Alaska RFM Data Deficient Framework (DDF)

Alaska Responsible Fisheries Management (RFM)
Certification Program
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RFM Data Deficient Fisheries Framework for RFM Fishery Standard Version 1.3
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Introduction

The Responsible Fisheries Management (RFM) Program's Data Deficient Framework (DDF) is an addendum to Version 1.3 of the RFM Scoring Guidance and has been designed for use by Assessment Teams in case of data deficient fisheries in Alaska that have been scoped out as such. The DDF entails the assessment of three key clauses of the RFM Standard using a modified but equivalent framework through the use of a risk assessment tool, the Productivity Susceptibility Analysis (PSA) as modified by Patrick et al. (2009) and previously used to demonstrate the utility of the vulnerability evaluation, on 166 U.S. fish stocks (within 6 fisheries) that had varying degrees of productivity, susceptibility, and data quality. The PSA evaluates an array of productivity and susceptibility attributes for a stock, from which index scores for productivity and susceptibility are computed and graphically displayed. The resulting vulnerability (to overfishing) score (1 = low and 3 = high, see Figure 1 for graphical representation) is used as a proxy score for the three selected (key) clauses (Figure 2) set to undergo a modified DDF assessment. All other clauses in Version 1.3 of the Standard are scored using the default system and information derived from the DDF can be used, if appropriate and as required, for various clauses in the RFM Standard.

Assessment Procedure

When a small scale and/or data deficient fishery/stock from Alaska applies for Certification to the Alaska RFM Program, the Certification Body (CB)'s Assessment Team in charge will conduct a Validation Assessment report for the fishery through the regular standard ad procedure. If key areas in the fishery are revealed as data deficient (i.e. not assessable with available data) then a modified assessment can be utilized for a number of clauses in Version 1.3 of the Standard, using the RFM Data Deficient Framework (DDF). The DDF provides for a risk assessment of clauses that require specific data and information about *1) the stock under consideration, 2) associated bycatch species (including retained and discarded catch), and 3) Endangered, Threatened and Protected (ETP) Species*. Retained bycatch includes those species which are retained but are not necessarily species of primary target, abundance or value. Among all, the main directive for the assessment of status of the stock under consideration using the DDF is a very conservative harvest, in line with the precautionary approach.

Habitats and ecosystem elements are not assessed under this framework as it is believed that sufficient scientific information is available Statewide in Alaska at the ecosystem and fishery level, to assess these items using the regular RFM clauses, for the majority of commercial fisheries currently in operation, small and large, State and federally managed. Among various published reports, key information sources include the yearly Ecosystem Sections of the Stock Assessment and Fishery Evaluation (SAFE)

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reports, the Ecosystem Considerations reports, and information relating to the Essential Fish Habitats (EFH) and related Habitat Areas of Particular Concern (HAPCs).

Data collection, site visits and stakeholder workshop

Prior to organizing the site visits, the assessment team shall have scoped the fishery through a validation assessment for available information on the fishery and more specifically on the productivity and susceptibility of the stocks and all the various attributes as tabled in the PSA tables. This information should be sent forward to the stakeholders prior to the site visits and stakeholder workshops due to the nature of this process. Given that the DDF is a risk assessment framework at its core, the presence of fishermen, industry operators, scientists, managers, experts and other informed stakeholders will be required during the site visit to help the assessment team complete the DDF. The assessment team shall therefore make all possible efforts to organize, effective and comprehensive workshops for these parties to attend and input expertise, information, as available and varied, across the stakeholder spectrum.

The PSA tables shall therefore be filled out during the workshops, which may be completed in one or two days, depending on the availability of fishery information and the complexity of the fishery and stock under consideration, and the associated bycatch and ETP species assessed.

Figure 1. Representative PSA scoring graph showing the overall scores to be applied and their relative level of risk[1]. Scores from 1 to 2.5 are consistent with a low potential risk or vulnerability to overfishing. Scores between 2.5 and 3 entail a medium risk or vulnerability to overfishing and shall incur in minor or major non-conformances for the stock under consideration. The cut off points are as follows: scores of 2.5 to 2.75 equate to a minor non-conformance, while scores of 2.75 to 3 equate to a major non-conformance. Note that here, the productivity values are inverted from left to right, opposite when compared to the PSA table as presented in the Patrick et al. 2009 report.

[1] http://www.oceansciencetrust.org/wp-content/uploads/2015/09/PSA-test-on-CA-Fisheries-Report-April2014.pdf

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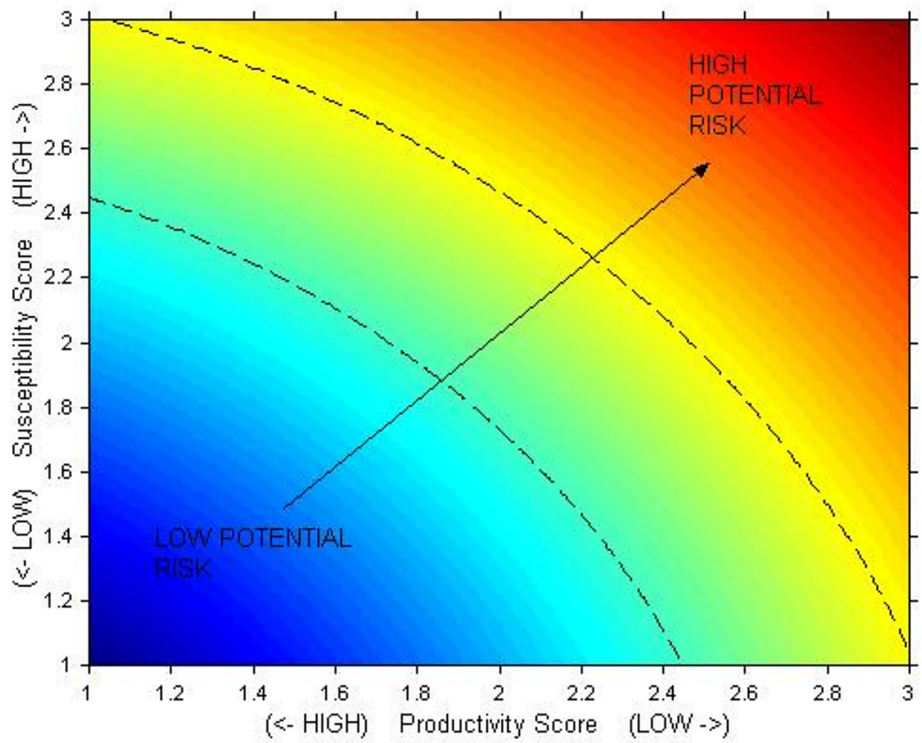

Figure 2. Primary Clauses of the RFM Standard Version 1.3 utilized within the Data Deficient Framework (DDF) in the case of an assessment involving a commercial fishery in Alaska with limited data availability.

- Assess **Stock Status** under Clause 6.3
- Assess **Associated Bycatch** under Clause 12.6
- Assess **ETP Species** under Clause 12.12

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Specific to deriving a score for the state of the stock under consideration, the Assessment Team will be using the PSA analysis and its results, including the available management measures in the fishery and other evidence to justify the score of clause 6.3.

6.3. Data and assessment procedures shall be installed measuring the position of the fishery in relation to the reference points. Accordingly, the stock under consideration shall not be overfished (i.e. above limit reference point or proxy) and the level of fishing permitted shall be commensurate with the current state of the fishery resources, maintaining its future availability, taking into account that long term changes in productivity can occur due to natural variability and/or impacts other than fishing.

