Monitoring Pacific Herring Abundance with Combined Acoustic and Optical Technologies

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Abstract - **The Prince William Sound Science Center has monitored the abundance of Pacific herring in Prince William Sound, Alaska, since 1993. The effort has expanded in the past three years because of the critical role of herring as winter-period forage for the endangered Steller sea lions. The new effort includes more seasonal coverage in Prince William Sound and expansion to herring populations around Kodiak Island. While acoustic applications for Pacific herring are well developed, species information has required expensive direct capture techniques. In the past three years, underwater cameras have been used for species identification. This application has become very effective both for identification and information on school structure and behavior.**

I. INTRODUCTION

There is increasing recognition of the failure of single-species models, and the corresponding need to change to an "ecosystem-based fisheries management". This recognition has been embodied in the recent reports of the US Commission on Ocean Policy and the PEW Oceans Commission [1] [2]. However, it is also clear that even these commissions do not adequately understand what "ecosystem-based fisheries management" is, and too many people view this as simply a mandate to go from single-species models to multi-species models. That is not the answer. The fundamental weakness of current fisheries management is the lack of fishery-independent observational data [3].

The vast extent of the marine environment makes direct sampling, or direct observation, very difficult. That difficulty is one of the main reasons why fisheries managers have neglected this approach in favor of fishery-dependent information such as catch data. However, the scales are not insurmountable with the correct approach [4]. That approach includes both application of high speed observational tools and optimized sampling strategies. In this paper, I use the acoustic monitoring program for Pacific herring in Prince William Sound (PWS), Alaska, to demonstrate how an ecosystem-focused observational program can address the deficiencies of historic fisheries management.

II. METHODS

It is well understood by experts in undersea warfare and by most 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. There are several reasons for this deficiency. 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 them back to you. However, history is making it increasingly clear that this approach has failed. Another limitation to acoustics is its complexity, which intimidates many biologists [5]. However, methods and equipment have become very standardized over the past decade. We use BioSonics digital echosounders at PWSSC, a legacy of my several years working for that company. We deploy the transducers on towing vehicles for flexibility, and typically use chartered commercial fishing vessels for our surveys. Our experience shows that acoustic methods are very precise. The precision (95%) of pollock population estimates in PWS is ±10%, that of herring ±20%.

One disadvantage of acoustic techniques is limited biological information including species and size/age structure [6]. Direct sampling using nets is typically required to overcome this limitation. We use both purse seines and midwater trawls. Direct capture is relatively expensive. When the herring survey effort was expanded to the Kodiak Archipelago in 2001, we developed underwater video cameras for species identification [7]. These proved to be very effective and have been expanded to all our acoustic surveys. More recently we have began to explore the use of cameras and lasers to obtain size information. We also added infrared scanning technology to our night-time surveys to collect additional biological data on associated marine mammal and bird abundance along our acoustic transects [8].

High speed sampling techniques alone are not the total solution for fish assessment. The vast extent of the marine environment mandates the application of efficient survey designs. The optimal survey condition for an organism is a contracted, stable distribution [4]. For herring, we take advantage of a highly contacted overwinter distribution. As a result, instead of needing to address all of PWS, a sampling area of 10,000 sq. km, we can normally focus on 1% of that. In addition, while scientific acoustics provides a relatively high speed sampler, but we improve that efficiency with aerial and sonar surveys and we also incorporate community observations from fishermen and hunters transiting PWS and community observations of spawn. Finally, we verify and update our procedures each year to make sure nothing has changed or been missed.

Acoustic surveys of herring in PWS were initiated 1993 after a collapse of the herring stock became apparent.

Previously, the stock had been managed using an age-structured model [9]. Acoustic surveys have been conducted annually since 1993.

