External Independent Peer Review

Center for Independent Experts

Recruitment Failure in the Southern New England Lobster Stock

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Executive Summary

- The ASMFC Lobster Technical Committee (TC) collated data on sea temperature, lobster shell disease and distribution of spawning females within the Southern New England (SNE) stock area. There is clear evidence that sea temperatures in excess of 20°C have been more frequent since the late 1990s and that chitinoclastic shell disease has increased from low levels prior to the late 1990s up to 25-35% in more recent years. Evidence of a redistribution of lobsters from shallow inshore waters to deeper waters further offshore over recent years is less clear, but data from the Ventless Trap Survey, a trawl survey in Long Island Sound and the Massachusetts Sea Sampling program indicate that such a shift probably has occurred. There is a need for a fuller presentation of the results of more comprehensive analyses.
- The TC report provides evidence from recent stock assessments, fishery landings, trawl surveys, spawning stock biomass indices and recruitment indices that the SNE lobster stock is at a very low level of abundance and experiencing very low levels of recruitment. Stock indicators are provided back to the early 1980s and recent values are in most cases at or near their lowest levels over this period. Taken individually, many of the indicators appear highly uncertain, but the combined picture shows that it is highly probable that the SNE stock is at a depleted level compared with the 1990s, and that this situation is being exacerbated by low levels of recruitment.
- The TC argue that a shift of spawning activity to deeper waters will be adverse for lobster recruitment because larvae released in offshore areas are likely to be transported away from favorable inshore settlement areas. This is supported by the results of satellite tracking of drifters deployed in different areas. There is a need for wider scale observations and hydrographic modeling to validate this picture of reduced settlement success resulting from an offshore shift in spawning.
- The TC concludes that there has been recruitment failure of lobsters in SNE, driven by overwhelming environmental and biological changes. This scenario is consistent with the available data for SNE and with current knowledge of lobster biology and ecology. However, the available data provide a limited historical perspective against which to compare recent observations, and there is a need to consider alternative scenarios such as a return to previous productivity levels after a period of much higher productivity during the 1990s. Sea temperature and disease incidence provide the strongest evidence that current conditions are different from those prevailing during the early 1980s, and thus that the TC scenario of recruitment decline is the most likely one.
- Environmental changes rather than fishing mortality are implicated in the recent stock decline and lower recruitment levels, i.e. stock abundance is probably low because recruitment has declined, as opposed to recruitment having declined because fishing has depleted the spawning stock. However, the TC identifies fishing mortality as an impediment to rebuilding the stock. Given other pressures on larval production and successful settlement, including disease incidence, increased sea temperatures, likely increases in natural mortality, and likely offshore shift of spawning females, removal of fishing mortality is the one opportunity available to managers to influence the likelihood of rebuilding the stock.
- Recruitment indices are an important tool for forecasting future stock and fishery trends and for providing an early indication of the success of management actions aimed at protecting spawning potential. It is essential that current recruitment indices are maintained and intensified, and if possible a spatially comprehensive overview of recruitment processes across the SNE stock area

should be attempted. Passive postlarval collectors represent a promising tool for measuring settlement indices.

- A five-year moratorium on the lobster harvest in SNE is put forward by the TC as providing the highest likelihood of rebuilding the stock to its target levels. This management action can be justified in a risk-based approach, considering (a) the probability that the TC's scenario of environmentally-driven recruitment decline is true, and (b) the risks under this scenario that rebuilding will not occur if management actions other than a moratorium are imposed. On the basis of the analyses presented by the TC, I would assess the probability of their recruitment failure scenario being true as being high and the risk of failing to rebuild if the moratorium is not imposed as high. However, it must be stressed that this is just an assessment of the most likely levels of probability and risk - *responses* to probability and risk are the domain of managers rather than scientists.
- There is a need to provide an improved evidence base for the TC scenario of environmentally-driven recruitment decline, together with an assessment of the likelihood of other conceivable scenarios being true (e.g. return to previous productivity levels).
- In the event of any harvest moratorium, monitoring activity needs to be continued and intensified. Sentinel fishing activities may be appropriate to compensate for the loss of fishery-related indices during any moratorium. The success of a moratorium should continually be assessed, with consideration of alternative management options that may allow some harvest to occur.
- The TC undertook stock projections involving reduced or eliminated fishing mortality and/or continuation of the Rhode Island v-notching scheme. The projections were highly sensitive to assumptions about natural mortality and future recruitment patterns, and indicated that under the most likely (or at least most pessimistic) scenario, rebuilding of the stock is unlikely to occur even if a complete moratorium on lobster harvest is imposed. An improved understanding of spatial dynamics and the role of spawning stock biomass in determining recruitment is needed to improve the utility of future projections.
- The TC infers an increase in natural mortality for 1998-2007 based on decreases in negative log-likelihood for the University of Maine length-based model. This increase is plausible given changes in environmental conditions, disease incidence and predator abundance, but there is a need to support this analysis with a fuller review of mortality factors and of the components of fit within the model.

Background

The American Lobster Stock Assessment Report for Peer Review (Doc8) was released in March 2009 and the report was accepted under Peer Review (Doc9) in May 2009. The assessment indicated that, unlike the lobster stocks in the Gulf of Maine and Georges Bank, the Southern New England (SNE) lobster stock was severely depleted. The American Lobster Board assigned the Atlantic States Marine Fisheries Commission Lobster Technical Committee (TC) with the following tasks:

(1) identify issues impeding stock rebuilding in SNE;

(2) develop a suite of measures to begin stock rebuilding in SNE; and

(3) develop deterministic projections of stock abundance using the University of Maine model that assume: (a) both *status quo* and reduced fishing scenarios, and (b) *status quo* recruitment, low, declining recruitment, and a stock recruitment relationship.

The TC had three months to report back to the American Lobster Board on their findings, and the result of their work was the report *Recruitment Failure in the Southern New England Lobster Stock* (Doc1). With the exception of temperature data and information on the redistribution of spawning females, all other fishery independent and dependent data used in this report were peer reviewed and accepted during the most recent (March 2009) ASMFC Benchmark Stock Assessment (Doc8, Doc9).

This report represents a review of the TC's report and associated documentation on stock projections and higher levels of natural mortality. The Terms of Reference for the review are included in the Statement of Work in Appendix II.

Description of Review Activities

The Statement of Work (Appendix II) and review documents (Appendix I) were supplied on 30 August 2010. I was able to read the review documents over the period 1-30 September 2010 and to collate my responses and write this report over the period 1-11 October. The review documentation and its references were comprehensive and necessitated no further queries.

Summary of Findings

1. Evaluate the quality and completeness of the data gathered since the assessment (temperature data and redistribution of spawning females); if inadequate, specify additional techniques that should have been considered.

Data collated on sea temperature and incidence of shell disease are adequate to demonstrate recent changes in conditions experienced by the SNE lobster stock. Data collated on the distribution of the lobster stock are strongly suggestive of a redistribution of spawning females, but a fuller description of available data sources, and of the spatio-temporal patterns evident within and between these sources, would be needed to demonstrate the existence of this redistribution with high probability.

A critical element in the TC's interpretation of a recent change in the productivity of American lobsters in SNE is the inference of a shift in the spawning distribution of females from shallow inshore grounds to deeper offshore areas. Three lines of supporting evidence are presented in Doc1:

(i) the Connecticut trawl survey in Long Island Sound showing recent (2000-08) catch rates much lower in shallow (<30ft) areas than deeper (>90ft) areas, compared with an earlier period (1984-91) when catch rates in the two areas were similar (Doc1 p.10);

(ii) the regional Ventless Trap Survey showing higher abundance in deeper strata in SNE, contrasting with the Gulf of Maine where higher abundance is seen in shallower strata (Doc1 p.10, Appendix A); and

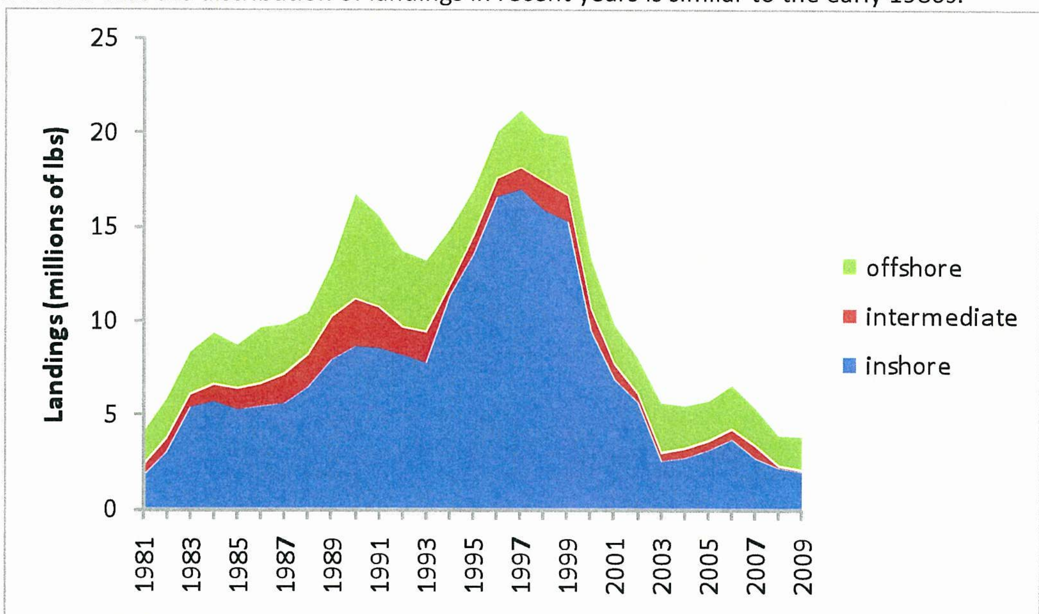
(iii) results of the Massachusetts Sea Sampling program, showing a shift in the lobster fishery from shallow inshore to deeper offshore waters, with spawning females increasingly seen in the deeper areas near the mouth of Buzzards Bay and in Vineyard Sound rather than in the shallower waters within the Bay itself (Doc1 p.10, p.19, Appendix B).

From the information given in Doc1, it is difficult to judge the quality and completeness of the data gathered in evidence of the shift in spawning distribution. The three items highlighted certainly point towards greater catches or catch rates (and hence, presumably, greater abundance) of lobsters in deeper water, but without a fuller presentation it is hard to judge how selective are these pieces of information and what contrary evidence might also exist. Item (i) is an excerpted statistic, not shown against the context of patterns in the whole data set. Quantitative values are not given and there is no information on the precision of catch rate estimates. Item (ii) is more convincing, in that I can see for myself that, particularly in SNE-LCMA2, the smaller bubbles on the maps (lower CPUE) are located in shallower waters, closer inshore, whereas the larger bubbles are located in deeper waters, further offshore. However, the Ventless Trap Survey lacks an historical perspective to show whether or not this pattern is typical of past decades or does in fact represent a real offshore shift. Item (iii) provides a longer perspective, at least back to 1998. Without any explanation of the data presented in Appendix B it is hard to know exactly how to interpret the plots, but I am presuming that the red spots show sampled lobster fishing locations and are considered representative of the distribution of the fishery (but is the sampling spatially stratified?). If this is the case, I can certainly see the fishery shifting out of the inner parts of Buzzards Bay and into Vineyard Sound between 1998 and 2006.

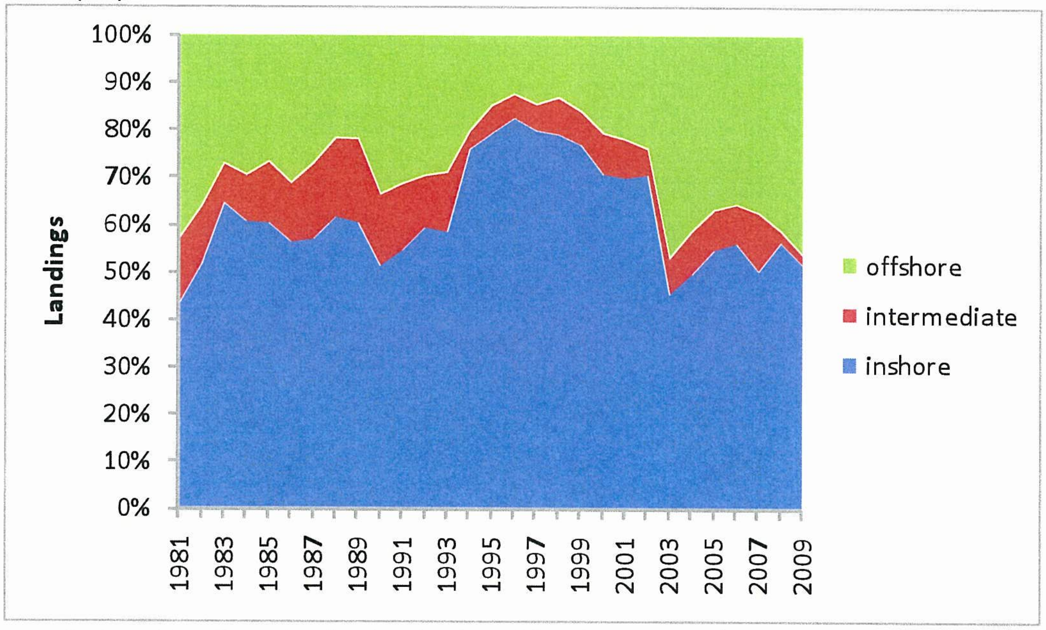
In general, I conclude that *on the basis of the data presented in Doc1* there does appear to be a movement of lobsters offshore and into deeper waters over recent years, at least over relatively short spatial scales. However, these data represent only snapshots rather than a full spatial and historical overview of distributional patterns, and must be regarded as a somewhat slender basis for robust inference. For the case to be truly convincing there needs to be a fuller presentation of all available data, and **I recommend that the TC be given the opportunity to conduct a comprehensive analysis** at an early opportunity. This analysis should include:

- Indices stratified by depth and/or distance for all available trawl survey series and presented with appropriate measures of uncertainty. Analyses should aim to provide the maximum historical *and* spatial perspectives. Candidate surveys might include the CT trawl survey in Long Island Sound, from which only a small excerpt was quoted as item (i), and the NEFC Fall trawl survey which is stated to give the best coverage for offshore areas in SNE (Doc1 p.11).
- Where it is not possible to provide both historical and spatial perspectives *within* individual surveys, effort should be made to make contrasts *between* surveys. This may be hampered by differences in methodology and catchability between surveys, but it should at least be possible to identify the spatial patterns of dominant temporal trends by using techniques such as dynamic factor analysis (Zuur *et al.* 2003, Zuur & Pierce, 2004) or principal components analysis.
- Fuller use of data from the Massachusetts Sea Sampling program, including the longest possible time series (Doc8 p.35 mentions the DMF program collecting data from 1981 – is this the same survey as referred to in item (iii) and does it cover SNE over these dates?). In addition to the distributional data shown in Appendix B of Doc1, CPUE data could be analyzed, stratified by depth and inshore/offshore.
- Tables or graphs of Ventless Trap Survey catch rates should be presented, stratified by depth and region.

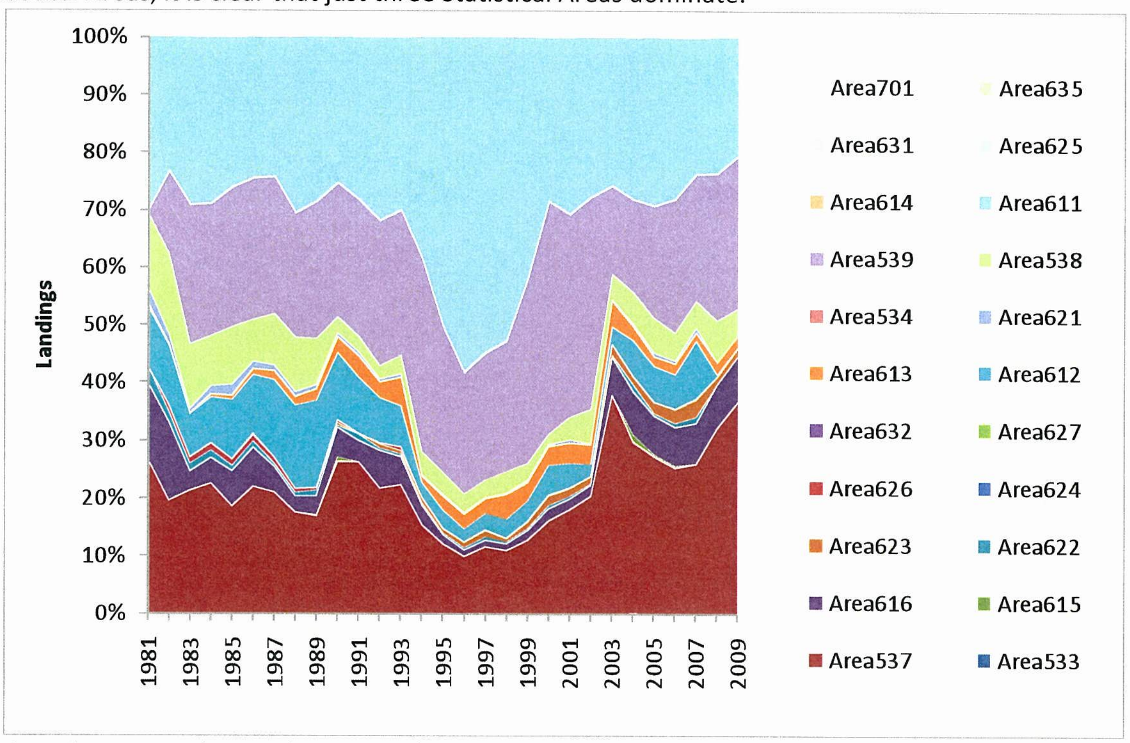
Aside from the Massachusetts Sea Sampling program data, strong evidence of an offshore fishery shift is not shown in the TC's report. Purely on the basis of landings by statistical area (data from Doc1, Figures 9-13), it seems that the distribution of landings in recent years is similar to the early 1980s:



In this figure, Statistical Areas 533, 537, 615, 616, 622, 623, 624, 626, 627 and 632 have been classified as 'offshore', 534, 538, 539, 611, 614, 625, 631, 635 and 701 have been classified as 'inshore', and 612, 613 and 621 have been classified as 'intermediate'. The distributional pattern is even clearer when expressed in proportional terms:



This shows 'inshore' landings dominating in the mid to late 1990s, but a roughly equal split between 'inshore' and 'offshore' in the early 1980s and over recent years. If the data are labeled by individual Statistical Areas, it is clear that just three Statistical Areas dominate:



Statistical Area 611 (Long Island Sound) accounted for up to 30% of landings in the early 1980s, similar to recent levels, but increased to almost 80% of the landings in the mid to late 1990s. Statistical Area

537, which I interpret as offshore on the basis of the map in Appendix C in the TC's report (Doc1), shows the opposite pattern, and much of the remaining landings were from Statistical Area 539. Of course, it would be possible to improve on my *ad hoc* classification of Statistical Areas as 'inshore' or 'offshore', and this classification has been made without any knowledge of the distribution of landings *within* Statistical Areas. Possibly, it is the fine-scale distributional patterns that are relevant, rather than the gross differences between reporting areas. This is hinted at in the analysis under item (i), which refers to patterns *within* Long Island Sound, and similarly the interpretation of data from the Ventless Trap Survey appears to consider patterns over a spatial scale that is small in relation to the size of SNE as a whole. If a robust case is to be made for strong management action on the basis that the current pattern of the lobster fishery/population is something different from what has been observed before rather than a return to a previous state, the supporting analyses must make very clear exactly what is the nature of the change that is observed – where are the distributional shifts, and over what spatial scales?

Data were also presented on sea temperature trends in SNE. *Assuming that these are the only data series available for the area*, this data gathering exercise appears to be complete and of high quality. Sea surface temperature data are presented for Woods Hole, two series of bottom temperature data are presented for Buzzards Bay and one series of bottom temperature data is presented for Long Island Sound. Two very minor queries arise in relation to these series: firstly, how does sea surface temperature relate to bottom temperature at Woods Hole, and would it be sensible to choose a higher threshold than 20°C at the surface to represent the suitability of the bottom conditions for lobsters? Secondly, why was 18°C rather than 20°C used as the threshold for the deeper Buzzards Bay site? However, neither of these queries detracts from the main message of the data presentation (Doc1 Figures 14-17) that SNE sea temperatures have been consistently warmer during the period from the late 1990s to present than in previous decades. If other data series exist, these should certainly be analyzed in a similar way, and every attempt made to collate a comprehensive spatio-temporal overview of bottom temperatures that could be used to map the thermal boundaries of lobster habitat in SNE waters. Further, I recommend making an explicit link between lobster distribution and sea temperature by including temperature variables as covariates in the analyses suggested above for lobster abundance indices. Generalized linear models, generalized additive models and dynamic factor analyses would all be suitable frameworks for such analyses. Large scale climatic variables, such as the North Atlantic Oscillation (NAO) index could also be used in this context.

In addition to data on temperature and lobster distribution, the TC also collated information on the incidence of chitinoclastic shell disease in SNE lobster catches. Data series for Rhode Island and Eastern Long Island Sound showed a consistent pattern of increased incidence from very low levels in the early to mid-1990s to 15-35% since the late 1990s. A shorter time-series for Massachusetts is also shows a consistent picture of high incidence levels recently. These data provide useful supplementary information on factors that may be implicated in any recruitment declines. It is to be hoped that information on disease incidence will continue to be collected (using survey samples), even during any commercial fishery closures.

Finally, new data were also presented on the regional incidence of females in the commercial SNE lobster catches. Whilst not informative of stock trends or shifts in distribution, these data are a useful demonstration of the potential for the fishery to remove females from the population, particularly in the deeper areas to which the fishery may be shifting.

2. Determine the appropriateness of the findings drawn in the TC report, if deemed inappropriate, provide alternative findings with justification.

I agree that the findings of the TC report are appropriate with respect to the current status of the SNE lobster stock, current low recruitment levels and factors likely to limit recruitment.

The TC report (Doc1) presents a great deal of information about trends in abundance, spawning stock biomass, recruitment, larval production and fishery landings of lobsters in SNE. Trends are reported, in most cases, back to the early 1980s, and the main findings are that recent values of stock indicators are, in most cases, at or near their lowest levels over this period. Taken individually, many of the indicators appear highly uncertain, often owing to low catch rates or low sample numbers, and some of the indicators have very restricted spatial coverage. However, taken in aggregate, a strong overall message emerges that the SNE lobster stock is currently at a low ebb with very low levels of recruitment and larval production.

Stock status is inferred principally on the basis of the University of Maine length-based model. This is an accepted peer-reviewed assessment and the model is considered to be statistically rigorous and the best current basis for inference about stock status (Doc8, Doc9). I concur with this view. The assessment has acknowledged issues related to uncertainty about the growth matrix and resolving apparently conflicting survey indices (arising because regional indices are treated as representing the whole assessment area). However, the gross picture emerging from the assessment is similar to that from results of Collie-Sissenwine analyses aggregated over different areas, and shows a close correspondence with trends in overall landings. On this basis, I consider that the current assessment of stock status provides a sound basis for the evolution of management advice and hence provides a reliable picture of stock trends as a background to the TC's report. I note that the threshold abundance used by the TC, being the 25th percentile of the 1984-2003 reference period, differs from the threshold proposed by the peer review panel (Doc9), which was half of the median abundance, considered more consistent with the ½ B_{MSY} threshold used in other assessments. This value is considerably lower than the 25th percentile and would result in the SNE lobster stock being considered not to be overfished (in addition to overfishing not occurring)[1]. However, I do not have a strong opinion on what would be the better choice of threshold, and given the lack of information on the form and parameters of a stock-recruitment relationship I believe this is largely an operational consideration for managers. I find the 25th percentile to be a useful flag for all the stock indicators presented by the TC, whether or not this is used as the basis for reference points.

Spawning stock biomass indices based on trawl surveys show different trends between areas, but there is a very general pattern of higher values during the 1990s and low values recently. Presumably the different trends are due to both statistical uncertainty and regional differences – it would be useful to see confidence intervals around estimates and some maps of the spatial coverage of each survey, to provide some insight into these sources of variation. Also, as noted above (p.7), it would be useful to integrate these surveys into a combined analysis to extract and interpret the dominant overall trends. The same points can be made about the overall abundance indices from the trawl surveys. Differences in the Rhode Island indices are highlighted in the report, attributed to the success of a v-notching scheme.

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[1] It is worth noting that, if the Collie-Sissenwine analyses were used as the main basis for stock assessment, the SNE lobster stock *would* be considered overfished, whichever definition of threshold was used.

Young-of-year settlement indices presented by the TC are restricted in their spatial coverage and appear to have a low statistical power of detecting changes, largely owing to low catch rates and small numbers of samples. However, taken together they provide a consistent picture of low recent abundance of larvae in the areas covered.

Taking all the stock indices together, I agree with the TC that there is a high probability that the SNE lobster stock is at a depleted level when compared with the 1990s, and that this situation is being exacerbated by lower levels of recruitment. The TC provide a detailed and useful discussion of the factors that may have limited recruitment and may continue to limit recruitment in the future. Central to their thesis is the idea that American lobsters are at the southern end of their geographical range in SNE waters, and that recent trends of increasing water temperature are shifting the thermal boundaries of optimal lobster habitat. A concise but thorough and convincing account of the implications for lobster physiology and immunocompetence of sea water temperatures in excess of 20°C is given in Doc1, and as noted above (p.9) there is good evidence that sea temperatures have exceeded this level in inshore waters of SNE more frequently since the late 1990s than in the previous few decades. I agree with the TC that a shift in spawning distribution from shallow inshore areas to deeper offshore areas is consistent with this change in temperature regime. This is notwithstanding the need to strengthen the evidence base for such a shift noted under ToR1, above (p.7).

The TC argue that a shift of spawning activity to deeper waters will be adverse for lobster recruitment because larvae released in offshore areas are likely to be transported away from their traditional inshore settlement areas. This inference is supported by the results of satellite tracking of drifters deployed at locations chosen to represent previous and current spawning areas. Whilst I agree that this is certainly a plausible, and even likely, explanation of recent low recruitment levels, the evidence base for this contention needs to be strengthened. A recent conference presentation on American lobster stock-recruitment relationships (Chang *et al.* 2010, quoted by permission of the lead author), emphasized the role of hydrographic processes in determining the scale at which stock-recruitment relationships apply in the Gulf of Maine. In the west of this area, stock-recruitment relationships appear to operate at relatively small spatial scales (<10 km), whereas in the eastern Gulf of Maine, where the coastal current is stronger, the relationships appear to operate at larger scales (>30 km). From the reports available for this review, it seems likely that the data are not available to repeat this analysis for SNE, but it would be instructive to examine large and fine-scale hydrographic models for the region and attempt to model larval transport based on different release locations. **I recommend that a modeling study of lobster larval transport in SNE be undertaken, supported by further drifter deployments as appropriate**. An improved understanding of the relationship between the parental lobster stock and subsequent recruitment in SNE is crucial as a scientific underpinning of any strong management action aimed at limiting the capacity of the fishery to reduce spawning stock size. Such understanding needs to include both a spatial component (location of spawners versus location of recruits) and a larval production component (quantity of spawners required to produce sufficient larvae).

3. **Determine the appropriateness of conclusions drawn in the TC report; if deemed inappropriate; provide alternative conclusions with justification.**

I believe that the conclusions drawn in the TC report are appropriate with regard to the environmental and biological conditions most likely to be prevailing in the SNE lobster stock, but I consider that the evidence basis for these conclusions needs to be strengthened and that other scenarios should also be considered. I believe that the conclusions in the TC report with regard to impediments to stock rebuilding are appropriate *under this most probable scenario of environmental and biological conditions*.

Two types of conclusion may be distinguished here. Firstly, the TC draws conclusions about the current lobster population regime in SNE – overall lobster abundance, spawning stock biomass, recruitment levels and the environmental drivers that may define the current production capacity of the stock. Secondly, the TC draws conclusions about the role of fishing mortality in determining the lobster population regime.

With regard to the conclusions about the lobster population regime, I believe the TC's conclusions are appropriate in the sense that the most probable explanation of the current evidence is that there has been an environmentally driven shift in spawning distribution away from areas favorable to successful settlement of juveniles, and that this has been exacerbated by increased natural mortality from disease and other factors. This scenario is consistent with the available data on SNE lobster trends and with current scientific understanding of lobster biology, although there is certainly scope for strengthening of some components of the evidence base, notably regarding the offshore spawning shift and larval transport. However, this does not exclude the possibility of alternative scenarios.

One feasible scenario is that the SNE lobster stock is currently returning to a previous, lower productivity regime, after an episode of much higher productivity in the 1990s. The reference period for which 25th percentile values of stock indicators are illustrated in the trend plots of Doc1 is only 20 years, over which many of the indicators show a very simple trend: low values in the early 1980s, increasing two- or three-fold to higher levels by the late 1990s before a return to lower values in the most recent years. Recent values of many stock indicators are at or close to their lowest levels – levels typically prevailing in the early 1980s. Thus, it could be argued, current values of, for example, spawning stock biomass or recruitment are at levels from which the stock has previously 'recovered' to much higher levels. The obvious question is: how representative of 'normal' lobster stock dynamics in SNE was the period during the mid to late 1990s? Was this a period of exceptionally high productivity, so that the current situation is simply a return to lower productivity levels rather than a recruitment failure as such? Is the median stock abundance over the 1984-2003 reference period an unrealistic target for rebuilding the stock? What needs to be demonstrated is that there is something about the most recent decade that is fundamentally different to the conditions experienced during the early 1980s. Temperature and disease incidence records presented in Doc1 are the most convincing evidence that such a change has happened: current temperatures and incidence of shell disease have been much higher in recent years that was evident for the early 1980s. The evidence of an offshore shift in spawning distribution is at least suggestive, as is the use of drifter observations to show the implications for settlement success of a changed location for larval release. There is at least statistical evidence that natural mortality levels are currently much higher than in previous years (Doc3), and such an increase is certainly plausible in the light of temperature effects on lobster biology, observations of disease incidence and trends in predator abundance. Altogether the TC report paints a plausible picture of a lobster stock at the southern end of the geographical range for the species declining as a result of environmental change and its ecological consequences. If true, and if this local environmental change is part of a larger pattern of climate change, then the outlook is indeed bleak for SNE lobster stocks and fisheries.

On the basis of the evidence presented by the TC, I believe that there is a significant probability that this scenario may be true, and that fishery management action should proceed on the basis of this risk. However, in my view it is very important that the evidence base be strengthened (or otherwise) by a more extensive and rigorous examination of the available data (as recommended under ToR1). It is also important that other possible scenarios are considered in this analysis, and that the risks for future stock trajectories associated with each scenario are quantified to the extent possible given the available information. A risk-based approach to fishery management needs to be a two-pronged approach: (i) to consider the probability that any given stock scenario is the correct one; and (ii) to quantify the risks under any scenario that any given management action will fail to achieve a desirable outcome.

The TC's report appears not to be suggesting that fishing mortality has played a role in the decline of lobster stock abundance since the late 1990s. Stock abundance is inferred as being low as a result of low recruitment, rather than recruitment having declined as a result of fishing driving down the size of the spawning stock. However, fishing mortality is very firmly identified as an impediment to rebuilding, particularly given the prevalence of females in the catches in the deeper water areas to which the fishery has shifted. Under the TC's recruitment failure scenario, it is certainly true that any increase in spawner mortality could adversely affect production of larvae. At higher levels of spawning stock biomass, there may well be recruitment bottlenecks that mean that the levels of successful settlement are not strongly related to the quantity of larvae release, provided that the quantity is 'enough'. At lower stock levels, attaining 'enough' larval production becomes a much more important issue, particularly if the probability of larvae reaching favorable inshore settlement areas is much reduced. The success of the Rhode Island v-notching program attests to the importance of local larval production (although I note that the benefits appeared to be short-lived, with declines in recruitment after 2005). The report also highlights that disease may affect spawning success in both males and females, and that larvae produced by first-time spawners may have lower survivability than those from older/larger females. All these factors mean that any increased pressure of mortality on the spawning stock will decrease the ability of the SNE lobster stock to rebuild itself from depleted levels. Thus, I concur with the TC that, *under the environmentally-driven recruitment failure scenario*, fishing mortality will be an impediment to rebuilding. Of course, this would not necessarily be true under other scenarios for the SNE lobster stock, such as a return to previously experienced levels of stock productivity.

Notes to the ToR for this review (Appendix II) summarize the main TC conclusions as:

a. The TC contends that the stock is experiencing recruitment failure caused by a combination of environmental drivers and continued fishing mortality.

b. It is this recruitment failure in SNE that is preventing the stock from rebuilding.

c. Overwhelming environmental and biological changes coupled with continued fishing greatly reduce the likelihood of SNE stock rebuilding.

