Independent Peer Review for the
Center for Independent Experts (CIE)

NMFS Climate Vulnerability Assessment Review

by

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EXECUTIVE SUMMARY

Purpose

The purpose of this independent review is assess the scientific credibility of the methodology used to undertake Climate Vulnerability Assessments for diadromous and marine fishes and marine invertebrates in the northeast United States by the National Marine Fisheries Service (NMFS). The assessment methodology was prepared in response to the need for increased understanding of how climate change might negatively affect finfish and shellfish, especially those directly or indirectly contributing to fisheries.

Comments and Recommendations

1. The Northeast Fisheries Climate Vulnerability Assessment (hereafter, NEVA) represents a highly scientifically credible methodology for evaluating climate vulnerability across a broad taxonomic suite of fish and shellfish. The method is useful for conducting assessments for data-rich and data-poor species. Although the review focused on species in the Northeast, the methods can be applied to marine and diadromous species elsewhere. The methodology more than adequately meets the design goals and objectives of the Review. Nonetheless, modifications intended to strengthen NEVA are likely necessary and merit consideration by NMFS; these are fully articulated in the main body of this review.

2. The conceptual basis for vulnerability assessments is well-founded. The methodology is consistent with existing tools and approaches being used by other organizations to assess natural resource climate vulnerability. Indeed, in several respects, the credibility and scientific defensibility of the methodology exceeds that of existing methods for terrestrial and marine species alike. These assessments have been used, and are increasingly being used, throughout the world: (i) to identify species perceived to be vulnerable to a changing climate; (ii) to identify the underlying reasons for why species differ in terms of their vulnerability; and (iii) to provide a scientifically and empirically defensible basis for future actions (including funding and other resource allocations) intended to mitigate the effects of climate change on reductions in species abundance and productivity.

3. The design process was well planned and well executed. The very considerable time and effort spent by the four key individuals involved in NEVA was time very well spent. The scientific strengths and credibility of the methodology are clearly a function of the preparatory and planning components of NEVA, including workshops, webinars, a two-phase process for scoring by experts, and comprehensive consideration and deliberation of the merits of including or excluding potential climate exposure factors and species sensitivity attributes.

4. The results will assist federal, state, local, and tribal fisheries managers in understanding and considering possible negative impacts of climate change on fish and shellfish. The results of the assessment will be readily understood and easily communicated to managers, decision-makers, and the public. Importantly, the assessment will allow managers and decision-makers to prioritize funding, research initiatives, and other resource allocations in support of efforts to enhance the resistance and resilience of those species forecast to be most vulnerable to climate change.

5. Before the methodology is applied in other regions, consideration should be given to recommendations that I judge would improve implementation of NEVA in the Northeast and in other regions. Among the several that are identified in the review, these would include:

    (i) changes to the descriptions of some sensitivity attributes to minimize ambiguities and improve clarity;
    (ii) strengthening of the presentation and visual depiction of data uncertainties (e.g., use of the Tally Method in data quality scores);
    (iii) demonstration that the results of NEVA are reproducible and not unduly influenced by expert bias; and
    (iv) enhanced use of direct and indirect means of estimating parameters of importance for scoring sensitivity attributes (the Population Growth Rate attribute provides an instructive example of how such improvements can serve to strengthen the assessment).

6. The methodology provides a useful ‘baseline’ framework for possible application to other NMFS trust resources. However, additional attributes should be considered before the methodology is applied or used formally in climate vulnerability assessments of protected species, endangered species, and critical habitats.

REVIEWER REPORT

I. BACKGROUND

The proposed assessment methodology is intended to identify the relative vulnerability of marine and diadromous fish and shellfish based on factors likely to affect the exposure of species to climate change and the sensitivity of species to that exposure. The methodology is intended to provide a basis for advice on how best to allocate limited research and assessment resources, in addition to providing a basis for NMFS to engage with managers, stakeholders, decision-makers, and the public.

The need for such vulnerability assessments comes from several quarters, not the least of which are Executive Orders (EOs) issued by the President. EO 13514 (*Federal Leadership in Environmental, Energy, and Economic Performance*; 5 October 2009) draws attention to the requirement for federal agencies to assess climate vulnerability and develop adaptation plans. EO 13653 (*Preparing the United States for the Impacts of Climate Change*; issued 1 November 2013) pertains to the need to prepare the U.S. for the impacts of climate change by undertaking actions to enhance climate preparedness and resilience. Other key drivers include calls for vulnerability assessments, adaptation planning, and promotion of resilience under initiatives such as the *National Fish, Wildlife and Plants Climate Change Adaptation Strategy* and the *National Ocean Policy*. It is also noteworthy that *Endangered Species Act* listing decisions must now explicitly account for the effects of climate change.

In response to the information needs required to fulfil these Executive Orders and to meet the objectives set forth by various policies and other initiatives, NMFS initiated a process that has culminated in a set of Climate Change Vulnerability Assessments for 79 fish and shellfish species inhabiting waters off the northeast coast of the U.S. It is hoped that the methodology associated with these assessments can be applied to undertake similar assessments throughout the U.S. and contribute to NOAA's objective to be, in a sense, 'climate ready'. The methodology appears to be directly relevant to objectives 4 and 7 of the draft NMFS *Climate Science Strategy*.

The primary goal is to produce a practical and efficient tool for assessing the vulnerability of a wide range of fish and shellfish stocks to a changing climate. The key objectives associated with this initiative are to:

(i) identify species that might be at risk (reflected by declining productivity and declining abundance);
(ii) identify species sensitivity attributes and climate-change exposure factors responsible for increasing the vulnerability of some species;
(iii) identify key data gaps and information needs;
(iv) assist in targeting more detailed assessments, particularly for species deemed to be most vulnerable; and
(v) increase awareness of how climate change is predicted to affect fish and shellfish and, by extension, fisheries for these species.

II. DESCRIPTION OF THE INDIVIDUAL REVIEWER'S ROLE IN THE REVIEW ACTIVITIES

I received the Review Materials on 16 October 2014 from Jon Hare, Narragansett Laboratory Director, Oceanography Branch Chief, NOAA Fisheries Service. I began my review of these materials on 20 October 2014. On 24 October, I requested additional materials for review. These were species narratives and species profiles for an additional eleven species. These were sent to me and the other reviewers by Jon Hare on 24 October 2014. I travelled to Narragansett, RI, on 27 October to attend the three-day review meeting that ended on 30 October 2014. My report was submitted to the Center for Independent Experts (CIE) on 1 November 2014, prior to the 14 November 2014 deadline stipulated in the Statement of Work (Appendix 2 of the present document).

III. SUMMARY OF FINDINGS IN ACCORDANCE WITH THE TERMS OF REFERENCE

1. Evaluate and provide recommendations on the conceptual basis (vulnerability assessments) and design-process (workshops, pilots, NE implementation) for the NMFS Fisheries Climate Vulnerability Assessment

For the most part, NMFS' Northeast Climate Vulnerability Assessment (hereafter, NEVA) represents a highly scientifically credible methodology for evaluating climate vulnerability across a broad taxonomic suite of fish and shellfish species. The method is useful for conducting assessments for data-rich and data-poor species. Although the review focused on species in the Northeast, the methods can be applied to marine and diadromous species elsewhere. The methodology more than adequately meets the design goals and objectives of the review.

The conceptual basis for vulnerability assessments is well-founded. These assessments have been used, and are increasingly being used, throughout the world to: (i) identify species perceived to be vulnerable to a changing climate; (ii) identify the underlying reasons for why species differ in terms of their vulnerability; and (iii) provide a scientifically and empirically defensible basis for future actions intended to mitigate the effects of climate change on species abundance and productivity (including research initiatives, management strategies, and financial/human-resource allocations).

The design process was well-planned and well-executed. The very considerable time and effort spent by the four key individuals involved in NEVA was time very well spent. The scientific strengths and credibility of the methodology is clearly a function of the preparatory and planning components of NEVA, including workshops, webinars, a two-phase process for scoring by experts, and comprehensive consideration and

deliberation of the merits of including or excluding potential climate exposure factors and species sensitivity attributes.

2. Evaluate and provide recommendations on the assessment structure, assumptions, and scoring procedures for the NMFS Fisheries Climate Vulnerability Assessment

In addition to the comments provided below (some of which are extensive), I have responded to the questions posed in the Terms of Reference by providing brief reviews of three of the pre-review manuscripts that were sent to panel members and by providing additional analysis of the scoring of the Population Growth Rate sensitivity attribute. These reviews and analysis are included at the end of this review document as separate Appendices and can be identified as follows:

> Appendix 4: Review of Morrison et al. 2014MS. Methodology for assessing the vulnerability of fish species to a changing climate. Submitted to *ICES Journal of Marine Science*.
>
> Appendix 5. Supplemental analysis of the inclusion of additional information on the scoring of Population Growth Rate.
>
> Appendix 6. Review of Hare et al. 2014MS. Northeast Fisheries Climate Vulnerability Assessment (NEVA): an application of the NMFS Fisheries Climate Vulnerability Assessment Methodology. Manuscript.

