Use of productivity and susceptibility indices to determine the vulnerability of a stock: with example applications to six U.S. fisheries.

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EXECUTIVE SUMMARY

In response to congressional action, the U.S. National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) in 2009 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. NMFS created a Vulnerability Evaluation Work Group (VEWG) in January 2008 to provide a methodology for determining vulnerability. While quantitative modeling 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 many of the stocks managed by NMFS. 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 methodology developed and six example applications to U.S. fisheries are contained in this document.

The vulnerability of a stock to becoming overfished is defined in the NS1 guidelines as a function if 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"). Upon review of several risk assessment methods, the Productivity and Susceptibility Assessment (PSA) was chosen as the best approach for determining the vulnerability of data-poor stocks. 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 in this 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.

The PSA methodology contains several modifications to previously published examples, including: 1) expanding the number of attributes scored from 13 to 22 to consider both direct and indirect impacts; 2) redefining the attribute scoring 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 (i.e., different gear types, different regions, etc.).

The PSA was applied to six U.S. fisheries, containing 162 stocks that exhibited varying degrees of productivity, susceptibility, and data quality. The PSA was capable of broadly distinguishing between stocks based on fishing pressure, as stocks that were known to be overfished or undergoing overfishing in the past had significantly higher vulnerability scores ($P = 0.002$) than other stocks, and *post* hoc analysis of four potential candidates for ecosystem component stocks had some of lowest vulnerability scores.

However, the vulnerability of non-target stocks was not significantly different from target stocks for three of the example applications (Hawaii longline-tuna sector, Hawaii longline-swordfish sector, and Atlantic shark complex), highlighting the need to carefully examine non-target stocks when determining ecosystem component stocks. Thresholds for low, moderate, and high vulnerability that could be used to distinguish ecosystem stocks will likely depend on the nature of the fishery to which the PSA is applied. It is recommended that the Councils and their associated Scientific and Statistical Committees jointly determine these thresholds to aid in their decision making process.

The degree of consistency within the productivity and susceptibility scores was determined from correlations of a particular attribute to its overall productivity or susceptibility score (after removal of the attribute being evaluated). High correlation scores were observed for the majority (i.e., 20 of 22 attributes) of the productivity and susceptibility attributes, indicating a high degree of consistency with the productivity and susceptibly attributes.

The PSA developed for this report considers missing data as an endpoint in a continuum of data quality. Data availability in the example applications was generally high for the majority of the attributes examined, averaging 88% and ranging from 30% to 100%. Data quality is a consideration in interpreting the vulnerability scores, and it is recommended that managers employ the precautionary approach when evaluating a PSA with limited or poor data. Resources for conducting a vulnerability analysis can be found at http://www.nmfs.noaa.gov/msa2007/catchlimits.htm/vulnerability.

1.0 INTRODUCTION

In 1976, the Magnuson-Stevens Fishery Conservation and Management Act (MSA) was signed into law to implement the management of living marine resources (Public Law 109-479). The Act has since been amended several times (National Research Council 1994, Darcy and Matlock 1999), most recently through the 2006 Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (MSRA). The MSRA added, among other things, new requirements for fishery management councils to set annual catch limits (ACLs) and establish accountability measures (AMs) for each of its managed fisheries to ensure that overfishing (i.e., $F > F_{MSY}$) does not occur (Public Law 94-265).

To assist the eight regional fishery management councils in implementing the new ACL and AM requirements, the U.S. National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) revised its National Standard 1 (NS1) guidelines, which provides guidance on how conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery (see 74 FR 3178, January 16, 2009). Because the guidelines are written for a general audience, greater technical detail has often been needed to further explain how certain aspects of the MSA should be implemented (Restrepo and Powers 1999). For example, in the NS1 guidelines, the "vulnerability" of fish stocks is referenced as one of the bases for: 1) differentiating between stocks that are "in the fishery" versus those that are "ecosystem components," 2) defining stock complexes, and 3) creating a buffer between target and limit fishing mortality reference points. While the NS1 guidelines define the term "vulnerability," during the scoping period NMFS received several public comments requesting that they further describe how the vulnerability of a stock should be evaluated, especially for stocks for which biological or fishery data are limited (termed “data-poor” stocks). In response, a Vulnerability Evaluation Work Group (VEWG) was established to develop a methodology for determining the vulnerability of data-poor stocks managed under a fishery management plan (FMP). The objective of this report is to explain the methodology developed for determining vulnerability and present six example applications to U.S. fisheries. We begin by reviewing the need for assessing vulnerability for the three tasks identified above.

