially shellfishes. The NWFSC is currently working with external partners to transfer the technology for commercialization.

Early warning system for Harmful Algal Blooms (HABs). The SAB report touched on monitoring the microbial component of marine ecosystems with a focus on the use of the Environmental Sample Processor (ESP) as part of an early warning system for HABs. The ESP is an advanced, automated, quantitative, in situ, biological sensing system that utilizes either genetic (DNA) or antibody-based detection methodology to identify species of phytoplankton that produce algal toxins or detect toxin presence directly. Species detection occurs via an onboard DNA-DNA hybridization assay on on-board microarrays, while toxin detection is through a competitive immunoassay (enzyme-linked immunosorbent assay). Deployment of an ESP allows extended, high frequency, and responsive surveys for HAB species or toxins with near real-time (~3 hours) data delivery. In partnership with NOS and funding through NOAA’s Integrated Ocean Observing System (IOOS) Program, NWFSC has carried out research since 2011 in a directed effort to incorporate data transmitted during deployment into a HAB early warning system in the Pacific Northwest. Two off shore deployments each in 2016 and 2017 off the coast of Washington State in conjunction with an oceanographic buoy managed by the Northwest Association of Networked Ocean Observing Systems (NANOOS) has demonstrated the value of the ESP in providing early warning for the phytoplankton *Pseudonitzchia,* which produces the biotoxin domoic acid and was the cause of the months long closures of the Dungeness crab fishery in 2016. The data from the ESP was quickly made available on the NANOOS Data Visualization System (http://nvs.nanoos.org) on the “Realtime HABs” website and incorporated into the Pacific Northwest HAB bulletin. The value of the ESP data and the HAB bulletin was recently demonstrated when the ESP detected a significant spike in the concentration of domoic acid the day before the opening weekend of the razor clam season. State and Tribal fisheries managers were notified, and analysis of additional samples found the clams to be safe for consumption. The transition to an operational forecast for the PNW HAB bulletin is currently in preparation.

‘Omics and environmental DNA (eDNA) to study the population structure of marine mammals. Genetic characterization of mitochondrial DNA (mtDNA) has long been used to characterize and differentiate population structures in a variety of eukaryotic species. In a collaborative study with the Alaska Fisheries Science Center(AFSC), the NWFSC has examined the population structure of the harbor porpoise (*Phocoena phocoena*) in Southeast Alaska, since analysis of 20-year abundance trends suggested multiple populations within the Southeast AK harbor porpoise stock. Historically, sufficient tissue biopsy samples from within Southeast AK stocks had been difficult to obtain for standard population genetic studies, although mtDNA sequence data generated from harbor porpoise strandings and fisheries bycatch tissue samples were sufficient to develop a sequence reference database. To expand the analysis of the stock structure, NWFSC/AFSC collected water samples in fluke prints of individual animals for eDNA analyses. First, a 2015 pilot study confirmed the ability to PCR-amplify harbor porpoise mtDNA in 2L surface seawater samples. eDNA sampling continued throughout inshore SE Alaska waters in 2016 via collection of 100 2.8L water samples. PCR amplification of these water samples followed by next generation DNA sequencing to examine mitochondrial genetic diversity confirmed the viability of using eDNA to differentiate marine mammal stock structures.

Improving techniques for estimating abundance and habitat use in nearshore marine habitats eDNA. As outlined in the SAB report, applications using eDNA and genomic sensors on marine environmental samples hold significant promise to increase temporal coverage of target species and ecosystems, and ultimately may reduce reliance on ship time. However, in order to move eDNA technology from species presence/absence determination to quantitative assessments, a number of methodological hurdles must be overcome, such as understanding DNA degradation rates and any internal bias in PCR amplification sensitivity. The goal of one study to understand the appropriate spatial scale for eDNA sampling and the potential value and pitfalls of eDNA surveys for understanding patterns of fish abundance is in progress at NWFSC. The study is designed to develop eDNA survey methods to quantify near shore fish communities, with a focus on salmon, herring, and smelt species. The efficacy of eDNA quantification methods on water samples using quantitative PCR (qPCR) and massively parallel DNA sequencing are being assessed in parallel with traditional net sampling methods. Resulting ‘omic data are then being assessed by a newly developed statistical framework to provide field estimates of the relationship between species abundance and eDNA.

Genomics Projects – AFSC, PMEL, NWFSC and external collaborators. Genetic and genomic techniques are simultaneously becoming more capable and cost-effective, similar to technologies surrounding early computers. DNA-based analyses are used within the Alaska Fisheries Science Center (AFSC) to efficiently assay many parts of the ecosystem including bacteria, plankton, invertebrates, fishes, and mammals. For example, Drs. Carol Stepien and Kim Andrews (PMEL) are collaborating with scientists in the AFSC-RACE Division to investigate how to characterize and quantify entire zooplankton and ichthyoplankton samples collected on stock assessment surveys using multiple customized high-throughput (next-generation) sequencing assays. Likewise, Jeanette Gann (AFSC-ABL-EMA) and Dr. Chris Kondzela (AFSC-ABL) are collaborating on a genomics project to investigate species composition analysis at sea. Analyses of eDNA (environmental DNA) to supplement survey data for catch composition was spearheaded by Dr. Mike Canino (AFSC-RACE) in collaboration with researchers at the Northwest Fisheries Science Center (NWFSC). This NPRB-funded work confirmed the presence of pollock and Pacific ocean perch in trawl hauls and identified a diverse array of other species.

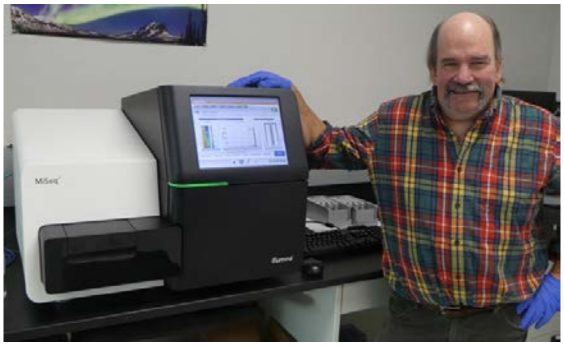
Next-generation sequencing is being applied to commercially exploited fish species in Alaska to assist in management decisions. In collaboration with geneticists at the University of Idaho and chemists at the Auke Bay Laboratories (ABL), Jacek Maselko (AFSC-ABL-RECA) is conducting a genome-wide association study to test novel hypotheses of selection during larval dispersion of Pacific ocean perch, a critical commercial species in the Gulf of Alaska. AFSC geneticists are examining population-level genetic diversity of the Alaska Skate, *Bathyraja parmifera*, in Eastern Bering Sea nursery areas with NPRB support (Hoff, Stevenson, Spies, and Orr). These researchers are proposing to use similar techniques to examine Alaska flatfishes to determine how well genetic population structure corresponds to management units.

Finally, Dr. Ingrid Spies (AFSC-REFM) is collaborating with the fishing industry and Dr. Lorenz Hauser at the University of Washington to answer management questions about Pacific cod in the Bering Sea and Aleutian Islands (BSAI) for the current stock assessment cycle. In 2017, a significant drop in Pacific cod in the Bering Sea and Gulf of Alaska was accompanied with survey information that showed a 9-fold increase in cod in the Northern Bering Sea. Researchers are undertaking next-generation sequencing analysis of spawning populations along the Eastern Bering Sea shelf that, in addition to existing data for other spawning populations throughout the BSAI, will be compared with a summer sample of cod from the Northern Bering Sea. Results will provide information on whether the cod in the Northern Bering Sea represent a distinct population or northward movement from known spawning stocks.

The AFSC maintains two salmon weirs in Alaska that are used to monitor important salmon runs and they provide excellent facilities for investigating fish migration timing and life history with genetic and genomic methods. For example, Scott Vulstek (AFSC-ABL) is collaborating with (1) Dr. David Tallmon (University of Alaska) using eDNA methods to quantitate fish passage and (2) Dr. Megan McPhee (University of Alaska) using parental-based genotyping to track hatchery versus wild salmon returns. eDNA methods are being developed within the AFSC to help support rockfish stock assessments in the Gulf of Alaska, especially in areas that are difficult to sample with traditional bottom trawls. Pat Malecha (AFSC-ABL), Chris Lunsford (AFSC-ABL), and Dr. Mike Garvin (Oregon State) are collaborating on a pilot study to examine the efficacy of eDNA methods for identifying the presence of Alaska rockfish, including Pacific ocean perch (*Sebastes alutus*), rougheye rockfish (*S. aleutianus*), blackspotted rockfish (*S. melanostictus*), shortraker rockfish (*S. borealis*), dusky rockfish (*S. variabilis*), and northern rockfish (*S. polyspinus*).

The spread of marine pathogens can play a dramatic role in species abundance and commercial fisheries. For example, the *Hematodinium* pathogen causes bitter crab disease in snow and Tanner crabs which can impact the quality and quantity of catch for these important commercial species. Dr. Pamela Jensen (AFSC-RACE) is collaborating with the University of Washington to investigate the physiological response to temperature change in healthy and *Hematodinium*-infected Tanner crab by sequencing messenger RNA using transcriptomics. Next-generation sequencing technologies are also

being used to examine the direct effect of changing ocean conditions on crab. Geneticists Dr. Ingrid Spies, Dr. Krista Nichols (NWFSC), and Dr. Robert Foy (AFSC-Kodiak Lab) are collaborating to examine the genomic response of Golden King Crab reared in a range of ocean acidification conditions using RNA transcriptomics.



In addition to providing an abundance of data, current genomic platforms offer a cost-effective alternative to current genotyping techniques. For example, the AFSC currently uses a suite of 43 single nucleotide polymorphisms to genotype Chinook salmon incidentally captured as bycatch in Alaska trawl fisheries. The number of markers available in the baseline is increasing and the laboratory is preparing to use new sequencing-by-synthesis approaches in the future. A next-generation DNA sequencer (Illumina MiSeq) has been purchased and will be tested this summer to investigate sleeper shark population structure (Tribuzio and Wildes), a species which shows limited population variability using traditional genotyping markers. To support these analyses, Ajith Abraham and John D. Miller (AFSC-OFIS) have provided access to the necessary computer resources including the virtual machine with the power to analyze the large data sets produced with next-generation DNA sequencing technologies.

2. Robotic Vehicles, Autonomy and Artificial Intelligence (RVAAI).

This is another area where significant strides have been made in a number of developments and applications. We are using these technologies not just for exploration, but also on the verge of changing the way we conduct surveys, and augmenting the activities that require our NOAA fleet.

<u>2a. Saildrones along the U.S. West Coast:</u> a joint activity between the NWFSC and SWFSC (NMFS), PMEL (OAR)

This summer, 2018, the Northwest Fisheries Science Center (NWFSC/NMFS), Southwest Fisheries Science Center (SWFSC/NMFS) and the Pacific Marine Environmental Laboratory (PMEL/OAR) are planning to conduct a Joint Acoustic Survey of Pacific hake and coastal pelagic species (CPS) using multiple Saildrones (up to 5) and the *FSV Reuben Lasker* over 100 days spanning a survey region from the Southern California Bight (SCB) to north end of the west of Vancouver Island.

The objectives of this proposed work are:

(1) Evaluate the operational feasibility of using Saildrones to conduct coast-wide autonomous acoustic surveys. A primary objective is to test whether the use of Saildrones with acoustic instruments can alleviate some of the survey demand in manned surveys. Since the proposed Saildrone survey will be conducted almost concurrently with the 2018 summer joint CPS Integrated Acoustic and Trawl survey and California Current Cetacean and Ecosystem Assessment survey (CPS-CalCurSEAS) conducted by the SWFSC (Figure 1).

(2) Extend beyond ship transects nearshore and offshore to concurrently acoustically sample any hake and CPS in those areas.

(3) Evaluate the present model for predicting favorable conditions for sardines. The present model uses satellite data on sea surface temperature and ocean color to estimate optimal conditions for sardines. The data suite from the drone extended surveys will allow further calibration of this model by including a larger surface area.

Operations:

There will be five Saildrones deployed for the survey, four of five Saildrones will be running the similar survey transects as the SWFSC CPS (Coastal Pelagic Survey) Acoustic and Trawl survey between the Southern California Bight (SCB) and north end of the west of Vancouver Island and the fifth one will be primarily running the extended nearshore transects (Figure 1). All Saildrone deployments and operations (navigation and data recording) will be provided by Saildrone, Inc., and the data analyses will be performed by the NWFSC and SWFSC and PMEL will place metocean data on the Global Telecommunication System (GTS). Sensors include:

a. Acoustic echosounder: Simrad ES38-18/200-18C two-in-one combination.
b. CTD, wind direction/speed, Dissolved oxygen, and other built-in meteorological and oceanographic data sensors

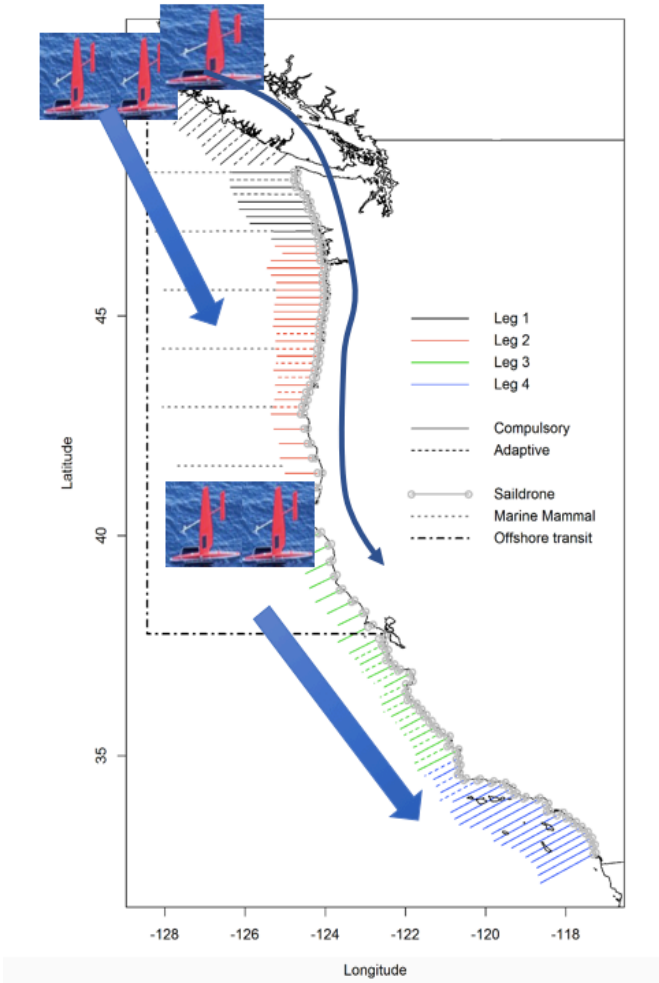


Figure 1. Cruise transects of the NOAA Ship *FSV Reuben Lasker* for 2018 summer joint CPS Integrated Acoustic and Trawl survey and California Current Cetacean and Ecosystem Assessment survey (CPS-CalCurSEAS). Four of five Saildrones will be running the same survey transects as *Reuben Lasker* and the fifth Saildrone will run extended nearshore transects (gray). Three Saildrones from be deployed from Port Hardy, Canada, and the other two will be deployed either in San Francisco, CA, or Newport, OR. Direction of all Saildrones will be from North to South. Deployments will be optimized to have the Saildrones at the correct survey start points in the most efficient manner. The first pair will sample from north of Vancouver Island to south between Newport, OR and San Francisco, CA and the second pair will sample from north between Newport, OR and San Francisco, CA to San Diego. Transects of the fifth Saildrone, each 4-nmi long, will extend the ship transects nearshore, off the U.S. west coast, to 10-m depth, from north of Vancouver Island to Sea Diego (gray lines in this figure).

<u>2b. Saildrone applications in Alaska:</u> a joint activity between the Alaska Fisheries Science Center (AFSC/NMFS) and PMEL (OAR). Contacts: Alex De Robertis (fish acoustics)
Carey Kuhn (fur seals), Jessica Crance and Catherine Berchok (marine mammal passive acoustics).

Advances in technology are making the use of autonomous vehicles as survey platforms more accessible. Engineers from Saildrone teamed with NOAA's PMEL and successfully deployed a suite of oceanographic instruments on a Saildrone unmanned sailing vehicle in 2015. The following year AFSC and Simrad joined the team to add custom low-power echosounders to detect fish, and passive acoustic recorders to detect marine mammal calls. Three AFSC projects have now jointly used Saildrones in the Bering Sea in 2016 and 2017 (Mordy *et al.*, (2017) Saildrone Surveys of Oceanography, Fish and Marine Mammals in the Bering Sea. *Oceanography*, 30(2):113-116): active acoustic observations of the abundance and distribution of walleye pollock, passive acoustic monitoring of marine mammals, and an assessment of the impact of prey (fish) availability on depleted northern fur seal populations.

The potential for these additional measurements to fulfill NOAA's needs must be considered in the context of the uncertainties associated with identifying acoustic targets. Fortunately, Alaska waters are a good test bed for fish measurements from autonomous vehicles as many locations are dominated by a single species (e.g., walleye pollock in the Bering Sea), and concurrent catch data may thus be less essential. We have used saildrones to help establish whether to increase the spatial coverage of a vessel-based pollock acoustic-trawl survey in the Bering Sea (2017). In 2018, we will conduct a Saildrone-based acoustic survey of Arctic cod which dominate the pelagic fishes in Chukchi Sea. This Saildrone survey will be supplemented with opportunistic trawl sampling from vessels (Figure 2).