In summary:

- I accept conclusion (a) as being demonstrated as the most probable explanation of the evidence available, but I believe that this needs to be strengthened by a more detailed examination of the available data together with a consideration of alternative scenarios such as a return to previously (early 1980s) prevailing productivity levels.

- Under the TC's scenario, I agree that continued recruitment failure would prevent the stock from rebuilding.
- Under the TC's scenario, I agree that there is a low likelihood of the SNE stock rebuilding if current environmental and biological conditions continue to prevail, and that fishing mortality would be likely to exacerbate the difficulties of rebuilding the stock.

4. Comment on the applicability of the recruitment indices to forecast future recruitment and landings to the inshore and offshore areas.

I believe that recruitment indices are of at least potential applicability in forecasting short-term recruitment and landings.

The TC's report describes four recruitment indices for the SNE area: two larval surveys in Long Island Sound and two young-of-year settlement surveys, one for Narragansett Bay and Rhode Island Sound, one for Buzzards Bay. All of these surveys, with the possible exception of the Rhode Island young-of-year survey, appear to be low in statistical power, and thus likely to be of limited applicability in forecasting recruitment. However, the surveys were able to show at least some features consistent with the inference of current low recruitment levels, and would presumably have some power to detect increased larval production and settlement levels that might give early warning of the success of any management measures. However, in addition to low statistical power, it must be recognized that the surveys are limited in their spatial coverage and thus must be of limited applicability in forecasting future recruitment in SNE as a whole and landings for both inshore and offshore areas.

Given the importance of recruitment to future stock trends, any early indication of a change in recruitment levels is highly useful as a guide to the success of current management in protecting spawning output and to how management should proceed in the immediate future. **It is thus imperative that present lobster recruitment surveys should be continued into the future, and if possible their sampling intensity should be increased to enhance their power to detect changes in larval or young-of-year abundance**. The TC report highlights work by Wahle *et al.* (2009) with passive postlarval collectors. Given the linkage between lobster settlement and subsequent recruitment to the fishery, this methodology would seem to have a great deal of potential as a tool for monitoring recruitment trends and forecasting future stock and fishery trends in SNE. **I recommend that the TC give consideration to designing new surveys within SNE using passive postlarval collectors**, with a view to developing a spatially comprehensive view of settlement processes. Such a survey would: (a) give some insight into recruitment processes in the area as a whole; (b) provide feedback for management actions; and (c) allow forecasts of recruitment and landings for both inshore and offshore areas. Such a spatially comprehensive overview could not currently be possible with the existing surveys.

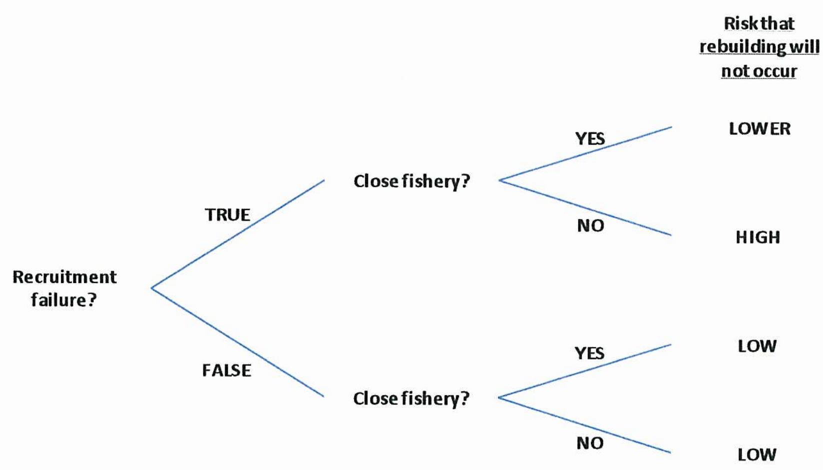
Finally, it is worth noting that, from the point of view of understanding recruitment processes, it is important that there be an improved understanding of larval transport within SNE (see comments above under ToR2, p.11). Set alongside such an improved understanding, monitoring of larval production and settlement has the potential to provide an holistic overview of the status of recruitment processes in SNE.

5. **Determine the appropriateness of the recommended action (5-year moratorium); if deemed inappropriate, provide alternative recommendations with justification.**

The proposed 5-year moratorium of lobster harvest in the SNE stock area would be justified under the scenario of environmentally-driven recruitment failure. Given an appreciable probability that this scenario is true, there is a strong risk that continued fishing mortality (among a number of other factors) would be a significant impediment to rebuilding.

As noted above (p.13), under a risk-based approach to fishery management, managers must consider two aspects: (i) what is the probability that a given scenario of stock status and its drivers is true; and (ii) in terms of targets to be achieved, or limits to be avoided, under any given scenario what are the risks associated with a given management action. It is, of course, a matter for managers rather than scientists to decide what is a sufficient probability for any given scenario to act on the basis that it might be true, and to decide what levels of risk are acceptable in relation to any given outcome. At present, I believe that the TC's report (Doc1) provides evidence that the environmentally-driven recruitment failure scenario is the most likely explanation of current stock status, and it seems reasonable to suppose that the management response would proceed on this basis. However, it must be re-iterated that this is not the only possible scenario; given the far-reaching social and economic repercussions of so drastic a management action as closing the fishery for five years, it is important that the evidence for the recruitment failure scenario be strengthened as much as possible, particularly with regards to the offshore shift in spawning distribution and its implications for transport of larvae to favorable settlement locations.

Considering just the TC recruitment decline scenario, we can illustrate the decisions that will need to be made by managers in assessing the risk that rebuilding targets will not be achieved within the required timescale. Of course, assumption of scenarios other than recruitment failure may necessitate re-assessing targets to reflect realistic productivity levels, and this will affect the definition of rebuilding and the probabilities of it being achieved.



According to this very notional decision tree, and depending on what view managers took about risks and probabilities being 'high', if the recruitment failure scenario was considered sufficiently probable the obvious course of action would be to close the fishery to achieve the 'lower' risk (noting that even in the most optimistic case, stock projections still indicate that rebuilding is unlikely – Doc2). Depending on the terms of reference for managers, there may be other risks that would need to be traded-off against this risk of not achieving rebuilding targets.

As stated above, in my view the environmentally-driven recruitment failure scenario is the most likely explanation of the available information and a harvest moratorium is an appropriate fishery management response to this situation. The TC report states that a moratorium "provides the maximum likelihood to rebuild the stock to a level that can support a sustainable fishery". Under the assumption to the recruitment failure scenario, I agree with this statement. The TC reviews three case studies of crustacean fisheries in the NW Atlantic and concludes: (i) that there is a need to understand the consequences of fishing after a moratorium is lifted; (ii) that there must be a spatial match between the area over which a moratorium is applied and the life-history of the target species; and (iii) survey data can be used effectively to allow management action to respond to favorable environmental conditions for recruitment. I agree with these conclusions. The corollaries for SNE lobster management are that management action would be supported by an improved understanding of the spatial dynamics of the stock, particularly as regards larval transport and subsequent recruitment, that surveys and monitoring should continue unabated, and preferably intensified, during any moratorium, and that the case for a moratorium needs continually to be revisited during the course of any fishery closure. Fishery closure inevitably involves a loss of fishery-related indices from any status assessment. This gap may partially be filled by sentinel fishery activities, and there may be scope for further industry participation in survey activities. The scope for such surveys should be investigated. The TC's report highlights the continued importance of ventless trap sampling, young-of-year surveys, larval surveys and trawl surveys in monitoring any recovery. I agree that these activities are highly important, and wholeheartedly concur with the TC's view that "new surveys and research are needed to further characterize lobster settlement and habitat in SNE".

Some of the possible management actions other than a complete harvest moratorium are considered in the stock projections undertaken by the TC (Doc2). Options include reduced levels of fishing mortality and continuation of the Rhode Island v-notching scheme. The main outcome of the projections is to show their sensitivity to assumptions about natural mortality and future recruitment, so it is difficult to comment on the appropriateness of management actions other than a complete harvest moratorium. Under the worst case scenarios, it appears that reduced (as opposed to eliminated) fishing mortality and v-notching will contribute little to stock rebuilding. However, **I recommend that further data- and model-based exploration of all feasible management actions be conducted with a view to modifying the management response in the future**. This should include consideration of v-notching, seasonal closures, closed areas within SNE, and maximum and minimum legal sizes. Some of these explorations may be contingent on an improved understanding of spatial stock dynamics. In the TC report there are some reservations expressed about the effects of discard mortality if technical measures such as maximum legal sizes are imposed. Discard mortality needs to be adequately characterized in any projections involving relevant technical measures.

6. **Evaluate the stock projection scenarios conducted to complete the task as outlined by the Board.**
    a. **Evaluate the deterministic projections conducted using the University of Maine Model.**
        i. **The Board directed the TC to provide projections within an extremely short time frame. Although stochastic projections and estimates of uncertainty (e.g. MCMC confidence intervals) could have been provided, the time frame for decision-making was too short to complete a more thorough analysis.**
    b. **Evaluate the chosen suite of fishing and recruitment scenarios presented in the report; if insufficient, provide suggestions for alternative scenarios.**
    c. **Determine if projection results and the TC's interpretation provided in the report are consistent with assessment model results.**
    d. **Comment on the reliability of the deterministic projections for use in SNE lobster stock management.**

The TC undertook stock projections based on the University of Maine length-based model for SNE lobsters. Projections involved reduced or eliminated fishing mortality and/or continuation of the Rhode Island v-notching scheme, under different scenarios of natural mortality and future recruitment. In my view the projections were both appropriate (proper consideration of management and stock scenarios) and reliable (within the limitations of the assessment model, its spatial structure and the information available). This being said, the projections were mainly informative about sensitivity to assumptions about natural mortality and future recruitment. Owing to time constraints, the TC was unable to perform stochastic projections. Although it will be important to provide such projections in the future (based on MCMC rather than estimated assessment model uncertainties) to quantify the risks and uncertainties associated with proposed management actions, I believe that the current fundamental uncertainties are such that stochastic projections would add little to the present debate.

The main conclusion from the projections is that "if poor environmental conditions continue, dampening the abundance of both spawners and recruits, only current levels may be attainable even in the absence of fishing" (Doc2 p.3). Under the most likely level of natural mortality (i.e. the value with most statistical support in Doc3), stock abundance (for an average stock trajectory) is likely to remain below both target and threshold levels in 2017, even under the most optimistic assumptions about recruitment (Beverton-Holt stock recruitment relationship). Under a more pessimistic view where recruitment remains at current low levels, which view could be justified in a risk-based management framework, the stock is projected to decline to much lower abundance levels, with very little prospect of rebuilding without a major change in mortality and/or recruitment regimes. Rebuilding only appears to be possible under a scenario of lower natural mortality than currently seems likely to be prevailing. The only scenarios where rebuilding occurs without a total cessation of fishing are those in which natural mortality is at moderate levels and recruitment responds to increased stock abundance through a Beverton-Holt stock recruitment relationship.

These projections paint a stark picture. In my view, although it is certainly possible to define additional management scenarios to explore, the projections outlined in Doc2 take the debate as far as it is possible to go at present[2]. The projections are based on the same population dynamics module as the

[2] One slight *caveat*: it is not clear whether the starting positions for the projections were consistent with the levels of natural mortality assumed to prevail into the future. If not, they should have been, i.e. projections with high M should assume that M has been high since 1998.

assessment module, and I am satisfied that the model and its application are technically sound. The main improvements to be aimed for in the future include:

- inclusion of spatial structure in both stock assessment and projections;
- improved information about natural mortality and its sources of variation;
- improved information on how changes in stock biomass translate to changes in recruitment;
- incorporation of environment-recruitment linkages, with projections performed under various future environment scenarios
- stochastic projections to allow risk assessment of management options.

The most important of these is perhaps the stock-recruitment relationship, since without knowledge of such a fundamental relationship we will always remain very uncertain about future stock trajectories.

As a background for management, these projections are mainly useful in highlighting the main issues and uncertainties rather than presenting realistic management options. This is necessarily so at present, but it is to be hoped that improved knowledge of SNE lobster dynamics (particularly in a spatial sense) and biological parameters will allow management to be better supported by projections in the future.

7. Review the M sensitivity analysis of the model that indicated a higher M as suggested in the 2009 assessment.

Natural mortality rates for a *k*-selected species such as American lobster would be assumed to be relatively low, but it is plausible that the SNE stock could be experiencing elevated natural mortality rates due to the effects of increased temperature, increased disease incidence and changes in the abundance of potential predators. In terms of estimating relative stock trends, the University of Maine length-based model is likely to be relatively robust to different assumptions about natural mortality, but the goodness-of-fit of the model may nevertheless be informative about its most likely levels. On this basis, the TC have demonstrated that an increase of 1.9 times the base level of $M = 0.15\ yr^{-1}$ up to $M = 0.285\ yr^{-1}$ for the period 1998-2007[3] provides the lowest negative log-likelihood of all the models considered (Doc3).

This is a useful analysis, and I am happy with it so far as it goes, but I would like to see some further exploration of the source of this improved fit. Given acknowledged model deficiencies, such as uncertainty about the growth matrices and the lack of spatial structure in the model, does this apparent change in *M* play proxy for some other biological change (e.g. increased growth rate) or spatial shift that is not accounted for within the model structure? Stock assessment models rarely have much power to estimate natural mortality rates, and inferences about natural mortality from model fit should be treated carefully. It would have been useful to see stock and recruitment trends estimated from the alternative models to see whether the estimates remained within the realms of plausibility. Further, it would be useful to see some discussion of how the likelihood components contributed to the overall change in fit. For example, the commercial female catch appears to have the biggest contribution, and would support a higher *M* still. This appears to be traded off against other components such as the

[3] The wording in Doc3 is somewhat ambiguous here, stating that "alternative model runs differed from the basecase only in that the assumed value of M was higher". I have assumed that this statement is intended to apply to 1998-2007 rather than the entire assessment period of 1984-2007.

length composition of males in survey 1 and the commercial catch. Is there any case for weighting these components differently, e.g. using estimates of survey precision? Is there any case for considering males and females separately, e.g. the possibility that females may be more vulnerable to increased mortality factors because of greater molting frequency? The projections outlined in Doc2 are highly sensitive to the assumed values of M, so it is very important to map out the real uncertainty associated with this parameter, as well as what are the most likely values.

In summary, I accept the case made by the TC that natural mortality of American lobsters is likely to have increased over recent years. The analyses undertaken by the TC using the length-based model provide some limited support for this inference, but further support could be provided by:

- an account of natural mortality factors for American lobsters in SNE, together with quantitative information on trends in these factors (e.g. predator abundance);
- consideration of trade-offs between M and other factors (growth uncertainty, spatial heterogeneity) in determining the fit of the length-based model;
- examination of whether it would be appropriate to weight the data sources differently in computing the overall negative log-likelihood for the model;
- examination of whether model fit can be improved by using different natural mortality values for males and females.

Conclusions and Recommendations

The main conclusion of my review is that the TC presents a coherent and plausible scenario of an American lobster stock at the southern of its geographical range experiencing recruitment failure owing to environmental and biological changes. I accept this scenario as the most likely explanation of the current evidence on stock and environmental conditions in SNE, including indices of stock abundance, spawning stock biomass and recruitment at much lower levels than the 1990s, unprecedentedly high levels of disease incidence, and evidence of a shift in spawning distribution to deeper, offshore locations unfavorable for successful recruitment. This takes place against a background of higher sea temperatures than previously seen, with implications for lobster mortality and reproduction. However, there needs to be further consideration of alternative scenarios, notably the possibility that current productivity is returning to previously seen lower levels after a period of higher productivity during the 1990s. I believe that there is currently sufficient information for fishery managers to make risk-based management decisions. However, if drastic management action is to be imposed, in the form of a five-year moratorium on the SNE lobster harvest, it is right that every effort should be made to strengthen the evidence base for the recruitment failure scenario, concentrating particularly on the offshore shift in spawning distribution and the implications of this shift for successful settlement. A spatially comprehensive model of the SNE lobster stock needs to be assembled, together with the data resources to support it.

Recommendations are given in the text under each Term of Reference for the review, and also assembled below:

- The TC should be given the opportunity to conduct a comprehensive analysis of distributional patterns in the survey data in order to make more robust inferences about any changes in spawning distribution. Suggestions for these analyses are given on p.7 and should include: survey indices stratified by depth and distance offshore; extraction of dominant survey trends using dynamic factor analysis or similar; fuller presentation of results from the Massachusetts Sea Sampling program; and tables or graphs of Ventless Trap Survey catch rates stratified by depth and region.
- Any new analyses of lobster trends distribution should attempt to make an explicit linkage of lobster habitat with environmental conditions by incorporating sea temperature (and/or other environmental or climatic variables such as the North Atlantic Oscillation Index) as model covariates.
- If there exist sea temperature data that have not been considered in the TC's report, these should be collated and analyzed in a similar way. Attempts should be made to collate a comprehensive spatio-temporal overview of bottom temperatures (possibly including physical modeling results) that could be used to map the thermal boundaries of lobster habitat within SNE.
- A modeling study of lobster larval transport in SNE should be undertaken in an attempt to improve the understanding of the spatial scales over which recruitment occurs and the relationship between the abundance and location of the parental lobster stock and subsequent recruitment. Such a study is likely to have a strong modeling component, e.g. particle tracking within hydrographic models, but should also be supported by satellite tracking of drifter deployments as appropriate.
- Lobster recruitment surveys should be continued into the future, and if possible their sampling intensity should be increased to enhance their power to detect changes in larval or young-of-year abundance. New surveys are also recommended to give a spatially comprehensive picture of spawning patterns across SNE. Deployment of passive postlarval collectors is a promising

methodology for such surveys. These surveys should be used (a) to improve understanding of recruitment processes, (b) to provide early feedback on the success of management measures aimed at protecting spawning potential, and (c) to allow forecasts of recruitment and landings for both inshore and offshore areas.

- The scope for instituting a sentinel fishery monitoring program should be investigated in the event that a harvest moratorium is imposed. The focus should be on plugging any gaps that will be left by the absence of fishery-dependent information during any moratorium.
- Feasible management alternatives to a harvest moratorium should continue to be investigated, particularly as new information comes in on the spatial dynamics of the SNE lobster stock. This should include consideration of v-notching, spatio-temporal input controls and technical measures. Discard mortality should be adequately characterized when technical measures are considered – this may involve the collection of new data.
- The projection methodology should be improved along the lines suggested on p.18. This includes incorporation of spatial structure, improved information about natural mortality, improved information on stock-recruitment relationships, incorporation of environment-recruitment linkages and stochastic projections based on MCMC.
- Qualitative and model-based information should be collated in evidence of a change in patterns of natural mortality. As suggested on p.19, this might include an account of mortality factors for lobsters in SNE, consideration of trade-offs between M and other factors (such as growth uncertainty and spatial heterogeneity) in the fit of the length-based model, examination of weighting factors for model likelihood components and consideration of sex-specific M.
- Finally, it is strongly recommended that the TC be given the opportunity to undertake a longer review of lobster stock and recruitment patterns in SNE, including consideration of evidence for alternative scenarios (e.g. return to lower productivity levels) in addition to strengthening the evidence for the environmentally-driven recruitment failure scenario.

Acknowledgments

I would like to thank Manoj Shivlani of the Center for Independent Experts for his usual efficiency in making all arrangements for this review, and Toni Kerns of the Atlantic States Marine Fisheries Commission (ASMFC) for making all review documents available in a timely manner. I would also like to thank the members of the ASMFC Lobster Technical Committee for undertaking the analyses and producing documents over what was clearly a very demanding time schedule.

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Zuur, A.F., Tuck, I.D. & Bailey, N., 2003. Dynamic factor analysis to estimate common trends in fisheries time series. *Canadian Journal of Fisheries and Aquatic Sciences*, **60**, 542-552.

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APPENDIX I: Bibliography of materials provided for review

Doc1. American Lobster Technical Committee, 2010. *Recruitment failure in the Southern New England Lobster Stock*. Atlantic States Marine Fisheries Commission, April 17 2010.

Doc2. American Lobster Stock Assessment Subcommittee, 2010. *Southern New England lobster stock projection estimates.* Atlantic States Marine Fisheries Commission, unpublished working document.

Doc3. American Lobster Stock Assessment Subcommittee, 2010. *Southern New England – University of Maine Model natural mortality (M) profile.* Atlantic States Marine Fisheries Commission, unpublished working document.

Doc4. American Lobster Technical Committee, 2010. *Recruitment Failure report figure data.xlsx*. Excel data file to support Doc1.

Doc5. American Lobster Stock Assessment Subcommittee, 2010. *newSNEprojections.xlsx.* Excel data file to support Doc2.

Doc6. Chen, Y., 2010. *A description of the projection model in the University of Maine statistical length-structured stock assessment model for American lobster.* Atlantic States Marine Fisheries Commission, unpublished working document.

Doc7. American Lobster Stock Assessment Subcommittee, 2010. *Model code.zip.* AD Model Builder code for lobster stock assessment models and projections.

Doc8. American Lobster Stock Assessment Subcommittee, 2009. *American lobster stock assessment for peer review.* Atlantic States Marine Fisheries Commission, Stock Assessment Report No. 09-01 (Supplement).

Doc9. American Lobster Stock Assessment Review Panel, 2009. *Terms of Reference and Advisory Report to the American Lobster Stock Assessment Peer Review.* Atlantic States Marine Fisheries Commission, Stock Assessment Report No. 09-01.

APPENDIX II: CIE Statement of Work

Attachment A: Statement of Work for Dr. Michael Bell

External Independent Peer Review by the Center for Independent Experts

Recruitment Failure in the Southern New England Lobster Stock

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

Project Description: The review would evaluate a report written on April 17, 2010 by the American Lobster Technical Committee (TC) of the Atlantic States Marine Fisheries Commission (ASMFC), entitled "Recruitment Failure in the Southern New England Lobster Stock" and the supplemental stock projection document, entitled "Southern New England Lobster Stock Projection Estimates". The report concludes that the stock is critically depleted, experiencing recruitment failure, and cannot rebuild. The cause is thought to be a combination of "environmental drivers" and continued fishing mortality. The TC recommends a five year moratorium on harvest. The review would be asked to consider the merits of this recommendation. The supplemental document provides stock estimates under various F scenarios and recruitment conditions. The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**.

Requirements for CIE Reviewers: Three CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. CIE reviewers shall have a combination of working knowledge and recent experience in the application of marine ecology, lobster biology and life history, recruitment dynamics, and population assessment. Each 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: Each CIE reviewer shall conduct an independent peer review as a desk review, therefore no travel is required.

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

Prior to the Peer Review: Upon completion of the CIE reviewer selection by the CIE Steering Committee, the CIE shall provide the CIE reviewer information (full name, title, affiliation, country, address, email) to the COTR, who forwards this information to the NMFS Project Contact no later the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to the CIE reviewers. The NMFS Project Contact is responsible for providing the CIE reviewers with the background documents, reports, 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 reviewers the necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE Lead Coordinator on where to send documents. CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein. The CIE reviewers shall read all documents in preparation for the peer review.

Desk Review: Each CIE reviewer shall conduct the independent peer review in accordance with the SoW and ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs can not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COTR and CIE Lead Coordinator.** The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements.

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

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

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Conduct an independent peer review in accordance with the ToRs (**Annex 2**).
3) No later than 11 October 2010, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and David Sampson, CIE Regional Coordinator, via email to *david.sampson@oregonstate.edu*.

Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in **Annex 2**.

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

The following dates are tentative, and the project contact will provide firm dates no later than 27 July 2010.

27 August 2010	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
10 September 2010	NMFS Project Contact sends the CIE Reviewers the report and background documents
17-27 September 2010	Each reviewer conducts an independent peer review as a desk review
11 October 2010	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
25 October 2010	CIE submits the CIE independent peer review reports to the COTR
1 November2010	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: Requests to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the COTR within 10 working days after receipt of all required information of the decision on substitutions. The COTR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the CIE reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

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

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

(3) the CIE reports shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

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

Support Personnel:

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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: Terms of Reference for the Peer Review

Review of TC report: Recruitment Failure in the Southern New England Lobster Stock

The American Lobster Board (Board) assigned the American Lobster Technical Committee with the following tasks:

1. Identify issues impeding stock rebuilding in SNE,
2. Develop a suite of measures to begin stock rebuilding in SNE,
3. Develop deterministic projections of stock abundance using the University of Maine Model that assume: a) both status quo and reduced fishing mortality scenarios, and b) status quo recruitment, low/declining recent recruitment, and a stock recruitment relationship.

The Technical Committee had 3 months to report back to the Board on their findings. From the above tasks the TC drafted the report: Recruitment Failure in the Southern New England Lobster stock. With the exception of temperature data and information on the redistribution of spawning females, all other fishery independent and dependent data used in the TC's report were peer reviewed and accepted during the most recent (March 2009) ASMFC Benchmark Stock Assessment.

Terms of Reference for Peer Review Panel

The peer review will cover the April 2010 Recruitment Failure Report and related TC tasks assigned by the Board as detailed above (tasks 1 – 3). The questions are listed in bold. The other information is meant to provide additional insight.

1. **Evaluate the quality and completeness of the data gathered since the assessment (temperature data and redistribution of spawning females); if inadequate, specify additional techniques that should have been considered.**

2. **Determine the appropriateness of the findings drawn in the TC report, if deemed inappropriate, provide alternative findings with justification**. The report findings include, but are not limited to:

    a. Stock Status: Review of recent monitoring information showing that the reproductive potential and abundance of the SNE stock is continuing to fall lower than data presented in the latest assessment.
        i. SNE spawning stock biomass indicators from 2002 -2009 in general were average to poor. The spawning stock abundance from the RI trawl survey increased to levels at or above the median from 2005 through 2008, during the V-notch program, but the 2009 estimate is below the 25th percentile.
        ii. The last several years have produced larval and YOY indices below the median and at or below the 25th percentile relative to the 1984-2003 reference

years. YOY indices show a statistically significant negative slope since 1992 and the 3-6 year cyclical pattern in larval indices has been replaced with sustained low values for eight of nine recent years. Sustained poor production can only lead to reduced recruitment and ultimately to reduced year class strength and lower future abundance levels.

iii. Fishery dependent and independent data suggest that the distribution of spawning females has shifted away from inshore SNE areas into deep water in recent years. This shift may impact larval supply to inshore nursery grounds.

iv. All but one of the SNE fall trawl survey relative abundance indices for recruit and legal size lobster are generally consistent, with a peak in the 1990's and then a decline to low levels in recent years. Recent recruit and legal indices have generally remained at or below the 25th percentile since 2002.

b. Fishery Status

i. The SNE landings peaked in 1997, declined to a low in 2003 and have remained low through 2007. Landings have been below the 25th percentile of reference period (1984-2003) landings since 2002.

ii. Landings peaked and fell below the 25th percentile in different years in the different stat areas, though there were similarities among a number of areas.

iii. Offshore landings trends in NMFS statistical area 616 stand out somewhat from other areas. Trends were similar to areas 537, 612, and NJ south with a peak in the early 1990's followed by a decline and low levels in 2002. Unlike the other areas, landings increased in 2003 and stayed above median landings for a number of years. Recent estimates have declined, but are still above the 25th percentile and may be underestimated due to the lack of NJ south landings data.

c. Impediments to rebuilding

i. There has been a widespread increase in the area and duration of water temperatures above 20^{0}C throughout SNE inshore waters. Long term trends in the inshore portion of SNE show a pronounced warming period since 1999.

   1. Prolonged exposure to water temperature above 20^{0}C causes respiratory and immune system stress, increased incidence of shell disease, acidosis and suppression of immune defenses in lobster. Lobsters avoid water greater than 19^{0}C.

ii. Loss of optimal shallow habitat area is causing the stock to contract spatially into deeper water

   1. The shift in abundance to deeper water may reflect increased mortality in shallow water by mid Atlantic predators (e.g. striped bass, dogfish, and scup) whose abundance has increased substantially in the last decade.
   2. Recent larval drift studies in area 2 suggest that the re-distribution of spawning females into deep water areas may be causing larvae to be transported away from traditional settlement areas and potentially into less favorable areas.

iii. Continued fishing pressure reduces the stock's potential to rebuild, even though overfishing is currently not occurring in SNE.
   1. Total trap hauls have declined significantly yet have not declined at the same rate as lobster abundance.
   2. Although current measures prevent the harvest of egg-bearing and v-notched lobster, the legal catch inshore and offshore represents a loss of egg production to the system.

3. **Determine the appropriateness of conclusions drawn in the TC report; if deemed inappropriate; provide alternative conclusions with justification.** The report conclusions include, but are not limited to:
   a. The TC contends that the stock is experiencing recruitment failure caused by a combination of environmental drivers and continued fishing mortality.
   b. It is this recruitment failure in SNE that is preventing the stock from rebuilding.
   c. Overwhelming environmental and biological changes coupled with continued fishing greatly reduce the likelihood of SNE stock rebuilding

4. **Comment on the applicability of the recruitment indices to forecast future recruitment and landings to the inshore and offshore areas.**

5. **Determine the appropriateness of the recommended action (5-year moratorium); if deemed inappropriate, provide alternative recommendations with justification.** The report recommendations include, but are not limited to:
   a. Given evidence of recruitment failure in SNE and the impediments to stock rebuilding, the TC recommends a 5 year moratorium on harvest in the SNE stock area.
      i. The moratorium provides the maximum likelihood to rebuild the stock in the foreseeable future to an abundance level that can support a sustainable long-term fishery.
   b. During the 5 year moratorium period, monitoring of all phases of the lobster life cycle should be intensified.
      i. Fishery dependent sampling will no longer be collected, therefore assessment of stock status will rely on current fishery-independent surveys (e.g., ventless trap, YOY sampling, larvae) which will need to be continued and intensified.
      ii. New surveys and research (e.g., sentinel industry surveys) are needed to further characterize stock status, lobster settlement and habitat in SNE.

6. **Evaluate the stock projection scenarios conducted to complete the task as outlined by the Board** (see above).
   a. Evaluate the deterministic projections conducted using the University of Maine Model.
      i. The Board directed the TC to provide projections within an extremely short time frame. Although stochastic projections and estimates of uncertainty (e.g. MCMC confidence intervals) could have been provided, the time frame for decision-making was too short to complete a more thorough analysis.

b. Evaluate the chosen suite of fishing and recruitment scenarios presented in the report; if insufficient, provide suggestions for alternative scenarios.
c. Determine if projection results and the TC's interpretation provided in the report are consistent with assessment model results.
d. Comment on the reliability of the deterministic projections for use in SNE lobster stock management.

7. Review the M sensitivity analysis of the model that indicated a higher M as suggested in the 2009 assessment.

Review of the Recruitment Failure Report and Stock Projection Estimates developed for the Southern New England Lobster Fishery by the American Lobster Technical Committee of the Atlantic States Marine Fisheries Commission

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Contents

1. Executive Summary

The Technical Committee (TC) provided evidence that, since 1999, temperatures in coastal waters of the SNE region had increased and cited studies that indicated that this might lead to increased natural mortality. Model fits using the data available for the lobster stock supported the hypothesis that, from 1998, natural mortality had increased. The TC proposed that this increased mortality, in combination with the possible impacts of increased temperature on settlement of larvae, survival of juveniles, suitability of habitat, and spatial distribution of lobsters, was one of the factors that may have contributed to the recent decline in recruitment that the stock had experienced. Further exploration may identify models with alternative assumptions that provide fits to the data of similar quality as that of the model that assumes an increased natural mortality from 1998. Thus, other hypotheses, *e.g.*, changes in selectivity resulting from changed distribution, should be assessed, and attempts made to identify a range of alternative explanations for the decline in abundance. Such alternative model structures, if identified, would provide information on the structural, *i.e.*, model, uncertainty of model predictions and, following assessment of the management implications of the different models, allow the selection of robust management strategies. With the evidence presented by the TC, the model that currently provides the best representation of the SNE lobster stock is that which assumes natural mortality to be 0.15 $year^{-1}$ till 1997, rising to 0.285 $year^{-1}$ from 1998.

The TC presented additional data to support their argument that recent female spawning biomass and lobster abundance now fell below the values in the 2009 assessment and that recent larval and YOY indices were at or among the lowest 25^{th} percentile of values recorded between 1984 and 2003. Neither statistical assessment nor assessment using an enhanced version of the University of Maine's model was undertaken, and the TC relied only on a subjective evaluation of the trends in the indices and patterns in the data to demonstrate a change in spatial distribution. Trends in the plotted data provided no indication of a recovery of spawning biomass or abundance, or increase of larvae or YOY. The data, which were presented, broadly supported the hypothesis of a change in spatial distribution of the stock, but statistical analyses would have provided a more conclusive demonstration that the distribution had changed. It would have been useful if the University of Maine's length-based model had been re-run using the updated time series of data that were reported by the TC. This model needs to be extended to allow use of the additional time series of data that are available for the SNE lobster stock

The Technical Committee's arguments that rebuilding of the stock is impeded by the increased natural mortality that it now experiences and by continued exploitation are sound.

