Center for Independent Experts (CIE) Report on the Independent Peer Review of the Kona Crab Benchmark Assessment

N. G. Hall

Unit 2
2 Wexford Street
Subiaco
Western Australia 6008
Australia
Phone: +61 8 9401 6891
Email: nghall@iinet.net.au

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1. Executive Summary

The benchmark assessment of the Main Hawaiian Island (MHI) Kona crab fishery is based on an analysis of commercial landings data. Catches per unit of effort (CPUE), measured as landings (kg) per trip, were standardised using a generalized linear model (GLM) to remove the influence of season and island platform. The resulting time series of standardized annual CPUE estimates was input to the ASPIC software package and used as an index of abundance in a generalized production model, which was conditioned on the annual landings by the commercial fishery. The model was fitted to data for 1970–2006 as it was suspected that earlier data had been considerably underreported and data after September 2006 had been affected by introduction of a prohibition on landing female crabs. The resulting parameter estimates for the production model provided the data required for status determination. Projections of future biomass were produced with the fitted production model using the reported commercial landings from 2007–2009 and assuming a constant annual catch in subsequent years.

The GLM method, which was used to standardise CPUE, is the most commonly used approach for such analyses, and the software is well tested and sound. The decision to employ a generalized production model to describe the MHI Kona crab fishery and assess the status of its stock was appropriate given the types of data available for analysis. The ASPIC software package, which was used to fit this model, is also well tested and sound, and provides the ability to project estimates of biomass for specified levels of future catch or fishing mortality.

Parameter estimates of the generalized production model fitted to commercial landings for 1970–2006 were used to establish Status Determination Criteria for the stock, i.e. a Minimum Stock Size Threshold (MSST) = 50% of B_{msy}, and a Maximum Fishing Mortality Threshold (MFMT) = F_{msy}. Both the point estimate of $B_{2007}/B_{\mathrm{msy}}$ and its upper 90% limit fell below 0.5, providing strong evidence that, in 2007, the MHI Kona crab population was overfished. The point estimate of $F_{2006}/F_{\mathrm{msy}}$ fell just below 1, and thus overfishing was not occurring in 2006. This latter conclusion should be viewed with caution, however, as the 90% confidence interval for this fishing mortality ratio was wide. It should also be noted that the influence of technological change and the likely hyperstability of the fishery-dependent index of abundance were not taken into account in the assessment, adding further unquantified uncertainty to the finding.

While the above status determination is the best available for the MHI Kona crab fishery, it is important to recognise that, because recreational landings data were not available, the generalized production model on which the assessment was based was fitted to commercial landings, not total landings. This introduced an important, unquantified uncertainty into the results of the assessment and the determination of stock and exploitation status, as the shape of a production model fitted to total landings data might have differed considerably from that of a model estimated using only landings data. If annual recreational landings were a constant proportion of total landings, however, the estimates of fishing mortality calculated by the model would have been the same as those of the population, and biomass and carrying capacity estimates would have been the same fraction of total biomass and population carrying capacity as the fraction that commercial catches comprise of total catches. Furthermore, status determination based on the model of commercial landings would correctly assess the status of the population. Thus, the extent to which the status determination derived from the production model fitted to commercial landings data reflects the true status of the MHI Kona crab population is dependent on the validity of the assumption that recreational landings are a constant proportion of total landings. Despite this additional uncertainty, given the decline in standardised CPUE in recent years and the very strong indication from the fitted production model that, in 2007, the stock was overfished, it is likely that, had a production model been fitted to total landings, it would still have been concluded that, in 2007, the stock was overfished. Whether it would still have been concluded that overfishing was occurring in 2006 is uncertain. Based on the projections of biomass presented in the Assessment Report, it is unlikely that the overfished status of the population would have improved by 2010.

Projections calculated using the production model fitted to the commercial landings data for 1970–2006, and employing the commercial landings made after September 2006 treat the later removals as a mixture of both females and males rather than just males, despite the introduction of the prohibition on landing female crabs. The projections also calculate biomass response using the fitted 1970–2006 production model, and thus assume that biomass would respond to the male-only removals and biomass change in the same way it would have responded prior to 2006 when landings comprised both females and males. As the proportion of females in the population will have increased with the move to a male-only fishery, the projected estimates of biomass calculated using the 1970–2006 production model are likely to have underestimated the production that would occur for a male-only fishery. While the projected biomasses reported in the Assessment Report are therefore likely to be conservative, this may be appropriate given the uncertainty due to the lack of recreational data.

The Benchmark Assessment provides a determination of stock status in 2007, and an updated assessment is needed. Because of the prohibition on landing females that was introduced in September 2006, such updating is not simply a matter of refitting the 1970–2006 production model to data from 1970–2015. Prior to September 2006, landings per trip reflected the biomass of legal-sized crabs, but afterwards reflected only the biomass of legal-sized males. The parameters of a production model fitted to the latter type of data will differ considerably from those of a model fitted to the 1970–2006 data, and such a model will have little ability to provide an assessment of the status of the spawning biomass of female crabs. It is not appropriate to discard the 1970–2006 data and fit a new production model to data for 2007–2015, as the latter data will lack the contrast necessary to produce reliable estimates of parameters. It is strongly recommended that a new model is developed to describe the dynamics of both the female and male Kona crabs, and which would make use of both the 1970–2006 commercial landings data and the male-only commercial landings reported by fishers following 2006. Such a model would also need to make use of data relating to the numbers of females that are released.

Although lack of data for the recreational fishery has introduced uncertainty, the benchmark assessment of the MHI Kona crab fishery provides the best available scientific advice regarding the status of the fishery and its level of exploitation, and thus, provided the risk associated with the unquantifiable uncertainty is recognised, estimates of stock status and projections are appropriate for use by fishery managers. The assessment team is commended for its efforts.

2. Background

2.1. Overview

A peer review of the 2010–2011 assessment of the Main Hawaiian Island (MHI) Kona crab (*Ranina ranina*) fishery, the report of which was prepared by Thomas et al. (2015), was undertaken in November 2015. As the most-recent, previous assessment of this fishery had been conducted over 30 years earlier and current stock status was classified as 'unknown', this new assessment was intended to provide a benchmark that would guide future management of the MHI Kona crab fishery. The external, independent reviewer appointed by the Center for Independent Experts (CIE) to undertake the review of this benchmark assessment was Dr Norman Hall.

A list of the background material provided for the review is presented in Appendix 1.

The Statement of Work (SoW) provided to Dr Hall by the CIE is attached as Appendix 2. This SoW required the production, following an independent peer review of the report describing the benchmark assessment for the MHI Kona crab fishery and other background material, of a report providing details of findings with respect to each Term of Reference (ToR) listed in the SoW.

2.2. Terms of Reference

The terms of reference for review of the Kona Crab Benchmark Assessment are presented in the Statement of Work (Appendix 2).

2.3. Reviewer

The review was undertaken by a single reviewer appointed by the CIE, i.e. Dr Norman Hall.

2.4. Date and place

The independent peer review was undertaken by the reviewer as a desk review, in his office at Perth, Western Australia. Reading of background material commenced on 6 November 2015, following its receipt, and the formal review commenced on 12 November, 2015, when the Terms of Reference became available on receipt of the Statement of Work for the review.

3. Description of Reviewer's role in review activities

Following its receipt on 6 November, 2015, the background material for the review was studied (Appendix 1). Subsequently, following receipt of the Statement of Work on 12 November, 2015, the background material was examined in greater detail, and in the context of the Terms of Reference specified in the Statement of Work. Based on this detailed examination, a report describing the reviewer's evaluation of the Benchmark Stock Assessment for MHI Kona crabs was prepared.

4. Summary of findings relevant to review of the Terms of Reference of the Kona Crab Benchmark Assessment

ToR 1. Evaluation of data quality and data application within the assessment model

In their report of the 2010–2011 assessment of the Main Hawaiian Island (MHI) Kona crab fishery (hereafter termed the 'Assessment Report'), Thomas et al. (2015) provide details of the data that are available for this fishery and describe the broad geographical distribution of this species throughout the sub-tropical Indo-Pacific region and the fisheries that exploit the species, noting that the MHI fishery lies at the eastern-most end of this geographical range. Thomas et al. (2015) also collate and present data on the taxonomic classification of the species, its behaviour, the habitat in which individuals of the species are found, and the biological characteristics of the species and its life cycle.

