Review of the eastern Bering Sea crab and groundfish bottom trawl surveys

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May 2012

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1. Executive Summary

1. Together with Dr Jon Vølstad and Professor Yong Chen, the author participated in a review of the eastern Bering Sea crab and groundfish bottom trawl surveys, which was held at Seattle from April 10-12, 2012.
2. The survey approaches that are being explored by the AFSC are "state-of-the-art". The research on factors affecting trawl performance and efficiency and on integration of acoustic and bottom trawling that has been undertaken by the AFSC is of high quality and innovative, as is demonstrated by the fact that papers describing much of this research have been published in fishery journals with high impact factors.
3. The eastern Bering Sea bottom trawl survey employs a fixed grid of trawling stations, but, to maintain consistency among annual surveys, the grid lacks a random starting point and is thus potentially subject to systematic bias. The variance estimate for the mean abundance of each species is currently calculated using the formula applicable for a random rather than systematic survey. The true values of variance estimates obtained from the systematic survey are likely to be less than the current estimates, and should be determined, noting that, because only one trawl is made within each grid cell, it will only be possible to obtain approximate estimates of these true values.
4. The precision of abundance estimates is adequate for most stock assessments, but the estimates for the stocks of red king crabs and Pribilof Islands blue king crabs would benefit from increased precision.
5. For consistency, it is recommended that the current survey design remains unchanged, but that simulation studies are undertaken to assess the benefits of additional random sampling to take into account any systematic bias and to improve the precision of abundance estimates for crabs at the Pribilof Islands.
6. The current approach to collecting reproductive data for female red king crabs in Bristol Bay is of an *ad hoc* rather than structured nature. It is recommended that an appropriate annual survey, which would supplement the standard EBS survey, is designed to collect time-varying reproductive data for female red king crabs in the Bristol Bay region and that this survey is then undertaken annually thereby providing a consistent time series of data on the reproductive characteristics of the crabs.
7. It is recommended that further exploration of migration patterns and rates of movement is undertaken, such that the effect of migration can be taken into account when calculating survey estimates of abundance for walleye pollock and other species.
8. It is recommended that a (statistically) well-defined process is developed to ensure that subsamples of fish for length measurement and otolith collection are randomly selected, that appropriate sample sizes are determined following calculation of effective sample size, and that the methods used to construct the age-length key for each stratum are reviewed to ensure that the non-random nature of the collection of otoliths is recognised and that this aspect of the analysis is sound.

9. The desire to maintain consistency in survey abundance estimates should not inhibit those changes to the survey that would improve the accuracy and precision of estimates or accommodate changing research and management needs. It is recommended that strategies for facilitating the introduction of change in survey design, operations and analytical procedures be developed, such that the bottom trawl survey can be modified to respond to changing needs and improved knowledge, while minimising the impact of data inconsistency resulting from such change through appropriate transition strategies that have been determined through simulation.
10. It is recommended that simulation studies are undertaken to investigate the impacts on stock assessments for the different species of a change from 30 to 15 minute survey trawl duration when employing each of a range of alternative implementation strategies, and thereby to determine which of the alternative implementation strategies would have the least overall impact, and the magnitude of that impact. Such analysis would provide the data necessary for an informed decision regarding whether a transition to 15 minute tows should be made.

2. Background

2.1. Overview

The Center for Independent Experts (CIE) contracted for an independent peer review of the eastern Bering Sea crab and groundfish bottom trawl surveys, which was scheduled to be undertaken from April 10-12, 2012.

On March 24, 2012, the address of the AFSC FTP site, from which the documents containing the required and general background reading for the meeting could be downloaded, was provided. A list of papers describing research on issues pertinent to trawl surveys was also included in the set of files available on the FTP site. A list of these documents is presented in Appendix 1.

The Statement of Work provided to Dr Norm Hall by the CIE is attached as Appendix 2. This report documents the findings of the independent review that was undertaken by Dr Hall in accordance with this CIE Statement of Work.

2.2. Terms of Reference

The terms of reference for this independent peer review of the eastern Bering Sea crab and groundfish bottom trawl surveys are presented in Annex 2 of Appendix 2. Note that, although referred to in the heading of this Annex as "tentative", these were the actual terms of reference required to be addressed in the review.

2.3. Date and place

The Review Meeting was held in Seattle, from April 10-12, 2012, and was chaired by Dr David Somerton, AFSC. The names of the CIE Panel Members who undertook the review are listed in Appendix 3

3. Description of Reviewer's role in review activities

As required under the CIE's statement of work, the reviewer familiarised himself with the documents that had been provided and then participated in the review meeting which was held at Seattle from April 10-12. As listed in the tentative Agenda (Annex 3 of the Statement of Work, Appendix 2), but with timing that was modified to accommodate the questions raised by the various members of the CIE Panel and the resulting discussions, scientists of the AFSC Survey Group gave detailed presentations describing different aspects of the eastern Bering Sea bottom trawl survey. Note that Dr Robert Foy, who was not physically present, viewed the presentations through video conferencing software and participated fully in discussions via telephone. All members of the CIE panel actively participated in the review by asking for more detailed explanation and by commenting and discussing different aspects of the survey, the methods of analysis, and the results of research. The members of the CIE Panel also visited the net shed and viewed a bottom trawl net of the type used in the survey, which had been hung in the shed in a manner that reflected its physical appearance during trawling operations.

In discussing findings from the review, it should be noted that (1) the 376 stations that are trawled in the annual eastern Bering Sea survey are the fixed sampling stations that were used in 1987, 356 of which had been sampled from 1982 onwards (Lauth, 2010); (2) the survey is conducted strictly in accordance with the trawl survey protocol specified by NOAA (Stauffer, 2004; Chilton *et al*., 2009; Lauth, 2010), much of which was apparently based on standards that were already being applied by the AFSC in the eastern Bering Sea survey; (3) monitoring of trawling operations has progressively improved with developments and innovation in technology, particularly in respect to measurement of the width between the wings, height of headrope, and the distance of the footrope and bridles from the bottom; (4) area swept calculations from 2009 employ the mean width between the wings, as measured or, if measurements are unavailable, calculated from the inverse of the scope (Chilton *et al*., 2009; Lauth, 2010); and (5) area swept calculations for the 2009 survey used distance trawled while the footrope was in contact with the bottom between endpoints determined from GPS (Chilton *et al*., 2009).

Changes to the design and operation of the EBS trawl survey are constrained by the fact that, to provide information to stock assessment models on population dynamics and response of the population to fishing, fishery scientists seek to ensure that the relative abundance indices within the time series maintain consistency and thus possess a constant catchability across years. In theory, the analytical methods used to derive abundance indices from the resulting survey data have greater flexibility and may be more readily modified than the survey's design or the trawling that is undertaken. Although change to the analytical methods would result in a new time series with different indices, if applied consistently to the data for all annual surveys, those new indices would possess a constant catchability across time, although the value of that constant catchability would differ from the catchability of the original time series of abundance estimates.

In practice, changes do occur in the design and operation of a survey, and in the eastern Bering Sea, this is evident in, for example, the expansion to the northwest of the survey area by 20 additional sampling stations in 1987 (Lauth, 2010), and refinements to consistency of trawling to improve conformity to the NOAA protocol for trawl surveys (Stauffer, 2004). Refinements to analytical approaches are also warranted, particularly when stock assessment employs survey estimates of abundance as estimates of absolute abundance or when the precision of the abundance estimates is improved, for example, through the use of auxiliary data collected during the survey to take into account the effect of factors, such as wing width, that influence the estimate of swept area at each station. Although, through lack of auxiliary data for earlier years, it may not be possible to apply such refinements to all years of data in the time series of abundance estimates, it is possible to produce alternative time series, *i.e.*, with and without application of the alternative method of analysis, for use in stock assessment, thereby allowing investigation of the implications of the alternative analytical approaches and thus providing continuity between the use of the alternative time series if the new method is adopted for use in future stock assessments.

