Proceedings of the First National Protected Species Assessment Workshop

Hosted by the National Marine Fisheries Service Alaska Fisheries Science Center and sponsored by the Office of Science and Technology

Edited by Laura Ferguson, Mridula Srinivasan, Erin Oleson, Sean Hayes, Stephen K. Brown, Robyn Angliss, Jim Carretta, Elizabeth Holmes, Eric Ward, John Kocik, Keith Mullin, Ron Dean, and Jeanette Davis

U.S. Department of Commerce
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NOAA Technical Memorandum NMFS-F/SPO-172
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National Oceanic and Atmospheric Administration
Benjamin Friedman, Deputy Under Secretary for Operations, Acting Administrator

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Letter: Comments from the outgoing Chief Scientist

In this letter, I will address three topics. First, I will reflect on what the NOAA Protected Species science community has accomplished, especially over the past five years. Next, I will suggest that we pay more attention to the work of NOAA's fisheries scientists. Finally, I will provide brief comments on how important it is to maintain a strong team with NOAA managers.

Reflect on what you have accomplished

The Marine Mammal Protection Act (MMPA) has been a remarkable conservation success that would not have been possible without strong scientific support for NOAA managers. Implementation of the Potential Biological Removal (PBR) concept and the Guidelines for Assessing Marine Mammal Stocks (GAMMS) workshops produced a protected species assessment methodology that is accepted and used by the scientific community. Support of the Take Reduction Teams by Center scientists has produced remarkable reductions in bycatch of marine mammals. As a collateral effect, much of what happened with marine mammals has led to reductions in other protected species bycatch. Because of this work, most marine mammal populations are on positive trajectories towards recovery to their Optimum Sustainable Population (OSP).

Just in the past five years, we have seen major leaps forward in Protected Species science. NOAA has again advanced the GAMMS. We have made great strides in understanding marine mammal stock structure, and we are beginning to reconcile Endangered Species Act (ESA) Distinct Population Segments and MMPA stocks. NOAA now has a National Ocean Noise Strategy, which follows on the heels of the successful development of CetMap and CetSound[1]. We have found a source of funding for our surveys by partnering with the Bureau of Ocean Energy Management (BOEM), first on the Atlantic Coast (Atlantic Marine Assessment Program for Protected Species (AMAPPS)), then later this year in the Gulf of Mexico (Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS)), and very soon in the Pacific (with Pacific Marine Assessment Program for Protected Species (PacMAPPS)). The Protected Species Toolbox initiative continues to provide new tools. Another new tool is the Protected Species Climate Vulnerability Assessment, which will shortly be piloted in New England. And now we have the first Protected Species Assessment Workshop (PSAW), a forum the Science Board fully embraces.

Take a breath and give yourselves a pat on the back for all you have accomplished since 1972.

Learn from the fish folks

But there is more you can do. One way to move ahead is to pay attention to what is happening on the fish side of the house. Recognize, just as the fisheries scientists have, that stock assessment is an evolving discipline. Some of the efforts going on over there to improve the quality of assessment advice include developing a national framework to prioritize assessments, recognizing that differing levels of assessments can be compatible with good management advice (one size does not have to fit all), and consciously moving out on Next Generation assessments

[1] http://cetsound.noaa.gov/cetsound

by updating the fish Stock Assessment Improvement Plan (proving an SAIP can exist as more than a budget exercise).

They have developed a National Policy on Ecosystem-Based Fisheries Management, and then provided a Roadmap for Implementation. This effort needs to be expanded to protected species. Do you remember the 2006 Protected Species SAIP Tier III Workshop[2]*? You should revisit the recommendations from that workshop for some guidance on where we could go to better deal with protected species in an ecosystem context.*

Think some about how we can better use observer data. Fisheries scientists and economists at the Northeast Fisheries Science Center are conducting a series of analyses of the biases/errors in observer reporting of fisheries catch. Undoubtedly, what they are finding has implications for the data reported about protected species bycatch. Think more about the use of advanced technology and alternative observing methods. The Agency fully supports expanded use of electronic monitoring and reporting of fish catch; is there more that can be done on the protected species side?

Finally, make sure to reach out and involve the small community of protected species economists and social scientists. It is clear to me that they are our most valuable, underappreciated resource.

Stay a Team with the Managers

I was heartened to hear that there are a number of staff from the Regional Offices and headquarters at the PSAW, so I probably don't need to say much. But recognize that we have worked hard over the years to bridge this gap between science and management. Always keep in mind that while we are in the business of conservation science, our science by itself does not produce conservation. It has to be translated into action by our management partners.

Worry less about the transition

Remember all that we have accomplished, and that the progress we have made in conservation won't be lost.

My advice is to focus on your science and keep building partnerships and constituencies.

Finally, trust your Leadership Team. Sam and Cisco have your backs!

Sincerely,

Richard Merrick

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[2] Report of the Protected Species SAIP Tier III Workshop, 7-10 March 2006, Silver Spring MD. NOAA Tech. Memo. NMFS-F/SPO-78

Executive Summary

The first National Protected Species Assessment Workshop (PSAW), *"Novel Methods for Abundance and Trends Assessment and Data-Poor Bycatch Estimation for Protected Species,"* was held January 17-19, 2017 at the Alaska Fisheries Science Center (AFSC) in Seattle. This workshop, organized by the National Marine Fisheries Service's (NMFS) Office of Science and Technology (F/ST), brought together 165 scientists and managers across regions, divisions, and taxa to share and discuss the latest research approaches to improve protected species stock assessments. Participants included representatives from NMFS headquarters offices, Science Centers and Regional Offices, as well as the Pacific States Marine Fisheries Commission, Fishery Management Councils, five universities, and one consulting firm.

The PSAW workshop was the result of a 2015 Protected Resources Board decision for F/ST to sponsor and organize a workshop similar to the National Stock Assessment Workshops (NSAW) and National Habitat Assessment Workshops (NHAW). Further, in the national synthesis of protected species science program reviews (https://www.st.nmfs.noaa.gov/Assets/science_program/NationalProgramReviewResponse2015_Final.pdf) NMFS committed to hold a biennial workshop to bring scientists together to exchange data, methods, and technologies, establish best practices, and ensure consistency. The theme of each workshop will vary but will include topics that provide opportunity for exchange across disciplines including the social sciences. The NSAW and NHAW workshops have led to notable technological and collaborative successes, and the expectation was that the PSAW workshop would enable similar advancements in protected species assessment science.

The inaugural PSAW provided a valuable forum for fostering communication and collaboration among scientists and managers on the best practices and latest analytical methods to study protected species populations. Workshop presentations and subsequent discussions also identified critical knowledge gaps and opportunities for future work and improvements.

Theme 1: Use of novel methods to assess abundance and trends

Over the first two days, participants explored novel analytical approaches and data combinations to: analyze population viability, risk, and trend; describe emerging technology applications and advanced mark-recapture models; and use habitat relationships to assess density and abundance. Several common issues and approaches emerged across taxa and geographic regions.

Top conclusions and recommended next steps:

- Bayesian hierarchical modeling is a technique that is broadly applicable in diverse contexts to assess abundance and trends.
- Researchers and managers should consider the research or management question when establishing model performance metrics and designating the appropriate time scale to estimate trends.

- Marine mammal stock assessments could be improved by reducing biases in estimating Potential Biological Removal (PBR[3]) (e.g. by using more accurate R_{max}[4] values), and incorporating trend information where available.
- Practical management of protected species stocks may require flexibility to group or split stocks according to management needs and conservation concerns.
- A mini-workshop for researchers working on similar datasets could clarify the optimal spatial and temporal scales for using habitat relationships to assess density and abundance.
- The F/ST Protected Species Science Branch can facilitate Science Center communication regarding tool development, available statistical expertise, and best practices in assessment methods.
- A database manager in each Science Center could help to alleviate some of the critical day-to-day data management challenges and ease dissemination of data across Centers.

Theme 2: Methods to deal with poor data quality in bycatch estimation
Participants explored new approaches to produce robust estimates of bycatch for rare events and variable fisheries effort, age-specific mortality, and data sources. Attendees also discussed the utility and feasibility of electronic monitoring to collect data for protected species bycatch assessments.

Top conclusions and recommended next steps:

- F/ST could organize dedicated workshops for NMFS bycatch scientists to use simulated and real datasets to cross-validate approaches and compare results.
- F/ST, Office of Protected Resources (OPR), Science Centers and Regional Offices could facilitate cooperation and collaboration by organizing working groups to discuss the technical aspects of bycatch estimation and application to varied management questions and taxa, supporting training and rotational assignments, and developing collaboration action plans.

As a result of the workshop, a cross-section of the protected species community learned about what different regions are doing to address similar problems in abundance and bycatch estimation. The workshop encouraged dialogue between new and established researchers and expanded research networks. This inaugural workshop was deliberately broad in scope, but future workshops could involve more focused topics (e.g., addressing uncertainty in bycatch estimation, using passive acoustics in stock assessments, using advanced genetic tools to address conservation problems). The organization of joint and concurrent sessions on different themes may promote interdisciplinary collaboration.

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[3] PBR is the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population.
[4] R_{max} is the maximum theoretical or estimated net productivity rate of the stock at a small population level. The default values are 0.04 for cetaceans and 0.12 for seals.

Introduction

The National Marine Fisheries Service (NMFS) Office of Science and Technology (F/ST) organized and held the agency's first National Protected Species Assessment Workshop (PSAW) on January 17-19, 2017 at the Alaska Fisheries Science Center's (AFSC) Sand Point Facility in Seattle, Washington. One hundred sixty-five scientists and managers attended in person or remotely, representing each NMFS Science Center and Regional Office, and NMFS headquarters offices (Office of Science and Technology, Office of Protected Resources (OPR), Office of Sustainable Fisheries), as well as the Pacific States Marine Fisheries Commission, Western Pacific Regional Fishery Management Council, North Pacific Fishery Management Council, five universities, and one consulting firm (a full list of participants is available in Appendix 1).

The National Protected Species Assessment Workshop was made possible through the direction of the PSAW Steering Committee. Thank you to NMFS leadership for supporting the workshop. Stephen Brown, Mridula Srinivasan, and Laura Ferguson from the Office of Science and Technology, Erin Oleson from the Pacific Islands Fisheries Science Center, Sean Hayes from the Northeast Fisheries Science Center, Robyn Angliss from the Alaska Fisheries Science Center, and Jim Carretta from the Southwest Fisheries Science Center dedicated considerable time and effort to organizing the workshop agenda and logistics, which greatly contributed to its success. Thank you to the volunteer note takers: Matthew Lettrich, Jeanette Davis, Eiren Jacobson, Paul Conn, Megan Winton, Marcia Muto, and Van Helker. Funding for the workshop was provided by the NMFS Office of Science and Technology.

Historical context of NOAA Fisheries first national protected species assessment workshop

Ned Cyr and Steve Brown

The first national PSAW follows in the tradition of other national assessment workshops, which NMFS has sponsored since 1991. There have been 12 National Stock Assessment Workshops (NSAWs), conducted at roughly two-year intervals, and National Habitat Assessment Workshops (NHAWs) were conducted in 2010 and 2012. These workshops address technical aspects of a priority assessment or science topic. They are primarily conducted by scientists for scientists, though some have had substantial manager participation. The workshops intend to increase understanding of the state of the science, develop guidance and best practices, and identify knowledge gaps and research needs. They facilitate communication across regions and disciplines, and create opportunities for networking, collaboration, and professional development.

The titles of the workshops provide insight into the hot topics over time and provide a window into how the science has evolved. The first two NSAWs were titled: "Determination of Allowable Biological Catches" and "Defining Overfishing – Defining Stock Rebuilding." Interestingly, the two most recent NSAWs were titled: "Characterizing Uncertainty to Improve Acceptable Biological Catches" and "Overfished? Overfishing? Approaches and Challenges Surrounding Stock Status Determination Criteria." The third NSAW was titled: "Bycatch and Discard Mortality," a topic closely related to a theme in our first PSAW.

The F/ST organized the PSAW in response to recommendations from the Protected Resources Board and the Protected Species Science Program Reviews[5]. As with the NSAWs and NHAWs, the goals of the PSAW are to advance the state of assessment science and to encourage cohesion and collaboration across regions.

Workshop Summary

At the inaugural PSAW, NMFS researchers shared significant advances in protected species assessment techniques to improve NMFS's collective ability to adapt and adopt new approaches. The PSAW steering committee designed an agenda to encourage broad and inclusive discussion with two days dedicated to the first theme, "Use of novel methods to assess abundance and trends," and one day focused on the second theme, "Methods to deal with poor data quality in bycatch estimation." The workshop followed a hybrid conference/workshop format with plenary presentations at the beginning of the day, followed by topical sessions containing 15-minute presentations and 15-30 minutes for open discussion. Each day concluded with open discussion of the day's theme and take-home messages. Throughout the workshop, discussion periods provided opportunities to extend conversations and raise overlooked topics of regional, management or taxonomical interest. A poster session provided opportunities to share works in progress, receive feedback, and discuss potential new methodological approaches.

The PSAW began with welcoming remarks from the steering committee co-chairs, Erin Oleson (Pacific Islands Fisheries Science Center) and Sean Hayes (Northeast Fisheries Science Center), F/ST Director Ned Cyr, and F/ST Assessment and Monitoring Division Chief Stephen K. Brown. The NMFS Chief Science Advisor, Dr. Richard Merrick, presented welcoming remarks that highlighted the accomplishments of protected species scientists and discussed his vision for the future of protected species science and scientists. Douglas DeMaster, Director, AFSC, presented the workshop's keynote address on management and conservation needs for marine mammal stock assessment reports.

Topical sessions held under the two workshop themes are summarized below.

Theme 1: Use of novel methods to assess abundance and trends

1. "Novel analytical approaches to population viability and risk assessment" included seven diverse presentations ranging from incorporating climate projections into risk assessment to modeling techniques for Endangered Species Act status reviews or population viability analyses.
2. "Novel data combinations for trend estimation" was composed of six presentations featuring techniques to meld sparse and dissimilar data sources.
3. The "special session on eDNA" had three presentations, which introduced this emerging technology and its applications for protected species assessment science.
4. "Advanced technology applications" included three presentations focused on using acoustic networks and thermal imaging surveys to assess species abundance.

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[5] https://www.st.nmfs.noaa.gov/Assets/science_program/NationalProgramReviewResponse2015_Final.pdf

5. “Using habitat relationships to assess density and abundance” included nine presentations that explored methods to improve habitat-based estimates of density and abundance.
6. “Advances in mark-recapture methods” had three presentations of new analyses and methods to advance this abundance-estimating technique.

Theme 2: Methods to deal with poor data quality in bycatch estimation

1. “New approaches to robust estimation for rare-event bycatch” included six presentations on how to overcome discontinuous and zero-inflated bycatch datasets.
2. “Incorporating spatial and temporal factors into bycatch assessments” comprised four presentations emphasizing the application of different methods to management needs.
3. “Cryptic mortality and serious injury” had three presentations on how to observe or account for unobservable takes.
4. “Electronic monitoring” included two presentations on video technology to complement fisheries observers to improve bycatch estimates.

Day 1: Introductory Remarks, Keynote Presentation, and First Day of Novel Methods for Abundance and Trends Assessment

Introductory Session

Keynote Speaker: MMPA stock assessments: Are they providing what we need for management and conservation?

Douglas DeMaster[6], Robyn Angliss, Paul Wade, Mridula Srinivasan, Kristy Long*

The Marine Mammal Protection Act (MMPA), as amended in 1994, provided a new, science-based framework for reducing direct impacts of commercial fisheries on marine mammal populations in U.S. waters. The amendments required NMFS and the Fish and Wildlife Service (USFWS) to develop stock assessment reports (SARs) for each marine mammal stock that include the basic information needed by managers, including stock description, geographic distribution, abundance, trend in abundance, and information on direct human-caused mortality and serious injury (M/SI) from all sources. The potential biological removal (PBR) level was included in the SARs to inform managers of the maximum number of marine mammals that could be removed from the stock annually, while still meeting the conservation objectives of the U.S. MMPA and the U.S. Endangered Species Act.

The first set of SARs was published in 1995. Guidelines for writing the SARs were developed and published in 1995 to help authors and ensure that the MMPA amendments were being applied consistently (Barlow et al. 1995). The most recent guidelines are provided at http://www.nmfs.noaa.gov/pr/sars/pdf/gamms2016.pdf.

Shortly after the amendments were passed, Read and Wade (2000) provided a summary of the 1996 marine mammal stock assessments. Here, we summarize key information in the 2015 SARs for comparison to the 1996 reports. The summary also provides information on the quality of the SARs, which the SAR authors report annually to analyze the adequacy of the assessments and how this is projected to change over time.

The number of marine mammal stocks recognized in U.S. waters has increased since 1996, as has the number of PBR estimates, while the proportion of stocks with sufficient information to calculate a PBR level has declined (Table 1). Read and Wade (2000) reported that the number of recognized marine mammal stocks in U.S. waters in the 1996 SARs was 155, and there was sufficient information on abundance for 63% of the marine mammal stocks from which to calculate a PBR level. By the publication of the 2015 SARs, the number of recognized marine mammal stocks had increased to 337; this increase was due primarily to the addition of 81 cetacean stocks in the western Pacific that were previously unrecognized, and the separation of various bottlenose dolphin, harbor seal, and harbor porpoise stocks into multiple units. The 2015 SARs included PBR levels for 48% of the 337 stocks; the decline in the percent of stocks for which a PBR level can be calculated is due to both the large proportion of stocks recently

[6] * indicates the presenting author.

identified for which no abundance information is available (and thus no PBR level can be calculated), and the guidelines for assessing stocks that recommend abundance estimates more than eight years old not be used in the assessment. In addition, the percent of stocks for which a PBR level can be calculated varies by region; that is, among the five regions the highest was 84%, while the lowest was 26%. Finally, the number of quantitative assessments of trend in abundance for individual stocks declined from approximately 25% to 20% between 1996 and 2015.

Table 1. Summary of key information in marine mammal SARs developed in 1996 (Read and Wade 2000) and information in marine mammal SARs for 2015. Unless otherwise specified, the number of stocks with takes refers to mortalities and serious injuries that occurred incidental to commercial fishing operations.

	1996		**2015**			
	# of stocks	**% with PBR level**	**# of stocks**	**% with PBR level**	**# of stocks with takes reported**	**Observer Programs for Category I/II fisheries?**
Gulf of Mexico	26	85%	63	40%	14	Yes
Atlantic & Carib.	33	55%	55	65%	32	Yes
Alaska	39	67%	51	67%	43 (29 subsistence)	Federal – Yes State – No
West Coast	37	81%	43	84%	30	Yes
Hawaii & W. Pacific	20	10%	125	26%	9	Yes
Total	155	63%	337	48%	128	

NMFS annually tracks the adequacy and quality of assessments for marine mammal stocks using criteria based on Merrick et al. (2004). The adequacy and quality of an assessment is scored after evaluating the availability and degree of uncertainty inherent in key assessment data and the frequency of the assessment. The agency projects the likely scores in future years to alert decision makers of changes in assessments that are likely to impact the availability of information. For example, a stock assessment would be considered inadequate if an unbiased estimate of abundance was not available. Overall, the percent of adequate stock assessments for marine mammals has remained constant along the U.S. West Coast, Gulf of Mexico, and Hawaii/Western Pacific Regions at approximately 60%, 3%, and 3%, respectively (Figure 1). The percent of adequate stock assessments in the Atlantic Region is projected to increase from 23% in FY2015 to approximately 45% by FY2019. The percent of adequate stock assessments in

Alaska is currently at 42%, but is expected to decline to 18% in FY2021 because funding will not be sufficient to support surveys needed to estimate abundance for a number of stocks.

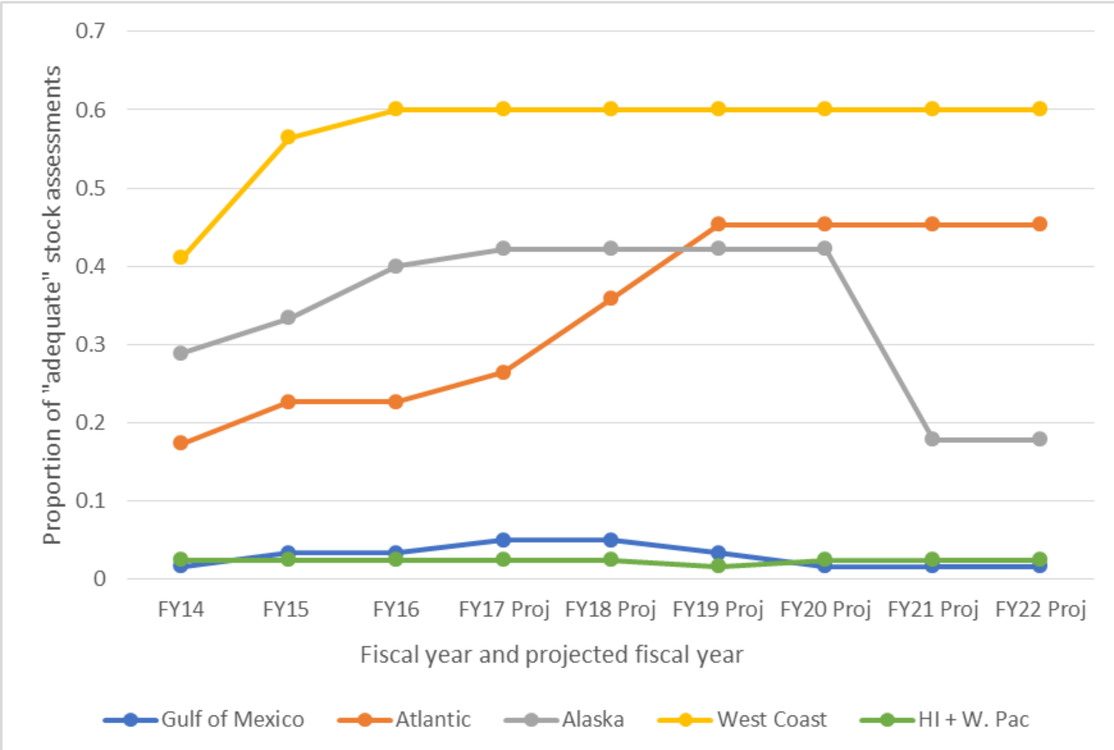

Figure 1: Proportion of “adequate” marine mammal stock assessments using criteria based on Merrick et al. 2004.

The 1994 amendments to the MMPA and subsequent regulations also require annual classification of U.S. commercial fisheries based on their level of M/SI relative to each stocks’ PBR level. “Frequent,” “occasional,” and “remote likelihood” of takes are defined by regulation in terms of the number of M/SI events relative to the PBR level of the impacted marine mammal stocks. NMFS has the authority to place observers on vessels in fisheries classified as “frequent” or “occasional.” Observer coverage levels vary by fishery and region. NMFS also has the authority to convene multidisciplinary teams that include representatives of all stakeholder groups to develop consensus recommendations for reducing M/SI of marine mammals in commercial fisheries with frequent or occasional levels of M/SI. The success of the Take Reduction Plans resulting from these efforts has been mixed. M/SI of harbor porpoise in the northeast and mid-Atlantic gillnet fisheries, false killer whales (inshore stock) in the Hawaii longline fishery, and various cetacean species in the Pacific drift gillnet fisheries have been reduced to below the PBR level for the marine mammal stocks of concern. However, sufficient declines in M/SI relative to PBR levels have not been realized for northern right whales and humpback whales in the Atlantic gillnet and trap/pot fisheries, for bottlenose dolphins in Atlantic nearshore fisheries, or for pilot whales in the Atlantic longline fishery. Take Reduction Plans with a narrower scope (e.g., one or two fisheries and one or similar species of marine mammals involved) have proven to be more successful. In some areas, such as Alaska and the western Pacific, fisheries that may result in M/SI of marine mammals at levels likely to trigger conservation concerns have not been adequately observed.

Overall, calculating PBR levels provides a simple, biologically-relevant reference point that can be used by managers to evaluate direct fishery-related impacts to stocks when there are limited data available. Although more marine mammal stocks have been identified in 2015 than in 1996 and more PBRs have been calculated in 2015 than in 1996, the percent of stocks with recent estimates of abundance – the most basic information needed to manage a stock – has declined. In addition, funding has never been available to support observer programs needed to evaluate levels of marine mammal bycatch. Evaluating – and reducing if needed – the level of M/SI incidental to commercial fisheries requires robust data on marine mammal bycatch. The Take Reduction Plan process has worked well when the scope of the plans is limited and the PBR for impacted marine mammal stocks is available and sufficiently high to accommodate some level of bycatch. However, there are other impacts to marine mammals that are not addressed by the Take Reduction Plan process, including management of subsistence hunting (accomplished through co-management agreements between agencies and their Alaska Native co-management partners), mortalities that occur incidental to scientific research, ship strikes, and incidental anthropogenic effects (e.g., anthropogenic noise).

Two conclusions are drawn from this analysis. First, the marine mammal stock assessment protocol in the U.S. is useful in providing the information that managers need for conservation and management in some, but not all, situations. And two, the success of the protocol is highly dependent on the Agency's ability to collect data on both abundance and mortality incidental to commercial fisheries.

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Plenary Speaker: National (fish) stock assessment: Status, challenges, and recent advancements

*Richard Methot**

The scientific community supporting fish stock assessments has a long history of organizing its efforts to support sustainable management of fisheries. This started most notably with the first National Stock Assessment Workshop in 1991, followed by publication of the Stock Assessment Improvement Plan (SAIP) (http://www.st.nmfs.noaa.gov/stock-assessment/saip) in 2001. The SAIP focused on growing a program that could support sufficient assessments for all major stocks. Simultaneous with the publication of the SAIP, the Expand Annual Stock Assessment (EASA) budget line was created and by FY2016 was at near $70 million. These resources have enabled a substantial increase in the number of stock assessments (Figure 2). Of the federally managed stocks in the Fish Stock Sustainability Index (FSSI) at the end of FY2016, 123 out of 199 (61.8%) were considered to have adequate assessments. However, many of the nearly 300 non-FSSI stocks have never been assessed, and have no survey to support an assessment. A recent review of the non-salmonid fish assessment program determined that the total program cost was $215 million in FY2015. This estimate included all budget lines that are directed towards observers, catch monitoring, fishery-independent surveys, research and staffing for assessments, and the cost of ship time for fishery-independent surveys on the NOAA fleet.