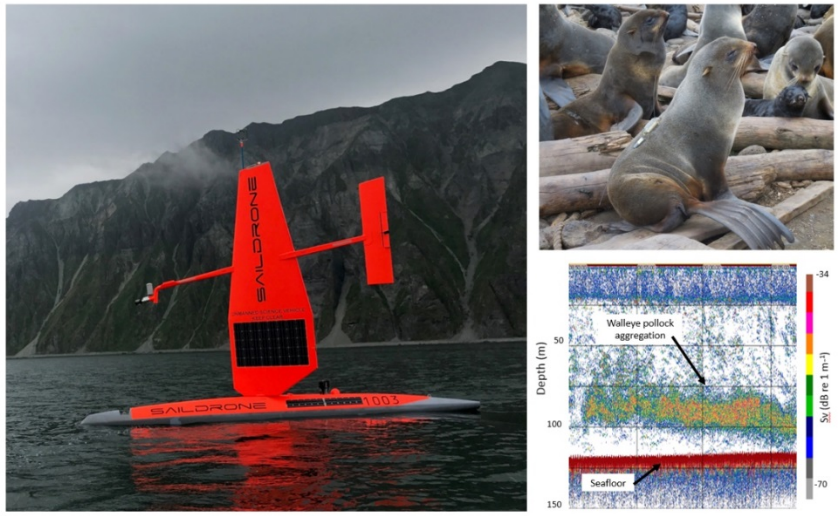
We have also been able to increase the survey coverage of marine mammals in the Bering Sea (including the critically endangered north Pacific right whale) using Saildrones. The integrated recorder allows for unobtrusive and opportunistic monitoring of marine mammals concurrently with any Saildrone project, furthering our mission of monitoring for marine mammals in Alaska waters. While the configuration is well-suited for detection of higher frequency species (e.g., killer whales), only minor modifications are needed to extend this success to other species.

One application that highlights the potential of Saildrones is a recent collaboration examining the impact of prey availability on depleted northern fur seal populations in Alaska. The Eastern Stock of northern fur seals is listed as depleted under the Marine Mammal Protection Act and pup production has decreased by approximately 49.7% since 1998. The Conservation Plan for the Eastern Pacific Stock of Northern Fur Seal proposes several objectives to restore and maintain this stock, which were used to identify conservation actions. These actions include: 1) quantify relationships between fur seals and the fish resources they rely on; and 2) describe and monitor essential fur seal habitat through continued oceanographic and fisheries surveys.

During the summer months, fur seals foraging on the Bering Sea shelf rely on walleye pollock as a primary food resource. Given the fur seals' wide-spread foraging range (> 200 km from the colony), measuring prey availability and distribution over the summer reproductive period (4+ months), would be prohibitively costly. As a result, few studies have been able to quantify how fur seal foraging behavior varies in response to fine-scale prey availability. In 2016 and 2017, we tested the ability of the Saildrones to create high resolution maps of the depth distribution and relative abundance of walleye pollock within a large portion of the fur seal foraging area (Figure 3). Net sampling during a concurrent *Oscar Dyson* survey confirmed that as in previous years, fish backscatter was almost entirely attributable to walleye pollock, with older fish distributed closer to bottom. Telemetry devices were attached to fur seals to record their location and diving behavior, and in 2017 cameras were attached to fur seals to observe feeding events and ground-truth the acoustic targets. These measurement of behavior and prey abundance (Figures 3-4), can be used to understand how the distribution and abundance of walleye pollock influence fur seal foraging behavior and foraging success, which is ultimately linked to survival and reproductive success.

Future surveys could expand the sampling region covering the entire fur seal foraging range for both Pribilof Island populations (St. Paul and St. George Island). In addition, continued surveys could address impacts of interannual variability in prey distribution and abundance on fur seal foraging behavior and reproductive success. This research will be used to fill significant gaps in our understanding of how northern fur seals in response to variations in prey resources in general, while specifically evaluating fur seal foraging behavior relative to pollock age structure.

Figure 2: Saildrone and satellite-tagged northern fur seal (top right) who's at-sea behavior was recorded while simultaneously measuring prey availability (bottom right) with the Saildrone's.



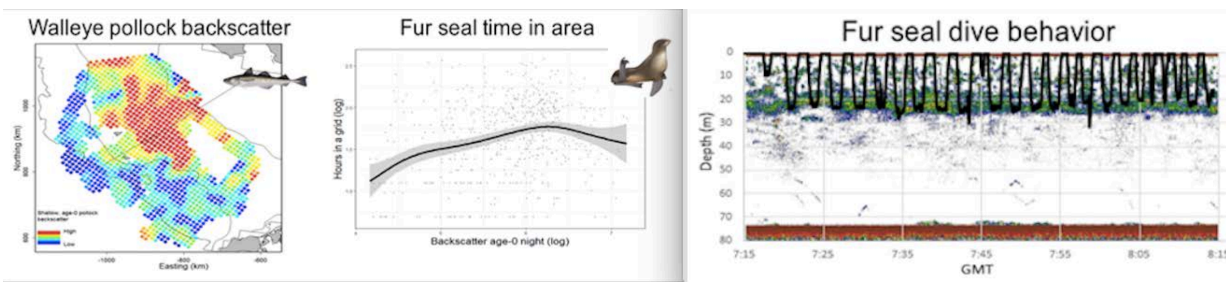


Figure 3. Examples of fine-scale relationships between fur seal behavior and prey distribution. Fur seal residence time (top right) increases with the abundance of age-0 pollock (top left) and fur seal dive behavior (bottom) is influenced by pollock depth distribution (Mordy et al. 2017).

Figure 4. In 2017, fur seals were equipped with satellite tags, dive recorders, and video cameras to quantify prey capture success in relation to prey availability measured by the Saildrone.

2c. Gliders and moorings in the Western Antarctic Peninsula: a joint activity between the SWFSC (NMFS) and Rutgers University

The Antarctic Ecosystem Research Division (AERD/SWFSC) is currently implementing a plan to replace its annual, ship-based acoustic surveys of Antarctic krill with surveys conducted by an array of upward-looking acoustic moorings and a fleet of autonomous gliders, also outfitted with acoustic sensors. The objectives of this work are 1) to quantify and understand interactions between krill, krill predators (e.g., penguins and seals), and the Antarctic krill fishery; 2) to estimate krill flux through and standing biomass in areas where krill, predators, and the fishery overlap in space and time; and 3) to identify sustainable harvest strategies for the krill fishery. The AERD's new research plan follows on the SAB's report's recommendation that robotic vehicles like gliders can now be adopted for operational studies of living marine resources. By implementing its plan, the AERD will demonstrate how an instrument-based research program, conducted in lieu of a ship-based program, can achieve NOAA's mission at reduced cost.

The AERD will leverage the strengths of both moorings and gliders to measure krill biomass across a hierarchy of temporal and spatial scales in an area used by both krill predators and the krill fishery (Fig. 5). Our moorings will measure krill flux every 20 minutes at single locations while our gliders will measure biomass on time scales of days to months and spatial scales of kilometers to hundreds of kilometers. Changes in the distribution, intensity, and timing of krill fishing have increased overlap between the fishery and krill-dependent predators around the Antarctic Peninsula. We need to address basic scientific questions about local depletion or accumulation, active aggregation, and advection of krill (collectively termed "flux"), and we need to measure the local circulation. We also need to provide estimates of krill biomass that are useful for setting catch limits. Thus, we have designed a research program that embeds local measurements of krill flux within acoustic surveys that are informative at fishery-management scales.

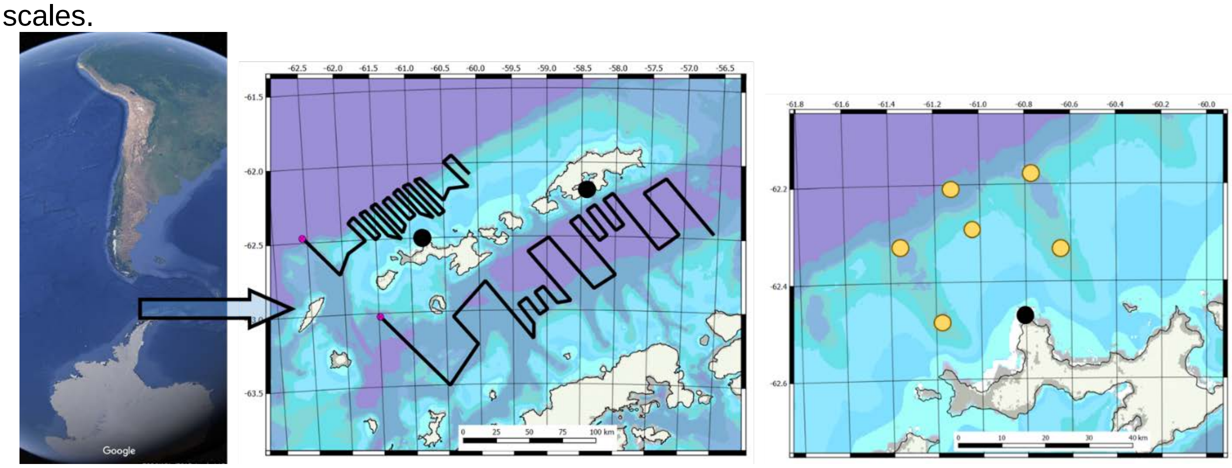


Figure 5. Planned glider tracklines (black lines with starting points indicated by magenta circles, center panel) and mooring locations (yellow circles, right panel) in the Antarctic Peninsula region (left panel, screenshot from Google Earth) during FY19. One glider will transit each set of tracklines, with the northern (upper) set transited approximately three times and the southern set transited twice during FY19. The AERD will revise this plan to include additional tracklines for the third glider procured in FY18. The black circles in the both the center and right panels indicate the approximate locations of seasonal field camps operated by the AERD. Personnel from the AERD will monitor foraging dynamics and reproductive successes (failures) of krill-dependent predators at both camps, these predators are known to forage in the locations where the glider tracklines are spaced relatively close together.

During FY17, the AERD procured six Signature100 acoustic Doppler current profilers (ADCPs) from Nortek (https://www.nortekgroup.com/) and two Slocum G3 gliders from Teledyne Webb (http://www.teledynemarine.com/webb-research/). The Signature100 profilers are the only ADCPs on the market integrated with a wideband echosounder. These “ADCP/Es” will be deployed in upward-looking moorings that are anchored on the seafloor (to minimize losses from icebergs) and used to simultaneously measure current direction, current velocity, and krill biomass. The moorings will also be outfitted with CTDs to synchronize the collection of hydrographic data with those on krill. The G3 gliders procured by the AERD are the largest gliders ever produced by Teledyne Webb, with a sensor payload intended to replace as many ship-based observation series as possible (CTD, O_2, fluorescence of *chl-a* and CDOM, transmissometry, and active acoustics at three frequencies) and additional batteries intended to maximize endurance (estimated to be nine months) (Figure 6).

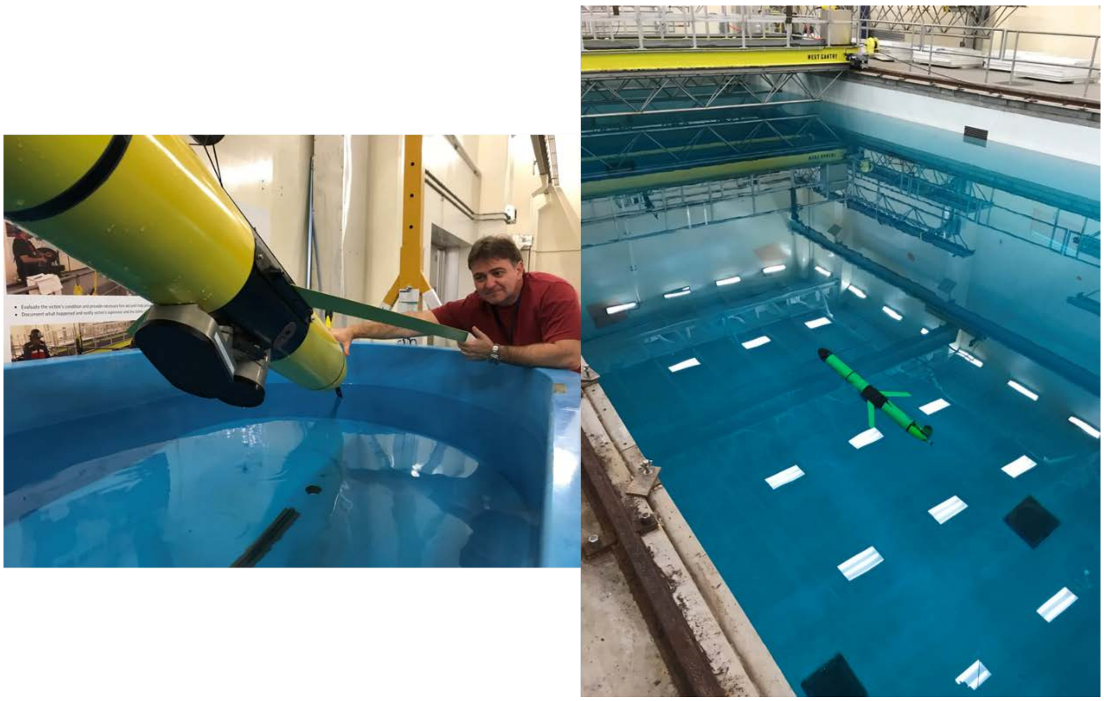
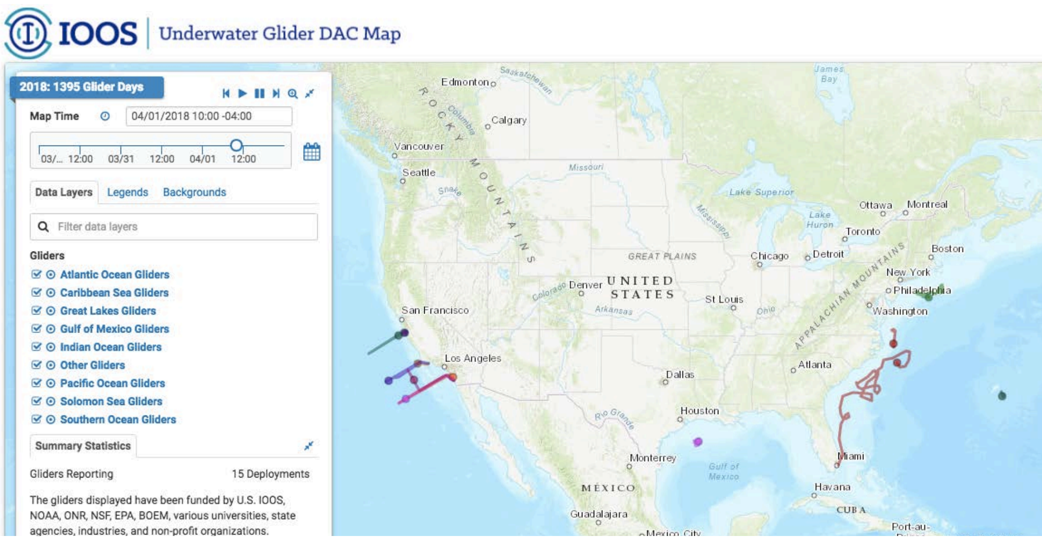


Figure 6. One of the AERD’s Slocum G3 gliders. The left panel shows the acoustic sensors (38, 68, and 125 kHz) mounted on the ventral surface of the glider as we lower into a small tank we use to ballast the vehicle. The fluorometer-transmissometer is barely visible as a small, brown circle on the port side of the vehicle, just above the aft-most acoustic transducer. The CTD is directly opposite the optical sensor on the starboard side of the vehicle (not shown), and the oxygen sensor is near the tail of the vehicle, just behind and beneath Dr. Christian Reiss’ right hand (also not shown). The right panel shows the glider surfacing from a training dive in the SWFSC’s Technology Tank.

During FY18, the AERD is testing and calibrating its new equipment, developing operating procedures to deploy and recover the gear in Antarctica, and training to become experienced glider pilots. We have tested the ADCP/Es and the gliders in the SWFSC’s Technology Tank (e.g., Figure 6), and engaged with engineers from both Nortek and Teledyne Webb to address a range of technical issues. We have planned the fine details associated with deploying and recovering our gear, including establishing an Interagency Agreement with the National Science Foundation to procure the sea-days needed for these operations. We will ship our equipment to Chile in August and implement our research plan in Antarctica in October.

2d. U.S. Integrated Ocean Observing System (IOOS) Glider Network (https://gliders.ioos.us/)

Gliders are a unique and important observing system used to serve a variety of subsurface observing missions. Gliders can monitor water currents, temperature, tagged animals and conditions that reveal effects from storms, impacts on fisheries, and the quality of our water. This information creates a more complete picture of what is happening in the ocean, as well as trends scientists might be able to detect. These versatile vehicles collect information from deep water, as well as at the surface, at lower cost and less risk than ever before. As scientists deploy more gliders, they are revolutionizing how we observe our ocean. These robots propel us closer to that revolution.