Given the extent and high quality of the research on bottom and acoustic trawling that is being undertaken by the AFSC, there will inevitably be continued improvement in the understanding of factors that affect the magnitude and composition of the catches obtained in survey trawls, the efficiency of the trawl in catching different sizes of animals, the effect of bottom temperature on the spatial distribution and migration of the animals, and the factors affecting the vertical distribution of fish species and the accessibility of those fish to the trawl gear. The challenge for the AFSC is to develop implementation strategies that will allow the improved understanding to be employed in the analytical techniques that are applied to the survey data, thereby gaining the benefits to stock assessment that should result from the improved accuracy and precision of future abundance estimates while minimising any adverse impact on stock assessment resulting from loss of data consistency.

Details of the information derived from the review and the resulting recommendations are presented below in the comments relating to the various terms of reference.

Terminology used in this report

Although the term "catchability" is used by fisheries scientists in several slightly different ways, it has been assumed in this report that it is the constant of proportionality that relates either a biomass index to absolute biomass or an abundance index to absolute abundance (Francis *et al.*, 2003), noting that different values of catchability will be associated with different indices of abundance. In its report on approaches to improve the collection, management, and use of marine fisheries data, the National Research Council (2000) noted that catchability was associated with the availability, accessibility, and vulnerability of the fish to the gear. Fish are considered to be *available* if they are in the area fished by the gear, *accessible* if their behaviour makes it possible for them to encounter the fishing gear, and *vulnerable* if, when encountering the gear, they are caught. Thus vulnerability may be considered to be equivalent to the efficiency of the fishing gear in capturing those fish that encounter that fishing gear (Arreguín-Sánchez. 1996). In stock assessment, length-dependent differences in relative vulnerability are typically represented by a selectivity function.

In this report, the following terminology has been adopted:

- Availability – Proportion of the stock within the surveyed area.
- Accessibility – Proportion of the available stock that the gear is able to access. Note that, although AFSC scientists have used the term "availability" when referring to the proportion of the fish that, because of their vertical distribution, lie between the bottom and the headrope of the survey trawl, and are thus accessible to the trawl, I have preferred to use the term "accessibility".
- Vulnerability – Proportion of the accessible fish that is caught by the gear.

Availability is likely to be affected by migration or shifts in geographical distribution in response to inter-annual changes in the distribution of bottom water temperature. Accessibility represents the proportion of the available fish that can encounter or be influenced by the gear and may be affected by environmental factors, *e.g.* temperature, light, etc. Invertebrates or fish occupying areas of rough bottom may be inaccessible to bottom trawlers, while fish with a vertical distribution, which are situated in water that lies above the height of the headrope of the bottom trawl, may be inaccessible unless they exhibit diving behaviour in response to the passage of the trawl warps through the water. Vulnerability reflects the efficiency of the gear in capturing accessible fish and invertebrates that lie in the path of the trawl.

Acknowledgement

Throughout the review, the CIE Panel was impressed by the shared commitment towards improving the quality of the survey and the accuracy and precision of abundance estimates that was exhibited by the scientists in the survey group at the AFSC. I extend my thanks to Dr Somerton and his colleagues for the hospitality that they extended during the course of the review, and for the excellent support they gave in providing the information regarding the eastern Bering Sea bottom trawl survey that the Panel required for its review.

4. Summary of findings

ToR 1. Evaluate the data collection operations and sampling design of the survey in term of their adequacy for producing consistent and precise estimates of relative abundance for the various fishes and invertebrates of concern.

Primary species

The primary species in the catch are walleye pollock, Pacific cod, yellowfin sole, rock sole, king crab and snow crab (David Somerton, Presentation to Review Panel). In 2010, a total catch of approximately 1.9 million metric tonnes with an ex-vessel value of approximately 1.3 billion dollars was taken from the eastern Bering Sea by commercial fishers (David Somerton, Presentation to Review Panel).

Survey design

Abundance and biological data for crabs and groundfish are collected using an annual systematic bottom trawl survey that employs a fixed rectangular grid of 20 by 20 nmi cells (*i.e.*, quadrats) that extends over the continental shelf of the eastern Bering Sea from the Alaska Peninsula to approximately the latitude of St Mathew Island. While initially covering only 356 grid cells, which have been sampled annually since 1982, the survey area was extended to the northwest in 1986 to include an additional 20 grid cells. Sampling of the grid cells in the survey area occurs at two densities. A single 30-minute trawl is undertaken at the center of each standard- and high-density grid cell. Additional 30-minute trawls are undertaken at the corners of the 20 by 20 nmi grid cells in two high-density sampling areas, which are located in regions adjoining the Pribilof Islands and St Mathew Island. Although not suggesting that the rectangular grid used in the eastern Bering Sea bottom trawl survey should be modified, Dr Vølstad observed that use of a hexagonal grid might offer advantages over use of a rectangular or square grid (*e.g.,* Birch *et al*., 2007).

It is recommended that, in order to maintain design consistency, the EBS bottom trawl survey should continue to trawl at the 376 standard trawl locations that have been employed since 1986.

Randomness of survey design

The design of the eastern Bering Sea bottom trawl survey differs from that typically used in systematic surveys, in that the starting point of the grid is not randomly selected for each annual survey. This results in sampling at a set of fixed stations, *i.e.* the center points of the grid cells, each year, potentially introducing systematic bias resulting from the specific characteristics of those fixed stations. Use of a random starting location for the grid rather than a fixed location would have ensured probability-based selection of station locations and provided a better survey design. The decision to employ a fixed rather than randomly positioned grid relates to a desire to ensure consistency among inter-annual samples, and thus comparability of results. It is argued in favour of the fixed grid that the trawls within a grid are not positioned with such precision that they pass directly over the center of the grid nor do they follow precisely the same trawl path in successive years. Nevertheless, they do pass over roughly the same central region of the grid cell each year, and cannot be considered to be randomly positioned within the grid. As the fixed grid has now been employed in annual surveys since 1986, and a major subset of the grid since 1982, it is appropriate that, as recommended above, the fixed grid should continue to be employed for future annual surveys.

In the absence of a randomly-selected starting point for the grid, however, there would potentially be value in supplementing the stations within the fixed grid with a set of additional random sampling stations selected annually using a probability-based approach. The combination of the fixed systematic stations and the probability-based random stations would help to overcome any issue relating to systematic bias, assist in improving survey precision, and facilitate calculation of the variance of the resulting abundance estimates (*e.g.,* Zinger, 1980). Simulation using kriged abundance data for selected species would assist in assessing whether the benefits of the additional random samples would be justified given the additional survey cost. Consideration should also be given, however, to the effect of the additional time required to complete an extended survey on the consistency of abundance estimates with those derived from previous surveys. If, as is considered later in this report, the duration of survey tows was to be reduced from 30 to 15 minutes, the introduction of a set of probability-based survey stations to supplement the fixed grid may then prove possible without increasing overall survey duration.

It is recommended that simulations be undertaken to explore the feasibility and benefit of supplementing the existing set of 376 trawl stations with an appropriate set of survey stations with locations determined using a probability-based rather than systematic approach, and thereby overcoming any systematic bias present in the current survey design.

Hot spots

Although abandoned in 2011, since the mid-1990s, stations producing catches of 100 or more legal-sized male red king crabs or Tanner crabs were considered to be "hot spots" and four additional trawls were made in each cardinal direction 5 nmi from the center of the grid cell containing the "hot spot", the intent being thereby to obtain more precise data on the abundance of the various crab species. The average density for all trawls at the "hot spot" was then calculated and used as the density estimate for the station when calculating the total abundance of the crabs (Chilton *et al.*, 2009), i.e. the grid cell was treated as a separate stratum (Plan Team, 2011). This is a rather atypical adaptive sampling approach (which would have benefited from further research if it had not been dropped from further use) and appears to have had the effect of reducing the influence of the initial high abundance observation that had initiated the additional sampling. By dropping the "hot spot" protocol, inconsistency has been introduced into the time series unless abundance estimates for earlier years have been recalculated excluding the data for the additional tows.

It is recommended that, for those years when the "hot spot" approach was employed, abundances and ancillary biological data are re-estimated using only the data for the trawls at the standard stations and excluding data from additional trawls associated with the "hot spots".