Guidance Box

Low Confidence Rating (Critical NC) [Vulnerability Score = > 3] High Susceptibility, Low Productivity = Very High Risk	Medium Confidence Rating (Major NC) [Vulnerability Score = 2.75-3] Medium - High Risk	Medium Confidence Rating (Minor NC) [Vulnerability Score = 2.5 -2.75] Low - Medium Risk	High Confidence Rating (Full Conformance) [Vulnerability Score = 1-2.5] Low Susceptibility, High Productivity = Low Risk
There is **no** measurement of the position of the fishery in relation to the reference points exists, and maintenance of the level of fishing permitted is resulting in an overfished status.	The measurement of the position of the fishery in relation to the reference points is carried out, but the maintenance of the level of fishing permitted is likely conducive to overfishing.	The measurement of the position of the fishery in relation to the reference points is carried out, but the maintenance of the level of fishing permitted may be conducive to overfishing.	Data and assessment procedures are installed measuring the position of the fishery in relation to the reference points. Accordingly, the stock under consideration is not overfished

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			(i.e. it is above limit reference point or proxy) and the level of fishing permitted is commensurate with the current state of the fishery resources, maintaining its future availability, taking into account that long-term changes in productivity can occur due to natural variability and/or impacts other than fishing.

Evaluation Parameters

Note for data deficient fisheries. If a formal stock assessment that uses clear quantitative information to define stock status and or/derive the relative reference points for management purposes (i.e. surplus production models, statistical catch at age models, and virtual population analysis models) is not available, then the PSA analysis of the RFM Data Deficient Framework can be utilized.

The Assessment Team shall calculate vulnerability scores for the stock under consideration and also document other existing information about the state of the stock under consideration. Other existing information to be reviewed may include existing stock assessment efforts and reports, reference point in force and harvest control rules. Vulnerability scores from 1 to 2.5 are consistent with a low potential risk or vulnerability to overfishing. Scores between 2.5 and 3 entail a medium risk and shall incur in minor or major non-conformances for the stock under consideration. The cut off points are as follows: score of 2.5 to 2.75 equate to a minor non-conformance, while scores of 2.75 to 3 equate to a major non-conformance.

The current status of the stock in relation to reference points, is used to determine the level of fishing permitted, to ensure the latter is commensurate with the current state of the fishery resources (i.e. close to or above target reference point and most importantly, not overfished or below its limit reference point or proxy) taking into account that long term changes in productivity can occur due to natural variability and/or impacts other than fishing. The stock should be ideally positioned, at a minimum, above the midway

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point between target and limit reference point.

Further to the vulnerability score applied, to help with proper assessment of the clause, the data quality score shall be computed and considered separately for the productivity and susceptibility scores as a weighted average of the data quality scores for the individual attributes. This denotes the overall quality of the data or belief in the score rather than the actual type of data used in the analysis. For example, a data quality score of 3 (related to limited data), could be derived from data equally divided among scores of "1, best data" and "5, no data." It is important to highlight the data quality associated with each vulnerability score when plotting the data on an x-y scatter plot.

The remaining clauses under Fundamental 6, clause 6.1, 6.2 and 6.4 shall be scored using standard methodology and by taking into account the available information, the information derived from the PSA analysis, reference points or proxies available and the management measures in place to responsibly manage the stock and fishery under consideration.

In terms of bycatch, clause 12.6 shall be addressed to assess the status of associated non-target species catch (retained and discarded).

Clause 12.6. Non target catches, including discards, of stocks other than the "stock under consideration" shall be monitored and shall not threaten these non-target stocks with serious risk of extinction, recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible; if such impacts arise, effective remedial action shall be taken.

Guidance Box

Low Confidence Rating (Critical NC) [Vulnerability Score = > 3] High Susceptibility, Low Productivity = Very High Risk	Medium Confidence Rating (Major NC) [Vulnerability Score = 2.75-3] Medium - High Risk	Medium Confidence Rating (Minor NC) [Vulnerability Score = 2.5 -2.75] Low - Medium Risk	High Confidence Rating (Full Conformance) [Vulnerability Score = 1-2.5] Low Susceptibility, High Productivity = Low Risk

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Non-target catches, including discards, of stocks other than the "stock under consideration" are **not** monitored and threaten one or more of these non-target stocks with serious risk of extinction, recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible. If such impacts arise, effective remedial action is **not** taken.	Non-target catches, including discards, of stocks other than the "stock under consideration" are **insufficiently** monitored and likely threaten one or more of these non-target stocks with serious risk of extinction, recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible. If such impacts arise, effective remedial action is **insufficiently** taken.	Non-target catches, including discards, of stocks other than the "stock under consideration" are **moderately** monitored and may threaten one or more of these non-target stocks with serious risk of extinction, recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible. If such impacts arise, effective remedial action is **moderately** taken.	Non-target catches, including discards, of stocks other than the "stock under consideration" **are** monitored and do not threaten these non-target stocks with serious risk of extinction, recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible. If such impacts arise, effective remedial action **is** taken.
Evaluation Parameters **Note for data deficient fisheries. If clear data is not available to establish the status of bycatch species associated with the target catch then the Data Deficient Framework can be used.** **For bycatch species, the assessment team is required to evaluate the effects of the fishery under assessment on bycatch in terms of Main Associated Species (90% of total catch by weight) and Minor Associated Species (10% of total catch by weight).** **The evaluation for Main Associated Species aims at establishing whether the overall effects of fishing on the unit of certification and all significant removals are accounted for, and that the management strategy and relative measures are effective in maintaining the Main Associated Species from experiencing overfishing and other impacts that are likely to be irreversible or very slowly reversible.** **The evaluation for Minor Associated Species would aim primarily at establishing that data is available for them, but an assessment similar to that performed for Main Associated Species is not required. However, if it is suspected or data is available showing that one or more of the Minor Associated Species stocks is suffering from overfishing or impaired recruitment/productivity, then the effects of the fishery on this species and its**			

significance shall be assessed and scored appropriately. In this effect, the management strategy and relative measures shall be effective in maintaining the Minor Associated Species from experiencing overfishing and other impacts that are likely to be irreversible or very slowly reversible.

Each Main or qualifying Minor Associated Species shall be assessed using the PSA tool.

Exceptions. If the target fishery catch is between 300 thousand and 1 million tonnes, the Minor Associated Species that make up 5% of the total catch by weight of the target species under consideration will be assessed in the same way as Main Associated Species. Furthermore, if a species or species group is highly affected by fishing (e.g. sharks and skates) due to it being relatively slow growing or a species highly susceptible to a given fishing gear, or already biologically depleted, then the threshold is 3% of total catch by weight, before the associated species is assessed as a Main Associated Species.

If catches endanger these stocks with serious risk of extinction, recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible serious risk of extinction, effective remedial action shall be taken by the management organization. Examples of irreversible or very slowly reversible effects on bycatch species include excessive depletion of very long-lived organisms. To mitigate effects that are likely to be irreversible or very slowly reversible requires those effects to be made less severe such that they are no longer likely to be irreversible or very slowly reversible. Examples of management measures may include incidental take allowances, bycatch caps, prohibited retention, safe release practices, or use of bycatch reduction devices or practices. Remedial action shall be considered effective if it reduces the impact of the fishery on non-target species to the point where there is no longer a risk of extinction.

Further to the vulnerability score applied, to help with proper assessment of the clause, the data quality score shall be computed and considered separately for the productivity and susceptibility scores as a weighted average of the data quality scores for the individual attributes. This denotes the overall quality of the data or belief in the score rather than the actual type of data used in the analysis. For example, a data quality score of 3 (related to limited data), could be derived from data equally divided among scores of “1, best data” and “5, no data.” It is important to highlight the data quality associated with each vulnerability score when plotting the data on an x-y scatter plot.

In terms of ETP species, clause 12.12 shall be used as the primary clause informing the status and risk to this class of species.

12.12 There shall be outcome indicator(s) consistent with achieving management objectives that seek to ensure that endangered species are

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protected from adverse impacts resulting from interactions with the unit of certification and any associated culture or enhancement activity, including recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible.