2.1 Does the methodology contain a valid list of attributes? Could any be added or removed?

2.1.1 Strengthening the descriptions and applications of sensitivity attributes

In general, I would judge the list of climate exposure factors and biological sensitivity attributes to be valid and appropriate. Although I would not recommend that any factors or attributes be removed or added, I do offer recommendations to strengthen the sensitivity attributes. In addition to improving the clarity with which some of these are described, I offer suggestions for the addition and/or removal of parameters bins used to provide a score for the Population Growth Rate sensitivity attribute.

Habitat Specificity

1. In the background section (5th sentence), there is an interesting conflation of the words ‘stocks’ and ‘species’. I suspect that the word ‘species’ should replace ‘stocks’.
2. What *precisely* constitutes a ‘habitat type’? Things such as mud, sand, pelagic, benthic?

3. In the section on Habitat Specificity Bins, the text for Bin 1 ("…included in this bin are stocks that are restricted to one physical habitat which is widespread and common…") confusingly includes text from Bin 3 ("The stock is a specialist that is restricted to a specific, but common biological habitat.") How do these differ?

Prey Specificity

1. The text generally looks fine and clear. The only suggestion I would offer is to the text associated with Bin 2. I suggest: "The stock can feed on a wide variety of prey [INSERT the word 'species'], but are restricted…". This might further clarify the distinction between 'prey species' and 'prey type'.

Sensitivity to Ocean Acidification

1. My primary concern is with the text associated with the bin descriptions. For example, "**Low: Stock not reliant on sensitive taxa.** The two sentences refer to different things. The first is neutral whereas the second refers to a positive response. Perhaps the text could be revised to state: "The stock either does not utilize sensitive taxa for food or habitat, or is expected to respond positively to ocean acidification."
2. The 4 bins represent a 'mixed bag'. The first three deal with stock reliance on sensitive food or habitat (i.e., indirect effects) whereas the fourth deals with direct effects on the stock/species itself.
3. Along these lines, it is not clear to me how an assessment under Bin 3 differs from one under Bin 4. I might have thought that a species highly dependent on sensitive taxa would have the same vulnerability as species that are themselves sensitive. In other words, the distinction between Bins 3 and 4 is not perhaps logically obvious.
4. Text in Bin 4: Spelling error. "Stock is a sensitive taxa" should be "Stock is a sensitive *taxon*".

Complexity in Reproductive Strategy

1. The third bulleted point is problematic for several reasons. An Allee effect is a pattern. It describes a decline in 'r' (more precisely, $r_{realized}$; see below) with reductions in abundance. Given that an Allee effect is a *pattern*, the presence of an Allee effect says nothing whatsoever about the mechanism(s) responsible for producing the effect. This is relevant to the following text: "If this is not known, does the stock share life history characteristics that would predict strong alee [*sic*] effects (e.g., at low densities, urchins can experience decreased fertilization and thus reduced recruitment)?" Notwithstanding the misspelling of "Allee", there are almost no empirical data in the peer-reviewed literature about species characteristics that might contribute to an Allee effect. (The text notes one of the few examples.)

2. Again, Allee effects reflect a *pattern* only, not a mechanism for generating Allee effects. An Allee effect can be produced, for example, by factors that have nothing to do with reproductive strategy. For example, an Allee effect is produced when *M* increases as abundance declines, all else being equal (Kuparinen and Hutchings. 2014). As another example, an emergent Allee effect can be experienced by prey when the abundance of a predator increases as the abundance of prey declines. In other words, Allee effects can be produced by factors that are not associated with the complexity of the reproductive strategy.

3. The text unhelpfully depicts an Allee effect as an 'on/off switch' or a 'black/white characterization'. I think the text could be appropriately modified to better capture the broader implications of an Allee effect. Perhaps the text associated with this bulleted point could be re-phrased as follows:

   "The stock experiences decreased recruitment per spawner, or a weakening in the strength of density dependence, at low stock sizes, potentially because of depensation/Allee effects. If this is not known or suspected, does the stock or its ecosystem have characteristics that might render it vulnerable to a weakening in compensation or that would predict Allee effects (e.g., significant changes in the relative abundance of the stock's predators/prey at low stock densities, decreased fertilization success at low stock sizes)?"

4. Lastly, perhaps the text on Allee effects might be better placed in the text associated with Population Growth Rate.

Sensitivity to Temperature

1. The opening text states the premise that "this attribute uses species (vs. stock) distributions as they better predict thermal requirements". As the text is written, I would disagree. There is increasing evidence that evolution and local adaptation in marine fishes occurs at spatial scales considerably smaller than the range of the species. Atlantic cod provides one such example. To identify two studies of suspected local adaptation, there are *genetic* stock-specific differences in thermal plasticity (Hutchings et al. 2007) and stock-specific differences in temperature-related Single Nucleotide Polymorphisms (SNPs) (Bradbury et al. 2010). (Note that cited references are included later in this review.)
2. Mid-page: Figure '1' should be '2'.
3. Descriptions of the Bins: Again, the premise that species-level sensitivities will appropriately capture stock-specific sensitivities comes up. I think it would be helpful if the text stated something along the following lines:

   "When information on stock-specific sensitivity, either known or suspected, is not available, data on temperature sensitivity at the species level, ideally within the vulnerability assessment area, should be used."

Early Life History Survival and Settlement Requirements

1. Again, the text under "How to use expert opinion" re-states the point made above about differences between stocks and species. But here the text (appropriately) acknowledges that "the specificity of these conditions varies between stocks".
2. Description for Bin 2: How is one to define what constitutes "relatively constant" recruitment?
3. Description for Bin 3: How is one to define what constitutes "highly variable" recruitment? It would be helpful to provide some guidance, perhaps something along the lines of: "Recruitment can be characterized as being 'highly variable' when the number of recruits per annum varies by more than xx orders of magnitude. Recruitment variability at levels lower than this can be characterized as being 'relatively constant'."

Stock Size/Status

1. Under "Relationship to climate change", the first sentence should replace "resilient" with "resistant". The word 'resilience' refers to ability to increase from low levels of abundance. **The text throughout NEVA should clearly distinguish *resistance* from *resilience.***
2. Rather than Musick (1999), cite the IUCN documents directly.
3. Re-word the following sentence to read: "The IUCN set a level of <10,000 individuals as the threshold at which a stock's extinction risk can be assessed as being Vulnerable."
4. Key point: The IUCN's criterion refers to ***mature individuals only***. Is that the intent here? It probably should be. For example, the text associated with Bin 4 should state explicitly "(or any stock below 10,000 mature individuals)".
5. The threshold of 1.5 B/Bmsy will likely strike many readers as being too high (i.e., too risk averse). What is the empirical or theoretical justification for 1.5Bmsy?

   One alternative to the current bin ranges might be:

   Low: B/Bmsy >1 (i.e. above 'target')
   Moderate: B/Bmsy between 0.5 and 1.0 (between 'overfished state' and 'target')
   High: 0.2-0.5 (between 'collapse' and 'overfished state')
   Very High: <0.2 ('collapsed' stock)

   Note that the definition of collapse here is the same as that used by Neubauer et al. (2013) and entirely consistent with that used by Worm et al. (2009).

6. Include text to draw attention to the fact that Bmsy can change over time. One concern here is that a reduction in Bmsy, leading to an *increase* in B/Bmsy (all else being equal), could be interpreted inappropriately as reduced vulnerability to climate change. There may be a need to include a metric of B/Bmax?

Other Stressors

1. Insert “of” in the appropriate subheading such that it reads: “Example of stressors the stock may be experiencing”.
2. Replace the word “anthropocentric” with “anthropogenic”.
3. Note that the fourth bulleted point describes an emergent Allee effect.

Population Growth Rate

1. The incorporation of this sensitivity attribute is highly appropriate. As the authors note, the parameter ‘r’ (actually r_{max}) is the parameter that best reflects the ability of a population (or stock or arguably species) to recover or increase following depletion. It is the parameter that best reflects ‘resilience’.
2. However, questions can be raised about the manner in which ‘population growth rate’ is being used in the assessments. The first concerns the meaning of the phrase ‘population growth rate’ and the extent to which the text clarifies or confuses what this parameter is and how it can be estimated. To address this comment, I suggest considerable re-wording of the text associated with this sensitivity attribute.

BEGINNING OF SUGGESTED REVISED TEXT

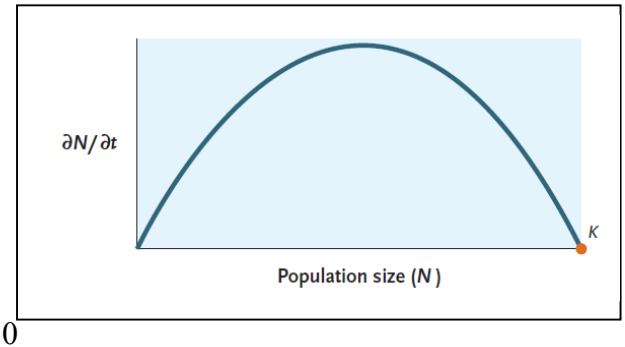
Population Growth Rate

Goal: To estimate the relative productivity of the stock.