Supplementary sampling of Bristol Bay red king crabs in cooler years

In years when colder water temperatures have delayed the reproductive cycle of female red king crabs, a number of stations in the Bristol Bay area are resampled at the conclusion of the standard survey, *e.g.* 32 stations were resampled between 27 and 30 July in 2009, to obtain data on the reproductive status of female red king crabs. It should be recognised, however, that such additional samples fall outside the design of the standard survey. Thus, if used in calculating abundance estimates for female red king crabs (as appears to be case; Plan Team, 2011), the resulting values are not strictly comparable with abundance estimates derived from the standard survey. If the data that are collected for female red king crabs in the standard systematic survey of Bristol Bay are inadequate because of inter-annual variability in reproductive development, and it is decided that additional bottom trawl surveys of Bristol Bay are required for female red king crabs at appropriate time intervals, then those additional surveys should be well designed (in the statistical sense) and should be undertaken every year, thereby building a new time series of comparable data. The current arrangement for these crabs appears *ad hoc* rather than well-designed.

It is recommended that an appropriate annual survey, which would supplement the standard EBS survey, is designed to collect time-varying reproductive data for female red king crabs in the Bristol Bay region and that this survey is then undertaken annually thereby providing a consistent time series of data on the reproductive characteristics of the female crabs, which would supplement the density estimates for female red king crabs derived from the standard survey data.

Frequency of EBS bottom trawl survey

Because the survey estimates are the essential data required for setting annual crab quotas, the survey must be conducted annually and survey data must be analysed in a timely manner. Results of the stock assessment for walleye pollock indicate that both abundance estimates and age-dependent selectivity exhibit considerable inter-annual variability (Ianelli *et al.*, 2011), suggesting that the stock assessment model relies strongly on the information provided by annual survey estimates.

It is recommended that the EBS bottom trawl survey should continue to be conducted annually.

Stratification and post-stratification

The precision of the estimates derived from the data collected during the EBS bottom trawl survey is determined by the number and density of trawls undertaken in the survey area. Spatial correlation between adjacent trawl stations will reduce the "effective number" of independent stations, however. Thus, while the distance of 20 nmi between stations in the standard density stratum is likely to be sufficient to justify the assumption that stations are independent, the distance between stations in the high-density strata reduces to approximately 14 nmi. Inter-station correlation would affect the variance of abundance estimates and, as discussed in ToR 2, needs to be considered when analysing data.

When determining the locations of the stations at which survey trawls would be undertaken, the EBS survey area was divided into three strata, *i.e.* one stratum in which stations are positioned 20 nmi apart in the centers of 20 by 20 nmi grid cells and two strata with a higher density of sampling stations, where those stations are located in the center and at the corners of each 20 by 20 nmi grid cell. The latter strata were introduced in regions adjoining the Pribilof Islands and St Mathew Island to produce more precise estimates of blue king crab abundance. Because of the desire to ensure that the survey employs consistent fixed trawl stations in accordance with its systematic design, no attempt has been made to use historical information from earlier surveys to define additional strata and allocate survey stations to those strata in densities that would produce abundance estimates with improved precision. Such stratification would have been hampered by fact that the survey is intended to provide abundance estimates of all species caught, not just the primary species or those of commercial concern.

The poor precision of the estimate of abundance, i.e. CV=0.58, derived from the 2009 EBS survey for the Pribilof Islands stock of blue king crabs and the fact that this species tends to occupy rough habitat that is inaccessible to the survey trawls raises the question of whether the current stratification and systematic design of the trawl survey within the high density sampling region of the Pribilof Islands is adequate. The potential exists that, within this relatively small region, the systematic grid that has been employed may produce systematic bias in abundance estimates. While it would be inappropriate to abandon the current systematic survey grid in this region, as this would introduce inconsistency into the time series of survey results, there would be value in exploring whether such systematic bias exists and whether an alternative survey design within this high density stratum might produce more reliable estimates of blue king crab abundance for this stock.

It is recommended that a simulation study is undertaken to explore the potential benefits to precision and accuracy of blue and red king crab abundance estimates of additional survey trawls undertaken within the Pribilof Islands high density sampling region at stations that are determined using a probability-based approach.

When analysing the survey data, use has been made of two post-stratification schemes. Post-stratification for analysis of the data for groundfish was designed to reflect the distribution of Bering Sea groundfish across the different oceanographic domains, and thereby to reduce the variance of abundance estimates. Thus, for groundfish, the survey area was divided into ten strata. For this, the survey area was first split by a line running from the southwest to the northeast, dividing the area into two geographic strata, *i.e.* a north-western stratum and a south-eastern stratum. Each of these geographic strata was then divided into three depth strata, using the 50-m, 100-m and 200-m isobaths as boundaries. The high-density sampling stratum at the Pribilof Islands was split in two, with one section falling within the north-western geographic stratum and the other in the south-eastern stratum, but both portions lying within the 50-100 m depth range. The high-density sampling stratum at St Mathew Island was also split in two, with one section falling within the 50-100 m depth range, and the other in the 100-200 m depth range. Together with the standard-density strata in each geographic region and depth range, each of these high-density sub-regions was considered a separate stratum when analysing the groundfish data.

The post-stratification that was employed for analysis of crab data was designed to produce the estimates of abundance required for the various management units defined for each species by the Alaska Department of Fish and Game (ADF&G). Although appropriate for the red king crab and blue king crab stocks, some improvement in the precision of estimates of abundance for snow and Tanner crabs might result from further division of the management unit strata into depth or area sub-strata, based on oceanographic domains or average distribution of temperatures of bottom water.

It is recommended that post-stratification of survey data of snow and Tanner crabs based on oceanographic domains and/or average distribution of temperature of bottom water is investigated to determine whether such post-stratification might result in more precise estimates of abundance.

Area surveyed

The survey area is bounded on the southwest by the Bering Sea continental slope, on the northwest by the U.S.-Russian Convention line, on the northeast by the northern Bering Sea shelf, and on the northeast and southeast by the near-shore shallow waters of the coast of Alaska, and to the south of the latter south-eastern boundary by the near-shore waters to the north of the northern portion of the Aleutian Island chain.

Distribution of principal species and coverage by survey

The highest densities of juvenile and mature female snow crabs recorded in the 2011 EBS survey were located in the northwest of the survey area, and the population appeared likely to extend both beyond the U.S.-Russian Convention Line and into the northern Bering Sea shelf (Plan Team, 2011). While the highest density of male snow crabs was located to the south of the distribution of mature female snow crabs and further to the southeast, between 170 and 175° W, the distribution of the male snow crabs again appeared to extend beyond the U.S.-Russian Convention Line.

The Tanner crabs recorded in the 2011 bottom trawl survey of the EBS were distributed to the south and southwest of the survey area (Plan Team, 2011). Although it is noted that Tanner crabs are also present in the eastern north Pacific Ocean, the bottom trawl survey appeared to provide good coverage of the population of Tanner crabs in the eastern Bering Sea.

Two stocks of red king crabs within the eastern Bering Sea are recognised by fishery managers. The major concentration of red king crabs is found in the Bristol Bay District, while the second stock is located in the Pribilof Islands region. Survey catches of red king crabs are also made at stations in the Northern District south and west of Nunivak Island. Other stocks of this species are located north of the survey area in Norton Sound and south of the survey area at Adak. The latter stocks exhibit genetic divergence from those in Bristol Bay, the Pribilof Islands District, and the Northern District of the EBS, but there is no indication that the latter assemblages of the stock are genetically distinct. While the EBS bottom trawl survey appears to provide good coverage of the assemblages of red king crabs in the Pribilof Islands and Northern District, the crabs in Bristol Bay may extend beyond the surveyed region into near-shore waters of the Bay.

The area covered by the bottom trawl survey of the eastern Bering Sea shelf encompasses the areas at the Pribilof Islands and St Mathew Island which are occupied by blue king crabs, although accessibility of those crabs to the trawls is constrained by the rough bottom of the habitat in which they are found.

Walleye pollock and Pacific cod are distributed over greater geographic ranges than are covered by the EBS bottom trawl survey. Maps of the distributions of survey estimates of abundances of yellowfin sole and combined northern and southern rock sole suggest that the distributions of their populations extend beyond the survey area into near-shore coastal waters.