Guidance Box

Low Confidence Rating (Critical NC) [Vulnerability Score = > 3] High Susceptibility, Low Productivity = Very High Risk	Medium Confidence Rating (Major NC) [Vulnerability Score = 2.75-3] Medium - High Risk	Medium Confidence Rating (Minor NC) [Vulnerability Score = 2.5 -2.75] Low - Medium Risk	High Confidence Rating (Full Conformance) [Vulnerability Score = 1-2.5] Low Susceptibility, High Productivity = Low Risk
There are **no** outcome indicators that seek to ensure that endangered species are protected from adverse impacts resulting from interactions with the unit of certification and any associated culture or enhancement activity, including recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible.	There are **insufficiently** effective outcome indicators that seek to ensure that endangered species are protected from adverse impacts resulting from interactions with the unit of certification and any associated culture or enhancement activity, including recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible.	There are **moderately** effective outcome indicators that seek to ensure that endangered species are protected from adverse impacts resulting from interactions with the unit of certification and any associated culture or enhancement activity, including recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible.	There **are** effective outcome indicators that seek to ensure that endangered species are protected from adverse impacts resulting from interactions with the unit of certification and any associated culture or enhancement activity, including recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible.
Evaluation Parameters **Note for data deficient fisheries. If clear data is not available to establish the status of**			

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ETP species associated with the target fishery then the Data Deficient Framework can be used.

ETP species must be acknowledged as such and recognized by national legislation adopted at the State and Federal level in Alaska, or when recognized through a binding International Agreement. Alternatively, species listed under Appendix 1 of the Convention on International Trade in Endangered Species (CITES) or under the IUCN Redlist and impacted negatively by the fishery (i.e. direct or indirect mortality) shall be assessed as ETP unless it can be proven that their status in Alaska waters is above the point where recruitment is impaired or where other similar proxies indicate that the species is not biologically depleted.

The Assessment Teams shall qualify ETPs based on recognized State and federally Endangered, Threatened Protected species in Alaska. To be considered effective, the assessment of ETP species within the RFM scheme has to ensure that a full score is assigned to those cases where ETPs are managed coherently starting from the policy/plan level (i.e. legally recognized as ETPs, formal and agreed management plans and measures) subsequently towards implementation and effectiveness of the management measures in achieving the objectives of the plan agreed for management of these species.

The team shall provide evidence for established outcome indicators (e.g. in a fishery management plan or other regulation) that seek to ensure that endangered species are protected (through state or federal regulations) from adverse impacts resulting from interactions with the unit of certification and any associated culture or enhancement activity, including recruitment overfishing or other impacts that are likely to be irreversible or very slowly reversible. Management objectives shall be achieved accordingly.

Further to the vulnerability score applied, to help with proper assessment of the clause, the data quality score shall be computed and considered separately for the productivity and susceptibility scores as a weighted average of the data quality scores for the individual attributes. This denotes the overall quality of the data or belief in the score rather than the actual type of data used in the analysis. For example, a data quality score of 3 (related to limited data), could be derived from data equally divided among scores of “1, best data” and “5, no data.” It is important to highlight the data quality associated with each vulnerability score when plotting the data on an x-y scatter plot.

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The Productivity Susceptibility Analysis (PSA) and Its Application[2]

Summary

In 2009, the National Marine Fisheries Service (NMFS) revised the National Standard 1 (NS1) guidelines that govern federal fisheries management in the United States. The term "vulnerability" is referenced in sections of the NS1 guidelines that deal with: 1) differentiating between "fishery" and "ecosystem components" stocks, 2) assembling and managing stock complexes, and 3) creating management control rules.

While quantitative modelling provides the most rigorous method for determining whether a stock is vulnerable to becoming overfished or is currently experiencing overfishing, insufficient data exist to perform such modeling for a number of commercially exploited stocks managed by federal and State agencies in Alaska. These relatively data-poor stocks highlight the need to develop a flexible semi-quantitative methodology that can be applied broadly to many fisheries and regions.

The vulnerability of a stock to becoming overfished is defined in the NS1 guidelines as a function of its productivity ("the capacity of the stock to produce MSY and to recover if the population is depleted") and its susceptibility to the fishery ("the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery").

The PSA evaluates an array of productivity and susceptibility attributes for a stock, from which index scores for productivity and susceptibility are computed and graphically displayed. The PSA methodology described here below scores attributes on a three-point scale (i.e., 1 = low, 2 = moderate, 3 = high). The weighted average of each factor's attribute scores is plotted in an x-y scatter plot and the ***vulnerability score*** of the stock is calculated by measuring the Euclidean distance of the datum point from the origin of the plot. Stocks that receive a low productivity score and a high susceptibility score are considered to be the most vulnerable, while stocks with a high productivity score and low susceptibility score are considered to be the least vulnerable.

The Patrick et al. (2009) PSA methodology contains several modifications to previously published examples, such as: 1) expanding the number of attributes scored from 13 to 22 to consider both direct and indirect impacts; 2) redefining the attribute scoring

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[2] The main text on the PSA has been modified from Patrick, W. S., P. Spencer, O. Ormseth, J. Cope, J. Field, D. Kobayashi, T. Gedamke, E. Cortés, K. Bigelow, W. Overholtz, J. Link, and P. Lawson. 2009. Use of productivity and susceptibility indices to determine stock vulnerability, with example applications to six U.S. fisheries. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-101, 90 p. Available online at: http://spo.nmfs.noaa.gov/tm/TM101.pdf

bins to align with life history characteristics of fish species found in U.S. waters; 3) developing an attribute weighting system that allows users to customize the analysis for a particular fishery; 4) developing a data quality index based on five tiers of data quality, ranging from best data to no data, to provide an estimate of information uncertainty; and 5) developing a protocol for addressing stocks captured by different sectors of a fishery (e.g., different gear types, different regions).

Data quality is a consideration in interpreting the vulnerability scores, and it is recommended that assessors employ the precautionary approach when evaluating a PSA with limited or poor data.

1. DIFFERENTIATING BETWEEN FISHERY AND ECOSYSTEM COMPONENT STOCKS

The NMFS defines a “fishery” as one or more stocks that can be treated as a unit for purposes of conservation and management and can be identified on the basis of geographical, scientific, technical, recreational, and economic characteristics; and any fishing for such stocks (see MSA § 3(13)). Given the broad definition of “fishery,” managers have had considerable discretion in defining the “fishery” in their FMPs (73 FR 32527, June 9, 2008). Some FMPs may include only one stock (e.g., Mid-Atlantic Council – Bluefish) while others include hundreds of species (e.g., Western Pacific Council – Coral Reef Ecosystem). The latter is an example of a fishery management council including all species within their management area into the FMP in order to monitor the impacts of the fishery on other parts of the ecosystem. Because the requirements for assigning annual catch limits (ACLs) and for establishing accountability measures (AMs) were meant to be applied to only those stocks and stock complexes considered to be “in the fishery”, NMFS suggests that species added to an FMP for data collection or ecosystem considerations could be exempted from ACL and AMs requirements and classified as “ecosystem components” (see NS1 Guidelines § 600.310(d)).

In general, stocks “in the fishery” include target stocks (those that are directly pursued by commercial fisheries) and non-target stocks (fish species that are not targeted but are caught incidentally in target fisheries). Stocks may be managed as single species or in stock complexes. All stocks “in the fishery” are generally retained for sale or personal use and/or are vulnerable to overfishing, being overfished, or could become so in the future based on the best available information.

Because ecosystem component stocks are a type of non-target stock not generally retained for sale or personal use, occasional retention of the species is not in and of itself a reason to classify the stock as “in the fishery”. In addition, ecosystem component stocks must not be subject to overfishing, becoming overfished, or likely to become so in the future based on the best available information, in the absence of conservation and management measures. While these NS1 definitions are useful, they lack technical details on how to determine whether a non-targeted stock is likely to become subject to overfishing or become overfished in the future. Instead, the NS1 guidelines refer generally to this likelihood as the “vulnerability” of a stock, noting that stocks in an FMP should be monitored regularly to determine whether their vulnerability has changed.