The conclusion by the TC that recruitment of the SNE lobster stock had failed is based on its definition of recruitment failure and the associated criteria that it employed to determine that failure had occurred. Alternative definitions and criteria, which might produce a different conclusion, could be specified. Whether or not recruitment failure has occurred, there is sound evidence that recruitment to the SNE lobster stock has declined and that low levels of recruitment have persisted despite relatively recent reduction in trap hauls and other management initiatives. This, in combination with the current low levels of lobster abundance, should be of concern to both managers and fishermen.

If, as appears to be the case given the data that the TC has presented, natural mortality has increased, then both the stock-recruitment and replacement functions will have changed. Thus, biological reference points for stock status, defined using the values in the reference period 1984 to 2003, will no longer be appropriate as values derived from data for this period relate to a "stock" with very different biological characteristics and dynamics. That is, assessments of current stock status that determine whether the stock is overfished and/or overfishing is occurring should avoid use of reference points based on the data for 1984 to 2003 without adjusting these reference points for the impact of increased mortality on the stock-recruitment and replacement relationships. New reference points will need to be determined that take the changes in the stock-recruitment and replacement relationships into account. The status of the stock based on these new reference points, and taking the increase in natural mortality from 1998 into consideration, will then need to be assessed.

The projections that the TC has produced indicate that rebuilding will require a marked reduction in exploitation. A moratorium on exploitation would be the most effective strategy to rebuild the stock, but, if continued exploitation is permitted, rebuilding under such exploitation is likely to be maximised if males are preferentially exploited and females protected to the extent possible. Monitoring programs would need to be established to ensure that preferential exploitation of males does not lead to reduction in the proportion of females that are mated or to reduced fecundity of females of different lengths. A highly precautionary approach to management is recommended, given the very considerable uncertainty regarding (1) the response of lobster abundance to continued exploitation, even at a very reduced level; (2) the form of the stock-recruitment relationship following the increase in temperature and its likely impact on larval settlement and juvenile survival; and (3) the value of the threshold reference point for stock abundance following the change in the stock-recruitment and replacement relationships. Accordingly, the proposal for a five-year moratorium appears appropriate, but needs to be accompanied by research to obtain as much information as possible from the response of the lobster stock to the change in exploitation.

The stock is at a crucial point, with continued low abundance of recruit and legal lobsters and a need to rebuild, with changes to its biology and dynamics as a result of increased temperature, and, if a moratorium on harvest is not introduced, with a possible reduction in exploitation that is likely to affect both the catchability and selectivity of the catches taken from the stock. There is increased need to undertake research to reduce the uncertainty that has arisen through the impacts on the biology of the stock of increased temperature. The proposed moratorium on harvest or change in the level of exploitation will produce a response from the stock that is likely to be very informative, providing fishery scientists with a rare and valuable opportunity to learn more about the biology of the SNE lobster stock and its dynamics. To maximise the information that is obtained from the proposed management change, appropriate fishery-independent surveys should be established and existing surveys reviewed and, if necessary, enhanced (while ensuring consistency with past survey data).

The TC has provided valuable insight into the biological and behavioural basis for the impact of temperature on the SNE lobster stock and has demonstrated that the data that are available for this stock support the hypothesis that, from 1998, there has been an increase in natural mortality. This finding by the TC has major implications for management of the SNE lobster stock, as the resulting change in model parameters/structure produces very different predictions of the response of the system to changes in exploitation and/or management from those produced using the earlier model, which assumed a constant natural mortality of 0.15 $year^{-1}$. The effects of temperature increase on larval transport and settlement, juvenile/pre-recruit survival, growth, size and age at maturity, and available habitat are also likely to be important factors influencing the population dynamics of the lobster stock. The impact of the change in natural mortality and the possible impacts of these other factors represent major uncertainties for assessment of the SNE lobster stock and predictions of the stock's response to management and fishery changes. Considerable additional research effort will be required to assess the full implications of the changes to the biology of the SNE lobster stock that have resulted from the increase in water temperatures to which the stock is now exposed. Further development and increasing flexibility and responsiveness of the University of Maine's length-based model will be essential if, given the uncertainty introduced by temperature/environmental change, fishery scientists are to respond to requests for research advice concerning the SNE lobster stock.

2. Background

2.1. Overview

The Center for Independent Experts (CIE) contracted independent reviewers to undertake a review from 17-27 September 2010 of "a report written on April 17, 2010 by the American Lobster Technical Committee (TC) of the Atlantic States Marine Fisheries Commission (ASMFC), entitled 'Recruitment Failure in the Southern New England Lobster Stock' and the supplemental stock projection document, entitled 'Southern New England Lobster Stock Projection Estimates'. The report concludes that the stock is critically depleted, experiencing recruitment failure, and cannot rebuild. The cause is thought to be a combination of "environmental drivers" and continued fishing mortality. The TC recommends a five year moratorium on harvest. The review would be asked to consider the merits of this recommendation" (Appendix 2 – Copy of CIE Statement of Work).

The 2009 stock assessment, which was reviewed earlier by another panel of experts, found that exploitation had declined since 2000, recruitment to the fishery had been poor since 1998, and the abundance of lobster in the SNE stock had fallen to a level that was assessed as "depleted". The contents of this stock assessment report and of the subsequent review of this report fall outside the terms of reference of the current review. It is pertinent to the current review, however, to summarise the criteria that were used in this stock assessment, *i.e.*, the indicator variables and the then current and/or proposed reference points that led to the conclusion by the TC that the assessment demonstrated that the stock was depleted.

The reference points for fishing mortality and abundance, which were adopted by the Atlantic States Marine Fisheries Commission (ASMFC) in section 2.3.1 of Addendum VIII of Amendment 3 of the Interstate Fishery Management Plan for American Lobster, were used within the Stock Assessment Report prepared by the ASMFC American Lobster Stock Assessment Subcommittee (SASC) and considered by the ASMFC American Lobster Technical Committee (TC) when assessing the state of the lobster stock of Southern New England (SNE). Thus, the indicator variables used for the SNE stock were the average fishing mortality, *F*, and average fishable abundance during the most recent three years considered by the assessment. The reference points for these indicators were determined from the median values computed for this stock from the data for 1984-2003, which were accepted as threshold reference points, while the median abundance plus one standard error, and the median fishing mortality less one standard error were considered as the target reference points. Overfishing was considered to be occurring if the average fishing mortality rate for the three most recent years was higher than the median threshold, and the stock was considered to be "depleted" if average abundance for the three most recent years fell below the median threshold level. If the stock assessment concluded that overfishing was occurring or the stock was classified as "depleted", corrective management action was expected to be taken.

Based on the results of the Collie-Sissenwine Model (CSM) and these reference points, the SASC reported that "the SNE stock is below the abundance threshold and target and above the *F* threshold and target" and therefore "the SNE lobster stock is both depleted and overfishing is occurring".

The SASC recommended that alternative reference points should be adopted instead of those that were currently accepted. Thus, the use of "reference abundance" and "effective exploitation" as indicator variables of annual abundance and annual fishing pressure rather than fishable abundance and *F*, were proposed, as the SASC considered that these new indicator variables would be more robust to changes in selectivity, such as those arising from changes in minimum legal length. Reference abundance was defined as "the number of lobster 78+ mm CL on January 1 plus the number that will molt and recruit to the 78+ CL group during the year" and "effective exploitation" as "the annual catch in number divided by the reference abundance". If the average effective exploitation rate for the three most recent years exceeded the median threshold calculated using data from 1984-2003 for the SNE lobster stock, "overfishing" was occurring, and if average reference abundance for the three most recent years fell below the median threshold level then the stock would be considered to be "depleted". On the basis of these alternative reference points and the results from the University of Maine's model, the 2009 assessment reported that the SNE lobster stock would be assessed as depleted but it would be concluded that overfishing was not occurring.

The ASMFC American Lobster Stock Assessment Review Panel, referred to subsequently as the "Panel", accepted that the current and proposed reference points are determined empirically but concluded that "the median exploitation rate was inappropriate for a threshold because the stock would be declared 'depleted' half of the time even if well managed". The Panel recommended using the median as the target instead of a threshold and proposed that the threshold reference point for 'reference abundance' should be half of the median and that for exploitation rate should be set at the 90th percentile.

The Panel also recommended that "managers be particularly vigilant of recruitment patterns ... and stand ready to impose substantial restrictions should recruitments decline".

Following this assessment and its review, the American Lobster Board asked the American Lobster Technical Committee to explore ways in which the lobster stock in the SNE might be rebuilt and to identify the impediments to such rebuilding, comparing projections of the likely responses of stock abundance with and without reduced fishing mortality under current or reduced levels of recruitment, or if recruitment was related to spawning stock.

The findings of the Technical Committee were submitted to the Board in the report, "Recruitment Failure in the Southern New England Lobster Stock", and the supplemental stock projection document, "Southern New England Lobster Stock Projection Estimates", which are the subjects of the current review. The terms of reference for this review note that "with the exception of temperature data and information on the redistribution of spawning females, all other fishery independent and dependent data used in the TC's report were peer reviewed and accepted during the most recent (March 2009) ASMFC Benchmark Stock Assessment".

For the SNE lobster fishery, "recruits" are defined as "lobster that are not legal size at the time of the survey but are expected to molt and grow to legal size during the next year" (2009 Assessment Report).

An independent peer review of the TC report on the failure of recruitment for the SNE stock was to be undertaken by three CIE reviewers from 17-27 September 2010. As the review panel did not meet, and the review was conducted as a desk study, the identities of the other two reviewers are unknown to the author.

On August 30, 2010, details were provided to reviewers of the ftp site from which the documents to be reviewed, and ancillary documents and files, could be downloaded. A list of these documents is presented in Appendix 1.

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

2.2. Terms of Reference

The terms of reference for this independent peer review of the American Lobster Technical Committee report: Recruitment Failure in the Southern New England Lobster Stock are presented in Annex 2 of Appendix 2.

2.3. Date and place

The independent review of the TC report on the recruitment failure of the SNE stock was conducted by the reviewer as a desk study, in Perth, Western Australia, between 17-27 September, 2010.

3. Description of Reviewer's role in review activities

As required under the CIE's statement of work, the reviewer familiarised himself with the documents that had been provided and then undertook the review that had been requested, addressing each of the terms of reference specified in the statement of work.

4. Summary of findings

ToR 1. Evaluate the quality and completeness of the data gathered since the assessment (temperature data and redistribution of spawning females); if inadequate, specify additional techniques that should have been considered.

In its report on the recruitment failure of the SNE lobster stock, the TC has updated the survey data presented in the SASC assessment report to include data collected since the 2009 assessment was undertaken. The TC has then considered the extended data series, deriving estimates of female spawning biomass, plotting time series indices of larval and YOY abundance, and exploring the trawl survey data in greater depth. These data will be evaluated, where appropriate, under subsequent terms of reference. As required for the current term of reference, consideration will be given here to the data that were collected by the TC to explore temperature change and the redistribution of spawning females.

Temperature data

Studies on American lobster reported in the scientific literature, and cited by the TC, demonstrate that:

- growth, length at maturity, period between extrusion of eggs and hatching, and between hatching and the post-larval stage are influenced by temperature.
- American lobster exhibit a preference for waters with temperatures between 12 and 18°C,
- lobsters, when subjected to prolonged exposure to waters with temperatures greater than 20°C, develop symptoms that are interpreted as reflecting physiological stress and become increasingly susceptible to disease.
- extreme temperatures, *i.e.*, greater than 28°C, lead to an increased rate of mortality, particularly if these temperatures are associated with dissolved oxygen concentrations less than 6.4 mg/L.

- female lobsters in nearshore waters require extended exposure to water temperatures less than 8°C for ovaries to mature and spawning to succeed,.

The report by the TC on the recruitment failure of the SNE lobster stock advises that, since 1999, sea water temperatures in the coastal waters occupied by the stock have experienced increased temperatures, with an increase in the spatial range and duration of water temperatures above 20°C and an increased number of days in late summer when mean bottom water temperatures have exceeded that temperature.

Although the TC made use in their report of sea surface temperature data recorded in Woods Hole, MA, by NOAA, no details are provided of the methods used to collect these data or the geographic region from which they were derived. A number of sources of surface water temperatures are available to NOAA, and it is possible that these may provide data additional to those considered by the TC. In addition to satellite-derived SST data that are available from NOAA, historical sets of sea surface data are available from moored buoys maintained by the National Data Buoy Center (NDBC) and from those monitoring stations maintained by the Coastal-Marine Automated Network (C-MAN) that are capable of recording sea surface temperatures, which lie within the bounds of the region occupied by the SNE lobster stock. Other data sets that might be accessed include the (presumably surface) water temperature data collected in Narragansett Bay (and other stations) by the National Oceans Service (NOS) through their Physical Oceanographic Real-Time System (PORTS®), data from the Chesapeake Bay Observing System (CBOS) and other partners within the U.S. Integrated Ocean Observing System (IOOS), and data collected from monitoring stations in the MYSound Project. While the time series of data available from these sources may be relatively short, they offer a possible opportunity to broaden the spatial extent of temperature data to encompass more of the area occupied by the SNE lobster stock. It may also be useful to refer to the collection of reports published by Armstrong (1998), as this would provide insight regarding seasonal changes in profiles of temperature with depth.

In its report on the recruitment failure of the SNE lobster stock, the TC proposes that the increase in water temperatures, particularly in nearshore areas, may have led to:

- the loss of lobster habitat, particularly that of juveniles;
- increased mortality of juvenile lobsters, which are less able to move to refugia with suitable temperature conditions;
- change in lobster distribution, with greater competition for scarcer habitat resources and hence greater mortality and vulnerability to fishing;
- change in the geographic distribution of spawning females, which could impact larval transport and settlement success;
- greater susceptibility of lobsters to physiological stress and disease, and hence increased natural mortality.

The TC notes that "it is not possible to draw a direct relationship between the decline of the Southern New England lobster stock and increased water temperatures", but infers that "the strong coincidence in the timing of the increase in water temperature with the timing of the decline in [lobster abundance] … strongly suggest that increasing water temperatures have played a primary role" in the decline.

The TC has provided sound evidence of the increase in water temperature by presenting time series of sea-surface temperature data recorded by NOAA in Woods Hole, MA, and bottom water temperature data from upper Buzzards Bay (Cleveland Ledge 30 ft- MADMF unpublished data), eastern Long Island Sound (Millstone Station unpublished data), and from the mouth of Buzzards Bay (70 ft- MADMF unpublished data). These data, in combination with the scientific evidence of the effects of temperature on the behaviour and physiology of the American lobster, and on the incidence of disease experienced by those lobsters, provide strong support for the argument that increased water temperatures in nearshore regions are likely to have resulted in a change in the spatial distribution of lobsters, *i.e.*, the relative numbers within the different regions, and a reduction of juvenile habitat. There is potential that the changed geographic distribution of the adult female lobsters may have affected the average success of settlement of the larvae produced by those females.

If water movement has been affected by the changes in water temperature, as is likely, then transport of larvae may also have been affected, but without exploration of the effects of changes in temperature on the hydrodynamics of the region, it is not possible to determine whether or not the changes to transport of larvae are likely to improve or reduce settlement success of larvae produced by female lobsters spawning in different regions of the fishery. Hydrodynamic modelling of water movement and the effects of temperature on water movement would be useful. Simulation of larval transport using such a model would also be informative to test whether temperature change has affected the distribution of the transported larvae from different regions.

It appears quite possible that natural mortality in nearshore regions will have increased, particularly for juvenile lobsters. The hypothesis that the change in water temperatures adversely affected the abundance of the SNE lobster stock is viable yet, as noted by the TC, remains untested. The influence of temperature is not yet included in the University of Maine's length-based model, but, as it appears likely to be affecting lobster survival, distribution, selectivity, catchability and recruitment, consideration should be given to extending the model to allow for this environmental factor.

Redistribution of spawning females

It has been proposed by the TC, in its report on the failure of the SNE stock, that the geographical distribution of spawning females has changed with a shift from nearshore areas to deeper water. In support of this, the TC drew attention to data from the CT trawl survey in Long Island Sound, in which the Committee claimed that, between 1984-1992 and 2000-2008, there had been a shift in the abundance of lobsters caught from the shallow, nearshore sites relative to that from the deeper offshore sites. The TC pointed out that "in 1984-1991, the geometric mean catch at sites <30ft depth was comparable to the mean for sites >90ft depth; in 2000-2008, the mean catch at shallow sites was less than half the mean for deep sites". The TC noted that this conclusion was supported by data from the regional Ventless Trap Survey in the SNE, which provided evidence of a greater abundance of lobster in the deeper strata of the surveyed region, and pointed out that this pattern contrasted with that observed in the Gulf of Maine, where the highest relative abundance is observed in the shallowest strata. The Committee also observed that data from the MA lobster sea sampling program also indicate that the fishery now operates to a greater extent in deeper, offshore waters than in the shallower, nearshore waters. The concern that this raised for the TC is that, with the shift in abundance to deeper offshore waters, transport and settlement of larvae in nearshore nursery habitat may be less successful than in earlier years. In support of this conjecture, the TC pointed to the initial results of studies using depth-stratified deployment of passive post-settlement collectors, which indicate that settlement in depths less than 20 m is now considerably reduced.

The plot of the CT trawl survey data presented in the SASC assessment report (Fig. 5.2.1.2.1.3.) shows only the combined abundance estimates for the fall survey. No other data are presented to support the statement that "in 1984-1991, the geometric mean catch at sites <30ft depth was comparable to the mean for sites >90ft depth; in 2000-2008, the mean catch at shallow sites was less than half the mean for deep sites". Neither confidence limits nor standard errors are presented, and it is thus not possible to assess whether, in a statistical context, the inshore and offshore abundances have changed significantly. It seems highly likely, however, that a change in magnitude of the extent described by the TC would be statistically significant. Nevertheless, a more robust statistical evaluation would be preferable to demonstrate that the conclusions are due to a signal rather than the (subjective) influence of noise in the data. The assessment report notes that "The trawl survey employs a stratified random sampling design with four depth strata (0-9 m, 9.1-18.2 m, 18.3-27.3 m, 27.4+ m) and three bottom substrate types (sand, mud, and transitional)", with sampling intensity of approximately one sample per 68 km^2. Fall surveys have been conducted since 1985 and spring surveys since 1985. It is suggested that the TC might find it useful to undertake a GLM analysis of the data, to demonstrate statistically that their conclusion is sound. Diagnostic plots should be presented to demonstrate that the model provides an adequate fit to the data.

The selection of a single trawl survey, *i.e.*, the CT trawl survey, to test the hypothesis that the relative distribution has changed, *i.e.*, that the interaction between depth and year is significant, appears arbitrary. It would be preferable to analyse the data from each of the trawl surveys, rather than examining only the data from the CT trawl survey.

The TC presented maps showing the locations and observed total number of lobsters caught per trap during the random stratified ventless trap survey, employing circles of different diameters to represent different abundance classes. Results from the trap surveys from 2006 to 2009 were presented for both LCMAs 2 and 6, with separate maps for each LCMA and year. The plots provided subjective support for the conclusion that the abundance of lobsters caught in the ventless trap survey were greater in deeper offshore water than in shallower, nearshore waters. It would again have been useful, however, to demonstrate this hypothesis by subjecting the survey data to a GLM analysis rather than relying on a subjective visual appraisal of the plotted data. The time series of data presented for the ventless traps is insufficient to determine whether there has been a change in distribution between 1984-1992 and 2000-2008.

The description of the methods used for the MA sea-sampling program in the 2009 assessment report is sketchy, and the meaning of the ellipses presented in Appendix B is not specified. The methods state that "Six fixed regions that include all three stock areas are sampled at least once per month from May-November by observers aboard commercial boats". The sampling frame appears poorly defined, and the method by which vessels fishing within the six fixed regions were selected for observation, such that sampling was random among vessels in those regions, is unclear. In particular, it is not clear whether the fishing effort exerted during observed trips represents a random sample of the fishing effort of the fishing fleet and thus whether it is appropriate to extrapolate from conclusions relating to the distribution of observed trips to conclusions that relate to the distribution of fishing effort. How were the data for the different regions weighted to determine the overall distribution of fishing effort? Again, rather than presenting a subjective assessment that these sea-sampling data indicate a shift in the distribution of fishing, it would be preferable to subject the data to statistical analysis to assess whether there is evidence that supports this hypothesis.

Subjectively, the data presented by the TC, in its report on the failure of recruitment the SNE, suggest that there has been a change in the spatial distribution of the lobster stock. Without analyses that demonstrate that the putative change in spatial distribution is statistically significant, however, the evidence is weak. There would be value in subjecting the data to appropriate statistical analysis, *e.g.*, through use of GLM. Consideration should also be given to analysing the data for the recruits and legal sized lobsters separately, and/or the female lobsters with carapace lengths less than or greater than the carapace length at which 50% of the females are expected to be mature.

The University of Maine's length-based model currently assumes that the stock occupies a single spatial region. The influence of spatial structure is considered only implicitly in the model through the forms of the selectivity curves (associated with the different surveys and with the fishery) that are used, rather than through an explicit representation. The possibility that the spatial distributions of the stock and the fishery have changed has implications for the structure of the length-based model. With the current model structure, the implication is that the model will need to be modified to allow for possible temporal changes in the selectivity curves. Alternatively, the model will need to be extended to include an explicit representation of the spatial structure. Such an extension would be demanding, however, as it would require information relating to the distribution of recruitment to and from different regions of the fishery, movement of lobsters (of different lengths and sexes) between regions, and greater resolution of fishery-dependent and fishery-independent data.

ToR 2. Determine the appropriateness of the findings drawn in the TC report, if deemed inappropriate, provide alternative findings with justification. The report findings include, but are not limited to:

a. Stock Status: Review of recent monitoring information showing that the reproductive potential and abundance of the SNE stock is continuing to fall lower than data presented in the latest assessment.

The TC has presented time series of spawning stock biomass, larval and YOY indices, trawl survey indices, and fishery landings in its report on the failure of recruitment of the SNE lobster stock. These time series include data that now extend to 2009, *i.e.*, two additional years of data than were considered in the 2009 assessment. The TC has also considered aspects of the data that were not presented in the 2009 assessment, *e.g.*, the development of indices of female spawning biomass from trawl survey data. The additional trawl survey abundance and fishery landings data that have been presented for 2008 and 2009 appear to have declined slightly from, or remained of similar magnitude, to the values of the survey indices and landings recorded between about 2002 and 2007. The subjective impression of the time series of spawning biomass that were presented by the TC is that, in general, the indices have declined and are now at levels that are among the lowest in the reported time series.

Without re-running the length-based model using the more recent data, it would be difficult to conclude that the estimates of reproductive potential and abundance likely to be produced by the model would have declined much beyond the levels indicated by the outputs of the 2009 assessment. It is highly unlikely, however, that, given the new data, the model's estimates of reproductive potential and of abundance are likely to have improved. It is thus reasonable to conclude that the abundance of the SNE stock remains at levels below the threshold reference point, and that the stock is showing no indication of recovery despite the recent management controls that have been introduced and the reduction in the number of traps and trap hauls since 1999. An important question that this raises is whether the newly-available indices are falling markedly below the trajectories that would have been anticipated given those management controls, recognising the lags that would be expected between management action and biological response, or whether the levels are consistent with model predictions. This question needs to be assessed using the integrated model.

i. SNE spawning stock biomass indicators from 2002 -2009 in general were average to poor. The spawning stock abundance from the RI trawl survey increased to levels at or above the median from 2005 through 2008, during the V-notch program, but the 2009 estimate is below the 25th percentile.

The SASC employed the NEFSC, RI and CT fall trawl surveys in the University of Maine's length-based model when undertaking the 2009 assessment. The trawl data for MA were only used for the GOM stock assessment. It is unclear whether the data from the MA trawl survey that are presented in Table 1 and Fig. 3 of the recruitment failure report were calculated using only those samples in this survey that were obtained from the region associated with the SNE stock. Without such assurance, it is not possible to determine the extent to which the female spawning biomass data from the MA fall survey contain information relating to the status of the SNE stock.

Broadly speaking, and ignoring the results for MA, it is true that "SNE spawning stock biomass indicators from 2002 -2009 in general were average to poor", apart from the indices derived from the RI trawl survey, which "increased to levels at or above the median from 2005 through 2008, during the V-notch program", but noting that, for this survey, "the 2009 estimate is below the 25th percentile". When examining the plots presented in Fig. 3, however, it should be noted that no standard errors or confidence intervals are displayed. The data exhibit considerable inter-annual variability.

The TC provides no indication of whether the data for the fall and spring surveys were combined when calculating the estimates of female spawning stock biomass, and, if so, how such combination was undertaken. It has therefore been assumed that (at least some of) the data employed in calculating female spawning stock biomass are from the fall trawl surveys. However, the time series of these fall trawl data to 2007 have already been employed in the 2009 stock assessment undertaken using the University of Maine's model, *i.e.*, other than the values for 2008 and 2009, the data presented in Fig. 3 are probably not independent of those used in the 2009 assessment. Thus, the question that now needs to be addressed is whether these new data contain information that would modify the assessment of the state of the SNE lobster stock from that determined at the last assessment.

The additional data that have become available for the survey indices suggest that the SNE spawning female biomass has continued to decline in 2008 and 2009. It would be preferable, however, to run the University of Maine's model with the new data to confirm this subjective assessment.

ii. The last several years have produced larval and YOY indices below the median and at or below the 25th percentile relative to the 1984-2003 reference years. YOY indices show a statistically significant negative slope since 1992 and the 3-6 year cyclical pattern in larval indices has been replaced with sustained low values for eight of nine recent years. Sustained poor production can only lead to reduced recruitment and ultimately to reduced year class strength and lower future abundance levels.

The plots presented in Fig. 4 of the recruitment failure report demonstrate that, since 2001, indices of stage 4 post-larval abundance from the Western Long Island Sound Larval Survey and estimates of the annual densities of larvae (of all stages) at the Millstone Power Station in Eastern Long Island Sound have been predominantly less than the median values with the density at the Millstone Power Station in 2009 being the lowest in the time series. No standard errors are provided for these estimates. No estimates of the 25th percentiles of the two data sets are presented in Fig. 4.

The indices of YOY settlement for Narragansett Bay and Rhode Island Sound collected by the Rhode Island Division of Environmental Management (RI DEM), which are presented in Fig. 5 of the recruitment failure report, exhibit a declining trend over the period for which data were available, *i.e.* from 1990, with the last five points in the time series lying below the median and the last two values falling below the 25th percentile. Only in the last year, however, did the error bars associated with the point estimate fall completely below that lower percentile. Note that there appears some confusion in reading Fig. 5, as the last value appears to be that for 2008, not 2009, the latter figure being the value reported in the document describing the failure of recruitment of the SNE lobster stock. Indices of YOY for Buzzards Bay collected by the Massachusetts Division of Marine Fisheries (MA DMF) vary about the median, but exhibit no consistent trend in recent years.

The larval and YOY indices were not employed when fitting the University of Maine's model for the 2009 assessment. It would be useful to include these indices in the integrated, length-based model, thereby assessing their consistency with other data sets and drawing information from the full set of data. It would be anticipated that, although influenced by survival to settlement, success of settlement, and, in the case of YOY, survival within the nursery grounds, there is likely to be some consistency between the female spawning biomass estimates of the parent stock that produced the larvae and YOY and the indices of abundance collected for those larvae and YOY. Similarly, noting that there is likely to be a lag of around four to nine years between settlement and recruitment to the fishery, it is likely that there should be a degree of consistency between the indices of settlement and YOY and the indices of subsequent recruit abundance, although the strength of the relationship will be diminished by the presence of the other year classes within the set of lobsters that are classified as recruits.

Although, subjectively, and recognizing the lag between the larval and YOY indices and subsequent recruitment, the larval and YOY indices appear consistent with the findings derived from earlier model results, it is not possible to assess whether the information that they might contain would modify markedly the values of the estimates of abundance (or the precision of those estimates) produced by the integrated model. One point that is clear, however, is that the trend in the more recent years provides no indication of a marked increase in larval settlement or YOY, suggesting that inclusion of these data in the length-based integrated model would be unlikely to produce results suggesting an increase in recent abundance.

Rather than examining the additional indices subjectively outside the assessment model, it is better modelling and stock assessment practice to include the indices within an integrated model. It would be useful to develop the model further such that the additional indices can be used and analyses can be undertaken, when required, using the data that are available at that time. Note that, when adding additional indices, model results will need to be assessed thoroughly to ascertain whether inconsistencies have been introduced and to assess the reliability and performance of the modified model.

iii. Fishery dependent and independent data suggest that the distribution of spawning females has shifted away from inshore SNE areas into deep water in recent years. This shift may impact larval supply to inshore nursery grounds.

While subjectively it appears that the TC is correct in claiming that fishery dependent and independent data suggest that there has been a change in the relative abundances in nearshore and offshore waters in favour of a greater abundance in the later habitat, more detailed statistical analysis is required to demonstrate that this conclusion is valid (see the response to ToR 1). If the finding is validated, the preliminary results from the satellite drifter studies reported by the TC suggest that the statement that larval supply to inshore nursery grounds may be impacted is likely to be true. More detail of these drifter studies is required, such that the soundness of the reported findings can be assessed. The potential impact on recruitment cannot be quantified, however. There is a need to consider the likely change in distribution of settlement as a whole, rather than the results from local studies. Computer simulation using information on the distributions of spawning female biomass (and egg production) at different times in the fishery's history, hydrodynamic models that account for changes in temperature, wind, etc., at these times, and data on movements of larvae should be considered.

iv. All but one of the SNE fall trawl survey relative abundance indices for recruit and legal size lobster are generally consistent, with a peak in the 1990's and then a decline to low levels in recent years. Recent recruit and legal indices have generally remained at or below the 25th percentile since 2002.

The findings reported in the above statement are demonstrated by the trends in the indices that are presented in Figures 7 and 8 of the Recruitment Failure Report. The RI, TC, and NMFS trawl survey data to 2006 were employed in the length-based model when producing the 2009 assessment. The additional data for the two most recent years that are presented by the TC in the recruitment failure report are broadly consistent with the low abundance estimates that were derived in that earlier assessment, and, although the recruit and legal-sized abundances in the RI data set rose above the median levels in 2008, these indices fell again to about the levels of the 25th percentiles in 2009. The trends for the NJ trawl data and for the SNE data subset within the MA trawl survey data are similar to those for the RI, CT, and NMFS data. Confidence limits are not displayed in the figures, however, which makes it impossible to assess the statistical significance of the trends. The data presented in the figures suggest that the fishery is not yet recovering, but further exploration is required to determine whether this subjective conclusion is supported by results of analysis using the length-based model.

b. Fishery Status

i. The SNE landings peaked in 1997, declined to a low in 2003 and have remained low through 2007. Landings have been below the 25th percentile of reference period (1984-2003) landings since 2002.

Figure 9 of the recruitment failure report supports the above statement by the TC. Indeed, although the data for 2008 and 2009 are incomplete, it appears that the landings from the SNE lobster stock in these last two years will be of similar magnitude to those recorded from 2003 to 2007. The data till 2007 have already been considered within the University of Maine's model for the 2009 assessment. The additional data for 2008 and 2009, which, in combination with the survey results discussed above, appear likely to lie well below the 25th percentile, reinforce the conclusions drawn from the previous results produced by the length-based model for the 2009 assessment, *i.e.*, it is unlikely that abundance estimates for the SNE lobster stock will improve when the length-based model is eventually re-run with the new data.

ii. Landings peaked and fell below the 25th percentile in different years in the different stat areas, though there were similarities among a number of areas.

The above description of the trends in the different statistical areas is supported by the data presented in the figures in Appendix D of the recruitment failure report. Note that the numbers of the figures should probably be prefaced by "D" rather than "E". I would dispute the statement that the trend for area 538 is similar to that for areas 539, 611, and 613. While the statement is true for data following the mid-1990s, landings for area 538 exhibited a declining trend from the early 1980s, whereas those in the other three areas progressively increased from the early 1980s to the mid- to late 1990s. It is likely that, in the statement on page 13 that "The landings trends in areas 527 (offshore RI and MA), 612 (NY Bight), and areas from NJ and south (combined) are similar to each other, and somewhat different from inshore areas to their north (Figure 12 and Appendix D)", the first area should be 537, not 527.

iii. Offshore landings trends in NMFS statistical area 616 stand out somewhat from other areas. Trends were similar to areas 537, 612, and NJ south with a peak in the early 1990's followed by a decline and low levels in 2002. Unlike the other areas, landings increased in 2003 and stayed above median landings for a number of years. Recent estimates have declined, but are still above the 25th percentile and may be underestimated due to the lack of NJ south landings data.