Effect of survey coverage on estimates of abundance and biological characteristics

For stocks of species that appear to be wholly contained within the standard surveyed area, such as Tanner crabs, the Pribilof Islands and (possibly) Bristol Bay stocks of red king crabs, and the Pribilof Islands and St Mathew Island stocks of blue king crabs, the estimates of abundance and biological data that are produced from the EBS survey are likely to reflect the abundance and biological characteristics of the entire population. Stock assessment analyses using such data can treat the survey estimates as either absolute estimates of the abundances of such stocks (if appropriately adjusted by estimates of vulnerability) or indices of abundance.

For those populations that appear not to be wholly contained within the survey area, *e.g.* snow crabs, walleye pollock, Pacific cod, yellowfin sole and northern and southern rock sole, the abundance and biological data collected in the survey are likely to represent only the data for those portions of the populations that lie within the survey area and are accessible to the bottom trawl. Thus, abundance estimates calculated from the bottom trawl survey will underestimate the abundances of such populations, and biological data will only reflect the characteristics of those individuals occupying the water accessible to the bottom trawl within the surveyed area. Assumptions that are made for stock assessment, *e.g.*, that the biomass estimate is an index of the population abundance (*i.e.,* a constant proportion of the full population is present within the survey area every year and is thus available to the survey), are likely to be invalid if the distribution of the population varies with inter-annual changes in distribution of temperature and location of the "cold pool". Such variation would result in inter-annual changes in the availability of the species to the survey. Estimates of the parameters of biological processes such as growth and maturation that are derived from survey data are likely to be biased if the distribution of the full population exhibits a size-dependent relationship with depth, temperature, or location.

While inter-annual variability in the availability of different age classes of the different species may be accommodated in stock assessment models for the various species through the introduction of time-varying catchability and selectivity at age, model complexity is increased accordingly. Estimates of annual availability are not available from the trawl survey, as such estimates would require survey data from untrawled areas. The annual survey does provide data on the relative spatial distribution of the different age or size classes of each species that are accessible to the bottom trawl and on the distribution of bottom water temperature within the survey area, which could provide information to stock assessment models that might assist in estimating annual catchability or age selectivity. Time series of the estimates of abundance of groundfish within each of the strata could prove useful indices of abundance for stock assessment. For species such as walleye pollock, the spatial distribution of abundance estimates from the bottom trawl would need to be accompanied by similar abundance estimates derived from data collected using acoustic trawl surveys.

It is recommended that further exploration of the relationship between the spatial distributions of the various age and size classes of the different species and the spatial distribution of bottom water temperatures in different years is undertaken.

Migration

The annual EBS bottom trawl survey is undertaken between early June and late July. The survey commences in Bristol Bay with the two vessels sampling alternative longitudinal columns of stations and moving progressively from east to west. This pattern of movement is intended to accommodate the movements of yellowfin sole, and possibly other species. Such movement may also result in changes in availability due to movement of individuals into or out of the survey area during the survey period. The large area covered by the survey and the extended period over which the survey is undertaken increase the potential that movement of fish may bias estimates of abundance and samples of fish that are collected to determine biological characteristics or estimate parameters of biological processes. McAllister (1998) has noted that the bias associated with even relatively small rates of movement or inter-annual variability in migration rates can be considerable. His findings suggest that there would be considerable value in determining patterns and rates of movement of the principal fish and invertebrate species such that any bias in estimates of abundance can be quantified. His findings would also suggest that, lacking information on migration rates and patterns of movement for many species, there would be value in maintaining a consistent inter-annual pattern of traversal between trawl stations and rate of progression of the survey from east to west, thereby attempting to ensure that any bias in annual estimates of abundance is likely to be relatively consistent across years.

It is recommended that a consistent inter-annual pattern of traversal between trawl stations and rate of progression of the survey from east to west is maintained in the annual EBS bottom trawl survey. It is also recommended that, when exploring the relationship between spatial distribution of fish and bottom water temperature, further exploration of migration patterns and rates of movement is undertaken.

Extended period of trawl survey and change in temperature

Bottom water temperatures recorded in Bristol Bay in early June 2009 differed markedly from those recorded when the region was resampled in late July 2009. This, combined with the fact that the bottom trawl survey is conducted over a period of approximately two months, suggests that bottom water temperatures recorded during the survey period represent both spatial and temporal changes. As water temperatures are likely to affect the spatial distribution, vertical distribution in the water column (and thus accessibility to the bottom trawl), and vulnerability of the fish and invertebrates in the survey area, there would be further value in maintaining a consistent inter-annual pattern of traversal between trawl stations and rate of progression of the survey from east to west, thereby attempting to maintain temporal consistency between survey years.

Precision of estimates of relative abundance

The coefficients of variation (CVs) for the 2009 estimates of abundance of legal-size snow and Tanner crabs were 12% and 21%, respectively, while that for blue king crabs at St Mathew Island was 26% (Chilton *et al*., 2009). Precision of the abundance estimate for Bristol Bay red king crabs was only 40%, however, while those for Pribilof Islands red and blue king crabs were only 66% and 58%, respectively (Chilton *et al*., 2009). As blue king crabs tend to occupy rocky, inshore, untrawlable habitat, it is probably not unexpected that the abundance estimate for this species should be less precise than the estimates for snow and Tanner crabs.

Survey estimates of the mean abundance of the more abundant commercial groundfish in 2009 were of relatively high precision, *e.g.*, the CVs for walleye pollock, Pacific cod, yellowfin sole, *Hippoglossoides* spp., Alaska plaice, arrowtooth flounder, and Pacific halibut were all less than 12% (Lauth, 2010). Data provided in the presentations to the Review Panel indicated that, on average, such precision had been obtained since 1982. Estimates of CVs for less abundant fish and invertebrates were greater than those for the main species, but, at a broader taxonomic level, still respectable, *e.g.* shrimps had a CV of 32%, Ophiuroidea 17%, and Echinoidea 39% (Lauth, 2010).

The precision of the snow and Tanner crabs, and for the more abundant commercial groundfish, appears adequate for use in stock assessment, but consideration should be given to ways in which more precise annual estimates of crab abundance could be obtained, while maintaining consistency of the design and execution of the annual EBS bottom trawl survey.

ToR 2. Evaluate the analytical methodology.

The eastern Bering Sea bottom trawl survey employs a fixed rectangular grid of sampling stations. Grid cells have dimensions of 20 by 20 nmi, and survey stations are located at the center of each grid cell. Two areas with higher sampling intensity have been established, one in the region of the Pribilof Islands and the other near St Mathew Island. Two forms of post-stratification are used, one for analysis of crab abundance and the other for use when analysing data for groundfish and other invertebrates. Both post-stratification schemes take the higher density sampling regions into account, and survey stations are assigned to the stratum in which they are located. Subsequent analyses of the survey data treat the data as a random rather than systematic sample from the stratum when calculating the variance associated with the mean CPUE, thus overestimating this value. The true variance of the systematic sample is likely to be less than the value that would have resulted if sampling stations had been allocated to the stratum using a probability-based approach to determine their geographic location. With only one station sampled within each grid cell, it is not possible to obtain an unbiased estimate of the true variance. An approximation to the variance could be calculated, however, using an approach such as proposed by D'Orazio (2003).

It is recommended that the approximate variance of the mean abundance of each species should be calculated using a method that recognises that a systematic grid of trawl stations was employed when sampling, rather than random station selection, and the resulting estimates of variance compared with those obtained using methods that assume random sampling.

The decision in 2006 to discontinue the practice of correcting survey data for differences in fishing power of the survey vessels appears sound (Lauth 2010). Certainly, the argument, which was presented by Munro (1998), that, unless the differences in fishing power were large, such correction is likely to increase imprecision of the abundance estimate appears valid. It is also true that, as noted by Lauth (2010), differences between the CPUEs of the two survey vessels could reflect real differences in abundance or, particularly in earlier surveys when monitoring of trawl performance was less advanced, differences in factors affecting trawl efficiency. Use of systematic rather than random selection of adjoining stations used in vessel comparisons is also likely to introduce bias into estimates of fishing power (Lauth, 2010). The fact that the data used to calculate fishing power were not independent of the survey data to which they were applied is a further issue to be considered. Lauth (2010) advises that, when stream data from survey trawls become available and swept area calculations are refined to reflect the improved understanding of factors affecting trawl performance that has resulted from the various studies that have been undertaken, the historical estimates of fishing power will be revised and new time series of survey abundance estimates will be produced. Until then, there will be no change to the time series of catches prior to 2006.

