CIE Review of the Gulf of Alaska Walleye Pollock

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Executive Summary

The Gulf of Alaska (GOA) pollock has been surveyed before a substantial fishery was developed. Several time series of fisheries-independent data have gone into the evaluation of the stock, which is important for a reliable assessment (Anon 1998). The stock is harvested with a relatively low fishing mortality (F~0.2), leaving other predators and environmental factors as the dominant influence on the stock's development. The collection of data and the assessment methodology are sound and thorough, and meet international standards. Substantial uncertainties are associated with basic assumptions, and survey methodologies and data collection procedures can be improved.

This review is based on background printed material and a series of talks and presentations between August 4 and 8, 2003 at the Alaska Fisheries Science Center. Aspects of the biology, stock structure, sampling of commercial and survey catches, survey methodology, and ageing were covered, although this review focuses primarily on matters related to survey methodologies.

Information on the dynamics of distribution and migration is very limited and our knowledge of the stock structure is inconclusive. Major issues of importance to stock assessment, involving the assumptions associated with applied methodologies, are related to intermingling with the Bering Sea pollock, the degree of coverage of the stock by the surveys, the availability of the total distribution of fish to the survey gear used (acoustic and bottom trawl), etc.

Surveys are carried out systematically and thoroughly, although there are details of the technology, equipment and procedures that could be improved. All surveys suffer from the lack of total vertical and horizontal coverage of the stock, which means that there is a high probability that different portions of the stock are covered in different years, particularly in situations of abrupt change, e.g. as caused by regime shifts or overexploitation.

The NMFS bottom trawl survey should consider the mesh selection of the trawl and ways of reducing it. The applied doors are very light (1,250 lbs), which may result in unstable bottom contact and may be responsible for variable efficiency in the herding zone and the trawl mouth. The use of survey outcome as absolute abundance estimates is questionable. This survey needs to be expanded with a simultaneous acoustic survey to encompass the total biomass of pollock, or at least to assess the availability of pollock to the trawl gear.

The echo integration trawl (EIT) survey has estimated the biomass of the stock in the major spawning area annually since 1981 and is a major element in the annual evaluation of the

stock. Vertical profiles of the stock distribution should be presented in order to evaluate annual variation and potential effects on survey results. These profiles should also be used to assess and compensate for the dead zone problem. Behavioural effects on survey results are being studied and need more detailed attention, in particular observations of escape effects during trawling, which is of importance for the reliability of both the bottom trawl and EIT surveys. The acoustic target strength (TS) used for pollock is based on studies of individuals during summer and is probably not representative of the TS during the spawning season.

The number of otholiths sampled seems to be low for both surveys and the commercial fishery. The problem of whether small sample sizes represent large catches needs further attention. Some confusion exists regarding stages of maturity and their current classification into mature or immature individuals. Much histological material exists that could resolve the issue and provide information about the number of first-time and multiple spawners.

Fish "leakage" to or influx from the Bering Sea probably occurs. This might be a periodic problem of unknown dimension. Tagging, although it has not been very successful so far, seems to be the only viable way of investigating this problem. Small, passive integrated transponder tags that can be automatically recognized on board factory trawlers could be worth trying.

Background

In the Gulf of Alaska, pollock (*Theragra chalcogramma*) have declined in abundance, and in 2002 their numbers fell to a 30-year low, despite being managed conservatively under North Pacific Fishery Management Council harvest policies. Both acoustic and trawl surveys are used to assess pollock abundance, but the interpretation of recent survey results has been problematic due to contradictory trends and potential changes in stock distribution. A reliable assessment of Gulf of Alaska (GOA) pollock stock status is important both for the Council's management of the fishery and for evaluating fishery impacts on the endangered Steller Sea Lion, for which pollock are important prey.

Compared to many other commercially exploited fish stocks, Alaska pollock is very conservatively exploited. With a fishing mortality F~0.2 compared to Fs in the order of 0.4-1.0 for many other gadoid stocks a serious decline caused by fishing is unexpected. The fact that fish stocks undergo long-term variations or shifts independent of exploitation - as seen for example in north-east Arctic cod (see e.g. Øiestad 1994, Godø 2003) and described as regime shifts in the GOA and in the Bering Sea - challenge modern stock assessments that do not normally take such events into account simply because they are easily described for past events but difficult to predict.

The GOA pollock data are in a unique position, in that scientific information exists from before and during the full development of a commercial fishery. Data were collected both from the fisheries and from surveys and have improved in quality and quantity in recent decades. There should thus be a reasonably strong basis for evaluating the likely causes of the current difficulties in evaluating the stock.