The above statement is supported by the trends shown in figures E5, E6, and E7 in Appendix D, and Figures 12 and 13, of the recruitment failure report. The trends in landings in the different statistical areas will reflect not only the trends in abundance and distribution of legal-sized lobsters but also the distribution of fishing effort (trap hauls) and the catchabilities within the different areas. In addition to presenting the trends in abundance, it would therefore be useful to present trends in fishing effort and in catch per unit of effort.

c. Impediments to rebuilding

i. There has been a widespread increase in the area and duration of water temperatures above 20^0C throughout SNE inshore waters. Long term trends in the inshore portion of SNE show a pronounced warming period since 1999.

The time series presented in Figures 13 to 17 of the recruitment failure report support the conclusion by the TC that there has been an increase in the number of days each year with water temperatures above 20ºC at the locations at which these data were collected. The data presented in the recruitment failure report demonstrate that the area affected by such increased water temperatures ranges from Long Island Sound to Buzzards

Bay, but no data are presented to demonstrate that the waters of LCM Area 5 have been similarly affected. The use of maps assists the interpretation of trends in spatial data. Sea surface temperature maps derived from satellite data would have assisted in demonstrating the extent of the area over which such temperature increases were experienced. It is noted that Fig. 2.5.4 of the Assessment Report suggests that a more marked increase in water temperature may have occurred in the SNE region between 1963 and the mid-1980s.

1. Prolonged exposure to water temperature above 20^0C causes respiratory and immune system stress, increased incidence of shell disease, acidosis and suppression of immune defenses in lobster. Lobsters avoid water greater than 19^0C.

The paper by Dove *et al.* (2005) demonstrated that prolonged exposure (>30 days) to water temperature above 20°C caused physiological stress to the American lobster, depressing phagocytic activity of hemocytes and resulting in significant acidosis. Steenbergen *et al.* (1978) demonstrated that the immune defences of lobster were reduced at higher water temperatures. Glenn and Pugh (2006) found "a significant correlation between disease incidence in Buzzards Bay and a series of warmer than average water temperatures from 1999 to 2003, which suggests that temperature may be a primary factor related to the recent outbreak of epizootic shell disease". Crossin *et al.* (1998) actually reported that "lobsters avoided water that was warmer than approximately 20°C", not 19°C, as was reported by the TC. Each of the journals in which these papers were published is well respected, and papers are accepted for publication only after peer review. Thus, the above statement by the TC is essentially correct.

ii. Loss of optimal shallow habitat area is causing the stock to contract spatially into deeper water

The TC has provided evidence that temperature in nearshore waters of SNE has increased to the extent that optimal lobster habitat has been reduced. Scientific studies cited by the TC indicate that lobsters can detect differences in temperature and, if able, will move to habitat that lies in the temperature range from 12 to 18°C and, if possible, avoid areas with temperatures in excess of 20°C. Studies were also cited by the TC which demonstrated that, if subjected to long periods in waters with temperatures in excess of 20°C, individuals will experience physiological stress and depressed immunity to disease, suggesting that they will experience greater natural mortality. It is therefore logical to conclude that temperature increase is likely to have caused the relative abundance of lobsters in nearshore waters to be reduced and in offshore waters to be increased.

1. The shift in abundance to deeper water may reflect increased mortality in shallow water by mid Atlantic predators (e.g. striped bass, dogfish, and scup) whose abundance has increased substantially in the last decade.

Evidence of an increased abundance of predators in shallow water was not provided by the TC in their report. Such increased predation, if relatively greater in nearshore than offshore waters, would be expected to reduce the relative number of lobster in nearshore shallow waters and increase the relative number of lobsters in offshore waters.

2. Recent larval drift studies in area 2 suggest that the re-distribution of spawning females into deep water areas may be causing larvae to be transported away from traditional settlement areas and potentially into less favorable areas.

The preliminary data reported by the TC suggest that the changed spatial distribution of female lobsters could affect the distribution of settling lobsters and their survival. Greater detail of these larval drift studies is needed to ascertain the extent of the spatial area within the SNE covered by the studies. Simulations based on sound hydrodynamic models, and taking into account vertical movements of larvae, would also prove informative.

iii. Continued fishing pressure reduces the stock's potential to rebuild, even though overfishing is currently not occurring in SNE.

Fishing pressure that removes females from the stock will reduce the reproductive potential of the stock and thereby reduce the potential for the stock to rebuild from an overfished state. That is, the stock is likely to rebuild more rapidly if exploitation is reduced, but, since "overfishing is currently not occurring", it would be expected that the stock would rebuild providing no other factors constrain its ability to recover.

While it was found in the 2009 assessment that, at that time, overfishing was not occurring, the conclusion that overfishing is currently not occurring is subjective, as the report on recruitment failure of the SNE lobster stock has based its "assessment" on a subjective appraisal of the trends in the time series data. The results of a fully-integrated quantitative assessment using the University of Maine's length-based model and employing the new data that have been collated by the TC are not yet available. Such an assessment would be required to balance inconsistencies among data sets, account for selectivity of surveys and landings, and take the noise in the data into account.

The TC has noted in its report that the change in relative distribution, which it believes has resulted from the increased warming of nearshore waters, may have increased the vulnerability of lobsters to fishing. There is a need to consider whether structural modification to the length-based model is required to allow for such change. The model would then need to be re-run, using the new data, to assess whether or not overfishing is now occurring as a result of the increased vulnerability of the lobsters.

A more serious question that will need to be addressed by the TC is whether, if natural mortality has increased, reference points derived from data from 1984 to 2003 are appropriate, noting that, for 70% of this reference period, natural mortality was assumed to be much lower, *i.e.*, M=0.15 year^{-1}.

From the improvement of fit of a model that employed an increased level of natural mortality from 1998 over the fit produced by a model that assumed no increase in mortality from the base level of 0.15 year-1, the TC demonstrated that the recruit and legal-sized lobsters, which are represented in the model, had experienced a marked increase in natural mortality over the last decade. It is highly unlikely that such increase in natural mortality was confined to the lobsters in the size range represented by the recruit and legal-sized lobsters. Thus, almost certainly, juvenile and pre-recruit lobsters will have experienced a similar, if not greater, change in natural mortality.

With the increase in natural mortality, fewer recruits now survive to maturity, *i.e.*, the replacement relationship has changed. Also, fewer juvenile and pre-recruit lobsters survive to attain the size at which they would be classified as recruits. Indeed, the studies reported by the TC suggest that the increased temperatures in nearshore waters since 1999 are likely to have impacted on the success of settlement of larvae, the amount of suitable habitat, and juvenile survival. Thus, it is very likely that the stock-recruitment relationship has also changed, with a decrease in the number of recruits that are now expected to result from a given level of female spawning biomass.

The changes in the stock-recruitment relationship and replacement relationship that have occurred or are likely to have occurred as a result of the changed environmental conditions to which the SNE lobster stock are now exposed would reduce the expected equilibrium abundance of lobsters at a given level of exploitation (Appendix 3). Thus, even if the stock-recruitment relationship remained unchanged, the increased natural mortality between hatching and spawning would reduce the reference level of exploitation that distinguishes whether or not overfishing is occurring and the reference level of abundance that determines whether or not the stock is considered to be overfished.

Reference points based on historical data, *i.e.*, for a period when natural mortality was lower and the stock-recruitment process had not been affected by increased temperatures in nearshore waters, are likely to be highly inappropriate for assessing the status of the stock given the changed environmental conditions that the SNE lobster stock is now experiencing.

1. Total trap hauls have declined significantly yet have not declined at the same rate as lobster abundance.

It is reported in the 2009 assessment report that the total number of traps was reduced by ~63% between 1999 and 2007. The number of trap hauls in CT and MA, the states for which data are available, reduced from 5.3 million in 1998 by ~58% to 2.2 million in 2007 (Table 3.2.1.2., assessment report). The reference abundance in 1998 was 35.8 million lobsters, and that in 2007 was 14.2 million (data plotted in Fig. 1 of the recruitment failure report), a decline of ~60%. The results for the base model, which were presented in the 2009 assessment, indicate that effective exploitation (combined sexes) was reduced by approximately 40% in this period, a decline that, as expected due to the nonlinear relationship between fishing mortality and exploitation, was less than that of fishing effort. The decline in trap hauls of ~63% is similar in magnitude to the decline in reference abundance, *i.e.*, ~58%, but the decline in effective exploitation, *i.e.*, ~40% is less than that of reference abundance. The important point to note is that, in theory, the reduction in trap hauls should have resulted in a possibly lagged increase in reference abundance.

2. Although current measures prevent the harvest of egg-bearing and v-notched lobster, the legal catch inshore and offshore represents a loss of egg production to the system.

This is true. Capture and landing of female lobsters removes them from the stock, such that they cannot spawn in subsequent spawning seasons.

ToR 3. Determine the appropriateness of conclusions drawn in the TC report; if deemed inappropriate; provide alternative conclusions with justification. The report conclusions include, but are not limited to:

a. The TC contends that the stock is experiencing recruitment failure caused by a combination of environmental drivers and continued fishing mortality.

As noted in Section 2.1 of the recruitment failure report, the TC has defined recruitment failure as "the point where environmental conditions and/or fishing have resulted in successive years of poor recruitment", while recruits are defined in the 2009 assessment report as "lobster that are not legal size at the time of the survey but are expected to molt and grow to legal size during the next year". The recruitment failure report, however, provides no definition of the number of successive years of poor recruitment that must elapse before it is considered that recruitment has failed, nor has it defined the criterion by which recruitment is assessed as "poor".

In order to assess the validity of the conclusions that the TC has drawn in the recruitment failure report, it has been necessary to infer, from the statements made in this and the assessment report, the criteria that the TC was likely to have used to assess whether recruitment had "failed". Thus, it appears probable that the TC adopted the criterion that values less than the 25th percentile of the recruitment data for the 1984-2003 reference period are "poor". In specifying the control rules used to assess whether the lobster stock is experiencing overfishing or the reference abundance is considered to be depleted, the SASC proposed that the average of the values of effective exploitation or reference abundance for the three most recent years should be calculated and compared with the associated reference point. Thus, it appears likely that the TC has considered that, if the number of successive years of poor recruitment is three or more, then recruitment failure has occurred.

For other fisheries, where estimates are available of the level of depletion of abundance from the unfished state and where stock-recruitment relationships have been developed, alternative definitions of recruitment failure would be likely to be proposed (Appendix 3). For the SNE lobster stock, where reference points for fisheries management have been defined from historical data, the definition of recruitment failure will, of necessity, be determined by those historical data or by values derived from those data. The definition of recruitment failure for the SNE fishery, which was proposed by the TC in its recruitment failure report, appears consistent with the reference point for reference abundance that was proposed by the SASC in the 2009 stock assessment. If the decision is made by the ASMFC to adopt the recommendation by the Panel that reviewed this assessment that the threshold reference point for reference abundance is reduced to half the median abundance for the reference period, consideration may need to be given to redefining "recruitment failure" to maintain similar consistency with the modified reference point.

Figures 7 and 8 of the recruitment failure report suggest that, other than for Naragansett Bay and RI Sound, the indices of recruitment from the fall trawl surveys in the SNE have been consistently less than the 25th percentile since 2002. According to the above definition, it appears reasonable to conclude that the SNE stock has experienced/is experiencing recruitment failure.

It is reasonable to propose that, for an exploited stock, recruitment failure is due to a combination of environmental factors and fishing mortality. Typically, a recruitment collapse in a fishery occurs when a heavily-exploited stock encounters adverse environmental conditions that reduce the level of recruitment from the average level that would have been expected. If exploitation is not reduced to compensate, the lower recruitment leads to lower egg production. If the adverse environmental conditions persist or worsen, the lower egg production then produces even lower recruitment, and the ratchet effect continues, driving the abundance of the stock to lower and lower levels. Thus, in such a case, a level of exploitation that may have been sustainable in the past becomes unsustainable when the productivity of the stock becomes reduced due to environmental change (Appendix 3). In such a situation, it is typically necessary to reduce exploitation to a level that allows the stock to become stable and/or recover. Recovery may also be achieved through fortuitous return of environmental conditions to those that had previously been experienced, however responsible management practice should not rely on chance.

b. It is this recruitment failure in SNE that is preventing the stock from rebuilding.

The data presented in the recruitment failure report provide little indication that recruitment is recovering from the low levels that have recently been experienced. As concluded by the TC in its recruitment failure report, continued low levels of recruitment are likely to prevent the stock from rebuilding, at least in the short term

An increase in the reference abundance would require an increase in recruitment and/or a reduction in exploitation sufficient to allow the number of legal-size lobsters in the stock to gradually increase as a consequence of their increased probability of survival. It should be noted that, if increased recruitment is to be brought about by reducing exploitation and allowing a greater number of lobsters to spawn, there will be a lag in response as the ratchet effect (of increased spawning biomass leading to increased recruitment, which leads to increased spawning biomass, etc.) works through the annual spawning-recruitment process and there is a lag of at least about four years between spawning and recruitment.

Recognising that recruitment to the fishery exhibits inter-annual variability, an increase in recruitment could be brought about by chance or by an improvement in environmental conditions. Increased recruitment resulting from such an event and/or such environmental change would be a bonus for the fishery, but relying on chance or environmental change is not considered to be responsible management practice. Thus, the alternative constraint that prevents the stock from rebuilding may need to be considered, *i.e.*, the level of fishing mortality to which the stock is exposed may need to be reduced to allow greater survival of female lobsters and thereby increased reproductive potential. The lag in recruitment response that results from reduced exploitation needs to be recognised when considering the effectiveness of alternative management approaches.

Recruitment failure is not really the factor that is impeding recovery of the SNE stock. It is actually a symptom of the factors that have caused recruitment to decline. The real issue is whether continued low levels of recruitment reflect a run of adverse but random environmental conditions, or whether the stock-recruitment and recruitment-stock relationships have experienced fundamental changes that now, in combination with exploitation, inhibit the stock from recovering to historical levels of abundance (Appendix 3). Indeed, the TC has proposed that natural mortality has changed due to the increased temperatures that are now being experienced by the SNE lobster stock, and has based projections on continued high levels of natural mortality. An increase in the level of natural mortality reduces the expected number of larvae that will be produced by each female recruit through its lifetime, thus affecting the replacement relationship. Such change in basic population processes will impact on the level of exploitation that the stock can sustain, requiring adjustment of the biological reference points used to guide management of the fishery.

c. Overwhelming environmental and biological changes coupled with continued fishing greatly reduce the likelihood of SNE stock rebuilding

The evidence presented by the TC in its recruitment failure report suggests that there has been a change in the temperature regime to which the SNE lobster stock is exposed. There is evidence in published studies of the population biology of the species that indicates that, as a consequence of the change in temperature, biological processes of growth, maturation, and reproduction will have changed. It is unlikely that the environmental conditions to which the SNE stock is currently exposed will revert to their previous state, at least in the immediate future. Thus, it appears highly likely that current environmental conditions will continue to adversely affect recruitment success. As noted above, for rebuilding to occur, it may be necessary to reduce the level of exploitation that the SNE lobster stock experiences, such that the reproductive potential of the lobsters that recruit can be increased through greater survival and increased number of spawning opportunities. It should also be noted that, if the stock has experienced biological changes, those changes are likely to constrain the extent to which the stock can rebuild, *i.e.*, it may not be possible for the stock to recover to historical levels of abundance or support historical levels of exploitation.

ToR 4. **Comment on the applicability of the recruitment indices to forecast future recruitment and landings to the inshore and offshore areas.**

The recruitment indices, *i.e.*, indices of the actual numbers of recruits, that were presented in the recruitment failure report were those indices derived from the fall trawl survey data, which were presented in Figs 7 and 8. Although the larval settlement and YOY indices were presented in the section of the report dealing with recruitment indices, given the definition of recruitment that has been adopted by the TC, it would probably have been more correct to identify these as pre-recruit indices. It has been assumed that this Term of Reference is intended to address the applicability of these larval settlement and YOY indices to forecast future recruitment and landings to the inshore and offshore areas.

It is assumed that the predictions that are the subject of this Term of Reference are those that forecast the relative abundance of recruits of the same year class that will become available when the lobsters in the year class have grown to attain the length at which they are classified as recruits, and the landings that are likely to be achieved from that year class (and the survivors of year classes that recruited in earlier years) by the fishery in the first year following the attainment of legal size by that year class.

It is noted by the SASC in the 2009 assessment report that, for a group of lobsters caught in Long Island Sound, "even within this fairly homogeneous group, animals one molt-group below the minimum legal size (72-83 mm) represented as many as eight year-classes". Wahle *et al.* (2004) indicate that, in Maine and Rhode Island, the age of lobsters in the recruit group ranged from 4 to 9 years. It follows that the relationship between the indices of larval and YOY abundance and indices of abundance of subsequent recruitment will be masked by the fact that the recruits will comprise a number of year classes. However, if the indices of larval and YOY abundance are consistently lower than average, as appears to be the case for the SNE lobster stock, it is likely that the indices of recruitment from the mix of poor year classes will also be lower than average.

Subjectively, there appears to be a level of consistency between the larval and YOY indices and the subsequent recruitment indices and landings. Such subjective assessment of consistency among pairs of indices is likely to be misleading, however, as it fails to consider the extent to which a time series of indices is consistent through time with the full set of other indices that are available for the stock. To avoid subjectivity, the larval and YOY indices need to be included as input to an integrated model and subjected to a rigorous assessment of the extent to which they are consistent with other time series of indices and the extent to which they contribute information that influences the model's predictions and parameter estimates. It is only through inclusion of the indices in such an integrated model that it will be possible to determine "the applicability of the recruitment indices to forecast future recruitment and landings to the inshore and offshore areas". For such assessment, it will also be necessary to extend the model to include indices of recruitment and landings to inshore and offshore areas, as current indices and landings relate to surveys or the combination of catches from both inshore and offshore regions.

There is always a temptation to include time series of data that are collected for other purposes in stock assessments. However, such inclusion of opportunistic data sets within an integrated stock assessment model has the potential of introducing inconsistencies among data sets. Rather than using such opportunistic data sets, a well-designed, statistically-sound survey that collects data that are representative of the component of the stock that is the intended target of the survey is likely, in the longer term, to provide more useful and informative data. If data sets from opportunistic surveys are used, it would be useful to subject the statistical design of those surveys to careful scrutiny to assess the extent to which the data sets are likely to be representative of the data that they are intended to represent, and to assess whether the statistical methods used to analyse the data are appropriate.

ToR 5. Determine the appropriateness of the recommended action (5-year moratorium); if deemed inappropriate, provide alternative recommendations with justification. The report recommendations include, but are not limited to:

a. Given evidence of recruitment failure in SNE and the impediments to stock rebuilding, the TC recommends a 5 year moratorium on harvest in the SNE stock area.

The results of a number of projections made using the University of Maine's length-based model (based on the 2009 assessment and employing data to 2007) and assuming alternative management, recruitment and natural mortality scenarios were considered and reported by the TC. The essential message of these projections was that, if recent low recruitment was to continue for the next ten years, it would not be possible to sustain the stock at current (low) levels even by setting exploitation to zero. The TC has correctly identified that the most effective management option to promote an increase in recruitment to the SNE stock would be to increase the stock's reproductive potential through allowing greater survival of lobsters, thus allowing more females to spawn. The proposal to impose a complete moratorium represents the maximum response that fisheries managers could make. It is unclear, from the documents that have been provided, whether the proposed moratorium is acceptable under the terms of the legal framework that governs this fishery. This question falls outside the terms of reference and would need to be considered within other fora.

The Term of Reference asks whether the recommended action is appropriate. The SASC concluded in the 2009 assessment that, based on current and its proposed reference points, the SNE lobster stock is overfished but overfishing is currently not occurring. The Panel concluded that, based on its suggested revision to the SASC's proposed reference points, the abundance of the SNE stock had declined and was nearing the point at which it would be considered depleted, but that overfishing was currently not occurring. The Panel also recommended, however, that there should be a "reduction in exploitation and implementation of a fishery rebuilding plan for the SNE stock". From the documentation that was provided for this review, it is unclear whether the ASMFC has decided yet whether to adopt one or the other, or neither, of the proposed reference points. There is consistency, however, in the recommendation that the SNE lobster stock should be rebuilt, and the mechanism to achieve such rebuilding is through a reduction in exploitation.

The change that has occurred subsequent to the 2009 assessment and its review by the Advisory Panel is that the TC has explored in greater detail the possibility that temperature increase has resulted in an increase in natural mortality. The TC has confirmed the preliminary results presented in the 2009 Assessment Report, that the model provides a better fit to the data if an approximately two-fold increase in natural mortality is assumed from 1998, providing support for the hypothesis that there has been in increase in natural mortality in recent years. Subjective examination of new data and time series of larval and YOY indices support the view that recruitment shows no sign of increase, and the fact that recruitment indices appear to continue to be low suggests that, without intervention, the abundance of the lobster stock is likely to decline further. The TC has provided the results of projections assuming a range of alternative recruitment, natural mortality and exploitation options, and has examined the effectiveness of the V-notch program as an aid to rebuilding the stock.

On the basis of the results that have been presented, and assuming that the model is sound, the data that are available support the hypothesis that natural mortality has increased in recent years. Accordingly, provided that the recruitment series used in the projections is accurate, the results of the projections presented in the Projection Estimates Report that assume a continued high level of natural mortality are likely to be indicative of the expected response of the SNE lobster stock to changes in exploitation. Thus, if the stock is to be rebuilt and the recruitment series is accepted as an accurate forecast, it is appropriate to use these projections to determine an appropriate management response to the reduced abundance of the SNE lobster stock. There appears no basis for the assumption that levels of natural mortality will reduce in forthcoming years to the level that was referred to by the TC as "moderate", *i.e.*, M=0.225 year^{-1}. Thus, it is more appropriate to consider only the projections based on continued high levels of natural mortality, *i.e.*, M=0.285 year^{-1}, when determining a management response.

The Beverton and Holt stock-recruitment relationship represents a more biologically-realistic scenario than the assumption that there is no relationship between spawning stock and recruitment. The results of the projections reported by the TC, which assume such a relationship, are based, however, on parameter estimates for the stock-recruitment relationship that have been derived from estimates of spawning biomass and recruitment produced by the assessment model. The majority of these estimates of spawning stock biomass and recruitment are therefore likely to have represented values arising from the stock-recruitment relationship that existed during the period when the stock was experiencing a low natural mortality, *i.e.*, M = 0.15 year^{-1}. Because of the probable impact of increased temperature on settlement success and juvenile mortality, the stock-recruitment relationship for this earlier period would be expected to differ markedly from that for the post-1998 period, when natural mortality was higher, *i.e.*, M = 0.285 year^{-1} (Appendix 3). It is suggested that, when calculating the parameter estimates for the stock-recruitment relationship to be used in the projections, the data should be restricted to values of stock and recruitment representative of the relationship that was likely to have existed for the post-1998 period. The estimates of recruitment that were derived for those projections reported in the TC's Projection Estimates Report, which employed the Beverton and Holt stock-recruitment model, are likely to be too optimistic. Without calculating the parameters of the stock-recruitment relationship for the post-1998 era, and re-running those projections that employed a Beverton and Holt stock-recruitment relationship, it is not possible to determine whether the resulting abundance estimates are likely to be better or worse than those produced by the projections that assumed low recruitment, which were reported by the TC.

Estimates of the parameters of the stock-recruitment relationship should be made within the integrated model, rather than outside, such that uncertainty in the estimates of projected lobster abundance can be properly assessed.

It is likely that the reference point for abundance, which was recommended by the SASC in the 2009 Assessment Report and was displayed by the TC in the plots of lobster abundance for the various projections in its Projection Estimates Report, will need to be reduced to accommodate the increased natural mortality to which the stock is now subjected and the change in the stock-recruitment relationship that is likely to have resulted from the impacts of increased temperature on the success of larval settlement and the natural mortality of juvenile lobsters. If the recommendation of the Advisory Panel is accepted by the ASMFC, it is also possible that a lower reference point may be adopted.

From the above, it appears that, given the changes in the replacement and stock-recruitment relationships that are likely to have accompanied the environmental change that the stock has experienced, the projections presented by the TC currently provide little information to assess the likely response to reduced exploitation or to determine the threshold level of lobster abundance to which the stock needs to be rebuilt. There appears to be strong evidence that the abundance of the stock has declined considerably, to a level that is of concern to both the TC and the Panel. While a five-year moratorium on exploitation appears extreme, the current low abundance and uncertainty regarding the response of the stock to even low levels of exploitation suggest that it would be wise to apply a very precautionary approach and adopt the proposed moratorium (Appendix 3). It would be important to monitor the response of the stock to the moratorium in order to maximise the information that is gained from this intervention. If the decision is made to allow a continued low level of exploitation, a scenario with reduced exploitation combined with a V-notch program (or male only fishing) likely to produce a significant level of rebuilding within a five year time frame should be developed and considered for adoption. Research needs to be initiated to assess how the parameters of the Beverton and Holt stock-recruitment relationship of the SNE lobster stock have changed as a consequence of the changed environmental conditions.

i. The moratorium provides the maximum likelihood to rebuild the stock in the foreseeable future to an abundance level that can support a sustainable long-term fishery.

It is true that the imposition of a moratorium will provide the stock with the greatest chance of rebuilding, and will produce such rebuilding in the shortest time. The approach is one that will have a considerable socio-economic impact on fishermen, however, particularly in the current economic climate.

What is missing from the reports prepared by the TC is consideration of the possibility that a change in natural mortality or in the stock-recruitment relationship represents a change in the dynamics of the stock (Appendix 3). Reference points that were based on previous levels of natural mortality and stock-recruitment become inappropriate. Thus, the median and 25th percentiles of abundance calculated for 1984 to 2003 are no longer relevant and new reference points will need to be determined. It should be recognised that, if the change in natural mortality and/or in the stock-recruitment relationship is extreme, the possibility exists that stock rebuilding may be minimal or may not occur even in the absence of fishing.

b. During the 5 year moratorium period, monitoring of all phases of the lobster life cycle should be intensified.

i. Fishery dependent sampling will no longer be collected, therefore assessment of stock status will rely on current fishery-independent surveys (e.g., ventless trap, YOY sampling, larvae) which will need to be continued and intensified.

If a moratorium on harvest is introduced, the loss of data from the commercial fishery will reduce the information that is available for use in stock assessment, and increase the uncertainty of parameter estimates and model predictions. There would be considerable value in enhancing the current fishery-independent surveys to provide other data that might compensate for the loss of length composition and catch data from the fishery. Care needs to be taken to ensure that consistency of time series is maintained, however, as changes in selectivity and catchability that are introduced when data collection programs are modified may introduce discontinuities in the data sets that the model cannot resolve. The integrated model will need to be enhanced to allow it to make full use of any additional data sets. Change in the level of exploitation will provide an invaluable opportunity to gain information on the dynamics of the SNE lobster stock but, to gain the maximum benefit from the change, will require the collection of appropriate additional survey and research data.

ii. New surveys and research (e.g., sentinel industry surveys) are needed to further characterize stock status, lobster settlement and habitat in SNE.

The TC is correct. Because of the increased uncertainty associated with changed environment and changes in biological parameters, and with both stock and recruit abundance having declined to persistent low levels, the fishery is now in unfamiliar territory. To resolve many of the uncertainties that are now emerging with respect to the biology of the stock, the availability of suitable habitat, and the distribution and status of the stock, it will be necessary to undertake new research and develop new surveys, *e.g.*, sentinel fishing industry surveys. Many changes in biological parameters are likely to have accompanied the increase in temperature that the SNE lobsters have experienced. Growth, length and age at maturity, selectivity and catchability may all have been changed and research studies will need to be undertaken to assess whether such changes have occurred, and if so, to determine the new parameters for these biological and fishery processes. The changes to the dynamics of the stock and the fishery that will have resulted from the changed distribution of lobsters and fishing effort will need to be identified and assessed.

ToR 6. **Evaluate the stock projection scenarios conducted to complete the task as outlined by the Board** (see above ToRs).

a. Evaluate the deterministic projections conducted using the University of Maine Model.

i. The Board directed the TC to provide projections within an extremely short time frame. Although stochastic projections and estimates of uncertainty (e.g. MCMC confidence intervals) could have been provided, the time frame for decision-making was too short to complete a more thorough analysis.

It is reported on p.63 of the 2009 assessment report that efforts "to estimate variances and characterize statistical uncertainty in estimates from the University of Maine model" were not successful. Subsequently, on p.75, the SASC explains that "It was not possible to characterize statistical uncertainty in results from the University of Maine model because asymptotic variances and likelihood confidence intervals were very small, implying unrealistically low levels of uncertainty. This was likely caused by specification (vs. estimation) of the growth transition matrix. Due to lack of time, it was not possible to use MCMC techniques to characterize uncertainty; therefore, the alternative model runs are the primary means for describing uncertainty in this assessment".

The Terms of Reference for the current review note that the TC had three months to complete the following tasks and report their findings

1. Identify issues impeding stock rebuilding in SNE,
2. Develop a suite of measures to begin stock rebuilding in SNE,
3. Develop deterministic projections of stock abundance using the University of Maine Model that assume: a) both status quo and reduced fishing mortality scenarios, and b) status quo recruitment, low/declining recent recruitment, and a stock recruitment relationship.

The projection module of the University of Maine's length-based assessment model includes options for setting the size-specific abundances at the start of the projection period to the values determined for the system state at the end of the assessment period using either (1) the maximum likelihood estimates of parameters, or (2) values selected from the posterior distributions of the parameter estimates, as determined using the MCMC procedure of AD Model Builder (Chen 2010). Other parameters used in the projection may be determined using either of these approaches, or may be input by the user through an easy-to-use interface. The projection module provides options to specify a constant catch or fishing mortality for the projection period or to input values of either catch or fishing mortality at each time step. Recruitment may be specified by the user, set to the average recruitment experienced during the assessment period, or determined from a stock-recruitment relationship, the values of which are specified by the user, and where the lag between spawning and subsequent recruitment is specified by the user. Recruitment variability can also be specified (Chen, 2010). The University of Maine's model thus appears to possess the tools that are necessary to undertake the exploration of a range of alternative projection scenarios.

It is acknowledged that running the MCMC module of AD Model Builder takes considerable time, where the duration depends on the number of parameters, the autocorrelation of those parameters, the correlations among parameters, and the number of parameter sets in the chain of estimates that must be skipped in order to obtain estimates that may be considered to be independent samples from the posterior distributions of the individual parameters. Typically when using AD Model Builder, estimates of uncertainty are first determined using the asymptotic estimates that are output when fitting the model. After reducing the number of scenarios to those most likely to achieve the management objectives, MCMC runs are usually undertaken to assess the uncertainty of model predictions with greater precision.

There is value in attempting a preliminary MCMC run to produce several chains of estimates such that these may be analysed to determine the number of parameter updates that are likely to be required and thereby to assess the time period likely to be required to complete a full MCMC assessment. By using the Bayesian estimates of parameters and of the system state at the start of the projection period, a more informed assessment of uncertainty will be derived. The concern expressed by the SASC in the 2009 assessment report, that, by failing to incorporate all sources of uncertainty, such as that associated with growth, into the assessment model, uncertainty is underestimated, will need to be considered also when assessing the results of MCMC analysis.

It is noted that the third item in the tasks that the TC was set required only that deterministic projections be developed. Apparently exploration of the results of projections based on MCMC parameter estimates was not requested at this time.

b. Evaluate the chosen suite of fishing and recruitment scenarios presented in the report; if insufficient, provide suggestions for alternative scenarios.

The TC considered projections that employed the status quo level of fishing mortality, *F*, and values of fishing mortality that were average (0.5*F*), low (0.25*F*) and zero. The TC has therefore satisfied the request for deterministic projections to be developed to explore both status quo and reduced fishing mortality scenarios.

The projections presented by the TC in the Projection Estimates Report included the results of assuming a Beverton-Holt stock-recruitment relationship and low levels of future recruitment. The TC noted that results of projections that assumed that the average recruitment from 2005-2007 would be sustained were similar to those that employed the Beverton and Holt stock-recruitment relationship, and thus only the latter were reported. It is assumed that the average recruitment from 2005 to 2007 would be equivalent to the status quo recruitment that the TC had been requested to explore. The low recruitment scenario explored by the TC assumed that recruitment was constant and equal to the lowest estimate of recruitment, *i.e.* that for 2004. This value would have represented a decline from the average values recorded for 2005-2007. The TC has therefore also satisfied the request for deterministic projections to be developed to explore status quo recruitment, low/declining recent recruitment, and a stock recruitment relationship. Note, however, that, as discussed for ToR5, it is likely that the parameter estimates of the Beverton and Holt stock-recruitment relationship were derived using (some) data relating to the period prior to environmental change, and thus are inaccurate estimate of the parameters of the stock-recruitment relationship that exists subsequent to that change. Accordingly, values of abundance calculated for those projections in the Projections Estimates Report that estimated recruitment from the Beverton and Holt stock-recruitment relationship are likely to be overestimated.