III. RESULTS

The PWS herring population in 1988 was estimated by the age-structured model to be above 100,000 mt [9]. The initial acoustic survey in 1993 resulted in an estimate of only 17,000 mt, thus verifying that a collapse had occurred. The population has remained far below the levels that occurred prior to the EXXON VALDEZ Oil Spill (EVOS) in 1989 (Fig. 1). Although all the acoustic surveys have been conducted after the population crash, we were able to compare the acoustic survey estimates from 1993 to 2002 with other measures of abundance [4]. We found a good correlation (r = 0.78) with the annual observations of mile-days of spawn from aerial surveys (Fig. 2). We used the correlation to hind-cast the herring abundance to 1973. The hind-cast suggests that the herring population gradually increased to a peak in 1988. During this period, the acoustic-based hind-cast and age-structure model estimates were virtually identical (Fig. 3). However, the hind-cast indicates that a precipitous decline began in 1989, the year of the spill. In contrast, the age-structured model estimates indicated continuing high population levels through 1992, followed by a catastrophic collapse.

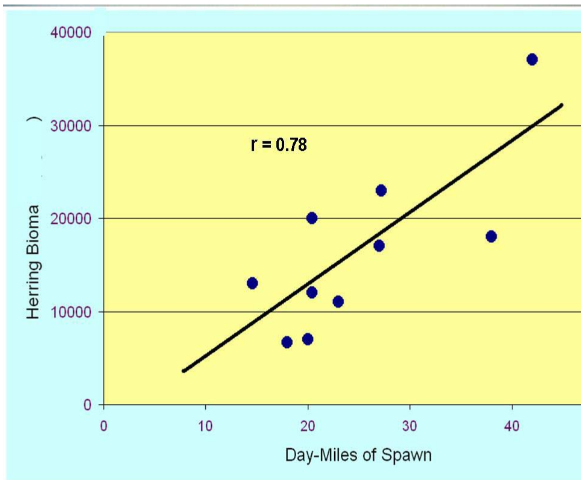

Fig. 2. Relation between acoustic estimates of herring biomass (mt) and aerial surveys of herring spawn (milt), 1993-2002

Research by Thorne and Thomas has documented that herring come to the surface to gulp air on a nightly basis [10]. This behavior provides a direct mechanism for contamination by a surface oil spill. Outbreaks of viral hemorrhagic septicemia, icthyofanus, and other disease factors were observed in herring after EVOS [11] [12] [13]. It is very likely that predator-induced natural mortality on herring increased subsequent to the oil spill as a result of their impaired condition.

IV. DISCUSSION

Age-structured models like the one used for PWS herring typically assume a constant natural mortality [9]. If natural mortality increases for some reason, the model will overestimate abundance. The deviation of the age-structured model estimates from that of the acoustic-based hindcast after 1988 suggests a substantial change in natural mortality synoptic with EVOS.

Additional evidence that the herring population decline began immediately after EVOS is provided by parallel collapses of marine birds and mammals that depend on herring for critical overwinter forage. The Steller sea lion trends provide the best evidence for two reasons. First, previous studies concluded that they were not directly impacted by the oil spill itself, unlike many seabird populations [14]. Second, Steller sea lions have been shown to migrate into PWS during winter in proportion to the abundance of herring [4] [7]. Comparison of SSL counts in PWS with herring abundance shows high correlation with the estimates from the acoustic-based hindcast, but poor correlation with the estimates from the age-structured model (Fig. 4).

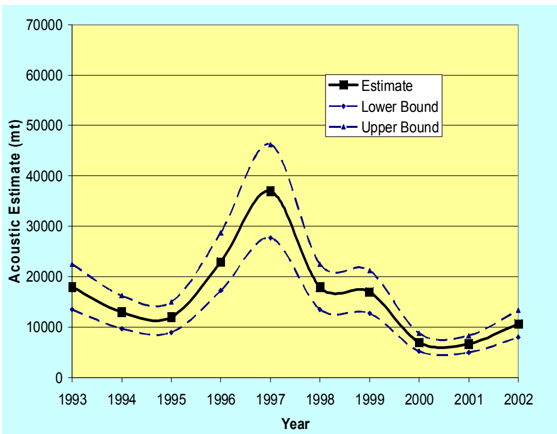

Fig. 1. Estimates of herring biomass from acoustic surveys from 1993 to 2002.