2.0 NEED FOR ASSESSING VULNERABILITY

2.1 Differentiating Between Fishery and Ecosystem Component Stocks

The NS1 guidelines recommend that ACLs and AMs are needed for all federally managed fisheries, unless they have been explicitly exempted by the MSRA (i.e., stocks managed according to international agreement, or a fish with a life cycle of less than 1 year). 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 – Bluefish) while others include hundreds of species (e.g., Western Pacific Council – Coral Reef Ecosystem). The latter is an example of a 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 ACLs and 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. As a default, NMFS declares that all stocks and stock complexes currently listed in FMPs are considered "in the fishery" and are required to have status determination criteria (SDC) and related reference points (see NS1 Guidelines § 600.310). 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.

2.2 Assembling and Managing Stock Complexes

Stocks with similar geographic distributions and life histories are sometimes grouped into stock complexes by managers. Stocks may be grouped into complexes for various reasons. For example, complexes may include stocks in a multispecies fishery in which it is difficult to harvest or target species independently (e.g., the Pacific west coast multispecies trawl fishery for the Dover sole - thornyhead - sablefish complex); stocks with insufficient data to make a status determination (e.g., undergoing overfishing, overfished, etc.); or stocks that are not reliably identified by fishermen (e.g., the blackspotted rockfish, *Sebastes melanostictus*, looks very similar to the rougheye rockfish, *S. aleutianus*).

The NS1 guidelines recommend that the vulnerability of stocks be considered when establishing or reorganizing stock complexes or when evaluating whether a particular stock should be included in an existing complex. Currently, the status of many stock complexes is monitored using indicator stock(s), which have sufficient data available to define their status determination criteria and to set an ACL (see § 600.310(d)). However, if the indicator stock is less vulnerable than other stocks in the complex, those other stocks could be undergoing overfishing or be overfished while the indicator stock is not (Shertzer and Williams 2008). Therefore, 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.

2.3 Modifying Control Rules

Restrepo and Powers (1999) define a *control rule* as “a variable over which management has some direct control as a function of some other variable related to the stock.” Within the NS1 guidelines, control rules are used to determine how fishing mortality rate (F) or catch (total weight or number of fish) should change as a function of spawning biomass of the stock or stock complex. The NS1 guidelines also state that the Acceptable Biological Catch (ABC) and Annual Catch Target (ACT) control rules should take into account scientific and management uncertainty, as well as other pertinent information (e.g., potential consequences of overfishing). In general, control rules are policies to help fishery managers, in consultation with fisheries scientists, establish fishing limits based on the best available scientific information. Control rules should be designed so that management actions become more conservative as biomass estimates, or other proxies, for a stock or stock complex decline and as science and management uncertainty increases (see § 600.310(f))

Within the NS1 Guidelines limit and target hierarchy (e.g., OFL ≥ ABC ≥ ACL ≥ ACT), the ABC control rule defines the buffer between the Overfishing Limit (OFL) and ABC. The OFL is the annual amount of catch that corresponds to F_{MSY} or its proxy (the fishing rate that results in maximum sustainable yield) applied to the current abundance of the stock, and is considered a maximum limit to catch. The ABC is set below the OFL to take into account the scientific uncertainty in the estimation of OFL, as well as other information that may be useful for determining the buffer (e.g., vulnerability to overfishing). Similarly, the ACT control rule is used as an AM to define the buffer between the ACL and ACT, and is intended to account for management or implementation uncertainty. A stock that is found to be particularly vulnerable to the effects of overfishing might be given a larger buffer between either the OFL and the ABC or the ACL and the ACT (but not in both control rules, so as not to "double count" and provide unduly cautious management advice). For additional information regarding the ABC and ACT control rules see § 600.310(f) and Methot et al. (*In prep*).

3.0 DETERMINING VULNERABILITY

The vulnerability of a stock to becoming overfished is defined in this report 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 our 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. The methods reviewed generally involved semi-quantitative analyses because the data necessary for fully quantitative analyses are not available for many fisheries (Dulvy et al. 2003). Previous examples of semi-quantitative risk assessments have addressed the fishery impacts on bycatch species (Jennings et al. 1999, Milton 2001, Stobutzki et al. 2001b), extinction risk (Musick 1999, Roberts and Hawkins 1999, Dulvy and Reynolds 2002, Cheung et al. 2005, Patrick and Damon-Randall 2008), and ecosystem viability (Jennings et al. 1999, Fletcher 2005, Fletcher et al. 2005, Astles et al. 2006). A modified version of the Productivity and Susceptibility Assessment (PSA) was selected as the best approach for examining the vulnerability of stocks due to its history of use in other fisheries (Milton 2001; Stobutzki et al. 2001a, 2001b; Environment Australia 2002; Gribble et al. 2004; QDPI 2004; Webb and Hobday 2004,; Braccini et al. 2006; Griffiths et al. 2006; Zhou and Griffiths 2008) and recommendations by several organizations and work groups as a reasonable approach for determining risk (Hobday et al. 2004, 2007; Smith et al. 2007; Rosenberg et al. 2007).