Active glider deployments from the Data Assembly Center (DAC) site (as of 4/1/2018). The gliders displayed have been funded by U.S. IOOS, NOAA, ONR, NSF, EPA, BOEM, various universities, state agencies, industries, and non-profit organizations. Please refer to https://gliders.ioos.us/map/ for additional information.

The IOOS Program Office has taken an active interest in this particular observing system as our regional operators collect a lot of the glider data around the coastal US and the gliders show extensive value in subsurface water column observing. As a result, we are managing a national glider data assembly center and we have established an Underwater Glider User Group (UG2). Glider Applications Include

- Ecosystem dynamics monitoring
- MBARI dye tracking experiment
- Test performance of acoustic receivers and other sensors
- Fish stock mapping of Red Grouper and others
- Glider speed testing in the Gulf Stream
- Harmful Algal Bloom (HAB) mapping
- Listening to tagged fish, whale acoustics
- Sustained and targeted ocean observations for improving tropical cyclone intensity and hurricane seasonal forecasts
- Upper ocean monitoring of U.S. Caribbean/ Atlantic Economic Exclusion Zone (EEZ)
- Sampling around Station ALOHA and other long term stations
- Hydrographic mapping
- Ocean acidification sampling
- Climate monitoring

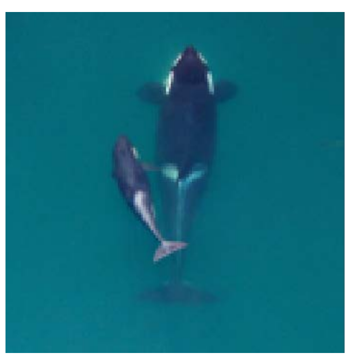
<u>2e. Small Unmanned Aerial Systems (sUAS, or “Drones”) as emerging technologies for NOAA</u>

John.Durban@noaa.gov, *Cetacean Health and Life History Program (SWFSC) in collaboration with OMAO (Office of Marine & Aircraft Operations) and OST (Office of Science & Technology).*

The report from the NOAA Science Advisory Board (December 2016) listed the use of "drones" or small Unmanned Aerial Systems (sUAS) as important to watch for future applications.

Flying cameras. Photographs from manned aircraft have historically been used by scientists to count aggregations of protected marine wildlife that are too numerous to estimate by eye. Similarly, aerial photographs of Endangered whales have allowed pregnancies to be documented and the health of free-swimming individuals to be assessed, to augment abundance-based stock assessments and facilitate targeted recovery actions. However, manned platforms are expensive, not always available in marine environments and remote locations, may disturb the animals being studied, and, in some cases, subject scientists in the field to an unacceptable level of risk. In response to these challenges, scientists from the Cetacean Health and Life History Program (CHLHP at the SWFSC), with support from NOAA's OMAO and the OST, began a program in 2009 to investigate the applicability of sUAS, piloted by scientists, as a tool for assessment of protected marine species. As a result, CHLHP has pioneered the use of sUAS over the past several years to monitor the status of protected species, particularly whales. CHLHP has now completed thousands of successful flights with small multi-rotor UAS platforms launched from a variety of boat and ship platforms, and from shore, in marine habitats ranging from the tropics to the poles in three ocean basins.

Application to whale health assessment. Because these small and quiet drones can operate at lower altitude without disturbance to the animals, we are obtaining images of higher quality than ever before. This allows us to identify individual whales based on natural markings and track their health and reproductive history (rather than just monitor at the population level). As an example, within the Endangered population of Southern Resident Killer Whales, a NMFS *"Species in the Spotlight"*, we are identifying whales in poor body condition and pregnancies that are not leading to successful births. This is advancing studies to identify health responses to key threats faced by the population, and thus support targeted recovery actions.



We are also using sUAS platforms to collect samples of whale breath from several species, including Endangered North Atlantic right whales, humpback whales and blue whales. Genetic analyses of these blow samples are being used to identify microorganisms from the respiratory tracks of the whales, to better-understand health and emerging disease issues.


Of relevance to the wider utility of sUAS across NOAA line offices, our successful applications have demonstrated that drones have the potential to offer the advantages suggested in the SAB's 2016 report: specifically providing more coverage and making more efficient use of large infrastructure assets, thus offering the potential for long-term cost savings. Additional utility is likely to be achieved as we develop longer-duration drones that can augment sampling from ships, and also adopt the routine use of sUAS platforms that can be easily and quickly deployed from ship, boat and shore platforms when needed, decreasing our dependence on the availability of manned aircraft.

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2f. Use of Unmanned aerial systems (UAS) for assessing marine mammals. Alaska Fisheries Science Center (contact: robyn.angliss@noaa.gov)

Unmanned aerial systems (UAS) technologies could augment or replace manned aerial surveys, particularly in areas that are very remote and challenging to access using manned aircraft. In addition, UAS are less to disturb marine mammals, they are less expensive for some applications, they reduce risks to people in aircraft, and they are able to collect data that cannot be collected using manned aircraft.

Short-range UAS have become a common tool for some AFSC research programs. The AFSC is now using one system, the APH-22 hexacopter, during routine field operations to collect imagery to assess Steller sea lion abundance and pup production (Sweeney et al 2016; Figure 7). We have expanded our use of this platform to collect imagery to assess Steller sea lions off the coast of Washington and Oregon in areas that are particularly hard to access, and in 2017 we used the platform to collect images of Cook Inlet beluga for photogrammetry and photo-identification. In 2018, the AFSC will evaluate the capability of two new short-range UAS for collection of imagery for mark-recapture of northern fur seals and enumeration of harbor seals, and is investigating the use of UAS for collection of large whale photogrammatic information.

Figure 7: Using the APH-22 hexacopter to collect images of Steller sea lions in the western Aleutians.

The AFSC first used UAS with long-range capability in 2008 (Moreland et al 2015; supported by the NOAA UASPO in partnership with the University of Alaska, Fairbanks; Figure 8), with the long-term plan of transitioning some long-range surveys for marine mammals to UAS. Results of a recent field comparison of manned and UAS surveys indicated estimates of UAS (Angliss et al in review, Ferguson et al in review; supported by BOEM, ONR, the NOAA UASPO, and in partnership with the Navy and Shell Oil).

Short-range, within line-of-sight UAS operations have provided outstanding mission-critical imagery of both pinniped and cetaceans. These surveys are relatively inexpensive and have become routine and highly successful for a number of projects. In contrast, long-range, beyond line-of-sight UAS surveys are complicated, expensive, and experimental. Considerable additional work will be needed to make long-range surveys effective and affordable. Transitioning to a new long-range UAS platform will require scientific rigor and substantial resources.

Outstanding needs for UAS operations:

- A small, inexpensive (< $10K) vertical take-off-and-landing system for short-range applications that is less expensive than the APH-22 or APH-28 (~$35K) and is approved for use by OMAO.

- Purchasing or partnering to access large, robust, weather-tolerant UAS capable of long-range flights.
- Autodetection and automated processing systems are needed to speed data analysis.
- Improved sensor technology.
- Ability to integrate and power multiple visual and infrared imaging sensors and digital data storage.
- A temperature and humidity sensor capable of detecting icing conditions should be available for UAS that are used beyond visual line-of-sight.
- UAS with additional “weatherproofing” that can fly in light precipitation.

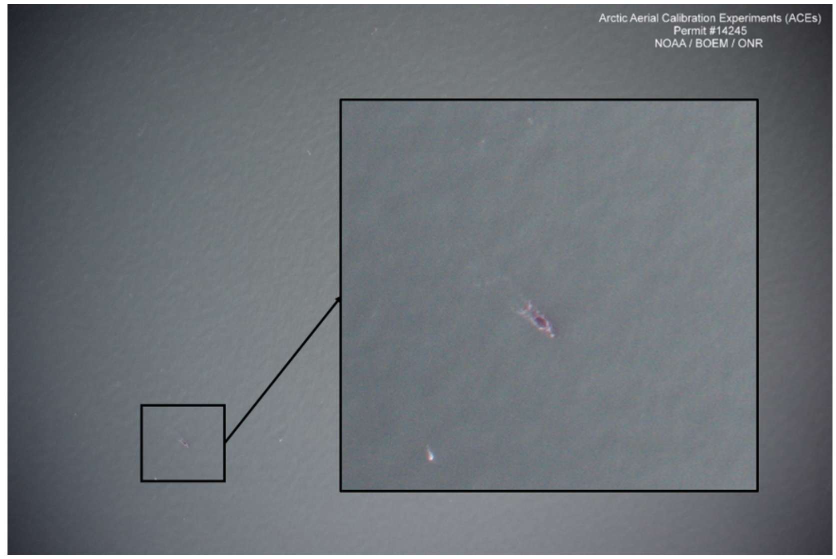

Figure 8: Bowhead whale image collected from a ScanEagle UAS in the Arctic, August 2015. Image is modified to show additional detail of the whale.

- Internal expertise embedded in Science Centers with the technical ability to interface various hardware and software needed for the UAS surveys.
- Expert assistance with planning a series of progressively complicated missions to enable the transition from manned to long-range, beyond line-of-sight UAS surveys along highly complex coastlines over long distances.

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3. Imaging

Following the December 2016 report from NOAA's SAB on Emerging Technologies for NOAA Ocean Research, Operations and Management in an Ecosystem Context, NOAA' Pacific Islands Fisheries Science Center (PIFSC), Alaska Fisheries Science Center (AFSC), and the Northeast Fisheries Science Center (NEFSC) continue to develop and improve sophisticated in situ imaging systems, e.g., with robotic vehicles, towed, etc., as well as machine learning systems (AI) and automated image analysis software. A brief review follows below.

3a. Robotic imaging (MOUSS) and machine learning (AI) systems. Pacific Islands Fisheries Science Center (contact: benjamin.richards@noaa.gov)

Imaging

PIFSC developed the MOUSS (Modular Optical Underwater Survey System; Figure 9) (Amin et al., 2017) to study abundance and identify juvenile habitat for deep-water snappers and to generate fishery-independent, species-specific, size-structured abundance estimates of the commercially important "Deep-7" bottomfish stock. These fishery-independent data were incorporated into the 2018 Bottomfish Stock Assessment (Langseth et al., 2018). These bottomfish, which include six species of deep-water snapper and one deep-water grouper, exhibit low rates of natural mortality and a susceptibility to overfishing, making non-extractive surveying methodologies particularly ideal in marine protected areas. MOUSS is a modular, low-light, stereo-video camera system designed to collect species-specific, size-structured abundance data using ambient light. MOUSS has been tested from vessels as small as 19' LOA and can effectively operate to a depth of 250m in Hawaiian waters.

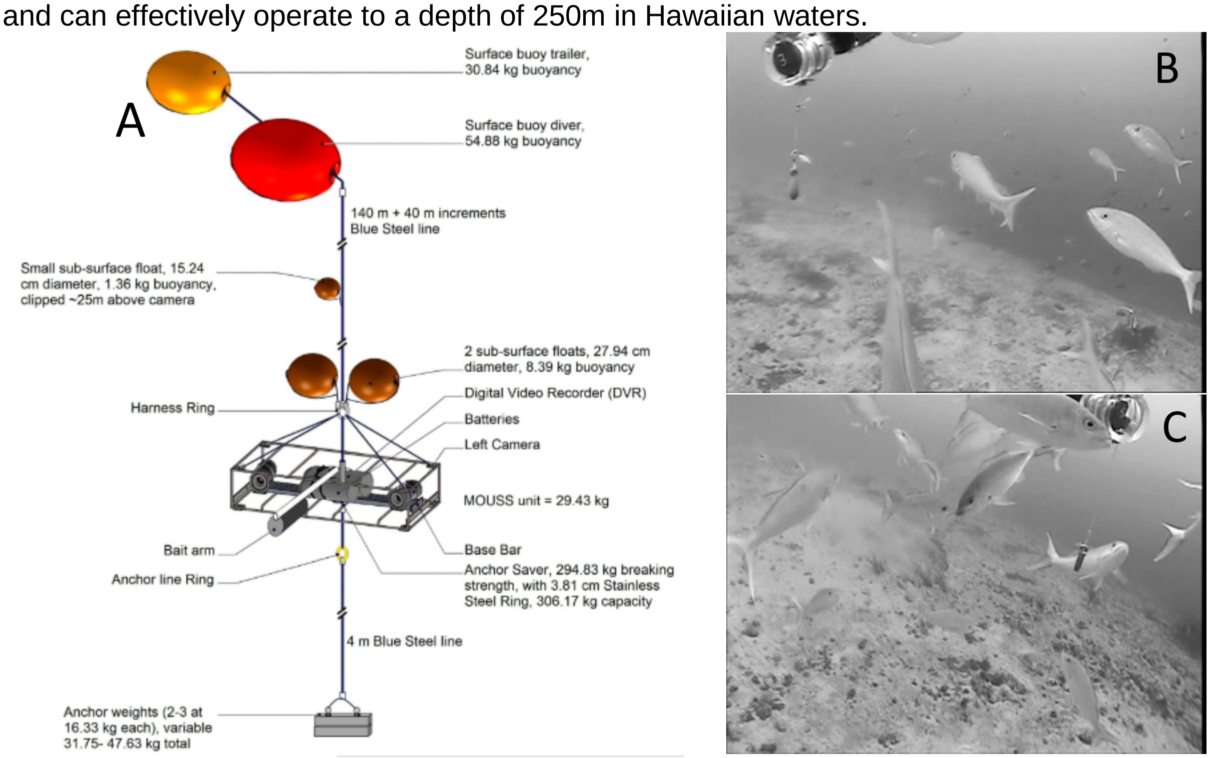

Figure 9. (A) The MOUSS (Modular Optical Underwater Survey System) used by the NOAA's PIFSC to collect fishery-independent, species-specific, size-structured abundance data for target species. Example images from MOUSS including Kalekale (B) and Opakapaka (C).

Automated Image Analysis & AI

Robotic imaging systems are capable of generating data volumes that quickly exceed the capabilities of human analysists. MOUSS typically generates hundreds of thousands of images over the 12 days of the BFISH survey. Other robotic imaging systems, including the AFSC CamTrawl (Williams et al., 2016) and the NEFSC HabCam (Howland et al., 2006), generate similar data volumes. In 2014, NOAA's Office of Science and Technology formed the Automated Image Analysis Strategic Initiative (AIASI) (Richards et al., 2018) to develop guidelines, set priorities, and fund research to develop broad-scale, standardized methods for automated analysis of still and video imagery for use in stock assessment. The goal of the AIASI was to create an end-to-end open source software toolkit allowing for the automated analysis of optical data streams to provide fishery-independent abundance estimates for use in stock assessment.

Figure 10. An example of the graphical user interface (GUI) for automated analysis of video data within VIAME. This example shows a single frame of a MOUSS video where three opakapaka (*Pristipomoides filamentosus*) have been automatically detected (yellow boxes).

In 2018, the AIASI began roll-out of VIAME (Figures 10 and 11): The Video and Image Analytics for a Marine Environment toolkit (Hoogs et al., 2018). VIAME is an open-source software system for analysis of underwater video and imagery that enables rapid, low-cost integration of new algorithmic modules, datasets and workflows. VIAME leverages developments in machine learning from the human surveillance and biomedical fields, as well as deep learning research funded through DARPA, to create automated analysis pipelines for processing of marine video data. VIAME has been tested at the AFSC and NEFSC for streamlined analysis of CamTrawl data for the Pollock and HabCam scallop surveys, respectively.

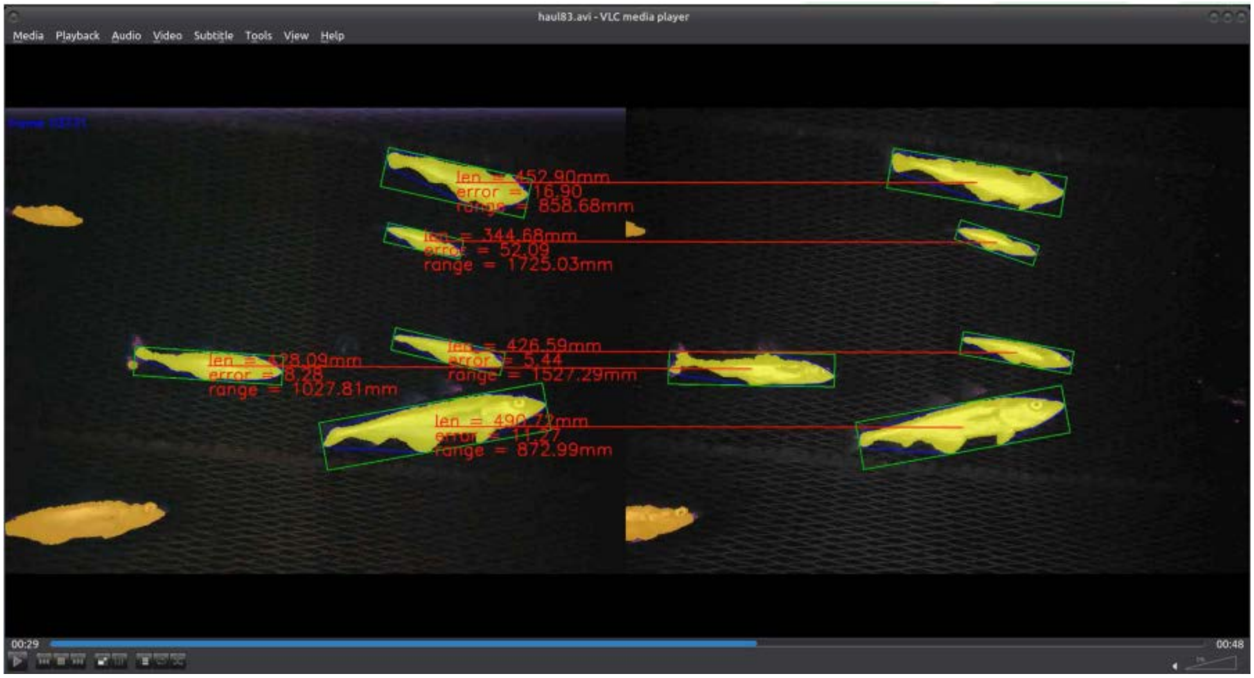

Figure 11. A screen-grab of the VIAME graphical user interface (GUI) showing automated detection and sizing of walleye Pollock from AFSC CamTrawl video.