Stock structure

A weakness of the data available for the assessment is that genetic information on stock structure of the Kona crabs in the waters of the Hawaiian Archipelago, and, more specifically, in waters around the MHI, is not available. Given the lack of such data, however, the decision to manage the MHI Kona crab 'stock' as a separate unit is sound, provided that the abundances of other presumptive 'stocks' in the Hawaiian Archipelago are maintained at appropriate levels. It should be recognised that, if managed stocks in different regions of the Archipelago are connected, an unacceptable decline in abundance of one population may affect the abundances of connected stocks. In the absence of genetic data, it would be prudent to monitor and be aware of the status of other managed stocks in the region when assessing the status of the MHI stock. Similarly, the status of the MHI stock should be considered when assessing the status of other managed Kona crab fisheries in the region. The possibility that Kona crabs in the waters of the MHI comprise more than one stock should also be recognised by monitoring and reporting the spatial distribution of the crabs in the different regions of the MHI (e.g., as was done by Thomas (2013)) with a view to detecting changes in distribution that might reflect local depletion.

Commercial landings

The Assessment Report advises that, in Hawaii, Kona crab is targeted by both commercial and recreational fishers and (presumably at the time when the report was prepared) comprised over 25% of all commercial crab landings. Note that it would have been useful to present the time series of commercial catches of Kona crabs and crabs of other species from the waters of the MHI as a table in the Assessment Report, such that the trend in the relative contribution of Kona crabs to the overall catches of crabs might be more readily assessed.

The long time series of commercial landings data for Kona crabs from the MHI fishery provided the key information on which the stock assessment is based, and is thus a strength of the assessment. Although Kona crab fishers with a commercial fishing license have been required to submit monthly landings reports since the 1930s, the time series of commercial data available for use in the assessment begins in 1948. From the

Assessment Report, it appears that these landing reports have provided details of the dates of the fishing trips, the statistical fishing area, and both the mass and number of crabs landed per trip by each commercial fisher for each month from 1948 to 2009. The Assessment Report notes that, from October 2002, more detailed effort and release data have been collected in the monthly reports supplied by commercial fishers. The additional data include details of the type and number of units of gear used on the trip, total soak time of the gear, number of crabs lost to predation and number of crabs that were released. The Assessment Report notes, however, that there have been inconsistencies in how the number of nets were reported by fishers after 2002, but does not report the action (if any) taken to resolve this issue, and whether the issue has now been resolved. Although the Assessment Report mentions "dealer" reports, no additional details of these are provided.

The Assessment Report advises that the monthly commercial landing reports are screened for missing data, statistical outliers, or data that were not consistent with reporting instructions, and that, if such errors or inconsistencies were detected, the reporting fisher was contacted for clarification. Reports that could not be verified amounted to <3% of all reported landings and effort and were removed. It is not clear from the Assessment Report whether, when fitting the generalized production model, any adjustment was made to account for the deleted records. Tables of the proportions removed each year should be included in the Assessment Report, however, and the assessment model should be modified to take estimates of these removed data into account.

No mention is made in the Assessment Report of any study that has assessed the accuracy and completeness of landings, effort, and statistical locations of fishing reported by commercial fishers through 1948 to 2009. The report also provides no details of whether or not illegal commercial landings of MHI Kona crabs were made between 1948 and 2009, and, if so, the likely magnitudes of those landings. Citing Brown (1985), the Assessment Report does advise that "landings during the early phases of the fishery are suspected to be underreported by as much as 50%". Based on this, the decision was made to exclude commercial data for years earlier than 1970 when fitting the stock production model to assess the status of the MHI Kona crab stock. Presumably some action was taken to improve accuracy of reporting. It would have been useful if the Assessment Report had included a comment to explain the improvement, and had advised the results of studies or data that support the view that data collected after 1970 are of sufficient accuracy and precision to be used in the benchmark assessment.

Prior to 2002, commercial fishers were allowed to retain undersized crabs for personal consumption. The Assessment Report provides no advice regarding the magnitude of the landings of such undersized crabs, nor does it advise whether such crabs were included in the landings reported by commercial fishers, or were unreported. The fact that commercial fishers were allowed to retain undersized crabs for personal consumption raises the question of whether or not recreational fishers were also allowed to retain such crabs for personal consumption in the years prior to 2002.

Recreational landings

Details of recreational landings of Kona crabs from the MHI stock are unknown but likely to be substantial, according to the Assessment Report, which cites Brown (1985) and Pooley (1993).

The lack of data relating to the recreational fishery is a serious impediment to accurate stock assessment and is recognised as a key source of uncertainty. While it is possible to use the CPUE of the commercial fishers as a measure of population biomass (albeit a possibly poor measure, as it may not be directly proportional to that biomass), reliable determination of how population biomass responds to changes in biomass is hampered if the total biomass removed from the population is unknown. Restating this, reliable determination of the status of a population or the level of exploitation that it is experiencing is difficult without both an index of its biomass and a time series of total removals data. Implicitly, the benchmark stock assessment of the MHI Kona crab population has assumed that recreational landings are directly proportional to commercial landings. If this assumption is true, commercial landings are a constant fraction of total landings and fishing mortality estimates calculated using the production model fitted to commercial landings will accurately reflect the fishing mortality experienced by the population, estimates of biomass and carrying capacity will reflect the same proportions of total biomass and carrying capacity as the proportion that commercial landings comprise of the total landings, and status determination based on the production model and commercial landings will accurately reflect the status of the MHI Kona crab population. Conclusions regarding stock status and exploitation of the population based on the results from the generalized production model that was fitted to commercial landings data are thus conditional on the validity of this assumption.

Removals through mortality of released crabs

It is important to note that a fishery production model, such as has been used for the Benchmark Assessment of MHI Kona crabs, describes the changes in biomass expected as a result of both biological processes, such as birth, growth and natural mortality, and removals from the stock that result from fishing. Such removals include landings made by all fishing sectors and deaths of released individuals that result from their capture and release experience. As noted above, the production model for MHI Kona crabs currently accounts only for commercial landings, and excludes recreational landings. It also fails to account for removals associated with mortality of crabs that have been released after disentanglement from the nets in which they were caught.

The Assessment Report provides no estimate of the biomass of crabs released each year, or of the biomass of released crabs that are expected to die as a result of capture and release. It is thus not possible to assess the extent to which failure to account for the mortality of released crabs in the production model is likely to have biased the results of the assessment. It is noted, however, that studies described in the Assessment Report have provided evidence that Kona crabs are incapable of autonomy, and that released crabs exhibit high mortality if they have lost limbs or any of their dactyli when disentangled from tangle nets. The Assessment Report notes that present fishing (and presumably disentanglement) methods in the MHI fishery are likely to result in elevated mortality of released crabs.

Fishery-dependent index of abundance

The measure of commercial effort used in the assessment is the 'fishing trip'. Inconsistencies in reporting the number of nets used precluded the use of 'nets set per fishing trip' as a measure of effort for data collected after October 2002. The Assessment Report did not advise whether action has been taken to address the reporting inconsistencies, and whether such action has proved successful. As noted in the Assessment Report, the effectiveness of 'fishing trip' as a measure of effort would be influenced by the number of nets set per trip. It would also be influenced by soak time, and by technological improvements such as radar, echo sounders, GPS, etc.

The production model used to describe the dynamics of the MHI Kona crab population from 1970 to 2006 employed the standardized catch per unit of effort (CPUE) calculated from commercial fishery landings as an index of population biomass and used the annual landings made by the commercial fishery as the measure of removals of biomass on which the model was conditioned. The standardized CPUE was calculated using the masses of crabs reported by commercial fishers as having been landed for the different fishing trips undertaken each year, and accordingly excluded undersized crabs and, in the spawning season when ovigerous females are present, berried (egg-bearing) females, which were released. A production model fitted using total landings would have provided a description of the dynamics of the biomass of the legal-sized females and males in the Kona crab population. The model fitted to the commercial landings data for 1970–2006 reflects the relationship between the legal-sized biomass (which varies in response to total landings) and the reported commercial landings, where the ratio of annual commercial to recreational landings may have varied through time with changing recreational fishing effort.

It should be noted that, from September 2006, landings by commercial fishers comprised only legal-sized male crabs, and the standardized CPUE calculated for this period was derived from the landings per trip of legal-sized males. A production model describing the dynamics of the post-2006 MHI Kona crab fishery, and employing removals and an index of abundance based on male-only landings would provide a representation of the legal-sized male portion of the biomass exploited by the commercial fishery; and thus, its dynamics would differ markedly from the dynamics of the 1970–2006 production model. If the post-2006 status of spawning female biomass is to be determined, it would be inappropriate to discard the data from 1970–2006, and to develop a production model for post-2006 data that describes only the dynamics of the biomass of legal-sized males. For future assessments of the MHI Kona crab fishery, a new model will need to be developed that describes the dynamics of both females and males, and which employs the data from both 1970–2006 and subsequent years. Such a model will almost certainly require data on released berried and non-berried females of legal size.