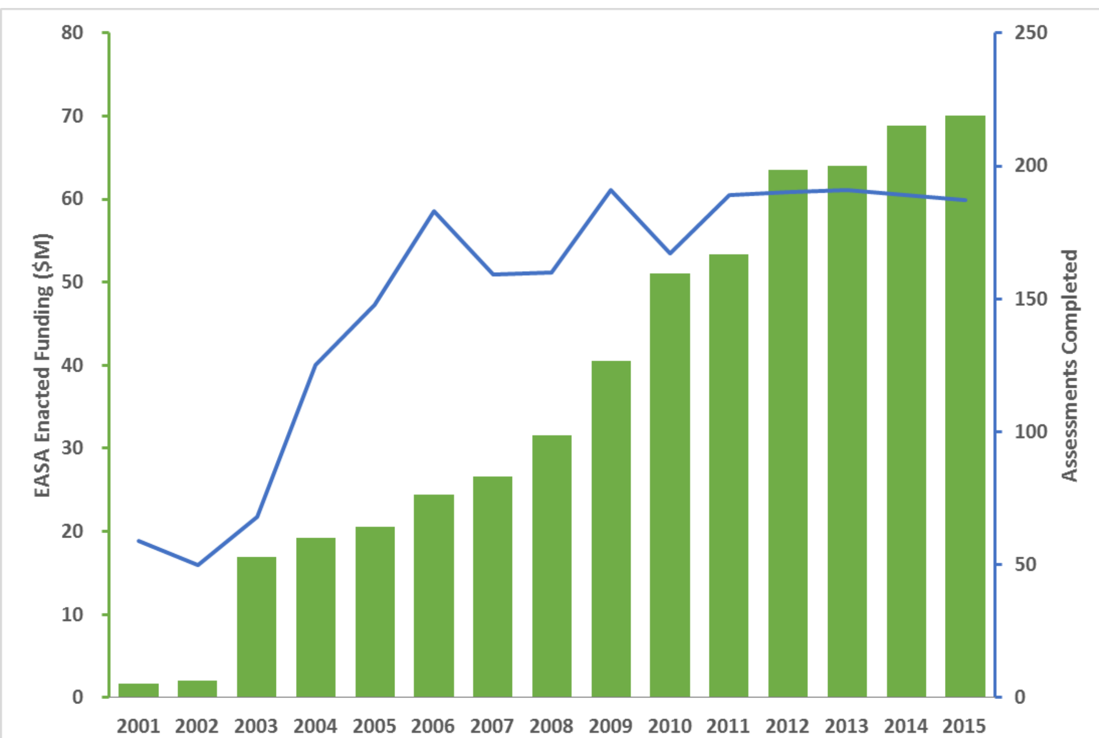

Figure 2. Growth in annual funding in the Expand Annual Stock Assessments (EASA) budget line (left axis, green bars) and in the total number of stock assessments completed per year for federally managed stocks (right axis, blue line), 2001-2015.

Here in this talk, I provide a brief overview of four relevant topics: Abundance Monitoring, Stock Productivity, Population Modeling, and Climate/Ecosystem Linkages. For background on the basics of fish stock assessments, please see: http://www.st.nmfs.noaa.gov/stock-assessment/stock-assessment-101.

Abundance Monitoring – Unlike cetacean and pinniped status determinations, which rely upon the most recent survey that provides a direct estimate of absolute animal abundance, fish assessments typically infer absolute abundance from a population model that is calibrated with time series of catch (absolute) and surveys of relative abundance. In many cases, this relative abundance measure comes from catch rates determined from fishermen's logbooks; hence, even the relative calibration of such an index can drift over time. This reliance on relative abundance is due to the difficulty in actually conducting a direct estimate of fish abundance. In comparison to photographing and counting pinnipeds on a beach from an airplane or a drone, fish are notoriously difficult to observe directly. Today, technological advancements are allowing more surveys that use acoustics, optics, or bottom trawls to work towards direct calibration to absolute abundance. The most recent examples are scallop surveys from towed video sleds (https://www.nefsc.noaa.gov/press_release/pr2015/scispot/ss1508/) and a testbed experiment in the Gulf of Mexico to measure the observability of reef-fish from various towed and robotic platforms.

Stock Productivity – Assessments for the most important fish stocks tend to be based on age-structured models in which the spawner-recruitment relationship plays a key role. Not only does it drive the expected level of future recruitments, but the simple, two-parameter shape of these curves means that the target abundance level, hence the rebuilding target, is determined by these two parameters. Several areas of investigation ensue from various aspects of this relationship.

- By expanding to three parameters, the target biomass level is less coupled with the shape of the spawner-recruitment curve. This third parameter cannot be well-estimated, but including it allows for more complete characterization of uncertainty and the more flexible curve may better be able to use ecosystem considerations to set the target biomass levels.
- Where there is insufficient time series data to estimate the curve, proxies are needed. The upcoming development of technical guidance for the Magnuson-Stevens Act's National Standard 1 will address regional and stock differences in these proxies.
- Temporal changes in spawner-recruitment parameters are receiving much attention with linkage to long-term climate drivers, regime shifts, and dynamic baselines among many ongoing investigations.

Population Modeling – The population models at the heart of stock assessments also continue to evolve. Considerable effort has gone into data-limited methods tailored for situations where we have little data other than catch (Carruthers et al. 2014). Various data-limited methods have been applied in global meta-analyses to help infer advice for these situations. Data-limited methods have also been embedded in a Management Strategy Evaluation framework to help determine what types of data and harvest approach would work in particular situations. Models that employ random effects are seeing much development, partly due to the advent of the Template Model Builder (TMB) code that greatly speeds execution of such models. TMB is also behind development of models with high spatial granularity and are now being used to explore true spatial-temporal population modeling (Thorson et al. 2015). Another transition underway is the increased use of professional programming approaches and code repositories. The use of ensemble modeling approaches is under development in order to better characterize the contribution of structural uncertainty to the overall uncertainty of assessment results. Finally, these better estimates of uncertainty feed into management approaches that implement an explicit buffer between the fishery limit and the fishery target in proportion to the degree of uncertainty.

Climate/Ecosystem Linkages – As noted earlier, climate effects on recruitment are an important research topic. In addition, there has been recent work to describe shifts in population distributions, with the decades-long time series of bottom trawl surveys serving a key role in this process (see a recent example: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0137382). Another extensive project has worked on identifying the vulnerability of each species to climate changes.

Stock Assessment Improvement Plan – In 2017, the Stock Assessment Improvement Plan will finally be updated (see http://www.st.nmfs.noaa.gov/stock-assessment/future-of-stock-assessment). The updated plan is divided into three arenas. One is to expand the scope of assessments to be more holistic of ecosystem, habitat, environmental and economic drivers and impacts. This includes harvest control rules designed to meet ecosystem and economic objectives and not just to preserve a fraction of the stock for reproduction. Another arena of activity is the use of technology to enable better data collection and more advanced analytical methods. The third arena, sometimes called the "4T's," gets at the assessment process to improve:

- throughput by producing results for more stocks;
- timeliness by conducting assessments more quickly;
- transparency by ensuring assessment results are well documented and clearly communicated; and
- thoroughness by ensuring that the most comprehensive assessments are conducted for highest priority stocks and that all assessments undergo an appropriate level of peer review.

More standardization of assessment methods and revision of the assessment review processes are key to addressing the 4T's.

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Novel Analytical Approaches to Population Viability and Risk Assessment (Part 1)

Session Highlights:

- Critical abundance thresholds, number of populations distributed globally, and time horizons implied by past listing decisions provide a basis for a standardized approach for ESA status reviews.
- Managing human-caused direct mortality may be the most important factor for marine mammal population recovery, but trade-offs between mixed fishery fleets and protected species requirements (i.e. prey populations) also play an important role.
- Multivariate autoregressive state-space (MARSS) models allow the use of time-series data that are multi-survey or multi-site, fragmented, and interrupted with unknown error levels.
- A statistical approach to answer a research question will be different from a statistical approach to inform a management decision.
- A model becomes more robust when more sites are added.

Model-based approaches to support consistent extinction risk assessment for ESA status reviews

Charlotte Boyd, Douglas DeMaster, Robin Waples, Eric Ward, Barbara Taylor*

The Endangered Species Act (ESA) is a powerful tool for species protection, but does not provide clear guidance on the levels of extinction risk that should lead to endangered or threatened listing decisions. We developed a modeling framework for consistent scientific analysis of extinction risks and used it to investigate the critical abundance thresholds, numbers of populations, and time horizons implied by past listing decisions. For 14 marine species previously assessed under the ESA, we used a Bayesian population modeling approach to assess the risks of declining below various abundance thresholds over various time horizons based on data available at the time of the listing decision. We found that in general endangered species faced consistently higher relative risks of declining below the critically low abundance thresholds of 250 mature individuals over a time horizon of five generations. In comparison, the narrow difference in relative risk levels faced by some threatened and not warranted species indicates the challenges of distinguishing between these two categories. Understanding the critical abundance thresholds, numbers of populations, and time horizons implied by past listing decisions provides a valuable basis for moving towards a more standardized approach to identifying endangered and threatened species under the ESA. The results of our analysis present a framework for science-based risk assessment consistent with past listing decisions and could enable more consistent, predictable, transparent, and efficient ESA status assessments while retaining flexibility to accommodate species-specific factors. This research has been published and can be found at: http://onlinelibrary.wiley.com/doi/10.1111/conl.12269/abstract.

Simulations to evaluate direct and indirect impacts of commercial fishing on marine mammal recovery

Laurel Smith, Robert Gamble, Allison Henry, Sarah Gaichas, Jason Link, Kevin Friedland*

In managing marine mammal populations, potential biological removals are calculated to determine the amount of allowed direct mortalities from fishing and other human interactions that will still maintain an optimum sustainable population. However, the indirect effects of commercial fishing including competition for prey are rarely considered. To explore these interactions, we used a multi-species production model to evaluate the interactions between mixed fleet fisheries, their target species, and marine mammals in a simulated ecosystem representative of the Northeast U.S. continental shelf. We used a multispecies production model to simulate changes in fisheries' effort, levels of mortality caused by bycatch and ship strikes, and dependence on prey species by marine mammals. We compared the resulting biomass and catch trajectories to associated biological reference points for commercially important finfish and current biomass levels of marine mammals. Marine mammal populations increased over time in our simulations under all scenarios, except when groundfish harvest of gadid fish and flatfish were increased by four times the current harvest (Figure 3). Under this scenario, mysticete whale populations declined by 30%, largely due to increased interactions with groundfishing gear as fishing effort increased. Our simulations suggest that managing human-caused direct mortality may be the most important factor for the recovery of marine mammal populations, but fishery management also plays an important role by avoiding the issues caused by reduced levels of prey populations. Therefore, it is important to take marine mammal consumption needs into account when designing harvest control rules for managed prey species. Additionally, we show that marine mammal predation can also affect trajectories and reference points for commercially fished species. Evaluations of direct human-induced mortalities as well as the trade-offs between mixed fishery fleets and protected species requirements are essential as we transition to Ecosystem-Based Fisheries Management.

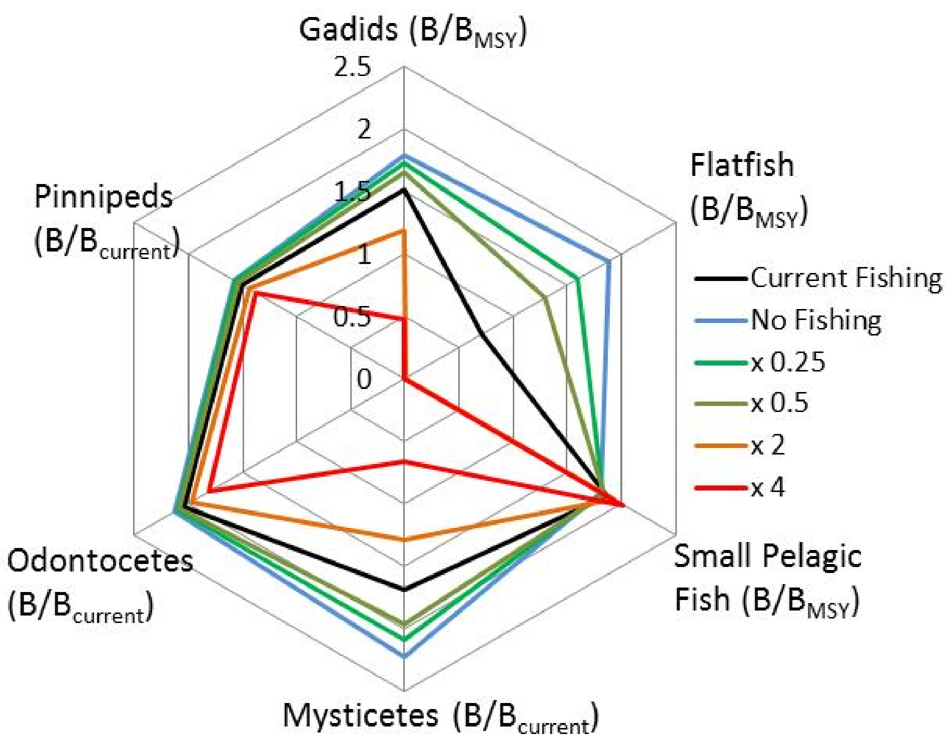

Figure 3. Changes in biomass *(B)* over 50 years relative to biomass targets, due to changes in groundfish harvest (gadids and flatfish removals) under the base scenario. B_{MSY} (biomass needed to deliver maximum sustainable yield) for the fish groups was a proxy defined as half of each group's average biomass in an unfished system, and $B_{current}$ for the marine mammal groups is the starting biomass in the model.

Multivariate autoregressive state-space models (MARSS): PVA for data-poor species

Nick Tolimieri, Elizabeth Holmes, Greg Williams*

Estimating the population's growth rate and year-to-year variance is a key component of population viability analysis (PVA). Standard PVA methods require a time series of counts using consistent survey methods. Here we illustrate how multivariate autoregressive state-space (MARSS) models allow the use of time-series data that are multi-survey or multi-site, fragmented, and full of gaps with unknown error levels. We estimate the long-term "population" growth rates for the total rockfish assemblage in Puget Sound using MARSS modeling to combine data from a recreational fishery survey, a scuba survey, and a fishery-independent trawl survey. We then infer the long-term trends of three ESA-listed rockfishes in Puget Sound (bocaccio, canary and yelloweye rockfishes) by evaluating evidence that these species increased or decreased as a proportion of the total rockfish assemblage. The recreational fishery and trawl surveys sample deep water and appear to track a different rockfish assemblage than the scuba survey, which targets shallow depths (< 40 meters). The rockfish trajectories associated with the deep-water surveys declined at 3.8-3.9% per year. The rockfish trajectory associated with the shallow REEF survey increased 4.1% per year. There was strong support for regional temporal independence but not regional differences in population growth rates. The listed species are associated with deep water and are observed in the recreational fishery data but rarely in the scuba and trawl surveys. All three species declined as a proportion of recreational catch, which suggests faster rates of decline than that estimated from the recreational fishery and trawl data.

Novel Data Combinations for Trend Estimation

Session Highlights:

- Combining multiple data sources can facilitate and improve precision for trend and abundance estimates that can be used to inform protected species management actions.
- Bayesian hierarchical modeling is a technique that can be applied in diverse contexts and to estimate trends in species abundance when there is considerable variability in data types, collection methods, and biases in estimating parameters.
- Two novel methods to overcome data-quality limitations such as short survey periods, infrequent capture-occasions, and low sighting probabilities are: 1) combining two databases that sample the same population with temporal overlap, and 2) using a Bayesian integrated population model to combine short-duration capture-recapture study with commercial bycatch data, historical fisheries information, and published estimates.
- The R package *agTrend* hierarchical model can augment missing abundance measurements and account for survey methodology changes and variability to analyze regional trends of abundance from sites with uneven sampling schedules over space and time.
- Life-cycle models can facilitate assessment of the impact of a variety of actions (e.g., hatcheries, harvests) and translate results into a common metric to aid in species recovery actions.
- There was convergence in the use of similar trend estimation tools by biologists working on different taxa and in different regions.
- More coordination and communication is necessary across the agency to share advances and shortcomings of various techniques and their management applications.

When every bit of information matters: Bayesian hierarchical models for combining data for protected species

Jay M. Ver Hoef, Peter Boveng, Devin Johnson*

When studying rare or elusive species, it is often difficult to obtain sufficient information to make precise estimates of abundance and trend. A relatively new idea is to use Bayesian methods to combine multiple data sources, which can improve knowledge about protected species, resulting in more informed decisions. Combining data generally involves creating likelihoods hierarchically, or as products, or using some combination of the two. We provide an overview with four brief examples. We show a hierarchical model for ecosystem data related to pup growth in Antarctic fur seals (Hiruki-Raring et al. 2012). As a second example, we show how trend and abundance estimation in western Aleutian harbor seals combined data from aerial survey counts, haul-out data from satellite transmitters attached to seals, and covariate effects from other stocks. As a third example, trend and abundance estimation for harbor seals in Lake Iliamna combined a Leslie matrix model with parameters taken from the literature, along with aerial survey counts, harvest information, and an unknown haul-out factor. As a fourth example, we combined historical counts of harbor seals from fixed locations in Glacier Bay with more recent aerial surveys, using a Bayesian calibration, again combined with haul-out data from satellite transmitters attached to seals. Finally, recent trend and abundance estimates for the highly endangered vaquita porpoise used multiple line-transect surveys across years, along with acoustic data (Jaramillo-Legorreta et al. 2016; Taylor et al. 2016). In the examples above, trend and abundance were either impossible without combined data, or precision was significantly improved by the additional information. Samples from the posterior distributions of trend and abundance can be used as input to functions important for the management of protected species, such as N_{min} or recovery factor, providing probability statements and uncertainty for such functions.

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Estimating cetacean abundance trends from survey time series: integrating multiple data sources within a Bayesian framework

Jeffrey Moore, Karin Forney, Jay Barlow, Barb Taylor*

Estimating temporal trends in marine mammal abundance is central to their management and our understanding of their ecology. However, detecting trends for marine mammals is challenging, particularly within a null hypothesis testing framework, because of variable detection rates across surveys (e.g. due to differences in observers, conditions, or even methods) and low precision of individual abundance estimates. We have achieved some successes in estimating trends for several species, from porpoises to large whales, by using a flexible Bayesian approach, consisting of a hierarchical model to explicitly model the state process (population trend) and the observation process (i.e., that which generates the data), and extending this model as needed to deal with different data types, spatial information, and so on. We use several case studies as examples of some of the challenges of analyzing different types of real-world survey data and how those can sometimes be addressed to produce useful population trend inferences.

agTrend: an R package for regional trend estimation from site level survey data

Devin S. Johnson, Lowell Fritz, Jay Ver Hoef*

We describe a method and open source R package *agTrend* for analyzing regional trends of abundance from sites with uneven sampling schedules over space and time. The method uses a hierarchical model to augment missing abundance measurements, while accounting for survey methodology changes and variability due to survey replication. A zero-inflated log-normal distribution is used to model abundance (normalized for methodology changes) and a log-normal distribution to model the observed abundance conditional on the true normalized abundance. The proposed method and software are demonstrated with an analysis of regional abundance index trends of Steller sea lions (*Eumetopias jubatus*) in Alaska. The package will be of most use to ecologists and resource managers interested in estimating regional trends of abundance surveys aggregated over several sites when sites have not been surveyed at concurrent times and hence regional abundance measurements cannot be directly calculated.

Bayesian capture-recapture models for assessing population trends in threatened oceanic manta rays

Joshua D. Stewart, Robert D. Rubin, Katherine R. Kumli, Brice X. Semmens*

Oceanic manta rays (*Manta birostris*) are listed as Vulnerable by the International Union for Conservation of Nature (IUCN) and are currently under consideration for listing under the Endangered Species Act. Almost no information on the abundance and trends of *M. birostris* subpopulations exists, and demographic information for the species is sparse. Consequently, quantitative population assessments for this data-poor species are nonexistent. While survey data for the species are scarce, manta ray aggregations are a popular attraction for dive tourists, who can collect images of individual-specific ventral spot patterns and contribute these photo IDs to regional databases. Here, we use Bayesian data-augmentation capture-recapture methods to estimate *M. birostris* abundance and population trends at two sites in the Tropical Eastern Pacific. We developed novel methods to overcome data-quality limitations such as short survey periods, infrequent capture-occasions, and low sighting probabilities. The first method combines two databases sampling the same population with temporal overlap: a long-term, low-effort database, and short-term, high-effort database. Simulations demonstrate that the incorporation of these two databases as separate observations into a single model increases the precision of abundance estimates by over 30%. The second method uses a Bayesian integrated population model to combine a short-duration capture-recapture study with commercial bycatch data, historical fisheries information, and published estimates of R_{max} in manta rays to estimate population trends over a far greater temporal period than the photo-ID database covers. These approaches provide frameworks for combining multiple data types to estimate abundance and population trends of threatened, data-poor marine species.

Combining sparse, dissimilar data sources in a Bayesian hierarchical model for assessment of a small harbor seal population

Peter Boveng, Jay M. Ver Hoef, David E. Withrow, Joshua M. London*

Harbor seals in Iliamna Lake, Alaska, are a small, isolated, and poorly documented population. A few surveys have been conducted over the past several decades, but most of those are from just the past 10 years and – as is typical for harbor seals – the counts are highly variable. Pups were counted separately from non-pups in some, but not all, of the surveys. There is a small, poorly quantified subsistence harvest by Alaska Native residents around the lake. A Bayesian hierarchical model was used to combine these dissimilar data types with prior information from the literature about vital rates and haul-out probabilities, to estimate abundance and trend of the population. Observational models were developed from aerial survey and harvest data. Underlying models of abundance and trend were based on a simplified Leslie matrix model. We developed three scenarios for variability in the priors and used them as part of a sensitivity analysis. The results indicated that after a period of growth in the 1980s, the population has been relatively stable at about 385 individuals (95% credible interval of 317-473). The production rate implied by the survival and reproductive rates was about 5% per year, very similar in magnitude to the average annual harvest, and therefore consistent with the overall stable population trend. The posterior distributions of the estimates allowed us to project the population forward in a population viability analysis that could be used as a framework for an extinction risk assessment.

Assessing populations of salmon using life-cycle models

*Rich Zabel**

Life-cycle models are valuable tools for assessing populations of Pacific salmon. In the interior Columbia River basin, we have been using life-cycle models to aid in recovering salmon populations. We have been using the models to assess a portfolio of actions (habitat, hydro, harvest and hatchery), while taking into account factors such as climate change. The models allow us to assess the impact of a variety of actions and translate results into a common metric.

Novel Analytical Approaches to Population Viability and Risk Assessment (Part 2)

Session Highlights:

- Integrating climate projections into population viability analyses is an important next step in conducting status reviews of sea turtle populations.
- Several of the Red List criteria use generation length for temporal scaling of population declines and these IUCN criteria for marine species listings typically follow Criterion A (rate of decline in abundance over 10 years or three generations, whichever is longest). Thus, accurate estimation of generation length is necessary to properly assess species extinction risk.
- Assessment of habitat changes from past to present (e.g., for comparisons before and after the onset of large-scale fishing or habitat modification) could be useful in setting realistic recovery criteria across the entire species range.
- To estimate sea turtle bycatch and assess population-level impacts in Hawaii longline fisheries, adult nester equivalent (ANE) for a Distinct Population Segment (DPS) of sea turtle could be calculated from observer data using three adjustment factors: 1) adult equivalence of juveniles, 2) ratio of females in the population, and 3) probability of mortality.
- Impacts based on future climate projections can be on lengthy time scales (100-200 years), which are in contrast with the short time scales that managers have to consider in decision-making.

Integrating climate projections into a population model for the Hawaiian green turtle

Summer L. Martin, T. Todd Jones, Shawn Murakawa, George Balazs, Jeffrey Maynard*

Climate change is a known critical knowledge gap limiting the ability of the NOAA Fisheries Science Centers and the U.S. Fish and Wildlife Service (USFWS) to comprehensively review the status of marine turtles listed under the Endangered Species Act (ESA). To estimate the future risk of populations falling below important biological thresholds, ESA status review teams use the best available science to conduct population viability analyses (PVAs). To date, PVAs for Pacific turtle populations have relied almost exclusively on nester abundance data and have not quantitatively included climate change impacts. However, increased temperatures may influence turtle populations through temperature-dependent sex determination and embryonic death, where temperatures above critical thresholds produce female biases and cause nest failures. Our objective here is to incorporate climate projections into a stage-based population model for the Hawaiian green turtle to explore possible impacts of warming sand temperatures on the population. Our approach includes: 1) compiling sand temperature data for East Island, Hawaii, the primary nesting site for the population, 2) using remotely-sensed data to develop sea/air and sand temperature regression models, 3) generating climate model projections of sand temperatures, 4) developing a stage-based population model of the turtle population, and 5) conducting population viability analyses inclusive of the implications of sand temperature projections on sex ratios and nest success. Results from this research will feed directly into the next status review for green turtles, and the climate integration approach can be applied to future assessments of turtle populations in the Pacific and other regions.

How do IUCN proxies for generation length perform?

Robin Waples and Han-Chi Fung*

The most widely used framework for assessing extinction risk of species in the wild was developed by the International Union for Conservation of Nature (IUCN). The IUCN considers five criteria to assess extinction risk, and each species is assigned a Red List risk category (ranging from least concern to extinct) based on the criterion that produces the highest estimated risk (Mace et al. 2008; www.iucnredlist.org). Several of the Red List criteria use generation length for temporal scaling of population declines. Criterion A focuses on the rate of decline in abundance over 10 years or three generations, whichever is longest, and IUCN listings of marine species are commonly based on this criterion. Therefore, it is important to have an accurate estimate of generation length (T): over- or under-estimates of T will cause the decline to be measured over the wrong time period, which in turn will lead to an over- or under-estimate of extinction risk.

A widely accepted general definition of generation length is the average age of parents of a newborn cohort (Charlesworth 1994; Caswell 2001). This is easy to calculate from vital rates (age-specific survival and fecundity), but these data are difficult to obtain. Therefore, proxies for generation length that require only some basic life history information are commonly used. We evaluated performance of two proxies recommended by the IUCN (2014): an adult-mortality proxy ($\hat{T}_d = \alpha + 1/d$), which depends on age at first reproduction (α) and annual adult mortality rate (d), and a reproductive-lifespan proxy ($\hat{T}_z = \alpha + z$*RL), which depends on α, reproductive lifespan (RL), and a coefficient (z) that must be estimated empirically based on information for other species.

We began by reviewing theoretical expressions for generation length for two different modes of reproduction. In the continuous model, individuals breed throughout the year, while in the discrete (birth-pulse) model, births are concentrated within a relatively short, seasonal time span. The birth-pulse model is simpler and more widely used. Simple analytical solutions for both models are possible if one assumes that vital rates are constant after age at maturity and that the lifespan can be arbitrarily long. We showed that under those conditions, the IUCN-recommended adult-mortality proxy is only correct for the continuous model of reproduction, and then only if instantaneous adult mortality (M) is used instead of annual mortality (d). We also showed that for the birth-pulse model under these same simplified conditions, true $T = \alpha - 1 + 1/d$, exactly one year less than the adult-mortality proxy $\hat{T}_d$ recommended by the IUCN. Accordingly, we propose an adjusted adult-mortality proxy for species with birth-pulse reproduction as $\hat{T}_{d(adj)} = \alpha - 1 + 1/d$.