Review activities

This review was divided into three tasks. The preparatory phase consisted of reading the documentation supplied before the scheduled review meeting. The meeting itself, which made up the second task, took place at the Alaska Fisheries Science Center (AFSC) on August 4-8 and included presentations and talks according to the following programme:

Monday
Overview – Dr. Martin Dorn
Reproductive biology – Dr. Bern Megrey
Echo integration trawl surveys – Dr. Chris Wilson

Tuesday
NMFS bottom trawl surveys – Mark Wilkins
Alaska Department of Fish and Game trawl surveys – Paul von Szalay

Wednesday
Stock structure – Dr. Kevin Bailey
Ageing – Dr. Dan Kimura
Ecological interactions – Pat Livingston, Sarah Gaichas
Harvest policy/management – Dr. Anne Hollowed, Dr. Jim Ianelli

Thursday
Fishery monitoring and sampling – Dr. Bill Karp, Martin Loefflad
Assessment model – Dr. Martin Dorn

Finally, completion of the report through reading of new documents and associated literature studies took place after the meeting and up to August 22.

Summary of findings

Evaluation of the state of fish stocks includes a synthesis of routinely collected data in accordance with framework/model that encompasses the general knowledge of the stock biology and dynamics. The quality of such evaluations depends not only on the quality of the data collected, but also on how well the applied model(s) are able to reflect the true stock dynamics, in both the short and the long term (regime shifts). In this review I offer some thoughts about the fundamental basics and associated assumptions of the GOA pollock and the routinely collected data, with the strongest emphasis on survey data. All evaluation is based on printed information supplied before or during the meeting (see references) as well as oral information obtained during the talks, and thus relies on the accuracy of that information. Additional information used to highlight specific points is also given in the References section.

General biology and stock dynamics

The core area of GOA pollock is the region between longitude 130 W and 170 W within the shelf and slope of the Gulf of Alaska (Barbeaux *et al.* 2002). Several spawning areas are known within the area but their long-term importance for total recruitment is still uncertain. The Shelikof Strait spawning has been believed to be dominant but changes in distribution and abundance in recent years have cast uncertainty on its temporal stability. The fish spread out over the feeding area after a well-defined spawning period, which seems to vary significantly in time from one spawning area to another. A major uncertainty is related to the potential leakage or influx of biomass from the Bering Sea stock of pollock. An animation of catches over time shown by Jim Ianelli indicated dependences in the geographic distributions in the GOA and the Bering Sea. A leakage would barely be recognised in the much bigger stock of the Bering Sea, and would appear in the form of an unexpectedly high fishing mortality, similar to what has been experienced in recent years (Dorn *et al.* 2002). Further, the stock is regarded as being confined to the shelf and slope area although gadoids are known to spread out to pelagic areas, like pollock off the shelf break in the Bering Sea and blue whiting in the northeastern Atlantic (Heino *et al.* 2003). The stock unit issue seems to be unresolved on the basis of the available genetic studies (Bailey *et al.* 1999) and as stated by Kevin Bailey during talks, if a mass tagging method for pollock could be developed, this would probably be the best means of resolving the management unit problem. Tagging, although not very successful, needs more attention. Small passive integrated transponder (PIT) tags that can be automatically recognized on board factory trawlers or by the shore based industry could be worth trying. Mortality during tagging seems to be the major limiting factor. Modern automatic tagging methods should be paid attention in order to see whether they can be modified for tagging pollock.

The conflicting annual signals given by the surveys might also be due to unknown variability in the three-dimensional distributional dynamics of the stock. Habitat preferences (pelagic/demersal) for year-classes of different strengths could cause a substantial problem (see Godø and Ona 1999). This problem will be further discussed under the survey sections.

Maturity at age information also causes problems for the assessment. The main source of information, the EIT survey, shows extremely variable maturity data from one year to the next (Dorn *et al.* 2002). Furthermore, a decline in abundance such as was observed during the late 1980s and 1990s would be expected to result in an earlier age at maturity while the opposite was actually observed (Dorn *et al.* 2002). No detailed studies of the causes of this problem seem to be available. As year class strengths vary greatly, the proportion of mature and immature fish may change as a strong year-class cascades through the stock. This phenomenon could alternatively be an artefact caused by unequal survey coverage of mature and immature fish over time. The data are based on a very detailed table for allocation to maturity stage after visual inspection. Bernard Megrey told the meeting about a large amount of gonads that have been sampled over a long period of time. Comparing the results of detailed histological studies of the gonads with the maturity stages employed could be very useful in validating the current protocol. Furthermore, such studies might well provide more information about the relationship between spawners and immature fish, and possibly between first-time and multiple spawners (see Saborido-Rey and Junquera 1998, West 2000 for more information). A European Union project is currently under way (Reproduction And Stock Evaluation for Recovery) and substantial new information from laboratory experiments and studies of fisheries data is expected. The web address http://raser.imr.no/projectstructure.php provides an overview of the project and lists active scientists for contact.