Subjectively, the plots of the spatial distribution of Kona crab CPUE and commercial fishing effort presented by Thomas et al. (2013) suggest a contraction of the range of the crabs and concentration of fishing effort on areas in which crabs remain relatively more abundant. This would tend to support the concern that commercial CPUE is likely to exhibit hyperstability. There would be value in investigating the extent to which CPUEs within the individual statistical fishing areas have been reduced, as the generalized production model assumes a whole-of-stock response and does not provide information on the extent to which the spatial structure of the stock may have been affected by fishing.

Fishery-independent indices of abundance

In the absence of fishery-independent indices of abundance, it was necessary to use the time series of fishery-dependent, standardized CPUE to inform the model of the ways and extent to which the exploited biomass responded to removals, i.e. in the case of the MHI Kona crab assessment, commercial landings. The absence of such fishery-independent data is a weakness that affects the quality of the assessment, as fishery-dependent indices of abundance often exhibit hyperstability, remaining high despite declining abundance (e.g. Harley et al., 2001).

Biological data

The lack of data relating to the specific biological characteristics of Kona crabs for the MHI population is a weakness that constrains the structure of the fishery models used to describe the dynamics of the population. The generalized production model fitted to the 1970–2006 landings and standardized CPUE for the commercial fishery requires no biological data, and thus avoids some of the limitations of the types of data that are available. Future extension of the model to incorporate size and sex structure, and to ensure that the dynamics of the model accurately reflect the biological processes of growth, maturation and reproduction, will require improved knowledge of the biology of the MHI stock. Such extension has the potential of contributing information on fishing mortality from size and sex compositions of samples collected from annual landings and releases, supplementing the information contained in standardized CPUEs calculated for landed and released crabs, and thereby improving the accuracy of stock assessment. Note that data on the size- and sex-dependent selectivity of the crabs to the fishing gear will also be required if the models are extended in this way.

The following issues relating to the biology of the MHI Kona crab stock were identified.

The Assessment Report notes that growth of Kona crabs and the sizes at which individuals of this species attain sexual maturity differ by region and sex. Citing a study by Onizuka (1972), the report advises that, in Hawaii, females and males grow on average 0.30 and 0.39 inches per molt, respectively. Without data on the average sizes of the individuals of each sex that are molting, and comparable data on the average molt increments for Kona crabs of similar sizes in other populations for which growth has been studied, it is not possible to assess how growth in the MHI population compares with that reported in those other studies. For clarity, it would have been useful to include in the Assessment Report a diagram showing how the carapace length of Kona crabs in the MHI is measured, and, when discussing data from growth and reproductive studies for this and other populations of this species, ensuring (and advising) that all lengths included in the Assessment Report are based on the same measurement.

Citing Fielding and Haley (1976), the Assessment Report advises that, “in Hawaii, the majority of males were found to have mature spermatozoa at a 2.9 inch carapace length”, i.e. 74 mm. Fielding and Haley (1976) report, however, that males with length > 60 mm have mature spermatozoa, and that secondary (morphometric) sexual characteristics develop at a carapace length of ~75 mm. Citing Onizuka (1972), the

Assessment Report advises that, “in Hawaii, over 87% of females were sexually mature with a 2.6 inch [66 mm] carapace length”. In contrast, Fielding and Hay (1976) found that, during the spawning season, the smallest carapace length class in which at least 50% of females were ovigerous was 70.0-74.9 mm. These inconsistencies may relate to differences in the size distributions of the crabs studied by Onizuka (1972) and Fielding and Hay (1976), but suggest that further studies on this aspect of the biology of MHI Kona crabs may be warranted. Despite the above inconsistencies, however, it is evident that both female and male crabs will have attained maturity at lengths smaller than the minimum legal carapace length of 4 inches for Kona crabs from the MHI fishery.

ToR 2. Evaluation of methods used to assess the stock:
- Are methods scientifically sound and robust?
- Are methods appropriate for the available data?
- Are methods applied correctly?

Methods used to assess the stock

The MHI Kona crab stock was assessed by developing a standardized time series of commercial landings (kg) per trip from landing reports for 1948 to 2009, then fitting a generalized production model to commercial landings data from 1970 to 2006 using these standardized CPUEs as an index of population biomass. The assessment, which was described in the Kona crab benchmark assessment report prepared by Thomas et al. (2015), was conducted in 2010 and 2011. The first stage of the assessment employed a generalized linear model (GLM) to standardize the CPUE data, following which, in the second stage, the ASPIC (ver. 5) software package was used to fit the generalized production model and to undertake subsequent sensitivity analyses and population projections.

Are methods scientifically sound and robust?

(a) Standardization of CPUE data

GLM analysis is the most common of the methods used to standardize CPUE data, and the software used to undertake the analysis is well-tested and sound (Maunder and Punt, 2004). If the number of fishers is small, however, consideration might be given to applying a generalized mixed-effects (hierarchical) model approach and using fisher as a random effect, thereby accounting for the correlation likely to exist among values of CPUE reported for the different trips undertaken by individual fishers (e.g. Dennard et al., 2010).

(b) Generalized production model

The ASPIC model (Prager, 1984) has been employed in numerous assessments and is well-tested and scientifically sound. The methods that are implemented in the software have been described in scientific papers that have been subjected to peer review and published.

Although not affecting the ASPIC software or assessment, there are several errors in the description of the model in the Assessment Report for MHI Kona crabs. In particular, the equations on page 12 of the report have been incorrectly transcribed. The correct equations are:

$$dB_t/dt = \gamma m\, B_t/K - \gamma m(B_t/K)^n - F_t B_t$$

$$\gamma = n^{n/(n-1)}/(n-1)$$

and

$$\phi = (1/n)^{1/(n-1)}$$

The equation on page 13 of the Assessment Report, which defines the convergence criterion, is also incorrect and should be:

$$2|L_1 - L_0|/(L_1 + L_0)$$

and the variables L_1 and L_0 in this equation should be defined as the highest and lowest values of the objective function at the points of the current simplex calculated by the Nelder and Mead (1965) optimization algorithm, which is used by ASPIC.

The Assessment Report advises that the ASPIC model was fitted to fishery data for 1970–2006 assuming a single catchability, and then to the same data assuming separate catchabilities for the fishery for 1970–1998 and 1998–2006. The resulting estimates of the Akaike Information Criterion (AIC) were compared to determine whether the data supported the hypothesis that catchability changed following prohibition on the use of crab nets on bottomfishing vessels. As it is unlikely that data for 1998 were included in both the earlier and later periods when the generalised production model was fitted under the assumption that the catchabilities of the two periods might differ, further clarification should be provided in the Assessment Report.

The Assessment Report advises that a t-test was also used to compare the two catchability estimates produced when separate catchabilities were assumed for the periods prior to and following the prohibition on the use of crab nets when bottomfishing. Reference is made to a paper by Prager, which was published in 2011, but this paper is not included in the list of literature that is cited. I would suggest that the use of this t-test is likely to be inappropriate, as the estimates of the two catchabilities produced by ASPIC are probably not independent, i.e. each parameter estimate is influenced by the values of the other parameters of the ASPIC model, where the extent of influence is reflected in the variance-covariance matrix for the fitted parameter estimates. The finding that the AIC for the two-catchability production model was substantially (>2 AIC units) less than that for the single catchability model is sufficient evidence that catchability changed when the regulation prohibiting the use of crab nets on bottomfishing vessels was introduced. Note that the actual AIC values for the two models should be presented in the Assessment Report, as the magnitude of the difference provides useful information.

Are methods appropriate for the available data?

(a) Standardization of CPUE data

As noted above, repeated measures of CPUE by individual fishers are likely to exhibit correlation. It may be worth considering the use of a generalized mixed-effects model, treating fisher as a random-effect, to address this issue.

It may be useful to consider applying the GLM analysis to the pooled data for 1948–1997, 1999–2005, and 2007–2009, rather than undertaking separate analyses for the three periods. The exclusion of data for 1998 and 2006 from the analysis would have avoided any influence of the within-year changes in regulations (and catchability) on the results of the GLM analysis. This approach would have produced estimates of year effects that reflected the combination of inter-annual variability in biomass and the different catchabilities within the three periods, while the estimates of the effects of season and the three area factors would have reflected the average influence of these factors over the full set of data. While the exclusion of data for 1998 would have been accommodated by the ASPIC software with this approach, the assessment results would have been based on data for 1970–2005 rather than 1970–2006, and the status determination would have related to the 2006 rather than 2007 population biomass, and the 2005 rather than 2006 fishing mortality.

