Effectively Addressing Ecosystem Understanding: Solutions to the Limitations of Current Fisheries and Oceans Policy

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Abstract - **There is increasing awareness of the need for "ecosystem-based" management, but insufficient recognition that the underlying limitations of current fisheries and ocean policy are centered on inadequate observational science. Fisheries management has relied on models based on fishery-dependent data and far too limited real-world verification. Oceanographic programs have been primarily bottom-up oriented. However, linkages between various trophic levels are simply too weak, and too much error is propagated through the ecosystem for this approach to be effective in understanding the status of upper trophic levels, including fishes, sea birds and marine mammals. We present an alternative approach to address the deficiencies of historic ocean and fisheries policy. The foundation of this approach is precision monitoring of the dominant biomasses of the ecosystem, based on high-speed, optimized sampling strategies and a new concept referred to as the "wasp waist" or middle-out forcing. This approach has been verified by research at the Prince William Sound Science Center (PWSSC) in Alaska. We have identified and focused on long-term assessment of the dominant biomasses, which include Pacific herring, walleye pollock and certain macrozooplankton. We were able to detect, separate and quantify the relative impacts of the 1989 Exxon Valdez Oil Spill and overfishing on the subsequent collapse of the PWS herring population. We have shown that the competition for dominance between Pacific herring and walleye pollock has major ramifications for the health of many seabirds and marine mammals, including the endangered Steller sea lion. We have shown that the Exxon Valdez Oil Spill indirectly harmed Steller sea lion and several seabird populations as a result of the subsequent collapse of the Pacific herring population. We have documented that pink salmon survival is strongly correlated with the abundance of dominant macrozooplankton. These successes have been achieved in a very limited program. Expanded application of these principles would overcome many of the current limitations of fisheries and ocean policy.**

I. INTRODUCTION

According to the recent report of the PEW Oceans Commission, there is consensus that "our oceans are in crisis and that reforms are essential" [1]. This conclusion is supported by the recent report of the U.S. Commission on Ocean Policy that calls for a "new governance framework, more investment in marine science and a new stewardship ethic by all Americans - all within the context of an ecosystem-based management approach - to halt the decline of this nation's oceans and coasts" [2].

Implicit in the consensus of crisis is the failure of existing research and management practices. The deficiencies of current fisheries management are widely recognized [3] [4] [5] [6] [7] [8] [9]. There are two fundamental problems. The mostly widely recognized is the focus on single-species management. Less recognized is the dependence on models rather than real-world observations. Fisheries management has been dominated by applied mathematicians who use fishery dependent data and numerical models to generate stock information. This approach is relatively inexpensive since it does not require funding for expensive observational programs. However, without observations to verify theoretical estimates and model predictions, there is no accountability other than when the fish stock suffers collapse. To many people, the solution to current fisheries problems is simply to go from single-species models to multi-species models. However, multi-species models alone do not address the larger problem of the lack of fishery-independent observational data, which results in lack of real-world validation [10].

The limitations of ocean research policy are less well recognized. Every major oceanographic program in the past four decades that has attempted to address ecosystem understanding has been bottom-up oriented. This is not surprising in a discipline dominated by physical oceanography. However, bottom-up approaches are seldom, if ever, successful in predicting upper trophic level responses with sufficient accuracy for management purposes. The linkages between various trophic levels are simply too weak, and too much error is propagated through the ecosystem for this approach to be effective.

While both the PEW Oceans and the US Commission on Ocean Policy reports recommend "ecosystem-based" approaches, neither provide specific insight into what might constitute such an approach. An alternative approach to effectively address the deficiencies of historic ocean and fisheries policy is presented in this paper. There are three elements to this approach: (1) a focus on dominant biomasses, (2) application of high speed observational tools, and (3) optimized sampling strategies.

II. FOCUS ON DOMINANT BIOMASSES

In most ecosystems, most of the carbon flow through the ecosystem from phytoplankton photosynthesis is captured and held by a relatively few species, an ecological concept referred to as the "wasp-waist" [11] [12]. These species include certain macrozooplankton, many forage fishes, and some commercial fishes. These dominant biomasses, which typically occupy the middle trophic levels, have been shown to have major impacts on the ecosystem.

Over the years, scientists have argued the relative importance of bottom-up versus top-down scientific approaches. Neither approach works to effectively understand ecosystem function because error propagates through the various levels of the ecosystem. No matter how precisely you can measure or predict certain physical processes, such as water circulation, that process is too weakly linked to upper trophic levels to be able to predict its impact on upper trophic levels with useable precision (Fig. 1). Conversely, no matter how precisely you can measure the abundance of an upper trophic level animal, such as Steller sea lions, you cannot predict what will happen to that animal population (or understand what has happened to it) without understanding what is happening to its forage base. However, as has been demonstrated by the PWSSC research, if you can precisely measure changes in the middle trophic levels, you can accurately predict the response. Further, you are much more likely to be able to understand and predict the impact of physical processes on the changes in dominant biomasses, which in turn leads to greater understanding of upper trophic level responses. In addition, and this is a critical point, because of the wasp-waist function, the number of species that need to be precisely measured is relatively small, so the measurement effort is economically feasible. However, it is not trivial, which is why high speed observational tools are needed.