To evaluate performance of the three proxies, we obtained 78 published life tables of vital rates for birth-pulse species (vertebrates, invertebrates, and plants) and used these to calculate true values of T. For each species, generation length was also estimated ($\hat{T}$) using the proxies, and the distribution of errors ($\hat{T} - T$) was calculated. Mean error rates in estimating generation length were 31% for $\hat{T}_d$, 20% for $\hat{T}_z$, and 16% for $\hat{T}_{d(adj)}$ (Figure 4, top). $\hat{T}_{d(adj)}$ also provided largely unbiased estimates regardless of the true generation length, whereas $\hat{T}_z$ was biased high for species with short generation length and biased low for species with longer generation time (Figure 4, bottom). $\hat{T}_d$ substantially overestimated T for species with short generation lengths, but the proxy became largely unbiased for species with true T > 10; this pattern can be predicted from theory because of the fixed error of one year $\hat{T}_d$ has in estimating true T.

Performance of $\hat{T}_z$ depends on having detailed data for comparable species, but our results suggest taxonomy is not a reliable indicator of comparability; species used to calculate the coefficient z must have similar life history traits. All three proxies depend heavily on a reliable estimate of age at first reproduction. Using mock conservation assessments for two species (desert tortoise and bocaccio rockfish), we showed that methods for estimating α and proxies for estimating T can influence the classification of risk under IUCN Criterion A. The relatively large mean errors, even for $\hat{T}_{d(adj)}$, emphasize the importance of collecting the detailed life history information necessary to calculate true generation length in species of conservation concern. The IUCN provides a worksheet (available at http://www.iucnredlist.org/technical-documents/red-list-training/red-list-guidance-docs) for calculating generation length, and this is the best option if age-specific vital rates are available. Unfortunately, publication of such data is less common than it was several decades ago.

For the more common situation where life-history information is more limited and proxies must be used, we have the following recommendations.

Birth-pulse reproduction

I. Vital rates approximately constant

Use $\hat{T}_{d(adj)}$ = α – 1 + 1/*d*.

II. Fecundity and/or survival change with age

Often it will be the case that one knows or strongly suspects that vital rates are not constant, but does not have the detailed information to calculate *T* directly. In that case, options are:

$\hat{T}_{d(adj)}$ = α – 1 + 1/$\overline{d}$, or

$\hat{T}_z$ = *a* + z * RL..

$\hat{T}_{d(adj)}$ appears to be fairly robust to non-constant vital rates, based on its overall performance across 78 published life tables. However, $\hat{T}_z$ might be a good option if an estimate of *z* is available for truly comparable species (where comparability reflects life history and not simply taxonomy).

Continuous reproduction

I. Vital rates approximately constant

Use $\hat{T}_d = \alpha + \frac{1}{M}$.

II. Fecundity and/or survival change with age

We did not evaluate continuous reproduction with non-constant vital rates. It seems plausible that some variation of $\hat{T}_z$ or $\hat{T}_{d(adj)}$ might be developed for this type of scenario. Provided that *M* is not too high, treating all continuous births as occurring in a pulse centered on the midpoint between ages *x* and *x* + 1 generally should be a reasonable approximation.

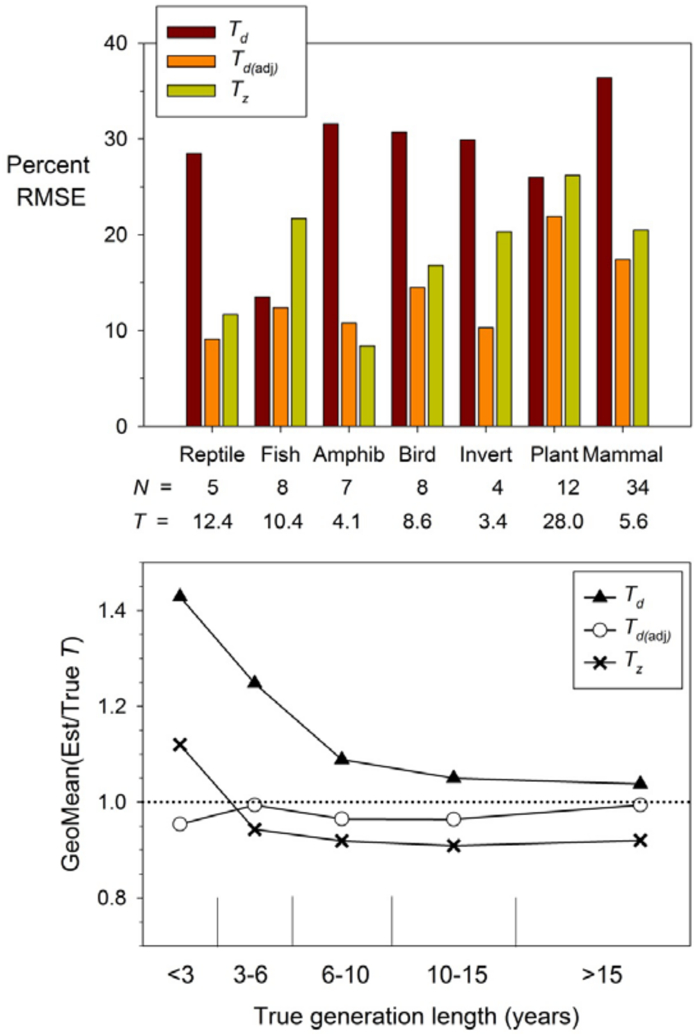

Figure 4. Performance of three proxies for generation length assessed using published life tables for 78 species with birth-pulse reproduction. Top: percent root-mean-squared-error (RMSE) in estimating true T. Sample sizes (N) and mean true generation length are shown for species from seven taxonomic groups. This figure plots data from Table 1 in Fung and Waples (in press). Bottom: bias of the three proxies across all species, as a function of the true generation length. Reproduced from Figure 3 in Fung and Waples (in press).

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Informing Gulf sturgeon (*Acipenser oxyrinchus desotoi)* recovery goals based on historical population size and extant habitat

Robert Ahrens, Bill Pine, Merrill Rudd, Stephania Bolden*

Conservation efforts to restore species in decline to levels that minimize jeopardy often establish restoration targets for populations. The establishment of realistic restoration targets given changes in habitats and ecosystems is difficult, particularly for populations that have experienced significant habitat alterations. We developed and assessed an approach for establishing quantifiable goals for the recovery of a threatened species, Gulf sturgeon *Acipenser oxyrhynchus desotoi* by 1) estimating historical population biomass prior to directed fishing, 2) identifying large-scale habitat modifications that limit available critical habitat, 3) assessing the relationship between historical baselines, habitat characteristics, and extant available habitat, and 4) using these relationships to inform recovery efforts in rivers where traditional stock assessment methods are not possible. We found that the current population levels in four of the seven river systems in the recovery plan are likely at or exceeding the mean carrying capacity, given the current levels of available habitat. In the remaining three rivers, extant Gulf Sturgeon populations are likely below their estimated carrying capacity levels. Our approach is of management importance because it establishes realistic recovery criteria through the assessment of changes in habitat from historic to present levels and is widely applicable across a species' range. An important application of this approach is to assess the potential benefits to fish species from management actions, such as dam removal or spawning habitat restoration, that are designed to restore habitat and promote species recovery.

Assessing population level impacts of marine turtle bycatch in the Hawaii longline fishery

T. Todd Jones and Summer L. Martin*

The PIFSC Marine Turtle Biology and Assessment Program conducts population-level impact assessments of marine turtle bycatch in the Hawaii longline fishery to support the Pacific Islands Regional Office in its Endangered Species Act jeopardy analyses. The longline fishery interacts with four species of turtles (loggerheads, leatherbacks, olive ridleys, and greens), spanning at least nine Distinct Population Segments (DPSs). We evaluate impacts to the total nester abundance for each DPS, as nesting beach data are the most consistent index of abundance. To calculate an adult nester equivalent (ANE) for a DPS, we apply three adjustment factors to a proposed number of interactions: 1) adult equivalence of juveniles, 2) ratio of females in the population, and 3) probability of mortality. Calculating the adult equivalence of a turtle requires fishery observer data on its size, and estimates of size at maturity, growth rates, and stage-specific survival rates for the population. The ratio of females in the population comes from published studies, although we plan to base this on observer data in the future. The probability of mortality is determined by observers in the case of confirmed dead turtles or by the Pacific Islands Regional Office (PIRO) using a post-release mortality rubric. Using the observer data and the three adjustment factors, we calculate individual ANEs for all previously observed interactions for the species, apply an overall observed ANE rate to the proposed number of interactions, and compare the estimated ANE to the nester population to determine significance. Here, we discuss the limitations and future directions of our current approach.

Special Session on eDNA

Session Highlights:

- Environmental DNA or eDNA sampling is an emerging tool to detect DNA shed into the aquatic environment by different species.
- eDNA could potentially be used to genetically identify deep sea organisms, assess distribution and habitat use, detect rare or cryptic species, sample sites for species presence/absence, and characterize regional patterns of biodiversity.
- eDNA research is in its infancy, and questions remain on the persistence of animal DNA in the water column and its use in estimating species abundance.

A novel approach for studying stock structure of enigmatic marine vertebrates using eDNA

Kim Parsons, Marilyn Dahlheim, Meredith Everett, Linda Park*

Harbor porpoise (*Phocoena phocoena*) are distributed throughout Alaskan waters and commonly inhabit regions less than 100 meters deep. This preference for shallow coastal waters makes them highly vulnerable to incidental fisheries bycatch. The nature and magnitude of incidental takes are currently unknown but may be significant in some Alaska salmon (*Oncorhynchus spp.)* and Pacific herring (*Clupea pallasi*) fisheries. Line-transect abundance estimates obtained from the inland waters of Southeast Alaska indicated an overall decline in porpoise abundance in the mid-1990s, and contrasting trends in abundance between northern and southern regions suggest the likelihood of population structuring within the currently recognized Southeast Alaska stock. Concern for localized impact on undefined harbor porpoise stocks has motivated population genetic analyses using archived tissue samples. Unfortunately, sample sizes are severely limited in some key geographic areas and efforts to supplement beach-cast strandings and fisheries bycatch with remotely collected tissue biopsies has proved challenging for these small, enigmatic cetaceans. Emerging technologies directed at amplifying DNA from shed cellular debris contained within environmental samples (eDNA) have proved useful in some applications for detecting rare species, and characterizing regional patterns of biodiversity in aquatic habitats. Using targeted seawater sampling, and a suite of taxon-specific genetic markers to detect porpoise DNA, we are exploring the use of eDNA as a novel approach for examining population genetic structure. Both traditional Sanger sequencing and next generation sequencing are being used to examine mitochondrial genetic diversity among harbor porpoise in the coastal waters of Southeast Alaska and to evaluate evidence for stock structure.

From population structure to eDNA: Next-generation sequencing technology opens a window into the biology of deep-sea corals

Meredith V. Everett, Linda K. Park, Ewann A. Berntson, Cheryl L. Morrison, Robert P. Stone, Anna E. Elz, Curt E. Whitmire, Aimee A. Keller, M. Elizabeth Clarke, Kathryn Kegel*

One of the primary challenges in the study of deep-sea corals remains the ability to collect samples. Emerging sequencing technologies are enabling additional understanding of deep sea corals by overcoming the analysis concerns associated with small sample sizes and providing opportunities for increased non-destructive sampling. Next-generation sequencing has the potential to increase our opportunities for sampling by enabling us to look at environmental DNA (eDNA). Environmental DNA methods require only a sample of water from close proximity to the specimen in question, and thus may be easier to obtain on a greater number of expeditions. In collaboration with the Ocean Exploration Trust, we have successfully sequenced eDNA from deep-sea corals to confirm species identification from eDNA samples collected in the presence of corals on the Cascadia margin. A second technique, restriction site associated DNA sequencing (RAD-sequencing), enables the development of thousands of novel single nucleotide polymorphism (SNP) markers in organisms with few existing genetic resources. We have successfully used this technique to develop more than 1,000 novel SNP markers in two species: *Swiftia simplex*, and, in collaboration with the U.S. Geological Survey (USGS) and NOAA Alaska Fisheries Science Center, *Primnoa pacifica*. We have used this technique to assess levels of connectivity among populations in these species, along the U.S. West Coast in *S. simplex*, and in southeast Alaska in *P. pacifica*.

Detection and quantification of Chinook salmon in Skagit Bay using environmental DNA

*James O'Donnell**

The successful transition of young salmonids from freshwater to the marine environment is a key determinant of survival and fisheries productivity. While accurate estimates of their abundance in nearshore habitats during transition are critical for stock assessment models, these estimates are difficult and expensive to obtain. In light of ongoing threats to nearshore habitat and efforts to mitigate its loss, accurate estimates of distribution and habitat use require improvements in sampling efficiency. We report preliminary results on the effectiveness of environmental DNA-based methods for assessing the distribution and habitat use of young Chinook Salmon (*Oncorhynchus tshawytscha*) in Skagit Bay, Washington. We obtained species-specific DNA concentrations using a quantitative polymerase chain reaction (qPCR) and measured community-wide relative DNA abundance using massively parallel sequencing, then compared our results to estimates using seine and fyke nets.

Final Discussion of First Day of Novel Methods for Abundance and Trends Assessment

Two management themes dominated the PSAW's first day concluding discussion. In the first discussion theme, participants asked if there is an ideal time frame or species-specific rule for trend estimation in marine mammals. Researchers throughout the day presented one of two approaches: placing a trend parameter in a model, or modeling changes through time to compute trend between two time periods.

In the second discussion theme, participants discussed the pros and cons of "lumping or splitting" designated stocks for management. Improved genetic understanding has resulted in splitting stocks into distinct population segments for management, but these designations have created challenges. There are not enough data to estimate abundance adequately (e.g. for calculating PBR) for the new, smaller stocks, yet "lumping" stocks in some cases may result in localized population declines. However, lumping some stocks may be more practical for managers to implement and address threats affecting multiple stocks of the same or different species. Allowing some flexibility in researching, designating, and managing multiple stocks could facilitate practical management of marine mammal stocks.

Day 2: Second Day of Novel Methods for Abundance and Trends Assessment

Plenary Presentation: New technology for estimating cetacean abundance and density

Jay Barlow, Wayne Perryman, Dave Weller, Megan Ferguson, Robyn Angliss, Mark Fennel, Kevin Sullivan*

Here we explore three new technologies for estimating cetacean abundance and density: passive acoustic surveys, long-wave infrared video cameras, and aerial photographic surveys using manned and unmanned fixed-wing aircraft.

Passive Acoustic Methods

Many advances have been made in the last decade in the use of passive acoustics to study marine mammals and the utility of this approach for marine mammal assessment has been reviewed recently by Heinemann et al. (2016). Digital hydrophone recording systems can be deployed using four general approaches: towed hydrophone arrays, bottom-moored recorders, surface drifters, and ocean gliders. The primary approach to density and abundance estimation are distance-sampling methods such as line-transect or point-transect that require empirical estimates of the range at which cetaceans are detected. This requirement to estimate range is difficult to achieve with most bottom-moored and slowly moving glider platforms. For towed arrays, sound sources can be localized using target motion analysis, which involves analyzing the change in bearing angle to a slowly moving target from a faster moving array. This approach has been used to localize dolphins and sperm whales on ship-based line-transect surveys (Barlow and Taylor 2005; Rankin et al. 2008), but does not work if the speed of the array is less than the typical speed of the animals, as would be the case for arrays towed by ocean gliders. For drifting recorder systems, detection range can be estimated by triangulation using the time-difference-of-arrival for signals received on hydrophones configured as a vertical array. In a few special cases, unusual sound propagation conditions can be used to estimate detection range from a single hydrophone. In some situations, range must be estimated indirectly by propagation modeling.

Acoustic methods to estimate abundance can use groups of animals, individual animals, or individual sounds as the basic unit of quantification. These are typically referred to as group-, individual-, or cue-based methods. Typically, purely acoustic methods cannot estimate group size, so group size information is needed from another source, such as visual sighting surveys. Given this limitation, group-based methods of acoustic abundance estimation would be best applied to species that have a low variance in group size. Individual-based methods require the ability to discriminate individuals within a group, which is not possible for most purely acoustic methods. Cue-based methods require estimates of the cue production rate, i.e., the rate at which individuals produce distinctive calls. Recent advances in acoustic recording tags have allowed direct measurements of call production rates for some species. However, this sort of tag has not been successfully deployed on dolphin species that are the size of bottlenose dolphins or smaller. Recording tags attached by suction-cups have successfully measured call production rates for baleen whales, sperm whales and beaked whales. For baleen whales, however, many calls are made only by males, and call rates vary tremendously with behavioral states, season, time-of-day, and many other factors. A large fraction of whale calls may be made by a small fraction of the individuals present in an area.

To date, purely acoustic methods to estimate abundance have been applied to relatively few species. These methods appear to work best for species such as sperm whales, beaked whales, and porpoises that produce regular echolocation signals when foraging and spend a large fraction of their time foraging. For delphinids, their variable and often huge group sizes coupled with an inability of acoustic methods to estimate group size are a major impediment to the use of group-based acoustic methods to estimate abundance. For both baleen whales and delphinids, the high variability in the production rate of social sounds and the difficulty and expense in measuring those rates are major impediments to using cue-based methods in place of group-based methods for abundance estimation. Purely acoustic methods of abundance estimation are not likely to replace the need for visual sighting surveys or photographic mark-recapture studies to estimate the abundance of baleen whales or delphinids in the near future. However, for beaked whale abundance (which is hard to estimate by visual methods) and sperm whale abundance, acoustic methods may now be able to improve abundance estimation methods. If acoustic methods are used for abundance estimation, survey design is an important consideration and hydrophone placement must be random with respect to the animals.

Infrared Video Methods for Gray Whales

The Southwest Fisheries Science Center and Toyon Research Corporation have collaborated on a Small Business Innovative Research (SBIR) project to develop a long-wave infrared video and software system to count migrating gray whales. The infrared video is recorded and analyzed in real time to detect whale blows, which are much more conspicuous in infrared than in the visual light spectrum. Three software systems are used to automate the estimation of whale numbers passing by a fixed land station: one that detects potential whale blows, one that allows a human operator to review potential whale blows to eliminate false positives, another to estimate the number of whales passing. The latter software uses a Bayesian particle filter to incorporate prior information on whale pod size, movement direction and speed, pod dimensions, and individual inter-blow intervals to estimate the number of whales passing from the number and location of confirmed whale blows. An experiment was conducted at the Granite Canyon gray whale survey site to compare the video system with an experienced team of visual observers. Preliminary analyses of these data show a good correspondence between estimates of the number of passing whales from the observers and the infrared video and software system. Advantages of the infrared system are: 1) increased consistency by eliminating between-individual difference in estimating whale numbers from blows, 2) ability to record the entire survey and re-estimate abundance at a later date as methods improve, and 3) ability to survey at night and thereby increase sample size used to quantify the entire migration.

Aerial Photographic Methods from Manned and Unmanned Fixed-Wing Aircraft

The Alaska Fisheries Science Center led an experiment to compare three aerial survey methods near Point Barrow, Alaska: aerial digital photographs taken from an unmanned aerial vehicle (UAV), aerial digital photographs taken from a manned aircraft, and human observers in a manned aircraft. The project was conducted in collaboration with the North Slope Borough and was funded by the Bureau of Ocean Energy Management, the Office of Naval Research, and

NOAA with additional in-kind support from Shell Oil. The UAV was an Insitu ScanEagle, and the manned aircraft was a twin-engine Turbo Commander. Both aircraft were flown at 1000-foot altitude and used Nikon D810 cameras shooting overlapping images. The ScanEagle, its launcher and retrieval unit, base station, radio dishes, and support facilities were delivered to Barrow on a Navy C-130 aircraft.

A total of 22 hours were flown with the UAV and 27 hours with the manned aircraft. Every third image was inspected by skilled analysts to identify the images of bowhead whales, gray whales, beluga whales, and walruses. Image analysis required approximately seven hours for every hour of flight time. The estimated number of bowhead whales in the study area was similar for all three methods (given the uncertainties in each estimate), but the visual observers had a wider field of view and detected more total whales. The cost of the UAV survey was approximately 10 times the cost of the manned aircraft survey due to the labor associated with operating the UAS, analyzing the images, and the need for a C-130 aircraft to deliver the equipment to Barrow. The main advantage of the UAV is in eliminating the flight risk to human personnel on board the survey platform. Both photographic survey records result in a record of the entire survey that can be re-analyzed at a later date. Photographic surveys aboard manned aircraft can reduce the number of people at risk if flown without visual observers. At this point, long-range UAV surveys to assess marine mammal density should be considered experimental. As with other experimental approaches for collecting data, costs are likely to decline with time and further refinements of data collection and analysis. For instance, automatic image recognition software is needed to speed the identification of marine mammal images from photographic surveys.

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Advanced Technology Applications

Session Highlights:

- Passive acoustic monitoring, infrared video detection, and unmanned aerial systems have great potential to complement and, in some cases, replace existing observation platforms for precisely estimating abundance and monitoring marine mammal population trends (e.g., for harbor porpoises, beaked whales, ice seals).
- Free-floating recording systems with a vertical array of two hydrophones offer an improvement over fixed acoustic recording systems to detect cetacean vocalizations and more accurately estimate beaked whale abundance than do visual surveys.
- Infrared-camera systems may not be effective in tropical waters due to the limited temperature differential between the ambient and animal temperature.
- An instrument-based survey approach pairing long wavelength infrared (LWIR) with machine-vision electro-optical (EO) color cameras could reduce the time to prepare data for ice seal abundance estimation and lead to completely autonomous surveys.
- Day-to-day management of the large datasets generated from these advanced technologies remains a challenge and is a hindrance to widespread use and to addressing technology limitations.

Statistical power of passive acoustic networks to detect trends in cetacean abundance

Eiren K. Jacobson, Karin A. Forney, Jay Barlow*

The ability to detect trends in cetacean abundance is crucial for effective management, particularly when populations may be declining due to cumulative sub-lethal anthropogenic impacts rather than mortality in fishing sets or other direct take. Statistical power to detect trends in abundance with traditional survey data is poor. For example, in 78% of dolphin and porpoise populations, a 50% decline would not be detected using current visual survey methods (Taylor et al. 2007). Fixed passive acoustic monitoring is a promising method for monitoring cetacean populations (Marques et al. 2013). Designing passive acoustic schemes for long-term monitoring of cetacean populations is now feasible; however, there is no framework for optimizing passive acoustic surveys to maximize their precision and the resulting statistical power to detect trends in abundance. We used available aerial survey and passive acoustic data from the Monterey Bay population of harbor porpoise to create simulated datasets representing hypothetical monitoring network designs and changes in abundance. From these simulations, we quantified the expected statistical power of passive acoustic surveys to detect trends in cetacean abundance.

The Monterey Bay, California population of harbor porpoise occupies a 2500 km^2 region between 36.3° N and 37.25° N, primarily in water less than 100 meters deep. Between 2000 and 2013, more than 100 fine-scale aerial line-transect surveys were flown in this region. We fit a two-dimensional spatial spline on these aerial survey data to obtain an average density surface for harbor porpoise across the study area on a decadal scale. In 2013, 2014, and 2015, a grid of 11 passive acoustic monitoring instruments (C-PODs; Chelonia Ltd., http://chelonia.co.uk) was deployed in the Monterey Bay study area. These repeated deployments allowed us to characterize the inter-annual and inter-instrumental variation in harbor porpoise detections in our study area. We used a generalized linear model to describe the passive acoustic detections as a function of the underlying average density and a year effect. Using the covariates estimated in this model with their uncertainties, we simulated artificial datasets given hypothetical scenarios. We simulated different numbers of passive acoustic sensors (ranging from 10-100) placed randomly throughout the study area and varying rates of change in the population (ranging from -50% to +50%) over a 10-year period. In each simulation, the artificial data were evaluated using a mixed-effects model (with year as a fixed effect and instrument as a random effect) to determine whether a change in the population would be detected (defined as p-value < 0.05 for the year effect). Each scenario was repeated 10,000 times. The statistical power of the hypothetical passive acoustic monitoring network was calculated as the proportion of those 10,000 scenarios in which a change in the population was detected and the sign of the year covariate (positive or negative) matched the sign of the simulated change in the population.

Preliminary results (Figure 5) indicate that a passive acoustic approach to monitoring trends in harbor porpoise abundance may have much greater power to detect trends in abundance than has been reported for traditional visual survey methods (Taylor et al. 2007). For example, power to detect a 50% decline would be greater than 0.8 with just 10 sensors deployed for 10 years, and power to detect a 25% decline would be 0.75 with 50 sensors. This represents an approximately threefold improvement in power over traditional visual survey methods (Figure 5). In the future, we plan to convert this analysis to a Bayesian framework. We will explore more complex scenarios including responses to disturbance and stratified monitoring designs. The simulation method presented here is generalizable to other species and regions. We plan to implement these methods through the development of an R package that would enable scientists and industry professionals to design optimally effective passive acoustic monitoring networks for specific monitoring and management needs.