The decision to use GLM to analyse the data for 1948–1998, 1998–2006, and 2006–2009 separately resulted in estimates of the effects of season and each of the three area factors, i.e. island platform, depth, or swell exposure, that differed among the three periods. Thomas et al. (2013) raised no *a priori* hypotheses of interactions between period (or year) and season or any of the three area factors. The temporal changes in the spatial distributions of CPUE in the figures presented by Thomas et al. (2013), however, suggest that an interaction between year and island platform may be present, as might be expected given the "temporal changes within island platform abundance by habitat degradation and fishing due to high human density" (Thomas et al., 2013). It would be useful to explore whether such interactions are present, as they may provide evidence of impacts of fishing that differ among island platforms, i.e., local depletion.

(b) Generalized production model

The method employed to assess the stock, i.e., the fitting of a generalized production model using the ASPIC (Ver. 5) software package, is appropriate given the available data.

The use of a generalized production model rather than a more complex age or length-structured fishery model in the MHI Kona Crab Benchmark Assessment was presumably dictated by the types of data that were available. Thus, as data from the recreational fishery and fishery-independent abundance estimates were not available, the assessment was based on the landings data that had been reported by commercial fishers. Although a small number of studies had been undertaken to obtain data on the biological characteristics of the MHI population of Kona crabs, much of the knowledge of the biological characteristics and life history of this species presented in the Assessment Report was derived from studies of populations of this species elsewhere in the Indo-Pacific region. Data on size compositions of the annual catches were not available. It was therefore appropriate to employ a production model for the MHI Kona crab assessment, as such a model requires only a time series of annual catches and the associated values of an index of abundance.

A production model treats the population as a single unit, and describes the dynamics of the population in terms of the derivative of biomass with respect to time, relating this to the current biomass, the carrying capacity, the maximum sustainable yield (MSY) and the biomass associated with MSY, i.e. B_{msy}. Recognising that the population had been fished for many years prior to the start of the time series of historical commercial fisheries data used for the assessment of the MHI Kona crab fishery, the biomass of the population in 1970 was assumed to have been reduced to 70% of the carrying capacity. Note that sensitivity to this assumption was explored later in the assessment.

The decision to explore whether blocking the data into the periods from 1970 to 1998 and 1998 to 2006, i.e. before and after the regulation that prohibited the use of crab nets when bottomfishing, and estimating separate catchabilities for the two periods, is sound.

Are methods applied correctly?

(a) Standardization of CPUE data

When undertaking the GLM analysis of the commercial CPUE (kg trip^{-1}) data, Thomas et al. (2013) decided to analyse the data for 1948–1998, 1998–2006, and 2006–2009 separately, where the first and second periods were separated by the date in June 1998 on which the use of crab nets when bottomfishing was prohibited, and the second and third periods were separated by the date in September 2006 on which landing of female crabs was prohibited. Details should be provided in the Assessment Report as to how the two different estimates of year effect for 1998, which resulted from inclusion of the data for this year in the GLM analyses for both 1948–1998 and 1998–2006, were combined for input to the ASPIC model. Similarly, details should be provided of how the two estimates of year effect for 2006 were combined.

(b) Generalized production model

The methods appear to have been applied correctly to produce both estimates for the parameters of the generalized production model and 90% confidence intervals for those estimates. The predicted CPUEs appear to match the data to which they had been fitted (Fig. 10), and the results of the diagnostic tests of the residuals suggest that the assumed distribution of residuals was appropriate. The decision to employ different catchabilities for the periods before and after the introduction of the prohibition on use of crab nets when bottomfishing was supported by the results of the model comparison that was undertaken, and the values of the resulting AICs. The plots of the trends in biomass, fishing mortality, and predicted versus observed CPUEs are appropriate and informative. It would have been useful, however, to include estimates of the 90% confidence intervals in the plot of CPUEs (Fig. 10), to allow assessment of the extent to which observed values fell within those intervals.

ToR 3. Evaluation of assessment findings:
- Are abundance, exploitation and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?
- Is the stock overfished? Is the stock undergoing overfishing? What information is available for this conclusion?
- Are key uncertainties acknowledged along with their potential consequences?

Assessment findings

Assessment of the fishery was based on fitting the generalized production model to commercial landings data for the MHI Kona crab fishery from 1970 to 2006 and associated standardized CPUE data. The assessment thus relates to the status of the commercial fishery at the commencement of 2007 and its level of exploitation in 2006. Because commercial landings rather than total landings were used when fitting the model, biomass estimates produced by the model are estimates not of the total biomass of legal-sized crabs, but of the portion of that total biomass relating to the share of total landings taken by the commercial fishing sector. Likewise, estimates of carrying capacity and maximum sustainable yield produced by the production model relate to that portion, not the total.

The fitted ASPIC model produced the following parameter estimates.

$B_{\mathrm{msy}} = 159{,}500$ lbs (90% C.I.: 72,360 to 198,500 lbs),
MSY = 40,400 (90% C.I.: 25,900 to 48,430 lbs),
$F_{\mathrm{msy}} = 0.25$ year^{-1} (90% C.I.: 0.20 to 0.38 year^{-1}).
$B_{2007}/B_{\mathrm{msy}} = 0.18$ (90% C.I.: 0.10 to 0.33), and
$F_{2006}/F_{\mathrm{msy}} = 0.92$ (90% C.I.: 0.50 to 1.64).

Are abundance, exploitation and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?

The estimates of exploitation and biomass produced by the generalized production model are consistent with the data input to that model and with the relationship (of production model form) describing the response (between 1970 and 2006) of standardized CPUE (kg trip^{-1}) of legal-sized MHI Kona crabs to the landings made by commercial fishers. The reliability of the estimates of exploitation and biomass, and their usefulness for status determination must be considered in the context of both the explicit uncertainty reported in the Assessment Report and the additional unquantified uncertainty associated with the assumptions made when undertaking the assessment to account for data that were unavailable.

If the standardized CPUE is a reliable index of the legal-sized portion of the MHI Kona crab biomass, and if the reported annual landings made by commercial fishers are accurate and a constant proportion of the total annual removals (landings and deaths of released crabs resulting from capture) from the stock, then the values of exploitation and of the biomass of legal-sized crabs estimated by the production model for 1970–2006 are likely to be reliable and useful to support status inferences. It is thus the extent to which these assumptions are satisfied that determines the reliability of the estimates.

When assessing the reliability of the results of the assessment and their usefulness in status determination, it may be useful to note that, as it is likely that fishing efficiency has increased as a result of technological improvements and as fishery-dependent indices of abundance are likely to exhibit hyperstability, the true decline in population biomass and true level of exploitation may be greater than the values of those variables estimated by the generalized production model. If recreational landings of Kona crabs have been an increasing rather than constant proportion of total removals from the MHI stock, however, the capacity of the stock to respond to exploitation may be greater than that predicted by the fitted generalized production model.

A more detailed assessment of the reliability and usefulness of the assessment results is presented below.

The generalized production model produced estimates of commercial CPUE that (subjectively, based on Fig. 10 of the Assessment Report) appear consistent with the values of "observed CPUE", where it is assumed that the latter are the standardized estimates of CPUE which had been input to ASPIC, and the distribution of residuals (subjectively, based on Fig. 11 of the assessment report) appears consistent with the form of distribution that had been assumed for this variable. Consistency in variable names should be maintained throughout the report. Thus, if the variable "observed CPUE" (in Fig. 10) represents the standardized estimates of CPUE, it should have been described as such in the caption to Fig. 10 of the Assessment Report.

As intended, the generalized production model fitted to the BHI Kona crab fishery produced estimates of biomass, not numbers of crabs. Subjectively, and as would be expected, the trend in estimated biomass (Fig. 7) appears to be consistent with the trend in standardized CPUE (Fig. 5), and appears to agree with the trend in fishing mortality (Fig. 8). As the fitted ASPIC model was conditioned on catch, estimates produced by the model are consistent with the time series of commercial landings that were input. The biological characteristics of the population are reflected in the parameters and structure of the generalized production model, i.e., the carrying capacity, the ratio of the biomass associated with maximum sustainable yield (msy) and carrying capacity, and the maximum sustainable yield, and the relationship between the instantaneous rate of change of biomass and these variables. It should be noted that the form of this relationship reflects the size and sex composition (and associated selectivity) of the portion of the total stock that is exploited. Thus, the nature of the modelled biomass and its associated productivity would have changed with the move in September 2006 to a male-only fishery. This change would be reflected in the parameters of a production model describing the dynamics of the stock after September 2006, if such a model was to be fitted. Further, there would have been a transition between the old and new population dynamics as the characteristics of the exploited biomass adjusted to the new regulation.