The results of the study by Kotwicki *et al.* (2006) on variation in the distribution of walleye pollock with temperature, and inferences regarding migration that were drawn from these results, are interesting. As noted by these authors, such migration can influence the availability of walleye pollock within the survey area and, as found by McAllister (1998), could produce considerable bias in survey estimates of abundance. Following Kotwicki *et al.* (2006), **it is recommended that fish migration vectors should be estimated for walleye pollock such that the effect of migration can be taken into account when calculating survey estimates of abundance.**

The age composition of the fish within each stratum is calculated from the estimated length composition for the stratum using an age-length key that has been determined for the stratum. It is not clear, however, whether the calculation of the age-length key recognises the way in which otoliths are collected from each station, *e.g.*, 3 otolith pairs from each cm length interval for each sex for each of a number of species or 4 and 6 otoliths from walleye pollock in low and high density strata, respectively, and the numbers of fish in each length class in the catch or total catch of the species at each stratum. **It is recommended that the methods used to construct the age-length key for each stratum are reviewed to ensure that the non-random nature of the collection of otoliths is recognised and that this aspect of the analysis is sound.**

The methods that are proposed to be introduced to improve area swept calculations were described in a presentation to the CIE Panel during the Review meeting. Proposed modifications to the methods used to calculate the distance fished included the use of spherical trigonometry rather than Euclidean geometry to calculate distance between points, use of a cubic spline rather than a moving average to eliminate the effect of noisy GPS data, and adjustment for wire retrieval. Proposed modifications to the methods used to calculate wing spread included the use of sequential outlier rejection rather than fixed lower and upper limits of 10 and 22 m, the use of a smoothed mean rather than mean to remove bias resulting from uneven density of data, adjustment of sound velocity for effects of temperature and depth rather than assuming a constant velocity of 1500 m/sec, and estimation of missing wing spread data using GAM model-based estimates to take into account a wider range of factors than just scope. The science on which these proposed changes were based appears sound, and use of the proposed methods should result in more accurate estimates of abundance. As the methods only affect the way in which the survey data are analysed, not the way in which the survey is undertaken, it is possible to produce time series of data using the old and new analytical methods, and thereby assess the effect on the stock assessment of the change to the new analytical approach.

It is recommended that proposed new approaches for calculating the area swept are used when calculating estimates of abundance, as these should improve accuracy and precision. As outlined above, these approaches include the use of spherical trigonometry, use of a cubic spline, adjustment for wire retrieval, sequential outlier rejection for wing width measurements, use of a smoothed mean, adjustment of sound velocity for effects of temperature and depth, and estimation of missing wing spread data using GAM model-based estimates.

ToR 3. Evaluate the procedures used for data quality control and archiving.

A presentation to the CIE Panel during the Review described the methods used to ensure data quality and to store and maintain data. These methods appeared very sound. The storage within the database of audit information relating to any changes to the data ensured that it was possible to extract a "snapshot" of the data that would have been present in the database at the time of any earlier extraction. **It is recommended that, when data are extracted for use in stock assessment or other analysis, read-only versions of the script that was used to generate the extracted data from the raw data in the database and the resulting extracted data are stored in an archive, together with the results of the stock assessment or analysis.** This will ensure that it is possible to determine precisely which trawl efficiency or other adjustments have been applied when extracting the data and that it is possible to explore how alternative models or analytical methods would have affected the results if applied to precisely the same data as used in the original analysis.

The reliability of species identification in surveys from 1982 to 2008 has been assessed subjectively and reported by Stevenson and Hoff (2009). These authors advise that the quality of species identification has improved in recent years and continues to improve. It is noted, however, that *Hippoglossoides* spp. (flathead sole *H. elassodon* and Bering flounder *H. robustus*) is one of the eleven most abundant species or species groups and is of sufficient importance to be discussed in greater detail in the groundfish data report, yet is reported in terms of the combined abundance (Lauth, 2010). This is surprising in view of the fact that length data were collected for the separate species, and otolith and dietary samples were obtained for flathead sole, suggesting that subsamples of the combined survey catches of the two species at each station could have provided data on the contribution to the catch of the individual species. While the report on groundfish and invertebrate data collected in the 2009 EBS survey advises that "fishes and invertebrates were identified and sorted to the lowest taxonomic level practicable" (Lauth, 2010), no data are presented to demonstrate or advise of the quality of species identification for the various abundance estimates that are reported.

ToR 4. Evaluate the research approaches to evaluate gear performance and estimate survey catchability.

Francis *et al.* (2003) define survey catchability as the constant of proportionality that relates the abundance or biomass of fish caught per unit of area swept to the total number or biomass of fish within the area swept. Note that, in the context of the eastern Bering Sea bottom trawl survey, the area swept by the trawl is taken to be the product of the average distance between the wings of the trawl and the distance swept by the net when the foot rope is in contact with the bottom. Lauth *et al.* (2004) advise that "Trawl survey catchability … is an estimate based on the inferred true abundance encompassing the entire spatial range of a fish population", where it is implicitly assumed that the full population is available within the survey area. They distinguish this catchability from "trawl catching efficiency", which they advise is an independent estimate of catchability, but which "only approximates trawl survey catchability because it is confined to the spatio-temporal scale of the experiment in which it is being estimated". This proportion, which Somerton *et al.* (1999) have referred to as "trawl efficiency" and have denoted by the symbol Q, is or may be affected by a number of factors including the species to which it relates, fish density, length, sex, depth, temperature, bottom type, and light intensity. Some inconsistency in terminology exists, however, as Somerton and Otto (1999), who cite Dickson (1993) as the source of their definitions, advise that "trawl efficiency" is the "proportion of animals that are captured within the area spanned by the trawl doors". In a subsequent paper, Somerton *et al.* (2007) use this same definition for the term "whole-gear efficiency". The term that Somerton and Otto (1999) employ for "the proportion of animals that are captured within the path of the trawl net" is "net efficiency". Trawl efficiency is thus considered to be a function of sweep efficiency and net efficiency, where "sweep efficiency" is the "proportion of animals within the path of the doors, bridles, and sweeps [*i.e*,. excluding those directly in the net path] that are herded into the net path".

It is essential that factors that affect the consistency of Q among different survey stations, *i.e.*, estimates of trawl survey catchability, are taken into account before producing survey-area wide estimates of relative abundance or biomass. Furthermore, an accurate estimate of Q is needed if absolute estimates of abundance or biomass within the survey area are required for fisheries management. If absolute estimates of total population abundance or biomass are required, estimates of the availability (in terms of abundance or biomass, respectively) of fish to the survey area and of the accessibility of those fish to the survey trawls, *e.g.*, the proportion of fish within their vertical distribution that occur between the bottom and the headrope of the net, will be necessary. Note that data relating to the characteristics of the size and age composition of the fish that are available and accessible to the trawls relative to those of the population, and the vulnerability of fish of different sizes that encounter the trawls are required before an estimate of the total abundance or biomass of the population, and its size and age composition, can be calculated. For these reasons, the research that has been undertaken by the AFSC to evaluate gear performance and to produce empirical estimates of trawl catching efficiency, and thus to facilitate calculation of estimates of total abundance or biomass in the survey area and trawl survey catchability, is of considerable value.

The background papers relating to research, which had been identified as being pertinent to the review, were examined. From the research results presented in these papers, it was evident that the AFSC has undertaken considerable, high quality research relating to factors affecting trawl performance, the efficiency with which animals of different sizes are caught by the trawl net, and, through use of acoustic data, how improved estimates of walleye abundance may be obtained.