The TC has recognised that, if natural mortality has increased in recent years, as models fitted to the data from 1984 to 2007 suggest, it is possible that projections may be influenced by higher levels of natural mortality than were experienced in the period from 1984 to 1997. The TC has therefore explored projections that assume both moderate (M=0.225 year^{-1}) and high (M=0.285 year^{-1}) levels of natural mortality.

Finally, the TC has examined how a V-notch program similar to that of the RI program might affect the number of legal lobsters when a constant catch (equal to the average catch from 2005-2007) is taken under conditions of moderate natural mortality and of both low recruitment and Beverton and Holt stock-recruitment-based recruitment. It would have been useful to have presented a similar pair of constant catch scenarios without the V-notch program to provide a basis for comparison of the effect of the latter program.

c. Determine if projection results and the TC's interpretation provided in the report are consistent with assessment model results.

The total lobster abundance that is presented in Fig. 1 of the Projection Estimates Report could represent either the fishable abundance or the reference abundance, as the caption does not identify which is displayed. It is likely that the data are those for the reference abundance, and that the results are those obtained when fitting the University of Maine's length-based model assuming that natural mortality is constant and that $M = 0.15$ year^{-1}.

It is unclear why the trend in the early 1980s in Fig. 2 of the Projection Estimates Report differs from that shown in Fig. 1 of this report. Is the number of legal lobsters in this and subsequent figures the fishable or the reference abundance? Is a difference between the variables the reason for the different trends, or does the difference result from fitting a model with

$M=0.15$ year^{-1} from 1982-1997 and $M=0.285$ year^{-1} for 1998-2007 to produce the results displayed in Fig. 2? It appears likely that the latter is the cause of the difference and that the data to 2007 (and associated medians and 25th percentiles) in subsequent figures have used the results from the latter model-fitting approach.

It appears likely that the parameters of a Beverton and Holt stock-recruitment relationship fitted to the results from the University of Maine's length-based model (and thus essentially assuming little or no change in the stock-recruitment relationship despite the impact of changed environmental conditions) would reflect a relationship producing approximately status quo levels of recruitment for recent levels of spawning stock biomass. Thus, it is not surprising that, with projections using the high level of natural mortality assumed for 1998-2007, there is little recovery even when fishing mortality is set to zero (Fig. 2, Projection Estimates Report). It is also not surprising that, when the projections are based on a moderate level of natural mortality, the stock has the opportunity to recover when the (almost constant) Beverton and Holt stock-recruitment relationship is assumed and fishing mortality is set to zero (Fig. 4, Projection Estimates Report). However, even with moderate natural mortality, it would be necessary to reduce fishing mortality to allow the abundance of lobsters to increase to the 25th percentile or median abundance of the 1984-2003 reference period. This set of projections illustrates the fact that, with a moderate increase in natural mortality to $M=0.225$ year^{-1} from the level that was assumed to be experienced between 1982 and 1997, *i.e.*, $M=0.15$ year^{-1}, and with essentially no change in the stock-recruitment relationship despite the changed environmental conditions, status quo levels of fishing mortality are likely to maintain the stock at current or lower levels of abundance. If natural mortality has increased, as appears likely given the results of the TC's analysis, the SNE stock will no longer be able to support the levels of exploitation to which it was subjected in the past. Furthermore, if the change in environmental conditions experienced by the SNE lobster stock has affected the stock-recruitment relationship, the values of abundance that would be expected to result from the new stock-recruitment relationship are likely to be lower than those presented in the Projection Estimates Report for those projections that employed a stock-recruitment relationship, where the parameters for the latter relationship were derived using (some) estimates of spawning biomass and recruitment from the period prior to the increase in water temperatures reported in the TC's Recruitment Failure Report.

The results presented in Fig. 3 of the Projection Estimates Report are consistent with the concern that the TC has expressed, *i.e.*, with high natural mortality and status quo fishing mortality, low levels of recruitment are insufficient to sustain the reproductive potential of the stock and abundance will continue to decline until it stabilises at the level associated with the constant low level of recruits that are assumed to be maintained. That is, under conditions of high natural mortality, whatever biomass remains from previous stronger year classes is gradually eroded until the stock is reliant on the low number of recruits that it continues to receive. If the natural mortality experienced between 1988 and 2007, *i.e.*, 0.285 year^{-1}, is reduced slightly to a moderate level, *i.e.,* 0.225 year^{-1}, throughout the projection period, a continued low level of recruitment would allow a slight recovery, and a very small amount of exploitation (less than a quarter of the current level).

The V-notch program produces a benefit if a stock-recruitment relationship exists, as it increases the reproductive potential above that which would be experienced without the additional protection afforded the female lobsters (Fig. 6, Projection Estimates Report). If low recruitment persists, and recruitment does not respond to an increased female spawning biomass, there will be no additional benefit afforded by the V-notch program

d. Comment on the reliability of the deterministic projections for use in SNE lobster stock management.

For the deterministic projections to be reliable, it is essential that the model used to assess the state of the SNE lobster stock is based on sound assumptions, has been properly implemented, and that the data to which that model is applied are informative and representative of the variables they are assumed to represent. It is sufficient to note here that the model and data have been reviewed elsewhere. It would be inappropriate to comment further on the University of Maine's length-based model or the results of the 2009 stock assessment, as such comment would fall outside the terms of reference of the current review. It should be noted, however, that the additional data discussed by the TC in its report on the recruitment failure of the SNE lobster stock is not considered when exploring the projections from the 2007. That is, the additional data are ignored and projections presented in the Projection Estimates Report rely on the data to 2007 that were analysed in the 2009 stock assessment. The fact that the new data were not employed in the assessments is beneficial in that, if management decisions are made as a consequence of that assessment, the decisions employ the same data and are not influenced by data that were not considered in the 2009 assessment and subjected to the necessary level of review. On the other hand, the data to 2007 are now considerably out of date, and both an updated assessment and a more responsive system of assessment and analysis might prove valuable to managers. The alternative is to allow for the lag between assessment and management decision by allowing information on observed levels of catches for years subsequent to the assessment, *i.e.*, in this case, for 2008 and 2009, to be input when projecting, such that the effect of fishing in these years can be based on historical fact rather than predicted by the model.

Other data such as larval and YOY indices cannot yet be included in the model. The fact that the TC found such data to be informative in their report on recruitment failure suggests that there would be considerable value in extending the length-based model to allow additional indices to be considered in the assessment.

At the risk of going beyond the terms of reference, I would urge the TC to consider the inclusion within the model of the parameters that are currently estimated outside the model, such that appropriate estimates of the uncertainty may be determined. The SASC has recognized that the uncertainties of model estimates are currently underestimated. That is, the model currently assumes, for example, that growth is known with absolute accuracy and precision and estimates based on this assumption thus fail to incorporate any uncertainty associated with the parameter estimates. There is a need to provide estimates of the precision of the projections such that it is possible to compare the different predictions with confidence, and to allow determination of whether the projections over a ten-year horizon are of sufficient precision to be informative. Without such estimates of precision, the reliability of the projections cannot be adequately assessed.

The TC has identified that the projections are sensitive to uncertainties relating to the assumptions concerning natural mortality and the stock-recruitment relationship. The TC has explored the failure of the SNE stock to recover when a Beverton and Holt stock–recruitment relationship exists by considering only the replacement function, *i.e.*, the survival of recruits to the spawning stock, and the effect that increased natural mortality has had on this survival. Currently, the stock-recruitment relationship is assumed to have a constant form, *i.e.*, constant parameters, and to be unaffected by the change in natural mortality or other impacts of environmental change. It is likely, however, that the stock-recruitment relationship has been affected by those changes (Appendix 3) and that, as a consequence, estimates of the parameters of the stock-recruitment relationship should have been derived using only data on spawning biomass and subsequent recruitment that were from the period that followed the change in natural mortality and/environmental change. The values of abundance that are presented by the TC for projections employing the Beverton and Holt stock-recruitment relationship are therefore likely to be overestimates. In its recruitment failure report, the TC has discussed aspects of the effect of temperature on nearshore habitat, larval settlement and survival of YOY that could well have influenced the shape of the stock-recruitment relationship, *i.e.*, resulted in a change in the parameters of the stock-recruitment relationship (Appendix 3). Selectivity functions may also have changed.

Are the projections reported in the Projection Estimates Report likely to be reliable? Subjectively, they appear consistent with the results produced in the 2009 assessment and the conclusions arising from that assessment. They are not affected by the data that were considered subsequently by the TC, *i.e.*, data for 2008-2009, temperature data, and larval and YOY indices, as these data were not employed by the length-based model. They are therefore not influenced by the conclusion drawn by the TC that recruitment of the SNE lobster stock has failed. The projections are influenced, however, by the additional analyses associated with exploration of the hypothesis that, from 1998, natural mortality had increased to a greater level and the assumption that natural mortality would persist at a higher level during the projection period.

The trends in the projected data that are reported in the Projection Estimates Report are consistent with the responses that, in theory, might be expected. The actual trajectory of lobster abundance will be determined by the form of the stock-recruitment relationship (if any) and future levels of natural mortality and recruitment variability. The conclusion that the opportunity for stock recovery will be maximised by reducing exploitation to a minimum and, if exploitation continues, protecting females from capture, appears sound.

ToR 7. **Review the M sensitivity analysis of the model that indicated a higher M as suggested in the 2009 assessment.**

In its memo of May 24 2010, the TC reported the results of fitting the University of Maine's length-based model using data to 2007 with values of M for 1998 to 2007 that ranged from that assumed for the base case, *i.e.*, M= 0.15 year^{-1}, to 0.9 year^{-1}. Values of M for the earlier years, from 1984 to 1997 remained set at 0.15 year^{-1}. The resulting negative log-likelihood attained a minimum when M for these later years of data was set to 0.285 year^{-1}. This value of M produced an improved fit (to that provided by the base case run) for the female length composition data for all surveys, an improved fit to the length composition data for the males for surveys 2 (CT DEP) and 3 (RI DEM), and an improved fit to the female catch data, but reduced the quality of the fit for male length composition data for survey 1 (NEFSC). Overall, the negative log-likelihood was improved by 154 units, with the greatest contribution being that for the catch of the females, *i.e.*, 40 units. Although the TC noted that the results obtained from the model that employed the higher value of natural mortality for later years did not alter its conclusions regarding stock status, it did not report these conclusions in its May 24 2010 memo. The statement in the memo is essentially consistent, however, with the results of the preliminary assessment that assumed a similar change in natural mortality, which were reported in Table 7.2.3.4 of the 2009 assessment report. In this respect, it should be noted that, although the results for M=0.225 year^{-1} that were reported in the TC's memo matched those reported in Table 7.2.3.4 of the SASC's 2009 assessment report, those for M=0.3 year^{-1} differed markedly, with the improvement in the log-likelihood in the assessment report being presented as only 39 likelihood units.

Based on the studies relating to temperature change, the stress induced by increased temperature, and increased prevalence of disease with increased temperature that were reported by the TC in both the 2009 assessment report and their more recent recruitment failure report, an *a priori* hypothesis that natural mortality of the lobsters in the SNE stock may have increased in more recent years is justified. Thus, the fact that the fit of a model assuming increased natural mortality in later years, given a mortality of 0.15 year^{-1} prior to 1998, was considerably better than that of a model that assumes that natural mortality is constant and equal to 0.15 year^{-1} from 1984 to 2007 indicates that the data provide greater support for the former hypothesis than the latter.

Other hypotheses remain to be explored, however. For example, would it be better to estimate rather than fix the value of natural mortality, and would the assumption of a constant mortality with magnitude greater than 0.15 year^{-1} produce a fit as good as that produced by the model assuming 0.15 year^{-1} between 1984 and 1997, and 0.285 year^{-1} subsequently? Would it be useful to consider a trend of increasing mortality rather than a sudden change between 1997 and 1998? Why should the increase have occurred between 1997 and 1998 rather than 1998 and 1999, or other pair of years?

The mortality profile results presented by the TC in their memo of May 24 2010 suggest that, as an alternative to changing natural mortality, a similar result might have been obtained by relaxing the assumptions relating to the form of the selectivity curves, particularly those for the female lobsters. In their recruitment failure report, the TC has drawn attention to a change in the distribution of fishing from nearshore to offshore. It appears highly likely that this change in distribution will have affected the selectivity associated with catches. There would be value in exploring other alternative structural assumptions to complement that of an increase in natural mortality following 1998, as these may provide fits to the data of similar quality.

5. Conclusions and recommendations

The TC is to be commended for producing such a comprehensive assessment of recent data for the SNE lobster stock and projection estimates of future catches within the three month time frame specified by the ASMFC. The strengths of the evidence that water temperatures have increased over recent years and the argument that, because of the biology and behaviour of the American lobster, such temperature increase would be expected to cause changes in natural mortality and distribution are convincing. The more detailed examination by the TC of the quality of the model fits to the data under a range of levels of increased natural mortality have demonstrated that the data support the hypothesis that natural mortality in recent years is almost twice that of the earlier years of the time series. The new data presented by the TC provide a subjective demonstration that there has been no improvement in recruitment in 2008 and 2009, while the larval and YOY indices provide a subjective demonstration that recruitment is likely to continue to be low over the next few years. The TC has produced solid arguments that, if, as expected, the SNE region continues to experience elevated water temperatures, the impact of these temperatures on the lobster stock will impede rebuilding of lobster abundance. The TC has correctly advised that continued exploitation also reduces the potential for the lobster stocks to rebuild, and has demonstrated in the comprehensive set of projections that it explored that imposition of a moratorium on exploitation maximises the opportunity for the stock to rebuild regardless of the alternative assumptions relating to future recruitment and future levels of natural mortality.

The above strengths of the analyses and arguments presented by the TC in its reports on recruitment failure and projection estimates for the SNE lobster stock could have been enhanced by addressing a number of weaknesses in the documents. For example, it appears that, as identified earlier in this review, other data sets exist that contain information on trends in surface water temperature. **It is recommended that these other sources of water temperature data are examined to determine whether they strengthen the evidence of increased temperatures throughout the region occupied by the SNE lobster stock.** More detailed statistical analysis of the trawl survey, sea sampling and landings data would have provided more convincing evidence of a change in spatial distribution of the stock and of fishing effort than the subjective assessments of the trends and distributions of plotted data that are currently presented in the recruitment failure report. **It is recommended that the survey, sea sampling and landings data are subjected to appropriate statistical analysis to determine whether the spatial distribution(s) of the stock and/or the fishery have changed in recent years from the spatial distributions that were present in earlier years.**

The current limitation of the University of Maine's model, that restricts the number of time series of indices to three, appears to have impeded a more detailed and useful assessment of the value of the information in the larval and YOY surveys, and the consistency of these indices with the trends displayed by other indices, which would have been possible if these indices were included in the integrated model. **It is recommended that the University of Maine's length-based model is extended to allow input and use of the other additional time series of indices of abundance or length composition that are available for the SNE lobster stock.** It is also surprising that the University of Maine's length-based model was not re-run using the new data that had become available for 2008 and 2009 for the surveys already employed in the model, as such runs would have provided updated estimates of recent trends in reference, spawning and recruit abundance based on the full set of survey indices. Subjective assessments of trends in survey indices cannot easily accommodate the different selectivities and lags of the different data sets, and are likely to be influenced by visual features of the data that are inconsistent with assumptions and the information contained in other data sets. By re-running the model using the updated data sets, information from recent length composition data could also have been assessed. **It is recommended that the University of Maine's length based-model is re-run, using the updated time series of data that are now available, to provide an updated assessment of the state of the SNE lobster stock.**

The decision by the TC that recruitment has failed is based on the definition that it has adopted for "recruitment failure", *i.e.*, "the point where environmental conditions and/or fishing have resulted in successive years of poor recruitment". Determination of whether recruitment failure has occurred thus also depends on the criteria by which recruitment is classified as "poor" and specification of the number of successive years of poor recruitment that must elapse before such classification is made. **It is recommended that the ASFMC adopts a definition of recruitment failure that is consistent with the criteria used to determine the threshold reference point that is used to assess whether the lobster stock is overfished.** As the ASFMC appears to have not yet decided between the alternative criteria for setting this latter reference point proposed by the SASC and the Review Panel, it is appropriate to defer a decision on the acceptability of the TC's definition of recruitment failure and its conclusion that, in accordance with this definition, the SNE lobster stock has experienced recruitment failure. Whether or not such failure has occurred, there is sound evidence that recruitment to the SNE lobster stock has declined and that low levels of recruitment have persisted despite the reduction in trap hauls and other management initiatives. This fact, in combination with the conclusion of the 2009 Assessment that the SNE lobster stock is overfished or the Panel's conclusion that the abundance of lobster has declined to a point that is approaching depletion, is likely to be of concern to both managers and fishermen.

If, as appears to be the case, the ASMFC is yet to determine whether to adopt the reference points proposed in the 2009 stock assessment or those recommended by the Review Panel, it would have been useful if the TC had displayed both sets of reference points in the figures presented in the recruitment failure and projection estimates reports.

While it is true that the results of model fitting provide support for the hypothesis that, given other model assumptions, natural mortality from 1998 to 2007 has increased, the choice of years and the assumption of a sudden rather than incremental change in natural mortality appear arbitrary. There would be value in exploring whether hypotheses other than an increase in natural mortality could also explain the recent trends in data, *e.g.*, changes in selectivities of the time series of survey and landings data might provide an equally plausible description of the data. If such alternative explanations exist, their implications for management may differ from those that are associated with increased natural mortality in recent years. Research studies to discriminate between alternative hypotheses may become necessary. **It is recommended that, by fitting appropriately-modified versions of the University of Maine's length-based model, the TC explores alternative hypotheses relating to natural mortality and changing selectivity functions to assess whether these hypotheses provide equally viable alternatives to that which was investigated by the TC and assumes an increase in natural mortality**.

If temperature increases in nearshore waters have impacted on transport of larvae and success of settlement, and on the survival of settling and juvenile lobsters in the nearshore habitat, then the relationship between spawning stock and recruitment (to the lobsters that will recruit to the fishery in the coming year) will have been modified (Appendix 3). Change in the availability of suitable habitat will also modify the stock-recruitment relationship. Similarly, the increased natural mortality that the recruit and legal size stock now appear to experience will have modified the expected number of eggs that a recruiting female will produce within its lifetime, thus modifying the relationship between recruitment and reproductive success, *i.e.*, the replacement relationship. Such changes in the stock-recruitment and replacement relationships modify the relationships between equilibrium abundance, "sustainable" catch, and exploitation and require an adjustment to the reference points that are used by fisheries managers to assess the effectiveness of management strategies. Accordingly, if increased temperatures have affected the SNE lobster stock through increased mortality and changes in larval and juvenile survival, it is inappropriate to continue to employ reference points derived from historical data for a reference period, 70% of which experienced lower natural mortality, and the remaining 30% of which still experienced the effects of transition from the old to new levels of natural mortality. **It is recommended that the TC determines new reference points for abundance and exploitation that are consistent with the changes in biological processes that are likely to have accompanied the increased temperatures now experienced by the SNE lobster stock.**

The current state of the SNE lobster stock, *i.e.*, a stock that is either overfished or approaching a depleted state, depending on which of the reference points is adopted, and for which the expected lag between spawning and recruitment is at least four years, is such that rebuilding will be a relatively slow process. The projections that the TC has produced strongly support the view that, if, as appears likely, natural mortality continues to be as high as estimated for recent years, rebuilding will require a marked reduction in exploitation. **It is recommended that, if and when exploitation of the SNE lobster stock is permitted, male lobsters are preferentially exploited and female lobsters are protected to the extent that is possible, *e.g.*, through use of a V-notch program or male-only fishery. It is also recommended that, if male lobsters are preferentially exploited, monitoring**

programs are established to detect whether such exploitation produces a significant reduction in the number of females that are mated, or a significant reduction in the fecundity of females of different lengths.

The results of the 2009 stock assessment and the recommendations of the subsequent Review Panel provide strong support for management action to reduce exploitation and thereby provide conditions that will allow the SNE lobster stock to rebuild. Without a decision by the ASMFC on the threshold reference point for stock abundance that should be adopted. *i.e.*, that proposed by the SASC and preferred by the TC or that proposed by the Assessment Review Panel, it is not possible to determine the extent of rebuilding that needs to be achieved. The documents provided for the current review provide no guidelines concerning the time period over which rebuilding should occur. There appears little doubt, however, that, if natural mortality has increased, the stock is now experiencing conditions unlike those that it has previously experienced. The stock-recruitment relationship for the SNE lobster stock will also have been affected by environmental change. A highly precautionary management approach is therefore warranted as these changes in the dynamics of the lobster stock make predictions of the abundance of lobsters that is likely to result from even very reduced levels of exploitation highly imprecise (Appendix 3). For this reason, the proposal by the TC that managers impose a five-year moratorium on exploitation of the SNE lobster stock is endorsed, as this should allow the stock to rebuild and will provide crucial data on the current dynamics of the stock such that future research advice becomes more reliable. **It is recommended that managers impose a five-year moratorium on exploitation of the SNE lobster stock**.

Information on larval and YOY abundance indices and indices from the ventless trap surveys are currently not employed within the University of Maine's model. As the SNE lobster stock appears to have experienced marked biological change as a result of recent coast-wide temperature increase, and will experience considerable change as a result of proposed reductions in exploitation, there is likely to be much value in the information that these indices contain. Expansion of the current larval and YOY surveys to well-designed, coast-wide surveys would provide valuable data for future assessment. The data from the ventless trap survey appears to offer considerable information that is currently unused in the assessment model. There is a need to expand research to assess the implications of changes in distribution of lobsters, changes in transport and settlement of larvae, changes in available lobster habitat, and changes in biological parameters that appear to have been impacted by recent temperature increases. With the reduction in exploitation that is likely to be implemented, there is potential that catchability and selectivity of catch data will be affected, thus increasing the need for additional or enhanced fishery-independent data. **It is recommended that fishery-independent research studies and surveys of the SNE lobster stock and fishery should be expanded and/or enhanced, and that the University of Maine's length-based model be extended to use the additional data in future assessments.**

In closing, it is useful to reflect on the fact that recognition by the SASC and TC that natural mortality of the SNE lobster stock may have increased in recent years has been a crucial element in interpreting the trends in data and in formulating appropriate management responses to address the decline in abundance. The TC has provided valuable insight into the biological and behavioural basis for the impact of temperature on the stock. To date, however, the TC has only explored the impact of the change in natural mortality, which is likely to have resulted from increase in temperature. The effect of temperature increase on larval transport and settlement, juvenile/pre-recruit survival, growth, size and age at maturity, and available habitat are likely to be important factors influencing the population dynamics of the lobster stock. The impact of these factors and the implications of possible further temperature increase/change represent major uncertainties for assessment of the SNE lobster stock and predictions of the stock's response to management and fishery changes and will require increased levels of research. Further development and increasing flexibility and responsiveness of the University of Maine's length-based model will be essential if, given the uncertainty introduced by environmental change, fishery scientists are to respond to the demands for research advice concerning the SNE lobster stock.

6. References

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Wahle, R. A., Incze, l. S., & Fogarty, M. 2004. First projections of American lobster *Homarus americanus* recruitment from a settlement index. *Bull. Mar. Sci.* **74**: 101-114.

Appendix 1: Bibliography of all material provided

Document #	*Title*	*Authors*	*Short Title (used to refer to document in the text of this report)*
09 Lobster Advisory Report.pdf	Stock Assessment Report No. 09-01 of the Atlantic States Marine Fisheries Commission. Terms of Reference & Advisory Report to the American Lobster Stock Assessment Peer Review, conducted on March 17-20, 2009, Boston, Massachusetts	ASMFC American Lobster Stock Assessment Review Panel (Sigler, M. (Panel Chair), Fu, C., Miller, T., & Muller, R.)	2009 Advisory Report
LobsterStock Assessment Report 2009 Final for viewing.pdf	Stock Assessment Report No. 09-01 (Supplement) of the Atlantic States Marine Fisheries Commission. American Lobster Stock Assessment Report for Peer Review, conducted on March 17-20, 2009, Boston, Massachusetts	ASMFC American Lobster Stock Assessment Subcommittee (McKown, K. (Chair), Glenn, R., Howell, P., Jacobson, L., Nesslage, G., & Wilson, C.)	2009 Assessment Report
SNE Recruitment Failure.docx	Recruitment Failure in The Southern New England Lobster Stock. Unpublished report dated April 17, 2010.	American Lobster Technical Committee, Atlantic States Marine Fisheries Commission	Recruitment Failure Report
Mprofile_SNE_UMM.docx	Southern New England – University of Maine Model - Natural Mortality (M) Profile. Memo, May 24, 2010	ASMFC Lobster Technical Committee	Natural Mortality Profile Report
Recruitment Failure report figure data.xlsx	Data that appear to have been used to produce the figures presented by the TC in its report on recruitment failure of the SNE lobster stock	Anon. (presumably produced by the ASFMC Lobster Technical Committee)	
newSNE projections.xlsx	List of the different scenarios explored in the projection analysis and data that appear to have been used to produce the figures presented in the projection report and other figures that were not presented.	Anon. (presumably produced by the ASFMC Lobster Technical Committee)	
Description of the projection module.docx	A description of the projection module in the University of Maine statistical length-structured stock assessment model for American lobster.	Chen, Y. (no date)	
SNE_projection.doc	Southern New England Lobster Stock Projection Estimates	Anon. (presumably produced by the ASFMC Lobster Technical Committee)	Projection Estimates Report
Model code.zip	Files containing the AD Model Builder source code that implements the University of Maine's length-based model, and the data for the SNE lobster stock and fishery that were analysed using this model	Anon (presumably produced by the ASFMC Lobster Technical Committee in collaboration with Dr Yong Chen, University of Miami)	

Appendix 2: Copy of CIE Statement of Work

Statement of Work for Dr. Norman Hall

External Independent Peer Review by the Center for Independent Experts

Recruitment Failure in the Southern New England Lobster Stock

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

Project Description: The review would evaluate a report written on April 17, 2010 by the American Lobster Technical Committee (TC) of the Atlantic States Marine Fisheries Commission (ASMFC), entitled "Recruitment Failure in the Southern New England Lobster Stock" and the supplemental stock projection document, entitled "Southern New England Lobster Stock Projection Estimates". The report concludes that the stock is critically depleted, experiencing recruitment failure, and cannot rebuild. The cause is thought to be a combination of "environmental drivers" and continued fishing mortality. The TC recommends a five year moratorium on harvest. The review would be asked to consider the merits of this recommendation. The supplemental document provides stock estimates under various F scenarios and recruitment conditions. The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**.

Requirements for CIE Reviewers: Three CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. CIE reviewers shall have a combination of working knowledge and recent experience in the application of marine ecology, lobster biology and life history, recruitment dynamics, and population assessment. Each 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: Each CIE reviewer shall conduct an independent peer review as a desk review, therefore no travel is required.

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

<u>Prior to the Peer Review</u>: 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 reviewers. The NMFS Project Contact is responsible for providing the CIE reviewers 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 reviewers the necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE Lead Coordinator on where to send documents. CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein. The CIE reviewers shall read all documents in preparation for the peer review.

Desk Review: Each CIE reviewer shall conduct the independent peer review in accordance with the SoW and ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs can not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COTR and CIE Lead Coordinator.** The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements.

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

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

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Conduct an independent peer review in accordance with the ToRs (**Annex 2**).
3) No later than 11 October 2010, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and David Sampson, CIE Regional Coordinator, via email to *david.sampson@oregonstate.edu*. Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in **Annex 2**.

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

The following dates are tentative, and the project contact will provide firm dates no later than 27 July 2010.

27 August 2010	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact

10 September 2010	NMFS Project Contact sends the CIE Reviewers the report and background documents
17-27 September 2010	Each reviewer conducts an independent peer review as a desk review
11 October 2010	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
25 October 2010	CIE submits the CIE independent peer review reports to the COTR
1 November 2010	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: Requests to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the COTR within 10 working days after receipt of all required information of the decision on substitutions. The COTR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the CIE reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

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

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

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

Support Personnel:

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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: Terms of Reference for the Peer Review

Review of TC report: Recruitment Failure in the Southern New England Lobster Stock

The American Lobster Board (Board) assigned the American Lobster Technical Committee with the following tasks:

1. Identify issues impeding stock rebuilding in SNE,
2. Develop a suite of measures to begin stock rebuilding in SNE,
3. Develop deterministic projections of stock abundance using the University of Maine Model that assume: a) both status quo and reduced fishing mortality scenarios, and b) status quo recruitment, low/declining recent recruitment, and a stock recruitment relationship.

The Technical Committee had 3 months to report back to the Board on their findings. From the above tasks the TC drafted the report: Recruitment Failure in the Southern New England Lobster stock. With the exception of temperature data and information on the redistribution of spawning females, all other fishery independent and dependent data used in the TC's report were peer reviewed and accepted during the most recent (March 2009) ASMFC Benchmark Stock Assessment.

Terms of Reference for Peer Review Panel

The peer review will cover the April 2010 Recruitment Failure Report and related TC tasks assigned by the Board as detailed above (tasks 1 – 3). The questions are listed in bold. The other information is meant to provide additional insight.

2. **Evaluate the quality and completeness of the data gathered since the assessment (temperature data and redistribution of spawning females); if inadequate, specify additional techniques that should have been considered.**

3. **Determine the appropriateness of the findings drawn in the TC report, if deemed inappropriate, provide alternative findings with justification.** The report findings include, but are not limited to:

    a. <u>Stock Status:</u> Review of recent monitoring information showing that the reproductive potential and abundance of the SNE stock is continuing to fall lower than data presented in the latest assessment.

        i. SNE spawning stock biomass indicators from 2002 -2009 in general were average to poor. The spawning stock abundance from the RI trawl survey increased to levels at or above the median from 2005 through 2008, during the V-notch program, but the 2009 estimate is below the 25th percentile.

        ii. The last several years have produced larval and YOY indices below the median and at or below the 25th percentile relative to the 1984-2003 reference years. YOY indices show a statistically significant negative slope since 1992 and the 3-6 year cyclical pattern in larval indices has been replaced with sustained low values for eight of nine recent years. Sustained poor production can only lead to reduced recruitment and ultimately to reduced year class strength and lower future abundance levels.

iii. Fishery dependent and independent data suggest that the distribution of spawning females has shifted away from inshore SNE areas into deep water in recent years. This shift may impact larval supply to inshore nursery grounds.
iv. All but one of the SNE fall trawl survey relative abundance indices for recruit and legal size lobster are generally consistent, with a peak in the 1990's and then a decline to low levels in recent years. Recent recruit and legal indices have generally remained at or below the 25th percentile since 2002.

b. Fishery Status
   i. The SNE landings peaked in 1997, declined to a low in 2003 and have remained low through 2007. Landings have been below the 25th percentile of reference period (1984-2003) landings since 2002.
   ii. Landings peaked and fell below the 25th percentile in different years in the different stat areas, though there were similarities among a number of areas.
   iii. Offshore landings trends in NMFS statistical area 616 stand out somewhat from other areas. Trends were similar to areas 537, 612, and NJ south with a peak in the early 1990's followed by a decline and low levels in 2002. Unlike the other areas, landings increased in 2003 and stayed above median landings for a number of years. Recent estimates have declined, but are still above the 25th percentile and may be underestimated due to the lack of NJ south landings data.

c. Impediments to rebuilding
   i. There has been a widespread increase in the area and duration of water temperatures above 20^{0}C throughout SNE inshore waters. Long term trends in the inshore portion of SNE show a pronounced warming period since 1999.
      1. Prolonged exposure to water temperature above 20^{0}C causes respiratory and immune system stress, increased incidence of shell disease, acidosis and suppression of immune defenses in lobster. Lobsters avoid water greater than 19^{0}C.
   ii. Loss of optimal shallow habitat area is causing the stock to contract spatially into deeper water
      1. The shift in abundance to deeper water may reflect increased mortality in shallow water by mid Atlantic predators (e.g. striped bass, dogfish, and scup) whose abundance has increased substantially in the last decade.
      2. Recent larval drift studies in area 2 suggest that the re-distribution of spawning females into deep water areas may be causing larvae to be transported away from traditional settlement areas and potentially into less favorable areas.
   iii. Continued fishing pressure reduces the stock's potential to rebuild, even though overfishing is currently not occurring in SNE.
      1. Total trap hauls have declined significantly yet have not declined at the same rate as lobster abundance.
      2. Although current measures prevent the harvest of egg-bearing and v-notched lobster, the legal catch inshore and offshore represents a loss of egg production to the system.