Although the standardized commercial CPUEs are likely to reflect changes in the overall CPUE experienced by both commercial and recreational fishers, and are thus appropriate for use in the generalized production model, the commercial landings that were input to the model and employed as the values of catch represent only a portion of the total removals. Recreational landings and deaths of released crabs that were injured when disentangled from fishing nets should also have been included in the total removals from the stock, as it is the response of the stock to these removals that is described by the generalized production model. If the production model is fitted using commercial landings as a proxy for total removals, inferences regarding stock status and trends in fishing mortality will be accurate only if landings of recreational fishers and other removals are negligible or remain a constant proportion of overall removals. A trend in recreational landings that differs from that of commercial landings will not have been taken into account, and resulting indicators of stock status and reference points derived from the fitted production model would not reflect the true state of the population.

The measures of abundance that are input to ASPIC are assumed to be directly proportional to the biomass of the portion of the stock exploited by the commercial fishery, the dynamics of which are represented by the generalized production model in ASPIC. An issue with the use of a fishery-dependent measure of abundance, such as CPUE, is that such indices typically exhibit hyper-stability. That is, fishers tend to avoid or move from areas of low abundance and focus on areas of greater abundance. Advances in technology increase the efficiency of fishing effort, resulting in an increase over time of the constant of proportionality relating CPUE to exploited biomass. Standardization of CPUE using GLM or similar approach typically fails to account for such hyper-stability or increase in efficiency, thereby producing parameter estimates that are biased and which suggest that the stock is more productive and resilient to exploitation than it actually is.

Is the stock overfished? Is the stock undergoing overfishing? What information is available for this conclusion?

As noted above, the fitted generalized production model for 1970–2006 produces parameter estimates that relate to the status of the MHI Kona crab fishery at the commencement of 2007 and its level of exploitation in 2006. The Assessment Report did not present a detailed exploration of the predictions of current levels of biomass and exploitation, and estimates of projected biomass following 2006 that were reported were based on the production model for 1970–2006 and did not take the change to a male-only fishery into account.

The Assessment Report did not provide details of the Status Determination Criteria for MHI Kona crabs. It is assumed that, as is typical for many fisheries elsewhere in the U.S.A., the Maximum Fishing Mortality Threshold (MFMT) is F_{msy}, and the Minimum Stock Size Threshold (MSST) is 50% of B_{msy}. Note that the biomass considered in the generalized production model that was fitted to the commercial fisheries data for MHI Kona crabs is the legal-sized biomass exploited by the commercial fishers, where biological data suggest that all legal-sized crabs are mature. Thus, although the biomass estimates produced by the production model represent the combined biomass of the females and males, and the proportions of those biomasses that are females and males may differ among years and be influenced by the level of exploitation, it is reasonable to accept the pooled biomass of the females and males as a measure of reproductive potential.

The MFMT may be expressed in terms of the fishing mortality ratio as $F/F_{\text{msy}} = 1$, where values of F/F_{msy} that exceed 1 reflect overfishing. The MSST may be expressed in terms of the biomass ratio as B/B_{msy} = 0.5, where values of $B/B_{\mathrm{msy}} < 0.5$ indicate that the stock is overfished. The Kobe plot presented as Fig, 9 in the Assessment Report provides a summary of the trajectory over time of the annual biomass (B/B_{msy}) and fishing mortality (F/F_{msy}) ratios estimated by the 1970-2006 generalized production model. As noted earlier, $B_{2007}/B_{\mathrm{msy}}$ = 0.18 (90% C.I.: 0.10 to 0.33) and $F_{2006}/F_{\mathrm{msy}}$ = 0.92 (90% C.I.: 0.50 to 1.64). Applying the Status Determination Criteria, $B_{2007}/B_{\mathrm{msy}} < 0.5$, which indicates that, in 2007, the biomass had fallen below the MSST and was therefore overfished. Indeed, even the upper 90% confidence limit of the biomass ratio was less than 0.5, indicating with a high degree of certainty that the stock was overfished. While the fishing mortality ratio estimate $F_{2006}/F_{\mathrm{msy}}$ was less than 1, there was considerable uncertainty in the estimate of the ratio, with a 90% confidence interval that ranged from 0.5 to 1.64. Technically, however, based on the point estimate of the fishing mortality ratio, it would be concluded that overfishing was not occurring in 2006.

As has been noted before, the lack of data for the recreational fishery and the assumptions that standardized CPUEs are directly proportional to population biomass and, together with commercial landings, may be used to assess the state of the population introduces uncertainty in the determination of stock and exploitation status. The risk associated with this unquantified uncertainty should be recognised when considering the results of the determination of stock and exploitation status based on results obtained by fitting the generalised production model to commercial landings data.

Because of the prohibition on landing female crabs that was introduced in September 2006, the current state of population biomass and level of exploitation are likely to differ considerably from those determined in the assessment using the production model for 1970–2006. An updated assessment is required to determine current stock status.

Are key uncertainties acknowledged along with their potential consequences?

The Assessment Report discusses a number of uncertainties, such as efficiency creep associated with introduction of new technology and the possibility that standardized CPUEs may not be proportional to population biomass, and has accounted for some of these sources of uncertainty. Thus, for example, the Report describes the results of the model comparison that demonstrated that catchability from 1970 to 1998, i.e. prior to the prohibition in June 1998 on the use of crab nets when bottomfishing, differed from the catchability for the period that followed. The production model used for the assessment allowed for this change in catchability. The statistical uncertainty associated with model fitting was taken into account by calculating bias-corrected 90% confidence intervals for each estimated parameter from 1,000 bootstrap runs.

One of the key uncertainties of the generalized production model was the assumption that, because the stock was likely to have been lightly exploited prior to 1970, the initial biomass parameter, B_{1970}/K was 0.7. An analysis was undertaken to explore the sensitivities of the AIC and the F-ratio in 2006, i.e. $F_{2006}/F_{\mathrm{msy}}$, to values of this initial biomass parameter ranging from 0.1 to 1. While the AICs of the models with values of B_{1970}/K that ranged from 0.3 to 0.6 were marginally lower than that for the model assuming an initial biomass parameter of 0.7, it was determined that the fit of the model was insensitive to the fixed value of B_{1970}/K. The inconsistency between the values of $F_{2006}/F_{\mathrm{msy}} = 0.87$, which was reported in Table 4 for the case when $B_{1970}/K = 0.7$, and $F_{2006}/F_{\mathrm{msy}} = 0.92$, reported in Table 3, needs to be reconciled. While the quality of the fit did not vary greatly in response to the different fixed values of B_{1970}/K that were used, $F_{2006}/F_{\mathrm{msy}}$ increased as B_{1970}/K was reduced. It would have been appropriate to present the values of $B_{2007}/B_{\mathrm{msy}}$ that resulted when the different fixed values of B_{1970}/K were applied, as it is the sensitivities of the status determination of both population biomass and fishing mortality that are of concern for fishery management. When setting $B_{1970}/K = 0.7$, the assumption was made in the Assessment Report, which cites Vansant (1965), that, prior to 1970, the stock was lightly exploited. On page 20 of the Assessment Report, however, the possibility is raised by Brown (1985) that the stock was overfished in the mid-1970s. The data supporting these rather conflicting views should be explored to determine which is correct, or whether the uncertainty will need to be carried into future assessments.

The lack of recreational landings data introduces considerable uncertainty into the results of the assessment. Implicitly, it has been assumed that recreational landings from 1970–2006 have been a constant proportion of the total landings of Kona crabs from the MHI fishery. It would have been useful to have explored the sensitivity of the estimates of $B_{2007}/B_{\mathrm{msy}}$ and $F_{2006}/F_{\mathrm{msy}}$ to alternative assumptions of a specified annual increase or decrease in the ratio of recreational to commercial landings. Such sensitivity runs would have provided insight into the implications of trends in recreational catches.

It was acknowledged in the Assessment Report that, in September 2006, a regulation that banned the landing of female Kona crabs was implemented. As no quantitative information was available as to how male-only harvest would impact catchability and production of the stock, data after August 2006 were excluded when fitting the model. The implications of the move to a male-only fishery, and its likely effect on stock and exploitation status, require exploration.

ToR 4. Evaluation of stock projections

- **Are methods consistent with accepted practices and available data?**
- **Are results informative, robust, and useful for inferences of probable future conditions?**
- **Are key uncertainties and their potential consequences addressed?**

Stock projections

The ASPIC model fitted to 1970–2006 commercial landings data used the reported commercial landings from 2007-2009 to estimate the biomass at the start of 2010, and then projected the population forward from this state to produce estimates of the biomass of the MHI Kona crab stock likely to result if commercial landings from 2010–2030 were held constant at each of 0, 7,000 and 8,000 lbs. A strength of the ASPIC software is that it includes a utility program that employs the fitted model to project the population's response to specified levels of future catches or fishing mortalities, thereby allowing exploration of how the fishery might respond to various alternative management controls. The software also provides the facility to calculate bias-corrected bootstrap estimates of results, and this was used to produce 90% confidence limits of predicted future biomasses, thereby characterising the uncertainty of the projections.