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3b. Stereo camera systems to address fisheries stock assessment needs: AFSC's CamTrawl.

Several innovative stereo camera systems have been developed by the AFSC, Midwater Assessment and Conservation Engineering (MACE) Program to improve efforts to address fisheries stock assessment needs. These camera systems serve to increase traditional acoustic-trawl survey efficiencies and/or to provide new assessment tools and methods to estimate fish abundance in areas where the traditional survey methods cannot be successfully utilized (e.g., untrawlable habitats). The MACE camera systems can be classified as an integrated camera-trawl system (CamTrawl), versus a class of camera packages that are deployed on their own, as units that are moored on the seafloor or lowered/raised via a conducting cable from a support vessel. Both classes of camera packages are described below.

CamTrawl is an integrated tool that involves placement of a stereo camera package inside a large midwater trawl, which is routinely used in traditional acoustic-trawl surveys (Figs. 12 and 13). The camera-trawl system provides a time/depth-specific species and size composition of fish passing through the midwater trawl over the entire haul path. This makes CamTrawl valuable for identifying acoustically sampled layers at finer resolution than possible when traditional trawl sampling methods (i.e., no CamTrawl) are used during acoustic-trawl surveys. Prior to the CamTrawl, survey scientists would often conduct multiple trawl hauls to separately sample shallow and deep fish acoustic scattering layers. Customized image analysis software has been developed by MACE to automatically process CamTrawl data. Thus, image-based estimates of fish length and species composition are quickly and efficiently extracted from image data. Analysis typically occurs aboard the vessel during an acoustic-trawl survey, and length measurements by species are entered into a database alongside bio-physical measurements.

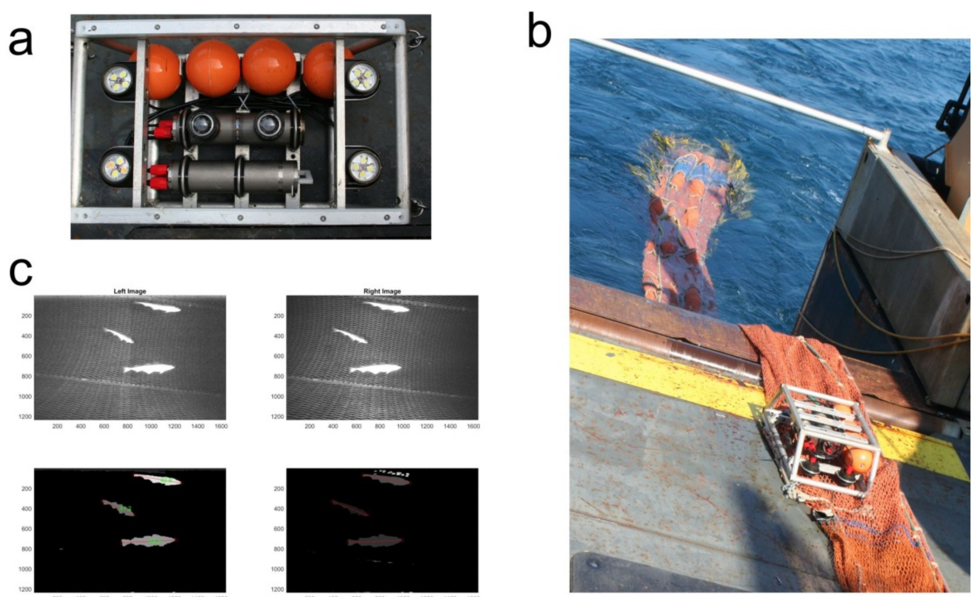


Figure 12. CamTrawl stereo camera system operations during a MACE acoustic-trawl Survey. A) The CamTrawl camera system consists of a camera / computer housing, four high power LED strobes, and a battery housing. B) The CamTrawl camera system is attached the midwater trawl forward of the codend. C) Example CamTrawl images viewed with the MACE customized automated image analysis software.

Image-based sampling with CamTrawl also has the potential to improve overall survey efficiency by reducing the need for traditional catch processing. MACE scientists are evaluating the conditions under which the CamTrawl image data may be used as the primary data for the survey, and will develop a set of guidelines that will further improve our efficiency and potentially allow more data to be collected with fewer sea-going staff.

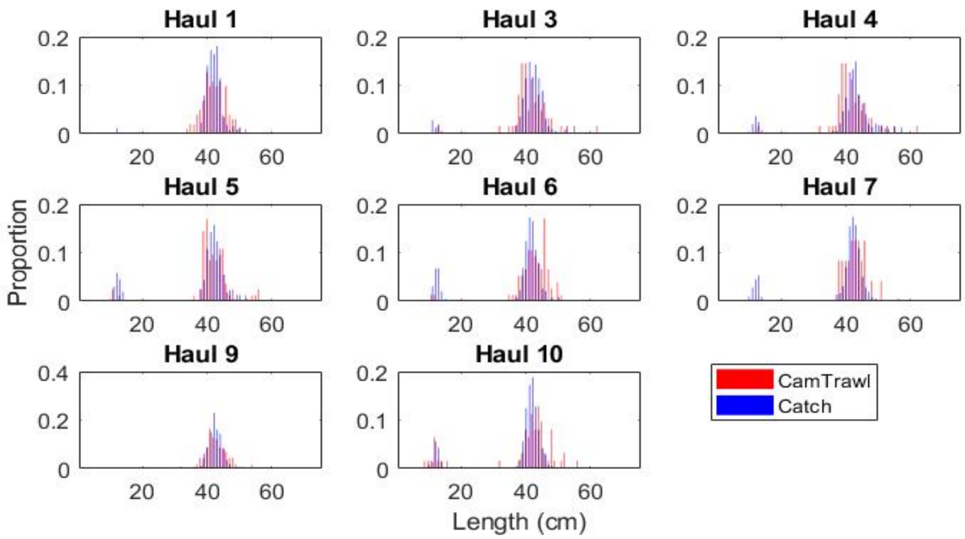


Figure 13. CamTrawl stereo image-based lengths (CamTrawl) compared with measured fish in the midwater trawl codend (Catch). CamTawl lengths were estimated via automated image processing.

Lowered stereo-cameras (LSC)
Primarily used to identify near-bottom acoustic backscatter in untrawlable grounds during exploratory surveys and studies (Fig. 14). This camera system provides a live image feed to the vessel to aid in maneuvering the instrument. Stereo imagery is processed manually using a stereo-analysis software built by MACE. In addition to species and length information extracted from CamTrawl imagery, LSC data can also be used to estimate fish orientation and position relative to the sea floor. The latter is a critical component in the use of acoustics near the sea floor, where fish density can be misrepresented by the interaction of the acoustic sensors with the sea floor. A newer miniaturized LSC device is currently being developed to sample pelagic fish aggregations. The small size of this device is less likely to elicit avoidance reactions from the fish, allowing for a new method of validating acoustic backscatter from the water column.

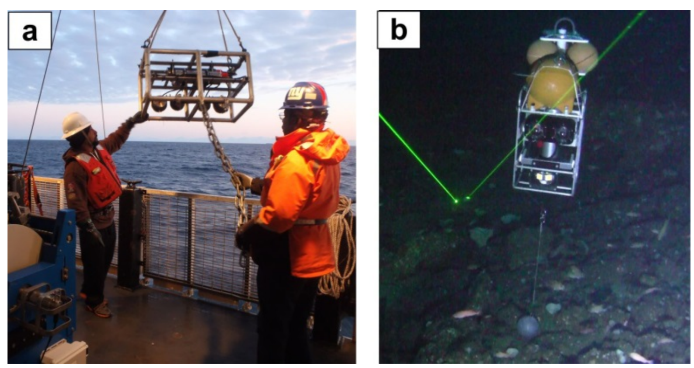


Figure 14. a) Lowered stereo camera (LSC), and b) moored stationary cameras used for assessing rockfish in untrawlable habitat.

3b. Towed camera systems to address fisheries stock assessment needs: NEFSC's HabCam. A collaboration between NOAA/NEFSC, NOAA/PIFSC and WHOI.

HabCam is a vessel-towed underwater digital camera system developed through collaborations of commercial fishermen and scientists from Woods Hole Oceanographic Institute (WHOI) and

NOAA (Figure 15a). HabCam documents the size and abundance of benthic and demersal organisms and maps sea floor habitats (Figure 15b). The cameras on HabCam take rapid-fire still photos of the sea floor (~6/sec) while the vehicle is towed at speeds between 5-7 knots at roughly 2 m above the bottom. Region-scale HabCam surveys have been conducted since 2011 (Figure 15c; 2016 survey). Other institutions are also using HabCam to document the scallop resource. These data are used in the sea scallop assessments and the sea scallop fishery is one of the nation's most valuable. Data collected in the summer of 2018 will be processed and used in an assessment conducted in early fall 2018 and the assessment results will be used to set catch limits and fishing areas for the 2019 fishing year. Other data are used in the assessment, but the NEFSC HabCam survey is an integral part and represents a successful application of new technologies to the NOAA Fisheries mission.

Figure 15 (a, b, c): HabCam system deployment, benthic and demersal organisms and habitat, and HabCam survey.

Although successful, there are several ongoing efforts that will improve the use of HabCam in NEFSC assessment activities. These improvements meet the ADOPT NOW recommendation of NOAA's SAB. The management of the large-set of image data related to the sea scallop survey is currently being transferred from WHOI to the NEFSC. This transfer requires investment by the NEFSC in servers, database systems for images, and storage. It also requires staff learning new data processing and management skills. A second effort involves automating the analysis of HabCam imagery. Currently, imagery is manually annotated, and these annotations are used as the basis for extracting information from the database. NEFSC scientists have been participating in the NMFS' Strategic Initiative on Automated Image Analysis. The goal of this initiative is to develop guidelines, set priorities, and fund projects to develop broad-scale, standardized, and efficient automated tools for the analysis of optical data for use in stock assessment. The tool under development is the VIAME: An Open Source Framework for Underwater Image Processing (see Section 3a above).

In addition to documenting the scallop resource, the NEFSC is interested in extending the use of HabCam to other fish and invertebrate resources and for benthic habitat characterization. These extensions meet the SAB's IMPORTANT, WATCH FOR FUTURE APPLICATIONS recommendation. Preliminary evaluations for surveying yellowtail flounder have been completed but extending this work is not currently a priority. Partners at the Center for Coastal and Ocean Mapping/ Joint Hydrographic Center and WHOI have been using HabCam imagery for bentho-pelagic habitat characterization. The NEFSC is supporting this work through dedicated HabCam deployments during sea scallop surveys and partners. This work has the potential to contribute to the scallop assessment, other assessment activities conducted by the NEFSC, and broader uses of benthic habitat information throughout the region (e.g., wind energy siting). The NEFSC will continue to extend the use of HabCam in the region, but the near-term priority is to complete the research to operations activities related to the sea scallop survey and assessment.

3c. Steller Watch: An online crowdsourcing project to analyze Steller sea lion images. Alaska Fisheries Science Center and NCEI (contact: katie.sweeney@noaa.gov)

The AFSC's Marine Mammal Laboratory (MML) has joined NOAA's National Centers for Environmental Information (NCEI) and NASA in the realm of crowdsourcing. Steller Watch is an online project that launched in the spring of 2017 in order to help MML biologists process hundreds of thousands of images. Twenty-one cameras have been stationed at six known Steller sea lion sites in the western and central Aleutian Islands (Fig. 16). These cameras are automated to capture images every 5-20 minutes, during daylight hours, year-round. This remote camera project is a long-term effort to help to study the endangered population of Steller sea lions in western Alaska.

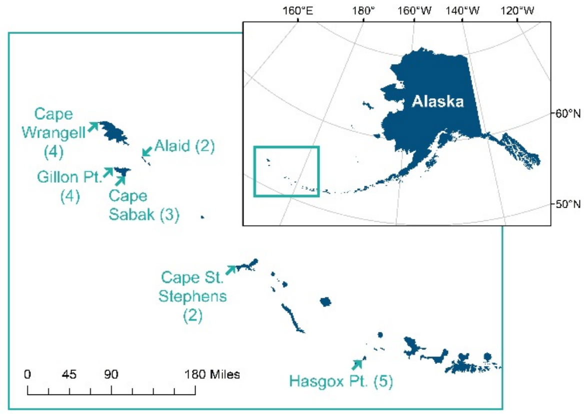


Figure 16. The six sites and number of cameras stationed at each site in the Aleutian Islands.

Because this area is so remote, AFSC can only access these cameras to retrieve images once a year during the annual research cruise. Retrieving these images is essential to collect sightings of known individuals that have been permanently marked with a unique symbol or letter and number (by hot-branding; Fig. 17). This is the only method that is feasible, safe for the animals in the short and long term, and most importantly, provides invaluable data towards understanding why this endangered population has declined 94% in the last 30 years in the western Aleutian Islands.

Figure 17. A marked animal is spotted in a remote camera image six sites and number of cameras stationed at each site in the Aleutian Islands.

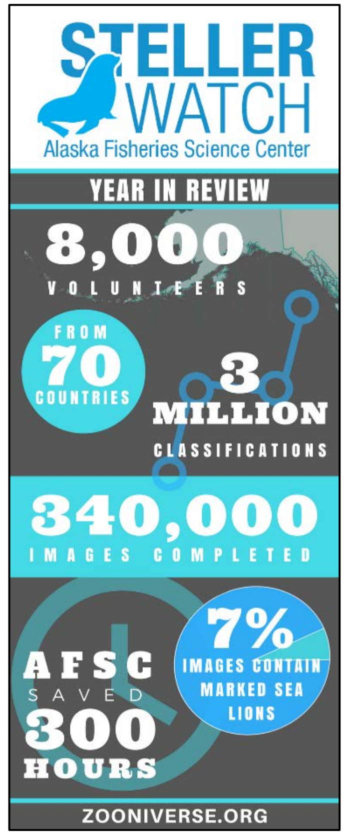
Since initiating this project in 2011, MML has collected up to half a million photographic images each year. Without the resources to process these images as quickly as they're collected a backlog has developed. However, timely review of the photos is necessary for current estimates of vital rates for this population. This information will offer insights into what is driving the population to continue to decline in the western Aleutian Islands and impeding recovery in the central Aleutian Islands[4]. In an effort to alleviate this backlog in processing, MML looked to the power of the crowd for identifying the most important images for MML biologists to review.

Crowdsourcing is becoming an ever-popular solution for addressing the challenges of processing or analyzing large amounts of data that cannot be automated as the task requires the particular abilities of the human eye. There are many different avenues and networks for

[4] Pendleton, G. W., Pitcher, K. W., Fritz, L. et al. (2006). Survival of Steller sea lions in Alaska: a comparison of increasing and decreasing populations. Canadian Journal of Zoology, 84(8), 1163-1172.

crowdsourcing and Zooniverse.org is one of the leading groups. This online platform has developed and hosts over 60 projects, welcoming anyone with a computer, tablet, or phone and an internet connection to participate, including Zooniverse's network of over a million registered citizen scientists. These projects have a simple interface that allows users to view media (most commonly images or video or sound recordings) and answer a set of questions. There is a short tutorial and guide available but these workflows are intended to be relatively straightforward, simple, and brief.

In the case of Steller Watch, our project workflows present images to the user who then answers one simple question about the image: Are there sea lions present? Are there marked sea lions present? Each answer by a single user is called a 'classification.' For quality control measures, each image must be viewed and classified by multiple users before the image is retired, or completed. The average or majority answer can then be appropriately accepted.



In addition to helping alleviate the burden of processing images so MML biologists may focus their efforts on other research priorities, Steller Watch is an invaluable avenue for outreach. Sharing the importance of NOAA Fisheries' mission, research, and conservation efforts of our Nation's protected resources is performed through the project site content and project blog. The project blog is a great way to engage and inspire continued interest in the project by sharing stories of recent field work, current research, and general information. There is also a forum where citizen scientists can engage, or "chat" with each other and MML biologists to ask questions, participate in thoughtful conversation, and share interesting images.

In our first year, we have had over 8,000 volunteers from 70 countries participate in Steller Watch. Our team of citizen scientists have conducted over 3 million classifications, completing almost 340,000 images. Their efforts help MML biologists narrow down hundreds of thousands of images to the 7% of highest priority images with sea lions present that have a readable mark. So far, this has saved MML over 300 labor hours of reviewing images.