4. **Determine the appropriateness of conclusions drawn in the TC report; if deemed inappropriate; provide alternative conclusions with justification.** The report conclusions include, but are not limited to:

a. The TC contends that the stock is experiencing recruitment failure caused by a combination of environmental drivers and continued fishing mortality.
b. It is this recruitment failure in SNE that is preventing the stock from rebuilding.
c. Overwhelming environmental and biological changes coupled with continued fishing greatly reduce the likelihood of SNE stock rebuilding

5. **Comment on the applicability of the recruitment indices to forecast future recruitment and landings to the inshore and offshore areas.**

6. **Determine the appropriateness of the recommended action (5-year moratorium); if deemed inappropriate, provide alternative recommendations with justification.** The report recommendations include, but are not limited to:
    a. Given evidence of recruitment failure in SNE and the impediments to stock rebuilding, the TC recommends a 5 year moratorium on harvest in the SNE stock area.
        i. The moratorium provides the maximum likelihood to rebuild the stock in the foreseeable future to an abundance level that can support a sustainable long-term fishery.
    b. During the 5 year moratorium period, monitoring of all phases of the lobster life cycle should be intensified.
        i. Fishery dependent sampling will no longer be collected, therefore assessment of stock status will rely on current fishery-independent surveys (e.g., ventless trap, YOY sampling, larvae) which will need to be continued and intensified.
        ii. New surveys and research (e.g., sentinel industry surveys) are needed to further characterize stock status, lobster settlement and habitat in SNE.

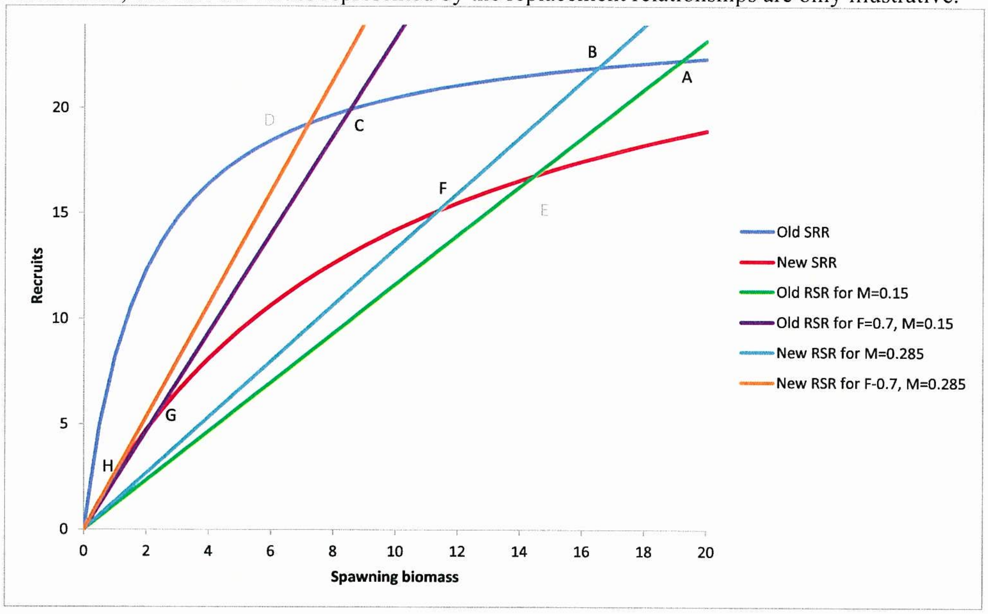
7. **Evaluate the stock projection scenarios conducted to complete the task as outlined by the Board** (see above).
    a. Evaluate the deterministic projections conducted using the University of Maine Model.
        i. The Board directed the TC to provide projections within an extremely short time frame. Although stochastic projections and estimates of uncertainty (e.g. MCMC confidence intervals) could have been provided, the time frame for decision-making was too short to complete a more thorough analysis.
    b. Evaluate the chosen suite of fishing and recruitment scenarios presented in the report; if insufficient, provide suggestions for alternative scenarios.
    c. Determine if projection results and the TC's interpretation provided in the report are consistent with assessment model results.
    d. Comment on the reliability of the deterministic projections for use in SNE lobster stock management.

8. **Review the M sensitivity analysis of the model that indicated a higher M as suggested in the 2009 assessment.**

Appendix 3: Effect of a change in stock-recruitment and replacement relationships

The relationship between spawning biomass and subsequent recruitment may be represented as shown, for example, in the curves "Old SRR" and "New SRR" in Fig. 1. In this case, the shape of each curve is assumed to be of the form of the stock-recruitment relationship described by Beverton and Holt. The relationship between the spawning biomass that results from a given level of recruitment and that recruitment may also be plotted on the figure, where the spawning biomass of the stock represents the sum over all ages of the spawning biomass at each age, and where the latter reflects a combination of survival, growth, and the proportion of females that are mature at each age. The relationship between the number of recruits and the subsequent (whole-of-life) spawning biomass is termed the replacement equation. The "slope" of the replacement equation is determined by the level of total mortality, increasing as this becomes greater. Four replacement equations are displayed on Fig. 1, two of which represent the replacement that might be expected for an unexploited stock and one of which reflects a higher level of natural mortality than the other. Two further replacement equations have been displayed, representing the effect of adding an approximately constant level of exploitation to each of the two levels of natural mortality, and thus reflecting total mortalities that differ in magnitude by the difference between the levels of natural mortality. Note that the stock-recruitment and replacement relationships shown in Fig. 1 are illustrative only, and not intended to represent the equations for the SNE lobster stock.

Figure 1. Conceptual diagram illustrating the effect of a change in a Beverton and Holt stock-recruitment relationship (SRR) from an old (Old SRR) to a new (New SRR) form with reduced recruitment for a given level of spawning biomass, and the effect of a change in a replacement relationship, *i.e.*, recruit to spawning stock relationship (RSR), resulting from an increase in natural mortality, with an approximately constant fishing mortality. The point of intersection of the replacement relationship with the stock-recruitment relationship represents the equilibrium spawning biomass and recruitment for the level of exploitation associated with the replacement relationship. Note that this diagram is not intended to represent the relationships for the SNE lobster stock, and that the values represented by the replacement relationships are only illustrative.



Consider the situation that might have existed for the SNE lobster stock prior to 1998, with a low level of natural mortality of $M = 0.15$ year^{-1} and a (relatively) high level of recruitment. The unexploited stock would have reached an equilibrium at the spawning stock and recruitment levels of the point of intersection of the stock-recruitment and replacement equations identified by the label “A”. With exploitation, the equilibrium would have been at the spawning biomass and recruitment of point “C”. If natural mortality of the recruited individuals increased, from $M= 0.15$ year^{-1} to 0.285 year^{-1}, but the spawning stock-recruitment relationship remained unchanged, the unexploited equilibrium would move to “B” and the exploited equilibrium to “D”. Provided the replacement curve for the exploited stock with high natural mortality allowed sufficient individuals to survive and spawn, the recruitment level at “D” might remain relatively high. However, if the combination of exploitation and higher natural mortality is excessive, it is possible that the slope of this replacement equation might approach or exceed the level at which it becomes tangential to the stock-recruitment curve, where the point of intersection is such that equilibrium is at zero spawning biomass and zero recruitment, *i.e.*, recruitment fails completely. The risk of recruitment failure increases greatly as the slope of the replacement equation approaches the tangent, and recruitment declines markedly as the point of intersection drops rapidly towards the origin.

Consider now the situation where environmental change not only reduces the survival of recruited individuals, but also the survival of individuals between spawning and recruitment, *i.e.*, larvae and pre-recruits. The effect of this will be a reduction in the number of recruits produced for a given level of spawning biomass. If, in addition, the amount of suitable habitat is reduced or the distribution of settling larvae or of pre-recruits changes, it is possible that the factors influencing the shape of the stock-recruitment relationship, *i.e.*, density-dependence, might change. The result might be to shift and change the shape of the stock-recruitment relationship from that of the curve labelled “Old SRR” to the curve labelled “New SRR”. The effect of this is that, under the increased level of natural mortality, equilibrium for the unfished stock is at the point labelled “F”, while that for the exploited stock is at the point “H”. Note that, with lag between spawning and recruitment, and both recruits and spawning females comprising a mixture of individuals from a number of year classes, it may take a number of years for the population to “reach” the new point of equilibrium, recognising that there will also be inter-annual variation in recruitment. I have deliberately chosen to place point “H” well down on the left-hand limb of the stock-recruitment relationship, “New SRR”, to highlight the uncertainty and possible risk associated with a change in the stock-recruitment relationship, but caution that there is insufficient information for the SNE lobster stock to determine whether or not the point of equilibrium of spawning stock and recruitment lies near the top of a new stock-recruitment curve, and is thus relatively stable although reduced, or well down on the left-hand limb of the stock-recruitment curve and thus faces considerable risk of further decline.

Southern New England Lobster Fishery Review

Dr. Stewart Frusher

Completed for the Center for Independent Experts

Executive Summary

This review does not support the conclusion that the Southern New England Lobster Fishery is experiencing recruitment failure. While recruitment failure is one possibility, overfishing is a stronger possibility. Recent abundance of lobsters is low in the fishery although equivalent to the early 1980s when records began. In the 1990s there was a large increase in abundance of lobsters which has been removed from the fishery through a concurrent increase in fishing effort. Thus there is uncertainty whether the abundance levels in the 1980s and 2000s are normal and the fishery experienced an unusual period of high recruitment OR whether routine periods of higher recruitment is a normal part of the dynamics of the fishery. If it is the former, then all the means, percentiles, thresholds and targets are positively biased by the inclusion of the recruitment period. A longer time series is required to determine if high recruitment periods are routine components of the fishery in this region. In addition to the current model runs, comparative model runs should be undertaken where the recruitment peak is removed from the analysis to demonstrate what a long-term fishery based on the 10 – 15 million lobsters looks like.

Irrespective of which scenario is correct, the current effort in the fishery is too high and is approximately 50% higher than when the abundance was a similar level in the early 1980s. A 50 – 75% reduction in effort is recommended immediately.

If the recent stabilization and slight increases in the catch rates recorded for 2004 – 2006 have been maintained from 2007 to 2010, then a 50% reduction may suffice. An economic cost-benefit analysis should be undertaken to look at the optimal MEY for a fishery between 8 (based on projections from YOY) and 14 million lobsters.

Future management should consider a decision rule approach that is accepted by both industry and government. The YOY and CPUE indices appear to be reasonable indices to base a decision rule on.

As the SNE fishery is at the southern limit of the "commercial" distribution of lobsters then any changes in physical properties related to warming are likely to move the southern extent of the "commercial" fishery further north. The increased warming recorded in the 2000s is of concern for the longer-term viability of the fishery.

Future research should focus on the YOY estimates and improved fishery dependent and fishery independent information that are depth stratified. Increased spatial and temporal sampling of water temperatures needs to be obtained through both increased permanent recording sites and from the fishery dependent and independent surveys (e.g. attaching thermistors to the ventless trap surveys and fisher's traps).

Background

The American Lobster Board (Board) assigned the American Lobster Technical Committee with the following tasks:

1. Identify issues impeding stock rebuilding in SNE,
2. Develop a suite of measures to begin stock rebuilding in SNE,
3. Develop deterministic projections of stock abundance using the University of Maine Model that assume: a) both status quo and reduced fishing mortality scenarios, and b) status quo recruitment, low/declining recent recruitment, and a stock recruitment relationship.

The Technical Committee (TC) had 3 months to report back to the Board on their findings. From the above tasks the TC drafted the report: Recruitment Failure in the Southern New England Lobster stock. With the exception of temperature data and information on the redistribution of spawning females, all other fishery independent and dependent data used in the TC's report were peer reviewed and accepted during the most recent (March 2009) ASMFC Benchmark Stock Assessment.

The review evaluated a report written on April 17, 2010 by the American Lobster Technical Committee (TC) of the Atlantic States Marine Fisheries Commission (ASMFC), entitled "Recruitment Failure in the Southern New England Lobster Stock" and the supplemental stock projection document, entitled "Southern New England Lobster Stock Projection Estimates". The report concludes that the stock is critically depleted, experiencing recruitment failure, and cannot rebuild. The cause is thought to be a combination of "environmental drivers" and continued fishing mortality. The TC recommends a five year moratorium on harvest. The review was asked to consider the merits of this recommendation.

Description of the Individual Reviewer's Role in the Review Activities

Three CIE reviewers were selected to conduct an impartial and independent peer review in accordance with the SoW and ToRs. Tasks included reading all documents in preparation for the peer review, conducting the independent peer review in accordance with the SoW and ToRs, and completing an independent peer review report in accordance with the SoW. Each CIE reviewer was to complete the independent peer review according to required format and content as described in Annex 1 and to complete the independent peer review addressing each ToR as described in Annex 2. This review report was completed and submitted to the CIE on 11 October 2010.

Summary of Findings for each ToR (weaknesses and strengths)

1. **Evaluate the quality and completeness of the data gathered since the assessment (temperature data and redistribution of spawning females); if inadequate, specify additional techniques that should have been considered.**

Temperature data:
The temperature anomalies presented indicate a consistent increase in the number of days that temperatures exceeded 20°C across all four sites in the last decade. The warmer period (since 1999) corresponds with the increased incidence of shell disease. However, many of the other indices (total abundance from both models, MADMF, RI & CT recruits) all indicate that the fishery has been in a similar, or worse, state previously when water temperature anomalies were not similar to the last decade.

This warmer period (since 1999) corresponds with the continued lower than average lobster recruitment indices for the western and eastern long island sound recruitment time series (Fig. 1). However, the large recruitment index in 1999 at both sites occurred during the year with the highest number of days >20°C at the Millstone Power Station – the same location that the ELIS data is obtained. Similarly, in 1997, a period of low recruitment occurred during the year when there were the fewest days above 20°C. Similarly, peaks and troughs in the recruitment indices are not correlated with days >20°C. Whether the sustained change in periods above 20°C has impacted the WLIS and/or ELIS sustained low recruitment indices is uncertain. However, the interpretation of the WLIS and ELIS indices is questioned in Section 4. The young of year (YOY) which provides a better correlation with future abundance in the fishery does not appear to be correlated with temperature change.

Thus for interpreting the current observed changes in the fishery, the temperature data appears of little value. However, this population of lobsters is on the southern (warmer) extent of its distribution. While the species has been found further south, the SNE population is the southernmost commercial population. Thus, overall increases in temperature are likely to impact the fishery making these regions less likely to support commercial populations and this is discussed further in the review. As such, I believe that the inclusion of the temperature data is warranted in understanding the dynamics of the SNE population and, as recommended in further research, should become a core component of monitoring the stock.

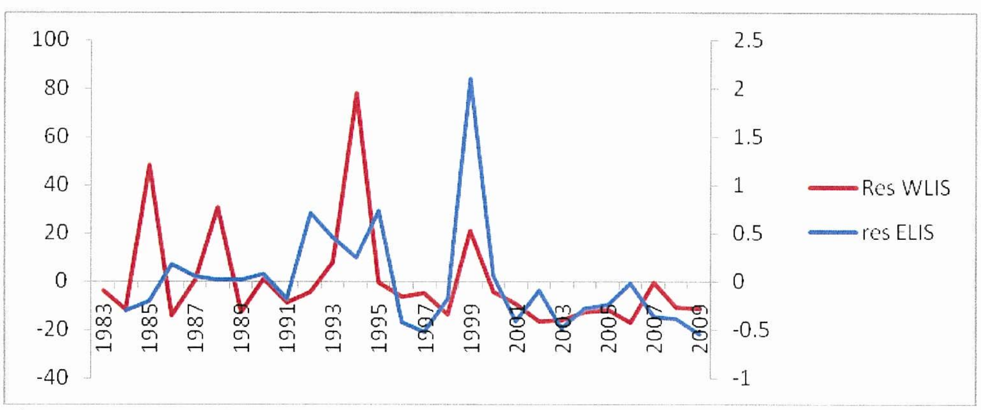


Fig. 1. Anomalies in the recruitment indices from WLIS and ELIS. Positive anomalies indicate periods when recruitment was higher than the 1983-2009 average.

Redistribution of spawning females:
The data on redistribution of spawning female are inadequate.

I cannot find any "evidence" that the distribution of spawning females has changed. Appendix A and the statement on page 10 of the report ("In 1984-1991, the geometric mean catch at sites <30ft depth was comparable to the mean for sites >90ft; in 2000-2008, the mean catch at shallow sites was less than half the mean for the deep sites.") indicate that effort has shifted to deeper waters and this is most likely to be a result of fisher's chasing improved catch rates. The increase in the % of the females in the marketable catch (Table 2 page 22) shows that only in CT has there been an increase in the % of females.

However, it is not the percentage of marketable catch in each region that is the issue; it is the overall number of potential mature females that are removed from the resource. For example, from Table 3.2.4.1 of the American Lobster Stock Assessment Report (ALSAR) it is possible to obtain the landings by year for the three regions: CT, RI and MA. By applying the percentages obtained in each year from Table 2 of the Recruitment failure report it is possible to determine the overall proportion of females removed from the resource. There is very little change in the contribution of females (Fig. 2) despite substantial changes in the contribution of each of the three regions to the overall catch (Fig. 3). Caveats to this analysis include the lack of information for the percentage of females that comprised the catch in the actual years shown (1981, 1999 and 2006) and landings may not adequately represent the proportion of females due to different average size of females or different size:weight ratios.

There is no information to relate Table 2 to deep water regions. While there has been a shift into MA regions which have a higher percentage of females harvested (which appears to be the case since 1999 – Fig. 3), there is less overall landings coming from MA in 2007 compared to 1981 when the SNE fishery was producing equivalent landings.

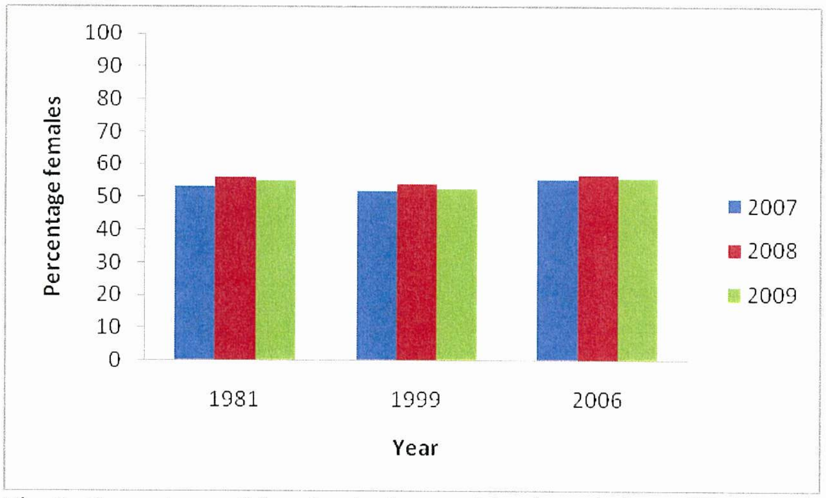


Fig. 2. Percentage of females in the combined catch from CT. RI and MA.

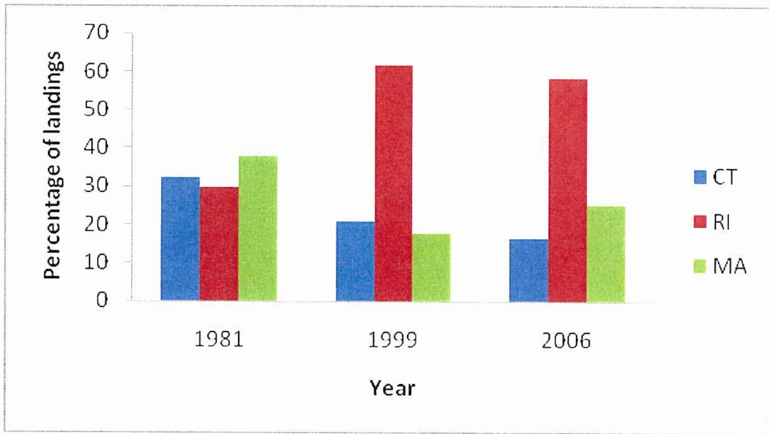


Fig. 3. Percentage contribution of CT, RI and MA to the combined SNE catch (CT+RI+MA).

Quantitative data should be available from the fishery independent surveys (ventless traps, trawl surveys) which should have information on catch rate by sex and depth. These data need to be analyzed to provide quantitative information to support the theory that the fishery has moved to deeper waters and that this has resulted in an overall increase in the harvest of females.

I am uncertain what information is reported in the fisher's logbooks. If catch, effort and depth are recorded then quantitative information should also be available from these logbooks for comparison with the fishery independent data.

Additional techniques:
The authors appear to have focused on models and fishery independent methods. While the ALSAR identifies concerns over the use of trap lifts as a form of effort, catch rate data (catch per unit of effort - CPUE) is necessary for interpreting catch data.

Fisheries science is not a precise science and confidence is often gained more from different sources of data showing similar trends than from one single piece of information. Thus I would encourage the authors to use trap data as a measure of effort and then use CPUE as an additional piece of information. Importantly, it does give an indication of trends in the fishery derived from the fishing sector.

Table 7.5.2.3.3, Column 13 of the ALSAR provides gross CPUE data for the SNE fishery and it is acknowledged that Rhode Island (RI) effort is only available for the latter part of the time series. From Tables 3.2.4.1 and 3.2.4.2 of the ALSAR it is possible to obtain CPUE data for the Connecticut (CT), Massachusetts (MA) and New York (NY) regions from 1884 and RI from 2000. Irrespective of which CPUE data are used, there are general trends in the data. Catch rates are relatively flat and variable with peaks in 1990 and 1996-1999 before a decline until the mid 2000s after which they have shown slight improvements (Fig. 4). As described in section 2b, this information is important in interpreting changes in the status of the fishery and the recruitment failure report would have benefitted from these figures being updated.

For this review I have use the CPUE trend from the Tot (CT, MA & NY) data.

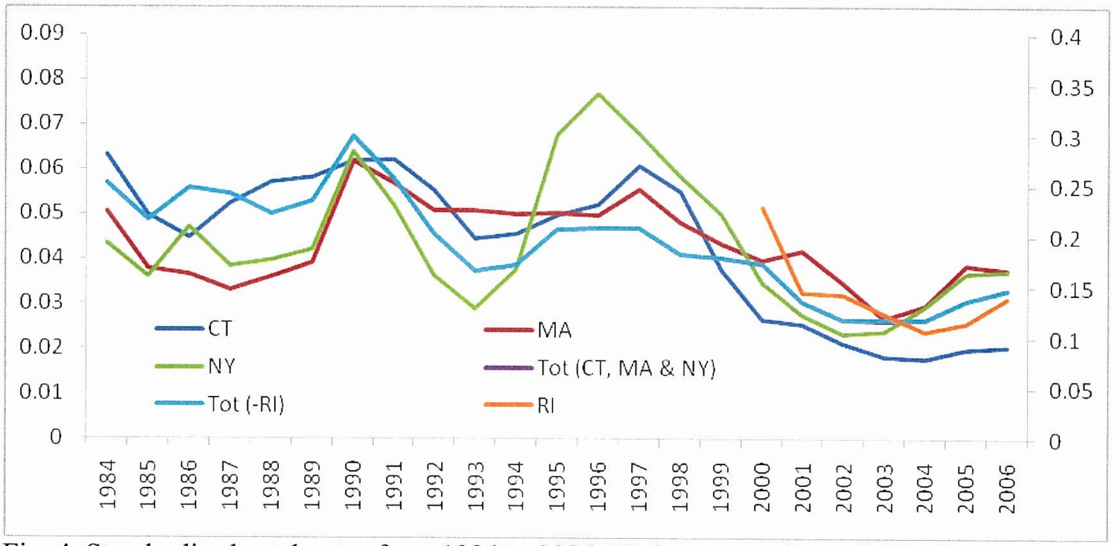


Fig. 4. Standardised catch rates from 1984 to 2006. RI data was only available since 2000 and RI standardized catch rates are provided on the secondary y-axis.

2. **Determine the appropriateness of the findings drawn in the TC report, if deemed inappropriate, provide alternative findings with justification. The report findings include, but are not limited to:**

a. **<u>Stock Status:</u> Review of recent monitoring information showing that the reproductive potential and abundance of the SNE stock is continuing to fall lower than data presented in the latest assessment.**

Stock status: Both the CS and UM models both show an increase in abundance in the mid 1990s. Whether this is due to a strong recruitment pulse or discovery of new unfished regions is not stated. However, as this fishery has been exploited for a long period in time it is unlikely that new grounds would have been discovered – as such this review assumes that the increased abundance in the 1990s is due to a period of high recruitment. Throughout the report reference levels have been based on medians and percentiles that represent the entire period including the large recruitment period. If this recruitment pulse is not normal in the fishery, then the medians and percentiles should be based on the normal fishery (early and mid 1980s and 2000s). I do not believe that these medians and percentiles are a true reflection of the fishery and have therefore not discussed these *per se*. Instead I have based my discussion on what had occurred previously in the fishery.

Abundance, landings and effort all increased from the mid-1980s to the late 1990s. Since the late 1990s abundance, landings and effort have declined (Fig. 5). Unfortunately effort did not decline at the same rate and in 2007 the fishery was using about twice the effort that was used to catch the same number of lobsters as in the early 1980s. Over these three decades it is considered that the unit of effort (fishing power) would have become more effective due to technological advances such as global positioning systems and echosounders. Thus effective effort is potentially greater than twice that of the early 1980s for the same amount of catch. The catch rate has declined to be lower than that of the 1980s when the total catch was similar (Fig, 4). However, recent trends in the catch rates (2004 – 2006) show slight increases in CT, MA, NY and RI suggesting recent improvements in abundances. These are consistent with the UMM abundance estimates that show a slight increase and stabilization since 2003.

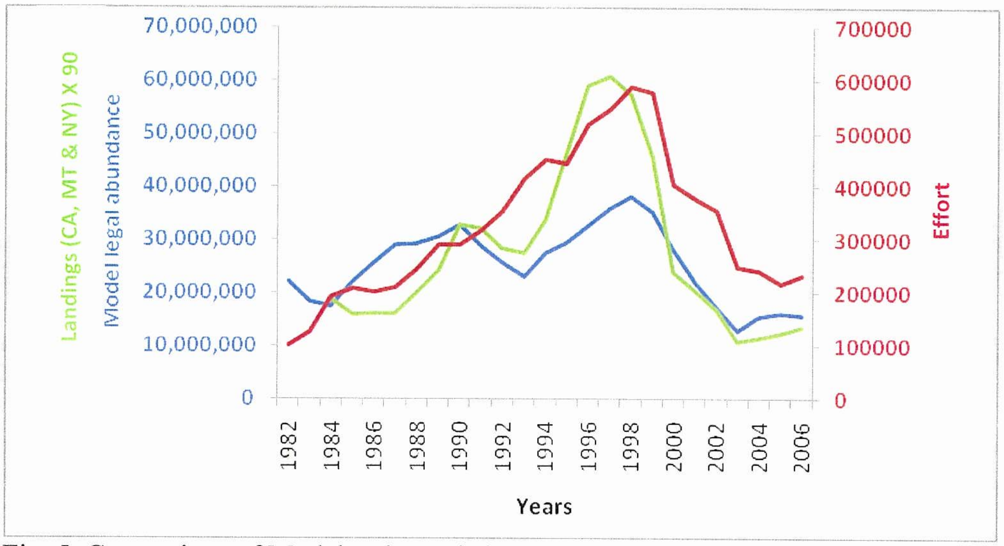


Fig. 5. Comparison of Model estimated abundance, landings and effort. Landings and effort are for CA, MT and NY combined.

i. **SNE spawning stock biomass indicators from 2002 -2009 in general were average to poor. The spawning stock abundance from the RI trawl survey increased to levels at or above the median from 2005 through 2008, during the V-notch program, but the 2009 estimate is below the 25th percentile.**

Spawning stock biomass (SSB): The bulk of the catch comes from the CT region where SSB indices indicate that the spawning stock has been consistently lower than previously recorded since 2002. Both the magnitude and duration of these low indices are of concern. However, the University of Maine model (UMM) indicates that the abundance of females since 2003 was estimated to be similar to the early 1980s (Fig. 6). The differences in these trends should be investigated. An inflated value for the UMM model could be due to the UMM model being total females (i.e. mature and immature). However this would suggest that there is currently a large number of smaller females which would imply forthcoming recruitment of females. As mentioned above the use of the median and 25th percentile are potentially biased high given that the large recruitment period in the 1990s may not be a "normal" component of the fishery and means and percentiles based on the SSBs in the 1980s and 2000s may be a more accurate reflection of the status of the spawning stock.

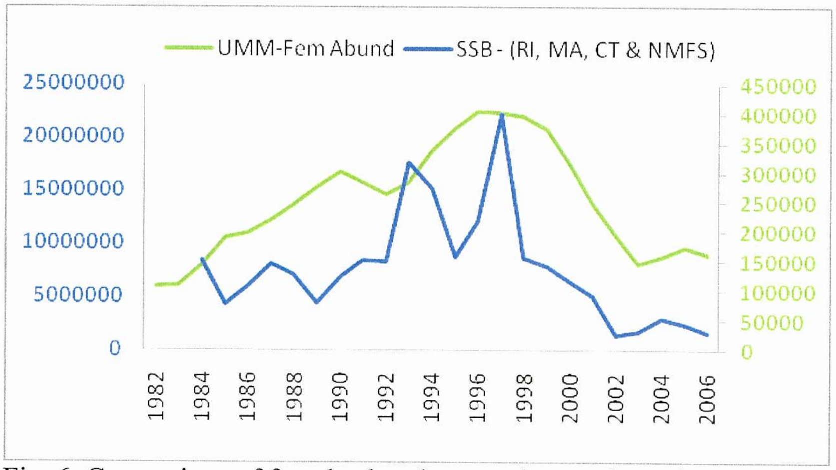


Fig. 6. Comparison of female abundance estimates from the UMM and spawning stock biomass.

ii. **The last several years have produced larval and YOY indices below the median and at or below the 25th percentile relative to the 1984-2003 reference years. YOY indices show a statistically significant negative slope since 1992 and the 3-6 year cyclical pattern in larval indices has been replaced with sustained low values for eight of nine recent years. Sustained poor production can only lead to reduced recruitment and ultimately to reduced year class strength and lower future abundance levels.**

The value of pre-recruit indices is determined by how well the indices relate to observed changes in the fishery or other indices to ensure that what is being measured is not an artifact of area sampled, method used etc. A difficulty with using these indices is the uncertainty as when the larvae or YOY animals will recruit into the fishery. It has been suggested that this can vary from 5-8 years. As the time interval is expected to decline with increased temperatures (i.e. assuming faster growth) I have used a 6 year lag period. Correlations between the larval and YOY indices show only a minor correlation between ELIS and WLIS and a moderate correlation between YOY and WLIS (Table 1). The lack of correlation is surprising as there is substantial variation between years. This would suggest that there are very localized recruitment patterns, which makes it difficult to link any index with the dynamics of the fishery as a whole. The strength of the ELIA:WLIS and WLIS:YOY correlations is based on the leverage of one of the twenty-five data points. Thus correlations between the indices are weak. Only the YOY appears to provide a reasonable correlation with future catches (Table 2 and Figs 7 & 8). The improved catch rates in the 2003-2006 period for most regions (Fig 4) would be associated with the higher YOY values in 1997-2000. The consistently lower values since 2000 and especially the 2009 value (Figure 5 of the report) would indicate that abundance and CPUE are expected to further decline over the next 6 years.

Table 1. Correlations between recruitment indices.

	Years compared	Correlation
ELIS:WLIS	1984 – 2009	0.31
ELIS:YOY	1989-2006 (ELIS) 1990-2007 (YOY)	0.11
WLIS:YOY	1989-2006 (WLIS) 1990-2007 (YOY)	0.42

Table 2. Correlations between recruitment indices and exploited indices.