The Assessment Report advises that, with no fishing, the population would have been expected to recover to 50% of B_{msy} by 2015, and would be expected to recover to B_{msy} by 2020. It would be expected to take over 18 years to recover to 50% of B_{msy} if an annual commercial harvest of 7,000 lbs was taken. If the annual harvest was 8,000 lbs, however, the biomass of the population would be expected to decline. The 90% confidence limits of these population estimates are wide, reflecting considerable uncertainty in the estimated recovery times, and in the trend that might result if annual catches of 7,000 or 8,000 lbs are maintained.

Are methods consistent with accepted practices and available data?

It is accepted practice to use the fitted assessment model, i.e., in this case, the ASPIC model, to produce projections of the future system state (and its uncertainty) likely to result under various scenarios of future catches or levels of fishing mortality. It is also accepted practice that, when the data used when fitting the assessment model do not extend to the current date, assumptions are made regarding catches in the intervening period such that the current state can be estimated prior to projecting the consequences of alternative management decisions. Re-stating this, the intent of projecting the state of the population under each of a set of alternative management decisions that could be made at this moment of time is to provide advice regarding the likely consequences of those management decisions. Thus, it would have been expected that an estimate would have been made of the biomass of the MHI Kona crab stock at the beginning of 2015 rather than 2010, such that the projection period used to explore the consequences of alternative management decisions would have commenced in 2015.

The only data available for 2007 to 2009, i.e., the period between 2006, the last year of historical data used when fitting the model, and 2010, the first of the years over which the population of MHI Kona crabs was projected, were the landings from the commercial fishery. The nature of these landings had changed from that of the landings for earlier years, however, as a regulation that prohibited the landings of female crabs had been implemented in September 2006. As recognized in the Assessment Report, this regulation would have introduced a change in both catchability and production, the latter modifying the form of the generalized production model describing the relationship between the rate of biomass change, biomass, and catch. With only three years of commercial landings data for the period following the move to a male-only fishery, and with limited contrast in population size during those three years, it would not be possible to fit a generalized production model to commercial landings data for 2007–2009, and thereby estimate the parameters of the production model that now describes the dynamics of this fishery.

The biomass projections produced for MHI Kona crabs, which were calculated using the parameters of the model fitted to 1970–2006 commercial landings, assume that the dynamics of the post-2007, male-only fishery are the same as those of the 1970–2006 fishery. The Assessment Report identified this issue, noting that, following the introduction of the regulation to ban the landing of female Kona crabs, there was likely to have been an increase in stock productivity. If such an increase in productivity had occurred, the projected biomasses presented in the Assessment Report may underestimate the true response of the population to the specified levels of constant annual commercial harvest. Note, however, that the Assessment Report also drew attention to examples from other crustacean fisheries in which the move to a male-only fishery had a negative impact on production. It also drew attention to aspects of the mating behaviour of Kona crabs that might make their populations sensitive to constraints on harvesting females.

Lack of recreational landings data precluded use of total removals when fitting the generalized production model to the MHI Kona crab fishery. If the resulting model is to be considered a reliable representation of the dynamics of this fishery, it is necessary to make the implicit assumption that recreational landings of crabs have been, and continue to be, proportional to commercial landings. The extent to which this assumption is invalid should be considered as introducing additional unquantified uncertainty in the estimates of the parameters of the generalized production model and results of projections. The latter will also be affected by any failure to maintain proportionality of recreational to commercial landings throughout the projection period.

The basis for the selection of the constant annual commercial landings of 7,000 and 8,000 lbs used in the projections is not discussed in the Assessment Report. While it is possible that these represent landings of magnitudes similar to those reported in recent years (based on Fig. 2 of the Assessment Report), it is conventional to explore in the projections how the population might respond when fished in accordance with, for example, the Overfishing Limit (OFL) or an Acceptable Biological Catch (ABC) that applies an adjustment to the OFL to account for uncertainty.

Are results informative, robust, and useful for inferences of probable future conditions?

The limited number of years of data and lack of biomass contrast for the post-2006, male-only Kona crab fishery have precluded estimation of the parameters of a model describing the post-2006 generalized production relationship. Projections were therefore based on the fitted model describing the 1970–2006 generalized production relationship for the MHI fishery, ignoring the changes in catchability and production function, and the change in the sex composition of landed crabs, associated with the prohibition on landing female crabs. This additional uncertainty combines with the uncertainty of the estimates of the parameters of the model describing the 1970–2006 generalized production relationship that arises from the lack of a time series of recreational landings. Thus, in addition to the quantified uncertainty present in the estimates of stock status and projections and stock status, as revealed in the 90% confidence limits presented in the Assessment Report, allowance should be made for the unquantified uncertainty associated with the move to a male-only fishery and the lack of recreational landings data for MHI Kona crabs. While short-term (e.g. over 3–5 years) trends in projected biomass are likely to be relatively informative, robust and useful, provided annual recreational landings of Kona crabs retain their current proportionality with annual commercial landings, longer term trends in projections are likely to drift from true values given the fact that the dynamics of the post-2006 Kona crab fishery differ from the representation provided by the fitted 1970–2006 generalized production model. It should be noted that the biomass estimates of the projections presented in the Assessment Report provide no indication that, by 2010, the overfished status of the population would have changed.

Are key uncertainties and their potential consequences addressed?

The Assessment Report advises that "to ensure that projected landings would not change the production function estimated from the historical fishery data all production parameters, except carrying capacity (K), were fixed to values estimated by the general production model with … Kona crab fishery data from 1970–2006". Thus, when calculating the projected population estimates and their confidence intervals, K was not fixed but other parameter estimates were fixed. It should be noted, however, that the parameters that describe the production function are estimated with uncertainty, and that this uncertainty should be propagated into the uncertainty of the projected biomass estimates. It would thus have been more appropriate to have used the parameter estimates calculated from the 1,000 bootstrap runs of the base model (when estimating the uncertainty of those parameters) when projecting the population from 2010 to 2030, thereby accounting for the uncertainty of all parameters, rather than that for just K.

Other sources of unquantifiable uncertainty that would have affected CPUEs, the assessment, or the projections are discussed. These included the increased effectiveness of fishing effort likely to have resulted from improvements in technology, fluctuations in recruitment or catchability associated with environmental change, changes in the spatial distribution of fishing, the form of the relationship between CPUE and stock abundance, recreational landings, and protection afforded to Kona crabs by coral habitat.

The state of the MHI Kona crab fishery at the beginning of 2010 was predicted from the estimated state at the end of 2007 by entering the catch data from 2007–2009 into the generalized production model that had been fitted to the 1970–2006 data. Estimates of future biomass were then obtained from the model by projecting the fishery through 2010 to 2030 assuming constant annual landings of 0, 7,000, and 8,000 lbs. As noted in the Stock Assessment report, this extrapolation and subsequent projections ignore any changes to production likely to have resulted from the prohibition on landing female crabs, which was introduced in September 2006.

ToR 5. Evaluation of whether the science reviewed is considered to be the best scientific information available.

Given the limitations and nature of the data available for the MHI Kona crab fishery, the scientific approaches that have been used are appropriate, and the software tools used to undertake the analyses are well-tested and sound. The results of the analyses are the best scientific information currently available, but when using these results, it will be important to recognise the risks associated with both the quantified and unquantifiable uncertainties that have been identified.

ToR 6. Recommendations for
- Data used in assessment
- Assessment methods
- Results and interpretation
- Stock projections
-Further improvements

Data used in the assessment

Following the prohibition on the landing of female crabs that was introduced in September 2006, landings by commercial fishers have comprised only legal-sized male crabs. If the status of spawning female biomass is to be determined for any year following 2006, a new assessment model that describes the dynamics of both females and males will need to be developed for the MHI Kona crab fishery. Such a model will require data on the biomasses and numbers of both landed males and released berried and non-berried legal-sized females, and may eventually make use of data on the biomasses and numbers of undersized female and male crabs that are released. From October 2002, commercial fishers have reported the numbers of crabs that were released. To facilitate the use of these release data in a new assessment model, it will be necessary to determine the numbers of undersize crabs of each sex, and the numbers of berried and non-berried, legal-sized females that were released in each trip. Estimates of the biomass of these various categories of released crabs, or size compositions of each category, will also be required. Note that, to reduce the cost of data collection, it may be possible to collect representative samples of released crabs from the commercial fishers, using a well-designed data collection program that stratifies the samples by season and island platform.