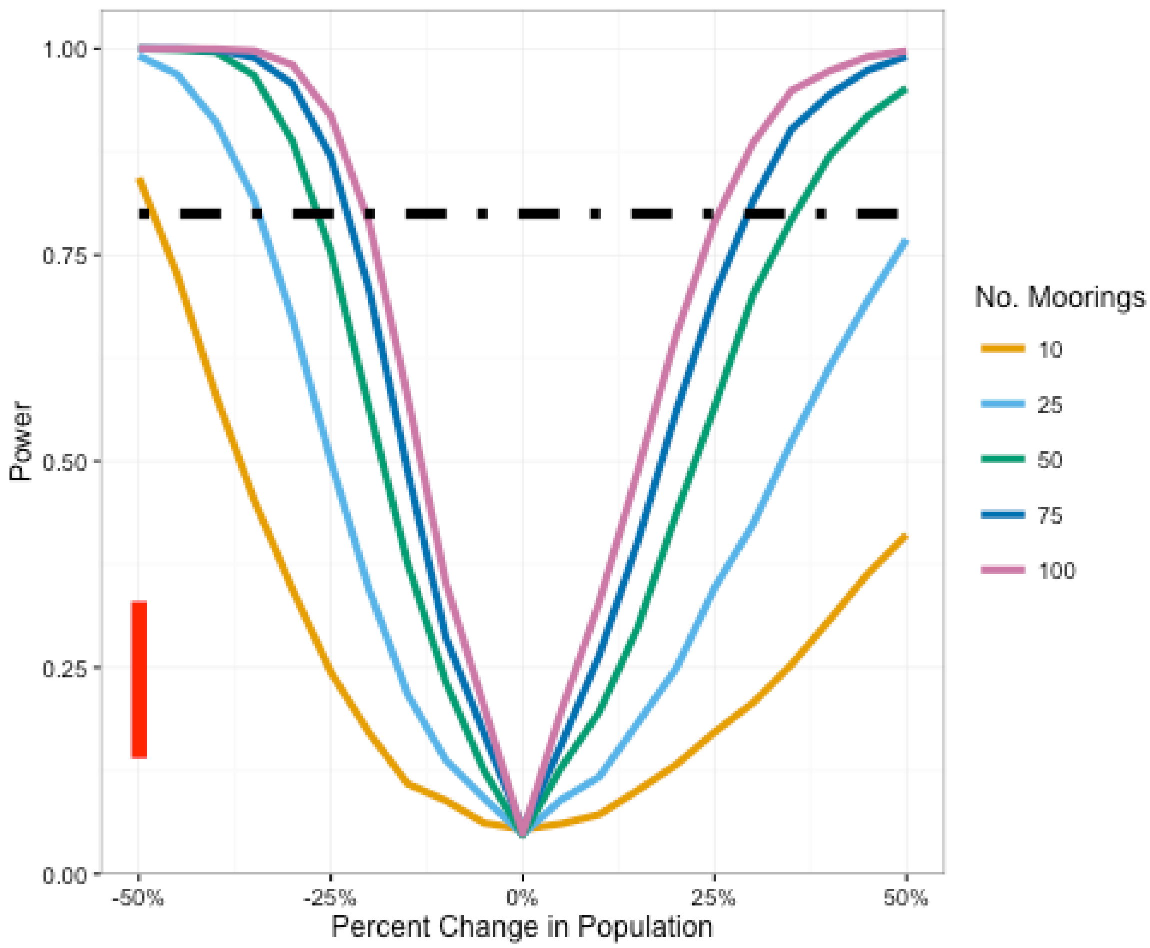

Figure 5. Simulated total percent change in the population over a 10-year period (x-axis) and resulting statistical power (y-axis) as simulated for 10-100 passive acoustic sensors (colored lines) with annual sampling. The black dashed line indicates conventionally acceptable power of 0.8 for an alpha level of 0.05. Reported statistical power to detect harbor porpoise using visual surveys (red bar) ranges from 0.14 to 0.33 for surveys conducted every three to seven years (Taylor et al. 2007).

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The use of free-floating vertical hydrophone arrays to estimate beaked whale abundance

Jay Barlow, Jeffrey Moore, Jennifer L. Keating, Emily T. Griffiths*

The estimation of beaked whale abundance using traditional visual sighting surveys is challenging. Beaked whales are difficult to see in rough seas, dive for long periods, and spend only short periods at the surface, and differentiating species is challenging in most conditions. Beaked whales are good candidates for acoustic survey methods because they produce regular echolocation clicks when foraging and these clicks appear to be species-specific (at least for all beaked whale species that have been recorded to date). We have developed an approach to estimating abundance for these species based on free-floating recording systems with a vertical array of two hydrophones at 100-meter depth. Detection distance is a critical component in estimating density and abundance. By using two hydrophones, the range at which vocalizing whales are detected can be determined by estimating the direct- and surface-reflected sound paths and by finding their intersection. This approach was implemented in a large-scale study of beaked whale abundance in a one million km^2 study area off the U.S. West Coast in August and September 2016. A total of approximately 400 days of recordings were obtained from 30 deployment locations.

Potential echolocation signals in recorded data were automatically detected and then reviewed by experienced acoustic technicians for validation and identification. Analysis of these data is still in early stages, but ~600 detections of beaked whales were found in reviewing the first 22 stations (Figure 6). This compares to ~30 beaked whale sightings per typical 120-ship-day visual sighting survey. We had more acoustic detections of beaked whales from this one 40-ship-day survey than the number of all previous beaked whale sightings on six previous visual surveys. Acoustic signals recorded on this survey correspond to Cuvier’s beaked whale, Baird’s beaked whale, Stejneger’s beaked whale, Blainville’s beaked whale and unidentified beaked whale signals that are likely Perrin’s beaked whale, Hubb’s beaked whale, and pygmy beaked whale. We plan to use group-based point-transect distance sampling methods to estimate density and abundance. We anticipate that this method will yield greater precision in total abundance estimates and the eventual ability to estimate species-specific abundance for all seven of the local beaked whale species.

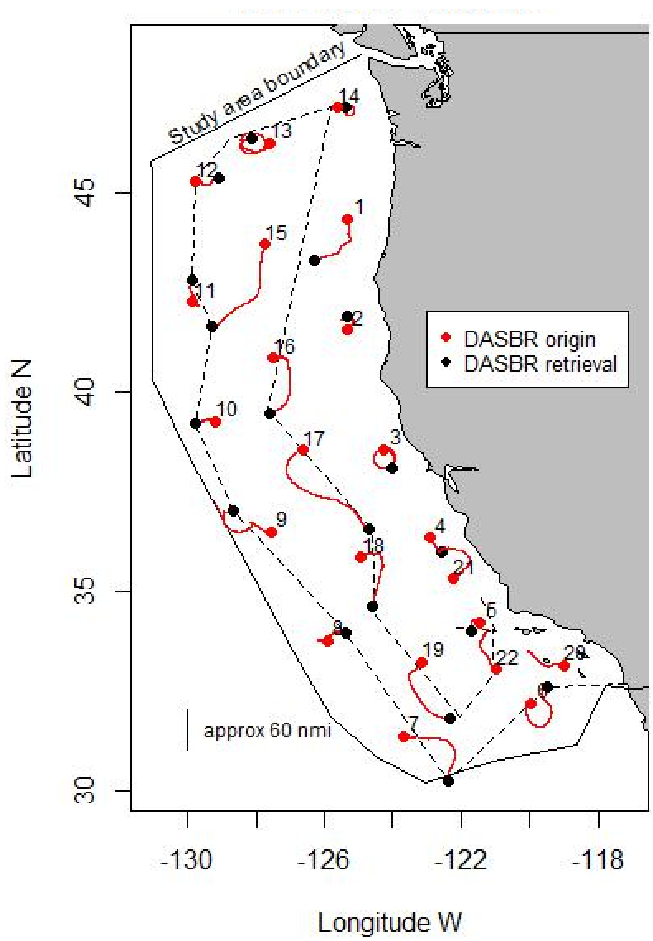

Figure 6. Drifting acoustic spar buoy recorder (DASBR) deployment locations (red circles) and retrieval locations (black circles) during SWFSC's 2016 Passive Acoustic Survey of Cetacean Abundance Levels (PASCAL).

Automated electro-optical, infrared surveys for ice associated seals and polar bears in the Chukchi Sea

Erin Moreland, Paul B. Conn, Benjamin X. Hou, Eric V. Regehr, Erin L. Richmond, Cynthia L. Christman, Michael F. Cameron, Peter L. Boveng*

Obtaining reliable abundance estimates for ice-associated seals and polar bears is vital for developing sound plans for management and conservation. These remote and broadly distributed species have been challenging to survey using traditional aerial survey methods. Advances in imaging technology have allowed aerial surveys of sea ice to be conducted from altitudes higher than visual-observation surveys, while maintaining or increasing the effective survey strip width and reducing the animals' response to the survey aircraft. We will describe our instrument-based survey approach that pairs long-wavelength infrared (LWIR) and machine-vision electro-optical (EO) color cameras. This includes automated data acquisition, data management, and ultimately, real-time detection of animals on the sea ice.

Two million colored and thermal images were collected during instrument-based surveys for ice-associated seals and polar bears of the Chukchi Sea in the spring of 2016 (Figure 7). The automated detection system detects 96% of bearded seals, 91% of ringed seals, and 78% of polar bears. Future development of the system will focus on incorporating color data to improve the polar bear detection algorithm as well as increasing the processing speed and data fusion to allow for real-time detection of animals on the sea ice. This will improve efficiency by reducing the time lag to prepare the data for abundance estimation and take us one step closer to completely autonomous surveys.

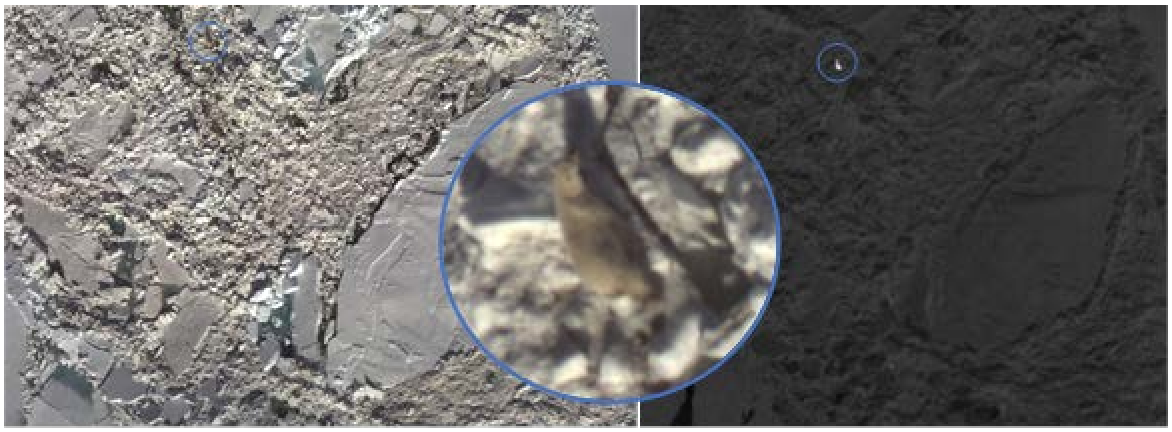

Figure 7. Paired color (left) and thermal (right) images of a polar bear on the Chukchi Sea ice. Images collected during 2016 instrument-based survey using an automated thermal detection system from an altitude of approximately 300 meters.

Using Habitat Relationships to Assess Density and Abundance (Part 1)

Session Highlights:

- Spatio-temporal hierarchical models may be used for count data and can account for variability in animal density in space and time.
- Regional Ocean Modeling System (ROMS) model-based abundance estimates for the California Current Ecosystem study area were statistically similar to standard line-transect estimates and are useful for dynamic species management. Daily updated ROMS data are being used to develop a near-real-time prediction to reduce protected species bycatch.
- Estimates of abundance trends or distribution shifts from multispecies models may not yield more accurate results than distribution shifts or abundance trends predicted by single-species models based on studies of fish.
- A new modeling approach for estimating abundance and trends of highly mobile species that accounts for spatio-temporal variation may offer more accuracy over conventional models.

Moving towards dynamic ocean management: Using modeled ocean products to predict species abundance and distribution patterns

Elizabeth A. Becker, Karin A. Forney, Paul C. Fiedler, Jay Barlow, Susan J. Chivers, Christopher A. Edwards, Andrew M. Moore, Elliott Hazen, Jessica V. Redfern*

Species distribution models (SDMs) are now widely used in marine conservation and management to predict the occurrence of protected species. Dynamic habitat variables have commonly included in situ and remotely-sensed oceanic variables ("measured data"), but now the Regional Ocean Modeling System (ROMS) provides historical estimates and forecast predictions of habitat variables such as temperature, salinity, and mixed layer depth. In this study, we compare SDMs based on ROMS data to those based on measured data. Shipboard line-transect surveys from 1991-2009 were used to develop predictive habitat-based models of animal density for 11 cetacean species in the California Current Ecosystem. Four different generalized additive models were compared: two that included a full suite of available predictors for ROMS or measured data, and two that were restricted to variables available from both data sources. Model performance was assessed using the percentage of explained deviance, root mean squared error, observed to predicted density ratios, and visual inspection of predicted and observed distributions. Predicted distribution patterns and quantitative measures of predictive ability were similar for models using ROMS and measured data (Figure 8). Both model types showed good concordance with observed sightings, and model-based abundance estimates for the study area were statistically similar to standard line-transect estimates. ROMS-based habitat models open new opportunities for dynamic species management because ROMS data are available in near real time and as forecasts. Updated models built with daily ROMS data and incorporating an additional year of survey data (2014) are currently being developed for integration into a near-real-time prediction tool to help reduce protected species bycatch.

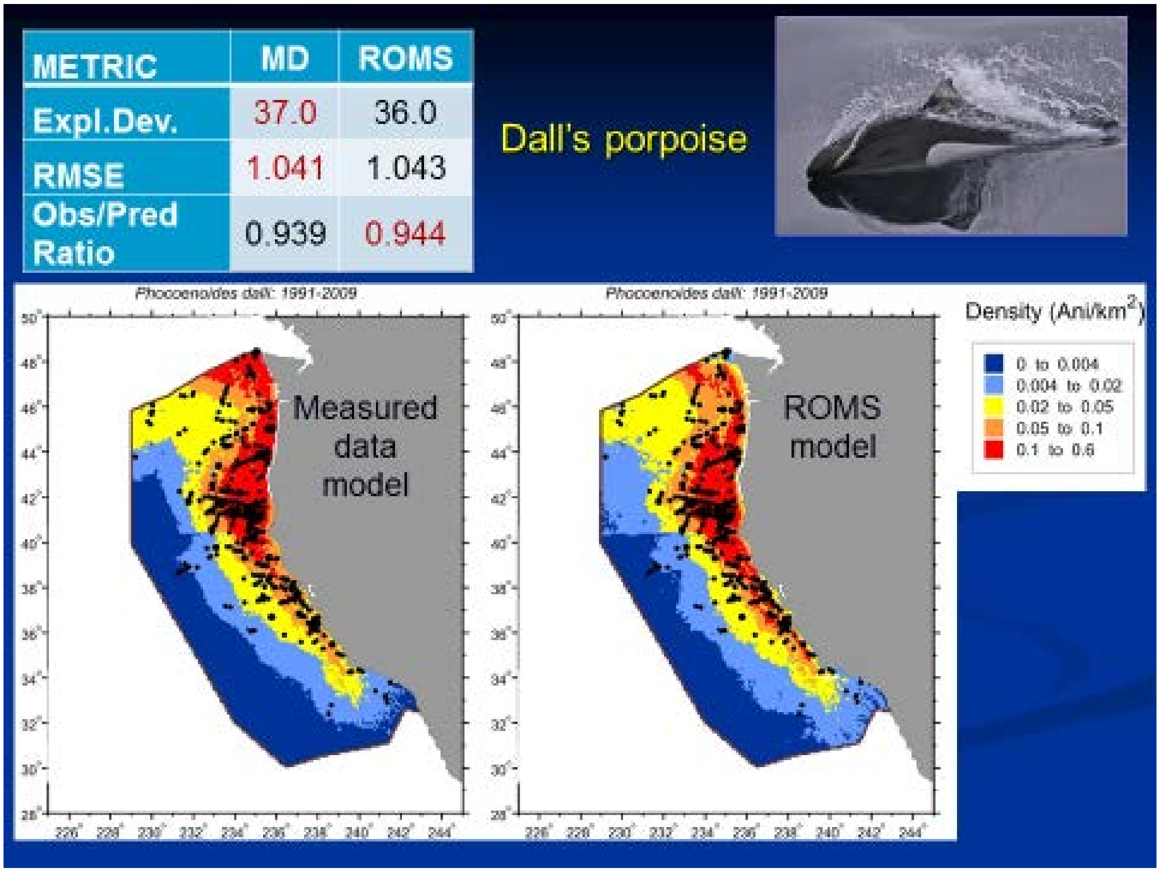

Figure 8. Predicted densities from the habitat-based density models built with measured data (left panel) and ROMS output (right panel) for Dall's porpoise (*Phocoenoides dalli*). Predictions are shown for the study area off the U.S. West Coast (1,141,800 km^2). Black dots show actual sighting locations from the ship surveys. Quantitative model performance metrics for the measured data (MD) and ROMS models include the percentage of explained deviance (Expl.Dev.), root mean squared error (RMSE) and ratios of observed to predicted density (Obs/Pred Ratio).

Does incorporating spatio-temporal correlations among fishes and biogenic habitat improve estimates of abundance trends and distribution shifts?

Jim Thorson and Lewis Barnett*

Several approaches have been developed over the last decade to simultaneously estimate distribution or density for multiple species (e.g., "joint species distribution" or "multi-species occupancy" models). However, there has been little research comparing estimates of abundance trends or distribution shifts from these multispecies models with similar single-species estimates. We therefore seek to determine whether a model including correlations among species (and particularly species that may affect habitat quality, termed "biogenic habitat") improves predictive performance or decreases standard errors for estimates of total biomass and distribution shift relative to similar single-species models. To accomplish this objective, we apply a vector-autoregressive spatio-temporal (VAST) model that simultaneously estimates spatio-temporal variation in density for multiple species, and presents an application of this model using data for eight U.S. Pacific Coast rockfishes (*Sebastes spp.),* thornyheads (*Sebastolobus spp.*), and structure-forming invertebrates (SFI). We identified three fish groups having similar spatial distribution (northern Sebastes, coastwide Sebastes, and *Sebastolobus species*), and estimate differences among groups in their association with SFI. The multispecies model was more parsimonious and had better predictive performance than fitting a single-species model to each taxon individually, and estimated fine-scale variation in density even for species with relatively few encounters (which the single-species model was unable to do). However, the single-species models estimated similar abundance trends and distribution shifts to those of the multi-species model with smaller standard errors. We therefore conclude that spatial variation in density (and annual variation in these patterns) are correlated among fishes and SFI, with congeneric fishes more correlated than species from different genera. However, explicitly modeling correlations among fishes and biogenic habitat does not seem to improve estimates of abundance trends or distribution shifts for these fishes.

Spatio-temporal species distribution models for marine mammal population assessment: ice-associated seals in the Bering Sea

Paul Conn, Devin S. Johnson, Jay M. Ver Hoef, Mevin B. Hooten, Joshua M. London, Erin E. Moreland, Michael C. Cameron, Brett T. McClintock, Peter L. Boveng*

Estimates of marine mammal abundance are often produced by fitting statistical models to count data from transect surveys. Most such models require that animal density remains constant across the seascape while sampling is being conducted. This assumption is problematic for animals inhabiting dynamic landscapes or otherwise exhibiting considerable spatio-temporal variation in density, and may be an impediment to inference about how changes in environmental conditions affect animals' spatial distribution. In this talk, we compare a suite of novel and existing spatio-temporal hierarchical models for animal count data that permit animal density to vary over both space and time. Models varied by the nature of the temporal structure (i.e., descriptive or dynamical), and whether total expected abundance was assumed constant over time (a pseudo-closure assumption). We gauge the relative performance (bias, precision, computational demands) of alternative spatio-temporal models when confronted with simulated and real datasets from dynamic animal populations. For the latter, we analyze counts of ice-associated seals from aerial surveys of the Bering Sea where both the quantity and quality of suitable habitat (sea ice) change dramatically while surveys are conducted.

Estimation of abundance and trends for highly mobile species with dynamic spatial distributions

Charlotte Boyd, Jay Barlow, Elizabeth Becker, Karin Forney, Tim Gerrodette, Andre Punt, Jessica Redfern*

Estimation of abundance and trends is challenging for highly mobile species, especially those with dynamic distributions associated with variation in suitable habitat. Abundance surveys often cover only a portion of a population's range, leading to variable abundance estimates within the survey area and hampering efforts to assess trends. Forney (2000) suggested that this could be addressed by incorporating habitat-based density relationships into models for estimating abundance and trends, but this is difficult to achieve using conventional distance sampling methods. We therefore developed a new modeling approach for estimating abundance and trends of cetaceans and other highly mobile species from distance sampling data in the context of substantial variation in the distribution of suitable habitat. We applied this approach to a case study of Dall's porpoise (*Phocoenoides dalli*), a cold-temperate species with distribution patterns closely tied to the distribution of cool sea-surface temperatures. We constructed three sets of models representing distinct hypotheses about variation in the abundance and distribution patterns of Dall's porpoise within the California Current Ecosystem survey region, to test the methodology. Our results indicate that the population size of Dall's porpoise within the survey region is relatively stable over summer/fall, but the population's distribution expands and contracts in line with the distribution of suitable habitat, leading to substantial variation in estimated densities. The modeling approach developed here is broadly applicable and has several advantages for estimating abundance and trends in dynamic habitats when compared to conventional approaches.

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Using Habitat Relationships to Assess Density and Abundance (Part 2)

Session Highlights:

- Bayesian hierarchical models (e.g., time varying, vector autoregressive, state-space models (TVVARSS)) can combine data from different sampling efforts regardless of survey design to estimate community abundance. Refining models could quantify and reduce uncertainty.
- Autoregressive state-space models can be used to evaluate the relationship between multiple environmental indicators and adult phenotypic variation in chum salmon to determine the extent that populations are distinct in marine growth rate over a time series, and to estimate their time-varying relationships between growth and environmental indicators.
- Space-time geostatistical mixed effects models may produce less biased, more precise parameter estimates and can predict the overall spatial distributions and seasonal shifts in densities of tagged loggerheads.
- A new assessment tool helps to predict density of juvenile sea turtles using a Lagrangian particle tracker, oceanographic circulation products, behavior rules, and demographics.
- Skeletochronology combined with stable isotope analysis can be a useful technique to identify the age-at-maturation, juvenile stage duration, and survivorship of east Pacific loggerhead turtles.
- Explicit consideration of the potential changes in the interactions among species following predator reintroduction, and predators' integrated effects on stability, may be more important than simply quantifying species abundance or diversity.

Development of a spatially explicit juvenile sea turtle density estimator

Paul M. Richards and Nathan F. Putman*

We developed a novel assessment tool for estimating the density of juvenile sea turtles (<40 cm) within user-defined regions. Our tool integrates remotely sensed habitat data, demographic data, and behavioral observations by utilizing a Lagrangian particle tracker, oceanographic circulation products, behavior rules, and demographics. The current state of the art in assessing sea turtle populations utilizes a time series of annual nest counts and regional aerial surveys. These assessments result in an incomplete picture of sea turtle populations because they either directly estimate trends in reproductive capacity for an entire DPS or estimate density for a restricted set of size classes in a portion of the available habitat. Of the many limitations these approaches have on sea turtle management, one is the uncertainty at the local and regional scales coupled with incomplete assessments of portions of the population. This leads to large uncertainty in setting take limits at the regional or localized scale because of the lack of information on the distribution of abundance of all life stages of turtles. This tool fills in one of the gaps by making explicit mechanistic and data-based predictions of the local density of juvenile sea turtles. We have also parameterized movement rules for size classes > 40 cm based on telemetry data. Future plans include expanding the tool to incorporate other types of data, such as ocean productivity and sea surface temperature, to make predictions of the distribution and density of all size classes of sea turtles as well as potential application to other species.

Using complementary techniques to estimate life history parameters for sea turtles: A case study on North Pacific loggerheads

Cali Turner Tomaszewicz, Carolyn Kurle, Hoyt Peckham, Larisa Avens, Jeffrey Seminoff*

For sea turtles, population abundance and trends are limited by a lack of knowledge on basic life history parameters such as juvenile stage duration, age-at-maturation, and longevity. During their long and complex life cycle, sea turtles migrate between and occupy widely disparate habitats, each with spatially explicit threats and survival rates. Better estimations of these demographic parameters would help generate more reliable population abundance and trend assessments. To investigate the age-at-maturation and duration and survivorship of endangered North Pacific loggerhead turtles (*Caretta caretta*) in an east Pacific high-bycatch juvenile foraging region, we combined skeletochronology with stable isotope analysis. We first determined the age of ~150 dead-stranded turtles from Playa San Lazaro, Baja California Sur, Mexico, to estimate stage duration. We then applied sequential stable isotope analysis to ~280 annual bone growth layers from 45 of these turtles to recreate multi-year habitat use patterns and assess the timing of ontogenetic habitat shifts. We found juveniles may spend up to 20 years in this high-bycatch region, reaching maturity at age ~25 years, and this long residency duration could result in low (~10%) stage survivorship given the previously estimated annual mortality rate (~11%) for loggerheads in this region (Koch et al. 2013). We also found a bimodal size/age distribution in the timing that juveniles underwent an ontogenetic habitat shift from the oceanic central North Pacific to the neritic east Pacific region near Baja California Sur, which could have implications on the stage survivorship for this segment of the population.

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Environmental correlates of marine growth in Oregon coast chum salmon

*Jeff Hard**

We evaluate the relationships between 22 environmental indicators and variation in adult chum size from five Oregon coastal streams using autoregressive state-space models to 1) determine to what extent these populations are distinct in marine growth rate over the time series, and 2) estimate their time-varying relationships between growth and environmental indicators. Most of these indicators have been monitored each year since 1996 in coastal waters off central Oregon. The analyses of spatial structure indicate that the temporal trend in marine growth of Yaquina River chum salmon has been distinct from that of the other four more northern populations (Nehalem, Kilchis, Miami, and Wilson). Correlations between chum salmon growth rate and regional environmental indicators were observed more often during the year of final ocean residence than during the year of ocean entry, suggesting that the environment experienced during the final year of marine residence is at least as important as that experienced during the year of seaward migration; the year of seaward migration is also likely to have a larger influence on marine survival. The indicators most commonly correlated with temporal variation in chum salmon growth were anomalies in the Pacific Decadal Oscillation (PDO), Oceanic Niño Index (ONI) and Coastal Upwelling Index (CUI); copepod biomass and diversity; sea surface temperature; and abundance of juvenile coho and chinook salmon in June.

Estimating loggerhead sea turtle densities from satellite telemetry data using geostatistical mixed effects models

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Data collected via satellite telemetry devices are often used to inform spatial conservation measures for threatened sea turtle populations. Most applied telemetry studies aim to reconstruct the continuous utilization distribution that underlies reported locations to characterize the relative intensity of space use. However, commonly applied space use estimators do not directly estimate the underlying distribution of interest and, perhaps more importantly, ignore correlations in space and time that may bias estimates. Here we describe how geostatistical mixed effects models, which explicitly account for spatial and/or temporal correlation using Gaussian random fields, can be applied to directly approximate densities from satellite telemetry data. We use simulation testing to compare the performance of space-time geostatistical mixed effects models with three commonly applied space use estimators: kernel densities, minimum convex polygons, and track densities, which correspond to the simplest approximation of a multinomial resource selection function. Results suggest that the proposed models may outperform conventional estimators when locations reported from tagged individuals shift in space over time.

We then apply a space-time geostatistical mixed effects model to estimate the distribution and relative density of 271 tagged juvenile and adult loggerhead sea turtles in the western North Atlantic from satellite telemetry data collected by six tagging programs from 2004-2016. We demonstrate how the full space-time model can be used to predict the overall spatial distribution of tagged loggerheads, as well as seasonal shifts in densities at smaller time scales (Figure 9). For tagged loggerheads, overall predicted densities were greatest in the shelf waters along the U.S. Atlantic from Florida to New Jersey. Monthly predictions highlight the importance of summer foraging habitat in the mid-Atlantic Bight.