The temporal dynamics of the GOA ecosystem are spectacular, with the dramatic increase in pollock during the late 1970s and early 1980s, the outburst of arrowtooth flounder, and the decline in Steller Sea Lion as the most prominent features. The recent difficulties in GOA pollock assessment need attention from an ecosystem perspective. The data presented open up the possibility that the unexploited stocks of Steller Sea Lion and arrowtooth flounder are competing for pollock alongside the commercial fisheries. The available information from surveys and fisheries is not designed, and hence is not adequate (see below) for carrying out reliable quantitative ecosystem studies.

Recommendations/Proposed research:

- Utilise available gonad samples for histological studies in order to validate maturity stages and determine whether the data can be used to study age at maturation
- Develop methodology for tagging
- Reanalyse available maturity at age data for potential year class effects

Catch data

Catch information and sampling from catches are being facilitated through the *Observer program* (Ito 2003). This is probably the best monitoring program for catches and the composition of catches in the world. Although there is still room for improvement, no obvious reason was identified that could substantially bias the catch statistics, discards or biological sampling. The lack of coverage in the small fleet of vessels in the GOA may need some attention. In particular, the behaviour of vessels with and without observers may represent a bias, although this is not believed to be a serious problem.

To establish the present stock situation and predict future development assessment methods we need quality data from scientific surveys (Anon 1998). As will be discussed later, there are several uncertainties related to the survey results, and catch and effort data from the observer programme could possibly be used to support survey data. First, spatial catch and effort data from pollock could be used to understand historic variations in distribution patterns and the potential effects of such variation on survey results. Furthermore, the most recent information on distribution might help the design of a more efficient distribution of survey efforts (although this has already been done to some extent).

Recommendations:

- Develop techniques for quantitative description of the geographic distribution of catches and use the information to evaluate the efficiency of surveys in the past and for the planning of surveys in the future.

Age data

Aging data are crucial for the understanding of stock dynamics, including annual variation in recruitment, growth, maturation, etc. Regular aging of pollock from otoliths started in 1981, and an improvement of the methodology was introduced in 1991 through the break and burn technique. The methodology and quality seem to be well established and well documented, both with respect to internal quality control and international agreement (Kimura and Lyons 1991, Kimura *et al*. 1992). Some key issues that were discussed include:

1. Is the number of otoliths for age determination large enough to ensure correct year class representation mean size by age?
   The response to this question was that all statistical analyses carried out so far have shown that the samples requested are adequate. Some problems might occur in the commercial fisheries to cover all gears, areas and time-slots in the sampling scheme. There is no evidence that this represents a significant problem in the assessment. Due to the low numbers aged, I still think this issue needs further consideration.

2. Can more information be extracted from the otolith readings, e.g. age at first spawning?
   Otoliths and fish scales resemble a time-environment recorder for fish. All important events in the life cycle are logged, but they are not always easy for the reader to detect. For several gadoid and clupeid stocks in the northeast Atlantic, the age at first spawning

and shift in geographic location over time can be determined on the basis of changes in the zone structure of the otoliths or scales (Rollefsen 1931, 1933, Runnstrøm 1936, Engelhard et al. 2003). Similar features might also possibly be found in pollock otoliths after the introduction of the break and burn technique. If age at first spawning could be determined it would help to resolve the problem of variability in maturity at age. A change in habitat from the Bering Sea to GOA might also be detectable as a change in the zone pattern due to the area difference in temperature. Histological studies of the sampled gonads have shown that studies of ovulatory follicles and gonad wall thickness may provide additional information on maturation dynamics (see also section above).

3. Can the effect of unreliable readings and discard of unreadable otoliths be reduced? The complexity and uncertainty of otolith readings increase with age with the result that in some cases, otoliths have to be discarded as unreadable. In most cases, this eliminates information about larger and older fish and thus biases small samples. To minimise the effect of this problem in assessment, a new routine has been introduced for Norwegian spring spawning herring. Instead of discarding the difficult age samples, the readers are asked to determine the minimum age of the fish leaving the assessment, with the possibility of doing the assessment with the group, which often takes place anyway (Ingolf Røttingen, Institute of Marine Research, personal communication)

Recommendations

- Combine information from histological studies of gonads with otolith structures in order to find out whether otoliths can be used to determine age at first spawning and possible immigration and emigration.
- Reduce discard of otoliths through introduction of reading minimum age

NMFS bottom trawl survey

The NMFS survey is a standard stratified random trawl survey that has been run regularly since 1984, originally as a tri-annual survey and since 1999 as a bi-annual survey. The trawl has been more or less unchanged, but the tow duration was reduced from 30 minutes to 15 minutes in the 1990s. Like many other bottom-trawl surveys the gear utilised is a modified commercial fish trawl fitted with a small-meshed liner in the codend. Routines and procedures have to some extent been changed pragmatically as knowledge and technologies have evolved. The survey is important in the assessment of Alaska pollock, although there are several uncertainties related to its ability to reflect true stock development. The major assumptions as expressed by the responsible scientist are listed in Box I. In the 2003 survey, acoustic data were collected during the complete survey for the first time. The data have not yet been made available for analysis and cannot be discussed here.