The NS1 guidelines recommend that if individual stocks within a complex have a wide range of
vulnerabilities, the stock complex should either be divided into smaller complexes with similar vulnerabilities, or an indicator stock should be chosen to represent the more vulnerable stocks within the complex. If data are insufficient to take these actions, then the stock complex should be managed more conservatively.

2. DETERMINING VULNERABILITY

The vulnerability of a stock to becoming overfished is defined here as the potential for the productivity of the stock to be diminished by direct and indirect fishing pressure. Vulnerability is expected to differ among stocks based on the life history characteristics and susceptibility to the fishery. This definition follows from Stobutzki et al. (2001b), and includes the two key elements of 1) stock productivity (a function of the stock’s life-history characteristics); and 2) stock susceptibility, or the degree to which the fishery can negatively impact the stock.

This definition differs from that often used in evaluation of species at risk of extinction, where the concern is the likelihood of recovering from a diminished abundance and the focus is placed upon the productivity of the stock (Musick 1999). In this case, a stock with a low level of productivity would not be considered vulnerable to fishing unless there was also some susceptibility of the stock to the fishery. The interaction between the productivity of a species and its susceptibility to the fishery has a long history in fisheries science (Beverton and Holt 1957, Adams 1980, Jennings et al. 1998, Reynolds et al. 2001, Dulvy et al. 2004). Several risk assessment methods were reviewed to determine which approach would be flexible and broadly applicable across fisheries and regions, and was best suited for the NS1 guidelines use of the term vulnerability.

3. THE PRODUCTIVITY AND SUSCEPTIBLITY ANALYSIS (PSA)

The PSA was originally developed to classify differences in bycatch sustainability in the Australian prawn fishery (Milton 2001, Stobutzki et al. 2001b) by evaluating the productivity of a stock and its susceptibility to the fishery. Stobutzki et al. (2001b)

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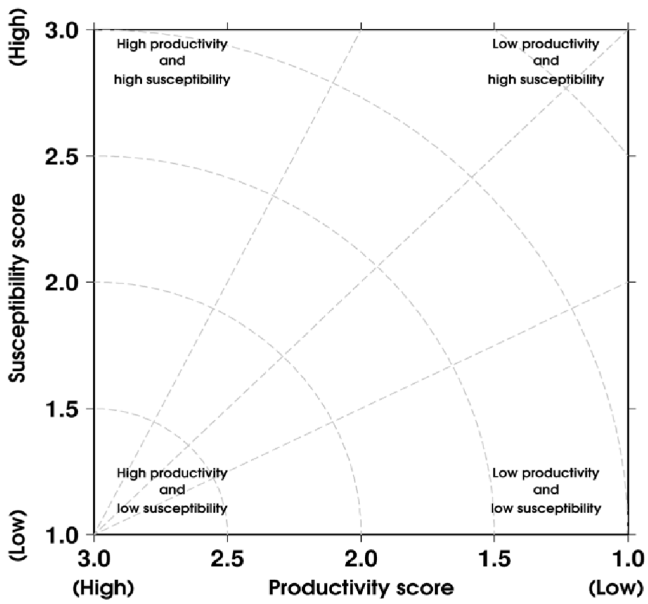
define "productivity" as the capacity of a species to recover once the population is depleted (i.e. resilience) and "susceptibility" as the likelihood or propensity of species to capture and mortality from the fishery. In the original form of the PSA, values for the two factors productivity (*p*) and susceptibility (*s*) of a stock were determined by providing a core ranging from 1 to 3 for a standardized set of attributes related to each factor. When data were lacking, scores could be based on similar taxa or given the highest vulnerability score as a precautionary approach. The individual attribute scores were then averaged for each factor and graphically displayed on an x-y scatter plot (Fig. 3).

Figure 3. An example of the productivity and susceptibility x-y plot. This plot has been modified slightly from Stobutzki et al. (2001b) by reversing the productivity scale to begin with 3 (high productivity) instead of 1 (low productivity).



The overall vulnerability score (*v*) of a stock is calculated as the Euclidean distance from the origin of the x-y scatter plot (i.e., 3.0, 1.0) and the datum point (note the x-axis scale is reversed):

$$v = \sqrt{(p-3)^2 + (s-1)^2}$$

Stocks that received a low productivity score and a high susceptibility score are considered to be the most vulnerable to overfishing, while stocks with a high productivity score and low susceptibility score are considered to be the least vulnerable. The PSA was later modified in 2004 by the Australian Ecological Risk Assessment (AERA) team (Hobday et al. 2004), who expanded the structure of the PSA to include habitat and community components so the tool could be used to assess the vulnerability of an ecosystem. In 2007, the AERA also modified the susceptibility score to be the product rather than the average of the susceptibility attributes (Hobday et al. 2007). Revisions to the PSA were also suggested in Lenfest expert working group reports on setting annual catch limits for U.S. fisheries (Rosenberg et al. 2007) and determining the risk of over-exploitation for data-poor pelagic Atlantic sharks (Simpfendorfer et al. 2008).

4. THE VULNERABILITY INDEX

4.1 Identifying Productivity and Susceptibility Attributes

Originally, the Stobutzki et al. (2001b) and Milton (2001) analyses were limited to 13 attributes (7 susceptibility and 6 productivity attributes). Using partial correlations, Stobutzki et al. (2001b) found no redundancy in the 13 attributes. Hobday et al. (2004) and Rosenberg et al. (2007) expanded to 75 the number of attributes that could be considered for scoring, none of which had previously been examined for redundancy. Development of the PSA utilized here began with examination of the attributes developed by Hobday et al. (2004). This list of attributes was reduced to 35 after removal of attributes perceived as redundant or pertaining more to risk analyses for fishing impacts on habitat quality or overall ecosystem health. The remaining attributes were evaluated in a two-phase process. In phase one, individual scores were provided (i.e., "yes", "no", or "maybe") to determine whether each attribute was: 1) scientifically valid for calculating productivity or susceptibility of a stock, 2) useful at different scales (i.e., stocks of various sizes and spatial distributions), and 3) capable of being calculated for most fisheries (i.e., data availability). Attributes receiving a majority of "yes" scores for all three factors were retained. In phase 2, attributes receiving mixed scores, as well as new attributes that had not been previously identified, were evaluated in a group discussion. Through this process, 18 (9 productivity, 9 susceptibility) of the 35 attributes were selected and four new attributes were added, including: 1) recruitment pattern, 2) management strategy, 3) fishing rate relative to natural mortality, and 4) desirability/value of the fishery. Overall, 22 attributes (10 productivity, 12 susceptibility) were selected for the analysis.

The PSA here described scores the productivity and susceptibility attributes on a scale of 1 to 3, although an intermediate score (e.g., 1.5 or 2.5) can be used when data span two categories.

Not all of the productivity and susceptibility attributes listed in Table 1 will be equally useful for determining the vulnerability of a stock. Previous versions of the PSA utilized an attribute weighting scheme in which higher weights were applied to the more important attributes (Stobutzki et al. 2001b, Hobday et al. 2004, Rosenberg et al. 2007). Patrick et al. (2009) recommend a default weight of 2 for the productivity

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and susceptibility attributes, where attribute weights can be adjusted within a scale from 0 to 4 to customize the analysis for each fishery. However, the authors did not recommend adjusting the weighting among stocks within any given fishery, as inconsistent weights for individual stocks within a PSA analysis can cause problems with transparency and interpretation of the results and analysis. In determining the proper weighting of each attribute, assessors should consider the relevance of the attribute for describing productivity or susceptibility rather than the availability of data for that attribute (e.g., data-poor attributes should not automatically receive low weightings). In some rare cases, it is also anticipated that some attributes will receive a weighting of zero, removing them from the analysis, because the attribute has no relation to the fishery and its stocks.