By conditioning estimates on space and time, we were able to estimate the overall spatial variation in tagged turtle densities in a manner analogous to conventional estimators, but in a predictive rather than ad hoc fashion. Here our interest was the prediction of spatiotemporal variation in loggerhead densities, and so our application focused on the use of geostatistical mixed effects models as a model-based approach to spatial smoothing rather than on parameter estimation. However, models of this type have also been shown to produce less biased, more precise parameter estimates in other applications, making them a potentially valuable tool for inferring relationships between environmental processes and seasonal shifts in relative densities. In addition, the models proposed here are compatible with the types of models applied to estimate relative densities from distance sampling data collected via shipboard or aerial line transect surveys, providing a logically consistent basis for integrating telemetry data into predictions of space use based on existing survey efforts.

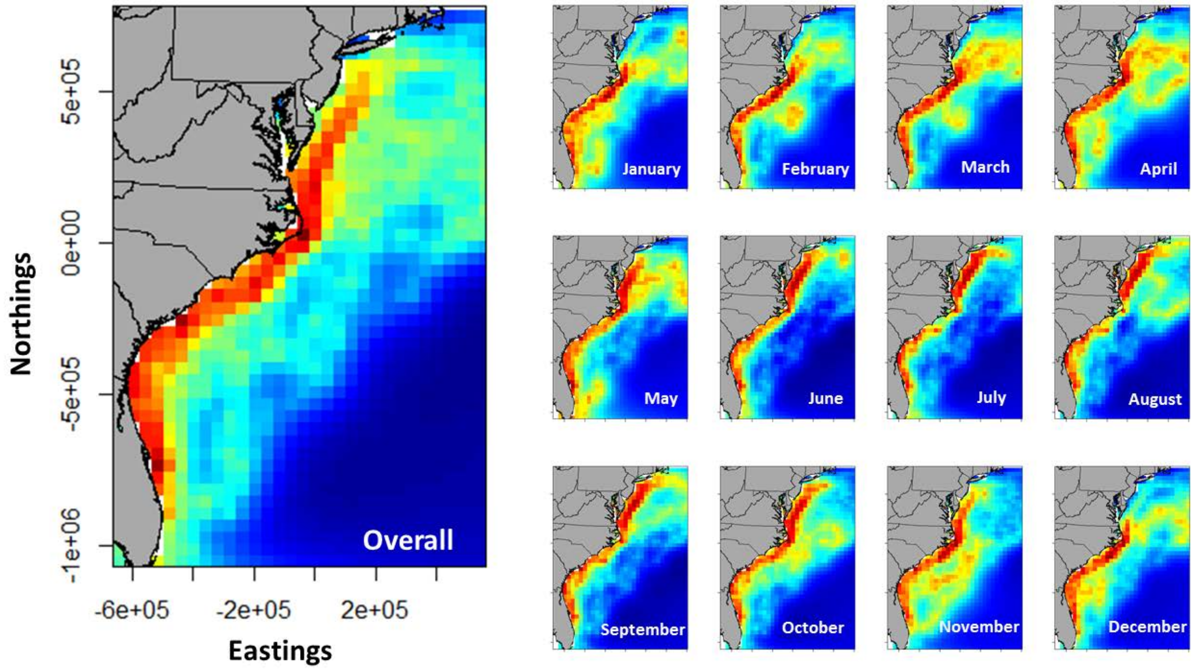

Figure 9. Overall and monthly log density of tagged loggerhead sea turtles per 40 kilometer resolution grid cell as predicted using a space-time geostatistical mixed effects model. Model predictions were based on daily locations reported from 271 large juvenile and adult loggerhead turtles tagged from 2004-2016. Coordinates are expressed in the universal transverse Mercator coordinate system (zone 19). All predictions were scaled from 0-1 for comparison purposes; grid cells with the highest densities are denoted in red and the lowest in blue. Individual tracks were weighted inversely according to their duration to account for differences in the length of tag deployment. The predicted distribution indicates relatively high densities of tagged loggerheads in the south Atlantic Bight (south of Cape Hatteras, North Carolina) year-round, with seasonal regions of high densities in the mid-Atlantic from May-October.

Estimating changes in species interactions and community stability in a kelp forest ecosystem

Mark Scheuerell, Eric Ward, Steve Katz*

Global-scale losses of apex predators have led to profound changes in community structure and ecosystem processes, but the effects of predator reintroductions on recipient ecosystems remain poorly understood. We examined a long-term data set from a California kelp forest to characterize how the reintroduction of sea otters, an ESA-listed species, has altered species interactions and the community's stability. To do so, we developed a hierarchical Bayesian version of a time varying, vector autoregressive, state-space model (TVVARSS). The general approach is that the log-density of an organism at time t is a linear combination of 1) its log-density at the previous time step t-1; 2) the sum of all pairwise interactions with predators, prey, and competitors at the previous time step t-1; 3) measured environmental drivers; and 4) random environmental variation not explained by the measured covariates or model. Our observation model allows for the direct use of the original count data, even though they arise from different survey designs, to estimate the true abundance of all community members. We found that several important interactions changed over time, including the density-dependent effects of species on themselves. Furthermore, the instability of the community appeared to decrease following the establishment of a viable otter population. Therefore, explicit consideration of the potential changes in the interactions among species following predator reintroduction, and their integrated effects on stability, may be more important than simply quantifying species abundance or diversity.

Advances in Mark-Recapture Methods

Session Highlights:

- A new methodology to estimate population abundance of the western stock of Steller sea lions in Alaska based on population reconstruction of pup abundance and survival information obtained from capture-recapture data offers an improvement over the use of simple multipliers of annual pup counts.
- Mark-recapture models may improve by addition of such variables as survival, age class, and terminal fisheries, as well as by coupling with genetic stock assignment data.
- A new analysis provides estimated ocean distributions for Chinook salmon from each region that accounts for seasonality, age-structure, sampling effort, regional differences in maturation schedules, and variation in juvenile survival, thus advancing our understanding of the spatial and temporal distribution of Chinook in the coastal ocean, which will be heavily impacted by changes in climate and fisheries.
- Spatio-temporal state-space models, like a branching patch-occupancy model within a Bayesian framework, can be used to estimate the probability of an individual moving past one of several detection points, as well as the probability of detection at each site. This can then be used to estimate escapement at a variety of spatial scales across an entire basin for salmon. The information can help evaluate the status and success of species recovery programs.

Estimating sea lion abundance from rookery pup counts and mark and recapture data

Devin S. Johnson, Jeff Laake, Lowell Fritz*

Assessing total abundance of sea lions and fur seals can be challenging due to the fact that the adult portion of the population is only partially observable during the year. Only pups are reliably available for counting at rookeries during summer months. Thus, stock assessment for sea lions and fur seals in Alaska has been determined as a multiple (~ 4.5x) of the current year's pup counts. This multiplier was initially determined as the ratio of pups to adults and juveniles in a population that is at a stable age distribution. Although this method is easily applied, it can give misleading results if the population is not at a stable age distribution. As an alternative to this overly simplified multiplier, we propose a new methodology based on population reconstruction using pup abundance and survival information obtained from capture-recapture data. Although adults are not reliably available for rookery abundance surveys, uniquely marked animals can be observed throughout adulthood to determine an age-specific survival schedule, which can be used to project forward to determine the number of adults alive in future years. By forward projection of past pup counts using the matrix model, the number of adults alive in the current year can be estimated without the assumption of a stable age distribution. Moreover, the method accounts for the more volatile nature of pup abundance versus adult abundance. We demonstrate this method by estimating the abundance of the western stock of Steller sea lions in Alaska. A Monte Carlo version is used to assess the error of estimation as well, which is unavailable using the multiplier method.

Estimating salmon escapement across the Snake River basin: a novel approach using PIT tags

Kevin See, Chris Beasley, Brice X. Semmens, Rick Orme*

Estimates of salmonid adult escapement are crucial to evaluating the status of threatened and endangered populations, the success of recovery programs and the productivity of populations. In the Columbia Basin, these estimates are often made using redd counts or mark-recapture models from weir data, but these methods have limitations. Redd counts have (potentially) unknown observation errors, and weirs can only be placed in certain locations. As an alternative method, we developed a branching patch-occupancy model (Royle and Dorazio, 2008) within a Bayesian framework that relies on adult salmon being Passive Integrated Transponder (PIT) tagged at Lower Granite dam and subsequently re-detected by the extensive array of instream PIT tag antennas across the Snake River basin. This state-space model estimates the probability of fish moving past each detection point, as well as the probability of detection at each site, and can then be used to estimate escapement at a variety of spatial scales across the entire basin. Estimates of steelhead and spring/summer Chinook from spawning years 2010-2015 compared favorably with independent estimates at a variety of locations, validating the model results.

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Fall Chinook salmon along the U.S. West Coast

Ole Shelton, Eric Ward, Will Satterthwaite, Brian Burke*

Enormous effort and expense has been expended on increasing Chinook salmon abundance through freshwater habitat improvements, hatchery production, fisheries regulation, and other management and restoration actions. Despite this large body of work, the spatial and temporal distribution of Chinook in the coastal ocean remains an understudied aspect of Chinook life-history. As future changes to the coastal ocean will be spatially variable – both in terms of climate and fisheries – determining the distribution of Chinook from different river systems in the ocean is a first step toward understanding how ocean changes may affect different stocks.

We developed a spatio-temporal state-space model to estimate the ocean abundance of fall Chinook salmon along the Pacific coast. We simultaneously model Chinook from rivers originating from central California to southern British Columbia over a 17-year period (1979-1995) using more than 70 million coded wire tag releases. Our analysis provides estimated ocean distributions for fish from each region that accounts for seasonality, age-structure, sampling effort, regional differences in maturation schedules, and variation in juvenile Chinook survival. We used ocean distributions in concert with smolt production estimates to provide projections of origin-specific abundance as well as aggregate abundance. Such estimates of Chinook ocean abundance have direct implications for protected species management, including informing critical habitat for Southern Resident Killer Whales and in targeting or avoiding Chinook from particular origins in ocean fisheries. Finally, we show how extensions to this model may provide a coherent method for understanding how oceanography may affect ocean survival and distribution.

Final Discussion of Novel Methods to Assess Abundance and Trends

There were two main topics in the first theme's final discussion: 1) transferability to other contexts and 2) management considerations.

Bayesian state space modeling can be applied broadly. It was suggested that researchers explore ensemble Bayesian state space modeling to consider all predictions and account for uncertainty, as is done in climate modeling methods. Other techniques that could serve in many regions and across taxa (e.g., pinnipeds and sharks) include using telemetry data to assess relative and absolute density, and examining bycatch impacts on certain age and sex classes and the subsequent impact on the population (e.g., albatross, sea turtles). Although some problems are unique to particular protected species, attendees suggested that a more focused workshop could increase awareness of approaches. A request was made to produce a working list of NMFS statistical experts and their expertise areas to facilitate new research connections and address methodological queries across centers.

Managers encouraged ensemble modeling because it might strengthen management decisions against criticism for selecting certain models; however, managers still need to understand and account for uncertainty within a model. The best model for managers will achieve the management goal, but may not assess the biology accurately. Researchers could explore the best models based on management questions, predetermined observation metrics, and/or the quality of data used to build the models. One way to compare models would be to follow the example of the International Whaling Commission and create a simulated dataset to test various models and algorithms. There was a brief discussion on the continued use of the PBR-framework to assess human-caused impacts on marine mammal populations. Managers in attendance did not think that use of the PBR approach would change in the near future, but that within MMPA directives, R_{max} estimates could be improved and trend information could be calculated and incorporated into stock assessments if suitable data are available.

Topics that were mentioned but not discussed due to time constraints include:

- Use of passive acoustics for fish stock assessments
- Stock definition and the flexibility to group stocks for management applications
- Optimal automated image recognition software and data management techniques
- Prioritization of stocks to determine where resources need to be invested
- Socioeconomics of protected species assessments
- Managing guilds rather than a single species

Day 3: Data-Poor Bycatch Estimation

Plenary Discussion: What does "data poor" mean in the context of bycatch estimation in the U.S.?

*K. Alexandra Curtis**

The challenge that rare-event bycatch poses to the analyst tasked with estimating an annual total from partial observer coverage is widely appreciated (e.g., McCracken 1994; Martin et al. 2015). Here, I consider "data poverty" in bycatch estimation more broadly, defining the term "data-poor" for this purpose as any situation leaving one wanting for more or different data on which to base an estimate. This overview of data-poor bycatch estimation was motivated and informed by a series of teleconferences with relevant scientists and managers in each NOAA Fisheries region, who identified a wide variety of challenges in bycatch estimation, most of which recur across regions. The objectives of this informal review are to identify common challenges in bycatch estimation with a view to 1) facilitating exchange of information among regions on how they are dealing with similar problems, and 2) highlighting areas of shared interest and challenges for potential future collaborative investigation.

The identified challenges to bycatch estimation can be organized into four categories that are nested in scope: sample size issues and sample design issues, both of which may affect the analysis itself; "meta-methods" issues (i.e., affecting work flow before or following the main analysis); and "meta-dataset" issues (i.e., affecting what data sets are available for analysis). Table 2 summarizes challenges and regions where each challenge occurs.

Individual regions have made progress on some of these issues through analytical or technological advances, some of which were highlighted at this workshop, or by improvising workarounds that make defensible use of available information to support management. A common – and important – strategy across regions for dealing with rare-event bycatch is to use model-based bycatch estimation methods that allow pooling of information across years (e.g., Murray 2009; Carretta and Moore 2014). Efforts addressing "meta-methods" issues, particularly at the "workaround" end of the spectrum, tend to be glossed over, so I highlight some here. In the case of insufficient or nonexistent taxonomic or genetic information, some analysts have estimated minimum and maximum plausible impact on each of the potentially affected species or stocks, incorporating spatial information as appropriate (Lyssikatos 2014; Soldevilla et al. 2015). Where effort records for the unobserved portion of the fishery are lacking, one approach is to use stratified expansion of observed bycatch based on landings information, since there is likely to be a stronger relationship between bycatch and landings within more homogeneous strata (Jannot et al. 2011). Alternatively, effort itself is modeled before being used for expansion of observed bycatch (Nance et al. 2008; Soldevilla et al. 2015). And missing effort or landings data for expansion have been inferred from known data (Murray 2009). Collectively, analysts have overcome substantial hurdles to provide useful information to management, so consultation with other regions that share similar issues may often provide a path forward.

Table 2. Challenges in bycatch estimation, and regions where each challenge currently occurs in one or more fisheries.

Challenges in bycatch estimation	NE	SE	SW	NW	AK	PI
Sample size issues						
Rare event	X	X	X	X	X	X
Low observer coverage (< 20% per Lawson 2006)	X	X	X	X	X	
Changes in fishery (regulations, gear, environment)	X	X	X	X	X	X
Hierarchical data (vessels, trips, hauls)	X	X	X	X	X	X
Sample design issues						
Unrepresentative observer coverage	X	X	X			X
No recent observer coverage		X	X		X	
Meta-methods issues						
Taxonomic resolution/accuracy	X	X				
Stock assignment						
>1 stock with little/no genetic data	X	X	X	X	X	X
Sample stratification not aligned with stock boundaries		X		X		
Paucity of external variables for modeling	X	X	X	X	X	X
No logbooks/effort available		X		X	X	
Effort/landings data challenges						
Effort/landings underreported	X	X				
Missing data for expansion (observed or external data set)	X			X	X	
Missing data not random with respect to bycatch					X	
Insufficient documentation of observer program (esp. potential sources of bias)			X		X	
Meta-dataset issues						
Unobservable interactions	X	X	X	X	X	X
"Unobservable" fisheries	X	X	X	X	X	X

Looking ahead, given the broad overlap in bycatch estimation challenges among regions, considerable potential exists for collaborative projects that contribute to solving or providing a way forward on one or more issues. Several ideas for such topics were raised during the region-specific teleconference calls or emerged from this review, including:

- maximizing utility of stranding, entanglement, or other opportunistic reports where observer coverage is low or nonexistent;
- maximizing utility of discontinued or sporadic observer data;
- adapting data-poor bycatch estimation methods (e.g., Zhou et al. 2011) to unobserved U.S. fisheries;
- streamlining development of models that integrate fisheries-dependent bycatch information and fisheries-independent species distribution information to support improved bycatch estimates, e.g., by accounting for climate change;

- assessing comparability of estimates from different bycatch estimation methods, especially for rare events;
- incorporating various sources of uncertainty in bycatch estimation;
- optimizing bycatch estimates when total effort is not available; and
- reviewing observer programs for opportunities for improvement in variables collected, sample design, and ancillary but related work undertaken.

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Discussion: Plenary session

Following the plenary presentation, several emerging bycatch issues were discussed, including: accurately estimating encounter rates across different fisheries, knowing fishery effort, observer coverage influencing fishing behavior, and the different interaction rates within a fishery based on gear diversity. In the Southeast Region, it is difficult to measure protected species interactions including such examples as when animals escape through turtle excluder devices (TEDs) or if they are deterred by pingers. Several solutions to this challenge were suggested from different regions, for example using pre-TED bycatch data to estimate the number of missed interactions or capturing interactions with electronic monitoring and underwater cameras.

Another challenge was estimating each fishery's effort, particularly if a large part of the fishery fleet is state-only. The Northwest and Southeast Regions use stratified landings and port interviews to calculate catch per unit effort (CPUE), location, finer resolution strata, and to model coarser resolution strata. The Southeast is now incorporating logbooks to characterize where effort originates and is working with industry to measure effort. Additionally, placing observers on state boats through cooperation with state fisheries that catch federally protected species would be helpful.

The influence observer coverage has on fishing behavior was also discussed, and, although vessels in a Category I or II fishery are required to accommodate an observer onboard vessel(s) upon request (50 CFR 229.7), this is not always implemented. Some ways to overcome observer behavioral bias is to move toward less observer coverage and greater electronic monitoring and/or tracking larger vessels through Automatic Identification System data streams, which could prove to be expensive and result in different data management challenges and biases. One final challenge to consider when estimating bycatch is gear diversity within a fishery fleet. Not all vessels in a fleet use the same gear in the same way to go after the same fish. For example, some sablefish trawl fisheries have fish meal plants which attract seabirds differently than those that do not.

The discussion ended with ideas for productive paths forward including a collaborative effort in one to three year projects following the protected species toolbox model. Table 2 served as a useful starting point for discussing shared issues in estimating bycatch.

New Approaches to Robust Estimation for Rare-Event Bycatch

Session Highlights:

- NMFS and other organizations (e.g., National Weather Service, NOAA Research, International Whaling Commission, United States Geological Survey) offer many examples of rare-event modeling, which can be used to help overcome the challenge of discontinuous bycatch observation data.
- A Bayesian estimator could produce similar bycatch and stock assessment results to those of conventional ratio estimates, but with more precision and less bias.
- Random forest regression tree models may result in more stable annual bycatch estimates than ratio estimates by increasing precision and reducing bias.
- A zero-inflated negative binomial modeling approach could be used to assess key factors influencing albatross bycatch rates from an observer sample with no extrapolations.
- A novel Monte Carlo test with complex adaptive sampling design might take into account the variable observer coverage when comparing observer interaction levels to a historical reference set to evaluate take levels.
- Two proposed steps to improve rare-event bycatch estimation were: 1) nationally sharing and coordinating computing power to generate and run models, and 2) forming a group to discuss the best ways to generate SAR estimates.

Informing rare-event bycatch estimation using prior knowledge

Christopher Orphanides and Joshua Hatch*

Small cetacean and pinniped bycatch in the U.S. New England sink gillnet fishery has been estimated annually since the 1990s, with the last significant change in methodology occurring in 2010. Despite this relatively long time series, historic bycatch has not been used to inform current estimates. In this study, we used a Bayesian estimator to inform the 2015 bycatch estimates of harbor porpoise using data from 2010 to 2014. We assumed observed bycatch followed a Poisson distribution, with Gamma priors being placed on the bycatch rates, resulting in posterior estimates that were also Gamma distributed via conjugacy. The resulting estimates were then compared to those obtained from the traditional ratio estimator used since 2010. The Bayesian estimate for the entire region was similar to that produced by the traditional ratio method, with overlapping 95% uncertainty intervals. The Bayesian estimates were more precise, but differences existed within strata between the two estimation methods. Those differences included positive estimates from the Bayesian estimator when no bycatch was observed in 2015, but where bycatch has been historically documented as captured in the prior. Bycatch events are rare and observer coverage in some regions can be low, though annual bycatch estimates have resulted in significant fisheries management implications. Any changes in methodology should therefore be thoroughly discussed and well supported. Advantages of a Bayesian approach include reduction in interannual variability in bycatch estimates and the ability to account for high percentages of false zeros when coverage is too low to detect bycatch events.

An R Shiny tool for Bayesian bycatch estimation from a time series of fisheries observer data

Jeffrey Moore, Howard Coleman, Eli Holmes*

In most fishery observer programs for marine mammal bycatch, only a fraction of fishing effort is observed. Uncertainty in bycatch estimates from the associated sampling error, along with true annual variation in bycatch, can lead to unstable bycatch inference through time, adding volatility to the management process. This can be especially problematic in "rare-event" situations, where the natural rarity of catches and low observer coverage results in the observed bycatch being zero or just a few animals. Conventional ratio estimates, commonly used for NOAA stock assessments, bounce between zero and large numbers, even though variation in the true bycatch is less. Pooling several years of estimates can help, but can yield results that are sensitive to user decisions. Here we demonstrate the utility of a Bayesian model-based approach to bycatch estimation and inference, and we describe progress toward making our approach available to others as an R Shiny application. Observer data are treated as random variables and expected annual catch is modeled as a function of fishing effort, whale abundance, and a catchability parameter, which itself can depend on covariates. The approach uses more available information than is commonly used for NOAA stock assessments because inference is based on a time series of information (rather than just one or a few years), and because population trend information is integrated if available. Advantages of the approach include not just improved estimation accuracy but also probabilistic inferences and forecasting capabilities.

Estimating bycatch from rare-event data with machine learning

James V. Carretta, Jeffrey E. Moore, Karin A. Forney*

Protected species bycatch was estimated for the California swordfish drift gillnet fishery for the 26-year period 1990-2015, using random forest regression trees. Tree estimates are compared with traditional annual ratio estimates generated from the same observer data. Ratio estimates suffer from systematic bias (under- and overestimation of bycatch) when observed bycatch is rare, bycatch rates are based solely on within-year data, and observer coverage is low. Random forest regression tree models result in more stable annual bycatch estimates with better precision, because estimates are informed by all available data. Even in years with zero observed bycatch, expected values from regression trees are usually positive (sometimes fractions of animals) and have error estimates (thus acknowledging the possibility that animals may be caught even when none are observed), whereas corresponding ratio estimates would be zero and have no error estimates. Regression tree models include a suite of oceanographic, location, and gear variables used as predictor covariates to estimate bycatch at the fishing-set level. Useful covariates were identified through a variable selection approach using the R-package rfPermute and validated with a simulated bycatch dataset. Results indicate that rfPermute can succeed in identifying significant predictor variables for rare bycatch events, even when these events represent <1% of all data.

Estimating short-tailed albatross bycatch in U.S. West Coast groundfish fisheries

Thomas P. Good, Eric Ward, Jason Jannot*

For West Coast groundfish fisheries in general, ratio estimators are used to extrapolate seabird bycatch from observed bycatch rates using fishing effort metrics (Jannot et al. 2011). However, rare bycatch events and/or low observer coverage creates problems for ratio estimators (Martin et al. 2015). The single observed short-tailed albatross (STAL) take in 2011 required a different method for estimating bycatch than in other years (Ford et al. 2012). The risk assessment and ensuing biological opinion (USFWS 2012) used black-footed albatross as a proxy species to estimate short-tailed albatross bycatch in West Coast groundfish fisheries. This proxy method, used to effect in Hawaiian pelagic longline fisheries (USFWS 2004; NMFS 2011), was also employed in subsequent analyses for the initial NMFS bycatch report to the Pacific Fisheries Management Council ESA Workgroup (Good et al. 2015).

The proxy estimation method makes assumptions and imposes limitations on bycatch estimates that are unlikely to apply to short-tailed albatross bycatch in West Coast groundfish fisheries. The methods assumed: risk to black-footed and short-tailed albatross from West Coast groundfish fisheries was equivalent and varied only as a function of the two species' global ratio; black-footed albatross proportional mortality relied on accurate, up-to-date global population estimates that are notoriously difficult to obtain; the "at-risk area" multiplier was based on the species' global geographic ranges (which are, for West Coast groundfish fisheries, completely overlapping); and the methods likely overestimated albatross bycatch by incorporating speculative drop-off rates into the calculations.

To explore alternative bycatch estimation methods for short-tailed albatross, we applied statistical models using data from the NWFSC West Coast Groundfish Observer Program for the fishery responsible for the only observed take – the Limited Entry sablefish longline fishery. We used simple Bayesian models while estimating variances of total bycatch, which has been used with cetaceans, delphinids, pinnipeds, sea turtles, and some sharks (Martin et al. 2015). We modeled bycatch rate as constant and inferred annual expected mortality, given a specified level of effort. Fleet-wide bycatch of short-tailed albatross from the sablefish longline fleet was estimated using levels of observer coverage.

The general modeling approach was to use a simple Poisson process model, where the total number of bycatch events were assumed to follow a Poisson distribution,

$$n_{take,y} \sim Poisson(\lambda_y = \theta \cdot E_y),$$

where $\mathbf{E}_y$ represents the effort in year y, $\boldsymbol{\theta}$ is an estimated bycatch rate, $\boldsymbol{\lambda}_y$ represents the mean expected bycatch, and $n_{take,y}$ represents the number of observed bycatch events (or take events) in year y. The estimated bycatch rate $\boldsymbol{\theta}$ is assumed constant through time, but the quantity $\boldsymbol{\theta} \cdot \mathbf{E}_y$ includes uncertainty (as $\boldsymbol{\theta}$ is estimated). A time series of mean bycatch can be generated for a given species, with a given metric of effort. All uncertainty in these time series originates from fluctuating levels of effort through time (percent observer coverage only affects the expansion). We used a Bayesian model (Martin et al. 2015) to generate mean and 95% CIs of the parameter $\boldsymbol{\theta}$, as well as for $\boldsymbol{\theta} \cdot \mathbf{E}_y$.

Because observer coverage is <100% and variable through time, we expanded estimated bycatch $\boldsymbol{\theta} \cdot \mathbf{E}_y$, to the fleet. One approach for expansion, to divide $\boldsymbol{\theta} \cdot \mathbf{E}_y$ by the percent observer coverage, ignores uncertainty in the expansion. We accounted for uncertainty in the expansion by treating the observer coverage and estimated bycatch ($\boldsymbol{\theta} \cdot \mathbf{E}_y$) as known ('p' and 'x', respectively) and sampling from the distribution of total bycatch (N) in proportion to the Binomial density function. This process was repeated for each Markov Chain Monte Carlo draw to propagate uncertainty in the estimates through uncertainty in the expansion.

The Bayesian analyses showed that fleet-wide estimates of bycatch were similar regardless of the measure of effort used. Expanding from observed hooks as the effort metric, mean estimates of fleet-wide bycatch for 2002-2014 ranged from 0.22 to 0.63 STAL/year, and the upper confidence limit ranged from 0.85 to 2.44 STAL/year (Figure 10).