Relationship to climate change: More productive stocks are, in general, better suited to rebound after the population is stressed by changes in the environment, such as climate change.

Background: The term Population Growth Rate has often been used to mean different things. In the classical sense, as evidenced from traditional models of population growth, ‘population growth rate’ and ‘per capita population growth rate’ (also called ‘intrinsic rate of increase’) are different entities. In the absence of density dependence, population growth rate ($\partial N/\partial t$) is given by the equation $\partial N/\partial t = rN$, where r is the *per capita* population growth rate and N is a metric of population abundance. In contrast to population growth rate, r has units of $\partial N/N(\partial t)$. In the absence of density dependence, the value of r does not change with changes in abundance and is always equal to the maximum per capita rate of population growth, that is, r_{max}.

In the density dependent case, the classic model of population growth can be given by: $\partial N/\partial t = r_{max}\, N\, (1 - N/K)$, where K is carrying capacity and for which population growth rate ($\partial N/\partial t$) is maximized at $0.5K$.



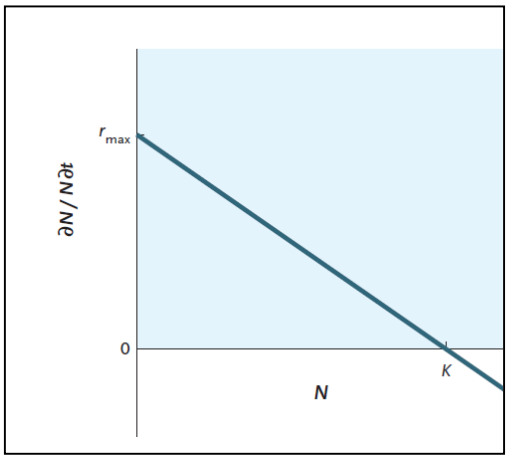
Given that $\partial N/N(\partial t) = r$, the equation can be re-arranged to yield:

$\partial N/N(\partial t) = r_{max}\ (1 - N/K)$

This allows us to distinguish the *realized* per capita rate of population growth ($r_{realized}$) from the *maximum* rate of per capita population growth (r_{max}), such that

$r_{realized} = r_{max}\ (1 - N/K)$.

Note that r_{max} is realized at the lowest levels of abundance (unless the strength of density dependence decreases as abundance declines, one consequence of which would be an Allee effect).



For the purpose of assessing population resilience (the rate of population recovery, or increase, at low population size), the parameter of interest is r_{max}. If direct measurements of maximum per capita population growth rate (r_{max}) are unavailable, other biological reference points that are correlated with r_{max} can be used: von Bertalanffy growth rate (k), age at maturity, maximum age and natural mortality. Scoring bins for these proxies were modified from Musick (1999) by an analysis of 141 marine fish species that were considered to be representative of U.S. fisheries (Patrick *et al*. 2009).

How to use expert opinion: Multiple proxies may be used to inform the final score, but the accuracy and precision of the different proxies should be considered. For example, a stock with a "good" estimate of age at maturity is in the range for a "High" score, and a "fair" estimate of maximum age is in the range for the "High" scoring bin. In that case, the scorer should use their expert opinion to weight their response according to their confidence in the estimates. If no estimates are available, estimate a relative score for the stock across a continuum of r-selected (low) vs. k-selected (high) species.

Population Growth Rate Bins:

Parameter	Low	Moderate	High	Very High
Maximum per capita rate of increase (r_{max})	> 0.50	0.16 - 0.50	0.05 - 0.15	< 0.05
von Bertalanffy K	> 0.25	0.16 - 0.25	0.11 - 0.15	<= 0.10
Age at maturity	< 2 yrs	2 - 3 yrs	4 - 5 yrs	> 5 yrs
Maximum age	< 10 yrs	11 - 15 yrs	15 - 25 yrs	> 25 yrs
Natural mortality (M)	> 0.50	0.31 - 0.50	0.21 - 0.30	< 0.2

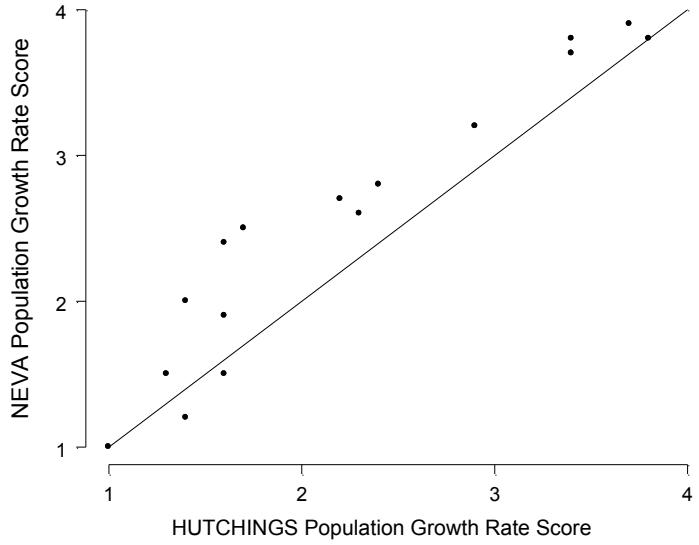
END OF SUGGESTED REVISED TEXT

3. There are data on r_{max} in the peer-reviewed literature that have not been incorporated into NEVA. For example, there is a compendium of r_{max} estimates available in the Supplementary Information associated with the following citation: Hutchings et al. 2012. Life-history correlates of extinction risk and recovery potential. *Ecological Applications* 22: 1061-1067.
4. Estimates of *M* often either are not available or are estimated with variable degrees of confidence. For species in which estimates of *M* are not available, I encourage the use of life-history invariants to estimate *M*.

Life-history invariants have been formulated since Beverton & Holt's time. More recently, many authors, including Charnov, Jensen, Mangel and others have used life-history invariants to estimate parameters that are difficult to specify. Indeed there is evidence of the use of life-history invariants in stock assessments undertaken by NMFS. One invariant that can readily be used here is that between the von Bertalanffy parameter *k* and *M*. Jensen (1996) reported that $M = 1.5k$, whereas Charnov (1991; Charnov et al. 2013) reported $M = 1.8k$ (reporting a range of 1.6 and 2.1, leading to a mid-range value of ~ 1.8).

In the analysis presented in Appendix 5 of this review, I used the estimates of r_{max} reported by Hutchings et al. (2012) and estimates of *M* as determined by the Jensen and Charnov life-history invariants. I applied these estimates to the scoring sheets for 16 species: Atlantic Menhaden, Striped Bass, Atlantic Croaker, Blueback Herring, Alewife, Atlantic Salmon, Dusky Shark, Porbeagle, Spiny Dogfish, Winter Skate, Little Skate, Atlantic Cod, Haddock, Pollock, Yellowtail Flounder, Atlantic Herring.

I find that the correlation between my scores (the simple average of the 5 vulnerability scores, ranging between 1 and 4) and those reported by the NEVA process is 0.95 and highly significant ($p<0.001$; see figure below).



I draw two primary conclusions from this exercise. The first is that the incorporation of addition information on r_{max} and *M* **supports** the NEVA Population Growth Rate scores, meaning that the scores are thus strengthened and (arguably) more defensible. The second conclusion is that the Population Growth Rate scores that incorporated more information on r_{max} and *M* tend to be lower than those based on the NEVA scores (which rarely included estimates of r_{max} and often not *M*). I'm not sure if this is a concern, but the observation is an interesting one.

5. Regarding the ranges of parameters within bins, I feel that most of these are good and defensible. The bin ranges are those below:

Parameter	Low	Moderate	High	Very High
Maximum per capita rate of increase (r_{max})	> 0.50	0.16 - 0.50	0.05 - 0.15	< 0.05
von Bertalanffy K	> 0.25	0.16 - 0.25	0.11 - 0.15	<= 0.10
Age at maturity	< 2 yrs	2 - 3 yrs	4 - 5 yrs	> 5 yrs
Maximum age	< 10 yrs	11 - 15 yrs	15 - 25 yrs	> 25 yrs
Natural mortality (M)	> 0.50	0.31 - 0.50	0.21 - 0.30	< 0.2

Ideally each parameter should reflect roughly similar sensitivities among bins. For *k* and *M*, I find this to be the case (see Table below).

Table: Estimates of 'annual survival' associated with *k* and *M*. For *M*, the annual proportion of the population that lives is given by 'annual survival' = 1 – exp(-*M*). To estimate the 'annual survival' associated with *k*, the following invariant was used, *M* = 1.8*k*, and the value of *M* substituted in the above equation to calculate annual survival.