During the presentation and the following discussions some major issues related to the quality of the survey results were covered:

- Pollock biology and survey efficiency
- Gear efficiency and selectivity
- Survey design

Pollock biology and survey efficiency

The pollock is a semipelagic fish with a vertical distribution that varies in time and space and according to its age. A bottom trawl with limited vertical opening will thus have serious limitations with respect to complete coverage of all sizes. This is also shown by the selectivity curve of the survey as used in the assessment (Dorn et al.2003). The recruiting age groups are more pelagic than the adults, and fish are assumed to become gradually more available with age/size. For a reliable assessment it is thus essential that the availability profile over time should be more or less constant. There is currently no information available to validate this, although this summer survey, which also collected acoustic data, will cast light on the problem. Information on gadoids from other areas indicates that vertical distribution is a dynamic feature that may be depth and density dependent and affected by year class strength, etc. (see e.g. Godø and Wespestad 1993; Aglen 1996, Aglen et al. 1999, Lawson and Rose 1999). Substantial information about the vertical distribution of semipelagic species and its effect on assessment exists, but no general methodology for quantifying its effects on assessment is yet available. The fact that most catches of pollock are taken by pelagic trawl underlines the potential difficulties in using bottom trawls for quantitative assessment purposes. There is thus a strong need for not only studying the vertical distribution in a given year but also to monitor its temporal dynamics over years to facilitate enough information to take it into account in the assessment process. Logging acoustic data from the vessels running the bottom trawl survey (as done in 2003) can easily be used to accumulate the information.

Box I. (Information supplied during meeting)

GOA bottom trawl survey's most troubling assumptions:

Assuming that we consider the estimates to be relative abundance estimates, there are two broad areas of assumptions. The first assumptions relate to the availability of fish to survey effort. These include:

1. Availability of fish (both overall and size/age classes) to survey effort does not change over time (e.g. no changes in depth distribution).
2. The use of different vessels and captains over time does not bias cpue observations.
3. The abundance and distribution of the surveyed species is similar in trawlable and untrawlable areas.
4. Movement patterns of fish during survey period do not change interannually.

The second group of assumptions relate to the ability of the gear to capture the available fish and these include:

1. Gear efficiency does not change due to interaction with physical variables such as depth/scope, substrate, or temperature.
2. Gear additions/modifications over time have had no effect on cpue observations.

If we were to assume that estimates were absolute abundance estimates (which we shouldn't), then a number of assumptions must be made, many of which we know not to be true, including:

1. No herding.
2. No escapement.
3. No fish in water column unavailable to gear.
4. Etc.

Gear efficiency and selectivity

The next issue relates to the ability of the sampling trawl to reliably reflect the biomass available to the trawl. Catching efficiency of trawl is a complex process, and I will raise some issues of particular concern for GOA trawl survey.

<u>The fishing gear:</u> The used trawl is a commercial fish trawl adjusted with a small meshed liner in the codend. This gives an abrupt change in mesh size from 5" to 1.25" stretched meshes. This probably gives a substantial selection of small fish mainly in front of the codend. Studies of water flow and fish behaviour have shown that fish often stop in such areas and will thus easily escape through the big meshes instead of entering the codend. This selection will be strongly size dependent, and if size at age vary among year, an estimated number by age will be unequally biased over time. The problem should be studied and the netting mesh sizes in front of the codend should be reconsidered to eliminate this effect.

A similar problem might be experienced in front of the trawl due to escapement under the net and under the bridles (Engås and Godø 1989, Godø and Walsh 1994). Studies of the GOA survey trawl shows escapement of fish under the trawl and under the bridles but indicates that this is negligible for pollock, although data are limited and all sizes not represented (papers and personal com from David Somerton and his group). The GOA survey trawl has very light doors (1,250 lb). This will probably reduce the herding (reduced sand cloud) and make bottom contact of the bridles and the roller gear unstable. Both factors reduce the overall efficiency, particularly in rough areas where direct observations is difficult.

Further complexity is added by the fact that a standard scope to depth table for warp is applied that changes the geometry of the trawl dramatically from shallow (high opening – low spread) to deep (low opening – wide spread) water. The change in area swept by the trawl is compensated for in the assessment, but AFSC observations (David Somerton personal communication; see also Godø and Engås 1989) has shown that trawl performance is changed with associated change in trawl efficiency. These changes are general problems for all surveys but are particularly strong for species covering a large depth range. In the Norwegian bottom trawl survey in the Barents Sea, a constriction rope is used to maintain equal geometry and performance in all hauls (Engås and Ona 1993). Although the effect of the rope is unknown (see e.g. Rose and Nunnallee 1998), this change in procedure helps to maintain geometry and performance constant, which is an important goal for a standardized trawl survey.