Table 1. Productivity and susceptibility attributes and rankings.

	Ranking		
Productivity attribute	**High (3)**	**Moderate (2)**	**Low (1)**
r	> 0.5	0.16 - 0.5	< 0.16
Maximum age	< 10 years	10 - 30 years	> 30 years
Maximum size	< 60 cm	60 - 150 cm	> 150 cm
von Bertalanffy growth coefficient (*k*)	> 0.25	0.15 - 0.25	< 0.15
Estimated natural mortality	> 0.40	0.20 - 0.40	< 0.20
Measured fecundity	> 10e4	10e2 - 10e3	< 10e2
Breeding strategy	0	Between 1 and 3	≥ 4
Recruitment pattern	Highly frequent recruitment success (> 75% of year classes are successful)	Moderately frequent recruitment success (between 10% and 75% of year classes are successful)	Infrequent recruitment success (< 10% of year classes are successful)
Age at maturity	< 2 year	2 - 4 years	> 4 years
Mean trophic level	< 2.5	Between 2.5 and 3.5	> 3.5

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Areal overlap	< 25% of stock occurs in the area fished	Between 25% and 50% of the stock occurs in the area fished	> 50% of stock occurs in the area fished
Geographic concentration	Stock is distributed in > 50% of its total range	Stock is distributed in 25% to 50% of its total range	Stock is distributed in < 25% of its total range
Vertical overlap	< 25% of stock occurs in the depths fished	Between 25% and 50% of the stock occurs in the depths fished	> 50% of stock occurs in the depths fished
Seasonal migrations	Seasonal migrations decrease overlap with the fishery	Seasonal migrations do not substantially affect the overlap with the fishery	Seasonal migrations increase overlap with the fishery
Schooling/Aggregation and other behavioral responses	Behavioral responses decrease the catchability of the gear	Behavioral responses do not substantially affect the catchability of the gear	Behavioral responses increase the catchability of the gear (i.e., hyperstability of CPUE with schooling behavior)
Morphology affecting capture	Species shows low selectivity to the fishing gear.	Species shows moderate selectivity to the fishing gear.	Species shows high selectivity to the fishing gear.
Desirability/Value of the fishery	Stock is not highly valued or desired by the fishery (< $1/lb; < $500K/yr landed; < 33% retention)	Stock is moderately valued or desired by the fishery ($1 - $2.25/lb; $500k - $10,000K/yr landed; 33-66% retention)	Stock is highly valued or desired by the fishery (> $2.25/lb; > $10,000K/yr landed; > 66% retention)
Management strategy	Targeted stocks have catch limits and proactive accountability measures; non-target stocks are closely monitored.	Targeted stocks have catch limits and reactive accountability measures	Targeted stocks do not have catch limits or accountability measures; non-target stocks are not closely monitored.
Fishing rate relative to *M*	< 0.5	0.5 - 1.0	> 1
Biomass of spawners (SSB) or other proxies	*B* is > 40% of *B0* (or maximum observed from time series of biomass estimates)	*B* is between 25% and 40% of *B0* (or maximum observed from time series of biomass estimates)	*B* is < 25% of *B0* (or maximum observed from time series of biomass estimates)
Survival after capture and release	Probability of survival > 67%	Probability of survival between 33% and 67%	Probability of survival < 33%
Fishery impact to EFH or habitat in general for non-targets	Adverse effects absent, minimal or temporary	Adverse effects more than minimal or temporary but are mitigated	Adverse effects more than minimal or temporary and are not mitigated

The scoring criteria should ideally be based on clear rules and leave as few attributes as possible up to subjective interpretation (Lichtensten and Newman 1967, Janis 1983, Von Winterfeldt and Edwards 1986, Bell et al. 1988). However, not all of the selected attributes translate into quantitative definitions for the scoring criteria, a situation also seen by Stobutzki et al. (2002). To reduce scoring bias, all weighting and attribute scores should be determined using a collaborative process (e.g., the Delphi method – Okoli and Pawlowski 2004, Landeta 2006), rather than being scored by one or two individuals (Janis 1983, Von Winterfeldt and Edwards, 1986, Bell et al. 1988).

4.2 Stock Productivity Attributes

"Productivity" is defined as the capacity of the stock to recover once the population is depleted (Stobutzki et al. 2001b). This largely reflects the life-history characteristics of the stock. While there is some redundancy among the productivity attributes, the inclusion of multiple life history traits allows a more comprehensive assessment of productivity. Many of these attributes are based on the Musick (1999) qualitative extinction risk assessment and the PSA of Stobutzki et al. (2001b). However, the scoring thresholds have been modified in many cases to better suit the distribution of life history characteristics observed in U.S. fish stocks (Table 2).

Table 2. Productivity attribute thresholds based on the empirical relationships between *tmax*, *M*, *k*, and *tmat* (noted as "Modeling"), as well as a survey of stocks landed by U.S. fisheries representing all six regional management areas (n = 141; noted as "US Fisheries").

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Attribute	Source	Productivity Low	Productivity Moderate	Productivity High
K	Modeling	< 0.10	0.10 - 0.30	> 0.30
	U.S. fisheries	< 0.15	0.15 - 0.25	> 0.25
	Threshold	< 0.15	0.15 - 0.25	> 0.25
M (*M*/yr)	Modeling	< 0.14	0.14 - 0.40	> 0.40
	U.S. fisheries	< 0.20	0.20 - 0.40	> 0.40
	Threshold	< 0.20	0.20 - 0.40	> 0.40
t_{max} (yrs)	Modeling	> 30	10 - 30	< 10
	U.S. fisheries	> 30	10 - 30	< 10
	Threshold	> 30	10 - 30	< 10
t_{mat} (yrs)	Modeling	> 9	3 - 9	< 3
	U.S. fisheries	> 4	2 - 4	< 2
	Threshold	> 4	2 - 4	< 2
L_{max} (cm)	Modeling	-	-	-
	U.S. fisheries	> 150	60 - 150	< 60
	Threshold	> 150	60 - 150	< 60

Information on maximum length, maximum age, age at maturity, natural mortality, and von Bertalanffy growth coefficient were available from 140+ stocks considered to be representative of U.S. fisheries (see Appendix A of the Patrick et al. 2009 publication for details). For these attributes, analysis of variance (ANOVA) was used to define attribute scoring thresholds that produced significantly different bins of data.

In order to ensure consistency in these attributes, the scoring thresholds from the analysis of variance were also compared to published relationships among maximum age and natural mortality (Alverson and Carney 1975, Hoenig 1983), von Bertalanffy growth coefficient, and age at maturity (Froese and Binohlan 2000).