Parameter	Low	Moderate	High	Very High
k	>0.36	0.25-0.36	0.18-0.24	<0.18
M	>0.39	0.27-0.39	0.19-0.26	<0.18

6. I think the range of parameters within each bin is generally defensible. Although I initially thought that the bin ranges associated with age at maturity were too narrow, I now agree with the ranges given. The ranges are consistent with empirical estimates of the association between age at maturity and r_{max} as estimated by Hutchings et al. (2012).
7. The final comment I would offer is that consideration be given to the inclusion of a size-based parameter, e.g., $L_{infinity}$, to the metrics of the Population Growth Rate attribute and that the metric of Maximum Age might best be excluded. The addition of a metric pertaining to body size, such as length at maturity L_{mat} or L_{inf} (from the von Bertalanffy equation), might be particularly advantageous for data-poor species. Another reason for considering L_{mat} and L_{inf} is that they are related

to *M*. For example, Charnov et al. (2013) have shown that $M = (L_{mat} / L_{inf})^{-1.5} \times k$, where *k* is the von Bertalanffy growth parameter. Thus, the addition of attributes based on body size could be used as another means of estimating *M*.

One issue with Maximum Age is that it represents an *extreme* rather than something that most individuals in the population experience (something that the other metrics generally achieve).

Dispersal of Early Life Stages

1. What is the basis for the 100 km threshold? The spatial scale of dispersal should probably be set relative to the spatial scale of the effects of climate change.

Adult Mobility

1. No comments.

Spawning Cycle

1. It is assumed that: "Stocks that spawn over an extended period of time will be more likely to be successful in a changing environment". Such stocks are described in the text as bet-hedgers, yet these species have characteristics that would render them *more* vulnerable to environmental change according to the Population Growth Rate sensitivity attribute, such as low r_{max}, low *M*, long lifespan, etc. Perhaps the text could be re-phrased: "stocks that spawn throughout the year will be more likely to be successful in a changing environment". Perhaps the text related to bet-hedging could be excised.

2.1.2 Correlations among factors and attributes (e.g. Air Temperature and SST)

Every attempt should be made to minimize the extent to which factors or attributes are correlated with one another. The greater the independence of factors and attributes, the stronger and more defensible the assessment. The issue of greatest import in this regard is the concern that inclusion of *both* Air Temperature and Sea Surface Temperature (SST) might unduly bias some assessments.

That said, I am not in favour of excluding both Air Temperature and SST. Nor would I necessarily be in favour of using a strategy of 'taking the higher of the two scores for Air Temperature and SST'. The latter strategy strikes me as being unduly arbitrary and, therefore, something undesirable in the methodology.

Another reason for including both is that the *link* between Air Temperature and SST as a *proxy* for the temperatures ***actually experienced by the species in question*** will differ considerably among the species functional groups. The deeper you live, the less that either SST or Air Temperature will affect you (unless deeper-dwelling species undertake vertical migrations to near-surface waters). Furthermore, inclusion of

both Air Temperature and SST provides a very good means of capturing multiple climate-change factors on diadromous species, such as Atlantic Salmon.

In the end, my preference would be to have the text clearly indicate that exposure factors and sensitive attributes will have varying degrees of inter-correlation among one another, meaning that they are not all independent of one another. The place to alert the reader to this caveat with specific examples would, I suggest, be in the species narratives, where the issue of inter-correlation between scores might present an issue for the Overall Vulnerability Score.

However, the issue surrounding the correlation between Air Temperature and SST (that is, whether one is double-counting the same exposure factor) is not, in my view, a fault of their correlation with one another (as noted above, other scores and attributes are almost certainly correlated with one another to greater or lesser degrees). Rather, the concern arises because of the fact that relatively few exposure scores (SST, Air Temperature, Ocean Acidification) had great influence on the Exposure Scores for many species and, thus, on the Overall Vulnerability Scores for the same species. Put another way, a lack of data leads to a reduction in the number of 'meaningful' exposure factors, which leads to an increase in the sensitivity of Exposure Scores (and Vulnerability Scores) to the logic rule, which can then contribute to potential charges of bias in the Overall Vulnerability Assessment Scores.

This does not reflect, in my view, deficiencies in the selection of exposure factors. Nonetheless, although the total number and identity of exposure factors was quite reasonable, the actual number that were influential was quite small – essentially three. ***This identifies a research need for greater effort to obtain improved climate data availability and resolution at small spatial scales, i.e., at the spatial scales of the assessments.***

2.1.3 Threshold vs continuous effects (e.g., Ocean Acidification)

Use of the exposure factor Ocean Acidification (OA) might require some further thought. Unlike most of the other factors and attributes, there is reason to believe that biological responses to changes in aragonite or calcium carbonate in the ocean might act in a threshold manner, as opposed to the continuous manner implicitly assumed by the scoring advice accompanying the description of this scoring factor.

On the other hand, one might argue that a threshold *is* implicit in the scoring of a taxon that is directly sensitive to OA, insofar as that taxon would automatically receive a score of 4. I suppose the challenge lies in the lack of data to identify where the threshold(s) exist for any particular taxon.

2.2 Does the methodology appropriately account for expert bias?

It is not clear that the methodology has accounted for expert bias as well as it might have. There is a need to have the vulnerability assessments undertaken by either a larger group of experts or by a different group of experts. This second set of assessments for the Northeast could perhaps be done concomitantly with the introduction of the methodology to other regions (for time-efficiency purposes).

End-users will, I suspect, require confidence that the vulnerability assessments are reproducible and are robust to expert bias. Perhaps not all 79 species need to be re-scored but a subset selected instead. Criteria for deciding which species to include in this subset might include: (i) balance between data-rich and data-poor species and (ii) balance among species functional groups (e.g., four species from each of the six functional groups).

2.3 Is the logic method appropriate?

The Component Scoring Rubric does not capture *all* scoring eventualities, and this limitation should be made explicit in all outputs associated with the methodology. For example, a species that receives a Moderate Vulnerability score of '2' on all exposure factors and sensitive attributes would be classified as having Low Vulnerability according to the logic model. Of course, one might reasonably argue that such scoring situations have low probability of manifesting themselves, but *full transparency* of the limitations of the logic method would be appropriate.

Another caveat associated with the logic method is that the vulnerability assessments become ***increasingly sensitive*** to reductions in the number of 'meaningful' (i.e., higher scoring) exposure factors and sensitive attributes. For example, with NEVA, the exposure scores in the Northeast are generally dependent on (or sensitive to) two or three factors: sea surface temperature, air temperature, and ocean acidification.

2.4 Is the methodology consistent with existing tools and approaches being used by other organizations to assess natural resource climate vulnerability?

The methodology is generally consistent with existing tools and approaches used by other organizations to assess natural resource vulnerability. For example, the climate-change exposure factors and sensitivity attributes are either identical or very similar to metrics used by other organizations. In several respects, the credibility and scientific defensibility of the NEVA methodology exceeds that of existing methods for terrestrial and marine species alike.

At the core of the Vulnerability Assessment Framework is the dependence on three components considered throughout the scientific literature to be fundamental to

vulnerability assessments: *sensitivity, exposure,* and *adaptive capacity*. However, the methodology differs somewhat from *some* (not all) other assessments in that the *adaptive capacity* of a species to respond to climate change is accounted for by the *sensitivity attributes* for each species. The primary reason for taking this approach lies in the logical and methodological difficulties in disentangling factors that relate to adaptive capacity from some of the sensitive attributes. Many commonly used biological attributes contribute to both sensitivity and adaptive capacity.

On balance, I accept the decision to incorporate *adaptive capacity* within the s*ensitivity attributes*. The logic behind doing so is sound and scientifically defensible. However, one recommendation I would have is that every effort be made, in the species narratives, to communicate the degree to which a species' climate vulnerability might be affected by its sensitivity, adaptive capacity, or both.

3. Evaluate the strengths and weaknesses of the methodology

The bulleted points below complement the strengths and weaknesses of the methodology identified elsewhere in this review.

3.1 Strengths

- Applicable to a broad taxonomic and functional breadth of species; the NEVA assessment includes: (i) all federally managed species; (ii) most state-managed species; (iii) some that are not managed; and (iv) some that are of conservation protected-species interest (e.g., listed or being considered for listing under the ESA);
- Multiple assessments can be undertaken in relatively short periods of time, thus meeting the time-sensitive information needs of the responsible agencies;
- The key outputs of the methodology (e.g., colour matrices, species narratives, identification of key exposure factors and sensitivity attributes) are clear and readily interpretable by a broad range of end-users;
- The 'Tally Method' of quantifying uncertainty is very informative;
- The boot-strapping analyses represent an appropriate component of the uncertainty elements of the assessment;
- With the caveats and limitations of NEVA made explicit in the assessment outputs, the results of the assessment will have broad applicability to a variety of end-users, including those working on climate change, socio-economics, reliance of communities on fish and fisheries, and endangered species.