The construction of trawl and rigging appears not optimal as also is shown in much of the excellent gear and fish behaviour studies at AFSC in recent years. Further, these investigations show that performance of the gear is depth dependent. There is a need for continued studies to facilitate a scientific base sound enough to perform a quantitative evaluation of the variation in efficiency of the gear with the ultimate goal of improving or replacing sampling bottom trawl gear and procedures. It should be underlined that AFSC survey is not unique in this respect as many surveys worldwide experience similar problems.

<u>Vertical fishing height.</u> Vertical fishing height of survey trawls is a concern for stock assessment of semipelagic gadoids (Ona and Godø 1990, Nunnallee 1991). Information presented at the meeting also demonstrated the potential increase of the vertical fishing height for Alaska pollock caused by vertical herding of vessel and warps (see further discussion about this under the EIT survey). Along with acoustic monitoring of the vertical distribution profiles of pollock there is a need to clarify effects of vertical herding. The effect on survey abundance estimates will probably dependent on *the vertical density profiles, fish depth, and fish density*. The effect might be strongly selective and will in best case only skew trends in abundance, but in worse case cause wrong signal in the stock development.

The complexity of the above problem is well demonstrated in the experiments by Rose and Nunnallee (1998), where the authors conclude from the results of a systematic experiment with constriction rope that catch differences could be caused by most of the factors discussed in the above paragraphs.

Survey design
The survey area is difficult for bottom trawling and hence only a limited part of the total habitat is represented in the survey. An unanswered question remains on the representativeness of the trawled locations. In the stratified random design, the trawled location changes from year to year. The motivation for the design is that it supplies a better scientific foundation for using the results for absolute abundance estimation. However, the approach potentially produces a more variable and imprecise representation of the total survey area. Further, the search for new trawlable locations takes time, time that could be used to

carry out more stations. Due to the intra-haul correlation in stock parameters, additional samples represent an important way to improve survey estimates (Pennington and Vølstad 1991, 1994, Bogstad et al 1995, Folmer and Pennington 2000). There is no reason to believe that the present design will yield a long-term positive effect, outweighing the positive effect of a fixed station design. In the fixed station approach, one could utilise the precise geographic information about trawlable location and set a net of stations substantially outnumbering the present design. An additional gain would be less net damage and a higher percentage of accepted hauls.

A concern was raised about the variation in skippers and vessel over time. It is known that these effects can be substantial. Well-defined procedures and comparative side-by-side trawling before survey-start are the best approach to evaluate and reduce such effects. Also, a design that leaves some of the survey stations to be repeated by all participating vessels without a too long a time lag might give an opportunity for statistical evaluation of the vessel effect.

Alaska Fish and Game Crab and demersal fish survey

The Alaska Fish and Game (AF&G) survey suffers from the same type of general uncertainty as the AFSC survey (see above). The use in assessment is further complicated by the difference in the timing of survey, trawl efficiency (von Szalay and Brown 2001, von Szalay in prep) and, most importantly, by the limited geographical coverage of the AF&G survey. The survey may give an indication of the variable importance of the inshore habitat, but it hardly represents a reliable index of the stock development as a whole. Due to the very different vertical sampling heights of the trawls, the two bottom trawl survey assessments cannot be reliably combined. The comparative trawling underlines the conclusion in the above section that the vertical distribution pattern is a major uncertainty of any bottom trawl survey coverage of Alaska pollock.

Echo integration trawl survey

The echo integration trawl (EIT) survey has the longest time series, starting in 1981, and, unlike the AFSC bottom trawl survey, is carried out annually. The survey is carried out according to international standards for acoustic resource surveys and uses up-to-date technology. The results thus need to be evaluated according to the match between the applied procedures and routines and the general characteristics of the species and the ecosystem, or if there are new developments in technology or information that can be taken into account. The scientists responsible for the survey supplied a list of assumptions (Box II) that, along with the information from the presentation and discussions, generated a discussion around the following issues:

Geographical representation: The EIT survey has covered what is assumed to be the central spawning area of GOA pollock. New evidence in recent years indicates that there are important temporal variations in the geographic extent of spawning. Furthermore, the survey is used to estimate maturity-at-age curves, which have exhibited wide annual variations. It is probable that the fractions of both the immature and mature stocks are wrongly represented in the survey, as a result of horizontal distribution dynamics. The extent of these errors is difficult to assess, although dynamics in distribution of commercial catches or comparison of abundance outside and inside EIT survey area during the NMFS survey might provide some indications. The situation could be improved by extending the survey area to include all potentially important spawning grounds.

Box II. Assumptions in the EIT survey

Most important assumptions for the Gulf of Alaska walleye pollock pre-spawning acoustic-trawl surveys: (the assumptions are NOT necessarily listed in the order of importance, although assumption #1 is the most important)

1) The amount of spawning pollock in Shelikof Strait represents a constant proportion of the Gulf of Alaska pollock biomass. This assumption has come into serious question during the last several years.