Probability-based methods are advantageous where bycatch is dominated by zeroes – reduced bias from rare events, incorporating uncertainty, and less reliance on assumptions. The model-based Bayesian approach has been employed with other rare bycatch species, including marine mammals, sea turtles, and sharks. These methods also reduce volatility by using all information in the time series, reduce arbitrary decisions about how many years of data to combine, and enable probabilistic inference for bycatch conditional on fishing effort.

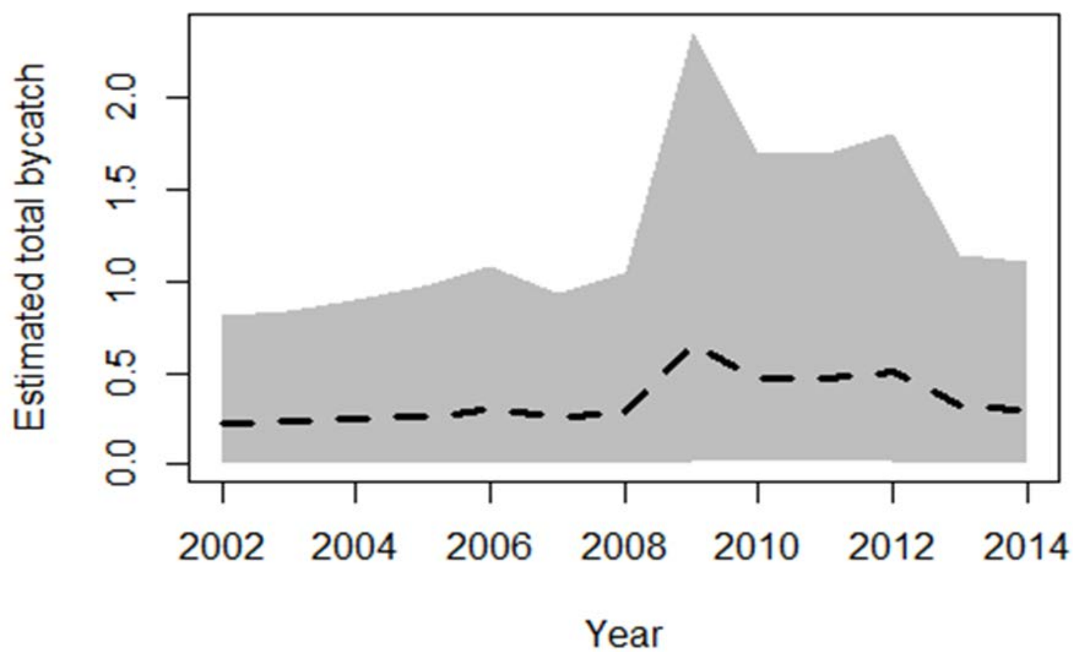

Figure 10. Total (fleet-wide) bycatch of short-tailed albatross (effort = observed hooks) estimated for 2002-2014. Dashed line is mean; gray area represents 95% confidence limits.

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Albatross bycatch in Alaskan longline fisheries: Modeling rates to inform trends

Kimberly S. Dietrich, Edward F. Melvin, Robert Suryan, Amanda Gladics*

Prompted by what appears to be a recent increasing trend in NMFS estimates of total albatross mortality in Alaska demersal longline fisheries and a lack of bycatch rate information since 2006, we conducted retrospective analyses of albatross bycatch data from the North Pacific Groundfish and Halibut Observer Program (1993 to 2015) to identify drivers, possible alternative management options, and useful metrics for annual bycatch reporting. We calculated standardized albatross bycatch rates (birds per million hooks; Bycatch per unit of effort (BPUE)) derived from the observer sample with no extrapolations. Mean rates were calculated for multiple strata (target fishery, processing type, year, month, time-of-day, area, and vessel). Results show that the annual means of albatross BPUE decreased by 89% following the voluntary adoption of bycatch mitigation (streamer lines) in 2002, and have remained stable through 2015. Our a priori assumptions were that lack of agreement in annual trends of albatross BPUE and estimated bycatch may be due to an increase in fishing effort, or that the extrapolation methodology used for all catch species may not be robust for rare events. We used a zero-inflated negative binomial modeling approach to assess which factors are most influential on albatross bycatch rates and discuss why annual reporting of BPUE in addition to estimated catch is important to evaluate progress toward albatross conservation in Alaska longline fisheries.

Was there an increase in leatherback sea turtle interactions in 2014?

*Marti McCracken**

At the beginning of 2014, there were an unusual number of observed interactions of leatherback sea turtles in Hawaii's deep-set longline fleet. The spike of observed takes occurred during a period when observer coverage was declining due to the need to delay the required training course for new observers. As this spike was noticeable, there was an interest in determining how unusual the level of observed takes in 2014 was compared to previous years. To take into account the variable observer coverage when comparing 2014 observer interaction levels to a historical reference set, a novel Monte Carlo test was derived. As leatherback sea turtles are listed as an endangered species, the Monte Carlo test was structured to control the risk of erroneously concluding that there was no increase in leatherback sea turtle takes. To control this risk, the concept of bioequivalence was employed. This presentation reviews the novel complex adaptive sampling design used to sample the deep-set longline fleet and why it is important to take into account this design when evaluating take levels. The novel Monte Carlo test will be presented along with the results of the analysis.

Incorporating Spatial and Temporal Factors into Bycatch Assessments

Session Highlights:

- Incorporating spatial information almost always improves model-based bycatch estimates.
- Integrated Nested Laplace Approximations (INLA) and Stochastic Partial Differential Equations (SPDE) can produce bycatch risk maps using large U.S. fisheries observer datasets, with random forests showing little variance for species with few bycatch occurrences and outperforming the parametric models.
- Bayesian hierarchical modeling through INLA indicates that patterns of bycatch are spatially explicit, with consistent hotspots over time within an area but with a high degree of interannual variability. A case study of green sturgeon illustrated how bycatch data for rare-encounter species can be effectively modeled in a novel statistical framework to identify and to assess the spatiotemporal characteristics of bycatch hotspots.
- Suggestions to improve spatial models varied from eliminating the bias in the Generalized Additive Models (GAM) to simulating observer coverage more realistically, and using effort data rather than effort models.
- Cross validation and statistical comparisons of different models could reduce estimation errors and improve confidence in choosing the right method for the specific issue.
- With limited coded-wire-tag recoveries, genetic mixture analysis may provide a novel alternative way to estimate proportions of evolutionarily significant units (ESUs) and possibly predict stock composition as a function of latitude.

The utility of spatial model-based estimators of bycatch: future or folly?

Eric J. Ward, Brian Stock, Jim Thorson, Yong-Woo Lee, Jason Jannot*

A basic challenge of model-based approaches to bycatch estimation is that there is generally very little correlation between metrics of fishing effort (sets, hooks, haul duration) and bycatch events. As an alternative, estimating bycatch from partially observed fisheries (observer coverage <100%) has typically relied on ratio estimators, expanding observed bycatch to the entire fleet based on the ratio of observed to total fishing effort. The recent advance and application of spatial models offers the opportunity to compare the utility of spatial model-based estimates of bycatch to traditional ratio estimation. In this talk, we use data from the NWFSC Observer Program (2011-2015). Using simulation testing during this period with 100% observer coverage, we evaluate the robustness of parametric and non-parametric model-based bycatch estimation, and compare the mean and variance of these approaches to traditional ratio estimation. Using case studies of 20 groundfish species on the West Coast (representing a range of occurrences and densities) we demonstrate that inclusion of spatial information almost always improves model-based estimates of bycatch. In data-limited situations, the ratio-based estimator offers reduced bias and variance. Future work will demonstrate examples of the utility of these spatial model-based approaches to different data types from other ecosystems.

Genetic mixture analysis and Chinook salmon ESU bycatch impacts under a new management scenario for Pacific hake

Paul Moran, Vanessa Tuttle, Susan Bishop, Becky Renko, Larrie LaVoy*

The U.S. West Coast Pacific hake fishery has the largest single-species landings of any fishery managed under the Pacific Coast Groundfish Fishery Management Plan. Despite efforts to minimize take of non-target species, bycatch remains a significant issue, particularly for Chinook salmon. As part of the U.S. Endangered Species Act Consultation and Environmental Impact Statement for this fishery, the Pacific Fishery Management Council posed the following question to NOAA: What will be the change in Chinook stock composition if the current restriction is removed for processing Pacific hake south of latitude 42 in the At-Sea sector? We used genetic mixture analysis to estimate proportions of Evolutionarily Significant Units (ESUs). Based on seven years of previous samples taken by NOAA observers, we developed a model to predict stock composition as a function of latitude. We then estimated the latitudinal distribution expected under the new management scenario. We used the resulting stock composition to quantify expected change in take of protected Chinook salmon ESUs with the elimination of the latitude 42 restriction, as desired by the industry. Our analysis suggested that the proposed change would virtually eliminate Puget Sound and Columbia River ESUs from At-Sea bycatch, but would show an increase in sensitive Southern Oregon/Northern California and Klamath-Trinity ESUs. We assume there might also be greater impacts on California coast and Central Valley ESUs, but the predictive ability of our model is poor for these. That limitation notwithstanding, genetic mixture analysis provided a novel alternative, given inadequate Coded-Wire-Tag recoveries.

Identifying bycatch hotspots in data limited scenarios: Bayesian spatio-temporal models for green sturgeon bycatch in California halibut fishery

Yong-Woo Lee and Eric Ward*

The southern distinct population segment (DPS) of green sturgeon (*Acipenser medirostris*) on the U.S. West Coast has been listed as threatened under the U.S. Endangered Species Act (ESA) since 2006. As with other species at risk, it is critical to identify and understand the spatiotemporal characteristics of the bycatch hotspots for conservation planning and management. However, sparse or zero-inflated data situations for rarely encountered species pose difficult challenges for modeling bycatch data. More challenges arise in data-limited scenarios when effectively trying to incorporate the temporal and spatial correlations in the data. For this case study, we applied a Bayesian hierarchical modeling approach through Integrated Nested Laplace Approximation (INLA), with space- and time-varying random effects, to the 2002-2013 green sturgeon bycatch data in the California halibut fishery, collected by the West Coast Groundfish Observer Program (WCGOP). To select the best performing model, we tested various model configurations, such as different underlying distributions for the likelihood function (Poisson vs. negative binomial) and spatiotemporal correlation structures (e.g., time-constant vs. time-varying spatial field). The data suggest that green sturgeon is encountered in the fishery consistently in a confined nearshore coastal habitat. The models indicate that the patterns of bycatch are spatially explicit with consistent hotspots over time within the area but with a high degree of interannual variability. This case study illustrates how bycatch data for rarely-encountered species can be effectively modeled in a novel statistical framework to identify and to assess the spatiotemporal characteristics of bycatch hotspots.

Predicting fisheries bycatch risk for dynamic spatial management

Brian Stock, Tomo Eguchi, Eric J. Ward, Jason E. Jannot, Eric Forney, Brice X. Semmens*

Nearly all marine fisheries have at least some bycatch, which concerns commercial and recreational fishermen, resource managers, conservationists, and the public. High bycatch rates reduce the efficiency and sustainability of fisheries, but even extremely low bycatch rates can be a problem for protected or rebuilding species. Spatial fishing practices affect bycatch rates, and understanding spatiotemporal patterns in bycatch offers a possibility to improve fisheries management. We demonstrate the ability of powerful new tools, Integrated Nested Laplace approximations (INLA) and stochastic partial differential equations (SPDE), to produce bycatch risk maps using two large U.S. fisheries observer datasets (West Coast Groundfish and Hawaii Longline Observer Programs). We compare the INLA-SPDE approach with two other spatial modeling frameworks, generalized additive models (GAMs) and random forests (RF), and show how the models' performance differs across a broad range of bycatch rates, from loggerhead sea turtles (0.15%) to blue sharks (89%) in the Hawaii longline fishery, and yelloweye rockfish (0.4%) to Pacific halibut (28%) in the West Coast groundfish fishery. For all six species, random forests outperformed the parametric models, although model performance varied little for species with few bycatch occurrences. Finally, we produce decision tables that show bycatch reduction of each species under alternative management actions (levels of fishing removed) for each model.

Cryptic Mortality and Serious Injury

Session Highlights:

- Unaccounted-for mortality and serious injury of marine mammals can impact management decision-making by causing underestimates of mortality and incorrect inferences of population status.
- Bayesian hierarchical models can use individual sighting histories of catalogued whales together with records of serious injuries and mortalities to produce latent entanglement-related mortality estimates.
- Ratio estimator combined with total minutes of trawling activity can be used to systematically quantify the magnitude of seabird cable strikes by species and strike type.
- Additional information on carcass fate, pinniped cryptic mortality and serious injury, and offshore species correction factor could help improve estimates of total mortality.

Cryptic mortality correction factors

*Dennis Heinemann**

If estimates of human-caused mortality and serious injury (MSI) exceed the potential biological removal (PBR) level for a marine mammal stock, management action may be required to ensure the viability of the stock. Apparently, however, most mortalities are never detected. The only carcasses we record are those detected and reported when they are killed, floating at sea, or stranded on shore. Carcasses at sea can escape detection if they sink and do not refloat. A carcass on shore may have stranded in that state, or a live animal may have stranded and died there. Carcasses can escape detection if they are scavenged beyond recognition, buried by sediments, or removed but not reported. Additionally, they may go undetected if they strand in a remote and/or sparsely populated area with little or no search effort, or on an inaccessible shoreline, even if they persist for long periods. Thirteen analyses of detection/stranding data (known mortalities) from 21 of cetaceans species (28 stocks) suggest that at most 35% of all mortalities in a population are detected, and in some cases the detection rate may be near zero (average: 10%). This implies that MSI estimates used in U.S. stock assessments need to be inflated by approximately a correction factor of three, at a minimum, and perhaps by a much larger factor (Table 3).

Three primary methods have been used to estimate a carcass detection rate, which is the ratio of the number of detected (known) to total mortalities. If all individuals in a population are known and monitored (e.g., Southern resident killer whales, or Sarasota common bottlenose dolphins) then the detection rate is simply the number of detected mortalities divided by the known number of mortalities in the population. The demographic approach is based on an estimated or assumed mortality rate for a population, the known or estimated population size, and the number of detected carcasses (mortalities). In this case, the detection rate is the ratio of the number of detected carcasses to the estimated total number of mortalities, which is the product of the mortality rate and population size. The third approach involves modeling and/or experimental examination of the processes that determine carcass fate. The detected rate can be empirically estimated though a designed release of a sample of “marked” carcasses at sea and waiting to see how many are detected. Alternatively, empirical or model-generated estimates of state transition probabilities (e.g., drifting to sinking, drifting to stranded, or stranded to found) can be used to estimate the probability that a carcass is detected.

In each case, the inverse of the carcass detection rate for a population is a correction factor that can be used to inflate the number of known human-caused MSI to obtain an estimate of the total number of human-caused mortalities in the population. However, this approach depends on a key assumption that the average carcass detection rate for the population is a good approximation of the detection rate of human-caused mortalities. This amounts to the assumption that the processes and factors that determine the average probability of carcass detection (i.e., for all types of mortalities) are not significantly different from those that determine the probability of detection of human-caused mortalities. For example, the buoyancy of a carcass strongly affects whether it will be found. Buoyancy varies among taxa (right whales float readily, while rorquals typically sink immediately), by condition (an emaciated whale is more likely to sink), scavenging rate (scavenging may alter the ratio of low-density to high-density tissues), by temperature and depth (a carcass that sinks in shallow warm water will likely refloat due to the accumulation of decomposition gases). The probability of refloating may be lower if the body cavity is breached, either by a vessel strike (cause of death) or through later scavenging. The potential for a carcass to strand is dependent on the length of time that it remains positively buoyant, which is dependent on the factors just described, and the probability that it does strand depends on its distance from shore, the current and wind patterns, and shoreline topography. A sick or injured cetacean may strand live and die on shore, and the probability of that happening is dependent on another set of factors. Once a carcass is on shore the probability that it is detected will depend on search effort, some of which is directed (e.g., beach surveys) while the rest is haphazard (e.g., discovered and reported by the public), population density or remoteness, accessibility, shore topography and vegetation, and the scavenging, decomposition and deposition rates. Moreover, if it is discovered but not recovered, then it is lost as a potential detection.

Typically, the generalized carcass detection rates are estimated using data collected over a number of years, and ideally as much of the stock's range as possible. Those rates are determined by the processes and factors affecting the full range of natural- and human-caused mortalities. Therefore, when correction factors based on those rates are applied to the estimate of a specific or range of human-caused MSI, any differences in the processes and factors affecting the human-caused detection rate, compared to the generalized rate, have to be considered. Further, to estimate total mortality, correction factors are typically applied to MSI estimates in a year subsequent to the period in which the generalized rate was estimated. However, if the processes and factors affecting the carcass detection rate are significantly different in that year compared to the "average" conditions, then the correction factor may be biased, which could lead to a significantly larger or smaller estimate of total human-caused mortality. Therefore, potential differences in the processes and factors affecting the carcass detection rate between the earlier period and the given year have to be taken into account.

Correction factors can be estimated and applied for a wide range of species/stocks in the U.S., as has been done for common bottlenose dolphins by the Southwest Fisheries Science Center. However, to improve the robustness and reliability of such estimates, research should be carried out on the processes and factors affecting the carcass detection rates associated with different causes of mortality (e.g. studies of carcass state-transition rates, drift experiments, and fate modeling).

Table 3. Estimates of carcass detection rate and corresponding correction factors for 21 species (28 stocks) of cetaceans from 13 analyses.

Species - Stock	Carcass Detection Rate	Correction Factor	Reference
False killer whale - Gulf of Mexico	0.0%	n/a	Williams et al. 2011
Killer whale - Gulf of Mexico	0.0%	n/a	Williams et al. 2011
Striped dolphin - Gulf of Mexico	0.0%	2273	Williams et al. 2011
Pantropical spotted dolphin - Gulf of Mexico	0.05%	2000	Williams et al. 2011
Atlantic spotted dolphin - Gulf of Mexico	0.1%	769	Williams et al. 2011
Clymene dolphin - Gulf of Mexico	0.2%	556	Williams et al. 2011
Harbor porpoise - North Atlantic	1.0%	100	Moore & Read 2008
Spinner dolphin - Gulf of Mexico	1.0%	100	Williams et al. 2011
Pygmy killer whale - Gulf of Mexico	1.2%	83.3	Williams et al. 2011
Short-finned pilot whale - Gulf of Mexico	2.0%	50.0	Williams et al. 2011
Killer whale - Northern resident	3.0%	33.3	Barbieri et al. 2013
Bottlenose dolphin - Coastal Gulf of Mexico	3.3%	30.3	Schwacke et al. 2015
Sperm whale - Gulf of Mexico	3.4%	29.4	Williams et al. 2011
Risso's dolphin - Gulf of Mexico	3.5%	28.6	Williams et al. 2011
Rough-toothed dolphin - Gulf of Mexico	4.4%	22.7	Williams et al. 2011
Gray whale - Pacific	5.0%	20.0	Heyning & Dahlheim 1990
Melon headed whale - Gulf of Mexico	6.1%	16.4	Williams et al. 2011
Cuvier's beaked whale - Gulf of Mexico	6.2%	16.1	Williams et al. 2011
Franciscana	7.6%	13.2	Prado et al. 2013
Common dolphins and harbor porpoise	8.0%	12.5	Peltier et al. 2012
Gray whale - Eastern North Pacific	8.5%	11.8	Punt & Wade 2009
Humpback whale - Gulf of Maine	10%	9.71	Robbins et al. 2009
Bottlenose dolphin - Estuarine Gulf of Mexico	11%	8.93	Schwacke et al. 2015
North Atlantic right whale	17%	5.88	Krauss et al. 2005
Killer whale - Southern resident	20%	5.00	Barbieri et al. 2013
Bottlenose dolphin - California Coastal	24%	4.17	Carretta et al. 2014
North Atlantic right whale	28%	3.62	Knowlton & Krauss 2001
Bottlenose dolphin - Sarasota Bay	33%	3.03	Wells et al. 2014

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Counting MIAs: Estimating latent entanglement-related mortality of North Atlantic Right Whales

*Richard M. Pace, III**

Unlike estimation efforts developed for fishing-related mortality of small cetaceans, no proper sampling frame exists for the primary causes of serious injuries and mortalities (SIMs) to large whales. In the U.S. Atlantic stock areas, assessments of fishing-related SIMs have been limited to counts of observed deaths and serious injuries despite the recognition that whale deaths go undetected. I used individual sighting histories of cataloged whales together with records of SIMs in a Bayesian hierarchical model to estimate latent entanglement-related mortality of right whales. I partitioned observed SIMs into entanglement related (SIME) or other (SIMO) based on evidence from necropsies or other observational evidence. Survival estimates included covariates for sex, age class, and random fluctuations in mean survival through time. The model estimated transition rates among six states: no apparent injury, seriously injured due to entanglement, mortality due to entanglement, seriously injured without evidence of entanglement, dead without evidence of entanglement, and an absorbing dead state. I included data on observed seriously injured and dead whales to help inform estimates of detection rates which could vary between entanglement related and other. Detection rates among types were separately estimated. In the example presented, detection rates of seriously injured whales and recovery rates of dead whales were held constant through time, but time-varying parameterizations are possible as well as incorporation of effort covariates if available. In the model demonstrated, an estimate of total entanglement-related SIMs was derived by summing the recovery-rate inflated observed SIMs over a five-year period of evaluation commonly used in marine mammal stock assessment reports:

Entanglement SIME = SI from Entanglement / detection rate + Entanglement Mortality / Recovery Rate,

with the resultant posterior presented along with the unadjusted average count (Figure 11). An alternative estimate is available by parameterizing the model to include Jolly-Seber-like assumptions on entry probability so that abundance is directly estimated and SIME is the sum of transition rates times abundance or SIME states. The demonstrated procedures produced estimated annual entanglement SIMs substantially greater than the number of detected deaths (median = 8.7 versus observed 4.2). Although verifying that an observed death is due to entanglement may be imperfect and hence render the demonstrated procedure still biased low, the estimated value is a much more realistic view of entanglement deaths.

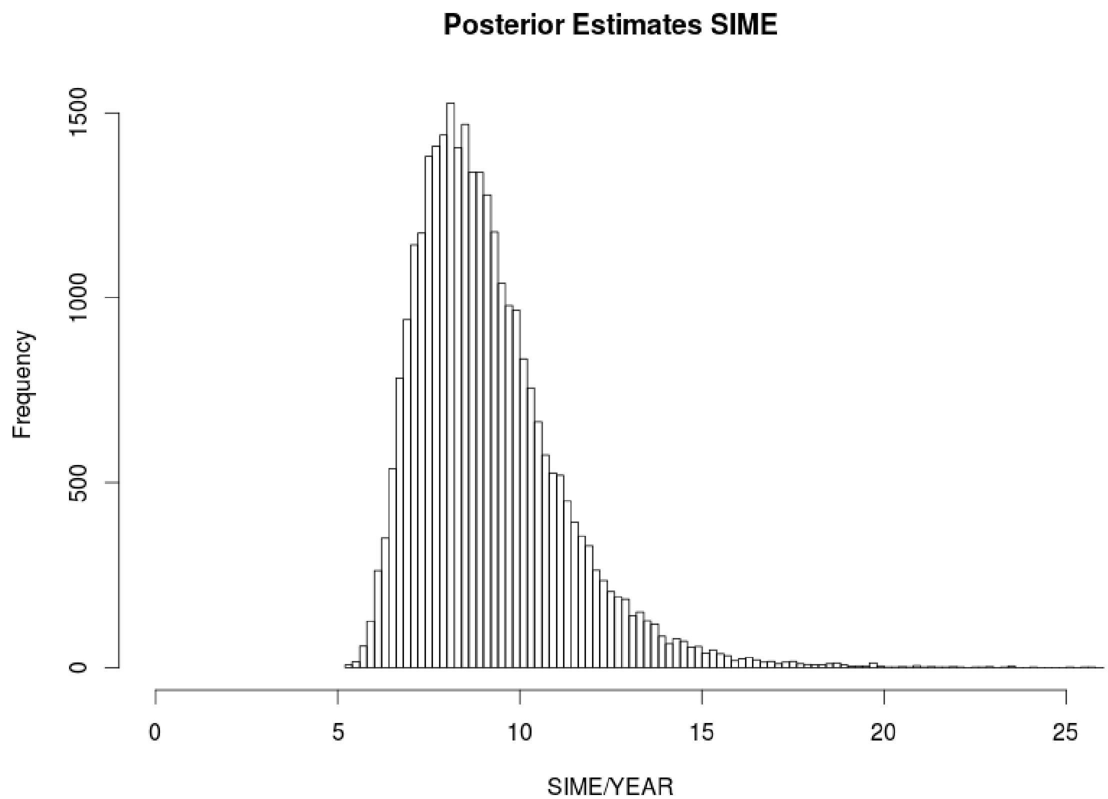

Figure 11. Posterior distribution of estimated entanglement mortality and serious injury from a hierarchical Bayesian model of right whale mark-resight-recovery data. Also shown is an x-axis reference mark for the unadjusted count of serious injuries and mortalities.

Unobserved seabird interactions with cables on at-sea hake CP vessels

Jason Jannot, Tom Good, Vanessa Tuttle, Cassandra Donovan*

Seabirds are an integral part of the California Current Marine Ecosystem (CCME) and protected by the U.S. Migratory Bird Act. Short-tailed albatross, which occur in the CCME and interact with fishing vessels, are protected in the U.S. under the Endangered Species Act. Managing seabird mortality requires unbiased estimates of seabird bycatch on U.S. West Coast groundfish fishery vessels.

Data from trawl fisheries in Alaska and the southern hemisphere indicate that seabirds colliding with trawl warp cables or the net transponder cable (aka third wire) can go unobserved, resulting in unaccounted for mortality (Bartle 1991; Melvin et al. 2011; Tamini et al. 2015). Seabirds in the air or on the water can strike a cable and the dead or injured bird then falls into the water, rarely being observed or recorded by fisheries observers. Seabird cable strikes have been documented on mid-water trawl nets fishing for hake (Williams and Capdeville 1996; Melvin et al. 2011; Parker et al. 2013; Tamini et al. 2015). Such gear is similar to that used by the U.S. West Coast (WA, OR) at-sea hake catcher-processor fleet.

The at-sea hake catcher-processor fleet carries observers during all fishing trips. Observers record any instances of seabird cable strikes that they witness. However, observations of cable strikes are infrequent because observer duties prevent them from being present for the majority of strikes. Because of this, strikes are not randomly sampled. Therefore, mortalities attributed to cable strikes are under-reported in fleet-wide estimates of seabird mortality. Quantifying the magnitude of seabird cable strikes and developing methods to estimate mortality from cable strikes will provide managers with less biased estimates of fishing-induced seabird mortality.