3.2 Weaknesses

- The data quality scores represent a fundamentally important component of the assessment. In particular, these scores can be used to guide decisions about how to allocate limited funding to fill data gaps. Thus, I highly recommend that the *Tally Point Scoring System* be applied to the Data Quality scores. Among other things, this might help alleviate expert bias in assessing data quality. For example, for one assessor, a single paper in the peer-reviewed literature on a

particular topic might be sufficient to generate a data quality score of '3', whereas for another it would be a '2'. Similarly, a datum based on a 'personal communication' might be scored as a '2' by one assessor, and a '1' by another (e.g., the estimate of 'r' in the Porbeagle species profile);

- The assessments were undertaken *only* by NMFS employees. Those doing the scoring – the experts – can usefully be broadened;
- The meaning of the term 'species' is often unclear in the documents. What emerged as a result of the review meeting and associated discussions is that when reference is made to using species-level data, what is *actually* meant is species-level data from within the area being assessed, rather than using species-level data from throughout the species' geographical range (Atlantic Salmon, Atlantic Cod, and Atlantic Herring providing good examples);
- It is recommended that the instructions associated with the methodology advise that experts should base their scores on the best available data appropriate for the species and region associated with their assessment. Given that the spatial scale of local adaptation and evolutionary responses to climate change can be much smaller than the spatial limits of either the species range or the region being assessed, experts should be advised that stock-level information (e.g., for sensitivity attributes such as Population Growth Rate) should be used when available.

4. Evaluate and provide recommendations on the application of the NMFS Fisheries Climate Vulnerability Assessment using the Northeast region case study as an example

It is extremely important that the assessment be applied in as consistent a manner as possible for the species inhabiting the waters under NMFS' jurisdiction. Ideally, there could be a *core* set of exposure factors and sensitivity attributes that is applied everywhere. This would contribute significantly to the consistent application of the methodology. There could also be a small sub-set of factors or possibly attributes that could vary from one region to the next. One example might be the inclusion of dissolved oxygen for the Gulf of Mexico; another would be sea-ice coverage for the Arctic.

This would accomplish a few things. First, it acknowledges that different regions face different levels of exposure to climate change. Second, it allows regions to 'fine-tune' their assessments in a way that the experts in the region feel is appropriate. Third, by retaining a core set of factors and attributes that are used in all regions, it allows for an 'equivalent' comparison of vulnerability assessments across regions to the greatest extent possible. There may be instances in which the *details* of the data differ across regions (e.g., in terms of the spatial scale at which reliable climate-change forecasts are available), but the core factors and attributes would remain the same.

It is fundamentally important that every effort be made, and necessary financial and human resources be allocated, to ensure that the NEVA methodology is fully

understood before it is applied in other regions. This might well entail pilot studies, webinars, and workshops, and multiple scoring sessions (a pilot and final stage). These would be resources very well invested.

5. Provide a recommendation as to whether the methodology provides results and information that can assist U.S. federal, state, and local fishery managers in understanding and considering possible climate impacts on fish stocks (fishery includes exploited shellfish and finfish species)

- The results will assist federal, state, local, and tribal fisheries managers in understanding and considering possible impacts of climate change on fish stocks. The results of the assessment will be readily understood and easily communicated to managers, decision-makers, and the public. Importantly, the assessment will allow managers and decision-makers to prioritize funding and other resource allocations in support of efforts to enhance the resistance and resilience of those species forecast to be most vulnerable to climate change;
- The results can assist managers by providing guidance in identifying species that might warrant Management Strategy Evaluations;
- The assessments can provide a basis for managers to take steps to increase the resistance and resilience of species assessed as being vulnerable to climate change. These might include, for example, the development of fishery reference points for 'breadth of age structure' (these once existed for summer flounder in 2002) or spatial distribution;
- There is potential for the methodology to be incorporated in human vulnerability assessments – ***subject to the caveats associated with the limitations of NEVA*** (i.e., what the methodology can and cannot be used for) – particularly for communities deemed reliant or dependent (directly or indirectly) on fishery resources. (Note however that the current methodology focuses on species that are predicted to respond negatively, rather than positively, to climate change.);
- The methodology provides information to managers as to which species require greater monitoring.

6. Provide a recommendation as to whether the methodology is appropriate for use in other regions. Has it provided useful information in the Northeast and could it provide useful information in other regions?

For the most part, the NEVA methodology represents a highly scientifically credible means of evaluating climate vulnerability across a taxonomic breadth of fish and shellfish. The method is useful for conducting assessments for data-rich and data-poor species. There are no obvious barriers to its implementation in other regions.

The panel was presented with an excellent example of how the vulnerability assessments can be used in conjunction with social-reliance indices from a fishing perspective for a community in Maine. Thus, there is a very good possibility of linking climate vulnerability assessments with social impact assessments (i.e., social measures of fishing community engagement and community reliance on fishing), subject to the caveats associated with the limitations of NEVA (i.e., what the methodology can and cannot be used for).

An example was presented to the panel of how the vulnerability assessments were useful to the preparation of a status review for Dusky Shark, a species that NMFS was petitioned to list under the ESA. Another use of the climate vulnerability assessments presented to the panel was the potential incorporation of the assessments in the Rhode Island State Wildlife Action Plan as a means of addressing the need and desire to incorporate climate change in the wildlife action plan. Given that there are 13 states in the Northeast for which State Wildlife Action Plans are required, the extent to which states can take advantage of the NEVA assessments is considerable.

There is every reason to believe that tribes in the U.S., particularly those in areas where tribes are heavily engaged in fisheries (e.g., Washington, Oregon), will be exceedingly interested in the methodology and in the vulnerability assessments.

The methodology provides a useful framework for possible application to other NMFS trust resources. But I would judge the methodology to represent a baseline framework before the method is applied to protected species, endangered species, and critical habitats. That is, I would think that additional attributes should be considered, such as:

(i) rate of decline in mature population size in the short-term (the greater of the last three generations or 10 years, to provide consistency with IUCN extinction-risk criteria) – the greater the decline, the potentially lower the adaptive capacity and the higher the sensitivity;

(ii) magnitude of decline in mature population size relative to some historical maximum (analogous to the Stock Status attribute, but perhaps comparing current abundance relative to a metric of unfished biomass or carrying capacity);

(iii) rate of decline in habitat quantity and(or) quality in the short-term (the greater of the last three generations or 10 years, to provide consistency with IUCN extinction-risk criteria) – the greater the decline, the potentially lower the adaptive capacity and higher the sensitivity;

(iv) magnitude of decline in habitat quantity and(or) quality relative to some historical maximum (analogous to the Stock Status attribute, but perhaps comparing current abundance relative to a metric of carrying capacity).

7. Provide recommendations for possible ways to improve the methodology or its application / use

- When applying the methodology in other regions, it would be highly advantageous to have a set of experts that scored a certain number of species in *every* region. This would increase the degree to which the methodology is, and is perceived to be, used in a consistent manner across regions.
- Always ensure that it is clear in any output from the methodology that 'vulnerability' refers to ***a reduction in productivity and (or) abundance caused by a changing climate***. It does not refer, for example, to extinction probability or probability of population/stock persistence.
- Following on from this point, it is fundamentally important that it be made ***clear what NEVA can and cannot be used for***. For example, NEVA *is* intended to identify species that are vulnerable because they are expected to decline in abundance or productivity because of climate change. NEVA is *not* intended to provide assessments of risk of extinction under climate change or to provide a full evaluation of *both* positive and negative species responses to a changing climate. NEVA does not provide an assessment of the magnitude of population changes in productivity or abundance. NEVA does not allow for an assessment of the population consequences of changes in abundance or productivity.
- The colour matrix of the overall climate vulnerability ranks is a very good way of depicting and communicating the results. I suggest the same type of matrix be constructed to capture data quality/uncertainty issues. One example would have vulnerability on one axis and data quality on the other axis.
- The use of the RCP (Representative Concentration Pathways) 8.5 climate change model could be better justified (it is the 'business-as-usual' model).
- It is important to underscore that these are relative ranks, i.e., relative vulnerability assessments. The assessments need to be interpreted *relative* to the other species assessed in the same region.
- When undertaking assessments, such as NEVA, at the spatial scale of Large Marine Ecosystems (or LMEs), consideration needs to be given to how to incorporate data from sources such as stock assessments and fisheries-independent surveys from outside U.S. waters, e.g., Canada. There might also be data quality issues to consider in this regard.
- The species scoring profiles should be clearly identified *not* as a product of the assessment but as an internal information resource to assist experts during the scoring phase of the assessment.

8. Brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations

The panel met initially just prior to the opening of the three-day panel review meeting.

Several presentations were made to the panel members, the most important of which were those from the four key NMFS personnel involved in NEVA: Jon Hare, Roger Griffis, Wendy Morrison, and Mark Nelson. The panel was very ably chaired by Anne Hollowed. The presentations to the panel and associated discussions were vitally important to the panel's work. In addition to providing clarification and justification on a variety of points, the interactions between panel members and NMFS personnel served to greatly increase the reviewers' understanding of NEVA.