2) The model estimated selectivity curve is appropriate? I'm not certain that we miss such a relatively large proportion of older fish.

2) The current pollock target strength to fish length relationship (TS = 20 log L – 66) is appropriate for spawning pollock. The above relationship is largely based on nocturnal distributions of non-spawning fish.

3) The current pollock TS to L relationship is appropriate for day *and* night distributions of pollock.

4) The selectivity of the midwater trawl (and to a lesser degree the bottom trawl, since fewer bottom trawls are conducted) is the same for pollock of all sizes. This includes mesh selectivity as well as selectivity from size (age) specific behavioral responses (e.g., large fish exhibit more pronounced diving reaction).

5) Eulachon and pollock have the same TS to L relationship. Of course, this is not true. But I do not believe that the relative contribution of euclachon in Shelikof Strait is so great that this will have serious implications. Besides, we will apply a eulachon TS to L relationship for this species during the next survey.

6) Nocturnal distributions of the subadult pollock, which form midwater layers, do not respond to underwater radiated noise from the survey vessel. The most recent buoy data suggest that SA values decline by about 20% based on an avoidance reaction (see my poster handout).

7) The proportion of fish within the dead zone remains constant among years. I am not certain about this assumption, but we can take a look at it. Of course, we will need to make some simplifying assumptions to apply dead zone corrections.

Acoustic dead zone: Pollock occupy the water column from the bottom well into the pelagic zone. There is always an uncertainty regarding the extent to which a substantial fraction of the biomass occupies the acoustic dead zone (the layer close to bottom outside the reach of the acoustic instruments (Ona and Mitson 1998)) and if the effect of this bias varies from survey to survey. Correcting for the dead zone for the whole time series can easily done and would form the basis for an evaluation of this problem.

Vertical distribution pattern: The acoustic survey gives a detailed vertical distribution of acoustic scattering. This information provides valuable ecosystem information and demonstrates near-bottom problems for the acoustic recording, the availability of pollock to the bottom trawl, diurnal migration dynamics, etc. Annual variations in vertical distribution profiles may thus change the absolute efficiency of the survey and the sampling efficiency of the sampling trawls. Vertical distribution profiles can easily be made for the time series and should be produced in order to evaluate changes over time (see e.g. Godø and Wespestad 1993).

Sampling errors (data scrutiny/survey selectivity/behavioural response):
The acoustic assessment methodology is susceptible to behavioural characteristics that affect the efficiencies of both acoustic and trawl gears. Diurnal characteristics disturb the day - night comparability of trawl catches (see e.g. Hjellvik et al 2002) as well as of acoustic recordings (Lawson and Rose 1999, Vidar Hellvik, Institute of Marine Research, unpublished data). Furthermore, species with escape reactions during trawling (Nunnalle 1991, Ona and Godø 1992), which GOA pollock presumably have (Wilson 2003), will be very susceptible to biased sampling. The lack of large fish in the survey as compared to assessment (Dorn et al. 2002) could reflect an inability of the trawls to catch large fish. If the large fish contribute substantially to the acoustic backscatters but are underrepresented in the trawls samples, the assessment will be substantially skewed towards small fish. This can easily be tested by using the selectivity curve from the stock assessment and adjusting the trawl catches before converting acoustic densities to fish abundance.

Data scrutiny and allocation of acoustic abundance to species is often a problem for acoustic surveys. In this case, the problem is mainly caused by the mixing of eulachon (*Thaleichthys pacificus)* and pollock. As eulachon has no swim bladder, it is very likely that the species can be separated using multi-frequency analysis (see Korneliussen and Ona 2002). To reach eulachon depths with the higher frequencies, noise reduction might be needed (Korneliussen 2000). Using frequencies of 38, 120 and 200 kHz would probably provide an adequate frequency response for improved species resolution.

As discussed above, the maturity at age information collected by the EIT survey displays unexpected variability. The opportunistic sampling strategy focus on representing different concentrations of fish and samples are therefore not distributed according to abundance. A correct representation can be obtained by weighting samples according to the abundance they represent.

Acoustic target strength:
The acoustic target strength (TS) used for pollock is based on old field experiments. These measurements were from individuals during summer months, and the observations are probably not representative of the TS during the spawning season. There is a strong need for repeating the measurements with modern equipment and procedures (ICES 1999).

Following up the above considerations, future acoustic stock assessments will use direct *in situ* observations of TS instead of length frequencies from trawl catches as a basis for abundance estimation. For dense aggregations like those observed for pollock, it is necessary to lower a transducer to the fish to resolve fish into single individuals (see e.g. ICES 1999, Heino et al 2003). Such tests should be initiated now in an attempt to minimize the problems of trawl sampling. A major improvement could be obtained by measuring the TS of eulachon*)*. This species mixes with pollock and is presently separated using a TS equal to that of capelin (Wilson et al. 2003). As this species lacks a swim bladder, the present approach probably causes a substantial overestimate, with a corresponding underestimate of pollock.