3.1 The Productivity and Susceptibility 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) 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 score 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 (Figure 1). The overall vulnerability score (v) of a stock was 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):

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

Stocks that received a low productivity score and a high susceptibility score were considered to be the most vulnerable to overfishing, while stocks with a high productivity score and low susceptibility score were 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). In the next section we review how we adapted previous applications of PSAs for this report, including descriptions of the productivity and susceptibility attributes and the methodology for defining attribute scores and assessing data quality.

4.0 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, 6 productivity). 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 been examined for redundancy.

Development of the PSA utilized in this report 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, the VEWG members provided individual scores (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, twenty-two attributes were selected for the analysis (10 productivity, 12 susceptibility).

4.2 Defining Attribute Scores and Weights

The original analyses performed by Milton (2001) and Stobutzki et al. (2001b) defined the criteria for which a score of 1, 2, or 3 should be given to a productivity or susceptibility attribute. For instance, the attribute scoring bins for the maximum size of a species were defined by Stobutzki et al. (2001b) by dividing the length of the largest species examined in their study by 3, thereby dividing the scoring bins into equal thirds. The PSA developed for this report also 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. Descriptions of the productivity and susceptibility attributes and explanations of the scoring criteria are given in the following two sections.

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). We recommend a default weight of 2 for the productivity and susceptibility attributes, where attribute weights can be adjusted within a scale from 0 to 4 to customize the analysis for each fishery. However, we do 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, users 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.

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).

4.3 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).

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 (Appendix 1). 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 (Froese and Binohlan 2000), and age at maturity (Froese and Binohlan 2000). We have 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 (t_{max}): 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 1). The t_{max} for a majority of these fish ranges between 10 to 30 years.

Maximum size (L_{max}): 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 1). The L_{max} 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 $k = 3/ t_{max}$ 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 t_{max}, 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 t_{max}. 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 t_{max} 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 we 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, we used Winemiller's (1989) index of parental investment. The index ranges in score from 0 to 14 and is composed of: 1) the 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, we 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 ten surface pelagic, three mid-water pelagic, three deep-water pelagic, 18 near-shore benthic, and nine offshore benthic stocks. Thirty-one percent of the stocks had a Winemiller score of zero, and 40 percent had a Winemiller score of 4 or higher, so 0 and 4 were used as the breakpoints between our 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, the VEWG chose 10 percent and 75 percent as the breakpoints between our ranking categories so that scores of 1 and 3 identified relatively extreme differences in recruitment patterns.

Age at maturity (t_{mat}): Age at maturity tends to be positively related with maximum age (t_{max}), 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 t_{max} of 10 and 30 However, the Froese and Binohlan (2000) used data from many fish stock around 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. 2000).

4.4 Susceptibility 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, Hobday and Smith 2009). Our 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, we have differentiated the catchability and management attributes as sub-categories 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 behavioral 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. We defined 12 susceptibility attributes:

4.4.1 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, if only a portion of the fishing effort was known to occur in the depth range occupied by a species, this would give an upper bound estimate of areal overlap.

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 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 CPUE is computed as

$$F(c) = 100\frac{\sum_{i=1}^{h}\sum_{j=1}^{n_i}\frac{A_i}{n_i}y_{ij}I(c)}{\sum_{i=1}^{h}\sum_{j=1}^{n_i}\frac{A_i}{n_i}y_{ij}} \quad \text{where} \quad I(c) = \begin{Bmatrix} 1, & \mathit{if}\ y_{ij} \le c \\ 0, & \mathit{otherwise} \end{Bmatrix}, \qquad [2]$$

h is the number of strata, y_{ij} is the CPUE of tow j in stratum i, and n_i and A_i are the number of tows and area, respectively, for stratum i. Equation 2 is used to compute the CPUE c_z 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

$$G(c) = \sum_{i=1}^{h}\sum_{j=1}^{n_i}\frac{A_i}{n_i}I(c) \quad \text{where} \quad I(c) = \begin{Bmatrix} 1, & \mathit{if}\ y_{ij} \le c \\ 0, & \mathit{otherwise} \end{Bmatrix}, \qquad [3]$$

and the minimum area corresponding to the 100 - z percentile is obtained by subtracting $G(c_z)$ from the total survey area A_T. For example, the area covered by 95 percent of the stock (D_{95}) is computed as

$$D_{95} = A_T - G(c_{05}) \, . \qquad [4]$$

The area covered by 95 percent of the concentration is then divided by A_T 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. 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 behaviors: This attribute encompasses behavioral responses of both individual fish and the stock in response to fishing.