The panel was provided with time at the end of Day 2 and at the beginning of Day 3 for *in camera* discussions. It was during these periods that panel members discussed key recommendations in addition to various issues that arose during the course of the review meeting and presentations. There was broad consensus amongst the reviewers on most points, although different perspectives were expressed on one or two issues, such as the most appropriate means of handling Air Temperature and SST in the exposure scores.

The panel also welcomed the additional presentations made by some stakeholders. However, one element that was missing in this regard were presentations by stakeholders from the conservation (e.g., ENGO) and industry sectors. Brief presentations from these sectors could have been useful as well.

In sum, the panel review meeting went very well, was exceedingly useful, and served to strengthen the reviews of the methodology.

9. Panel Chair prepare a short summary to be presented to NMFS Fisheries Climate Vulnerability Assessment leads and NMFS Leadership at the end of the Panel Review (Day 3)

Based on lengthy discussions with all three reviewers, the Panel Chair presented a PowerPoint presentation to NMFS Leadership during a teleconference at the end of the Panel Review. The presentation lasted for approximately 55 minutes and included time for questions and discussion. The presentation was provided to all participants on the teleconference by the Panel Chair.

IV. CONCLUSIONS AND RECOMMENDATIONS

1. The Northeast Fisheries Climate Vulnerability Assessment represents a highly scientifically credible methodology for evaluating climate vulnerability across a broad taxonomic suite of fish and shellfish. The method is useful for conducting assessments for data-rich and data-poor species. The methods can be applied to marine and diadromous species elsewhere.

2. The conceptual basis for vulnerability assessments is well-founded. The methodology is consistent with existing tools and approaches being used by other organizations to assess natural resource climate vulnerability. Indeed, in several respects, the credibility and scientific defensibility of the methodology exceeds that of existing methods for terrestrial and marine species alike.

3. The design process was well planned and well executed. The very considerable time and effort spent by the key individuals involved in NEVA was time very well spent. The scientific strengths and credibility of the methodology are clearly a function of the preparatory and planning components of NEVA.

4. The results of the methodology will assist federal, state, local, and tribal fisheries managers in understanding and considering possible negative impacts of climate change on marine and diadromous fish and shellfish.

5. Recommendations that would improve implementation of NEVA in the Northeast and in other regions would include the following (in addition to those identified elsewhere in this review):

    (i) changes to the descriptions of some sensitive attributes to minimize ambiguities and improve clarity;
    (ii) strengthening of the presentation and visual depiction of data uncertainties;
    (iii) demonstration that the results are reproducible and not unduly influenced by expert bias; and
    (iv) enhanced use of direct and indirect means of estimating parameters of importance for scoring sensitivity attributes.

6. Every effort should be made to ensure that the assessment is applied in as consistent a manner as possible in other regions.

7. The methodology provides a useful ‘baseline’ framework for possible application to other NMFS trust resources. But additional attributes should be considered before the methodology is applied or used formally in assessments of protected species, endangered species, and critical habitats.

APPENDIX 1:
BIBLIOGRAPHY OF MATERIALS EXAMINED FOR THE REVIEW

Bell, R.J., Hare, J.A., Manderson, J.P., and D.E. Richardson. 2014. Externally driven changes in the abundance of summer and winter flounder. *ICES Journal of Marine Science*. In press.

Bradbury, I. et al. 2010. Parallel adaptive evolution of Atlantic cod on both sides of the Atlantic Ocean in response to temperature. *Proceedings of the Royal Society B* 277: 3725-3734.

Charnov, E.L. 1991. Life history invariants. Oxford University Press, Oxford, UK.

Charnov, E.L., Gislason, H., and J.G. Pope. 2013. Evolutionary assembly rules for fish life histories. *Fish and Fisheries* 14: 213-224.

Chin, A., Kyne, P.M., Walker, T.I., and R. McAuley. 2010. An integrated risk assessment for climate change: analysing the vulnerability of sharks and rays on Australia's Great Barrier Reef. *Global Change Biology* 16: 1936-1953.

Foden, W.B. et al. 2013. Identifying the world's most climate change vulnerable species: a systematic trait-based assessment of all birds, amphibians and corals. *PLoS One*, 8(6), e65427.

Glick, P., and B.A. Stein, editors. 2010. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. Draft. National Wildlife Federation, Washington, D.C.

Hare, J.A. et al. 2012. Cusk (*Brosme brosme*) and climate change: assessing the threat to a candidate marine fish species under the US Endangered Species Act. *ICES Journal of Marine Science* 69: 1753-1768.

Hare, J.A., Morrison, W.E., Nelson, M.W. et al. 2014. Northeast Fisheries Climate Vulnerability Assessment (NEVA): an application of the NMFS Fisheries Climate Vulnerability Assessment Methodology. Manuscript.

Hutchings, J.A. et al. 2007. Genetic variation in life-history reaction norms in a marine fish. *Proceedings of the Royal Society B* 274: 1693-1699.

Hutchings, J.A., Myers, R.A., García, V.B., Lucifora, L.O., and A. Kuparinen. 2012. Life-history correlates of extinction risk and recovery potential. *Ecological Applications* 22: 1061-1067.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Can. J. Fish. Aquat. Sci.* 53: 820–822.

Johnson, J.E., and D.J. Welch. 2009. Marine fisheries management in a changing climate: a review of vulnerability and future options. *Reviews in Fisheries Science* 18: 106-124.

Kroeker, K.J. et al. 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. *Global Change Biology* 19: 1884-1896.

Kuparinen, A., and J.A. Hutchings. 2014. Increased natural mortality at low abundance can generate an Allee effect in a marine fish. *Royal Society Open Science* 1: 140075.

McClure, M.M., et al. 2014. Incorporating climate science in applications of the U.S. Endangered Species Act for aquatic species. *Conservation Biology* 27: 1222-1233.

Morrison, W.E., Nelson, M.W., Howard, J.F., Teeters, E.J., Hare, J.A., Griffis, R.B., Scott, J.D., and M.A. Alexander. 2014MS. Methodology for assessing the vulnerability of fish species to a changing climate. Submitted to *ICES Journal of Marine Science*.

Moyle, P. B., Kiernan, J. D., Crain, P. K., and R.M. Quinones. 2013. Climate change vulnerability of native and alien freshwater fishes of California: a systematic assessment approach. *PloS one*, *8*(5), e63883.

Morrison, W.E., Nelson, M.W., Howard, J.F., Teeters, E.J., Hare, J.A., Griffis, R.B., Scott, J.D., and M.A. Alexander. 2014MS. Methodology for assessing the vulnerability of fish species to a changing climate. Submitted to *ICES Journal of Marine Science*. *Supplemental Information: Sensitivity Attribute Definitions and Bins.*

Myers, R.A., and G. Mertz. 1997. Maximum population growth rates and recovery times for Atlantic cod (*Gadus morhua*). *Fishery Bulletin* 95: 762-772

Neubauer, P., Jensen, O.P., Hutchings, J.A., and J.K. Baum. 2013. Resilience and recovery of overexploited marine populations. *Science* 340: 347-349.

NEVA species profiles for: Alewife, Atlantic Cod, Atlantic Croaker, Atlantic Menhaden, Atlantic Herring, Atlantic Salmon, Atlantic Sea Scallop, Blueback Herring, Dusky Shark, Haddock, Little Skate, Pollock, Porbeagle, Spiny Dogfish, Winter Skate, Yellowtail Flounder.

NEVA species narratives for: Alewife, Atlantic Cod, Atlantic Croaker, Atlantic Menhaden, Atlantic Herring, Atlantic Salmon, Atlantic Sea Scallop, Blueback Herring, Dusky Shark, Haddock, Little Skate, Pollock, Porbeagle, Spiny Dogfish, Winter Skate, Yellowtail Flounder.

Nye, J.A., Link, J.S., Hare, J.A., and W.J. Overholtz. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. *Marine Ecology Progress Series* 393: 111-129.

Pecl, G.T., Ward, T., Doubleday, Z., Clarke, S., Day, J., Dixon, C., Frusher, S., Gibbs, P., Hobday, A., Hutchinson, N., Jennings, S., Jones, K., Li, X., Spooner, D., and R. Stoklosa. 2011. Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia. Part 1: Fisheries and Aquaculture Risk Assessment. Fisheries Research and Development Corporation, Project 2009/070.

Richardson, D.E., Palmer, M.C., and B.E. Smith. 2014. The influence of forage fish abundance on the aggregation of Gulf of Maine Atlantic cod (*Gadus morhua*) and their catchability in the fishery. *Canadian Journal of Fisheries and Aquatic Sciences* 71: 1349-1362.

Seney, E.E., Rowland, M.J., Lowery, R.A., Griffis, R.B., and M.M. McCLure. 2014. Climate change, marine environments, and the U.S. Endangered Species Act. *Conservation Biology* 27: 1138-1146.

Williams, S.E., Shoo, L.P., Isaac, J.L., Hoffmann, A.A., and G. Langham. 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. *PLoS Biology* 6(12), e325.

Worm et al. 2009. Rebuilding global fisheries. *Science* 325: 578-585.