Stock assessment and management

The following paragraphs offer some considerations about the potential implications of difficulties in the surveys for stock assessments. Malcolm Haddon provides the general review of assessment methodology.

In an earlier evaluation of the performance of various assessment models, one main conclusion was that quality input from scientific surveys was the best guarantee of quality output of assessment models (Anon 1998). Furthermore, a recommendation under the section titled '*New approaches' calls* to "*develop new means to estimate changes in average catchability, selectivity, and mortality over time, rather than assuming that these parameters remain constant"*. This statement goes directly into the difficulties of pollock stock assessment. There is strong evidence of substantial ecosystem changes over time in the northern Pacific (Bailey 2000, Conners *et al.* 2002) and there is every reason to believe that such changes may have a strong effect on the persistence and comparability of survey results over time. The influential effect on assessment by the factors discussed in the survey section needs to be evaluated under this perspective. This will directly affect how selectivity curves are estimated, and the use of survey estimates as absolute or relative values. There is good reason to believe that the major assumptions hold in most cases. However, when substantial changes in the ecosystem occur, this will also affect survey estimates, e.g. through distributional and behavioural changes, and cause errors in evaluations of stock development trends. It is in these critical situations that assessment and management are in most urgent need of reliable survey data. There is thus a great need to study more carefully some of the major uncertainties, as listed under surveys. Such studies demand active interaction between survey scientists and assessment modellers. Based on the evaluation of the surveys, it is not unexpected that the violation of the basic assumptions may cause the observed contradictory trend in the survey assessments. In particular, such discrepancies are expected when changes in the ecosystem (e.g. regime shifts) take place with associated dynamics in vertical and horizontal distribution. Without a thorough knowledge of the dynamics connected to such ecosystem events the only way to improve quality of assessment seems to be to improve surveys along the lines suggested above (see also recommendations).

A peculiarity, not thoroughly discussed under the EIT survey, is the lack of old fish (age$\geq$8). This needs further attention as the fish are probably in the area and are recorded by the acoustics but not sampled by the trawls. The geographical variation in size also raises the question of geographical inconsistency (Wilson et al. 2000) or a habitat preference by size.

The effect of regime shifts in the Bering Sea and the GOA is widely discussed. However, the shifts are difficult to take into account in assessment and management. If, as suggested, such shifts affect both the relationships used in the assessment models (e.g. stock recruitment relationships) and the performance and selectivity of surveys, more attention should be paid to taking these characteristics into account.

The same applies strongly to management issues. The calculated reference points are based on the data from the whole time series, while ideally only data belonging to each regime should be used. One example is the treatment of SSB-recruitment relationships. If such relationships change with regimes, a useful exercise could be to study the frequency of rich year-classes and recruitment levels in different periods (see e.g. Godø 2003).

Evaluation and Recommendations related to specific requests

In this section I summarise the specific requests raised in the *Statement of Work* with particular reference to those aspects relevant to surveys. These add to the recommendations given under the sections preceding the survey section.

Strengths and weaknesses of current survey for assessing Gulf of Alaska Pollock abundance trends

Strengths

- All surveys are well designed and the calculation methods follow international standards.
- The surveys are run by well-qualified personnel.
- The procedures and routine follow international standards.
- The AFSC bottom trawl survey has reasonably good coverage of the distribution area of pollock.
- The surveys are backed up by a continuous experimental activity on fish behaviour and gear technology that on the long term can supply a scientific basis for survey improvement in equipment, routines and parameterization of assessment models.

Weaknesses

- The AFSC bottom trawl survey lacks vertical coverage and does not representatively cover the stock due to size dependent vertical distribution.
- The limited geographic coverage of the EIT survey makes it very susceptible to changes in the distribution of the stock.
- The bottom trawl survey gear uses an old fish trawl that is non-optimal for sampling purposes.
- No reliable recruitment indices are available from the AFSC bottom trawl survey due to the selectivity of the trawl and the lack of vertical coverage.
- The EIT survey bases the assessment on an old acoustic target strength, which was measured during feeding season.
- The bottom trawl used in both the NMFS and EIT surveys is highly size selective and changes in growth over time may cause inter-annual changes in catchability by size.
- The surveys are particularly susceptible to critical assumptions during periods of ecosystem instability (regime shifts) due to the gaps in geographic and vertical coverage.

Recommendations for survey improvements (see details in the main text)

- Design and run a combined acoustic – bottom trawl survey during summer based on the 2003 survey experience. A simple logging of the acoustic data may give adequate results but a full integration of the two techniques is preferable, i.e. both the acoustic and the bottom trawl data are treated during the survey.
- Improve geographic coverage of spawning areas during the EIT survey.
- Establish *in situ* TS relevant for the mature pollock and for separation of eulachon in mixed recordings during the EIT survey (see also research priorities).
- Implement multi frequency data collection and analysis for species separation in the EIT survey.