3d. Multi-spectral imaging for surveys of seals in the Arctic. Alaska Fisheries Science Center (contact: peter.boveng@noaa.gov)

The Alaska Fisheries Science Center has replaced traditional visual survey observers with coupled thermal and color imaging systems in aerial surveys for four species of ice-associated seals (Conn et al. 2014, Sigler et al. 2015). Thermal imagers enable detection of warm-bodied seals against the cold background of the sea ice, and the paired, high-resolution color cameras enable identification of species and age class of the seals (Fig. 18). Advantages of this imaged-based approach include:

- It produces a permanent record of the ‘sightings’ that can be used to quantify detection rates and species misclassification rates, both of which are difficult to do for visual surveys, and the image-based detection rates are higher;
- It allows the survey aircraft to fly higher and faster, enabling greater coverage and making surveys safer for personnel and less disruptive to target species;
- It requires fewer personnel in the aircraft, reducing risk and costs; and
- The detection process and, potentially, the species identification can be automated by image analysis and machine-learning approaches.

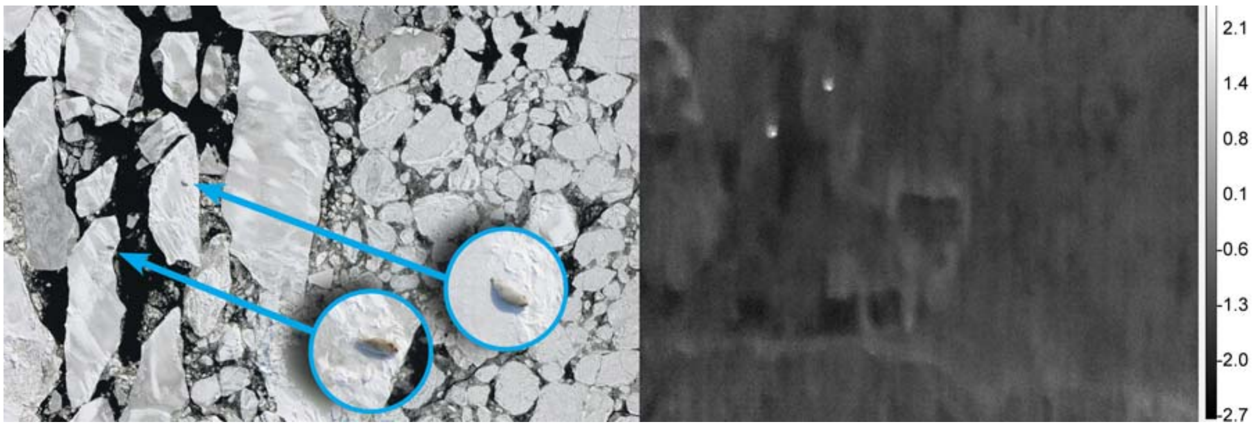


Figure 28. Example of two adult bearded seals detected using thermal (right panel) imagery.

This imaged-based approach and associated advances in statistical methods have enabled the first comprehensive surveys for seals in the entire sea-ice-covered zones of the Bering and Chukchi seas (e.g., Fig. 19), where no reliable abundance or trend estimates have been available to support stock assessments.

Remaining transition challenges include:

- Development of machine-learning algorithms to increase effectiveness of automation (reduce false positives that require manual intervention) in image analysis, thereby reducing the time and cost for post-processing of survey data;
- Incorporation of a broader spectral range—for example by adding a UV imager or replacing the thermal-color system with a hyperspectral system—could increase the reliability of automated detection and make the method applicable to polar bears as well as seals. Combining species would enable cross-departmental leveraging of resources with U.S. Fish and Wildlife Service and U.S. Geological Survey(Conn et al. 2016).

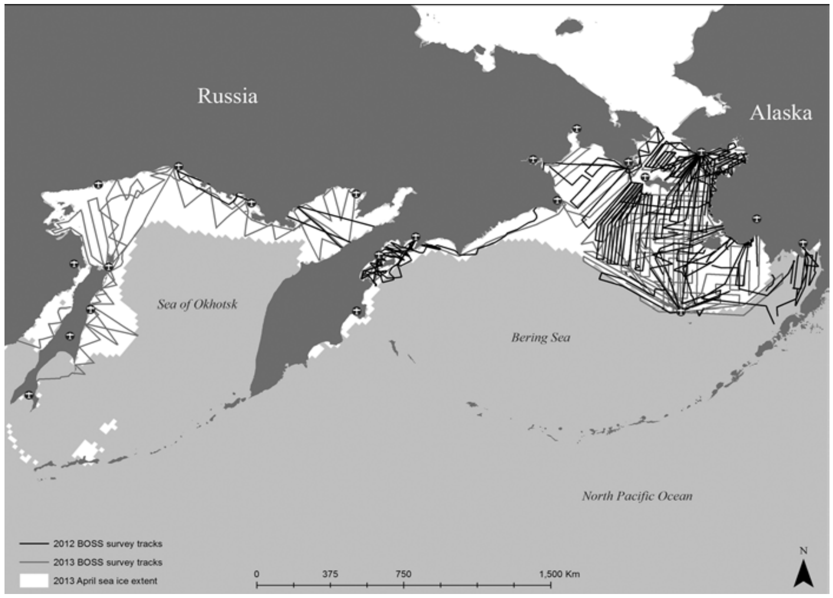


Figure 19. Track lines from joint U.S. – Russia image-based aerial surveys of the Bering and Okhotsk Seas, 2012-2013.

References

Conn, P. B., E. E. Moreland, E. V. Regehr, E. L. Richmond, M. F. Cameron, and P. L. Boveng. 2016. Using simulation to evaluate wildlife survey designs: polar bears and seals in the Chukchi Sea. Royal Society Open Science **3**:150561.

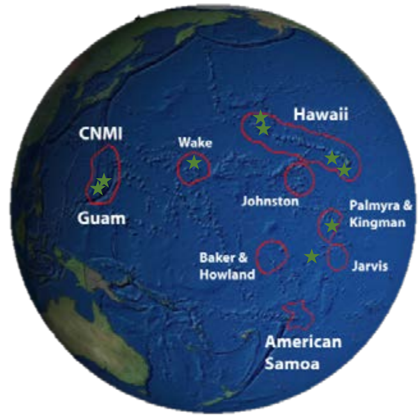
Conn, P. B., J. M. Ver Hoef, B. T. McClintock, E. E. Moreland, J. M. London, M. F. Cameron, S. P. Dahle, and P. L. Boveng. 2014. Estimating multispecies abundance using automated detection systems: ice-associated seals in the Bering Sea. Methods in Ecology and Evolution **5**:1280-1293.

Sigler, M., D. DeMaster, P. Boveng, M. Cameron, E. Moreland, K. Williams, and R. Towler. 2015. Advances in methods for marine mammal and fish stock assessments: thermal imagery and CamTrawl. Marine Technology Society Journal **49**:99-106.

4.   Other technologies: Passive Acoustics, drones, orbital platforms

A range of other emerging and advances technologies are being used in NOAA. We briefly discuss Passive Acoustic Methods and other methods not discussed above.

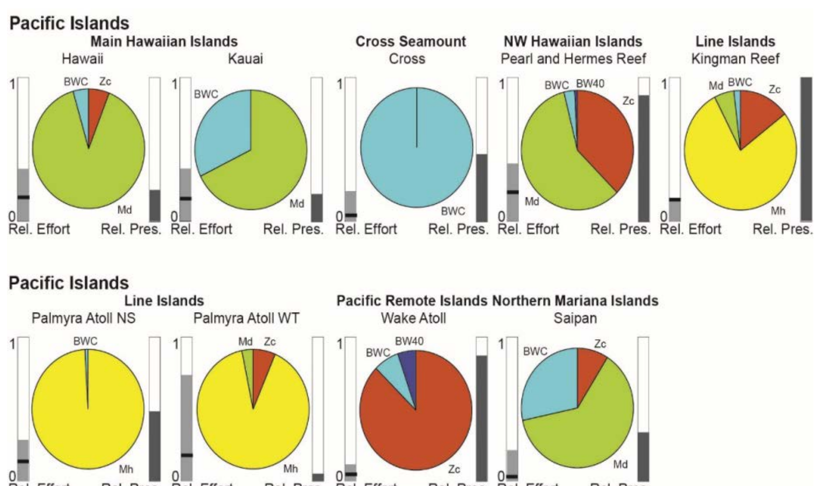
<u>4a) Passive Acoustic Tools for Cetacean Research within NMFS Science Centers.</u> All NMFS Science Centers use passive acoustic tools to listen for cetaceans in our areas of responsibility.



Pacific Islands Passive Acoustic Network

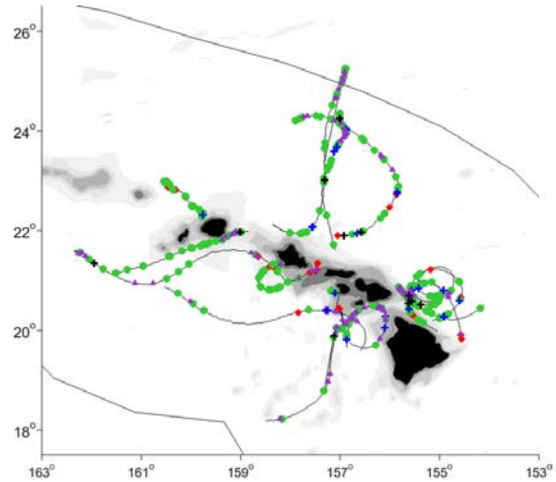
Long-term Autonomous Recorders outfitted with large battery packs and hard drives, provide a capacity for continuous recording for days to years. At PIFSC, long-term acoustic recorders are used to monitor for cetaceans, ambient, and human-caused noise at Pacific Island Passive Acoustic Network (PIPAN) sites. PIPAN data collection began in 2006 and provides species occurrence, seasonality, and long-term changes in species distribution. The data can be combined with visual survey, oceanographic, and other datasets to relate the known occurrence of specific animals with the acoustic record, to understand behavioral context of sounds, and to evaluate environmental drivers of cetacean occurrence.

Geographic occurrence of beaked whales at PIPAN sites across the central and western Pacific. Zc = Ziphius cavirostris (Cuvier's beaked whale), Md = Mesoplodon densirostris (Blainville's beaked whale), BWx = unidentified beaked whales with specific signal characteristics. Adapted from Baumann-Pickering, et al. 2014, PlosONE 9.1: e86072.



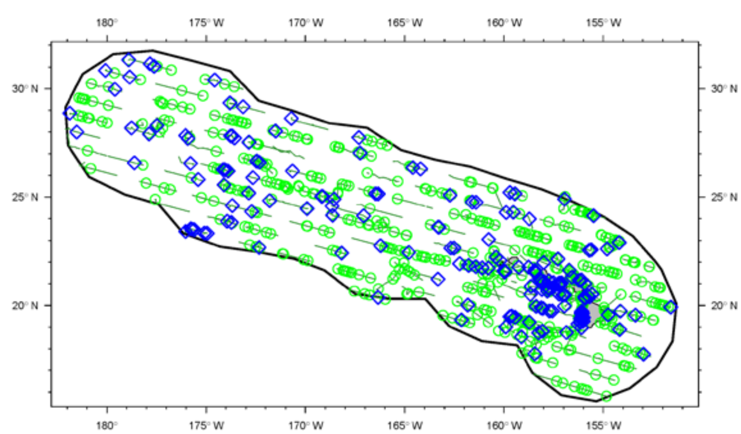
Long-term recorders have been adapted for use on fishery vessels for the purpose of monitoring cetacean occurrence around fishing gear to assess patterns in bait and catch depredation. The recorder detects sounds produces by cetaceans as well as by the fishing vessel or gear and vessel enabling specific analysis for acoustic cues by the vessel or gear that may attract cetaceans, and particularly false killer whales to fishing gear.

Several Science Centers have recently begun using drifting long-term recorders, enabling monitoring over a broader area and not tied to specific bathymetric features or island areas. Drifting Acoustics Spar Buoy Recorders (DASBRs) include a satellite transmitter at the surface that sends position information back to shore to enable recovery of instruments weeks to months after deployment. A vertical array of two hydrophones spaced 10m apart provides the data needed to track the depth and therefore distance of vocal groups form the DASBR, allowing for point-transect estimates of vocal animal density throughout the study area. Thirteen DASBRs were deployed during the 2017 Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS). Analyses of those data for beaked whale echolocation clicks revealed the occurrence of four species [shown in map: Blainville's (green), Cuvier's (purple), and Longman's beaked whales (blue), as well as an unidentified beaked whale (BWC) (red)]. This dataset represents the richest dataset on beaked whale distribution around the main Hawaiian Islands collected to date and will be used to generate abundance and density estimates for these species in the coming months.



Real-time Acoustic Monitoring

All NMFS Science Centers use towed hydrophone arrays during shipboard cetacean surveys to augment visual survey encounters. Since 2012 all Centers have been using consistent hardware and software to enable consistency among datasets and exchange of hardware among Centers. The PIFSC large-scale Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) in 2017 included daytime real-time acoustic monitoring on two research vessels. Towed hydrophone array components and the data acquisition system on each ship were designed to be as similar as possible to ensure the acoustic recordings would be comparable between the two ships. The recording system archived high quality recordings, including simultaneous sampling of all hydrophones at 500 kHz, and all real-time metadata from field efforts. The real-time tracking system used separate cetacean echolocation click and whistle detectors and classifiers to provide real-time location information for tracking vocal groups at sea. The data will be used in upcoming analyses to assess abundance of false killer whales and other species.



Daytime real-time acoustic monitoring effort (dark green lines) and acoustic detections made in the Hawaii EEZ (black outline) during HICEAS 2017. Concurrent sightings and acoustic detections are shown as blue diamonds. Acoustic detections without a concurrent visual sighting are shown as green circles. All detections are shown, independent of survey effort type.

Ocean Observations Using Tagged Animals. The multi-agency U.S. Animal Telemetry Network (ATN), hosted by the US. IOOS Program Office (https://ioos.noaa.gov/project/atn/), is implemented to, among other things, create alliances to coordinate, support, maintain and enhance baseline observations of marine animal movements and behaviors. This includes the support and application of advanced tagging technology that enables temporary attachment of miniaturized data loggers on marine animals to collect oceanographic profiles of temperature and conductivity. Because many marine mammals travel long distances throughout the oceans and travel to places where oceanographic ships rarely venture, the application of these techniques can enable the availability and use of a significantly and increasingly large amount of valuable oceanographic data that would otherwise not be collected. This evolving technology has been in place for more than 15 years and an international data base now contains nearly 500,000 profiles. Many of these profiles have been, and continue to be made available in near real-time to oceanographic and meteorological models worldwide though the WMO Global Telecommunications System (GTS). The U.S. ATN, together with our international partners, is working to improve the tagging technology and to implement robust and streamlined real-time quality control and data dissemination/exchange pathways and protocols for these datasets.

4b) Sentinel, Space-borne LIDAR, and Drone technologies

SENTINEL. Ocean topography and ocean color provided by the Sentinel 3A and Sentinel 3B satellites represent exciting developments. Ocean topography, specifically the ability to derive convergence and diverge zones in the ocean, can help scientists map areas of potentially high fisheries productivity. MODIS on NASA's Aqua and Terra satellites, VIIRS on NOAA NPP and NOAA-20, and OLCI on Sentinel 3A and Sentinel 3B provide a range of ocean color observing options (Figure 20). OLCI on the Sentinel series provides additional wavelengths to enable enhanced performance in coastal areas and presents the opportunity to identify specific plant pigments. This provides NOAA scientists the potential to identify not just chlorophyll-*a* concentration, but the derivation of phytoplankton functional groups. The additional coverage provided by the Sentinel series and the enhanced radiometric observations will provide increased benefit to NOAA and further NOAA's usage of these satellite systems.