	Years used	CPUE	ELIS	WLIS	YOY
Abundance (UMM)	1991-2007	0.74	0.05	0.13	0.46
CPUE	1991-2007		-0.05	0.28	0.60
ELIS	1985-2001			0.19	0.00
WLIS	1985-2001				0.35
YOY	1985-2001				

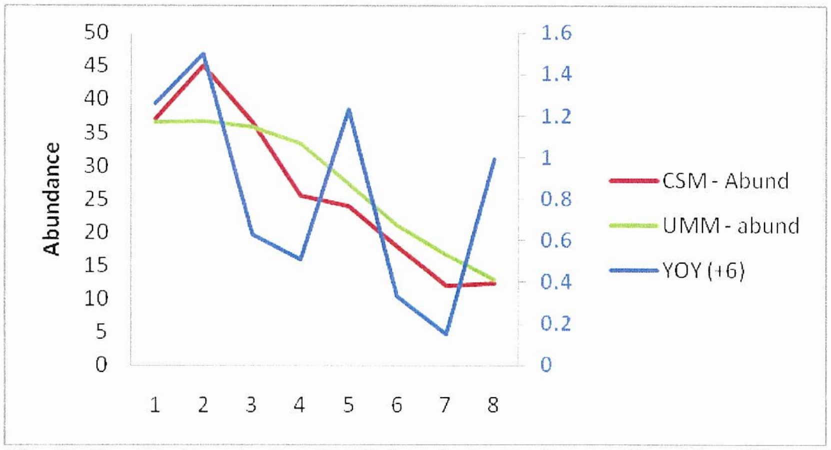


Fig. 7. Comparison in trends of abundance estimates from the CS and UM models and YOY index. The YOY index was advanced 6 years as an estimate between YOY and recruitment to the fishery.

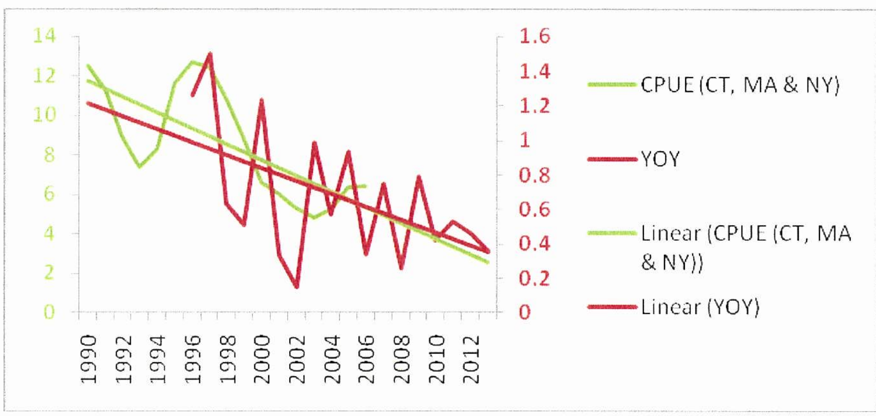


Fig. 8. Comparison in trends of catch rate (CPUE – CT, MA & NY) and YOY index. The YOY index was advanced 6 years as an estimate between YOY and recruitment to the fishery.

iii. **Fishery dependent and independent data suggest that the distribution of spawning females has shifted away from inshore SNE areas into deep water in recent years. This shift may impact larval supply to inshore nursery grounds.**

The shift in spawning females from inshore to deep waters is difficult to assess in the current document (see section 1). If females have shifted distribution then it is possible that the currents in the relocated area are different from the original area and thus there could be an impact on recruitment. Currently there is no evidence to support a shift in spawning females.

iv. **All but one of the SNE fall trawl survey relative abundance indices for recruit and legal size lobster are generally consistent, with a peak in the 1990's and then a decline to low levels in recent years. Recent recruit and legal indices have generally remained at or below the 25th percentile since 2002.**

In general, a strong correlation should exist between the catch rates of recruits of a specific year and the catch rates of legal sized animals of the following year. While correlations between the catch rate of recruits and legal sized lobsters in the following year for the RI, CT, MA and NEFC Fall fishery independent surveys is moderate, the correlation between recruits and legal sized lobster for the same year in all surveys is stronger (Table 3). This is of concern as there are strong individual peaks in the recruits which would be expected to recruit (molt) into the legal category in the following year. Strong correlations for the same year indicate that differences between years may not be solely due to recruitment compared to changes in events that affect both size classes equally such as catchability. Catchability changes could be due to biological events (e.g. increased catchability with increased water temperature, increased concentration of lobsters on fishing grounds due to increased immigration to fishing grounds) or technological improvements (e.g. GPS, improved echosounders). It is assumed that because these are fishery independent surveys that technological improvements can be ruled out.

For the CT, NJ, MADMF and NEFC surveys the recent trends in legal size and recruits have been lower than previously recorded in the fishery. With the exception of CT and NJ legal-sized lobsters, all other surveys show strong peak(s) in catch rates in the 1990s suggesting positive recruitment periods during the 1990s. While the overall trends in catch rates for legals or recruits are non-significant due to the variability in catch rates, the trends in all regions except RI are negative with the majority of the recent data points being below the trend lines.

Table 3. Correlations between the catch rates of recruits and catch rate of legal lobsters in the same year or the following year obtained from fishery independent trawl surveys.

Fall Trawl Survey	Legal catch rate of flowing year	Same year
NMFS	0.40	0.77
RI	0.49	0.85
CT	0.48	0.80
MA	0.46	0.74

The accuracy or usefulness of the trawl surveys is their value in indicating changes in the fishery. Moderate correlations exist between the regional catch rates derived from Tables 3.2.4.1 and 3.2.4.2 and the regional trawl survey catch rates (Table 4). Stronger correlations were obtained between the regional trawl survey catch rates and the abundance estimates from the UMM for NY and RI. Thus the recent declines in the trawl survey catch rates provide additional support that the fishery is performing poorly. The only positive note is that the RI values did not show a declining trend over time and this region of the fishery accounted for 43% of the catch in 2007.

Table 4. Correlations between regional trawl survey catch rates and CPUE and abundance indices. The percentage that each region contributes to the catch is also presented.

	CT	MA	NY(NJ)	RI	NMFS
CPUE	0.69	0.37	0.56	0.37	
Abundance (UMM)	0.61	0.06	0.76	0.54	0.44
% landings in 2007	10	16	17	43	14

b. **Fishery Status**

i. **The SNE landings peaked in 1997, declined to a low in 2003 and have remained low through 2007. Landings have been below the 25th percentile of reference period (1984-2003) landings since 2002.**

ii. **Landings peaked and fell below the 25th percentile in different years in the different stat areas, though there were similarities among a number of areas.**

iii. **Offshore landings trends in NMFS statistical area 616 stand out somewhat from other areas. Trends were similar to areas 537, 612, and NJ south with a peak in the early 1990's followed by a decline and low levels in 2002. Unlike the other areas, landings increased in 2003 and stayed above median landings for a number of years. Recent estimates have declined, but are still above the 25th percentile and may be underestimated due to the lack of NJ south landings data.**

Interpretation of the fishery status based on landings is inadequate. Comparison of landings between regions or years is only valid if effort is constant during the comparisons. Standardization of landings is usually achieved by conversion to catch rates by dividing the catch by the effort. For example, the increase in landings in the three statistical areas in figure 9 could reflect increases in effort or increased recruitment to the fishery. The one year lag in peak catches from statistical area 611, 613, 539 could be due to changes in the fishing fleet as it shifts to new regions as catches start to decline or, it may represent changes in the peak time of recruitment (e.g. regional delays from a single larval recruitment period due to temperature impacts on growth). Similarly the increase in landings in 616 could be due to an increase in effort.

The use of the percentiles is also inappropriate as they assume that the fishery has experienced relatively average recruitment. Clearly this is not the case and the fishery has experienced a large recruitment period in the 1990s. Either side of this recruitment the landings and effort are substantially lower. It is likely that this is the normal condition of the fishery and thus expectations should be based on these lower levels. As has been mentioned previously and reiterated below, the poor performance in the fishery is exacerbated by the higher effort that remains in the fishery compared to when there were equivalent landings in the 1980s.

However, it was possible to obtain catch rates from tables 3.2.4.1 and 3.2.4.2 of the ALSAR for different states/units (Fig. 10). In all regions, the catch rate is declining but it is declining more rapidly in CT than either NY or MA. Caution is needed in interpreting the trend in RI as reliable data were only available from 2000. Interestingly, the recent catch rates have started to improve in all regions (Fig. 11). More recent data would be beneficial to determine if these upward trends continue.

By comparing the catch rates (CPUE) against effort (Fig. 12) it is possible to gain insights into the dynamics of the fishery in each of the regions. For MA and CT CPUE remained relatively stable as effort substantially increased from the mid 1980s to the late 1990s. Thus fishers were able to immediately adjust their effort to harvest an increasing legal sized biomass. This increase in legal sized biomass was either due to improved recruitment to the fishery or fishers locating new ground. It is assumed that it is the former as the fishery has operated for a considerable period in time and it would be expected that new undiscovered grounds are unlikely. In NY there was a slight increase in CPUE as effort increased indicating that fishers were slower in responding to improved catches than in the other regions. In all regions there has been a decline in CPUE with reducing effort since the late 1990s. This has resulted in the CPUE being equal (NY) or lower (CT, MA, RI) for the equivalent effort in the 1980s. Thus for the equivalent effort there are fewer legal sized lobsters available suggesting that recruitment is lower than previously. However, during the last few years (Fig. 11) CPUE has increased slightly indicating that recruitment has been slightly better recently than the lows of the early 2000s.

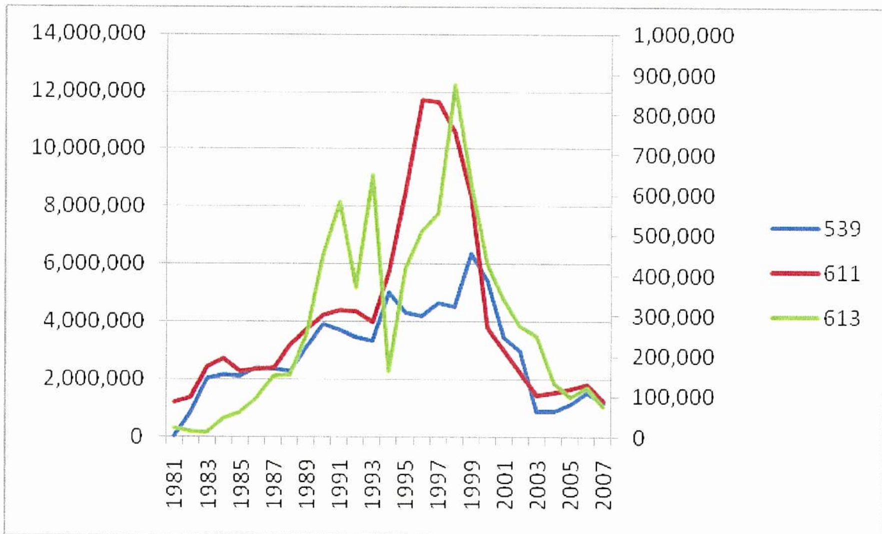


Fig. 9. Comparison of landings for NMFS Statistical Areas 539, 661, 613.

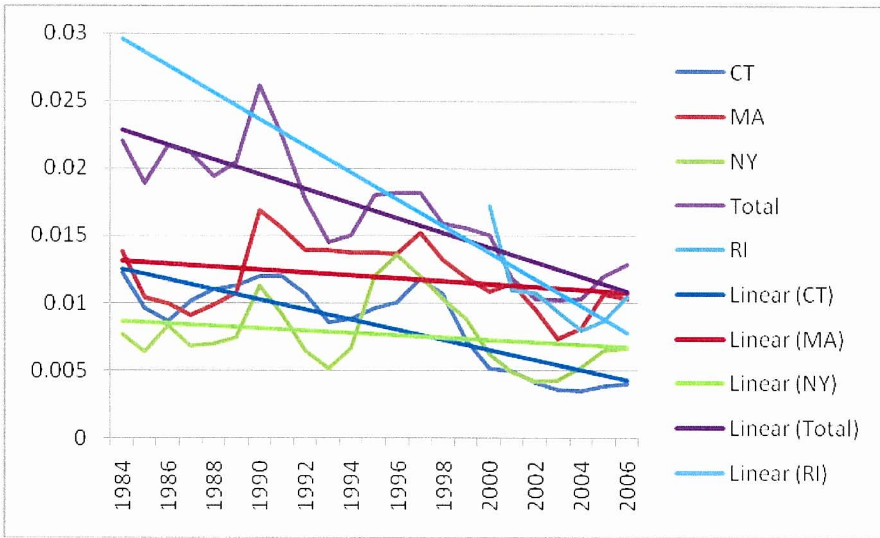


Fig. 10. Trends in catch rates in 4 states from 1984 to 2006. Note that the trend for RI is only based on the data since 2000 (6 years only).

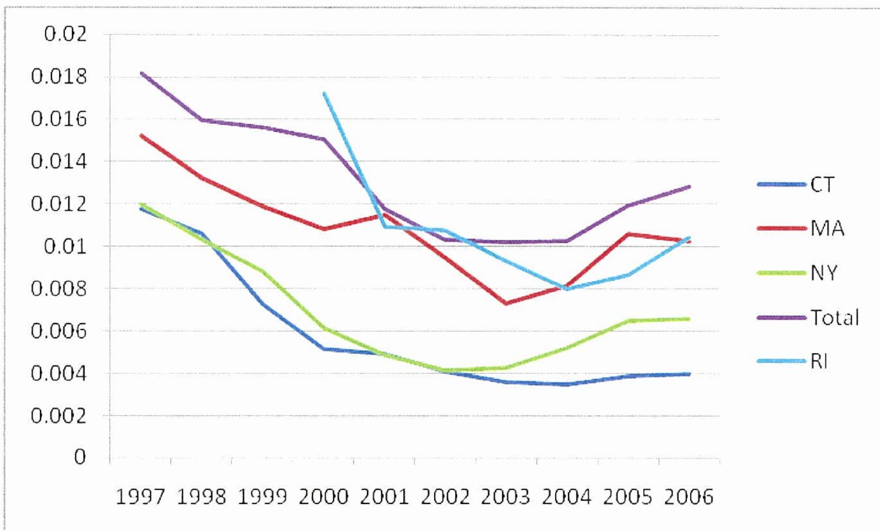


Fig. 11. Recent trends in catch rates for the SNE lobster States.

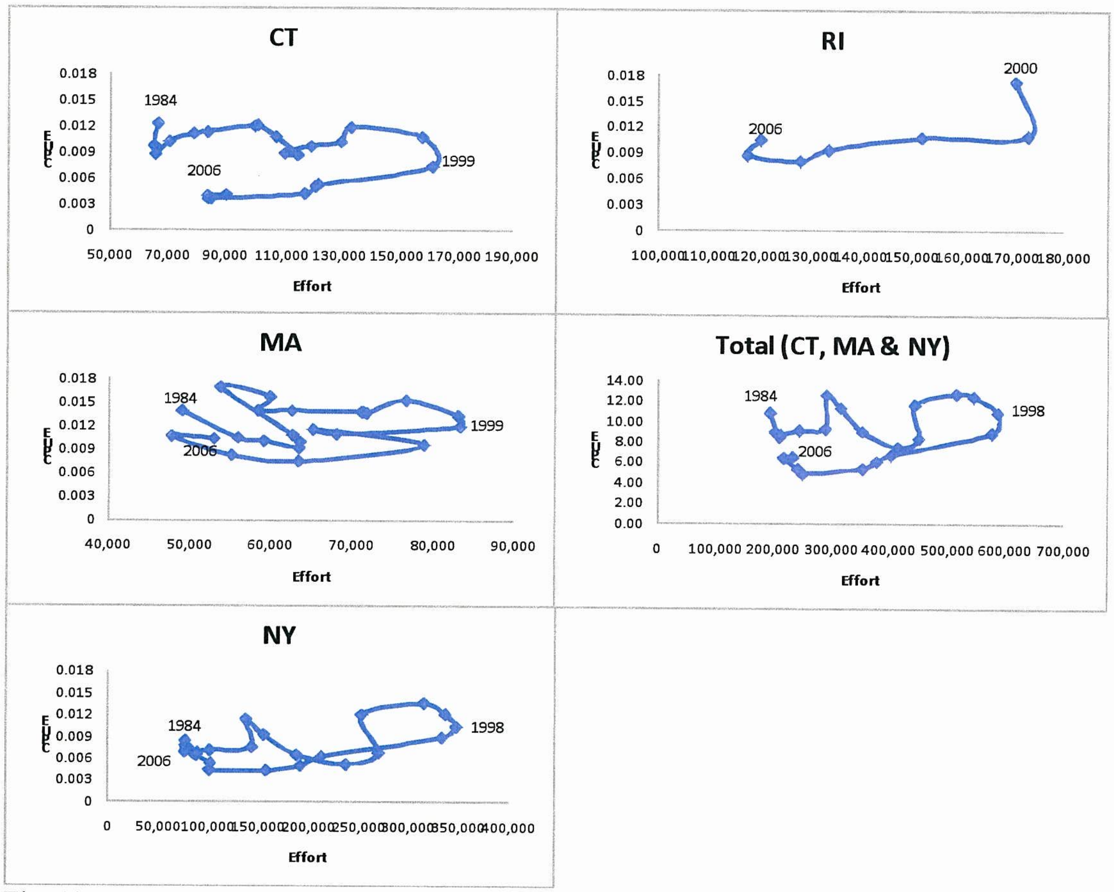


Fig. 12. Comparison of catch rates and effort

c. **<u>Impediments to rebuilding</u>**

There has been a widespread increase in the area and duration of water temperatures above 20^{0}C throughout SNE inshore waters. Long term trends in the inshore portion of SNE show a pronounced warming period since 1999.

1. **Prolonged exposure to water temperature above 20^{0}C causes respiratory and immune system stress, increased incidence of shell disease, acidosis and suppression of immune defenses in lobster. Lobsters avoid water greater than 19^{0}C.**

The information provided in the documentation clearly indicates the increase in the number of warmer days. The scientific papers cited indicate that these warmer periods would be less favorable for lobsters and this is also supported by the natural distribution of the species. As SNE is on the equatorial margin of the natural distribution of the species, then it is plausible that any warming would see this margin become less favorable (i.e. the environmental envelope for the species moves north). It is the same theory that has seen a large number of more mobile species move poleward due to warming waters around the world.

However, lobsters do have the option to move into cooler deeper waters. It is currently unknown if lobsters are distributing themselves in deeper waters, or if lobsters settle in deeper water, or if suitable settlement and juvenile habitat is available.

ii. Loss of optimal shallow habitat area is causing the stock to contract spatially into deeper water

Given the maps in appendices A and B it should be possible to provide a table of potential habitat in each of [say] 10-meter bins.

> **1. The shift in abundance to deeper water may reflect increased mortality in shallow water by mid Atlantic predators (e.g. striped bass, dogfish, and scup) whose abundance has increased substantially in the last decade.**

While this is a reasonable theory, there is no evidence to support this either by reference to the literature or data. Furthermore, there is no evidence provided to indicate that these species eat lobsters, in what quantity or what size range.

> **2. Recent larval drift studies in area 2 suggest that the re-distribution of spawning females into deep water areas may be causing larvae to be transported away from traditional settlement areas and potentially into less favorable areas.**

There is no evidence to suggest that females have re-distributed themselves in deeper waters. However, if this is the case then it is reasonable to accept these statements.

iii. Continued fishing pressure reduces the stock's potential to rebuild, even though overfishing is currently not occurring in SNE.

> **1. Total trap hauls have declined significantly yet have not declined at the same rate as lobster abundance.**

What appears to have occurred in this fishery is a large recruitment event that has increased the number of lobsters on the fishing grounds during the late 1990s. Fishers have responded to this increase by increasing their effort (Fig. 5). Once the recruitment pulse had been exploited the landings declined and this is followed by a decline in effort. The effort has not returned to the same level of the early 1980's when the landings were similar to today. In many fisheries worldwide, it is recognized that there have been several significant advances in technological that has increased catch efficiency. Examples of this include global positioning systems and echo sounders. While it is uncertain how these technologies would have impacted on the lobster fishery, it is reasonable to expect that the efficiency of effort in recent years is greater than in the early 1980s. Since the high landings of the late 1990s it is reasonable to expect that catching efficiency would have improved as effort has declined in the fishery. It is normally the less efficient fishers that leave the fishery first or fishers remove their least efficient traps from the fishery first. Thus current catch rates are likely to overestimate abundance compared to the 1990s and 1980s. This implies that recruitment to the fishery is lower than in the 1980s. While there are encouraging signs that catch rates are improving, effort is approximately twice what it was in the 1980s and needs to be reduced to improve legal sized biomass.

While decreasing effort should see an improvement in catch rates and thus profit per trap for the fisher, stock rebuilding will be a result of an increased proportion of the existing lobsters being left on the fishing grounds due to lower exploitation rates. Stock rebuilding associated with improved recruitment to the fishery will only occur with decreasing effort if there is a stock recruitment relationship. Correlations between SSB and YOY of the following year have minor positive correlations for all regions (RI, CT, NMFS, MA) (Table 5). However, there are no correlations between the SSB and the catch rates in six or 7 years time (Table 5) or total SSB and total abundance (UMM) in 6 (r=-0.22) or 7 (r=-0.42) years. These suggest that there is no relationship between SSB and future recruitment to the fishery. While this is not surprising as stock recruitment relationships in lobster fisheries globally have proven to be elusive, the large spawning stock in the late 1990s would be expected to result in improved recruitment in the 2000s. This would suggest that recruitment to the stock is most likely affected by post-spawning issues (e.g. environment) and that improving SSB is likely to have limited value. However it would be beneficial to know if the SSB is substantially lower than in the early 1980s (which resulted in high recruitment in the 1990s) as indicated by the fall trawl surveys or is above the 1980s as indicated by the UMM estimates of female abundance.

Table 5. Correlations between regional SSB estimates and YOY of the following year and regional catch rates in 6 or 7 years.

	RI	CT	NMFS	MA
YOY+1	0.28	0.12	0.37	0.31
CPUE+6	-0.36	-0.50	0.02	0.16
CPUE+7	-0.36	-0.63	-0.10	-0.05

2. Although current measures prevent the harvest of egg-bearing and v-notched lobster, the legal catch inshore and offshore represents a loss of egg production to the system.

The information provided is inadequate. It is not the percentage of marketable catch in each region that is the issue; it is the overall number of potential females that are removed from the resource. See TOR 1 regarding the contribution of spawning (egg bearing) females.

3. Determine the appropriateness of conclusions drawn in the TC report; if deemed inappropriate; provide alternative conclusions with justification. The report conclusions include, but are not limited to:

a. The TC contends that the stock is experiencing recruitment failure caused by a combination of environmental drivers and continued fishing mortality.

From the information provided in the "Recruitment failure in the SNE lobster stock" and the "American Lobster Stock Assessment Report" the SNE stock appears to be in a poor state. The recruitment indices (Fig. 1), YOY index (since early 1990s) and catch rates (Figure 4) all indicate that recruitment and catch rates have been declining since the early 1980s. The lack of rebuilding of the stock after effort has been reduced since the late 1990s (Fig. 12) also indicates that recruitment to the stock is less than has occurred previously. In the early 1980s when the landings were equivalent to what they were in 2004-2007, the effort was half of what it is in 2007 (Fig 13). Similarly, for the equivalent average effort expended in 2003-2007, fishers were obtaining 67% more catch in 1984-1988.
The effort is too high for the current abundance and the indices available to the reviewer indicate that recruitment to the fishery is declining.

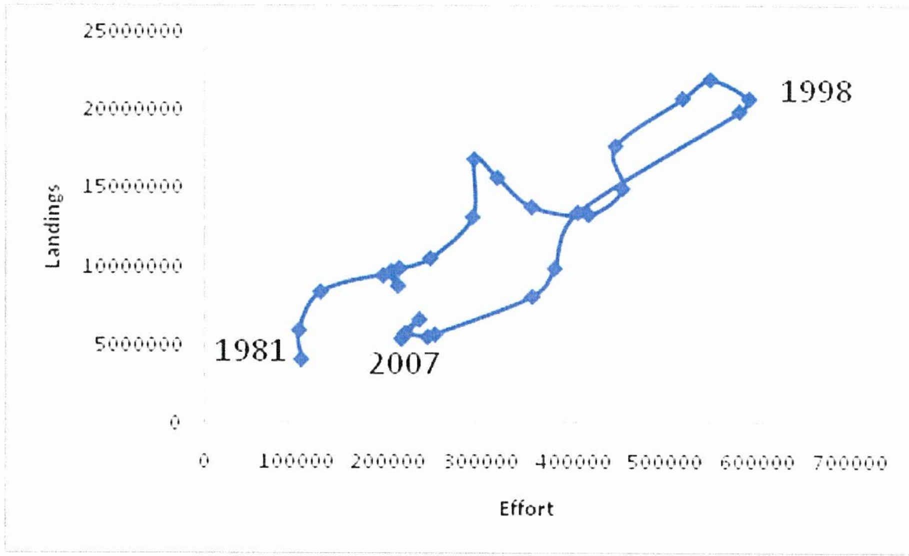


Fig. 13. Comparison of total landings and total effort from 1981 to 2007.

b. It is this recruitment failure in SNE that is preventing the stock from rebuilding.

The larval and YOY indices are all declining since the early 1990s (Figure 14). However, the lack of correlation between these indices suggests that either the settlement is very localized and different between regions or that these indices are not representative of future catches (see Section 4). The improvement in regional catch rates in 2005 and 2006 in all regions of the fishery indicate that there is improving recruitment to the fishery (Figure 11). It is unfortunate that updated figures for 2007 – 2009 are not available. Thus while recruitment is low, and has been low in the fishery for several years, there is no solid evidence for recruitment failure. For species at the edge of their distribution it is not unusual for recruitment to be highly variable and often limited to large peaks when all the favorable conditions come together at the same time. The pattern observed in the fishery over the last 30 years is a fishery that has responded to one larger recruitment pulse (when all conditions influencing recruitment appeared to be favorable). However, on either side of this period abundance, as estimated by the CSM and UMM, is at a lower level. If this lower level is more normal for the fishery then recruitment has returned to its relatively normal level. However, the comparisons between effort and CPUE for all regions except NY indicate that there are fewer lobsters than in the 1980s and thus recruitment now is lower than at this time. Thus the stock is currently experiencing lower recruitment than expected. However, recent positive trends in catch rates from 2004 – 2006 indicate that recruitment might be improving.

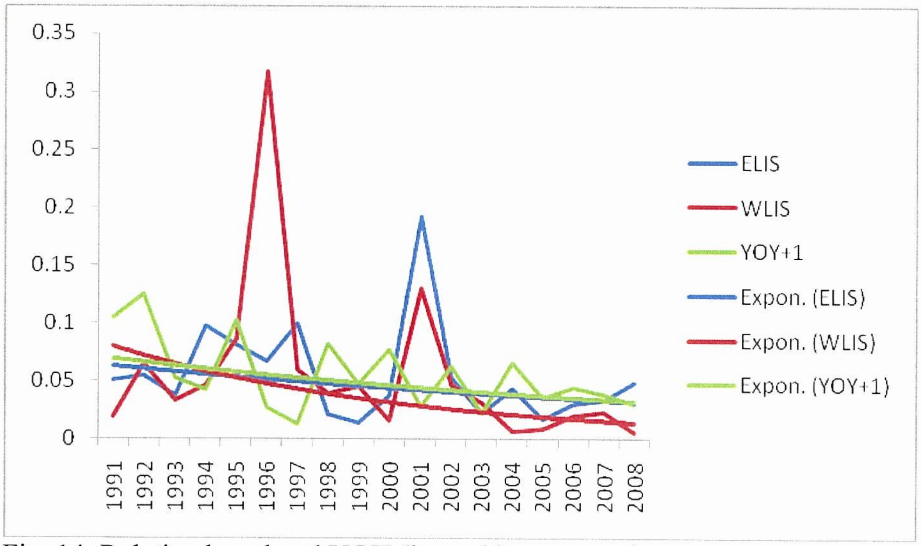


Fig. 14. Relative larval and YOY (lagged by one year)

c. Overwhelming environmental and biological changes coupled with continued fishing greatly reduce the likelihood of SNE stock rebuilding

The evidence for environmental and biological changes preventing the stock from rebuilding is low. The evidence for fishing pressure to prevent stock rebuilding is higher. Compared to the early 1980's when the catch was similar to the last 4 years, current effort is nearly twice that of the early 1980s. The slight improvement in catch rates in the last two years of available data (2005 & 2006 – Fig. 11) indicate that despite this higher effort there is a slight improvement in the stock.

4. Comment on the applicability of the recruitment indices to forecast future recruitment and landings to the inshore and offshore areas.

In the documentation provided, the only indication of a metric for splitting inshore and offshore water is the NEFC survey which is considered the best survey of offshore areas. Thus it is not possible to link recruitment indices to inshore and offshore regions. Thus I will comment on the applicability of recruitment indices to forecast future recruitment and landings.

Correlations between WLIS and ELIS larval abundance indices, YOY, catch rates of recruits and legal-sized lobsters from the fall fishery independent surveys and UMM estimated abundance and CPUE have been discussed in section 2a(ii) & (iv).

Neither larval index provides a correlation when lagged by 6 years. In contrast the YOY provide moderate correlations for legal catch rates for all regions except MA (Table 6). The correlation for recruits is improved for the deeper water site and weaker for the shallower sites. There was a substantial improvement in correlation between YOY and recruits at MA compared to legal lobsters. Catch rates for the fishery only showed a meaningful correlation with CT.

These results would suggest that the YOY is the only useful recruitment index for predicting regional and total catch rates from fishery independent and fishery dependent data sources respectively.

Table 6. Correlations between legal and recruit lobsters from the regional trawl surveys and larval, YOY, CPUE and abundance estimates.

	Legal				Recruits			
	NEFC	RI	CT	MA	NEFC	RI	CT	MA
Abundance (UMM)	0.46	0.55	0.63	0.13	0.61	0.57	0.79	0.40
ELIS	0.05	-0.09	-0.05	-0.01	0.03	-0.04	0.03	-0.08
WLIS	-0.06	-0.09	0.14	0.23	0.04	-0.05	0.13	0.39
YOY	0.53	0.62	0.64	0.27	0.69	0.54	0.54	0.45
CPUE	0.38	0.06	0.60	0.29	0.25	-0.12	0.23	0.20

5. Determine the appropriateness of the recommended action (5-year moratorium); if deemed inappropriate, provide alternative recommendations with justification.

Closing the fishery will increase stock rebuilding fastest if the recruitment decline is associated with fishing. If the recruitment decline is associated with environmental issues such as rising temperatures, which are expected to increase with global warming, then the fishery in this region has a limited future. Under a global warming scenario, the prospects for a fishery in deeper water will only occur if the larvae can settle, survive and recruit to the fishery in deeper water.

There is no information provided on the social and/or economic status of the fishers. Do the fishers have access to other regions of the fishery (GOM, GB)? If not, fishers and their families will be removed from the income derived from the fishery. If they do have access to other regions then managers need to consider what the re-direction of effort to these regions is likely to do to the overall stock.

Effort has been too high in the fishery for too long and needs to be reduced at a minimum by 50% to be equivalent to the effort that was harvesting an equivalent abundance in the early 1980s. However, given the increase in the efficiency of the effort which would be expected with improvements in fishing technology, a greater than 50% reduction in effort is required. Doubling of the efficiency in fishing effort since the early 1980s is not unreasonable and many fishers are prepared to acknowledge this. If this were the case then a 75% reduction in effort would be a minimum target to enforce immediately. A recommendation would be to try to survey fishers to determine what they consider their improvement in efficiency is. However, there is a positive correlation between the YOY and catch rates in the fishery lagged by six years. The recent YOY indices indicate that the overall catch rates in the fishery are likely to fall from approximately 25-27 to approximately 20-23 pounds per trap fished. The viability of fishers with reduced catch rates and reduced number of traps needs to be ascertained.

Whether a substantial cut in effort or a total closure is required is a socio-economic question. If effort is a primary cause of the declining stock then the more effort that is removed the faster the stock will recover but the greater the impost on fishers, processors and others activities that service the fishing industry. A recommendation would be for a detailed socio-economic study to be undertaken to determine the implications of substantial effort reductions (e.g. 75%) and total closure on the fishery.

Given the uncertainty of the drivers for the decline (i.e. fishing mortality or environmental) a specified closure time period seems inappropriate. Instead it would be recommended that a decision rule be implemented that is transparent and agreed to by both managers and fishers. If fishing is allowed then the decision rule could be based on YOY and CPUE indices such that a decline in a combination of these would result in further restrictions on effort in the fishery. If fishing is completely stopped, then the decision rule would need to be based on YOY and recruits from the fall trawl surveys.

The fishery also appears to have been sustained in the past by a large recruitment event that resulted in increased catches in the late 1990's. Large and irregular recruitment fluctuations at the edge of a population's distribution are not uncommon. If recent environmental changes are not influencing recruitment to the fishery then it is likely that large recruitments will occur in the future. Management of effort during such an event would be required to maximize the benefit of the recruitment pulse to enhance stock rebuilding.