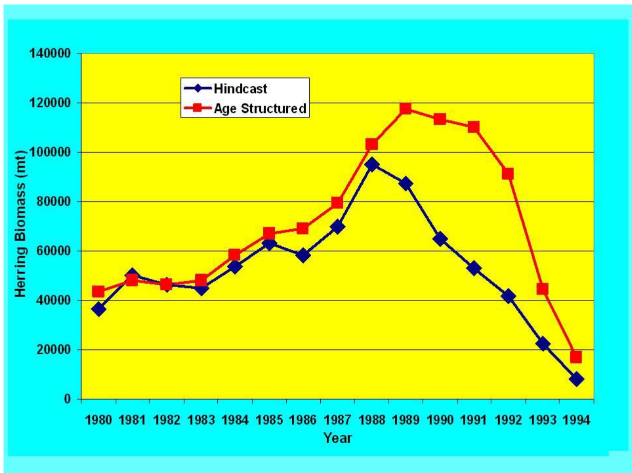

Fig. 3. Comparison of estimates from age-structured model and acoustic-based hindcast, 1980-1994.

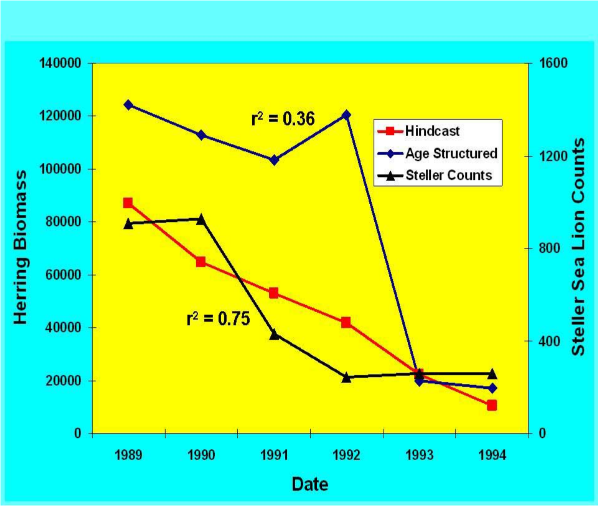

Fig. 4. Comparison of herring biomass estimates in PWS from age-structured model and hindcast with counts of Steller sea lions, 1989-1994

An examination of the geographic distribution of Steller sea lion declines throughout the Gulf of Alaska in the decade following EVOS shows that the focal point of the decline was PWS. It is apparent that the catastrophic loss of critical over-winter forage associated with the herring population crash caused impacts well beyond the geographic boundaries of PWS itself.

V. CONCLUSIONS

Past fisheries management practices have generally failed because of the reliance on fishery-dependent data, single-species focus and lack of independent observational data. It is clear from the recent report of the U.S. Commission on Ocean Policy, that the need for "ecosystem-based fisheries management" is recognized. However, without corresponding recognition of the need for effective long-term fishery-independent observational data, we will continue to mismanage commercial fisheries and be unable to understand ecosystem changes and their consequences.

Acoustic techniques are the well suited for aquatic applications because of their high sampling power. However, the techniques need to be used in combination with efficient survey designs that take full advantage of the distributional characteristics of the target organisms. Optical and capture techniques have limited sampling power, but can add to observational capability when used in conjunction with acoustics.

Use of this approach has allowed us to document both immediate and long-term damage to the herring population in PWS from EVOS, as well as indirect impacts of EVOS that resulted from the subsequent herring population crash, including previously undetected damage to the endangered Steller sea lion population.

Acknowledgments

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