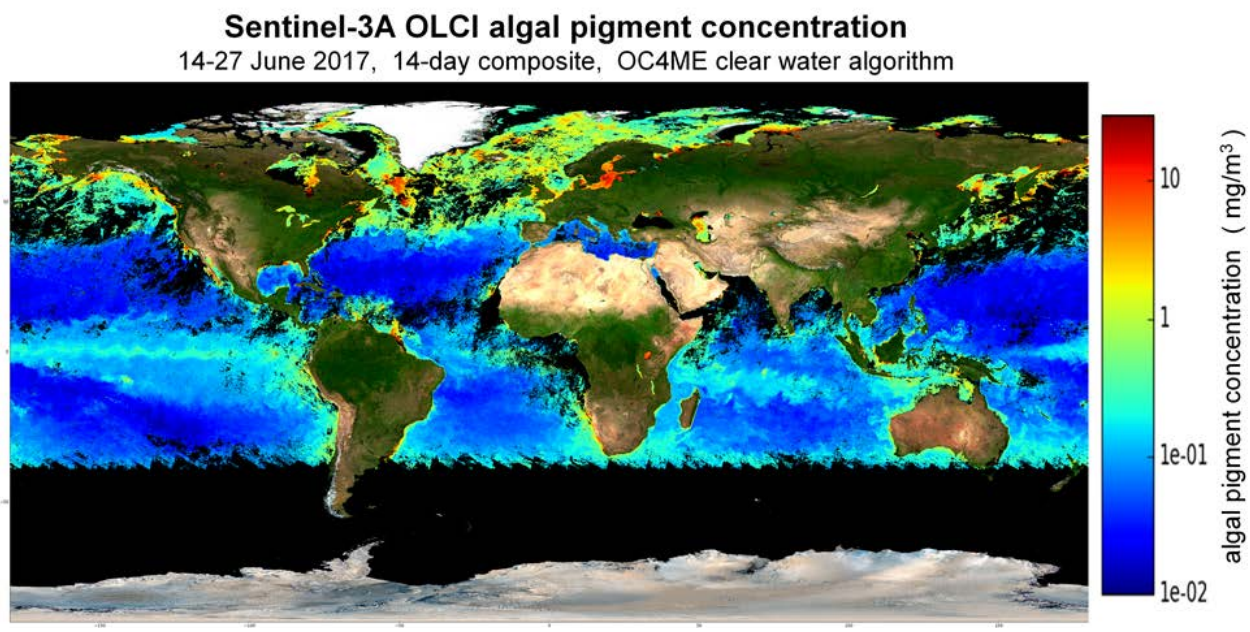
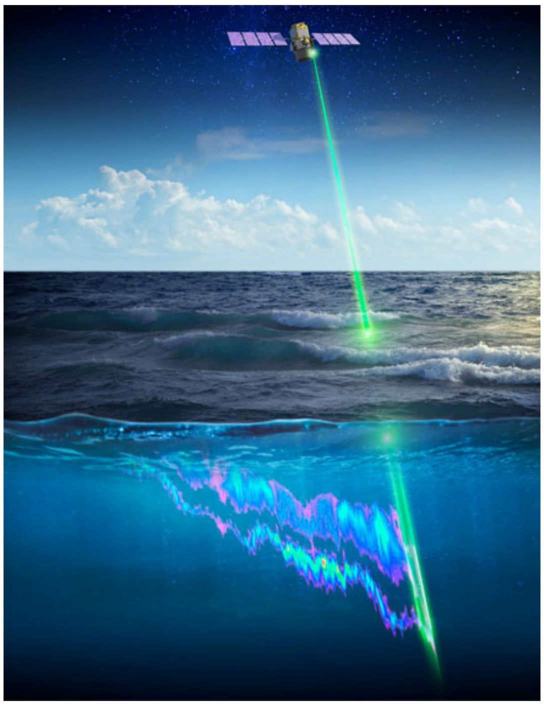


Figure 20: Representative image of chlorophyll a concentration from OLCI on Sentinel 3A. Increases in spatial resolution and the number of wavelengths make this a valuable sensor for NOAA Science. Source: ESA

SPACE BORNE LIDAR. The CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) instrument aboard NASA's CALIPSO spacecraft has inspired oceanographers and perhaps heralded the age of LIDAR (Light Detection and Ranging) for fishery oceanography. LIDAR can provide new data about ocean productivity with its ability to penetrate through clouds, atmospheric aerosols, and to make nighttime measurements (Figure 21).



NOAA interests in space-borne LIDAR include: better vertical resolution, more detection bands, and more laser emission wavelengths. If space borne LIDAR can achieve a vertical resolution of 1-3 meters and a deeper penetration of the water column, estimates of primary productivity can be greatly enhanced with the vast spatial extent and rapid refresh rate of satellite measurements. More detection bands will allow additional detail about the phytoplankton assemblage. The ability of LIDAR to collect phytoplankton pigment at night represents a powerful tool to compare day and night differences in phytoplankton communities with a rapidly refreshing set of global observations. Increasing the laser spectral emissions will facilitate the ability to separate phytoplankton from other ocean organic material and the ability to examine particle size distribution of the algal assemblage. The result is a more in-depth description of the phytoplankton community, even to the level of physiological state.

Figure 21: Space borne LIDAR can penetrate the water column to provide detailed information about primary productivity in support of fisheries science. Source: Hostetler et al. (2018) Spaceborne lidar in the study of marine systems. Annual Review of Marine Science, Vol. 10, pp.121-147.

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DRONES. Placing cameras and simple instruments aloft can advance NOAA's science mission. The use of drones can provide assessment of populations efficiently. For example, with imaging systems capable of resolving the length and width (a measure of condition) of whales, NOAA scientists can determine the size and health of populations. With easy deployments, drones allow NOAA scientists to access remote areas that might be harmed by landing a science team (Figure 22). Seals and turtles in secluded coves can remain undisturbed as state of the art drones survey the area collecting data to support NMFS Science. The increase in capabilities combined with the decrease in platform size make this emerging technology a candidate for further investment.

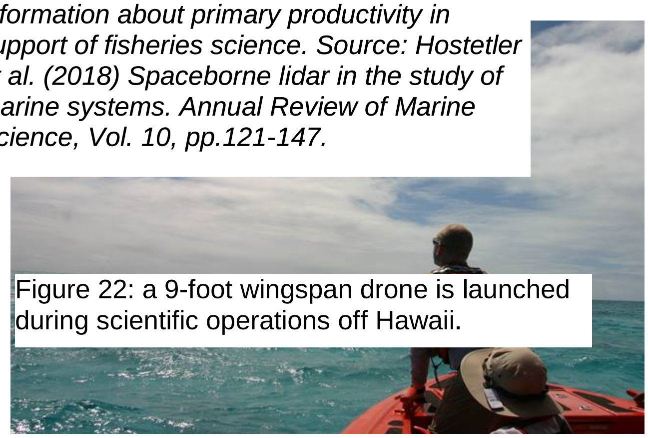


Figure 22: a 9-foot wingspan drone is launched during scientific operations off Hawaii.

Appendix A

Meeting report on developing and in-development OAR/AOML 'omics programs

Meeting Summary

AOML 'Omics Program Overview & Coordination with NOAA Programs, Lines, and Partners

Point of Contact: Kelly D. Goodwin (kelly.goodwin@noaa.gov)
http://www.aoml.noaa.gov/ocd/people/goodwin/

Meeting Overview

A meeting to summarize NOAA investigations that employ molecular biological techniques and to introduce the new OAR/AOML 'omics program was held on Tuesday November 21, 2017 at NOAA's Atlantic Oceanographic & Meteorological Laboratory (AOML). The aim was to foster linkages across line offices, programs, and external partners to help transition NOAA research to applications. Science presentations covered 'omics activities across the fields of coral, fisheries, biodiversity, and microbial science, as well as modeling and bioinformatics.

A series of brief science talks ("Ignite" format) highlighted research supported by the AOML 'omics program. These were complemented with longer presentations that summarized 'omics activities with emphasis on joint activities between NOAA's Ocean and Atmospheric Research (OAR) and National Marine Fisheries Service (NMFS) line offices; NMFS protected resources and fisheries projects; and work related to the recently established 'omics laboratory at OAR's Pacific Marine Environmental Laboratory (PMEL). Program overviews were provided by the Coral Research and Conservation Program (CRCP) and the U.S. Integrated Ocean Observing System (IOOS) Integrated Marine Biodiversity Observing Network (MBON). In addition, extramural MBON research was presented. These talks were accompanied by a "manager's narrative" in which managers from the National Ocean Service (NOS) Florida Keys National Marine Sanctuary (FKNMS) and the NMFS Southeast Regional Office provided perspective on applying 'omics to NOAA mission. This was immediately followed by a discussion session led by NMFS Chief scientist, Cisco Werner, that focused on research transitions.

Meeting presenters hailed from NOAA's OAR, NMFS, and NOS line offices. University representatives included University of Miami, University of South Florida, Nova University, and University of Florida. The meeting was offered on Webex with demand for more than 25 lines. NOAA leadership attendance on site also included NMFS director of science and technology, Ned Cyr, and OAR Deputy Assistant Administrator for labs and Cooperative Institutes, Gary Matlock. The meeting agenda and attendees' list are provided below.

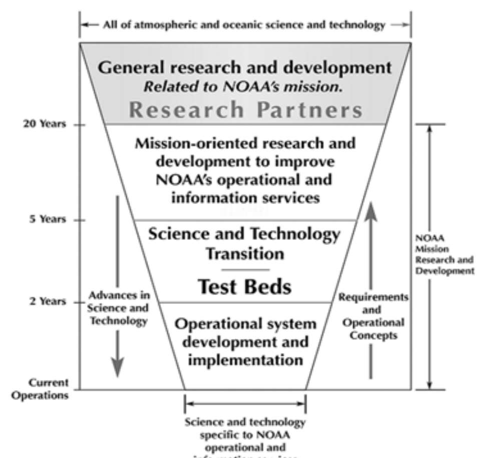
Meeting Background

In 2013, the OAR Senior Research Council and the NMFS Science Board formally identified "genomics" as one of five cross-line office collaborative science opportunities and a request for a whitepaper on the subject was made. NMFS-OAR bilateral meetings were held in 2014, 2015, and 2016. These meetings included a presentation on cross-line ‘omics activities provided by the Point of Contacts (POCs) for OAR (Kelly Goodwin) and NMFS (Mark Strom). In late 2016, OAR initiated the AOML ‘omics program with core themes of technology development, corals, and strengthening collaboration with fisheries. At the 2016 bilateral meeting, ‘omics was acknowledged as a good topic for a trilateral meeting that included NOS. Providing a bridge to tri-lateral collaboration that includes NOS was a desired meeting outcome.

Science Background

As the nation’s lead ocean science agency, NOAA scientists are engaging in the “genomic revolution” to improve observation and assessment tools that can be applied broad spectrum to various regions of the country and to questions that are unique to NOAA goals and mandates. The term ‘omics refers to a suite of advanced biological tools (e.g., genetics, genomics, metagenomics, metatranscriptomics, epigenetics, metabolomics, etc.) and includes analysis of eDNA in seawater to detect cells that have been excreted or sloughed from organisms. Benefits that include decreased dependency on animal biopsies or trawling for sample collection.

As is true in medicine, these tools applied to ocean science can improve NOAA’s products and services while reducing costs. ‘Omics approaches are attractive for NOAA mission applications because there is an increasing need to understand detailed biological information, including the mechanisms of adaptation. High throughput sequencing and bioinformatic analysis can be used to study the genetic mechanisms that help marine communities remain healthy. Applications include combating toxic algae, harmful bacteria, and invasive species; increasing fisheries and aquaculture productivity; and helping corals, which provide essential fish habitat and fuel tourist economies. Genetic measurements can be sentinels for ecological status by measuring biodiversity and food web function. NOAA is using ‘omics to track sustained ocean productivity and to understand how individuals, populations, and communities adapt. This knowledge is needed to sustain ecosystem services.



NOAA Research & Development Funnel

Preservation of ecosystem services speaks directly to NOAA’s research & development mission, which can be summarized as “responsibilities to protect people, property, ecosystems, and the promotion of well-being” (Matlock et al. 2013). To achieve these outcomes, research must be transitioned to routine use; simply translated, successful research gets used. Transitions occur through a series of stages; gaining more usage and ultimately transitioning into routine use, or operations. Ensuring that advances in science and technology are transitioned has become a major priority for NOAA. We know that critical elements include understanding of mission requirements, multi-disciplinary teams, and collaborations with the people slated to use the products.

Medical science provides many examples of transition success for 'omics, including science used to guide decision making; for example, decisions regarding preventive surgeries based on human or microbial gene sequence. Advances in medical science have enabled progress in environmental and other sciences. However, modern DNA sequencing is synonymous with Big Data, which is why the tool is both transformational and disruptive. The demand for 'omic information has driven huge computational demand, with biology rivaling the needs of astrophysics or the internet (Stephens et al. 2015). The need for bioinformatics expertise and computing power is a priority identified across NOAA line offices and across federal agencies, in general (Stulberg et al. 2016, FTAC-MM 2015). Strategic partnerships are one approach NOAA has used to address the gap in bioinformatics expertise and computing power, with examples provided below.

Big Data

'Omic approaches provide a broad taxonomic viewpoint (microbes to mammals) and identify functional pathways that underpin biogeochemical cycles. Therefore, 'omic data can provide a holistic view of ecosystem function that can be used to better predict tipping points, elucidate conditions that enable ecosystem resiliency, and develop successful management scenarios. Furthermore, as ship time and labor costs increase, 'omic technologies promise efficiencies because such tools are amenable for use *in-situ* and on ROV platforms that relay information in near real-time and do not rely on labor-intensive sorting techniques.

Overall, 'omic approaches are valued for their promise to improve evaluation of baseline and changed ecosystem function, provide new understanding of biodiversity to aid exploration and stewardship, help protect health and economies by allowing stakeholders to manage and mitigate contamination issues, and engage international, academic, and commercial partnerships. Applications include assessment of commercially important eggs and larvae; detection and control of invasive species; protection of critical breeding populations; enumeration of pathogens and harmful algae; detection of microbial/geochemical shifts in response to stressors (e.g., hypoxia, temperature changes, ocean acidification and combinations thereof); recording regional and large-scale changes to biological pathways that affect an array of ecosystem services (e.g., nutrient and metal cycles); and understanding factors that control pathogen virulence with consequences to commercial fishing, aquaculture, and animal health -- e.g., marine mammals, turtles, abalone, corals, and humans.

NMFS-OAR Joint Activities in 'Omics

NMFS-OAR Joint Activities in 'omics began in 2013, with participation in three bilateral meetings between 2014-2016. An early NMFS-OAR Joint Activity established a strategic partnership with J. Craig Venter Institute (JCVI) and the Scripps Institute of Oceanography (SIO). Starting in 2014, this project integrated 'omic sampling into the California Cooperative Fisheries Investigations (CalCOFI) to capture microbial diversity (which includes phytoplankton and zooplankton). The biodiversity data provided by DNA sequencing is information-rich compared to a chlorophyll value or zooplankton volume measurement. This project ("NCOG"; http://calcofi.org/field-work/bottle-sampling/ncog-project/525-noaa-calcofi-genomics-project.html) is jointly supported by the NMFS Office of Science and Technology (ST) and the OAR Ocean Exploration Research (OER) Program.

Data from the NCOG project is now being transitioned to ecosystem models through a new joint project involving AOML and the Southwest Fisheries Science Center (SWFSC), through support from the AOML 'omics program. Ecosystem models help keep track of complex interactions and non-linear responses to drivers. NOAA is working to integrate molecular biology and physical oceanography into models to improve prediction and utility to resource and conservation managers.

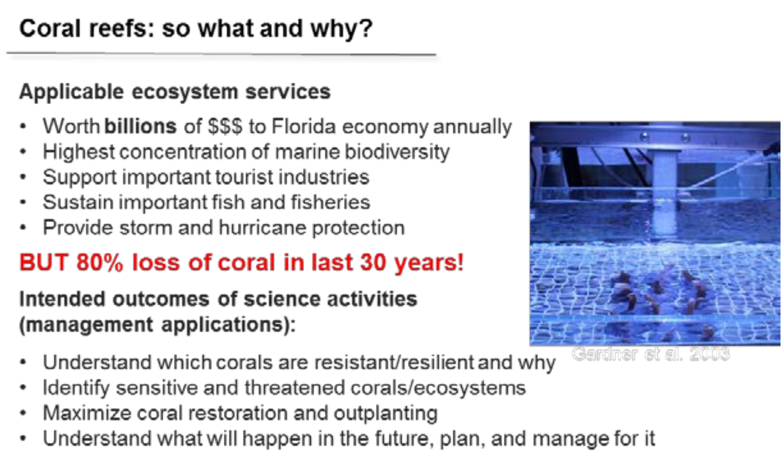
The activities described in this report are not NOAA's comprehensive portfolio in 'omics. The examples here provide a brief summary of topics covered during meeting presentations.

OAR Activities in 'Omics

The 'Omics Program at AOML. The AOML 'omics program began in late 2016. The program has three pillars - technology development, corals, and strengthening collaboration with fisheries. Although the program is new, it has the benefit of many established collaborations. One goal of the meeting was to introduce the many elements to each other, including science and resource managers, early in the research process.

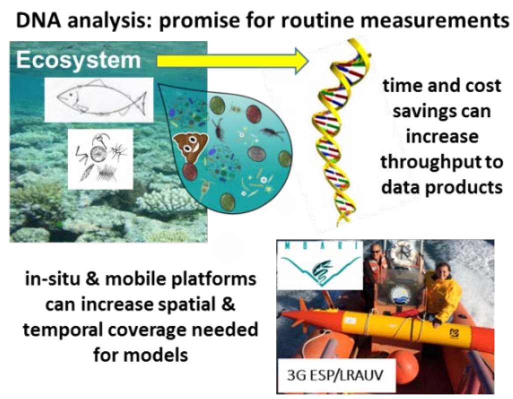
The activities & outputs of the AOML 'omics program includes process study innovation, advancing biological measurements, analytical improvement, emerging technologies, and 'omic-powered indices, models and products; all fueled through building bioinformatics and IT capability. Expected outcomes include aiding restoration and sustaining ecosystem services; time and cost savings to increase throughput to data products; and increased spatial and temporal coverage to improve ecological modeling. Specific projects discussed during the meeting include:

- In-depth field research of coral bleaching patterns revealed that some corals are more resistant to bleaching from heat stress. Those are associated with particular genetic signatures that are adapted/acclimatized to +1.0°C hotter than others of the same species. These results provide hope of using resistant genotypes to ensure survival of endangered species and restoration of reef habitat.
- The new Experimental Reef Laboratory can finely manipulate ecosystem stress. The lab is an engineering feat that provides an unprecedented level of pH control and rapid removal of CO_2. In contrast, the error in laboratory control of other aquaria was routinely an order of magnitude higher than experimental conditions. Experiments will help identify genes that allow some corals to resist bleaching and disease. More resilient corals can be used to restock reefs and provide ecosystem recovery. In



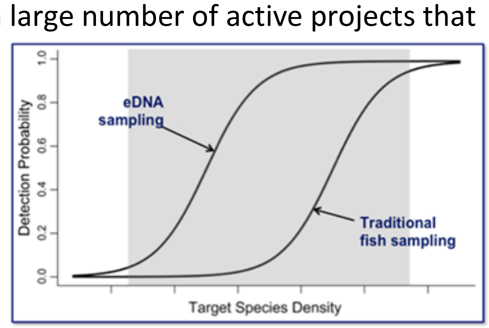
addition, the aquaria of the Experimental Reef Laboratory are isolated, allowing true experimental replication and introduction of additional stressors, such as disease agents. Furthermore, field studies are conducted to determine biodiversity in coral systems using metagenomics to characterize the microbiome of corals and adjacent sediments; trends in biodiversity are a proxy of ecosystem function.