Results of the research that was undertaken suggest that bottom type and hardness affect trawl performance and efficiency, and thus, when estimating abundance, there would be value in adjusting trawl efficiency to account for this factor. **It is recommended that the spatial distribution of bottom types and hardness over the survey area is mapped.**

It was also found in the research studies that, for some species, light intensity at the headrope of the net influences the efficiency of the trawl. Accordingly, to take such variation into account, light intensity at the headrope should be monitored during survey and experimental trawls. **It is recommended that light intensity at the headrope is monitored in future trawls undertaken during the annual survey or experiments.**

Through the research that has been undertaken, understanding of the factors affecting trawl performance and efficiency, and of the proportion of fish within their vertical distribution that are accessible to the trawl, has evolved. With the improved understanding of the factors involved, *e.g.,* the effect of bottom type and hardness, it is possible that improved experimental design could be employed to ensure that, rather than being representative of only those locations at which earlier experiments were undertaken and the specific values of the factors, *e.g.,* depth, temperature, light, bottom type, etc., that were experienced at those locations during those experiments, the results of trawl efficiency studies could be applied to data collected from trawl stations throughout the entire survey area taking into account the different values of the factors at those locations.

It is recommended that those earlier experiments, which produced the currently-used estimates of trawl efficiency, are reviewed in the context of current understanding of the factors influencing trawl catches and area swept to determine the extent to which it is appropriate to apply the resulting estimates of trawl efficiency to trawl stations throughout the full survey area, and to identify whether additional experiments are required to assess the influence on trawl efficiency of factors that were not considered in the original experiments.

ToR 5. Evaluate the collection of ancillary biological and environmental data in support of an ecosystem approach to fisheries management.

Although the individuals sorting and measuring the fish (subsequently termed "sorters" in this report) are instructed to measure all fish of the commercially important species in the catch (or subsample of the catch obtained through use of a cargo net and splitting bin) from each survey trawl, this is not always possible when very large catches are made. In such cases, the sorters are advised of the absolute minimum number of fish to be measured from a representative subsample from the catch of the species (or from each of two sorted and weighed subgroups if the catch of the species exhibits a distinct bimodal appearance). Instruction is also provided to the sorters of the number of fish to be randomly sampled for collection of otoliths. No instruction appears to be given as to how such random samples are to be selected for length measurement or otolith collection.

Chilton (2009) advises that, when sorting and measuring crabs, subsamples of large catches are also taken and that chela height and carapace width measurements were obtained from other subsamples of the male *Chionoecetes* spp. crabs at each station, but no details of the methods by which random subsamples are selected are provided in the data report.

There is considerable potential for bias if sorters attempt subjectively to select a random subsample. A second subsample selected with the same subjective bias might prove to have similar characteristics to the first subsample, and thus comparison of the two subsamples would be unlikely to assess whether the selection was unbiased. **It is recommended that a (statistically) well-defined process is developed to ensure that subsamples of fish for length measurement and otolith collection are randomly selected, and that details of the sampling protocols are included in appendices of future data reports for both the crab and the groundfish and other invertebrates.**

The EBS bottom trawl survey has collected a valuable time series of data on species composition and abundance of groundfish and invertebrates, and is yielding valuable data on the compositions of the diets of many of the fish species. The Review Panel was advised during the meeting that the quality of the data was adequate and the data were valuable for the ecosystem modelling that was being undertaken by the AFSC. Given the importance of the fisheries of the eastern Bering Sea, there is little doubt that a high priority should be placed on ensuring that the structure and function of this ecosystem is maintained. The long time series of data on the abundances of the various taxonomic groups that are now available as a consequence of the annual EBS bottom trawl survey, and the time series of data relating to removals by the commercial fisheries, places the AFSC in a strong position as the availability of such data should facilitate the development and refinement of ecosystem models relating to the resource.

ToR 6. Evaluate whether the survey data could be collected more cost effectively.

A reduction in the number of stations trawled during the annual survey would reduce the precision of estimates of abundance and could, if the removed stations were located at the edge of the survey area, reduce the area surveyed. While such change would introduce a discontinuity and affect the consistency of the current time series of abundance estimates, it would be possible to re-analyse the existing data to exclude the stations that had been dropped from the survey, and thereby produce a revised, consistent time series. Prior to implementing such a change, analyses of existing data would allow assessment of the extent to which precision was likely to be reduced and, if the time series were carried through into stock assessment models, the impact on the results of stock assessment. Such exploration using alternative spatial distributions of station removals would allow selection of the approach that would have least impact on the abundance estimates and stock assessment results. Note that, as observed elsewhere in this report, it would be inappropriate to consider reducing the frequency of the currently-annual bottom trawl survey.

Sample sizes appear excessive for the length measurements taken from the catches of the more abundant species at each station. **It is recommended that consideration is given to calculating the effective sample size for both the length and age composition data for the different species (*e.g.* Pennington *et al.*, 2003), and that, based on these effective sample sizes, appropriate sample sizes (allowing a conservative buffer) are set for the length data and for the numbers of fish, the otoliths of which are subjected to age determination. It is also recommended that otoliths are collected from a greater number of fish than are required for age determination, with a randomly-selected subset being subjected to age determination and the remainder stored to ensure that the age sample size could be increased if subsequent analysis indicated that such increase was required.**

The research that has been undertaken suggests that reducing tow duration from 30 to 15 minutes would have little effect on the CPUE for fish but would increase the CPUE for snow and Tanner crabs (Somerton *et al.*, 2002). Because of the reduction in the area swept, there would be less catch to process if tow duration was reduced. Overall survey time would not be greatly reduced, however, as this is determined by the time taken to travel between survey stations. Nevertheless, a reduction in tow duration could free up sufficient time to allow additional random trawl tows to be made within a subset of the grid cells, and would thus be of value to the AFSC. The question is how the transition from 30 to 15 minute tows might be achieved without breaking the consistency of the time series, and thereby reducing its value for stock assessment. Whether such a transition is possible without having a major impact on continuity and thus on stock assessment will require consideration.

It is recommended that the impacts on stock assessments for the different species of alternative approaches to implementing 15 rather than 30 minute tows in survey trawls are investigated through simulation modelling, to provide data on which an informed decision regarding a transition to 15 minute tows could be based. Such simulation modelling could be based on existing survey data and the results reported by Somerton *et al.* (2002) and other studies. While prohibitively expensive, the transition to the shorter tow duration would probably best be achieved through a considerable period of overlap, during which period the annual survey was replicated using both 30 and 15 minute tows while still covering the survey area within the same two month survey period. An approach such as this would maintain continuity, while providing the comparisons necessary to calibrate the new method. An alternative approach, if research funds permitted, might be to augment the existing annual survey with a relatively large number of randomly-positioned 15 minute tows for several years, then progress to use of 15-minute tows at the standard survey locations with additional randomly-positioned 30 minute tows for several years, before phasing out the 30 minute tows completely. If research funds do not allow additional sampling, it may be necessary to consider replacing a proportion of the existing 30-minute trawls in the annual survey by 15-minute trawls, and exploring in the simulations whether such substitution should be distributed systematically or randomly over the stations and the number of years over which the proportion of 15-minute trawls should progressively be increased. Ultimately, the question of whether to introduce the new survey approach will be determined by the extent to which the impact of the transition can be minimised, and the extent to which consistency and stock assessment are compromised by the change.

ToR 7. Provide recommendations for further improvements

Much of the research over recent years has been directed at ways in which trawl performance could be made more consistent and estimates of area swept more reliable. While there has been continued refinement to improve conformity with NOAA's standards for survey trawling (Stauffer, 2004), the greatest improvements have been to the technology used to monitor net geometry and performance. Although area swept calculations were modified in 2009 to employ the mean width between the wings of the trawl net rather than a fixed constant, many refinements to the accuracy and precision of area swept calculations, which have been made possible by the improved monitoring methods, have yet to be introduced into the standard analytical techniques employed to produce survey abundance estimates. In discussing whether these improved approaches for estimating area swept should be introduced, despite the fact that their introduction will introduce inconsistency in the time series, Kotwicki *et al.* (2011) argue that the change is to the analytical methods, not the data that are collected, and that those methods can be applied retrospectively to data extending back to the 1990s, with estimates for earlier years being derived from modelling.

Similar arguments can be applied to the introduction of the improved estimates of trawl efficiency that have arisen and will continue to arise from research experiments. Provided that appropriate correction is made to all years of data, consistency of survey catchability will be maintained throughout the adjusted time series and data will satisfy stock assessment needs.