Purpose:	Collection of data required to facilitate development of an assessment model to account for the male-only fishery
Priority:	High

A key uncertainty of the current assessment was associated with the lack of recreational data. To address this, there is a need to collect historical data and to establish programs to collect future data from recreational fishers. There would be value in developing, through recall surveys and consultation with recreational fishers, fishery managers, bait and fishing gear suppliers, etc., a time series representing the best available estimates (and lower and upper bounds for those estimates) of the trends in relative magnitude of recreational landings from 1970 to the present day, such that these might be employed in future stock assessments. It is noted in the Assessment Report that, from 2001, the State of Hawaii has conducted random telephone surveys and boat ramp interviews to obtain data on recreational fishing. While the Report advises that these creel surveys have yielded few data relating to catches of Kona crab, it is unclear whether or not these data are likely to be sufficient to inform future assessment models of trends in recreational landings and fishing effort. There would be value in examining the data to determine their adequacy, and, if inadequate, considering whether these creel surveys might be supplemented by focussed on- or off-site surveys to obtain the necessary indices of recreational Kona crab landings and fishing effort.

Purpose:	To improve the accuracy of the assessment by accounting for recreational catches
Priority:	High

A weakness of the current assessment is that no data have been provided of the biomass of crabs lost from the population as a result of capture and death following release. Prior to September 2006, such deaths affected only undersized crabs and legal-sized berried females, but following introduction of the regulation prohibiting landing of female crabs, both undersized crabs and all legal-sized female crabs that are released may be affected by mortality associated with their capture, disentanglement from the net and release. To assess whether such mortality is of a magnitude likely to affect estimates of stock status and fishing mortality, it is recommended that a study is undertaken to collect data on the proportions of crabs of different sizes and sexes that lose limbs or dactyli when disentangled from the nets in which they were caught, and whether these proportions have changed over time or differ between recreational and commercial fishers.

Purpose:	Improving the accuracy of the assessment by accounting for release mortality
Priority:	Low

The current assessment made use of the biomass landed by commercial fishers on each trip, but made no use of the reported numbers of crabs that were landed. As noted in the Assessment Report, it is possible that the average size of the crabs that are caught may provide information on the level of exploitation that the crabs have experienced. To make use of such data, or other size composition data, it will be necessary to develop an improved model of the growth of the female and male Kona crabs in the MHI population. It is recommended that a study is undertaken to develop such growth models, and that a further study is undertaken of the selectivity of crabs to the nets.

Purpose:	To make use of information on fishing mortality that might be contained within the size compositions of Kona crabs
Priority:	Medium

The Assessment Report noted that there had been inconsistencies in how the number of nets were reported by commercial fishers after 2002, but did not report the action (if any) taken to resolve this issue, and whether the issue has now been resolved successfully. If such inconsistencies are still being detected in commercial landings reports, appropriate action should be taken.

Purpose:	To improve the quality of data available for future stock assessment
Priority:	Medium

Assessment methods

It is recommended that a GLM analysis is undertaken using the pooled commercial landings per trip data for 1948–1997, 1999–2005, and 2007–2009, rather than separate analyses for the three periods, thereby exploring whether this might provide a more appropriate method for standardizing CPUE. This approach would avoid any influence of the 1998 and 2006 within-year changes in regulations (and catchability) on the results of the analysis, and would allow exploration of both main and interaction effects of years, seasons, and island platform (or alternative area factor), and, in particular, the possibility of a significant interaction between year and island platform.

Purpose:	To explore whether the approach used in standardizing CPUE could be improved
Priority:	Medium

It is recommended that the pooled commercial landings per trip data for 1948–1997, 1999–2005, and 2007–2009 are analysed using a generalized mixed-effects model rather than a GLM, and treating fisher as a random-effect, to explore whether this might provide a more appropriate method for standardizing CPUE. This approach would take into account the fact that repeated measures of CPUE by individual fishers are likely to exhibit correlation.

Purpose:	To explore whether the approach used in standardizing CPUE could be improved
Priority:	Medium

The generalized production model that was fitted to the commercial fishery data from 1970–2006, and used to assess the state of the stock in 2007 was directly applicable to the MHI Kona crab fishery only for the period when both female and male crabs were harvested. A generalized production model fitted to commercial fisheries data for the period following the prohibition on landing female crabs would describe only the biomass of legal-sized males, and the dynamics of that biomass in response to male-only harvest. Use of such a model for future assessment would essentially discard information on the dynamics of the combined female and male population contained within the 1970-2006 data. Such a model would also fail to provide the information on spawning female biomass that is crucial for assessing stock status. To avoid this, a new assessment model will need to be developed that describes the dynamics of both females and males, and which employs the data from both 1970–2006 and subsequent years. Such a model will almost certainly require data on released berried and non-berried females of legal size. It is strongly recommended that such a model is developed.

Purpose:	Development of a model that describes the dynamics of both female and male biomasses, makes use of the commercial fisheries data for 1970–2006, and can accommodate the move in September 2006 to male-only harvest
Priority:	Very high (noting that the form of this model may determine data needs)

Conclusions regarding stock status and exploitation of the population based on the generalized production model fitted to 1970–2006 commercial landings data are conditional on the validity of the assumption that recreational catches are a constant proportion of total landings. Until such time as it is possible to develop a time series of estimates (and lower and upper bounds) of historical recreational catches, it is recommended that an exploration be undertaken of the sensitivity of the status determination for the MHI Kona crab stock to assumptions that, over time, recreational landings were an increasing (or decreasing) proportion of the total of the commercial and recreational landings.

Purpose:	To provide information on the extent to which trends in recreational landings might influence estimates of population biomass and exploitation
Priority:	Low

There would be value in undertaking a retrospective analysis. A retrospective pattern in the results would indicate a change in the values of the parameters of the production model from those that previously described the dynamics of population biomass, and may provide a signal that the current description of those dynamics is inadequate.

Purpose:	To confirm that the parameters of the production model continue to provide an adequate description of the dynamics of the Kona crab population
Priority:	Medium

Results and interpretation

It is recommended that the generalized production model fitted to the 1970–2006 commercial landings data is used to calculate the minimum population biomass of MHI Kona crabs (as a percentage of B_{msy}) that would be expected to rebuild to B_{msy} in ten years with a constant fishing mortality of F_{msy}, taking into account the uncertainty of the estimates of the parameters of the fitted production model. The resulting estimate of biomass should be compared with 50% of B_{msy}, and consideration then given as to whether the larger of the two percentages should be employed to calculate the value of the Minimum Stock Size Threshold (MSST) in future stock assessments.

Purpose:	To ensure that the Status Determination Criterion for biomass, i.e. MSST, is set at an appropriate level in future stock assessments
Priority:	Medium

It is recommended that details of the Status Determination Criteria, the values of the biomass and fishing mortality ratios, and conclusions regarding overfished and overfishing status are included in future stock assessment reports.

Purpose:	To improve communication of assessment results
Priority:	Medium

Stock projections

It is recommended that, rather than considering only the effect on parameter estimates and status determination of the various sensitivity analyses that are conducted, the sensitivity analyses are carried forward into population projections.

Purpose:	Improve communication of the uncertainty associated with different sensitivity analyses
Priority:	Low

Further improvements

In future assessment reports, it is recommended that non-confidential data are presented in tabular form as well as in plots. Access to such data facilitates review of the assessment as it allows confirmation that the data output from one stage of the analysis match the data input to the next stage, and allows the reviewer to probe and explore the data and results of the assessment in greater detail than in the ways presented in the Assessment Report.

Purpose:	To facilitate review of stock assessments
Priority:	Low

For future reviews of stock assessments, it is recommended that background material should include copies of reports and papers that are not available in the primary fisheries literature. Such material might include, for example, copies of the unpublished thesis of Vansant (1965), the paper by Onizuka (1972), and the report by Brown (1965).

Purpose:	To facilitate review
Priority:	Low

5. Conclusions and recommendations

The data that were available for the Benchmark Assessment of the MHI Kona crab fishery were limited. Although the stock is exploited by both commercial and recreational fishers, landings data are available for only the commercial sector. While there is considerable knowledge of the biology and life history of the species, much of this knowledge is derived from other populations elsewhere in the Indo-Pacific region. Data on key biological processes for the MHI population, such as growth and reproduction, have not been subjected to detailed study. Details of the size and sex compositions of the crabs caught at the different island platforms are unavailable. The decision to base the assessment on the long time series of commercial landings data is thus well justified, and the use of a generalized linear model (GLM) to standardize the CPUE data and of a generalized production model (ASPIC) to describe the dynamics of the population was appropriate. The software for both of these models is well-tested and sound.

The analyses took the changes in regulations into account, applying separate catchabilities in the production model to the years prior to and after the prohibition on the use of crab nets when bottomfishing, and fitting the model only to data from 1970 to 2006, thereby avoiding the change in catchability and production that would have been associated with the move to a male-only fishery. While sensitivity to initial system state was investigated, a key uncertainty that could not be quantified was the effect of the recreational fishery. Implicitly, recreational landings were assumed to remain a constant proportion of total landings, as, in theory, under this assumption, the function describing a production model fitted to the commercial fisheries data would be a scaled version of a production model describing the population biomass of legal-size crabs, with values of carrying capacity, biomass at MSY, and MSY reflecting the proportion of the annual harvest taken by the commercial fishers. Thus, if this assumption was valid, a status determination based on the results of the production model fitted to the commercial landings would provide a reliable determination of the status of the MHI Kona crab fishery.