The report recommendations include, but are not limited to:

a. **Given evidence of recruitment failure in SNE and the impediments to stock rebuilding, the TC recommends a 5 year moratorium on harvest in the SNE stock area.**
   i. **The moratorium provides the maximum likelihood to rebuild the stock in the foreseeable future to an abundance level that can support a sustainable long-term fishery.**

The concept of a sustainable long term fishery needs to be determined. If environmental factors aren't preventing normal recruitment to the fishery then the fishery can be sustainable at its current level with a reduction in effort. What is uncertain in the fishery is what an appropriate abundance level is. If the abundance levels obtained in the 1990's are due to a recruitment period that is an abnormal event then a sustainable fishery at higher abundance levels is unlikely. If the abundance levels of the early 1980s and mid-2000s are normal then the current fishery is likely to be at a more normal abundance level. The recent improvement in catch rates indicates that the stock is beginning to respond to the reduced effort although the last couple of YOY estimates suggest that at least a couple of years of lower than expected catch rates can be expected.

b. **During the 5-year moratorium period, monitoring of all phases of the lobster life cycle should be intensified.**
   i. **Fishery dependent sampling will no longer be collected, therefore assessment of stock status will rely on current fishery-independent surveys (e.g., ventless trap, YOY sampling, larvae) which will need to be continued and intensified.**
   ii. **New surveys and research (e.g., sentinel industry surveys) are needed to further characterize stock status, lobster settlement and habitat in SNE.**

Larval sampling appears to provide no benefit in the understanding of the stock and should be the lowest priority for future monitoring. The Rhode Island YOY appears a good index and should be continued. The Massachusetts YOY index appears a low priority as the number of YOY encountered is small and variable. Spawning stock biomass (SSB) indices are not correlated with RI YOY for the same or following year (Table 5). No correlation exists between the SSB and CPUE of the fishery in six years time. The fishery independent trawl surveys do correlate with estimates of current abundance.

The ventless traps surveys have not been underway for sufficient time to determine their potential. However, using a sampling gear similar to the fishery has considerable merits, especially if the fishery is to be closed.

In addition to these surveys it is recommended that future surveys be depth stratified so that catch by depth can be obtained.

If not available, maps on available lobster settlement habitat within the region need to be determined with a focus on identifying potential areas for lobsters to settle in deeper cooler waters. Once identified, these areas would need to be surveyed to determine if juvenile lobsters are utilizing these areas. This may pose difficulties as divers are restricted by depth so other juvenile estimation techniques may need to be developed.

Bottom temperature data need to be improved by the establishment of reference stations that are depth stratified (these could be thermistors that are attached to time release buoys and retrieved annually). Thermistors should also be attached to sampling gear (ventless traps, trawl gear) to increase knowledge of the bottom water temperature values.

6. **Evaluate the stock projection scenarios conducted to complete the task as outlined by the Board** (see above).

a. **Evaluate the deterministic projections conducted using the University of Maine Model.**

  i. **The Board directed the TC to provide projections within an extremely short time frame. Although stochastic projections and estimates of uncertainty (e.g. MCMC confidence intervals) could have been provided, the time frame for decision-making was too short to complete a more thorough analysis.**

The "faith" in the projections is reliant on two main factors. Firstly, how well the model estimates the actual data for the periods of overlap (1982 – 2007) and, secondly, how realistic are the parameters used to project forward.

The model is strongly correlated with the landings (catch) data ($r^2 = 0.82$, Fig. 15). Generally, landings are considered an inappropriate measure of abundance as it can reflect changes in effort which is independent of abundance. While there are concerns over the use of traps as an indication of effort, the large changes in effort since the 1980s would suggest that landings cannot be a true reflection of abundance. The correlation between CPUE and model estimated legal abundance is high ($r^2 = 0.61$, Fig. 16). Thus the UMM model appears to be able to represent the past relatively well and thus there should be confidence that it will also predict the short term future relatively well providing that the biophysical relationships that the model assumes remain constant. Thus if increased warming inhibits recruitment to the fishery then the model will have no "knowledge" of a change in the recruitment relationship.

There is no support for the statement "The major conclusion to be drawn from these projections is that if poor environmental conditions continue, dampening the abundance of both spawners and recruits, only current abundance levels may be attainable even in the absence of fishing". As indicated in this review, there is no firm evidence for poor environmental conditions and the most likely current situation is that the fishery is returning to a "normal" level after a period of elevated recruitment. The low recruitment and reduced effort (quarter F) scenario in Fig. 5 of the Stock Projections Report is potentially the "normal" situation (i.e. low recruitment is actually normal recruitment) and the number of legal lobsters tends to be stabilizing at approximately the current level. As it is uncertain what "very low recruitment" is, the low recruitment scenario may well be too low. Any increase in recruitment above the "very low" scenario would result in the number of legal lobsters stabilizing at a higher value.

The target and threshold levels in the fishery are based on the fishery that was dominated by a high recruitment period in the 1990s. If this recruitment is not normal for the fishery then the threshold and target values would be biased high. Targets and thresholds based on the low recruitment of the early 1980s and 2000's should also be developed.

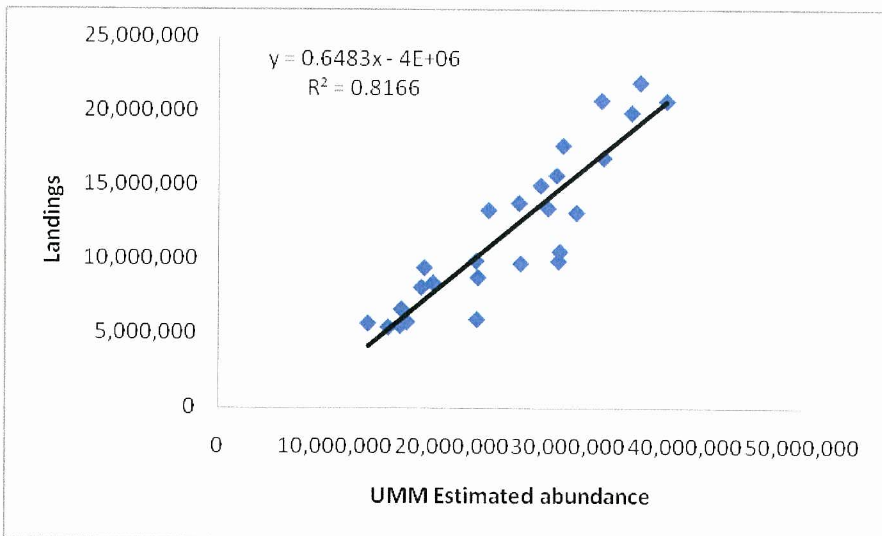


Fig. 15. Relationship between total landings for the SNE fishery and UMM estimated abundance.

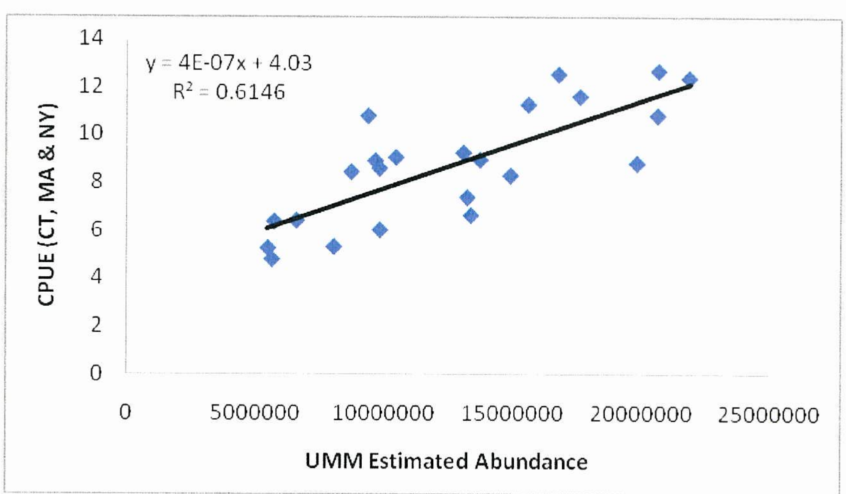


Fig. 16. Relationship between CPUE for the CT, MA & NY regions of the SNE fishery and UMM estimated abundance.

b. Evaluate the chosen suite of fishing and recruitment scenarios presented in the report; if insufficient, provide suggestions for alternative scenarios.

As already indicated, the current fishing effort is substantially higher than when the abundance of legal lobsters was at an equivalent level in the early 1980s. Quarter and half F scenarios are similar to what this review has suggested in Section 2b. As a moratorium is being suggested then no fishing also needs to be a scenario. All models assuming constant or average F are inappropriate as they do not reflect the dynamics of the fishery – that is, they are based on a large recruitment event that has passed through the fishery. There is uncertainty whether such an event has occurred previously or will occur again and over what time period (i.e. was it a 1in 50 year event?).

The fishery experienced a recruitment event in the 1990s that led to the increased landings and effort in the late 1990s after which it has returned to similar levels as was the case in the early 1980s. For populations at the edge of their distribution, large scale recruitment events can occur at sporadic intervals. However, it is inappropriate to manage the fishery on the expectation of such an event. As such, it is inappropriate to use a recruitment relationship that incorporates this large recruitment event as it will be overly optimistic as indicated by the authors of the report. Rather, recruitment in the model should be restricted to periods either side of this peak. Fortunately this is covered in the model by the "very low" recruitment scenarios although there is no indication as to what "very low" is. Is "very low" equivalent to 50% of the BH estimate? The authors need to justify what the "very low" value is and how it compares to the BH-based R value.

It is plausible (and highly likely) that values lower than the BH-based R are not low recruitment but normal recruitment and that the BH-based R is high (and unrealistic) recruitment.

The following scenarios are those that should be considered:

Natural Mortality	Recruitment	Fishing mortality
High M	Low R	Half
Moderate M		Quarter
		None

As model abundance and CPUE tend to track each other (Fig. 7) and CPUE and YOY (Fig. 8) also track each other the authors should consider incorporating YOY as a recruitment index in the model to produce short-term (6 year) future predictions.
Projections that incorporate V notching (Fig. 6 of the Stock Projection Report) also need to incorporate half or quarter F and not constant average catch as current effort levels in the fishery are considered too high for the number of animals available.

c. Determine if projection results and the TC's interpretation provided in the report are consistent with assessment model results.

The main issue with the projections is that the targets and thresholds are based on a fishery that has seen a large recruitment period in the 1990s and is now returning to pre-1990s status. While a longer time series would be ideal, the recruitment is just as likely to be an abnormally high event rather than what is "normal" for the fishery. Thus the thresholds and targets, which incorporate this large recruitment as "normal" would be too high for a "normal" fishery that does not incorporate the large recruitment event.

Unfortunately there appeared to be no attempt to constrain effort when the recruitment period occurred and passed through the fishery. As a result the catch rates rapidly declined in the late 1990s to the mid-2000s after which they appear to be stabilizing. If the slight improvements in catch rates in all regions from 2004 – 2006 (Fig 11) are continuing after 2006 then reductions in the effort to half or quarter F should see improvements in the fishery. As can be seen in figure 5 of the Stock Projections Report, the low recruitment scenarios tend to be stable after an initial increase and decrease in the number of legal lobsters. Thus the long term future of the fishery is likely to be at this level (between 8 – 14 million legal lobsters) if the low recruitment value is accepted. However, while I have argued that recruitment lower than the BH-based R is required, it is uncertain what the low R used in the model is based on, or how much lower than the BH-based R it actually is. If the low R value was too low, the predicted number of legal lobsters would stabilizing at a lower value than expected.

Projections that incorporate V notching (Fig. 6 of the Stock Projections Report) indicate that the BH-Based recruitment has a large positive bias due to the incorporation of the large recruitment period in the fishery in the 1990s. The low recruitment scenario which this reviewer believes is more "normal" in the fishery (but see concerns above about what low actually is) indicates that v-notching has limited value under the constant average catch scenario. This is not surprising as all the evidence indicates that the current effort in this fishery is too high and needs to be reduced by between 50 and 75%. Scenarios with half and quarter F would need to be determined. However, the reductions in the catch that result from the decreased effort would possibly be equivalent to the v-notching program and thus may not be too different to the projections in figure 5 of the Stock Projections Report.

d. Comment on the reliability of the deterministic projections for use in SNE lobster stock management.

The threshold and target values are based on a fishery that has seen a large recruitment period in the 1990s. Prior to (1980s) and after this event (2000s) recruitment has been low in the fishery as reflected in the abundance estimates of the models. What is "normal" in the fishery is debatable and a longer-time series is required to determine this. Managing the fishery on the average threshold and target values will be overly optimistic if recruitment is consistently high as in the 1990s and be overly pessimistic if the recruitment is low as in the 1980s and 2000s. Thus I believe that the current target and threshold values are too high for the current fishery. To meet any of the targets would require recruitment to be an average of the high and low periods. The most likely scenario is that the lows of the 1980s and 2000s are the normal pattern and the highs of the 1990s were a period of improved recruitment. How often these improved recruitment scenarios occur is unknown. From a precautionary perspective, the fishery should be managed assuming that the low recruitment is the normal recruitment to the fishery. Unfortunately the projections do not indicate how low recruitment has been adjusted to for use in the "low R" scenarios. The low R scenario is possibly too low as the recent catch rates in the fishery (2004 – 2006) indicate minor improvements. Data beyond 2006 would be useful to see if this trend is continuing.

However, despite these concerns the projections do indicate that a substantial reduction in fishing mortality is required and this is supported by other trends in the fishery.
This review supports the use of the projections in the SNE lobster stock management as one "line of evidence" as the model is one piece of information amongst several other indices. It is the strength of the patterns observed in all indices that provide the robustness for management decisions. However, targets and thresholds are required for a low R fishery and greater transparency is required to determine what "low R' actually is.

7. Review the M sensitivity analysis of the model that indicated a higher M as suggested in the 2009 assessment.

The M sensitivity analysis is a good addition to the assessment. However, caution needs to be used in interpreting what this actually means. Most models have difficulty in separating M from F. Thus, would an increase in fishing mortality from 1998 – 2007 and leaving M at 0.15 produce the same results?

It is possible that the increased deaths in the fishery are a result of improved efficiency of the fishing gear or F not accounting for the rapid reduction in legal lobsters and slower reduction in effort that occurred from 1998 as the recruitment pulse was fully exploited by the fishery.

From the model outputs, an increase in total mortality (M + F) is accounted for in the model which, whether M or F, should provide more realistic outputs. However, if the increase in M is really an increase in F then the required reductions in F to meet an appropriate F reference point would need to be greater.

If the authors can be 100% certain that M is completely independent of F in the model then the increase in M would suggest that environmental issues (water temperatures, predation rates) have negatively impacted on the fishery. I would recommend that further studies are required to gain an understanding of how to attribute the increase in mortality between M and F.

The increase in shell disease is definitely an indication of increased mortality to the fishery in this region which would imply that M is higher than prior to the 2000s. The incorporation of an increased M in the stock assessment projections is an appropriate inclusion and well justified.

Conclusions and Recommendations (in accordance with the ToRs)

TOR 1
Temperature is likely to be important in a warming world and the SNE population supports the most southern distribution of the species that is commercially viable. Increases in temperature are likely to move the southern limit of the fishery north.

Recommendation 1: It is recommended that increased temperature stations be established and that temperature measurements be routinely collected as part of fishery dependent and independent surveys. Consideration should be given to ways of encouraging fishers to also link bottom temperature with catch (e.g. volunteer logbook).
There is insufficient information to be conclusive about the redistribution of females or a shift of the population to greater depths.

Recommendation 2: It is recommended that a more formal analysis of catch rates at depth be undertaken and that future surveys be depth stratified. Consideration should be given to ways of encouraging fishers to record depth with catch (e.g. volunteer logbook).

Although there are concerns over the use of trap lifts as effort, catch rate (catch per unit of effort [CPUE]) data is an important metric for standardizing and interpreting catch data.

Recommendation 3: It is recommended that CPUE data be used as an additional metric in assessing the fishery.

TOR 2
The UMM abundance estimates provided in the "Recruitment Failure in the Southern New England lobster stock" report and the CPUE estimates described in this review do not support the conclusion that the SNE stock is continuing to fall.
There is inconsistency between the female abundance estimates from the UMM model, which indicates that the abundance of females is greater in the 2000s than in the early 1980s, and the model used in the report to produce Fig. 3, which indicates that the recent SSB estimates are lower than the 1980s.

Recommendation 4: It is recommended that these models be investigated to determine which estimates are most likely.

The WLIS and ELIS larval indices show no correlation with each other or with other indices of the fishery such as abundance, CPUE or YOY indices. The WLIS and ELIS are considered to be of limited value for assessment or prediction in the fishery. The Rhode Island (RI) YOY was found to be correlated with abundance and CPUE. The Massachusetts (MA) YOY index has no power for correlation or prediction due to the low and variable numbers recorded during surveys.

Recommendation 5: It is recommended that YOY be prioritized as the preferred recruitment index for the fishery. Further effort should be directed to expanding this index to other regions and that the MA YOY survey sites are altered to a region where improved numbers of YOY are encountered.

Part 2a (iii) of TOR 2 is addressed by recommendation 2.

The trawl surveys are weakly to moderately correlated with CPUE (CT and NY) and UMM model abundance estimates (CT, NY and RI). Only the CT and NEFC surveys, which are in regions that account for less than 25% of the catch, have catch rates lower than reported in the early 1980s. The weaker correlation that exists between recruits of one year and legal sized lobsters of the following year compared to correlations between recruits and legals of the same year needs further explanation.

Recommendation 6: It is recommended that a study be undertaken to determine why there is a weaker correlation between recruits of a year and the legal sized lobsters of the subsequent year.

Recommendation 7: It is recommended that the MA survey be relocated to a region where it is a better prediction of abundance and CPUE in the MA region.

The use of the landings data as an abundance index is biased without an understanding of the effort.

Recommendation 8: It is recommended that more reliable effort data is routinely collected from the fishery and that CPUE replace landings in assessing the fishery.

Recommendation 9: It is recommended that the regional CPUE data used in this review is updated to 2009.

The fishery has experienced a large increase in recruitment that was reflected in the landings. As recruitment and landings have returned to lower levels equivalent to the early 1980s, effort has not reduced to the equivalent level in the 1980s.

Recommendation 10: It is recommended that effort be reduced in the fishery to a level equivalent to the 1980s and that a socio-economic study be implemented to determine the economic viability of effort reductions.

Part 2c (i) of TOR 2 is addressed by recommendation 1
Part 2c (ii) of TOR 2 is addressed by recommendation 2
Part 2c (iii - 1) of TOR 2 is addressed by recommendations 8 & 9.
Part 2c (iii – 2) of TOR 2 is addressed by recommendation 2

TOR 3

Although recruitment to the SNE fishery is lower in the 2000s compared to the 1990s, there is no overwhelming evidence that the stock is experiencing recruitment failure. Rather, it is most probable that the fishery is returning to "normal" recruitment that was evident in the early 1980s. While abundance estimates are equivalent between the early 1980s and the mid to current 2000s, current effort in the fishery remains substantially higher than in the early 1980s. See recommendation 10.

TOR 4

YOY is the best of the recruitment indices to predict regional and total catch rates from both fishery independent and fishery dependent data sources respectively. See recommendation 5.

TOR 5

The fishery is currently at an abundance level similar to the early 1980s. Only the SSB index for CT (which is derived from the CT fall surveys) indicates that abundance is lower than the early 1980s. The other abundance indices including the UMM abundance estimates indicate that the current abundance in the fishery is slightly higher or equivalent to the early 1980s. Projected low YOY in 2009 would see the fishery decrease to the UMM abundance estimate of 1982 & 1983. Recent regional CPUE estimates indicate a slight recovery in the fishery in the 2004 – 2006 period (see recommendation 9). While abundance is equivalent to the 1980s, fishing effort is almost double the 1980s effort and needs to be reduced (see recommendation 10).

If the changes in environment are affecting larval recruitment (i.e. the free swimming phase) then the fishery has limited future. If the environment is affecting the settlement or post-settlement phase (e.g. water is too warm) then the fishery in this region only has a future if settlement and post-settlement can occur in deeper (cooler) waters. Further information is required to determine this (see recommendation 2).

The SNE fishery is the southern range of the commercial fishery and increased warming in this region is expected to shift the southern boundary of the commercial fishery further north. Understanding the longer term effects of global warming is required.

Recommendation 11: It is recommended that a study be undertaken to investigate the longer term future of the fishery. This could be achieved by using the downscaled IPCC climate models.

There is limited support for a total closure or for a closure for a defined period. There is a need to substantially reduce effort (see recommendation 10) with reviews undertaken to adjust effort if required. Consideration of an agreed decision rule process is recommended.

Recommendation 12: It is recommended that a decision rule process be considered that involves both government and industry and that incorporates both fishery independent (e.g. YOY) and fishery dependent (e.g. regional CPUEs) indices.

TOR 6

The UMM provides good correlations with fisheries performance attributes such as total landings and CPUE. Future projects need to be based on recruitment and F scenarios that are realistic for the current fishery. Estimates that are averaged over the history of the fishery factor in a large recruitment event in the 1990s which will inflate future projections. While the low recruitment scenario addresses the need to consider the future of the fishery based on low recruitment, it is uncertain how "low" the low recruitment value is in the projections.

Recommendation 13: It is recommended that several low recruitment scenarios be determined and included in the projections. Each scenario needs to define what the recruitment value is compared to a base case (e.g. the BH-R).

Recommendation 14: Targets and thresholds should be determined for the low (normal) recruitment scenarios.

TOR 7

Natural mortality (M) is a difficult parameter to estimate and separate from fishing mortality (F). Thus it is uncertain if some of the increase in M could be attributed to increases in F. The increased incidence of shell disease would increase M although it is unknown if this would account for the increase from 0.15 to 0.285. While the model projections will remain appropriate if the increase in mortality is assigned to F or M, the management implications will be different. Essentially management can influence F but seldom M.

Recommendation 15: Further studies are undertaken to attempt to separate F from M.

Appendix I: Background Material

American Lobster Technical Committee, 2010. *Recruitment failure in the Southern New England Lobster Stock.* Atlantic States Marine Fisheries Commission, April 17 2010.

American Lobster Stock Assessment Subcommittee, 2010. *Southern New England lobster stock projection estimates.* Atlantic States Marine Fisheries Commission, unpublished working document.

American Lobster Stock Assessment Subcommittee, 2010. *Southern New England – University of Maine Model natural mortality (M) profile.* Atlantic States Marine Fisheries Commission, unpublished working document.

American Lobster Technical Committee, 2010. *Recruitment Failure report figure data.xlsx.* Excel data file to support Doc1.

American Lobster Stock Assessment Subcommittee, 2010. *newSNEprojections.xlsx.* Excel data file to support Doc2.

Chen, Y., 2010. *A description of the projection model in the University of Maine statistical length-structured stock assessment model for American lobster.* Atlantic States Marine Fisheries Commission, unpublished working document.

American Lobster Stock Assessment Subcommittee, 2010. *Model code.zip.* AD Model Builder code for lobster stock assessment models and projections.

American Lobster Stock Assessment Subcommittee, 2009. *American lobster stock assessment for peer review.* Atlantic States Marine Fisheries Commission, Stock Assessment Report No. 09-01 (Supplement).

American Lobster Stock Assessment Review Panel, 2009. *Terms of Reference and Advisory Report to the American Lobster Stock Assessment Peer Review.* Atlantic States Marine Fisheries Commission, Stock Assessment Report No. 09-01.

Appendix II: CIE Statement of Work

Attachment A: Statement of Work for Dr. Stewart Frusher

External Independent Peer Review by the Center for Independent Experts

Recruitment Failure in the Southern New England Lobster Stock

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

Project Description: The review would evaluate a report written on April 17, 2010 by the American Lobster Technical Committee (TC) of the Atlantic States Marine Fisheries Commission (ASMFC), entitled "Recruitment Failure in the Southern New England Lobster Stock" and the supplemental stock projection document, entitled "Southern New England Lobster Stock Projection Estimates". The report concludes that the stock is critically depleted, experiencing recruitment failure, and cannot rebuild. The cause is thought to be a combination of "environmental drivers" and continued fishing mortality. The TC recommends a five year moratorium on harvest. The review would be asked to consider the merits of this recommendation. The supplemental document provides stock estimates under various F scenarios and recruitment conditions. The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**.

Requirements for CIE Reviewers: Three CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. CIE reviewers shall have a combination of working knowledge and recent experience in the application of marine ecology, lobster biology and life history, recruitment dynamics, and population assessment. Each 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: Each CIE reviewer shall conduct an independent peer review as a desk review, therefore no travel is required.

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

Prior to the Peer Review: Upon completion of the CIE reviewer selection by the CIE Steering Committee, the CIE shall provide the CIE reviewer information (full name, title, affiliation, country, address, email) to the COTR, who forwards this information to the NMFS Project Contact no later the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to the CIE reviewers. The NMFS Project Contact is responsible for providing the CIE reviewers with the background documents, reports, 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 reviewers the necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE Lead Coordinator on where to send documents. CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein. The CIE reviewers shall read all documents in preparation for the peer review.

Desk Review: Each CIE reviewer shall conduct the independent peer review in accordance with the SoW and ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs can not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COTR and CIE Lead Coordinator.** The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements.

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

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

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Conduct an independent peer review in accordance with the ToRs (**Annex 2**).
3) No later than 11 October 2010, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and David Sampson, CIE Regional Coordinator, via email to *david.sampson@oregonstate.edu*. Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in **Annex 2**.

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

The following dates are tentative, and the project contact will provide firm dates no later than 27 July 2010.

27 August 2010	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
10 September 2010	NMFS Project Contact sends the CIE Reviewers the report and background documents
17-27 September 2010	Each reviewer conducts an independent peer review as a desk review
11 October 2010	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
25 October 2010	CIE submits the CIE independent peer review reports to the COTR
1 November2010	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: Requests to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the COTR within 10 working days after receipt of all required information of the decision on substitutions. The COTR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the CIE reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

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

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

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

Support Personnel:

William Michaels, Contracting Officer's Technical Representative (COTR)
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Key Personnel:

NMFS Project Contact:

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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: Terms of Reference for the Peer Review

Review of TC report: Recruitment Failure in the Southern New England Lobster Stock

The American Lobster Board (Board) assigned the American Lobster Technical Committee with the following tasks:

4. Identify issues impeding stock rebuilding in SNE,
5. Develop a suite of measures to begin stock rebuilding in SNE,
6. Develop deterministic projections of stock abundance using the University of Maine Model that assume: a) both status quo and reduced fishing mortality scenarios, and b) status quo recruitment, low/declining recent recruitment, and a stock recruitment relationship.

The Technical Committee had 3 months to report back to the Board on their findings. From the above tasks the TC drafted the report: Recruitment Failure in the Southern New England Lobster stock. With the exception of temperature data and information on the redistribution of spawning females, all other fishery independent and dependent data used in the TC's report were peer reviewed and accepted during the most recent (March 2009) ASMFC Benchmark Stock Assessment.

Terms of Reference for Peer Review Panel

The peer review will cover the April 2010 Recruitment Failure Report and related TC tasks assigned by the Board as detailed above (tasks 1 – 3). The questions are listed in bold. The other information is meant to provide additional insight.

8. **Evaluate the quality and completeness of the data gathered since the assessment (temperature data and redistribution of spawning females); if inadequate, specify additional techniques that should have been considered.**

9. **Determine the appropriateness of the findings drawn in the TC report, if deemed inappropriate, provide alternative findings with justification**. The report findings include, but are not limited to:

    a. Stock Status: Review of recent monitoring information showing that the reproductive potential and abundance of the SNE stock is continuing to fall lower than data presented in the latest assessment.

    i. SNE spawning stock biomass indicators from 2002 □2009 in general were average to poor. The spawning stock abundance from the RI trawl survey increased to levels at or above the median from 2005 through 2008, during the V-notch program, but the 2009 estimate is below the 25th percentile.

    ii. The last several years have produced larval and YOY indices below the median and at or below the 25th percentile relative to the 1984□2003 reference years. YOY indices show a statistically significant negative slope since 1992 and the 3-6 year cyclical pattern in larval indices has been replaced with sustained low values for eight of nine recent years.

Sustained poor production can only lead to reduced recruitment and ultimately to reduced year class strength and lower future abundance levels.

iii. Fishery dependent and independent data suggest that the distribution of spawning females has shifted away from inshore SNE areas into deep water in recent years. This shift may impact larval supply to inshore nursery grounds.

iv. All but one of the SNE fall trawl survey relative abundance indices for recruit and legal size lobster are generally consistent, with a peak in the 1990's and then a decline to low levels in recent years. Recent recruit and legal indices have generally remained at or below the 25th percentile since 2002.

b. Fishery Status

i. The SNE landings peaked in 1997, declined to a low in 2003 and have remained low through 2007. Landings have been below the 25^{th} percentile of reference period (1984-2003) landings since 2002.

ii. Landings peaked and fell below the 25th percentile in different years in the different stat areas, though there were similarities among a number of areas.

iii. Offshore landings trends in NMFS statistical area 616 stand out somewhat from other areas. Trends were similar to areas 537, 612, and NJ south with a peak in the early 1990's followed by a decline and low levels in 2002. Unlike the other areas, landings increased in 2003 and stayed above median landings for a number of years. Recent estimates have declined, but are still above the 25th percentile and may be underestimated due to the lack of NJ south landings data.

c. Impediments to rebuilding

i. There has been a widespread increase in the area and duration of water temperatures above 20^{0}C throughout SNE inshore waters. Long term trends in the inshore portion of SNE show a pronounced warming period since 1999.

    1. Prolonged exposure to water temperature above 20^{0}C causes respiratory and immune system stress, increased incidence of shell disease, acidosis and suppression of immune defenses in lobster. Lobsters avoid water greater than 19^{0}C.

ii. Loss of optimal shallow habitat area is causing the stock to contract spatially into deeper water

    1. The shift in abundance to deeper water may reflect increased mortality in shallow water by mid Atlantic predators (e.g. striped bass, dogfish, and scup) whose abundance has increased substantially in the last decade.
    2. Recent larval drift studies in area 2 suggest that the redistribution of spawning females into deep water areas may be causing larvae to be transported away from traditional settlement areas and potentially into less favorable areas.

iii. Continued fishing pressure reduces the stock's potential to rebuild, even though overfishing is currently not occurring in SNE.

1. Total trap hauls have declined significantly yet have not declined at the same rate as lobster abundance.
2. Although current measures prevent the harvest of egg□bearing and v-notched lobster, the legal catch inshore and offshore represents a loss of egg production to the system.

10. **Determine the appropriateness of conclusions drawn in the TC report; if deemed inappropriate; provide alternative conclusions with justification.** The report conclusions include, but are not limited to:
    - **a.** The TC contends that the stock is experiencing recruitment failure caused by a combination of environmental drivers and continued fishing mortality.
    - **b.** It is this recruitment failure in SNE that is preventing the stock from rebuilding.
    - **c.** Overwhelming environmental and biological changes coupled with continued fishing greatly reduce the likelihood of SNE stock rebuilding

11. **Comment on the applicability of the recruitment indices to forecast future recruitment and landings to the inshore and offshore areas.**

12. **Determine the appropriateness of the recommended action (5-year moratorium); if deemed inappropriate, provide alternative recommendations with justification.** The report recommendations include, but are not limited to:
    - **a.** Given evidence of recruitment failure in SNE and the impediments to stock rebuilding, the TC recommends a 5 year moratorium on harvest in the SNE stock area.
        - i. The moratorium provides the maximum likelihood to rebuild the stock in the foreseeable future to an abundance level that can support a sustainable long□term fishery.
    - **b.** During the 5 year moratorium period, monitoring of all phases of the lobster life cycle should be intensified.
        - i. Fishery dependent sampling will no longer be collected, therefore assessment of stock status will rely on current fishery□independent surveys (e.g., ventless trap, YOY sampling, larvae) which will need to be continued and intensified.
        - ii. New surveys and research (e.g., sentinel industry surveys) are needed to further characterize stock status, lobster settlement and habitat in SNE.

13. **Evaluate the stock projection scenarios conducted to complete the task as outlined by the Board** (see above).
    - **a. Evaluate the deterministic projections conducted using the University of Maine Model.**
        - **i. The Board directed the TC to provide projections within an extremely short time frame. Although stochastic projections and estimates of uncertainty (e.g. MCMC confidence intervals) could have been provided, the time frame for decision-making was too short to complete a more thorough analysis.**
    - **b. Evaluate the chosen suite of fishing and recruitment scenarios presented in the report; if insufficient, provide suggestions for alternative scenarios.**
    - **c. Determine if projection results and the TC's interpretation provided in the report are consistent with assessment model results.**

    d. **Comment on the reliability of the deterministic projections for use in SNE lobster stock management.**

14. **Review the M sensitivity analysis of the model that indicated a higher M as suggested in the 2009 assessment.**