Our goals are to systematically quantify the magnitude of seabird cable strikes and develop methods to improve fleet-wide estimates of seabird mortality in this fishery. This work, in collaboration with the fishing industry, will lead to mitigation strategies to reduce seabird cable strikes. In 2016, we trained observers to sample seabird cable strikes during daylight trawling activities twice per day, at randomly selected 15-minute intervals. Observers recorded the species and number of birds involved, the date and time, the type (heavy or light) and outcome (e.g., injury, mortality) of strikes, weather conditions, the configuration of cables, and characteristics of the offal discharge—the main attraction for seabirds. Heavy strikes result in the bird changing course, falling into the water, or being dragged under water, whereas light strikes result in the bird being lightly touched by a cable and moving away in a controlled manner. Heavy strikes are more likely to result in mortality (Sullivan et al. 2006a; Sullivan et al. 2006b; Melvin et al. 2011). Data collection methods were modified from Melvin et al. (2011). We obtained fishing activity data from the observers, including net deployment/retrieval location, date and time, to estimate total minutes of trawling activity during daylight hours for the entire at-sea catcher-processor fleet during the 2016 fishing season.

We used a ratio estimator combined with the total minutes of trawling activity during 2016 to estimate the total number of strikes by species and strike type.

$$S_k = \frac{s_k}{A_o} \times A_T$$

S_k = estimate of the total number of strikes of type, k
s_k = observed number of strikes of type, k
A_o = time (minutes) observing cable during trawl activity
A_T = total time (minutes) of daylight trawl activity for 2016

We focus on black-footed albatross because there has been no documented short-tailed albatross take in the at-sea hake fishery. In 2016 observers recovered two black-footed albatross carcasses that were attributed to cable strikes. The estimated number of black-footed albatross heavy strikes was 738 (Figure 12). Currently there is no mortality rate estimated for heavy strikes of black-footed albatross with cables. Therefore, we estimated the mortality rate of heavy strikes of black-browed albatross as 12%, based on data from a similar fishery in the southern hemisphere (Tamini et al. 2015). Assuming this mortality rate for black-footed albatross, our estimate of black-footed mortality from cable strikes in 2016 is 85 individuals.

Our preliminary data and analysis suggests the potential for large amounts of unaccounted for seabird mortality in this fishery. Data collection, methods and analyses for this project are developing and ongoing. We will continue to collect data on seabird cable strikes, and develop model-based estimates of cable strike mortality to provide unbiased estimates of seabird mortality in this fishery.

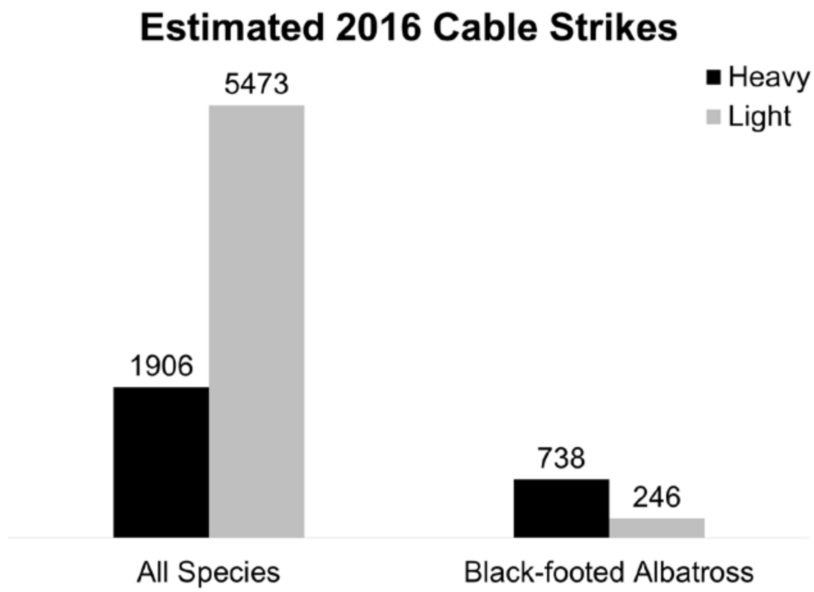

Figure 12. Estimated number of seabird cable strikes by type during the 2016 at-sea hake fishing season.

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Electronic Monitoring

Session Highlights:

- Electronic monitoring could be an alternative, or addition, to employing fisheries observers by providing a more comprehensive coverage of fisheries and by avoiding the problem of observer-caused changes in fishing behavior.
- Electronic monitoring may be transferable to different regions and taxa but would require a large dataset to enable automated image analysis.
- Infrared technology is a useful thermal imaging tool for detecting warm-blooded species in low visibility conditions to help estimate species abundance.
- Electronic monitoring systems fitted on commercial vessels could be used broadly for estimating catch and bycatch of multiple species, not just targeted species.
- Increased collaboration and open source technology may lead to innovation such as advanced electronic monitoring sensors.

Can electronic monitoring improve estimates of protected species bycatch?

John Carlson and Elizabeth Scott-Denton*

Analysis of bycatch data from at-sea observer programs relative to the take of smalltooth sawfish, a federally-listed endangered species, in the commercial shrimp trawl fishery indicated the level of take was higher than mandated. However, the level of take of smalltooth sawfish had high levels of uncertainty due to the rarity of sawfish captures combined with low levels of observer coverage. A priori analysis indicated the sample size required to observe a sawfish with a coefficient of variation (CV)=0.3 was 11,380 tow hours/year that results in a cost of about $1,000,000 to increase observer coverage in the eastern Gulf of Mexico. In light of the costs associated with observer coverage and given the rare event of capturing a smalltooth sawfish, increasing observer coverage to refine the take estimates of smalltooth sawfish may not be practical. We explored the use of electronic monitoring to provide a valid alternate to increased observer coverage. Preliminary testing on a contracted commercial shrimp trawl vessel found the system performed well in capturing video for a total of 109 hauls over 62 days at sea. While no sawfish were observed, many sightings of dolphins occurred, which suggests interactions with other protected species could be captured with these systems. Pairwise comparison of video versus that collected by observers found little difference in monitoring of larger species of teleosts and elasmobranchs. Electronic monitoring may provide an alternative to increase sample sizes, which in turn can reduce the uncertainty around bycatch estimates.

The era of machines that see?

Farron Wallace and Shannon Fitzgerald*

The National Marine Fisheries Service (NMFS) and the North Pacific Fishery Management Council are on a path to integrate electronic monitoring (EM) technology into the North Pacific fisheries Observer Program. The objective is to implement EM systems to collect images of catch including protected species to provide scientific data that can be used to estimate bycatch. In an effort to evaluate the efficacy and inform implementation, EM systems have been deployed among volunteer longline vessels since 2014. Research and development of new technologies has been in progress at the Alaska Fisheries Science Center (AFSC) Observer Program to help address challenges for using EM to collect scientific data. One of the challenges identified is that image quality can be greatly compromised by environmental conditions, light conditions, camera maintenance and the limitations of current EM systems. Problems encountered with poor image data include species identification and length estimation, two current goals of our research. Leveraging the latest development in camera technology and computer vision may offer potential solutions. EM systems in development at AFSC incorporate a variety of new technologies that are designed to improve image quality and support development of computer vision algorithms that extract data from images for species identification. Initial testing indicates that these systems could greatly improve our ability to monitor and estimate seabird bycatch in fisheries.

Final Discussion of Data-Poor Bycatch Estimation

The final discussion for "Data-Poor Bycatch Estimation" proposed steps to improve bycatch estimation and to improve cross-center collaboration. The Bayesian hierarchical modeling technique could be used to estimate human-caused mortality of harbor porpoises in the Alaska gillnet fisheries. Another step forward would be to estimate bycatch commonalities among different fisheries. Finally, revising R_{max} to be species specific and prorating bycatch to account for time spent outside of U.S. waters may be important in PBR calculations, where feasible. Future bycatch-focused workshops could analyze a simulated dataset to better understand methodologies and reduce biases.

Several ideas were proposed to improve cross-center collaboration, including: raising awareness of regional bycatch products (e.g., National Bycatch Report http://www.st.nmfs.noaa.gov/Assets/Observer-Program/bycatch-report-update-2/NBR%20First%20Edition%20Update%202_Final.pdf), extending bycatch workshop invitations to fish and protected species bycatch scientists, rotational visits to Science Centers, and mini-courses in stock assessment techniques and training programs similar to the Stock Assessment Professional Development Program. Collaboration between science and management could also be improved by incorporating communication and collaboration strategies into each unit's action plan. Lastly, it was suggested that F/ST and OPR facilitate the organization of working groups to discuss the technical aspects of bycatch estimation and application to varied management questions and taxa.

Final Discussion of PSAW

The final discussion of the PSAW focused on developing future PSAW topics based on the ideas participants had shared throughout the workshop. A workshop on image analysis for bycatch enumeration in artisanal fisheries and advanced technology sensors (e.g., telemetry[7] and drones[8]) for stock assessments are workshop topics that F/ST or other offices have already supported. Nascent topics like eDNA may be more suited for a broader audience such as the Society for Marine Mammalogy Biennial Conference. Two ideas were identified as necessary but beyond the scope of a PSAW: 1) a combined fish and protected species image analysis and data management workshop, and 2) a workshop with information technology and database staff on automated analysis, data management, and data archiving.

[7] https://ioos.noaa.gov/project/atn/
[8] http://www.nmfs.noaa.gov/pr/uas.html

There were several ideas for which there was some support. They fall under three themes – advanced technology, analytical methods, and species interactions – and are presented in the bulleted lists below.

Improving applications of advanced technologies

- Passive acoustics for fish stock assessments
- Advanced technologies to monitor entanglements, behavior, and outcomes of gear modification
- Thermal imaging to detect seabirds
- Advanced genetics tools to address conservation and scientific questions, including defining distinct population segments

Development of novel analytical methods

- Quantitative methods towards defining critical habitat
- Unobservable interaction estimates, specifically large whale and vertical lines from pots, traps
- Decision-support tools that optimize survey or analytical methods, or help evaluate success of mitigation measures
- Bycatch estimation with R and package demos
- Uncertainty in population and bycatch estimates

Ecosystem Interactions

- Effect of increasing fisheries catch on marine mammal abundance
- Marine mammal effects on fish and fisheries
- Ecosystem modeling with a protected species focus
- Climate change predictions and protected species assessments

There were also several suggestions for the format of future PSAWs, including hosting fewer talks to dedicate more time to discussion and organizing dedicated sessions focused on a specific management or scientific question or methodology used (e.g., different quantitative methods for measuring growth, recruitment, abundance, etc.). In addition, future PSAWs could improve inclusivity by ensuring broader taxa representation (more seabirds, corals, non-salmon protected fish), and by inviting representatives from other agencies with whom NMFS shares jurisdiction or expertise needs (e.g., USFWS, USGS).

The discussion concluded with a final reflection on the outcome of the first PSAW. Many expressed that the PSAW provided a necessary space for NMFS researchers to share research challenges and solutions, and propose new ideas. There was high participation with 165 attendees, 107 people in person and 58 people online, and a strong roster of speakers and poster presenters. Participants thanked F/ST for ensuring critical NMFS leadership support for the workshop and working to organize and coordinate the workshop. Overall, the first PSAW was a success, and achieved its objective of encouraging cross-regional and cross-taxa collaboration.

Poster Session

Conditional smolting predicts abundance trends of Carmel River steelhead trout

Juan Lopez Arriaza, David Boughton, Kevan Urquhart, Marc Mangel*

Threshold effects are common in ecosystems and can generate counterintuitive surprises in management interventions. A threshold effect recently discovered in threatened anadromous steelhead (*Oncorhynchus mykiss*) is conditional smolting, in which juveniles transform to smolts only if growth exceeds a threshold body size by the time of a "decision window" prior to migration season. Conditional smolting suggests that efforts to improve survival of juvenile steelhead may backfire if they increase density-dependent competition and reduce growth. We asked whether conditional smolting explained declining numbers of adult Carmel River steelhead. This threatened population has been the focus of two decades of habitat restoration, as well as active translocation and captive-rearing of juveniles from channels dewatered by groundwater pumping. The decline of adults is not explained by juvenile abundance; it is clearly linked, via conditional smolting, to reduced juvenile growth rates in the lower river. Consequently, since 2005 most returning adult steelhead were captively-reared. Within-river translocations of juveniles from drying reaches succeeded in increasing juvenile abundance at the end of the dry season, but did not appear to translate to improved adult abundance. Our results show that the threshold effect of conditional smolting should be carefully considered when evaluating efforts to recover threatened steelhead populations.

ESA-listed Puget Sound rockfish: how did we get here and how do we assess progress?

Kelly S. Andrews, Krista Nichols, Jason M. Cope, Anna Elz, Nick Tolimieri, Chris Harvey, Robert Pacunski, Dayv Lowry, K. Lynne Yamanaka, Dan Tonnes*

In Puget Sound, Washington, rockfish abundance has significantly declined over the last 50 plus years because of commercial and recreational fishing, long-lived, late-maturing life-history characteristics and the isolated geography of Puget Sound. In 2010, this decline resulted in listing three species of rockfish under the Endangered Species Act: yelloweye rockfish *Sebastes ruberrimus*, canary rockfish *S. pinniger* and bocaccio *S. paucispinis*. During NOAA's Biological Review, there were limited data available to directly determine whether these three rockfish populations met the criteria of being "distinct and significant" from outer coast populations and whether the risk of extinction was high enough to be considered for listing. However, genetic data and life-history characteristics from other rockfish species suggested that rockfish populations in Puget Sound were genetically distinct from outer coast populations and species composition data suggested that these three species were declining at a rate greater than rockfish as a whole. Thus, each species was determined to have a distinct population segment (DPS) within the Puget Sound/Georgia Basin region and that yelloweye and canary rockfish were "threatened", while bocaccio were "endangered".

Since the listings, targeted research and recovery planning has begun to address major data gaps. First, we began a cooperative research program with the recreational fishing community and Washington State's Department of Fish and Wildlife to address questions related to the recovery of these species. One project was to non-lethally target these three species and collect tissue samples for genetic analysis. We collected tissue samples from 50 yelloweye rockfish, 51 canary rockfish and three bocaccio within the Puget Sound/Georgia Basin DPS and received tissue samples of each species from the outer coast of Washington and Oregon, as well as British Columbia, Canada. We used three primary approaches to determine population structure for each species: principal components analysis, a population genetics based model-clustering analysis (STRUCTURE), and calculation of population differentiation (F_{ST}) among geographic groups. These analyses revealed strong evidence that yelloweye rockfish collected from the Puget Sound/Georgia Basin DPS were distinct from individuals collected on the outer coast. Moreover, we found that yelloweye rockfish collected in Hood Canal, Washington appeared to be distinct from other Puget Sound/Georgia Basin individuals (Figure 13). In contrast to yelloweye rockfish, we found no evidence that canary rockfish collected within the DPS were genetically distinct from canary rockfish collected from the outer coast. This cooperative research effort among federal and state agencies and the recreational fishing community has led directly to the delisting of canary rockfish from the Endangered Species List as well as a boundary change of the DPS for yelloweye rockfish.

Assessing recovery of yelloweye rockfish and bocaccio within the DPS is dependent upon our ability to monitor and measure changes in the distribution and abundance of these species moving forward. To monitor these populations, a video-based remotely operated vehicle (ROV) survey conducted by Washington State was designed based on a habitat suitability model for yelloweye rockfish. The survey will focus on sites where the bathymetry and habitat suggest a high probability of encountering yelloweye rockfish. This survey will be performed every five years and provide count data and length estimates for all fish identified in the video. Once enough data are available from these surveys, we will assess each species with a length-based spawner potential ratio (LB-SPR), which has been developed for use in data-poor stock assessments. For this method, we need length composition estimates (from an ROV survey), a natural mortality to growth ratio (from the outer coast's stock assessment) and an estimate of maturity (from the outer coast's stock assessment). Recovery planning efforts have developed specific delisting criteria for both species based on the LB-SPR analysis. For example, yelloweye rockfish can be removed from the Endangered Species List when they reach an LB-SPR of 15% and sustain this value for a minimum of 20 years (approximately one-half of the period of one generation). In addition, there must be evidence that individuals are present across juvenile (~3-20 cm fork length), subadult (~20-35 cm) and adult (~35-90+ cm) size classes. New research activities, monitoring of the population, assessment methods and recovery planning are all critical components of assessing progress towards the delisting of these ESA-listed rockfish species in Puget Sound.

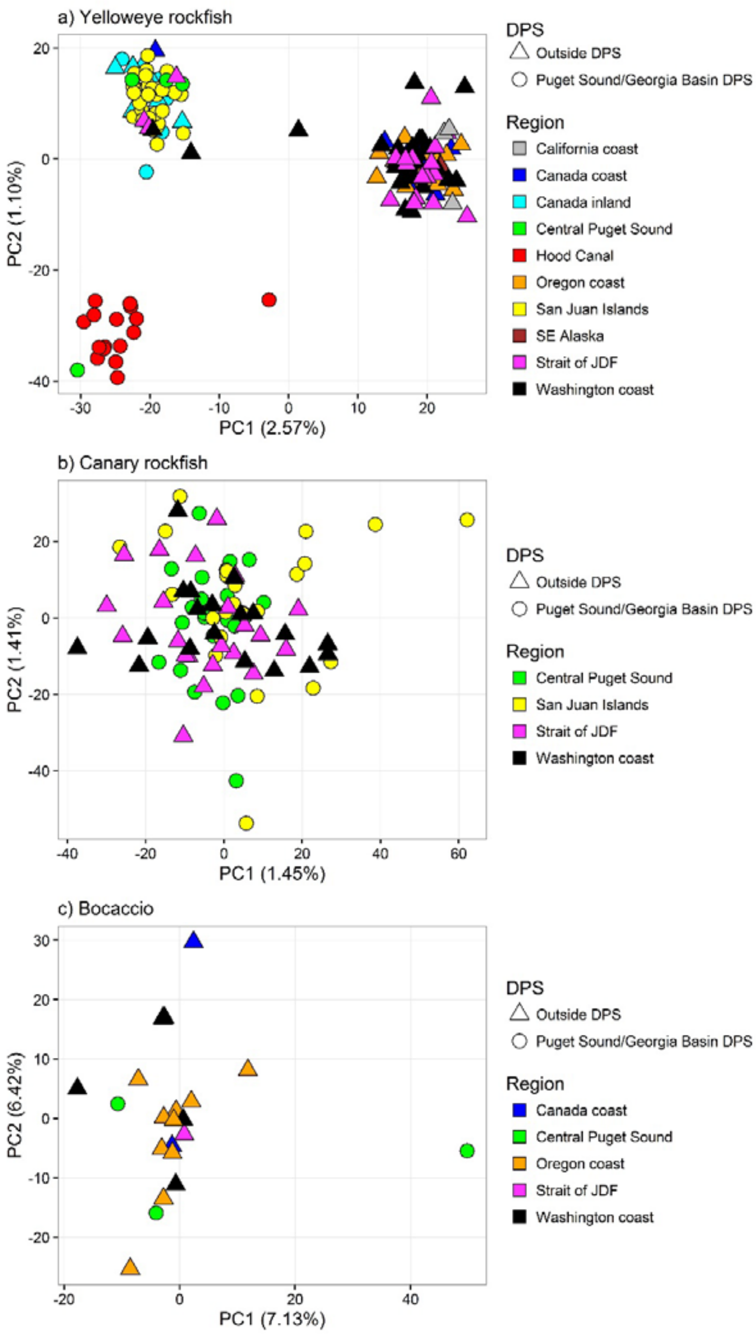

Figure 13. Principal components analysis reveals 1) three distinct populations in yelloweye rockfish (7405 RAD-seq loci), 2) no population structure in canary rockfish (7024 RAD-seq loci) and 3) insufficient data to determine the presence/absence of structure in bocaccio across sampled geographic regions (1135 RAD-seq loci). Each symbol represents an individual fish and the scores of its first two principal components as determined by the variation in genotypes at thousands of locations in the genome.

Dam impact analysis model: a tool for assessing protected Atlantic salmon and supporting management

Timothy F. Sheehan, Julie L. Nieland, Rory Saunders, Jeff Murphy, Dan Tierney*

Atlantic salmon populations in Maine are listed as endangered under the Endangered Species Act. Marine survival, dams, and the inadequacy of regulatory mechanisms for dams are considered primary impediments to recovery. Science Center researchers and Regional Office managers partnered to build a quantitative tool to assess the effects of marine survival and dams on species productivity and to support permitting requirements for Federal Energy Regulatory Commission (FERC) licensed dams. The Dam Impact Analysis model (DIA) is a multi-state population viability analysis that can be used to evaluate the future persistence and dynamics of an Atlantic salmon population under various modeling scenarios. Model inputs were generated via field data, literature, and expert opinion. Modeling was performed via Monte Carlo re-sampling, and performance metrics (e.g. abundance and distribution of wild- and hatchery-origin adult salmon) were summations of 10,000 iterations. DIA results have been instrumental in helping us understand the governing role of marine survival and dam impacts on Atlantic salmon population dynamics. They have helped to guide realistic expectations for a variety of ongoing restoration efforts. The DIA has also been an invaluable tool in supporting and informing jeopardy analyses required for FERC-relicensing efforts. Evaluating the impacts of marine survival and dams while quantitatively supporting jeopardy analyses with the DIA model can help frame expected outcomes of possible management options to facilitate recovery across the species' U.S. range.

Marine mammal and sea turtle climate vulnerability assessment

*Matt Lettrich**

Climate change is expected to influence the distribution and viability of many species in marine and coastal ecosystems. These changes have significant implications for conservation of protected species – those already at high risk due to a variety of stressors. NOAA's National Marine Fisheries Service (NMFS) is developing and testing a methodology for assessing the vulnerability of marine mammal and sea turtle species to provide decision-makers with information on what species may be most vulnerable and why, in order to help guide science and management actions. The methodology provides a rapid but generalized approach that uses empirical data and expert judgement to assess exposure, sensitivity, and capacity to adapt to climate change. The methodology combines exposure and sensitivity/adaptive capacity scores to produce relative vulnerability scores for each species, provides information on what attributes contribute most significantly to the species vulnerability, and identifies key information gaps. By jointly assessing current life history traits, current distributions, and projections of future climate, the methodology produces a forward-looking assessment of potential species response in abundance, distribution, and phenology. These coarse, qualitative projections of trends in abundance, distribution, and phenology can assist managers in preparing for future management activities. The assessment will be run for marine mammals and sea turtles separately. A pilot implementation of the assessment is underway for 15 marine mammal species in the Northeast United States and preliminary findings of that pilot will be presented.

Respiratory microbiome of southern resident killer whales as a health assessment tool

Linda D. Rhodes, M. Bradley Hanson, Candice K. Emmons*

Southern Resident Killer Whales (SRKW) are an endangered species ranging throughout Pacific Northwest coastal regions. Disease is considered a high impact factor on recovery, but knowledge of health status is low with few diagnostic samples from living animals. Non-invasive samples such as scat or exhaled breath can be used for certain health assessments. Because respiratory infections are a leading cause of mortality among marine mammals, assessment of the respiratory microbiome offers an opportunity to detect potential pathogens. A multi-year effort collecting exhaled breath moisture identified both benign and potentially pathogenic bacteria and fungi through culture-based methods. The microbial communities from breath were distinctly different from proximal sea surface microlayer, demonstrating that the pole-based sampling methods were not merely collecting seawater spray. Although breath-specific microbes were found, there was some overlap between breath and sea surface microlayer, suggesting that seawater is a potential source of respiratory microorganisms. Because culture-based assessments detect <10% of known bacteria, use of high throughput sequencing (HTS) can greatly extend the information gleaned from a sample. HTS of four breath samples from September 2015 demonstrated different bacterial community patterns among the four sources, with bacteria from the Methylobacteriaceae, Oxalobacteriaceae, and Sphingomonadaceae families representing between 19% and 46% of the identified bacteria. These results demonstrate that evaluation of respiratory microbiome for SRKW is possible, and can serve as a health assessment tool for this population.

Relevance: Application of microbiomic technologies to non-invasive breath samples as a health assessment tool is a novel method for this endangered population.

Acknowledgments: The following people were crucial for the sampling methods and culture-based results: J.P. Schroeder (Marine Mammal Research Associates); S.A. Raverty and E. Zabek (British Columbia Ministry of Agriculture); C.E. Cameron and A. Eshghi (University of Victoria, B.C.).

Relative reproductive success of Wenatchee River steelhead

Michael J. Ford, Andrew R. Murdoch, Michael Hughes, Todd R. Seamons, Eric LaHood*

Many protected salmon populations are supplemented with hatchery-produced spawners. These fish spawn in the wild with the intent of increasing the natural breeding population size, but they originate from captivity in the prior generation. Assessing the reproductive performance of such spawners is therefore important for an accurate evaluation of population trends and status in many salmon populations. In this study, we used genetic parentage analysis of 6200 potential parents and 5497 juvenile offspring to evaluate the relative reproductive success of hatchery and natural steelhead (*Onchorhynchus mykiss*) when spawning in the wild between 2008 and 2011 in the Wenatchee River, Washington. Hatchery fish originating from two prior generation hatchery parents had <20% of the reproductive success of natural origin spawners. In contrast, hatchery females originating from a cross between two natural origin parents from the prior generation had equivalent or better reproductive success than natural origin females. Males originating from such a cross had reproductive success of 26-93% that of natural males. The reproductive success of hatchery females and males from crosses consisting of one natural origin fish and one hatchery origin fish was 24-54% that of natural fish. Our results indicate that incorporating natural fish into hatchery broodstock is clearly beneficial for improving subsequent natural spawning success, even in a population that has a decades-long history of hatchery releases, as is the case in the Wenatchee River.

Seasonal occurrence of cetaceans along the Washington Coast from passive acoustic monitoring

Candice K. Emmons, Bradley M. Hanson, Marc O. Lammer*

Seasonal occurrence of cetaceans along the Washington coast has been difficult to characterize due to decreased daylight and inclement weather conditions resulting in a lack of survey effort throughout the year. Acoustic recorders were deployed at four sites spanning the Washington coast from April 2008 to August 2013 to record and detect sound-producing cetaceans. The most frequently detected cetaceans were gray whales (*Eschrictius robustus*), humpback whales (*Megaptera novaengliae*), sperm whales (*Physeter macrocephalus*), and killer whales (*Orcinus orca*). Unlike previous surveys, year-round acoustic monitoring indicates that migratory species such as gray, humpback and sperm whales use parts of the Washington coast throughout the year. This information is essential for estimating the potential for human interactions such as entanglement or ship strikes with these species. The seasonal occurrence of the four species monitored was variable between the four sites, even among those sites that were closest in proximity. These results indicate that caution must be used when extrapolating the results of site-specific monitoring to a larger scale. Utilizing a loose network of passive acoustic recorders, we were able to characterize the spatial and seasonal occurrence of cetaceans on the Washington coast during times of the year in which aerial and ship surveys are not feasible. Additionally, we provide a baseline for monitoring yearly shifts in occurrence due to changing population demographics, oceanographic conditions, or anthropogenic inputs.