III. APPLICATION OF HIGH SPEED OBSERVATIONAL TOOLS

The vast extent of the marine environment makes direct sampling very difficult. However, the scales are not insurmountable with the correct approach. This approach includes both application of high speed observational tools and optimized sampling strategies. The PWSSC research uses a combination of acoustic and optical techniques. It is well understood by the U.S. Navy and commercial fishermen that underwater acoustics is an extremely powerful tool for detecting and quantifying objects in the ocean, whether fish, submarines, or even zooplankton. However, fisheries managers, with rare exceptions, have not adequately used this powerful tool.

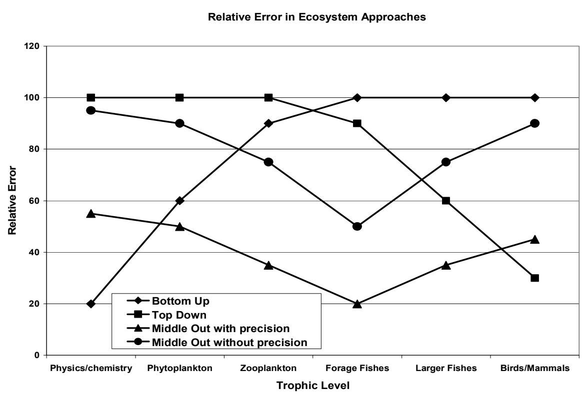

Figure 1. Error associated with various ecosystem approaches.

There are several reasons for this deficiency [13]. One is the historic stress by management on fishery catch data. Why make the effort to actually look at what is in the ocean, when fishermen will bring it back to you. This approach has clearly failed, as cited above. Other limitations to acoustics are its complexity, which intimidates many biologists [14]. However, methods and equipment have become very standardized over the past decade. The research at PWSSC shows that acoustic methods are very precise [15]. The precision (95%) of pollock population estimates in PWS is ±10%, that of herring ±20%.

One limitation of acoustic techniques is limited biological information including species and size/age structure. Direct sampling using nets is typically required to overcome this limitation, and such sampling is relatively expensive [16]. However, recent developments in underwater cameras have reduced the need for extensive direct sampling [17]. The need can also be reduced by optimized sampling strategies as discussed below. Another optical technique that has been incorporated into the PWSSC research is the infrared scanner. This system allows synoptic assessment of marine mammal and seabird foraging. The pioneering application of the infrared scanner in the detection of nighttime foraging by Steller sea lions, as described in a 2001 paper in the Journal Nature by PWSSC researchers [18], was a major breakthrough in understanding the importance of herring as winter-period forage for Steller sea lions.

IV. OPTIMIZED SAMPLING STRATEGIES

High speed sampling techniques alone are not the total solution for fish assessment. The spatial scales associated with the ocean environment are immense. The problem is discussed in detail in an article by PWSSC authors in the journal, Aquatic Living Resources [15]. A random survey to assess herring in Prince William Sound would require over 2 years of shiptime to achieve useable precision, an impractical level. Optimized sampling strategies were able to reduce the shiptime requirement to 10 days. Optimized survey strategies take advantage of distributional behaviors in order to design an effort that achieves the required precision with minimum effort. The optimal survey condition for an organism is a contracted, stable distribution. Two of the factors that usually impact distributions are seasonal changes and diel changes. For both herring and pollock, we take advantage of a highly contracted overwinter distribution. Optimized survey strategies require a learning process. You can not increase the effectiveness of a survey without knowledge of the distributional characteristics of the survey target. Most current applications of acoustics in fisheries management do not adequately apply optimal sampling strategies. As a result, the cost of the assessments is greater than necessary and the usefulness to fisheries management is reduced.

V. APPLICATIONS IN PRINCE WILLIAM SOUND

In Prince William Sound, three dominant biomasses have been identified: Pacific herring, walleye pollock, and the large-bodied copepods of the genus Neocalanus [19]. The PWSSC has monitored the abundance of herring in

Prince William Sound each year since 1993. Hindcasts, based on 10-years of acoustic observations, were able to document that the herring population crashed following the Exxon Valdez Oil Spill in 1989 [15]. The collapse of a wasp-waist species had major ramifications on the populations of seabirds [20] and several marine mammals, including the endangered Western stock of Steller sea lions. Our high speed observational tools were able to show that Steller sea lions focused on herring overwinter populations [15] [18]. Both herring and Steller sea lions declined between 80% and 90% in the eleven years following the oil spill (Fig. 2). Since PWS has no rookeries, the substantial decline of Steller sea lions can only be explained by changes in the immigration behavior from a much wider Steller sea lion distribution. A detailed examination of Steller sea lion declines in the entire Gulf of Alaska over the same time period showed that the magnitude of the decline was a function of proximity to PWS (Fig. 3). Previous research had not been able to detect the impact on Steller sea lions [21]. The impact was only detected through the accurate, long-term monitoring of the herring population.