- Autonomous sampling coupled with DNA analysis is being evaluated to combat rising ship-time costs, with emphasis on fisheries applications. Innovative techniques are being used to assess higher trophic levels (fish, turtles) from filtered seawater via capture of sloughed or excreted cells (eDNA) so that samples can be collected without animal capture, tissue processing, or trawling through sensitive habitats. 'Omic indices offer improvement over bulk biological measurements, such as chlorophyll and zooplankton biomass. The potential is to improve the predictive power of models & forecasts to help manage ecosystem services.



- Use genetics to sustain economic resources. Examples include studies to differentiate saline tolerant and sensitive subpopulations of Florida Bay Spotted Seatrout to inform freshwater flow watershed management.
- Engage fisheries and coral biologists, modelers, and bioinformaticians to develop 'omic indices and integrate into models to assess economically important fish species. Integrate molecular biology and physical oceanography into recruitment models to improve restoration outcomes for protected and endangered species. Use operational models, artificial intelligence techniques, and open-source components to transition results to day-to-day resource management.
- Explicitly addresses bioinformatic workforce and IT capability to ease the bottleneck in data analysis and interpretation. AOML secured a server dedicated to bioinformatic analysis through an HPCC grant, hired young scientists to help with analysis, and created user groups (local and NOAA-wide) to provide support. One new hire is lead on a major Nature paper describing the Earth Microbiome Project (EMP).

The 'Omics Laboratory at PMEL. The 'omics laboratory at the Pacific Marine Environmental Laboratory (PMEL) was initiated in the fall of 2016 when NOAA hired Dr. Carol Stepien to lead the Ocean Environment Research Division (OERD). The laboratory is home to the "Genetics & Genomics Group" (G3), which includes a variety of research scientists and students. The group has a large number of active projects that utilize metagenomics, defined as the simultaneous study of genetics & genomics of entire communities. The focus is to discern marine and aquatic community dynamics (in terms of space, time, and/or life history). Samples include organisms (whole or in part) collected from water (e.g., plankton) or sediment, as well as gut contents and tissue

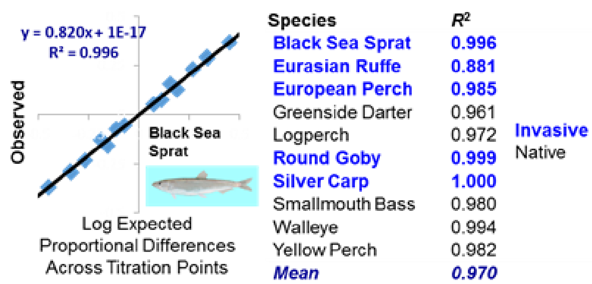


adapted by Stepien lab from Darling & Mahon (2011) samples. Benefits shown for metagenomic and eDNA analysis include:

- Increased sensitivity and accuracy over conventional sampling.
- Address prior inability to identify important species and populations whose early life stages cannot be visually discerned.
- High throughput identification of multiple taxa, from many samples, all at once.

The lab provides technical expertise in primer design and bioinformatics and has demonstrated improved quantification through use of internal controls. Method applications include tracking, forensics, & community response for: invasive species, adult fish & spawning aggregations, plankton communities, marine mammals, and hydrothermal vent/seeps.

Internal Standard Improves Quantification



Mock Fish Community. Illumina MiSeq, varying DNA concentrations, 10 species in 10 reps using Internal Standard method with cytochrome b gene

NMFS Activities in ‘Omics

Fundamental legal mandates for NOAA include the Sustainable Fisheries Act, the Endangered Species Act, and the Marine Mammal Protection Act as well as legislative advice to maintain healthy marine ecosystems and vibrant coastal communities. The NOAA approach to meet these mandates has been to develop long-term monitoring programs to evaluate the demographic status and trends of various marine populations. An implicit assumption of management is that trends in abundance can be understood and managed on the basis of measuring and adjusting rates of harvest mortality and bycatch mortality to recover and maintain sustainable populations.

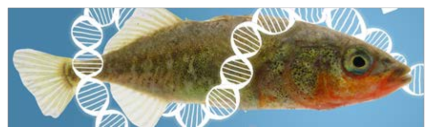
A variety of NMFS applications could benefit from ‘omics, including eDNA analysis. Activities currently being explored include: analysis of species relative abundance in trawls (e.g., surveys and stock assessments), species abundance in un-trawlable and near-shore habitats, distribution of non-native species, species identification of deep sea corals, stock structure of protected vertebrate species, early warning systems/ecological forecasting (for example harmful algal blooms for seafood safety applications), and a variety of aquaculture uses. Specific projects discussed during the meeting include:

- Current winter hake (Pacific whiting) survey to compare eDNA with trawl data (acoustic and fishing) to augment survey data for fisheries stock assessments.
- Development of eDNA survey methods to quantify near-shore fish communities with focus on salmon, herring, and smelt species. Methods include quantitative PCR (qPCR), massively parallel DNA sequencing, and development of a new statistical framework to provide field estimates of the relationship between species abundance and eDNA.
- Monitoring the distribution on non-native walleye in Lake Washington using eDNA.
- Non-invasive, non-destructive, and species-level identification of deep-sea corals (which are difficult to identify by sight); work includes forensics applications.
- Use of eDNA to differentiate stock structure of harbor porpoise to overcome difficulties in obtaining biopsies in southeast Alaska.

- ➢ Use of genomic sequencing to establish baseline genomic variation and information for potential recovery of the world's most endangered marine mammal, the Vaquita porpoise.
- ➢ Use of the Environmental Sample Processor (ESP), to provide near real-time data delivery of ecosystem status in Puget Sound with regard to harmful algae and algal toxins. This work represents a successful transition of research to data products.
- ➢ Applications of genomics, epigenetics, transcriptomics, and metabolomics to guide sustainable marine aquaculture. Efforts include identification of desirable genetic traits (growth rate, disease resistance, etc.), identification of genes/molecular pathways involved in sex differentiation that could be targeted for sterilization methods, development of improved diets, understanding mechanisms of fitness loss in hatchery-raised fish, and the effects of large scale environmental change on fisheries resilience.
- ➢ Population genomics to aid conservation, management, and recovery of rockfish, sockeye, and protected turtle and marine mammal species.
- ➢ Enhancement of bioinformatics and IT enhancement to address bottlenecks in data analysis and interpretation include NOAA fisheries computer cluster resources at NWFSC and SWFSC.

NOAA Fisheries Activities that can utilize 'Omics

- Species abundance, ID, distribution (manage ecosystem resources)
- Stock structure of protected species (populations to conserve)
- Early Warning of harmful algae (ecological forecasting)
- Aquaculture applications (food safety & security)



NOS Program Interest and Investment in 'Omics

Program overviews were provided for the CRCP and U.S. IOOS/MBON. Both of these programs are interdisciplinary and collaborative across lines, traits required for success of NOAA 'omic activities.

Although CRCP technically sits in NOS, it is a true matrix program. The potential for 'omics to mitigate the severe threat to corals worldwide includes improving reef resilience through management of reef connectivity, stress and disease tolerance, and assisted adaptation. Assisted adaptation includes directed breeding, but genetic modification is considered due to the severity of threat. Management will apply research results to devise intervention strategies for population enhancement and recovery.

NOAA CORAL REEF CONSERVATION PROGRAM

MBON is working to build the biological component of U.S. IOOS. This capacity is needed because "we cannot manage what we cannot measure." To preserve the ecosystem services upon which humans rely, long-term data about the distribution, abundance, habitat, and movement of multiple species (microbes to whales) is needed. 'Omic analysis is key to meeting the IOOS goal of providing operational, long-term biological observations and access

Traditional methods need improvement:

- ➢ Human observers, visual counts
- ➢ Net and other samples
- ➢ Ship-based surveys
- ➢ Labor-intensive and costly
- ➢ Invasive
- ➢ Some areas difficult to access (deep ocean, under ice)

Seek technologies and methods to automate observing; data & modeling solutions

to biological data. As such, IOOS in investing in, implementing, and managing multi-agency biological observing systems. All of the current U.S. MBON demonstration projects (launched in 2014) incorporate some aspect of ‘omics, particularly with regard to advancement of eDNA technologies and integration of molecular data into operational streams. Other U.S. MBON focal areas related to ‘omics include products to support the United Nations Sustainable Development Goal 14 (SDG14), which focuses on marine resources. [Please refer to Appendix B in this “Response to SAB recommendations” for a list of relevant funded projects.]

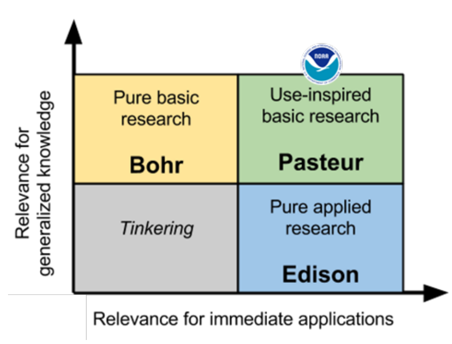
In addition, IOOS invests in an ocean technology program (~$2M/year) that sponsors the transition of emerging marine observing technologies. Potential projects must show an existing operational requirement, demonstrate commitment to integrate into operations, and be within readiness levels 6 through 8 to qualify. [More information is available on the project website at https://ioos.noaa.gov/project/ocean-technology-transition/. Two projects with particular applications to ecosystem monitoring are described in Appendix C herein.]

Management Narrative and Discussion

The manager narrative reflected interest and readiness to receive the outputs of presented research. In general, managers (and participants) were pleasantly surprised to learn the scope and depth of NOAA ‘omic research and requested to stay in active communication. For corals, directed breeding and outplanting is needed to save these ecosystems and any activities that can “buy time” until this ability is operational are important. The benefit of using the research aquaria to test the stability of directed breeding before release into the environment was noted. In addition to outright mortality, the ability to monitor sub-lethal stress was a need brought up by managers. ‘Omics is well-suited for the task, but activities in this area of research were not represented in the science portfolio presented. Other topics mentioned as important included: information that could help manage water quality/pollution impacts, informing restoration efforts across trophic levels (e.g., species to ecosystem), and species/community sensitivity, particularly place-based assessments.

The management narrative was followed by a discussion of the future of ‘omics within NOAA, including a focus on developing a timeline for when specific ‘omics applications would be operational or ready for use in resource management decision-making. There is a goal and expectation that ‘omics will be used in fisheries stock assessments within five-years and used by NOS for coral restoration decision-making starting immediately.

To conceptualize the transition process, a matrix was sketched with a list of topics and whether these topics appealed to scientists or managers. The topic rated as important to managers was “better answers”, which includes reduced uncertainty and perhaps more integrated/holistic information and filling information gaps. More efficient/less expensive methods were also noted as important, particularly to those responsible for managing mission costs. All of these topics also were rated as important to scientists. In addition, intellectual merit is a research motivator, but



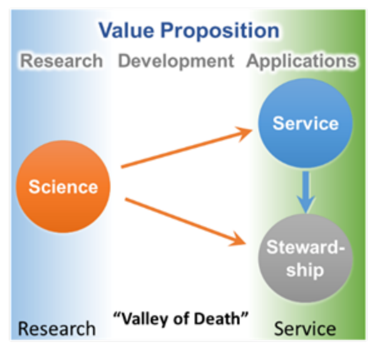
communication on this level ("cool factor") can create a cultural gap between scientists, managers, and science portfolio directors.

How do we determine if we derived a better answer? The traditional approach is side-by-side testing. This approach is time-consuming, expensive, and logically flawed if the traditional measure inadequately addresses the fundamental question that is trying to be addressed. Principles of the Quantitative Observing System Program (QOSAP) were suggested as an alternative. Biological observing system simulation experiments (OSSEs) could create a simulated 'real-world' or 'nature run' to evaluate how well different assessment methods perform.

A matrix was sketched that listed 'omic applications against estimated time to operational readiness. Actual timelines are difficult to estimate because they are sensitive to pending technological innovation and to resource investment. For technology advancement, examples include confidence that affordable whole cell and long-read sequencing will remove barriers that currently restrain progress for a number of applications. For investment, coral restoration science and management are already tightly coordinated such that added science manpower would advance timelines. However, a remaining scientific challenge will be that corals only spawn once a year and grow slowly.

Applications rated to have the highest readiness levels (0-3 years to transition) included:

- Presence/absence
- Forensics
- Community composition
- Abundance by qPCR



Several examples of presence/absence utility were offered. For example, population ranges will change under large-scale forcing; there is no need to monitor where a stock no longer lives. eDNA measurements offer an economical means to assess such scenarios. Forensics activities (e.g., for protected species) also utilize presence/absence results, and NOAA has a variety of these applications (protected species; seafood). Community composition (biodiversity) is an important indicator of ecosystem function; lower trophic level measures are most readily at hand. qPCR (as opposed to sequencing) can provide quantitative data now for defined targets (e.g., when you know what it is you want to count), particularly for microbes because the entire organism is captured during sampling. A variety of management applications could benefit by integrating 'omics into ecosystem status assessments in order to decrease costs and increase efficiency.

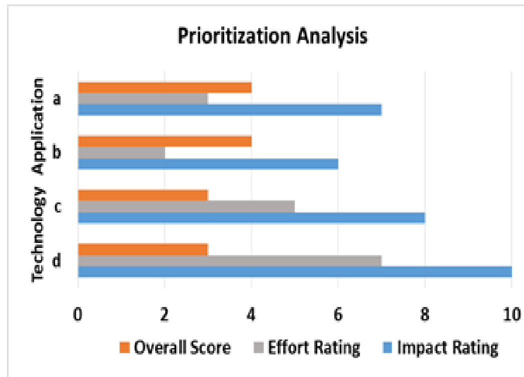
Applications rated to have intermediate readiness levels (~5 years to transition) included:

- Relative Abundance
- Time series of ecosystem status, including efficacy of management action
- Age determination
- Survivorship (e.g. salmon, turtles)
- Organism condition (e.g., aquaculture; sub-lethal stress)

The application rated to have the longest research-to-operation pipeline length, absolute abundance, was also the application rated to have the highest potential impact. This fact touched off a discussion on how science portfolio directors can best prioritize research investment. A list of factors to consider when evaluating research projects/applications include:

- Most impact
- Most needed
- Most value added
- Most reachable

There a variety of conceptual and quantitative models available to rate investments. It was noted that a rubric specifically designed for ‘omic applications could be designed to capture these parameters. For example, an Overall Score could be derived by subtracting Effort from Impact ratings. It was noted that rubrics and expert opinion can guide research investment but are not free from subjectivity and, particularly for ‘omics, can become quickly outdated due to rapid advances in technology. Assessment of effort should include resistance to adoption due to a variety of forces, including perception and regulatory hurdles. It is prudent to devise an ‘omics to operations “roadmap” that detours around such delays. Lessons can be learned from other technology transitions, including movement of qPCR into regulated water quality applications in the United States and European Union utilization of eDNA in ecosystem assessments. Overall, this is a complex topic that could not be fully explored in the time available but is ripe for future discussions.



Conclusion

Participants garnered a better appreciation for various mission/program mandates and learned about NOAA’s 'omics activities across the fields of coral, fisheries, biodiversity, and microbial science, as well as modeling and bioinformatics. The meeting provided networking opportunities on multiple levels, including: postdoctoral students that form the core of the (newly minted) bioinformatics user group, field scientists working to move interdisciplinary research to useful outcomes, and leadership looking for synergies that complement and enhance program success. Consensus opinion was that the meeting illustrated connections across a network of research disciplines and management applications. Conversation and coordination should continue to most efficiently move research efforts into management.

STRATEGIC PRIORITIES

- Deliver world-class science observations to advance understanding and prediction of ecosystem impacts from changing ocean conditions.
- Innovate to enhance efficiency and promote research-to-applications.
- Provide organizational excellence and best use of emerging environmental data.