The authors defined 10 productivity attributes:

Population growth (*r*): This is the intrinsic rate of population growth or maximum population growth that would be expected to occur in a population under natural conditions (i.e., no fishing), and thus directly reflects stock productivity. The scoring definitions were taken from Musick (1999), who stated that *r* should take precedence over other productivity attributes (e.g., given a weighting of 4) as it combines many of the other attributes defined below.
Maximum age (*tmax*): Maximum age is a direct indication of the natural mortality rate (*M*), where low levels of *M* are negatively correlated with high maximum ages (Hoenig 1983). The scoring definitions were based on the ANOVA applied to the observed fish

stocks considered to be representative of U.S. fisheries (Appendix A of the Patrick et al. 2009 report). The *tmax* for a majority of these fish ranges between 10 to 30 years.
Maximum size (*Lmax*): Maximum size is also correlated with productivity, with large fish tending to have lower levels of productivity (Roberts and Hawkins 1999), though this relationship tends to degrade at higher taxonomic levels. The scoring definitions were based on the ANOVA applied to the observed fish stocks considered to be representative of U.S. fisheries (Appendix A of the Patrick et al. 2009 report). The *Lmax* for a majority of these fish ranges between 60 to 150 cm TL.
Growth coefficient (*k*): The von Bertalanffy growth coefficient measures how rapidly a fish reaches its maximum size, where long-lived, low-productivity stocks tend to have low values of *k (*Froese and Binohlan 2000). The attribute scoring definitions based upon the ANOVA applied to the fish stocks considered to be representative of U.S. fisheries was 0.15 to 0.25. This is roughly consistent with the values obtained from Froese and Binohlan's (2000) empirical relationship $k = 3/\ tmax$ of 0.1 to 0.3, based upon tmax values of 10 and 30.
Natural mortality (*M*): Natural mortality rate directly reflects population productivity, as stocks with high rates of natural mortality will require high levels of production in order to maintain population levels. Several methods for estimating *M* rely upon the negative relationship between *M* and *tmax*, including Hoenig's (1983) regression based upon empirical data, the quantile method that depends upon exponential mortality rates (Hoenig 1983), and Alverson and Carney's (1975) relationship between mortality, growth, and *tmax*. The attribute scoring thresholds from the ANOVA applied to the fish stocks considered to be representative of U.S. fisheries was 0.2 to 0.4, and were roughly consistent with those produced from Hoenig's (1983) empirical regression of 0.14 to 0.4, based on *tmax* values of 10 and 30.
Fecundity: Fecundity (i.e., the number of eggs produced by a female for a given spawning event or period) varies with size and age of the spawner, so the authors followed Musick's (1999) recommendation that fecundity should be measured at the age of first maturity. As Musick (1999) noted, low values of fecundity imply low population productivity but high values of fecundity do not necessarily imply high population productivity; thus, this attribute may be more useful at the lower fecundity values. The scoring definitions were taken from Musick (1999), which range between fecundities of 1,000 and 100,000.
Breeding strategy: The breeding strategy of a stock provides an indication of the level of mortality that might be expected for the offspring in the first stages of life. To estimate offspring mortality, the authors used Winemiller's (1989) index of parental investment. The index ranges in score from 0 to 14 and is composed of: 1) the

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placement of larvae or zygotes (i.e., in nest or into water column; score ranges from 0 to 2); 2) the length of time of parental protection of zygotes or larvae (score ranges from 0 to 4); and 3) the length of gestation period or nutritional contribution (score ranges from 0 to 8). To translate Winemiller's index into our 1-3 ranking system, the authors examined King and McFarlane's (2003) parental investment scores for 42 North Pacific stocks. These 42 stocks covered a wide range of life-histories and habitats, including 10 surface pelagic, 3 mid-water pelagic, 3 deep-water pelagic, 18 near-shore benthic, and 9 offshore benthic stocks. Thirty-one percent of the stocks had a Winemiller score of zero, and 40% had a Winemiller score of 4 or higher, so 0 and 4 were used as the breakpoints between the ranking categories.
Recruitment pattern: Stocks with sporadic and infrequent recruitment success often are long-lived and thus might be expected to have lower levels of productivity (Musick 1999). This attribute is intended as a coarse index to distinguish stocks with sporadic recruitment patterns and high frequency of year-class failures from those with relatively steady recruitment. Thus, the frequency of year-class success (defined as exceeding a recruitment level associated with year-class failure) was used for this attribute. Because this attribute was viewed as a course index, 10% and 75% were chosen as the breakpoints between the ranking categories so that scores of 1 and 3 identified relatively extreme differences in recruitment patterns.
Age at maturity (*tmat*): Age at maturity tends to be positively related with maximum age (*tmax*), as long-lived, lower productivity stocks will have higher ages at maturity relative to short-lived stocks. The attribute scoring definitions based upon the ANOVA applied to the fish stocks considered to be representative of U.S. fisheries was 2 to 4 years. This range is lower than that observed from Froese and Binohlan's (2000) empirical relationship between *tmat* and *tmax*, which was 3 to 9 based upon values of *tmax* of 10 and 30. However, Froese and Binohlan (2000) used data from many fish stocksaround the world, which may not be representative of U.S. stocks. For the PSA, the thresholds obtained from the ANOVA applied to stocks considered representative of U.S fisheries were used.
Mean trophic level: The position of a stock within the larger fish community can be used to infer stock productivity, with lower-trophic-level stocks generally being more productive than higher-trophic-level stocks. The trophic level of a stock can be computed as a function of the trophic levels of the organisms in its diet. For this attribute, stocks with trophic levels higher than 3.5 were categorized as low productivity stocks and stocks with trophic levels less than 2.5 were categorized as high-productivity stocks, with moderate productivity stocks falling between these bounds. These attribute threshold roughly categorize piscivores to higher trophic levels, omnivores to intermediate trophic levels, and planktivores to lower trophic levels (Pauly et al. 1998).

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4.3 Susceptibility to fishing attributes

Susceptibility is defined as the potential for a stock to be impacted by a fishery. Previous applications have focused on the catchability and mortality of stocks, and addressed other attributes such as management effectiveness and effects of fishing gear on habitat quality in subsequent analyses (Hobday et al. 2007). The susceptibility index includes all these attributes in an effort to make the results of analysis more transparent and understandable. However, since these attributes address different aspects of susceptibility, the authors have differentiated the catchability and management attributes as subcategories under the susceptibility factor.

Similar to AERA's susceptibility attributes (Hobday et al. 2007), catchability attributes provide information on the likelihood of a stock's capture by a particular fishery, given the stock's range, habitat preferences, and behavioural responses and/or morphological characteristics that may affect its susceptibility to the fishing gear deployed in that fishery. Management attributes consider how the fishery is managed: fisheries with conservative management measures in place that effectively control the catch in the fishery are less likely to have overfishing occurring. For some of these attributes, criteria are somewhat general in order to accommodate the wide range of fisheries and systems. The authors defined 12 susceptibility (7 catchability and 5 management) attributes.

4.3.1 Catchability

Areal overlap: This attribute pertains to the extent of geographic overlap between the known distribution of a stock and the distribution of the fishery. Greater overlap implies greater susceptibility, as some degree of geographical overlap is necessary for a fishery to impact a stock. The simplest approach is to determine, either qualitatively or quantitatively, the proportion of the spatial distribution of a given fishery that overlaps that of the stock, based on known geographical distributions of both. If data regarding spatial distributions are lacking, inferences on areal overlap may be made from knowledge of depth distributions of the fishery and the stock. For example, an upper bound estimate of areal overlap may be made from knowledge of the portion of fishing effort that occurs in the areas which encompass the depths occupied by a species.
Geographic concentration: Geographical concentration is the extent to which the stock is concentrated into small areas. The rationale for including this attribute is that a stock with a relatively even distribution across its range may be less susceptible than a highly aggregated stock. For some species, a useful measure of this attribute is the