APPENDIX 2:
STATEMENT OF WORK FOR DR. JEFFREY HUTCHINGS

Attachment A: Statement of Work for Dr. Jeffrey Hutchings

External Independent Peer Review by the Center for Independent Experts

NMFS Fisheries Climate Vulnerability Assessment Review

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: Through in-depth investigations of specific fish stocks, NMFS has a strong understanding of how climate change may impact some high profile fish species (e.g. Hare et al. 2010, Hollowed et al. 2009, Hazen et al. 2012). However, repetition of these detailed analyses for all managed stocks (~450) is not feasible as these studies are resource intensive and require data sets that are not available for many fish stocks. Given the pace at which climate change is expected to occur and the need for NMFS to develop science priorities and management considerations now, there has been a demand to develop a practical and efficient tool to assess the vulnerability of a wide range of fish stocks in a changing climate. This tool would not replace detailed studies. Rather, it is designed to provide information until detailed studies can be completed and to help guide more detailed studies by identifying high risk species and important climate factors. To develop this tool - a climate vulnerability assessment for marine fish and invertebrate species - NMFS convened a working group composed of fishery scientists and managers from across the country. The methodology was built off a standard vulnerability assessment framework and specifically incorporated elements of two prior marine species climate vulnerability assessments. The methodology was recently implemented in the Northeast region for 79 fish and invertebrate species. This methodology was designed to identify the relative vulnerability of exploited species based on a series of life history attributes and

projections of the expected changes in key physical or chemical characteristics of the species' environment with changes in the planet's climate system. The vulnerability information is intended to be used to help inform considerations of how best to focus limited research and assessment resources (e.g., focus on stocks of highest concern). Additionally, the results are intended to promote conversation among scientists, managers, fishermen and other stakeholders about what climate-related changes are expected in marine ecosystems, how climate change may impact living marine resources, and what actions could be considered to reduce impacts and increase resilience of these important marine resources in a changing climate.

NMFS plans to use this methodology to assess climate vulnerability of managed species in other regions as part of the scientific advice provided to support fisheries management under the Magnuson-Stevens Act. Vulnerability assessments are now being used extensively by federal, state and tribal natural resource agencies and partners to identify key resources at risk and inform planning for how to reduce risks and increase resilience in a changing climate. In addition, the methodology is responsive to several mandates for federal agencies to assess climate vulnerability and advance adaptation planning to promote resilience of natural resources (e.g., Executive Order 13653 "Preparing the United States for the Impacts of Climate Change"; National Fish Wildlife and Plants Climate Adaptation Strategy, and the National Ocean Policy).

The objective of the CIE review is to assess the scientific credibility of the methodology including its structure and process, utilizing the results of the Northeast Assessment as a worked example. Key questions for the CIE review are:

- Does the methodology adequately meet its design goals and objectives?
- Is it consistent with existing tools and approaches being used by other organizations to assess natural resource climate vulnerability?
- Do the results assist federal, state or tribal fisheries managers in understanding and considering possible impacts of climate change on fish stocks?
- Are there changes or modifications that should be made before implementing in different regions?
- Are there improvements that can be made in the implementation of the methodology based on the worked exampled in the Northeast?
- Does the methodology provide a useful framework or model for possible application to other NMFS trust resources (e.g., protected species, endangered species, and critical habitats)?

We envision a three-day review. Day one will focus on the methodology. Day two will focus on the implementation in the Northeast. Day three will provide the review panel time for discussion and preparation of their review and also a summary meeting with the methodology designers and members of NMFS leadership. The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**. The tentative agenda of the panel review meeting is attached in **Annex 3**.

Requirements for CIE Reviewers: 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 the following expertise: the application of natural resource climate vulnerability assessments, ecosystem-based approaches to natural resource management, and climate change effects on marine species and ecosystems. We do not expect all of these skills to be represented by each reviewer, but request that review panel as a whole have the expertise to cover the topics listed above. Vulnerability assessments have been widely used in terrestrial systems and terrestrial scientists with experience in vulnerability assessments would be appropriate. Each CIE reviewer's duties shall not exceed a maximum of 14 days to complete all work tasks of the peer review described herein.

The chair or the panel will be chosen by NMFS and will be a fisheries scientist with an understanding of current marine fisheries issues in the Northeast Region.

Location of Peer Review: Each CIE reviewer shall conduct an independent peer review during the panel review meeting scheduled in Narragansett, Rhode Island from 28-30 October 2014.

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

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

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

http://deemedexports.noaa.gov/compliance_access_control_procedures/noaa-foreign-national- registration-system.html

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

1. Methodology Manuscript
    a. Database Description
    b. Sensitivity Attribute Definition Document
2. Northeast Application Manuscript
    a. Exposure Factor Definition Document
    b. Species Profiles Example
    c. Species Narrative Examples
3. Chin et al. (2009) Paper
4. Johnson and Welch (2009) Paper
5. Moyle et al.(2013) Paper
6. Pecl et al. (2011) Report
7. Foden et al. (2013)
8. National Wildlife Foundation - A Guide to Climate Change Vulnerability Assessment

For more examples see: http://www.natureserve.org/conservation-tools/standards-methods/climate-change-vulnerability-index.

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

Contract Deliverables - Independent CIE Peer Review Reports: Each CIE reviewer shall complete an independent peer review report in accordance with the SoW. Each CIE

reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

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

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

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Participate during the panel review meeting at Narragansett, Rhode Island from 28-30 October 2014 as specified herein, and conduct an independent peer review in accordance with the ToRs (**Annex 2**).
3) No later than 14 November 2014, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Dr. Manoj Shivlani, CIE Lead Coordinator, via email to mshivlani@ntvifederal.com, and Dr. David 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.

Please provide the actual dates in the following table. Please use this table format.

22 September 2014	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
14 October 2014	NMFS Project Contact sends the CIE Reviewers the pre-review documents
28-30 October 2014	Each reviewer participates and conducts an independent peer review during the panel review meeting
14 November 2014	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator

28 November 2014	CIE submits CIE independent peer review reports to the COTR
5 December 2014	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

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

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

Applicable Performance Standards: The contract is successfully completed when the COTR provides final approval of the contract deliverables. The acceptance of the contract deliverables shall be based on three performance standards:

(1) The CIE report shall completed with the format and content in accordance with **Annex 1**,
(2) The 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.

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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.

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

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

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

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

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

3. The reviewer report shall include the following appendices:

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

Annex 2: Terms of Reference for the Peer Review NMFS Fisheries

Climate Vulnerability Assessment Review

1. Evaluate and provide recommendations on the conceptual basis (vulnerability assessments) and design-process (workshops, pilots, NE implementation) for the NMFS Fisheries Climate Vulnerability Assessment
2. Evaluate and provide recommendations on the assessment structure, assumptions, and scoring procedures for the NMFS Fisheries Climate Vulnerability Assessment including:
    a. Does the methodology contain a valid list of attributes? Could any be added or removed?
    b. Does the methodology appropriately account for expert bias?
    c. Is the logic method appropriate?
    d. Is the methodology consistent with existing tools and approaches being used by other organizations to assess natural resource climate vulnerability?
3. Evaluate the strengths and weaknesses of the methodology
4. Evaluate and provide recommendations on the application of the NMFS Fisheries Climate Vulnerability Assessment using the Northeast region case study as an example.
5. Provide a recommendation as to whether the methodology provides results and information that can assist U.S. federal, state, and local fishery managers in understanding and considering possible climate impacts on fish stocks (fishery includes exploited shellfish and finfish species)
6. Provide a recommendation as to whether the methodology is appropriate for use in other regions. Has it provided useful information in the Northeast and could it provide useful information in other regions?
7. Provide recommendations for possible ways to improve the methodology or its application / use.
8. Brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations
9. Panel Chair prepare a short summary to be presented to NMFS Fisheries Climate Vulnerability Assessment leads and NMFS Leadership at the end of the Panel Review

Annex 3: Tentative Agenda
NMFS Fisheries Climate Vulnerability Assessment Review

Narragansett, Rhode Island
Security POC: Jon Hare

Day 1 – 28 October 2014

9:00-9:15	Introductions / Logistics
9:15-9:30	Charge to the Review Panel (Chair)
9:30-10:30	Review of Process for establishing methodology
10:30-12:00	Open Discussion
1:00-3:00	Review of methodology 3:00-5:00 Open Discussion

Day 2 – 29 October 2014

9:00-9:15	Logistics
9:15-10:45	Northeast Implementation
10:45-12:00	Open Discussion
1:00-2:00	Broader Application (Stakeholder POVs)
2:00-3:00	Open Discussion
3:00-5:00	Closed Panel Discussion

Day 3 – 30 October 2014

9:00-11:00	Closed Panel Writing
11:00-12:00	Panel Summary with POCs and NMFS Leadership Adjourn

APPENDIX 3:
PANEL MEMBERSHIP OR OTHER PERTINENT INFORMATION FROM THE PANEL REVIEW MEETING

There is no information on panel membership or other pertinent information from the panel review meeting additional to that presented in Section 8 of this review.