Meeting Schedule

8:00am: Check in at AOML
8:15am: Tour the Experimental Reef Laboratory, located across the street on the RSMAS campus
9:00am: Welcome. Dr. Bob Atlas, Director of AOML

9:15-10:45am: Science Talks
<u>Program & Research Overviews</u>

- Kelly Goodwin (OAR) & Mark Strom (NMFS): NOAA 'omics - a brief view from the joint OAR/NMFS perspective
- Gabrielle Canonico (NOS): MBON and 'omics: Building the biological component of U.S. IOOS
- Jennifer Koss (CRCP): Coral Reef Conservation Program overview

<u>Ignite Presentations: AOML 'Omics</u>.
A fast-paced and informative overview of AOML 'omics activities from the following presenters (ignite talks are 5 minutes each):

- Ian Enochs: The CIMAS Experimental Reef Lab: a tool for simulating dynamic future conditions on contemporary reef organisms
- Derek Manzello: Genetically determined variation in bleaching tolerance across Florida Keys reefs in the threatened coral *Orbicella faveolata*.
- Xaymara Serrano: Using 'omics to characterize the transcriptomic basis of disease resistance in endangered *Acropora* corals

-break-

11:00am-12:30pm: Science Talks
<u>Program & Research Overviews</u>

- Frank Muller-Karger (USF): Advancing MBON science using eDNA
- Carol Stepien (NOAA/PMEL): Discerning our oceanic communities and their responses to chemical, physical, and biological parameters with metagenomics

<u>Ignite Presentations: AOML 'Omics</u>

- Lew Gramer: Currents and Drift: Connectivity indices for Florida Keys corals
- Chris Sinigalliano: Characterizing reef microbiome communities by next-generation-sequencing and microbial source tracking to enhance marine biodiversity observations
- Luke Thompson: Massive metagenetic surveys: lessons from the EMP and OSD
- Ben Vandine: Genotyping by sequencing (GBS) to understand genetic structure and population dynamics of *Cynoscion nebulosus* in Florida Bay
- Dovi Kacev/Andrew Thompson/K. Goodwin: Technology development: ichthyoplankton metabarcoding and mobile genomic sensing in the California Current Ecosystem
- Chris Kelble: Do 'omics measurements improve our ability to predict Living Marine Resources?

12:30-1:30pm: Lunch

1:30-1:45 Manager's Perspective

Florida Keys National Marine Sanctuary: Beth Dieveney, Deputy Superintendent

NOAA Fisheries, Southeast Regional Office: Steven Giordano, Ecosystem Restoration and Environmental Compliance Program Manager; Alison Moulding, Coral Recovery Coordinator; Jennifer Moore, Protected Coral Coordinator. Moderator: Chris Kelble

1:45-3:15pm Working Together to Enable Transitions that Meet Management Needs
Discussion session moderator: Cisco Werner (NMFS)

Attendee List (Note: some web attendees may not be represented)

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Appendix B

U.S. MBON focal areas related to ‘omics include products to support the United Nations Sustainable Development Goal 14 (SDG14), which focuses on marine resources.

- **MBON Sanctuaries Genomics Team Overview:**

The Sanctuaries MBON Genomics team includes researchers at Stanford, Monterey Bay Aquarium Research Institute (MBARI), the University of South Florida (USF), and the Florida Fish and Wildlife Research Institute (FWRI). The Sanctuaries Genomic team is led by Francisco Chavez at MBARI and Mya Breitbart at USF. The MBARI research group has extensive expertise in methods development and instrumentation engineering. Breitbart’s lab uses molecular techniques to examine the diversity, distribution, and ecological roles of viruses and bacteria in a wide range of environments - including seawater, animals, plants, insects, zooplankton, coral reefs, and stromatolites.

The Sanctuaries Genomic team has developed standardized sample collection plans and methodologies for use in the Florida Keys and Monterey Bay National Marine Sanctuaries locations. The researchers are conducting tests to determine the most effective choices of filter type and DNA extraction method to capture eDNA from multiple trophic levels simultaneously (i.e. bacteria phytoplankton, zooplankton, vertebrates). Methods for morphological zooplankton identification were completed in Feb 2015, which will enable comparison of zooplankton data between the Florida Keys and Monterey Bay sites.

To support consistent sample process and analysis, Stanford and MBARI established a bioinformatic pipeline, and USF and FWRI are testing parts of the system. This pipeline will provide a standardized data analysis framework for different gene markers used by the Sanctuaries MBON genomics teams.

The Stanford team is also comparing two library prep methods for Next Generation Sequencing data (NGS). The analysis will help to determine whether this step should become standardized in all three MBON projects, as they work in collaboration with the AMBON and SBC MBON genomics researchers.

- **MBON Florida Genomics Keys Sampling Overview:**

The USF/FKNMS genomics team is collecting monthly samples in the Florida Keys near major coral reefs at the designated MBON stations. Samples are collected with help of the USF remote sensing group and scientists at the FKNMS during cruises on the R/V Walton Smith and on small boats.

The USF/FKNMS is collecting three samples from surface and bottom at each of the three key MBON stations - 18 samples per cruise. In 2015, the team collected 198 samples from the three MBON stations and an additional 286 samples from the surrounding ocean. The USF group has also collected samples for zooplankton morphological identifications, eDNA genomics, and for sequencing tissue of whole zooplankton communities. The goal is to ground-truth the eDNA method for zooplankton and move forward to eventually use only eDNA to assess zooplankton diversity and seasonal oscillations in the Florida Keys.

- **MBON Monterey Bay Genomics Sampling Program Overview:**

The effort and expense associated with sample and data collections for long oceanographic time series are, in part, driving the development of autonomous platforms, sensors and sample collectors. MBARI is testing means to autonomously collect, preserve, and process discrete samples. The MBARI team has validated oceanographic samples collected by an autonomous underwater vehicle.

In fall 2015, samples were collected during the MBARI CANON cruise to assess the spatial distribution of vertebrate eDNA across nearshore and offshore locations (Figure 9). The six-month time-series at station M1 in Monterey Bay (6 cruises,10 depths sampled per cruise from 0-200 m) has yielded very low/absent amplification for 12S mt DNA (vertebrate eDNA). Stanford provided aliquots of this time-series to MBARI researchers who successfully amplified phytoplankton and zooplankton eDNA.

To test if water volume is related to vertebrate eDNA concentration in offshore waters, the team collected and filtered 1-L, 10-L, and 100-L seawater samples at station M1 using tangential flow filtration (TFF). The researchers are comparing species richness and diversity across these volumes, and, to conventional vacuum filtration. Samples have been processed and the experiment may be repeated in another location.

- **eDNA (Environmental DNA) Sampling in Sanctuaries MBON Project:**

New sequencing technology allows researchers to examine eDNA samples to obtain information about all trophic levels, from bacteria to vertebrates, and learn more about their interactions. To obtain eDNA, a seawater sample is concentrated to capture everything larger than 0.2 microns (in comparison, a human hair is approximately 75 microns in diameter).

This approach will easily catch not only small single-celled planktonic organisms like bacteria and phytoplankton, but also cells from larger organisms such as whales and turtles that may have recently passed through the water. This novel approach is integrated with remote sensing data and ecosystem modeling studies to improve our understanding of connections among biota and their environment, as well as to identify species indicators that can be used to monitor and predict ecosystem change in the future. The eDNA work is being conducted as part of the Marine Biodiversity Observation Network, a project funded by the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Integrated Ocean Observing System, and the Bureau of Ocean Energy Management, that involves collaborators from all over the country.

When this project is completed, the eDNA methods employed will ideally be incorporated into routine and/or event response sampling at FWC, specifically to address questions or events that encompass multiple trophic levels. Staff suspect it might be most useful for HAB event response during fish kills, as scientists hypothesize that dead fish may release more DNA into the water than live fish, allowing better taxonomic assessment of mortality and bloom tracking. It may also be helpful during comparative analysis of seawater and gut content samples associated with other wildlife mortality events, especially for more motile species such as turtles or whales. During these mortality events, HAB toxins may be found in the affected wildlife when no known HAB is present, and eDNA may help provide insight into food web dynamics necessary to better understand the trophic transfer of toxins.

Source: Story Map produced by Florida Fish and Wildlife Conservation Commission http://myfwc.maps.arcgis.com/apps/Cascade/index.html?appid=fae996592ba74da7bd6ddba3ee66b159

Appendix C

Two IOOS projects with particular applications to ecosystem monitoring are the Data Integration of the Imaging Flow CytoBot and the detection of Harmful Algal Blooms (HABs). These are described below

1) Imaging Flow CytoBot Data Integration

San Francisco Bay has long been recognized as a nutrient-enriched estuary, but one that has exhibited resistance to some of the classic symptoms of nutrient over-enrichment, such as high phytoplankton biomass and low dissolved oxygen. However, recent observations suggest that the Bay's resistance to high nutrient loads is weakening. The combination of high nutrient concentrations and changes in environmental factors that regulate the Bay's response to nutrients has generated concern about whether the Bay is trending toward, or may already be experiencing, nutrient-related impairment.

The San Francisco Estuary includes the drainage basins for the Sacramento and San Joaquin rivers. (Click graphic for expanded view.)

To address growing concerns about San Francisco Bay's changing response to nutrient loads, the San Francisco Bay Regional Water Quality Control Board worked collaboratively with the Bay Area Clean Water Agencies (BACWA) and other stakeholders to develop the SFB Nutrient Management Strategy, which calls for a range of activities to develop the scientific foundation for well-informed management decisions. An initial activity within the Nutrient Strategy was to develop a conceptual model for nutrient load-response in the Bay, and identify critical data and conceptual gaps. That draft report, developed with input from a group of regional scientists and funded by the SF Bay Regional Monitoring Program (RMP), was recently completed (Senn et al., 2013).

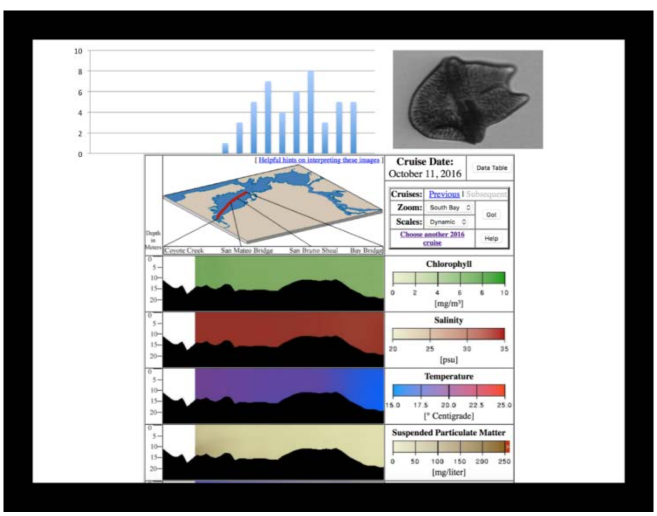
The conceptual model report made two broad recommendations: 1. Develop science plan(s) for SFB's sub-embayments that targets the highest priority management and science questions; 2. Develop and implement an integrated program that combines observation/assessment, prediction of ecosystem response, and process-level studies that combined inform impairment assessment and decisions about how to best manage nutrients. Of relevance to the IOOS Ocean

Technology Transition program, both recommendations call for analysis and continued development of a 40-year time-series that includes hydrographic parameters, nutrients, phytoplankton biomass and community composition, and occurrence of potentially harmful species.

The report recommended developing a moored sensor sub-program that complements an existing ship-based monitoring program by providing high temporal resolution data for a range of parameters (chl-a, DO, nutrients, turbidity) to i) identify the onset of events (e.g., large blooms); ii) improve understanding about the processes that influence phytoplankton blooms in order to predict future responses; iii) assess oxygen budgets; and iii) quantify nutrient fate.

The University of California Santa Cruz was awarded a three-year grant by IOOS' Ocean Technology Transition Project to incorporate consistent and cost-effective observations of Harmful Algae Bloom (HAB) and phytoplankton composition into the San Francisco Bay monitoring program to use as a metric to support ecosystem assessments. The project will integrate the Imaging Flow CytoBot (IFCB) into existing USGS R/V Polaris vessel transects, onto a planned mooring in the South San Francisco Bay, and on existing piers and/or fixed platforms monitoring to evaluate the potential to replace or augment phytoplankton enumeration (traditional microscopy) and HPLC pigment analysis to monitor phytoplankton composition and HABs in the San Francisco Bay.

Societal Benefits: The PIs were able to use the IFCB on USGS cruises and at the Santa Cruz Wharf to document an Akashiwo bloom in the coastal ocean. These data were used to inform several management groups and the public (via news reports) about the presence, cell density, and potential impact of the bloom event. The image below shows an example of the data, processed using the automated classifier, for the San Francisco Bay.



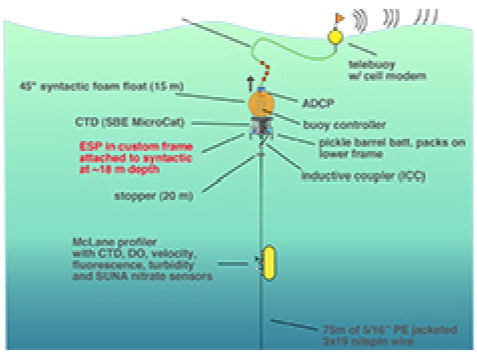
The IFCB detected an Akashiwo bloom in SF Bay in September 2016, and successfully classified it using the automated classifier. The upper plot shows cell density along the cruise track. The lower plots show the ancillary cruise data. The data were used by several management groups in response to the bloom.

2) Detecting Harmful Algal Blooms in the Pacific Northwest

Shellfish contamination from harmful algal blooms (HABs) is both costly and a significant health risk to coastal communities. Blooms of Pseudo-nitzschia can produce the neurotoxin domoic acid (DA). DA can bio-accumulate in marine shellfish and finfish and be transferred to humans and wildlife through consumption of contaminated seafood (Scholin et al., 2000). DA poisoning causes gastrointestinal effects (vomiting, nausea, and diarrhea) and neurological effects (headache, dizziness, confusion, disorientation, short-term memory deficits, and motor weakness), with more severe cases resulting in seizures, cardiac arrhythmias, coma, and possibly death (Perl et al., 1990; Teitelbaum, 1990). Short-term memory loss is permanent; thus, the illness is termed amnesic shellfish poisoning (ASP).

In addition to being a significant health risk, toxic blooms of Pseudo-nitzschia have caused coast-wide, yearlong closures of the razor clam fishery in WA resulting in an estimated $24.4 million in annual lost expenditures (Dyson and Huppert, 2010). Coastal Tribal communities may be disproportionately impacted by toxic HABs because shellfish are an integrated part of the culture as well as being significant dietary items and income sources.

To assess the risk of toxic Pseudo-nitzschia blooms impacting coastal beaches, managers use a number of different data types to develop HAB forecasts, including modeled surface currents, observed coastal wind time series, Columbia River flow, satellite imagery, and (critically) the type, number, and toxicity of Pseudo-nitzschia cells. Information on Pseudo-nitzschia is obtained from beach monitoring; however, the primary source of toxic cells of Pseudo-nitzschia is offshore.



Pacific Northwest Razor Clams. Credit: Larry Workman, Quinault Indian Nation. Diagram of a buoy mooring and buoy in the Gulf of Maine ESP schematic. [Click graphic for expanded view (pdf).]

In 2014, IOOS awarded a grant to the University of Washington Applied Physics Lab (APL-UW) to place an autonomous, underwater, robotic marine biosensor (i.e., the Environmental Sample Processor [ESP]), developed by the Monterey Bay Aquarium Research Institute (MBARI) and operated by the NOAA Northwest Fisheries Science Center, on a proven APL-UW/Northwest Association of Networks Ocean Observing System (NANOOS) subsurface mooring located 15 miles offshore of La Push, Washington within the Olympic Coast National Marine Sanctuary. This effort will improve the ability to provide advanced warning of toxic Pseudo-nitzschia blooms and reduce both the negative health and economic impacts of HABs on the Washington

Coast. In near real-time the ESP will detect Pseudo-nitzschia cells and their associated toxin DA that escapes from the nearby Juan de Fuca eddy, which has previously been identified as source of HABs.

These observations will be distributed to coastal shellfish managers and other users to enable informed and timely management decisions. Additionally, the project will engage Tribal communities on seafood safety and advanced environmental monitoring through outreach, education, and training, which will include summer internships and Summer Science and Art Camps through the Northwest Indian College.   Development and inshore testing of this system will begin in the fall of 2014, with the first offshore operational deployment scheduled for the shellfish harvesting seasons in the spring-fall of 2016.

The environmental intelligence generated by this project will advance the ability to improve forecasts of natural hazards (i.e., toxic HABs), and minimize public health risks associated with consumption of shellfish contaminated with HAB toxins. Specifically, this project will help Washington State managers and Tribes mitigate the risks associated with HABs by providing sustained, reliable, and timely observations and forecasts of HABs and their toxins. By providing a regional context for interpreting local monitoring results, managers of coastal clam resources can inform their communications with stakeholders and community members, so that they may plan a safe, productive season.

This project is comprised of a multi-sector team of partners that combines expertise from academia [UW's Applied Physics Laboratory and School of Oceanography, Northwest Indian College (NWIC), and Woods Hole Oceanographic Institute (WHOI)], IOOS (NANOOS), government (NOAA's Northwest Fisheries Science Center and Center for Coastal Environmental Health and Biomolecular Research), and the private sector (MBARI).