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minimum estimate of the proportion of area occupied by a certain percentage of the stock (Swain and Sinclair 1994), which can be computed in cases where survey data exist. First, the cumulative frequency of the survey catch per unit effort (CPUE) is computed as: $$F(c) = 100\frac{\sum_{i=1}^{h}\sum_{j=1}^{n_i}\frac{A_i}{n_i}y_{ij}I(c)}{\sum_{i=1}^{h}\sum_{j=1}^{n_i}\frac{A_i}{n_i}y_{ij}} \quad \text{where} \quad I(c) = \begin{cases} 1, & \text{if } y_{ij} \le c \\ 0, & \text{otherwise} \end{cases},$$ *h* is the number of strata, *yij* is the CPUE of tow *j* in stratum *i*, and *ni* and *Ai* are the number of tows and area, respectively, for stratum *i*. Equation 2 is used to compute the CPUE *cz* associated with a particular percentile *z* of the species CPUE data. The cumulative area associated with a particular density level *c* is then estimated as: $$G(c) = \sum_{i=1}^{h}\sum_{j=1}^{n_i}\frac{A_i}{n_i}I(c) \quad \text{where} \quad I(c) = \begin{cases} 1, & \text{if } y_{ij} \le c \\ 0, & \text{otherwise} \end{cases},$$ and the minimum area corresponding to the 100 - *z* percentile is obtained by subtracting *G*(*cz*) from the total survey area *AT*. For example, the area covered by 95% of the stock (*D95*) is computed as: $$D_{95} = A_T - G(c_{05}).$$ The area covered by 95% of the concentration is then divided by *AT* to get the proportion of the survey area occupied by the stock. For many stocks, this index gives a general index of areal coverage that relates well to geographic concentration. However, some stocks can cover a small area even though the stocks were not concentrated in a small number of locations (i.e., a "patchy" stock that is distributed over the survey area). Thus, some refinements to the index may be necessary to characterize geographic concentration in these cases.
Vertical overlap: Similar to geographical overlap, this attribute concerns the position of the stock within the water column (i.e., demersal or pelagic) relative to the fishing gear. Information on the depth at which gear is deployed (e.g., depth range of hooks for a pelagic longline fishery) and the depth preference of the species (e.g., obtained from archival tagging or other sources) can be used to estimate the degree of vertical overlap between fishing gear and a stock.
Seasonal migrations: Seasonal migrations either to or from the fishery area (i.e.

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spawning or feeding migrations) could affect the overlap between the stock and the fishery. This attribute also pertains to cases where the location of the fishery changes seasonally, which may be relevant for stocks captured as bycatch.
Schooling, aggregation, and other behaviour's: This attribute encompasses behavioural responses of both individual fish and the stock in response to fishing. Individual responses may include, for example, herding or gear avoidance behaviour that would affect catchability. An example of a population-level response is a reduction in the area of stock distribution with reduction in population size, potentially leading to increases in catchability (MacCall 1990).
Morphology affecting capture: This attribute pertains to the ability of the fishing gear to capture fish based on their morphological characteristics (e.g., body shape, spiny versus soft rayed fins). Because gear selectivity varies with size and age, this measure should be based on the age or size classes most representative of the entire stock.
Desirability/value of the fishery: This attribute assumes that highly valued fish stocks are more susceptible to overfishing or becoming overfished by recreational or commercial fishermen due to increased effort. To identify the value of the fish, the authors suggest using the price per pound or annual landing value for commercial stocks (using the higher of the two values) or the retention rates for recreational fisheries (Table 3). Commercial landings and recreational retention rates can be found at: www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html and www.st.nmfs.noaa.gov/st1/recreational/queries/index.html

Table 3. The susceptibility scoring thresholds for desirability/value of a stock.

		Susceptibility score		
Sector	**Measure**	**Low (1)**	**Moderate (2)**	**High (3)**
Commercial	$/lb	< $1.00	$1.00 - $2.25	> $2.25
	Annual landings value	< $500,000	$500,000 - $10,000,000	> $10,000,000
Recreational	% Retention	< 33%	34 - 66%	> 66%

4.3.2 Management

Management strategy: The susceptibility of a stock to overfishing may largely depend on the effectiveness of fishery management procedures used to control catch (Sethi et al. 2005, Rosenberg et al. 2007, Shertzer et al. 2008, Dankel et al. 2008). Stocks that are managed using catch limits for which the fishery can be closed before the catch limit is exceeded (i.e., in-season or proactive accountability measures) are considered to have a low susceptibility to overfishing. However, stocks that do not have specified catch limits or accountability measures are highly susceptible to overfishing if their abundance trends are not monitored. Stocks that are managed using catch limits and reactive accountability measures (e.g., catch levels are not determined until after the fishing season) are considered to be moderately susceptible to overfishing or becoming overfished.
Fishing mortality rate (relative to *M*): This criterion is applicable to stocks where estimates of both fishing mortality rates (*F)* and (*M*) are available. Because sustainable fisheries management typically involves conserving the reproductive potential of a stock, it is recommended that the average *F* on mature fish be used where possible as opposed to the fully selected or "peak" *F*. The authors based their thresholds on the conservative rule of thumb that the *M* should be an upper limit of *F* (Thompson 1993; Restrepo et al. 1998), and thus *F*/*M* should not exceed 1. For this attribute, intermediate *F*/*M* values were defined as those between 0.5 and 1.0; values above 1.0 or below 0.5 are defined as high and low susceptibility, respectively.
Biomass of Spawners: Analogous to fishing mortality rate, the extent to which fishing has depleted the biomass of a stock relative to expected unfished levels offers information on realized susceptibility. One way to measure this is to compare the current stock biomass against an estimate of *B0* (the estimated biomass with no fishing). If *B0* is not available, one could compare the current stock size against the maximum observed from a time series of population size estimates (e.g., from a research survey). If a time series is used, it should be of adequate length (e.g., > 5 years). Note that the maximum observed survey estimate may not correspond to the true maximum biomass for stocks with substantial observation errors in survey biomass estimates. Additionally, stocks may decline in abundance from environmental factors not related to susceptibility to the fishery, so this should be considered in evaluating depletion estimates. Notwithstanding these issues, which can be addressed with the data quality score described below, some measure of current stock abundance was viewed as a useful attribute.
Survival after capture and release: Fish survival after capture and release varies by

species, region, and gear type or even market conditions, and thus can affect the susceptibility of the stock. When data are lacking, the VEWG suggest using NMFS' National Bycatch Report to estimate bycatch mortality (see the following for Alaska Region http://www.nmfs.noaa.gov/by_catch/BREP2011/Factsheets/NBRfactsheet_AK.pdf). The report provides comprehensive estimates of bycatch of fish, marine mammals, and non-marine mammal protected resources in major U.S. commercial fisheries, and should allow users to develop a proxy based on similar fisheries.
Fishery impact on habitat: A fishery may have an indirect effect on a species via adverse impacts on habitat. Defining these effects is the focus of environmental impact statements or essential fish habitat evaluations that have been conducted by NMFS, and this work can be used to evaluate this attribute. Thus, the impacts on habitat may be categorized with respect to whether adverse impacts on habitat are minimal, temporary, or mitigated.

4.4 Data Quality Index

The uncertainty associated with data-poor stocks can lead to errors in risk assessment (Astles et al. 2006, Peterman 1990, Scandol 2003). As a precautionary measure, ecological risk assessments have often provided higher-level risk scores when data are missing in an attempt to avoid incorrectly identifying a high-risk stock as a low risk (Milton 2001, Stobutzki et al. 2001b, Astles et al. 2006). While this approach can be viewed as precautionary, it also confounds the issues of data quality with risk assessment. For example, under this approach a data-poor stock may receive a high-risk evaluation either from an abundance of missing data or from the risk assessment of the available data, with the result that the risk scores may be inflated (see Hobday et al. 2004). In contrast, the authors considered missing data within the larger context of data quality, and report the overall quality of data as a separate value. A data quality index was developed that provides an estimate of uncertainty for individual vulnerability scores based on five tiers ranging from best data or high belief in the score to no data or little belief in the score (Table 4).

Table 4. The five tiers of data quality used when evaluating the productivity and susceptibility of an individual stock.

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Data quality score	Description	Example
1	(Best data) Information is based on collected data for the stock and area of interest that is established and substantial.	Data rich stock assessment, published literature that uses multiple methods, etc.
2	(Adequate data) Information with limited coverage and corroboration, or for some other reason deemed not as reliable as Tier 1 data	Limited temporal or spatial data, relatively old information, etc
3	(Limited data) Estimates with high variation and limited confidence and may be based on similar taxa or life history strategy.	Similar genus or family, etc.
4	(Very limited data) Expert opinion or based on general literature review from wide range of species, or outside of region	General data – not referenced
5	(No data) No information to base score on – not included in the PSA, but included in the DQI score.	