APPENDIX 4:

REVIEW OF MORRISON ET AL. 2014MS. METHODOLOGY FOR ASSESSING THE VULNERABILITY OF FISH SPECIES TO A CHANGING CLIMATE. SUBMITTED TO *ICES JOURNAL OF MARINE SCIENCE*.

Below is a brief review of this manuscript, comprising suggested edits, comments, and questions. Please note that these comments were prepared *prior* to the 28-30 October 2014 Panel Review Meeting.

Questions:

1. Page 7: How does one deal with changes in life history traits attributable to exploitation (changes in r_{max}) such as reductions in age at maturity, size at maturity, lifespan, etc.
2. Lines 114-116: The definition of "highly vulnerable" seems a bit odd in that it can mean something quite different from a 'fishery' vs 'fish species' perspective. For example, species productivity and abundance can decline but the probability of persistence/extinction can remain unchanged. Perhaps this text could use greater clarification.
3. Line 116-117: Paradoxically this definition is consistent from a species perspective (distributional shift) but would not be good from a fishery perspective. I suggest the text be clarified to ensure that the reader is very clear on the intention of the methodology to assess the climate vulnerability of *species* rather than *fisheries*. The information can, of course, be applied to fisheries, but it is species that is of primary interest here. And perhaps the example of 'distributional shift' can be replaced by another example (again, to improve clarity).
4. Line 161-162: "…sensitivity attributes should stay consistent [across regions]…" I would disagree with the notion that sensitivity attributes do not vary from one region to the next or from one stock/population to the next. Natural selection rarely acts across a species' entire range. Rather, it acts at 'local' levels. This results in local adaptation. This means that sensitivity attributes are quite likely to vary among regions and among stocks.

   However, perhaps this simply reflects confusion on my part. That is, perhaps the text means that the attributes themselves would be the same across the species range but that the values/scores need not (i.e., they can vary among stocks). Perhaps the text can be clarified.
5. Line 196: Spelling error re "known".
6. Line 214: I very much like the notion of 'tallies' and the ways these have been used to characterize uncertainty.
7. Line 224: It seems that 'tallies' are not used to provide a data quality score. I wonder why not? For example, it seems rather odd that the estimate of 'r' for porbeagle, based on a personal communication, is assigned a data quality score of '2'. Why not '1'? Or better yet, why not use tallies?

8. Line 281: Regarding the divergence of the vulnerability matrix assignments (when one score is ‘very high’, overall vulnerability is increased by one rank): This might strike some readers as being unduly arbitrary insofar that the practice potentially compounds one subjectively arrived-at score (albeit expert-based) with even more subjectivity. It is probably ok, but could be better defended in the text.

9. Lines 335-337: Again, I would disagree with the emphasis on species-level attributes. Also, the three points (lines 338-342) made here seem intended (perhaps unintentionally) to dissuade efforts associated with ‘digging a little deeper into the literature’ rather than underscoring the benefits (and logic) of undertaking assessments at the stock level.

   Indeed, in addition to being contrary to what we know about the spatial scale of evolution and local adaptation, the species-level palette (essentially) argued for here runs counter to the spatial scale at which managers can manage.

10. Line 397: Emphasis here (and elsewhere) is placed on ‘mean’ values from an *exposure* perspective. This is fine and I agree with it. However, variability about the means is also an important consideration when forecasting metrics of climate change. Among other considerations if the degree to which temperature *maxima* will change (not just the mean temperature). Although the existing literature on climate vulnerability assessments seems not to account for variability (at least not explicitly), this seems like an important consideration (and indeed one that the Hare et al. manuscript addresses).

11. Lines 482-483: “Species able to adapt to climate change via distributional shifts are more likely to be scored as “low vulnerability” in this assessment”. I wonder if there isn’t perhaps an inconsistency arising here. That is, although the title refers to the ‘vulnerability of fish species’, much of the justification for the work centres on the need to undertake such assessments for the purpose of adapting humans and managers to the ways in which climate change are likely to affect fisheries. Given that the spatial scale of a species is typically far greater than that of a fishery, the degree to which a distributional shift out of one area will be perceived to have ‘low vulnerability, will depend on the spatial scale. For example, if cod shift from NAFO 5Z northward into 4x or 4VsW, this might well reflect ‘low vulnerability’ from a species perspective, but ‘very high vulnerability’ from a fishery perspective.

    I suppose what I am arguing for here is greater clarity in the text.

12. Line 490: The word ‘adapt’ is not really used correctly here. Adaptation implies genetic change. What is meant here is that “species that have a combination of life history characteristics…have the potential to *resist* climate change by changing distributions.

13. Lies 506-508: On another note, the word ‘resilience’ is incorrectly used, at least from the perspective of the classical and contemporary literature. That said, given that it is increasingly misused, perhaps it doesn’t matter (McClanahan et al. 2012 use it incorrectly, for example). But sometimes clarity can be helpful.

Specifically, the definition for ‘resilience’ on line 508 is actually the definition for ‘resistance’. Resilience, in contrast, is a measure of the ability of depleted species/stocks to recover.

14. Line 513: Thus, ‘resilient’ here should be changed to ‘resistant’.
15. Line 517: I suspect ‘later’ is meant to be ‘latter’.
16. Line 520: The text surrounding age structure also leads to the potential to establish age-structure-based reference points for highly vulnerable species.
17. Table 1 and Figure 2: What are the units of ‘population growth rate’? The text is ambiguous as to whether this term is intended to refer to ‘population growth rate’, defined as dN/dt, or ‘per capita population growth rate’, defined as dN/Ndt, and also known as ‘r’. (Note that ‘r’ is *not* population growth rate…it is *per capita* population growth rate.) Also, I think what is intended to be used here is r_{max}.

APPENDIX 5:
SUPPLEMENTAL ANALYSIS OF THE INCLUSION OF ADDITIONAL INFORMATION ON THE SCORING OF POPULATION GROWTH RATE.

The empirical basis for the scoring of the Population Growth Rate sensitivity attribute can be strengthened by (i) using estimates of r_{max} from the primary peer-reviewed literature and (ii) using estimates of M derived from life-history invariants. The estimates of r_{max} used here are from a Supplemental Data Table associated with Hutchings et al. (2012). There is also a single estimate of r_{max} for Georges Bank cod reported by Myers and Mertz (1997). The life-history invariants those reported by Jensen (1996), who estimated that $M = 1.5k$, and by Charnov (1991) and Charnov et al. (2013) who estimated that $M = 1.8k$.

This appendix has three sections. The first provides estimates of r_{max} from Hutchings et al. (2012) and estimates of M from the aforementioned life history invariants (simple arithmetic means were used when multiple estimates were available).

The second section represents details of a comparison between the NEVA scores for the Population Growth Rate attribute and those made by the reviewer. In calculating the score, I retained the values of k, age at maturity, and maximum age used by NEVA. However, the estimates of r_{max} and M were those estimated by me, as described above. Note that the 'calculated' NEVA score represents the mean of the attribute's 'sub-scores' for the parameters k, age at maturity, etc. Note also that the 'Hutchings scores' follow the NEVA scores. The third section provides a summary table of these comparisons.

APPENDIX 6:

REVIEW OF HARE ET AL. 2014MS. NORTHEAST FISHERIES CLIMATE VULNERABILITY ASSESSMENT (NEVA): AN APPLICATION OF THE NMFS' FISHERIES CLLIMATE VULNERABILITY ASSESSMENT METHODOLOGY.

Below is a brief review of this manuscript, comprising suggested edits, comments, and questions. Please note that these comments were prepared *prior* to the 28-30 October 2014 Panel Review Meeting.

Questions:

1. Line 49: "species with inherently low population growth rate" might be better phrased as "species with inherently low maximum per capita population growth rate".
2. Line 102: Spelling error: "elasmobranch".
3. Lines 125-126: The text here raises the question as to whether it is appropriate to weigh all attributes equally.
4. Line 133: Spelling error: "schemes".
5. Line 136 and following: Reference to Sam Dupont's excellent work on ocean acidification could be made (http://www.bioenv.gu.se/english/staff/Sam_Dupont_eng#Impact).
6. Line 345: The NEVA assessments were most sensitive to population growth rate, adult mobility, and stock status. One can interpret this to mean that these attributes merit the greatest attention in terms of strengthening their empirical bases (as is also noted on lines 503-504).
7. Lines 352-353: The observation that stock status and population growth rate were also characterized by low data quality scores underscores the previous point.
8. Lines 386-387: The ms has appropriately acknowledged that "expert bias is a concern". As solid as the NEVA methodology appears to be, acceptance of the methodology by other individuals in other regions for other sets of species will almost certainly demand a reasonably high level of repeatability in vulnerability assessments and scores.
9. Lines 429-440: Pursuant to the previous point, the apparent disagreement between the assessments and the conclusions of some more detailed studies might be perceived to be problematic when evaluating the utility of the NEVA methodology.
10. Line 545 and following: The conclusion about stock status and climate-change vulnerability is a key one.