- Improve or replace bottom sampling trawl with a less selective one. Such a replacement must be preceded by the needed gear and fish behaviour studies along the lines of those already done and planned at AFSC (see also research priorities).
- Produce routine information on vertical and horizontal distribution patterns from the EIT survey (see also research priorities below).
- Correct for the acoustic dead zone.
- The AF&G crab and fish survey seems to represent limited additional information to the stock assessment and, if possible, activity should be transferred to strengthen the above items.

Suggested research priorities to improve the stock assessment.

- Establish a time series of distribution characteristics (vertical and horizontal) and assess potential effects on consistency of time series. Make an annual evaluation of this effect.
- Study distributional characteristics from both surveys in relation to environmental changes for potential prediction of factors of importance to survey efficiency and assessment reliability.
- Continue studies of behavioural effects on sampling efficiency. Of particular interest in both the EIT and the NMFS bottom trawl survey is the effect of vertical herding (efficient catching height by size).
- Establish methodology and instrumentation for *in situ* TS measurements during surveys to study TS variation and over time possibly reduce demand for trawling.
- Recalculate age at maturation curves from the EIT survey by weighing the samples with associated biomass. Attempt also to include the potential effect of the sampling selectivity curve into this analysis.

APPENDIX I

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APPENDIX II

STATEMENT OF WORK

Consulting Agreement Between The University of Miami and Dr. Olav Rune Godø

General

The Alaska Fisheries Science Center (AFSC) requests review of the Gulf of Alaska walleye pollock (*Theragra chalcogramma*) assessment. Pollock in the Gulf of Alaska have declined in abundance, and in 2002 dropped to a 30 year low, despite being managed conservatively under North Pacific Fishery Management Council harvest policies. Both acoustic and trawl surveys are used to assess pollock abundance, but interpretation of recent survey results has been problematic due to contradictory trends and potential changes in stock distribution. Reliable assessment of Gulf of Alaska pollock stock status is important both for council management of the fishery and for evaluating fishery impacts on endangered Steller Sea Lions, for which pollock are important prey. These factors create a compelling need for independent peer review of the Gulf of Alaska pollock assessment.

The assessment review will require two consultants, 1) a stock assessment expert, and 2) an expert on survey methodology for fish resources (both acoustic and trawl surveys). Consultant 1 should to be thoroughly familiar with various subject areas involved in stock assessment, including population dynamics, separable age-structured models, harvest strategies, the AD Model Builder programming language, and have experience conducting stock assessments for fisheries management. Consultant 2 should be thoroughly familiar with survey methodology (both bottom trawl and acoustic), its application in stock assessments, and have experience planning and conducting resource assessment surveys. The consultants will travel to Seattle, Washington, to discuss the stock assessment with the lead analyst, the chief survey scientist, and other scientists at the Alaska Fishery Science Center involved in the Gulf of Alaska pollock assessment. The report generated by the consultant(s) should include:

a. The strengths and weaknesses of the Gulf of Alaska pollock assessment and harvest strategy;
b. Recommendations for improvement to the assessment model and harvest strategy;
c. Strengths and weaknesses of current survey for assessing Gulf of Alaska pollock abundance trends;
d. Recommendations for survey improvements to better assess Gulf of Alaska pollock;
e. Suggested research priorities to improve the stock assessment.

AFSC will provide copies of stock assessment documents, AD Model Builder code for the stock assessment model, survey reports, and other pertinent literature.

Specific issues that should be addressed in the review are the following:

a. The appropriateness and statistical rigor of the assessment approach.
b. Adequacy of existing surveys to monitor abundance trends of GOA pollock.
c. Whether the stock assessment takes into account major uncertainties in data and assumptions.
d. Whether the current management approach is precautionary, given current stock status and trend.

Specific

1. Read and become familiar with the relevant documents provided to the consultant;
2. Discuss the stock assessment with the lead assessment scientist and survey scientists in Seattle, Washington, from August 4 to August 8, 2003;
3. No later than August 22, 2003, submit a written report[1] consisting of the findings, analysis, and conclusions, addressed to the "University of Miami Independent System for Peer Review," and sent to Dr. David Die, via email to ddie@rsmas.miami.edu and to Mr. Manoj Shivlani, via email to mshivlani@rsmas.miami.edu.

ANNEX I: REPORT GENERATION AND PROCEDURAL ITEMS

1. The report should be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the report should consist of a background, description of review activities, summary of findings, and conclusions/recommendations.

3. The report should also include as separate appendices the bibliography of materials provided by the Center for Independent Experts and the center and a copy of the statement of work.

Please refer to the following website for additional information on report generation: http://www.rsmas.miami.edu/groups/cie