The data quality score is computed for the productivity and susceptibility scores as a weighted average of the data quality scores for the individual attributes, and denotes the overall quality of the data or belief in the score rather than the actual type of data used in the analysis. For example, a data quality score of 3 (related to limited data), could be derived from data equally divided among scores of "1, best data" and "5, no data." It is important to highlight the data quality associated with each vulnerability score when plotting the data on an x-y scatter plot (Fig. 4).

Figure 4. Overall distribution of productivity and susceptibility x-y plot for the 166 stocks evaluated in the Patrick et al. 2009 study, as well as the associated data quality of each datum point (see Table 5 of the Patrick et al. 2009 report for reference IDs).

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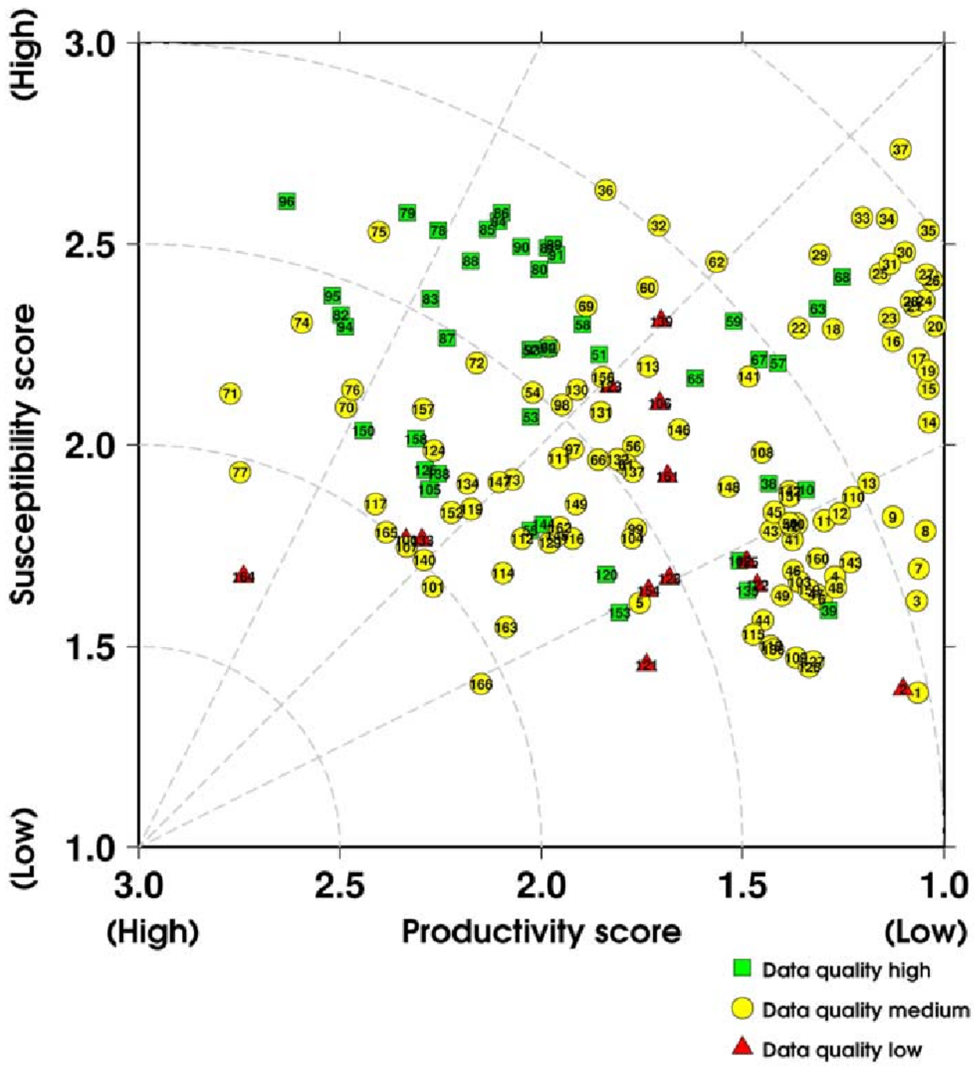

Similar to Webb and Hobday (2004), the authors suggested dividing the data quality scores into three groupings (low > 3.5; moderate 2.0 to 3.5; and high < 2.0) for display purposes. In the case of missing data for an attribute (data quality score of 5), this attribute would not be used in the computation of the vulnerability score but would be reflected in the computation of overall data quality. Thus, a stock with missing data for many attributes would have a low overall data quality score. Data quality scores can be used to reflect the extent to which historical data on productivity and susceptibility pertains to current conditions.

Productivity and abundance of marine stocks often show low-frequency trends or "regime shifts" that reflect environmental variability (Spencer and Collie 1997, Hare and Mantua 2000), and erroneous estimates of productivity could occur if historical data that do not reflect current conditions are utilized. A lack of recent data reflecting current environmental conditions can be reflected in the data quality score.

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For stocks with relatively short generation times it is important to conduct the PSA analysis frequently to monitor environmental driven changes in stock status and productivity.

4.5 Different Sectors and Gear Types

As noted earlier, the PSA was first developed to evaluate the sustainability of bycatch species in the Australian commercial prawn fishery, which consists of a single sector (i.e., trawl fishery), and subsequent applications to other fisheries have also consisted of single sectors. However, PSA scores may vary between sectors of a single fishery (e.g., gear sectors, commercial versus recreational sectors), or between multiple fisheries that harvest a single stock. For example, the susceptibility score for "survival after capture and release" may differ greatly between trawl and gill net gears. Similarly, the "degree of habitat disturbance" would vary greatly depending on the habitat type and gear used to capture a species (e.g., bottom trawl versus longline). In these cases, each sector of a fishery or each fishery should have its own vulnerability evaluation performed to determine which stocks in that sector or fishery are most vulnerable.

5. Scoring the PSA

Generally, attributes are scored as 1, 2, or 3 mean Low, Medium, and High risk. The attribute scores contributing to a PSA have to be averaged in some way to estimate productivity and susceptibility scores. Smith et al. (2007) recommend taking the arithmetic mean (**AM**) of productivity attributes, and the geometric mean (**GM**, i.e. the *n*'th root of the product of *n* attribute scores) of the susceptibility attributes. Trial calculations may indicate which method gives the most convincing scores, or whether some other method of summarising attributes is needed, e.g. taking the minimum or maximum value. Stobutzki (2001) additionally used a weighting system (range: 1, 2, 3) for the different attributes depending on their perceived relevance to productivity or susceptibility. Weighting adds a complication that is only justifiable if it definitely reduces the subjectivity of scoring. The approach used shall be clearly documented and justified.

Last Step, Determining Vulnerability

The vulnerability of a stock to becoming overfished is defined in the NS1 guidelines as a function of its productivity ("the capacity of the stock to produce MSY and to recover if the population is depleted") and its susceptibility to the fishery ("the potential for the stock to be impacted by the fishery, which includes direct captures, as well as indirect impacts to the fishery"). The PSA methodology described in this

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document scores attributes on a three-point scale (i.e., 1 = low, 2 = moderate, 3 = high). The weighted average of each factor's attribute scores is plotted in an x-y scatter plot and the **vulnerability** score of the stock is calculated by measuring the Euclidean distance of the datum point from the origin of the plot. Stocks that receive a low productivity score and a high susceptibility score are considered to be the most vulnerable, while stocks with a high productivity score and low susceptibility score are considered to be the least vulnerable to overfishing.

The overall vulnerability score (*v*) of a stock is calculated as the Euclidean distance from the origin of the x-y scatter plot (i.e., 3.0, 1.0) and the datum point (note the x-axis scale is reversed):

$$v = \sqrt{(p-3)^2 + (s-1)^2}$$

Full resources for conducting a productivity vulnerability analysis can be found at http://nft.nefsc.noaa.gov/PSA.html and then clicking the PSA hyperlink at the following page http://nft.nefsc.noaa.gov/Download.html.

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