PWSSC began to monitor macrozooplankton abundance in 2000. The goal was to determine the role of macrozooplankton, especially Neocalanus, in the survival of juvenile pink salmon. The program has completed five years of fieldwork, associated with four subsequent years of pink salmon returns. Pink salmon survival has been shown to be a function of the abundance of Neocalanus and euphausids during the nursery year. Over 98% of the variability in pink salmon survival could be explained from these two components (Fig. 4).

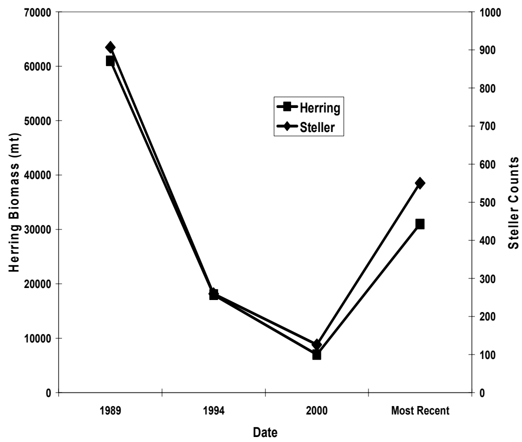

Figure 2. Changes in herring biomass and Steller sea lion (SSL) abundance in PWS from 1989 to present.

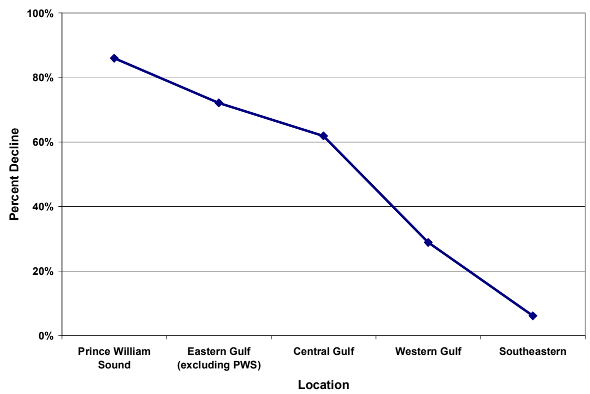

Figure 3. Declines in Steller sea lion abundance during the 1990s as a function of location

IV. CONCLUSIONS

The application of a wasp waist approach with precise monitoring is key to advancing our understanding of how coastal marine food webs function. Understanding the roles of dominant, wasp waist fishes can yield causal relationships between predators and prey that can explain long-term population change.

This approach has been verified by the research in Prince William Sound. We have identified and focused on long-term assessment of the dominant biomasses, which include Pacific herring, walleye pollock and certain macrozooplankton. We were able to detect, separate and quantify the relative impacts of the 1989 Exxon Valdez Oil Spill and overfishing on the subsequent collapse of the PWS herring population. We have shown that the competition for dominance between Pacific herring and walleye pollock has major ramifications for the health of many seabirds and marine mammals, including the endangered Steller sea lion. We have shown that the Exxon Valdez Oil Spill indirectly harmed Steller sea lion and several seabird populations as a result of the subsequent collapse of the Pacific herring population. We have documented that pink salmon survival is strongly correlated with the abundance of dominant macrozooplankton.

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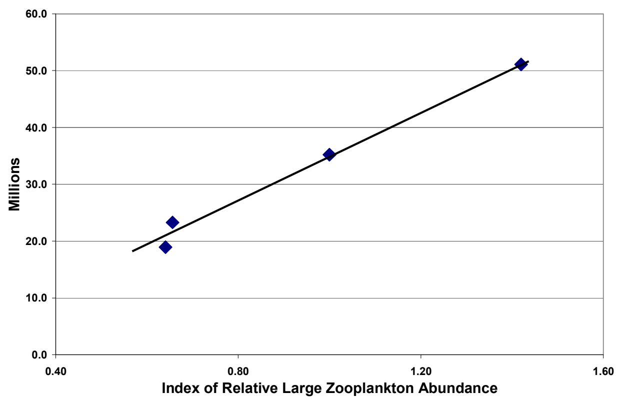

Figure 4. Relation between Pink Salmon returns to Prince William Sound and macrozooplankton abundance in nursery year.

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