It is recommended that, after appropriate evaluation and review by the AFSC, improved analytical methods of calculating abundance and improved estimates of catch efficiency should be introduced to ensure that current and future estimates are as accurate and precise as knowledge allows. It is inappropriate to produce estimates that are inaccurate or imprecise when more reliable estimates are available.

It is recommended that, when changes to analytical approaches or trawl efficiency estimates are made, a time series of estimates derived using the original analytical methods and original estimates of trawl efficiency should continue to be produced to accompany the improved time series, thereby allowing assessment of the effect and implications of the changes that have been made to the time series, and thus providing "continuity" between the old and new time series. By continuing to produce time series of abundance estimates derived using the previous analytical techniques and estimates of trawl efficiency, in parallel with time series of new improved estimates, for as many years as required, stock assessment models can continue to employ the original series thereby maintaining continuity, while commencing to "phase in" the new time series.

The value to stock assessment of a consistent time series of abundance estimates, covering a long time period, is indisputable. The value of consistency, however, should not constrain exploration of ways in which alternative survey design or data collection techniques could be introduced, the effect of the change determined, and the impact on the precision of stock assessment minimised. Some changes are likely to be inevitable, *e.g.,* the current need to introduce new floats for the headrope of the trawls due to the cessation of manufacture of the current aluminium floats. **It is recommended that simulation studies, which use existing survey data, should be initiated to explore the impact of alternative survey designs and procedures on the cost of surveys and the precision of stock assessment results.** Four issues that would be worth exploring are (1) a move from 30-minute to 15-minute tows; (2) introduction of a small random survey to operate in parallel with the fixed systematic survey, and thereby assist in overcoming any systematic bias that might exist; (3) a reduction in sampling density (by eliminating either a systematic or random set of stations), thereby assessing whether survey costs can be reduced while still maintaining a high quality survey; and (4) a reduction in survey cost of a specified amount, while determining the set of fixed stations, which should still be monitored, that would produce abundance estimates for different species with the greatest precision.

5. Conclusions and recommendations

A requirement to maintain absolute consistency of survey results, such that data from different years are comparable and that estimates of annual abundance are likely to be proportional to the true abundance of the population, has the potential to constrain the introduction of improved analytical approaches or improved estimates of selectivity or gear efficiency. Implicitly, there is an assumption that the survey estimate is biased, and that, through maintaining consistent survey methods and analytical approaches, such bias will be consistent. By standardising the way in which trawl surveys are conducted (Stauffer, 2004), NOAA has attempted to ensure that each trawl is as consistent as possible to all other trawls in this or other annual surveys. By standardising the design of the systematic EBS trawl survey, any systematic survey bias that exists may be assumed to be constant. By standardising analytical approaches, the time series of abundance estimates for earlier years will remain constant and new abundance estimates will be consistent with the old. The inevitable result of strict adherence to such demand for consistency is that the survey cannot adapt to new knowledge or respond when circumstances change, nor can new approaches be adopted to improve the accuracy and precision of future estimates of abundance.

Clearly, a certain level of flexibility is necessary if survey approaches are to be refined to accommodate changing research resources and allow the introduction of new analytical methods or data that will result in more reliable estimates of abundance. Yet it is also clear that sufficient continuity and consistency will need to be maintained to ensure that time series of abundance estimates provide the information that is required by stock assessment models and fishery managers.

The major recommendations that have been proposed in this report are intended to introduce a strategy that will allow progressive improvement of survey methods, analytical techniques, and trawl efficiency estimates while still meeting the needs for consistency and continuity. Thus it is proposed that simulation is undertaken to explore ways in which transition from one survey method to another might be implemented over a series of years while ensuring that the impact of that transition on stock assessment is minimised, and that, by producing time series of estimates calculated using both old and new analytical approaches and efficiency estimates for a number of years, the new approaches and estimates might be introduced while still providing consistent data for use in stock assessment models.

A great strength of the trawl survey group in the AFSC is their commitment to high quality and innovative research. By adopting a strategy that encourages continued improvement of analytical techniques and trawl efficiency estimates and which overcomes any “inertia” that currently results from the desire for continuity and consistency, the abundance estimates that are produced from the trawl surveys will be assured of being as accurate and precise as knowledge and data allow.

6. References

Note: References are also made in the text to documents and papers listed in the bibliography of materials provided for the review (Appendix 1).

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Appendix 1: Bibliography of all material provided

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In addition to the above documents, a document entitled "Groundfish Assessment Program literature on trawl catchability, survey standardization, acoustics and survey data analysis" was provided to the panel. This document provided a select bibliographic list of the publications by Groundfish Assessment Program staff on issues related to the various topics considered in the CIE review. Apart from one paper, which is still in preparation and was not yet available, the papers in that bibliography, which are listed below, were also accessed and read prior to the CIE review.

Trawl catchability

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Appendix 2: Copy of CIE Statement of Work

Statement of Work for Dr. Norm Hall

External Independent Peer Review by the Center for Independent Experts

Eastern Bering Sea Crab and Groundfish Bottom Trawl Surveys

Scope of Work and CIE Process: The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. The Statement of Work (SoW) described herein was established by the NMFS Project Contact and Contracting Officer's Technical Representative (COTR), and reviewed by CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest. CIE reviewers are selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee and the report is to be formatted with content requirements as specified in **Annex 1**. This SoW describes the work tasks and deliverables of the CIE reviewer for conducting an independent peer review of the following NMFS project. Further information on the CIE process can be obtained from www.ciereviews.org.

Project Description: The Alaska Fisheries Science Center (AFSC) requests a Center of Independent Experts (CIE) review of the eastern Bering Sea crab and groundfish bottom trawl surveys. The data from this survey are used in more than 25 stock assessments conducted by the AFSC as well as the State of Alaska and the International Pacific Halibut Commission. Although all AFSC bottom trawl surveys, as well as those conduct by other NMFS science centers, were examined closely during the development of the NOAA Bottom Trawl Protocols in 2004, the AFSC surveys have never been formally reviewed by a CIE panel. The AFSC has conducted considerable research on factors affecting trawl performance and catchability and their impacts on resulting survey estimates of distribution and abundance. However, in recent years the trawl and survey performance and results of this multi-species survey have come under scrutiny by industry, particularly with respect to Bering Sea red king crab, snow crab, and Pacific cod. Considering the importance of the data produced by the Bering Sea bottom trawl surveys, a CIE review in 2012 would be timely and beneficial. The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**. The tentative agenda of the panel review meeting is attached in **Annex 3**.

Requirements for CIE Reviewers: Three CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. CIE reviewers shall have working knowledge and recent experience in the application of stock assessment, including population dynamics, survey design and methodology, and statistical analysis. It is not expected that each of the three reviewers have all of these specialized areas of expertise, rather that at least one of the three reviewers should be knowledgeable in each of these areas. Reviewers should also have experience conducting stock assessments for fisheries management. Each CIE reviewer's duties shall not exceed a maximum of 14 days to complete all work tasks of the peer review described herein.

Location of Peer Review: Each CIE reviewer shall conduct an independent peer review during the panel review meeting scheduled in Seattle, Washington tentatively during April 10-12, 2012.

Statement of Tasks: Each CIE reviewers shall complete the following tasks in accordance with the SoW and Schedule of Milestones and Deliverables herein.

Prior to the Peer Review: Upon completion of the CIE reviewer selection by the CIE Steering Committee, the CIE shall provide the CIE reviewer information (full name, title, affiliation, country, address, email) to the COTR, who forwards this information to the NMFS Project Contact no later than the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to the CIE reviewers. The NMFS Project Contact is responsible for providing the CIE reviewers with the background documents, reports, foreign national security clearance, and other information concerning pertinent meeting arrangements. The NMFS Project Contact is also responsible for providing the Chair a copy of the SoW in advance of the panel review meeting. Any changes to the SoW or ToRs must be made through the COTR prior to the commencement of the peer review.

Foreign National Security Clearance: When CIE reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for CIE reviewers who are non-US citizens. For this reason, the CIE reviewers shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/sponsor.html).

Pre-review Background Documents: Two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to the CIE reviewers the necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE Lead Coordinator on where to send documents. CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein. The CIE reviewers shall read all documents in preparation for the peer review.