The Effectiveness of Eulachon Smelt bycatch reduction devices in the U.S. West Coast pink shrimp fishery

Ryan Shama, Jason Jannot, Bo Whiteside, (Jon McVeigh[9])*

In 2015, the U.S. West Coast pink shrimp fishery landed a record 46,667 metric tons of shrimp generating $110+ million in revenue for Washington, Oregon, and California. However, this fishery also catches large amounts of eulachon smelt; a problem because the southern Distinct Population Segment is listed as threatened under the ESA. Experimental research has recently shown that LED lights secured along the main fishing line above the ground line can illuminate escape routes for eulachon and substantially reduce bycatch of eulachon and other fishes. This research prompted a large number of vessels in the pink shrimp fleet to use LED lights as a bycatch reduction device (BRD). In 2015, the West Coast Groundfish Observer Program (WCGOP) observed ~200 trips with this BRD in place. We used the WCGOP data on the pink

[9] Presenter was not a co-author, but is listed here in parentheses for presenting on behalf of the authors.

shrimp fleet to compare the 2014 eulachon bycatch, before the fleet adopted light BRDs, to 2015 bycatch, when a majority of the fleet used light BRDs. Understanding how light BRDs reduce bycatch in the fishery will provide managers with insight into how best to incorporate light BRDs into the regulations and will also act as an example for other programs in the U.S. and around the globe.

Green sturgeon - post release impacts in California halibut trawl fisheries

*Jason Vestre and Jon McVeigh**

The Goal: To understand green sturgeon post-release impacts, provide further insights on green sturgeon movements, and strengthen NMFS and CDFW research collaboration with fishermen. Project partners: California halibut fishermen, West Coast Groundfish Observer Program (WCGOP), California department of Fish and Wildlife, Researchers from the NMFS Northwest and Southwest Fisheries Science Centers.

Background: Green Sturgeon (*Acipenser medirostris*) are an anadromous fish found in coastal waters along the entire eastern Pacific Ocean. Green sturgeon spawn in at least three rivers along the West Coast: Klamath River, Sacramento River, and Rogue River. After they enter the ocean, they appear to make a northern migration and concentrate in coastal estuaries, particularly the Columbia River estuary and coastal Washington estuaries.

There are two Distinct Population Segments (DPSs) of green sturgeon along the West Coast, divided by whether their spawning site is north (northern DPS) or south (southern DPS) of the Eel River in Northern California. In 2006, the southern DPS (sDPS) of green sturgeon was listed as threatened under the Endangered Species Act (ESA).

The sDPS fish are encountered as bycatch in fisheries along the West Coast, including the California halibut bottom trawl fishery. California halibut trawlers are typically small vessels making day trips, serving live or fresh markets. The impact to the species is difficult to understand given the lack of information on the effects of catch and release on green sturgeon in these fisheries.

To address this question, this collaborative partnership has implemented a study on the post-release survival of green sturgeon incidentally caught in the California halibut fishery. Genetic analysis of tissue samples taken by observers when compared to observer data show that, of vessels covered by WCGOP, the highest concentration of southern DPS green sturgeon bycatch is on California Halibut trawl vessels landing near San Francisco Bay.

Methods: Observers put great effort into sampling green sturgeon. Aside from the challenges of working on small vessels with limited space and completing their regular catch sampling duties, observers must extensively sample each individual fish. This can be difficult and is time consuming in the race to return the fish to sea without further harm.

Because green sturgeon is an ESA-listed fish, observers give high priority to sampling them and immediately releasing them in good condition. Observers collect fork length, weight, presence/absence of scute markings, PIT tags, fish condition, and tissue samples from all sturgeon, as well as collecting sex and fin ray samples from dead fish. Additionally, all fish are photographed and PIT tagged if a tag is not already present.

Observers insert a PIT tag under a specific scute to all incidentally caught green sturgeon unless numbers are overwhelming. In that case they subsample.

Implementation of satellite tagging began in 2015 to determine post-release mortality and gain behavioral insights.

Incidentally caught green sturgeon are randomly selected and tagged by observers or, when no observer is present and tags are available, by fishermen. These satellite tags provide information on temperature, depth, acceleration and location (when at the surface). The tags are programmed to pop off the fish and resurface after a time period and transmit via satellite. Efforts are made to retrieve each tag to gain the most complete data.

Results and Discussion: Since 2014 WCGOP observers have PIT tagged more than 200 green sturgeon. Six fish have been recaptured to date, but this has been attributed to releasing them while the vessel had the net in the water and was fishing; they were recaptured on the very next haul after being tagged.

Observers have deployed at least 72 satellite tags since 2015.

Data is evaluated and then, using a statistical classification tree method along with the locations data, a story is developed for each tag and each fish is assigned survived or deceased.
Problems with retrieving data from the satellite tags, such as poor transmission of data, time gaps in data, no or bad locations data, or early release from the fish have made interpreting the data a challenge. Recovery of the physical tag helps to get a complete data set in a timely manner. Twenty-eight (28) tags have been recovered to date by the public. Recovered tags are re-charged and re-deployed.

Conclusion: Efforts to understand post-release impacts on green sturgeon are ongoing. WCGOP observers will continue to sample and deploy tags while collaborators work towards completing data analysis and updating fishermen.

Observer participation is critical in a project like this and shows just one of the many types of research in which observers are an invaluable resource.

An overview of protected species data collection in West Coast fisheries by observers

Vanessa Tuttle and Ryan Shama, (Jon McVeigh[10])*

The Fisheries Observation Science program (FOS) at the Northwest Fisheries Science Center (NWFSC) deploys observers in 15 fisheries along the West Coast. A wide variety of vessel and gear types are represented, including the bottom and pelagic trawl fisheries and fixed gear. The list of protected species encountered in these fisheries includes marine mammals, seabirds, sea turtles, salmonids, green sturgeon, and eulachon. Sampling of these protected species is a top priority for observers, and protocols have been developed, often in collaboration with partners both inside and outside of the NWFSC, to capture meaningful information on each encounter. This data is used for in-season and annual reporting, as well as to answer key questions about life history, distribution, injury or mortality, genotype, mitigation, etc. This presentation will provide an overview of the protected species sampling protocols employed by the FOS, as well as a summary of data collected over the past 15 years.

Preliminary findings of fishery interaction modeling of cetacean bycatch in the California drift gillnet fishery

Nicholas B. Sisson, Kylie Scales, Elliott Hazen, Dana Briscoe, Elizabeth Becker, Steven Bograd, Rebecca Lewison, Larry Crowder, Sara M. Maxwell*

Maintaining sustainable seafood harvest while minimizing bycatch is a continuing challenge for fishers and fisheries managers alike. The California drift gillnet (DGN) fishery is a limited entry fishery managed by the Pacific Fisheries Management Council (PFMC) that primarily targets swordfish (*Xiphias gladius*) in federal waters along the U.S. West Coast. Bycatch of non-target species is common in gillnet gear. However, many of the species are rare or difficult to observe using standard telemetry or survey methods. The incidental catch of endangered species has resulted in repeated legal action and widespread fishery closures in response to protection under the Endangered Species Act and Marine Mammal Protection Act. Currently the PFMC is considering whether the protected species mandates can be met with reduced closures because of the negative economic impact closures are having on fishers. Furthermore, the use of “hard caps” in fisheries has recently been implemented for high priority protected species (HPPS) that include bottlenose dolphins as well as sperm, fin, grey and short-finned pilot whales. When two catches (four for bottlenose dolphins and short-finned pilot whales) of high priority protected species occur over a two-year rolling period, the fishery will be shut down for the remainder of the year. Fisheries observers have recorded bycatch events for 310 short-beaked common dolphins, the largest number of bycatch events across cetacean species in the fishery, with observer coverage averaging 18% from 1990 to 2014. Using fishery-dependent data (observer data) and Regional Ocean Modeling System (ROMS) environmental parameters, a preliminary fishery interaction model was built using a Generalized Additive Mixed Model (GAMM). The model was constructed using short-beaked common dolphin occurrence as the response variable to describe the environmental features that may lead to higher interaction with fishing gear.

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[10] Presenter was not a co-author, but is listed here in parentheses for presenting on behalf of the authors.

Preliminary models suggested that short-beaked common dolphin bycatch was correlated with both standard deviation of sea surface temperature ($p = 0.0163$) and standard deviation of sea surface height ($p = 0.0321$). The model indicated that bycatch was higher with increased standard deviation of sea surface temperature (>0.6 °C) and decreased standard deviation of sea surface height variability (<0.01 cm). The standard deviation of sea surface temperature and standard deviation of sea surface height are both proxies for (sub) mesoscale frontal activity. However, this model is preliminary and further work will be conducted to examine these environmental relationships and validate model results. In addition, future work is aimed at developing similar models with density as the response variable as well as for species with fewer bycatch events, requiring the use of rare-event models. The goals of this research are to 1) design fisheries-based predictive models of bycatch events of cetacean species in relation to environmental parameters in the California Current Ecosystem, and 2) determine if hotspot areas of high diversity of bycatch species exist across environmental parameters and spatio-temporal scales. By determining not only where fishery interaction is likely to occur, but also where it is likely to occur in higher levels in relation to specific environmental variables, we can refine management actions to reduce bycatch while still allowing fishers to meet their quotas.

Appendix 1: PSAW Attendees (alphabetical by last name)

One hundred and sixty five people attended the inaugural PSAW. One hundred and seven people attended in person, while 58 attended via webinar. Below is a list of names and affiliations of attendees in alphabetical order by last name.

Last Name	First Name	Affiliation
Ahrens	Robert	University of Florida
Andrews	Kelly	NWFSC
Angliss	Robyn	AFSC
Avens	Larisa	SEFSC
Baker	Jason	NOAA
Ballance	Lisa	SWFSC
Barkley	Yvonne	PIFSC
Barlow	Jay	SWFSC
Barre	Lynne	NMFS West Coast Region
Becker	Elizabeth	SWFSC
Bengtson	John	NOAA
Berchok	Catherine	AFSC
Boughton	David	SWFSC
Boveng	Peter	AFSC
Boyd	Charlotte	SWFSC/AFSC
Bradford	Amanda	PIFSC
Brandon	John	SWFSC
Brost	Brian	NOAA
Brown	Steve	NMFS F/ST
Burkanav	Vladimir	NOAA
Cahalan	Jennifer	Pacific States Marine Fisheries Commission
Cameron	Michael	NMFS
Carlson	John	SEFSC
Carretta	James	SWFSC
Carter	Julie	NWFSC
Chavez	Sam	NEFSC
Chumbley	Kathryn	AFSC
Clapham	Phil	AFSC / NMML
Conn	Paul	NOAA
Crance	Jessica	AFSC
Curtis	K. Alexandra	SWFSC
Cyr	Ned	NMFS F/ST
Dahlheim	Marilyn	NOAA
Davis	Jeanette	NMFS F/ST
De Maio	Lauren	WCRO
Dean	Ron	NMFS OPR

del Rosario	Rosalie	WCRO
DeMaster	Doug	NOAA
Detlor	David	NMFS F/ST
Dietrich	Kim	NOAA subcontractor
Drake	Jon	NWFSC
Eich	Anne Marie	NMFS SF
Ellgen	Sarah	PIRO
Emmons	Candice K.	NWFSC
Everett	Meredith	NWFSC
Fahy	Tina	WCRO
Faig	Amanda	NOAA Affiliate (UW employee)
Ferguson	Laura	NMFS F/ST
Ferguson	Megan	AFSC
Fitzgerald	Shannon	AFSC
Ford	Michael	NOAA
Friday	Nancy	NOAA
Fritz	Lowell	AFSC
Garrison	Lance	SEFSC
Gasper	Jason	AKRO
Gelatt	Tom	AFSC
Gerke	Brandee	NMFS SF
Gray	Andrew	NOAA
Gustafson	Rick	NWFSC
Guyon	Jeff	NOAA
Haas	Heather	NEFSC
Hanson	Brad	NWFSC
Hard	Jeff	NWFSC
Hayes	Sean	NEFSC
Heinemann	Dennis	Marine Mammal Commission
Hobbs	Rod	AFSC
Holt	Marla	NOAA
Hou	Ben	AFSC
Ishizaki	Asuka	Western Pacific Regional Fishery Management Council
Jacobson	Eiren	Scripps Institution of Oceanography
Jannot	Jason	NWFSC
Jansen	John	AFSC
Johnson	Devin	NOAA
Johnson	Kelli Faye	University of Washington
Jones	T. Todd	PIFSC
Lee	Jennifer	NOAA SERO
Lee	Yong-Woo	NWFSC
Lettrich	Matt	NOAA

Link	Jason	NMFS
London	Josh	NOAA
Long	Kristy	NOAA
Lynch	Patrick	NMFS F/ST
MacLean	Steve	North Pacific Fishery Management Council
Martin	Summer	PIFSC
McCracken	Marti	PIFSC
McVeigh	Jon	NWFSC
Melvin	Ed	Washington Sea Grant, UW
Merrick	Richard	NMFS
Methot	Richard	NOAA
Miller	Maggie	OPR
Moore	Jeffrey	SWFSC
Moran	Paul	NMFS
Moreland	Erin	AFSC
Moreno	Paula	University of Southern Mississippi
Mullin	Keith	SEFSC
Muto	Marcia	NOAA
Myers	Jim	NOAA NMFS
Neely	Kathleen	NMFS
Noren	Dawn	NWFSC
O'Donnell	James	NWFSC
Oleson	Erin	PIFSC
Orphanides	Chris	NEFSC
Pace	Richard	SEFSC
Palka	Debbie	NEFSC
Park	Linda	NWFSC
Parsons	Kim	AFSC
Pascual	Monte	AFSC
Peschon	John	PIRO
Pine	Bill	University of Florida
Punt	Andre	University of Washington
Rhodes	Linda D.	NWFSC
Richards	Paul	SEFSC
Rowse	Mindy	NWFSC
Rule	Gary	WCRO
Ruvelas	Penny	NMFS West Coast Region
Sasso	Chris	SEFSC
Satterthwaite	Will	SWFSC
Scheuerell	Mark	NWFSC
See	Kevin	Quantitative Consultants, Inc
Sheehan	Timothy	NOAA
Shelden	Kim	AFSC

Shelton	Ole	NOAA
Sisson	Nick	Old Dominion University
Smith	Laurel	NOAA
Soldevilla	Melissa	SEFSC
Somers	Kayleigh	NOAA
Spromberg	Julann	NWFSC
Srinivasan	Mridula	NMFS
Sterling	Jeremy	AFSC
Stern	Jennifer	University of Washington
Stewart	Joshua	Scripps Institute of Oceanography
Stock	Brian	Scripps Institute of Oceanography
Sweeney	Kathryn	NOAA
Swimmer	Yonat	PIFSC
Teerlink	Suzie	NMFS Alaska Region
Testa	Ward	AFSC
Thorson	Jim	NOAA
Towell	Rod	AFSC
Trnka	Maureen	NMFS OPR
Turner Tomaszewicz	Cali	UCSD/SWFSC
Vardi	Tali	NOAA ST
Ver Hoef	Jay	AFSC
Wade	Paul	NOAA
Wainwright	Tom	NWFSC (retired)
Waldeck	Daniel	PFMC
Wallace	Farron	NMFS
Waples	Robin	NWFSC
Ward	Eric	NWFSC
Warlick	Amanda	NWFSC
White	Lisa	OPR
Williams	Mari	NWFSC
Winton	Megan	University of Massachusetts
Withrow	Dave	AFSC
Young	Nancy	OPR
Youngkin	Dale	OPR
Zabel	Rich	NMFS
Zador	Stephani	AFSC
Zerbini	Alexandre N.	AFSC

Appendix 2: PSAW Steering Committee Members

Sean Hayes, NEFSC
Erin Oleson, PIFSC
Robyn Angliss, AFSC
Jim Carretta, SWFSC
Eli Holmes, NWFSC
Eric Ward, NWFSC
John Kocik, NEFSC
Keith Mullin, SEFSC
Mridula Srinivasan, F/ST
Stephen K. Brown,F/ST
Ron Dean, OPR
Jeanette Davis, F/ST
Laura Ferguson, F/ST

Appendix 3: Protected Species Assessment Workshop Agenda

National Protected Species Assessment Workshop: Novel methods for abundance and trends assessment and data-poor bycatch estimation for protected species

AFSC Sand Point Facility, Seattle, WA
Building 4, Traynor Conference Room
January 17–19, 2017

Tuesday, January 17

8:00 Registration

INTRODUCTORY SESSION

8:30 Welcome and logistics **(Erin Oleson and Sean Hayes)**
8:40 Historical context of NOAA Fisheries first national protected species assessment workshop **(Ned Cyr and Steve Brown)**
8:50 Chief Scientist Perspective **(Richard Merrick)**
9:10 Keynote Speaker **(Doug DeMaster)**
9:55 Plenary Speaker **(Rick Methot)**

10:25 BREAK

NOVEL ANALYTICAL APPROACHES TO POPULATION VIABILITY AND RISK ASSESSMENT (PART 1)

10:40 Model-based approaches to support consistent extinction risk assessment for ESA status reviews **(Charlotte Boyd)**
10:55 Old model, new tricks: Eulachon recovery assessment via a reconditioned salmon model **(Tom Wainwright)**
11:10 Simulations to evaluate direct and indirect impacts of commercial fishing on marine mammal recovery **(Laurel Smith, presented by Jason Link)**
11:25 MARSS models for PVA **(Nick Tolimieri, presented by Elizabeth Holmes)**
11:40 Discussion

12:00 LUNCH

NOVEL DATA COMBINATIONS FOR TREND ESTIMATION

13:00	When every bit of information matters: Bayesian hierarchical models for combining data for protected species **(Jay M. Ver Hoef)**
13:15	Estimating cetacean abundance trends from survey time series: integrating multiple data sources within a Bayesian framework **(Jeffrey Moore)**
13:30	agTrend: an R package for regional trend estimation from site level survey data **(Devin S. Johnson)**
13:45	Bayesian capture-recapture and integrated population models for assessing population trends in threatened oceanic manta rays **(Joshua D. Stewart)**
14:00	Combining sparse, dissimilar data sources in a Bayesian hierarchical model for assessment of a small harbor seal population **(Peter Boveng)**
14:15	Assessing populations of salmon using life cycle models **(Rich Zabel)**
14:30	Discussion

14:45	BREAK

NOVEL ANALYTICAL APPROACHES TO POPULATION VIABILITY AND RISK ASSESSMENT (PART 2)

15:00	Integrating climate projections into a population model for the Hawaiian green turtle **(Summer Martin)**
15:15	How do IUCN proxies for generation length perform? **(Robin Waples)**
15:30	Informing recovery goals based on historical population size and extant habitat **(Bill Pine, presented by Bob Ahrens)**
15:45	Assessing population-level impacts of marine turtle bycatch in the Hawaii longline fishery **(T. Todd Jones)**
16:00	Discussion

SPECIAL SESSION ON eDNA

16:15	A novel approach for studying stock structure of enigmatic marine vertebrates using targeted eDNA sampling **(Kim Parsons)**
16:30	From population structure to eDNA: Next-generation sequencing technology opens a window into the biology of deep-sea corals **(Meredith Everett)**
16:45	Detection and quantification of Chinook salmon in Skagit Bay using environmental DNA **(James O’Donnell)**
17:00	Discussion

DAY 1 WRAP-UP

17:15	General Discussion of Day 1
17:30	Adjourn

Wednesday, January 18

8:30	Welcome and logistics
8:45	Plenary Speaker **(Jay Barlow)**

ADVANCED TECHNOLOGY APPLICATIONS

9:30	A simulation framework to investigate the statistical power of passive acoustic networks to detect trends in cetacean abundance **(Eiren Jacobson)**
9:45	The use of free-floating vertical hydrophone arrays to assess the abundance of beaked whales and sperm whales **(Jay Barlow)**
10:00	Automated electro-optical, infrared surveys for ice-associated seals and polar bears in the Chukchi Sea **(Erin Moreland)**
10:15	Discussion
10:30	BREAK

USING HABITAT RELATIONSHIPS TO ASSESS DENSITY AND ABUNDANCE (PART 1)

10:45	Moving towards dynamic ocean management: Using modeled ocean products to predict species abundance and distribution patterns **(Elizabeth A. Becker)**
11:00	Does incorporating spatio-temporal correlations among fishes and biogenic habitat improve estimates of abundance trends and distribution shifts? **(Jim Thorson)**
11:15	Spatiotemporal species distribution models for marine mammal population assessment: ice-associated seals in the Bering Sea **(Paul Conn)**
11:30	Estimation of abundance and trends for highly mobile species with dynamic spatial distributions **(Charlotte Boyd)**
11:45	Discussion
12:00	LUNCH

USING HABITAT RELATIONSHIPS TO ASSESS DENSITY AND ABUNDANCE (PART 2)

13:00	Development of the spatially explicit juvenile sea turtle density estimator: utility to management and validation methods **(Paul M. Richards)**
13:15	Using complementary techniques to estimate life history parameters for sea turtles: A case study on North Pacific loggerheads **(Cali Turner Tomaszewicz)**
13:30	Environmental correlates of marine growth in Oregon coast chum salmon **(Jeff Hard)**
13:45	Estimating loggerhead sea turtle densities from satellite telemetry data using geostatistical mixed models **(Megan Winton)**
14:00	Estimating changes in abundance, species interactions, and community stability in a kelp forest ecosystem following the reintroduction of sea otters **(Mark Scheuerell)**
14:15	Discussion

14:30 BREAK

ADVANCES IN MARK-RECAPTURE METHODS

14:45	Estimating sea lion abundance from rookery pup counts and mark and recapture data **(Devin S. Johnson)**
15:00	Estimating salmon escapement across the Snake River basin: a novel approach using PIT tags **(Kevin See)**
15:15	Beyond cohort reconstruction, understanding Chinook salmon abundance and oceanic distribution in a changing world **(Ole Shelton)**
15:30	Discussion

15:45 POSTER PITCH SESSION

DAY 2 WRAP-UP

16:30 General discussion of Theme 1- Days 1 and 2

17:00 Adjourn at Sand Point, travel to Silver Cloud Hotel

17:30-19:30 POSTER SESSION, Silver Cloud Hotel

Thursday, January 19

8:45 Welcome and logistics

9:00 What does poor data quality mean in the context of bycatch estimation in the U.S.? **(Alex Curtis)**

9:15 Discussion

NEW APPROACHES TO ROBUST ESTIMATION FOR RARE-EVENT BYCATCH

9:45 Informing rare-event bycatch estimation using prior knowledge **(Chris Orphanides)**

10:00 An R shiny tool for Bayesian bycatch estimation from a time series of fisheries observer data **(Jeffrey Moore)**

10:15 Estimating bycatch from rare-event data with machine learning **(James V. Carretta)**

10:30 BREAK

NEW APPROACHES TO ROBUST ESTIMATION FOR RARE-EVENT BYCATCH (cont.)

10:45 Estimating short-tailed albatross bycatch in U.S. West Coast groundfish fisheries **(Thomas Good, presented by Eric Ward)**

11:00 Albatross bycatch in Alaskan longline fisheries: modeling rates to inform trends **(Kim Dietrich)**

11:15 Was there an increase in leatherback sea turtle interactions in 2014? **(Marti McCracken)**

11:30 Discussion

12:00 LUNCH

INCORPORATING SPATIAL AND TEMPORAL FACTORS INTO BYCATCH ASSESSMENTS

13:00 The utility of spatial model-based estimators of bycatch: future or folly? **(Eric Ward)**

13:15 Genetic mixture analysis and Chinook salmon ESU bycatch impacts under a new management scenario for Pacific hake **(Paul Moran)**

13:30 Identifying bycatch hotspots in data limited scenarios: using Bayesian spatial models to estimate bycatch of green sturgeon in California halibut fishery **(Yong-Woo Lee)**

13:45 Predicting fisheries bycatch risk for dynamic spatial management: how do different spatial models compare? **(Brian Stock)**

14:00 Discussion

14:15 BREAK

CRYPTIC MORTALITY AND SERIOUS INJURY

14:30	Cryptic mortality bias correction for estimates of human-caused mortality and serious injury **(Dennis Heinemann)**
14:45	Latent right whale entanglement mortality **(Richard M. Pace, III)**
15:00	Unobserved seabird interactions with trawl cables on U.S. West Coast Pacific hake at-sea catcher processor vessels **(Jason Jannot)**
15:15	Discussion

ELECTRONIC MONITORING

15:30	Can electronic monitoring improve estimates of protected species bycatch? **(John Carlson)**
15:45	The era of machines that see **(Farron Wallace)**
16:00	Discussion

DAY 3 WRAP-UP AND WORKSHOP CONCLUSION

16:15	General discussion on Day 3 and Discussion of next PSAW topics
17:00	Adjourn

Poster Session

Wednesday, January 18, 2017
17:30-19:30
Silver Cloud Hotel

P1. Assessing the role of conditional smolting in abundance trends of Carmel River steelhead **(David Boughton)**

P2. ESA-listed Puget Sound rockfish: how did we get here and how do we assess progress towards recovery planning goals? **(Kelly Andrews)**

P3. Estimating the bycatch fisheries of common shark species on fishing gear at Kedonganan and Pengambengan Fishing Port, Bali Province **(Ranny Ramadhani)**

P5. Use of 20+ years of U.S. observer data from pelagic longlines to identify spatial and temporal trends of bycatch and capture risk for sea turtles **(Yonat Swimmer)**

P7. Dam impact analysis model **(Timothy Sheehan)**

P8. Marine mammal and sea turtle climate vulnerability assessment **(Matt Lettrich)**

P9. Respiratory microbiome of southern resident killer whales as a health assessment tool **(Linda D. Rhodes)**

P10. Using genetic data to assess reproductive success of hatchery and natural salmon **(Michael Ford)**

P11. Seasonal occurrence of cetaceans along the Washington Coast from passive acoustic monitoring **(Candice K. Emmons)**

P12. How catch shares and incentive programs are being utilized for bycatch reduction and how they impact abundance estimates **(Alan Haynie)**

P13. Using observer data to quantify the effectiveness of eulachon smelt bycatch reduction devices in the U.S. West Coast pink shrimp fishery **(Ryan Shama, presented by Jason Jannot)**

P14. Green sturgeon - post release impacts in California halibut trawl fisheries **(Jon McVeigh)**

P15. An overview of protected species data collection in West Coast fisheries by observers **(Vanessa Tuttle, presented by Jon McVeigh)**

P16. Comparing the performance of bycatch estimation methods under data-poor scenarios **(Alex Curtis)**

P17. Acoustic monitoring of the Hawaii longline fishery **(Ali Bayless)**

P18. Fishery interaction modeling of cetacean bycatch in the California drift gillnet fishery **(Nick Sisson)**