Based on the results of the production model for the commercial landings data, it was concluded, with a high degree of certainty, that, in 2007, the Kona crab fishery was overfished. With considerably less certainty, it was concluded that, in 2006, overfishing was not occurring but fishing mortality was close to the MFMT. Subjectively, it appeared likely that the decision regarding the overfished status of the fishery would be robust to the uncertainty associated with the lack of data for the recreational fishery. While it was possible that the determination relating to the status of fishing mortality might remain unchanged. i.e., overfishing was not occurring, the lack of recreational data increased the uncertainty of this conclusion. It was recognised that technological change and the possibility that the fishery-dependent nature of the standardized CPUE series were not taken into account when fitting the production model, and thus introduce additional uncertainty that needs to be considered when examining the results of the assessment.

Projections of future biomass were likely to be conservative as the projected values had been calculated using the production model fitted to commercial landings for 1970–2006, when both males and females had been harvested, and had not taken the change to a male-only harvest into account. It was likely that the stock had become more productive as a result of the release of females. The quantifiable uncertainty of projections grew as the predictions extended further into the future, but only the uncertainty of the estimate of carrying capacity, and not that of the full set of parameter estimates, was taken into account when projecting the biomass using the 1970–2006 production model. The additional unquantified uncertainty associated with the lack of recreational fishery data and the change to a male-only fishery should also be recognised when assessing the implications of the population projections. The take-home message of the projection analysis is possibly that, with the biomass of Kona crabs at a reduced level, it would be appropriate to ensure that total harvests are of a commensurate level such that the stock is not further depleted.

The Benchmark Assessment of the MHI Kona crab fishery is already out of date, and should be updated. It is not appropriate to simply fit the model to the data from 1970–2015, as the parameters of the production model describing the fishery prior to 2006 would differ markedly from those of a production model describing the dynamics of a male-only fishery. A production model fitted to only the post-2006 commercial landings would discard information from 1970–2006, would lack the contrast required for reliable parameter estimation, and would provide no information on the spawning biomass of female crabs. It is recommended that a new model is developed, which describes the dynamics of both the males and females, and which uses both the commercial landings and data relating to the numbers of female crabs that are released.

Summarizing the above, it appears likely that, in 2007, the Kona crab population was overfished. Projected population estimates provide no evidence of a recovery, and it is likely that the stock remains overfished. Harvests will need to be constrained to levels commensurate with current population biomass to avoid further reduction in biomass. An updated assessment is required to determine current stock status, but, with the move to a male-only fishery, this is likely to require development of a new model and collection of data on the numbers of legal-sized female crabs that are released. A key source of uncertainty for assessment of the MHI Kona crab fishery is the lack of data for the recreational fishery.

6. References

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Appendix 1: Bibliography of materials provided

Thomas, L. R., DiNardo, G. T., Lee, H.-H., Piner, K. R., and Kahng, S. E. 2013. Factors influencing the distribution of Kona crabs *Ranina ranina* (Brachyura: Raninidae) catch rates in the Main Hawaiian Islands. Journal of Crustacean Biology, 33(5): 633–640.

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Appendix 2: Copy of the CIE Statement of Work

Statement of Work

External Independent Peer Review by the Center for Independent Experts

Kona Crab Benchmark Assessment

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 reviewer is 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. The 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 Kona crab (*Ranina ranina*) benchmark assessment will provide the basis for the management of this iconic Hawaiian species. The Kona crab fishery is one of three commercial crab fisheries Hawaii. Historically, Kona crab landings make up over 25% of all commercial crab landings and up to 5% of all commercially landed reef species in Hawaii. Kona crabs are found in sandy habitat adjacent to fringing reefs and rocky areas in depths from 2 to 200 m. The fishing methods (baited tanglenets) are generally thought to be benign to habitat (when not set too close to coral reefs) and take little bycatch. However, basic biological information for the Kona crab is generally unavailable, and commercial landings data are the main indicator available to determine stock abundance. The commercial Kona crab landings in Hawaii have declined over the last 18 years. Because the most recent stock assessment of the Kona crab fishery was conducted over 30 years ago (Vansant 1978) the need for a contemporary assessment of the stock and review of the fishery was identified at the 2008 National Oceanic and Atmospheric Administration (NOAA) Pacific Coral Reef Ecosystem Integrated Observing System (CREIOS) Workshop and prioritized within the Coral Reef Ecosystem Fishery Management Plan (CMFMGP). To date stock status is classified as "unknown". Though it is mentioned peripherally in fisheries management plans regulations regarding closures are "best guess" only. The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**.

Requirements for CIE Reviewer: One CIE reviewer shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. The CIE reviewer shall have working knowledge and recent experience in the application of stock assessment for fisheries, and it is desirable to have working experience with stock assessment of marine invertebrates. The CIE reviewer's duties shall not exceed a maximum of 10 days to complete all work tasks of the peer review described herein.

Location of Peer Review: The CIE reviewer shall conduct an independent peer review as a desk review, therefore no travel is required.

Statement of Tasks: The CIE reviewer 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 the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to the CIE reviewer. The NMFS Project Contact is responsible for providing the CIE reviewer with the background documents, reports, and other pertinent information. Any changes to the SoW or ToRs must be made through the COTR prior to the commencement of the peer review.

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 reviewer 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 reviewer is responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein. The CIE reviewer shall read all documents in preparation for the peer review.

Desk Review: The 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.** The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements.

Contract Deliverables - Independent CIE Peer Review Reports: The CIE reviewer shall complete an independent peer review report in accordance with the SoW. The CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. The CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

Specific Tasks for CIE Reviewer: The following chronological list of tasks shall be completed by the 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) Conduct an independent peer review in accordance with the ToRs (**Annex 2**).
3) No later than 22 November 2015, the CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Dr. Manoj Shivlani, CIE Lead Coordinator, via email to mshivlani@ntvifederal.com, and Dr. David Die, CIE Regional Coordinator, via email to ddie@rsmas.miami.edu. The 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 ***tentative*** schedule.

October 17, 2015	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
October 24, 2015	NMFS Project Contact sends the CIE Reviewer the report and background documents

November 1-14, 2015	The reviewer conducts an independent peer review as a desk review
November 22, 2015	CIE reviewer submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
December 9, 2015	CIE submits the CIE independent peer review report to the COTR
December 16, 2015	The COTR distributes the final CIE report 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 reviewer 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 report 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 (Allen Shimada, via Allen.Shimada@noaa.gov).

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 reviewer 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 report 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 deliverable (CIE independent peer review report) to the COTR.

Support Personnel:

Allen Shimada
NMFS Office of Science and Technology
1315 East West Hwy, SSMC3, F/ST4, Silver Spring, MD 20910

Allen Shimada@noaa.gov Phone: 301-427-8174

Manoj Shivlani, CIE Lead Coordinator
Northern Taiga Ventures, Inc.
10600 SW 131st Court, Miami, FL 33186
mshivlani@ntvifederal.com Phone: 305-383-4229

Key Personnel:

NMFS Project Contact:

Beth Lumsden
FRMD/PIFSC/NMFS/NOAA
1845 Wasp Boulevard., Bldg. #176
Honolulu, Hawaii 96818
Beth.Lumsden@noaa.gov Phone: 808-725-5330

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.

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

Annex 2: *Tentative* Terms of Reference for the Peer Review

Kona Crab Benchmark Assessment

1. *Evaluation of data quality and data application within the assessment model*
2. *Evaluation of methods used to assess the stock:*
   - *Are methods scientifically sound and robust?*
   - *Are methods appropriate for the available data?*
   - *Are methods applied correctly?*
3. *Evaluation of assessment findings:*
   - *Are abundance, exploitation and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?*
   - *Is the stock overfished? Is the stock undergoing overfishing? What information is available for this conclusion?*
   - *Are key uncertainties acknowledged along with their potential consequences?*
4. *Evaluation of stock projections*
   - *Are methods consistent with accepted practices and available data?*
   - *Are result informative, robust, and useful for inferences of probable future conditions?*
   - *Are key uncertainties and their potential consequences addressed?*

5. *Evaluation of whether the science reviewed is considered to be the best scientific information available.*
   -
6. *Recommendations for*
   - *Data used in assessment*
   - *Assessment methods*
   - *Results and interpretation*
   - *Stock projections*
   - *Further improvements*