Panel Review Meeting: Each CIE reviewer shall conduct the independent peer review in accordance with the SoW and ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs can not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COTR and CIE Lead Coordinator.** Each CIE reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the ToRs as specified herein. The NMFS Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The NMFS Project Contact is responsible for ensuring that the Chair understands the contractual role of the CIE reviewers as specified herein. The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

Contract Deliverables - Independent CIE Peer Review Reports: Each CIE reviewer shall complete an independent peer review report in accordance with the SoW. Each CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each

CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

Other Tasks – Contribution to Summary Report: Each CIE reviewer may assist the Chair of the panel review meeting with contributions to the Summary Report, based on the terms of reference of the review. Each CIE reviewer is not required to reach a consensus, and should provide a brief summary of the reviewer's views on the summary of findings and conclusions reached by the review panel in accordance with the ToRs.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables**.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Participate in the panel review meeting in Seattle, Washington during April 10-12, 2012.
3) In Seattle, Washington during April 10-12, 2012 as specified herein, conduct an independent peer review in accordance with the ToRs (**Annex 2**).
4) No later than April 26, 2012, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and CIE Regional Coordinator, via email to David Die ddie@rsmas.miami.edu. Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in **Annex 2**.

Schedule of Milestones and Deliverables: CIE shall complete the tasks and deliverables described in this SoW in accordance with the following schedule.

March 6, 2012	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
March 27, 2012	NMFS Project Contact sends the CIE Reviewers the pre-review documents
April 10-12, 2012	Each reviewer participates and conducts an independent peer review during the panel review meeting
April 26, 2012	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
May 10, 2012	CIE submits CIE independent peer review reports to the COTR
May 17, 2012	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: This 'Time and Materials' task order may require an update or modification due to possible changes to the terms of reference or schedule of milestones resulting from the fishery management decision process of the NOAA Leadership, Fishery Management Council, and Council's SSC advisory committee. A request to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent changes. The Contracting Officer will notify the COTR within 10 working days after receipt of all required information of the decision on changes. The COTR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the CIE reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

Acceptance of Deliverables: Upon review and acceptance of the CIE independent peer review reports by the CIE Lead Coordinator, Regional Coordinator, and Steering Committee, these reports shall be sent to the COTR for final approval as contract deliverables based on compliance with the SoW and ToRs. As specified in the Schedule of Milestones and Deliverables, the CIE shall send via e-mail the contract deliverables (CIE independent peer review reports) to the COTR (William Michaels, via William.Michaels@noaa.gov).

Applicable Performance Standards: The contract is successfully completed when the COTR provides final approval of the contract deliverables. The acceptance of the contract deliverables shall be based on three performance standards:
(1) each CIE report shall be completed with the format and content in accordance with **Annex 1**,
(2) each CIE report shall address each ToR as specified in **Annex 2**,
(3) the CIE reports shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Distribution of Approved Deliverables: Upon acceptance by the COTR, the CIE Lead Coordinator shall send via e-mail the final CIE reports in *.PDF format to the COTR. The COTR will distribute the CIE reports to the NMFS Project Contact and Center Director.

Support Personnel:

William Michaels, Program Manager, COTR
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Manoj Shivlani, CIE Lead Coordinator
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Roger W. Peretti, Executive Vice President
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Key Personnel:

David Somerton, NMFS Project Contact
NMFS Alaska Fisheries Science Center
7600 Sand Point Way NE., Seattle, WA 98115-6349
david.somerton@noaa.gov Phone: 206-526-4116

Annex 1: Format and Contents of CIE Independent Peer Review Report

1. The CIE independent report shall be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether the science reviewed is the best scientific information available.

2. The main body of the reviewer report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Summary of Findings for each ToR in which the weaknesses and strengths are described, and Conclusions and Recommendations in accordance with the ToRs.

   a. Reviewers should describe in their own words the review activities completed during the panel review meeting, including providing a brief summary of findings, of the science, conclusions, and recommendations.

   b. Reviewers should discuss their independent views on each ToR even if these were consistent with those of other panelists, and especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the Summary Report that they feel might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The CIE independent report shall be a stand-alone document for others to understand the weaknesses and strengths of the science reviewed, regardless of whether or not they read the summary report. The CIE independent report shall be an independent peer review of each ToRs, and shall not simply repeat the contents of the summary report.

3. The reviewer report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of the CIE Statement of Work
   Appendix 3: Panel Membership or other pertinent information from the panel review meeting.

Annex 2: Tentative Terms of Reference for the Peer Review

Eastern Bering Sea Crab and Groundfish Bottom Trawl Surveys

1. *Evaluate the data collection operations and sampling design of the survey in term of their adequacy for producing consistent and precise estimates of relative abundance for the various fishes and invertebrates of concern.*
2. *Evaluate the analytical methodology.*
3. *Evaluate the procedures used for data quality control and archiving.*
4. *Evaluate the research approaches to evaluate gear performance and estimate survey catchability.*
5. *Evaluate the collection of ancillary biological and environmental data in support of an ecosystem approach to fisheries management.*
6. *Evaluate whether the survey data could be collected more cost effectively.*
7. *Provide recommendations for further improvements*

Note – CIE reviewers typically address scientific subjects, hence ToRs usually do not involve CIE reviewers with regulatory and management issues unless this expertise is specifically requested in the SoW.

Annex 3: Tentative Agenda

CIE Review of the Eastern Bering Sea Crab and Groundfish Bottom Trawl Surveys
Alaska Fisheries Science Center
7600 Sand Point Way NE, Seattle, WA 98115
Building 4; Room 2076 (April 10-12, 2012)

Review panel chair: David Somerton, david.somerton@noaa.gov

Survey group leaders: Robert Lauth, bob.lauth@noaa.gov (groundfish) and Robert Foy, robert.foy@noaa.gov (crab)

Security and check-in: Ron Erickson, ron.erickson@noaa.gov
Sessions will run from 9 a.m. to 5 p.m. each day, with time for lunch and morning and afternoon breaks.
Discussion will be open to everyone, with priority given to the panel, presenters, and survey group leaders.

Tuesday, April 10th

0900 Welcome and Introductions. The EBS environment and commercial fisheries (*Somerton*)

0930 The EBS survey (*Lauth & Foy*)

History of the EBS survey, current sampling design including the use of charter vessels. Description of the trawl pre- and post- 1982. Wheelhouse activities and catch processing procedures – i.e. how we do a tow. Area swept estimation – how we do it and why.

10:30 break

11:00 The EBS survey (continued**;** *Lauth & Foy*)

11:30 Database, data editing and QA (*Vijgen*)

12:00 Lunch

13:00 Survey standardization (*Weinberg*)

14:00 Tour of net shed

1530 Analytic methodologies used for the estimation of relative abundance (*Lauth & Foy*)
Area swept estimation: new approaches. Biomass and variance calculation.
The fishing power correction. Post hoc sampling for crab – hot spots and retows.

Wednesday, April 11th

0900 Q research - demersal fish and crabs (*Somerton*)
Snow crab selectivity. Escapement and herding of flatfish. Vertical availability of Pcod. Light and vertical distribution

10:15 Break

10:30 Use of acoustics on the EBS survey (*Kotwicki*)

AVO project (collect acoustics for others). Acoustic and bottom trawl blind zones (combining acoustic and bottom trawl survey for pollock). Using acoustics to estimate pollock between stations to improve biomass estimate.

12:00 Lunch

1300 Presentations on the survey estimates and uncertainty relative to model assumptions and structure: introduction (*Somerton*)

13:15 Snow crab (*Turnock*)

13:45 Pollock (Ianelli)

14:15 Break

14:30 Discussion between CIE committee and survey scientists

Thursday, April 12th

0900 -1200 Presentations on the survey estimates and uncertainty relative to model assumptions and structure (continued)

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noon -1300 Lunch

1300 -1700 Discussion and wrap-up

Appendix 3: Membership of Review Panel

Members of the review panel:

- David Somerton (Chair)
- CIE Reviewers
    - Jon Vølstad, Head of Research Group on Fisheries Dynamics, Institute of Marine Research, Bergen, Norway.
    - Yong Chen, Professor, School of Marine Sciences, University of Maine, Orono, ME.
    - Norman Hall, Professor, Centre for Fish and Fisheries Research, Murdoch University, Australia.