Individual responses may include, for example, herding or gear avoidance behavior 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, etc.). 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, we 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

4.4.2 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, Anderson and Semmens *in press*). 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. We base our 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, we define intermediate F/M values 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 B_0 (the estimated biomass with no fishing). If B_0 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 (due to be published in the summer of 2009) to estimate bycatch mortality. 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. Once published the report can found at:
http://www.st.nmfs.noaa.gov/st4/nop/Outreach/NBR_Factsheet_Final.pdf.

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.

4.5 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, we 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). 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 (Figure 2). Similar to Webb and Hobday (2004), we suggest dividing the data quality scores into three groupings (low > 3.5; moderate 2.0 to 3.5; and high < 2.0) for display purposes. We also recommend that the data quality scores be: 1) plotted as a separate graph noting how many attributes were used in the analysis (Figure 3; Appendices 1- 6) and 2) listed in a table to provide decision makers with more information on the scores, such as mean score, range, mode, variance, etc. 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. 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.

4.6 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, etc.), 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 rod and reel). 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. An overarching vulnerability evaluation score should be calculated for each stock listed in an FMP using a weighting system based on the sectors landings over some predetermined time frame (i.e., based on average landings).

5.0 EXAMPLE APPLICATIONS

To demonstrate the utility of the vulnerability evaluation, we evaluated six U.S. fisheries that had varying degrees of productivity, susceptibility, and data quality (see Appendices 2 – 10). These example applications show that there can be considerable variation in vulnerability within currently grouped complexes, and between sectors (see Northeast Groundfish and Pacific longline studies). Please note, however, this report should not be considered the “official” vulnerability analysis for the six fisheries we examined. The Councils and their SSC, or in the case of Highly Migratory Species NMFS scientists, who are charged with managing these fisheries should perform their own vulnerability analysis or modify ours to meet their data quality standards.

5.1 Northeast Groundfish Multi-species Fishery

Within the NMFS Northeast Region, 19 groundfish stocks are assessed as a group on a 5-year planning horizon by the Groundfish Assessment Review Meeting (GARM) committee for the New England Management Council. The GARM stocks include gadoids (i.e., Atlantic cod, haddock, red hake, etc.), several flatfish (i.e. yellowtail, witch, plaice, and winter flounders), and related demersal stocks, which are overall valued at about $75 million (NMFS 2008). Previously, the entire complex was overfished during the International Commission on of the Northwest Atlantic Fisheries (ICNAF) era (1960s to1970s) and also after extended jurisdiction in 1976. More recently this complex has been managed by the New England Fishery Management Council under the Multispecies Groundfish FMP. The fishery is currently managed with area closures, mesh-size regulations, and effort reduction procedures (days at sea), and is almost entirely prosecuted with bottom trawl gear, with small amounts of landings by gill nets and longlines. The fleet fishes mostly on Georges Bank, but also has a significant component in the Gulf of Maine and in the Southern New England region. Several stocks in the complex have recovered (e.g., Georges Bank haddock, redfish), but many are still chronically overfished (e.g. Southern New England yellowtail flounder, Georges Bank cod).

Data quality for the entire group is relatively high, with long-term time-series of catch and research vessel survey data available; however, information for windowpane flounder, ocean pout, and Atlantic halibut is not quite as good as for the other members of the group. Life history information for most of the stocks is relatively complete, many are assessed with fairly detailed analytical stock assessment models, and new research on movements, morphometrics, bycatch, and improved survey techniques is ongoing.

These stocks range from relatively low (e.g. ocean pout) to high productivity (e.g. Georges Bank haddock) in their life histories, and some are more susceptible than others to overfishing (e.g. halibut, white hake), habitat disturbances (e.g. winter flounder), and gear interactions (e.g. Gulf of Maine and Georges Bank cod). We note that the spread across GARM stocks is smaller than that in other fisheries (see below) due to their similarities in life history and targeting fishing gear. Overall, these GARM stocks clustered into two groups based on differences in productivity (Figure 4). The first cluster of stocks contains cod, haddock, and most of the flatfish etc. The second cluster contains redfish, white hake, and halibut, and is somewhat more vulnerable to overfishing because the life histories of these stocks suggest they are generally less productive.

5.2 Highly Migratory Atlantic Shark Complexes

Atlantic shark species are divided into four management groups under the current Highly Migratory Species (HMS) FMP: 1) large coastal, 2) small coastal, 3) pelagic, and 4) prohibited. The four groups were designed to facilitate management, but do not necessarily reflect the exact habitat preferences or life histories of the component species. In general, large coastal sharks are large sharks characterized by slow growth rates, low fecundity, late age at maturation, and long lifespan. These species generally utilize estuaries and nearshore waters during at least part of their life cycle, but also occur in and sometimes beyond waters of the continental shelf. Typical large coastal sharks are blacktip, sandbar, bull, tiger, and hammerhead sharks. By contrast, small coastal sharks reach a smaller size, tend to grow and mature more rapidly and have shorter lifespans, and are generally restricted to more coastal waters. Atlantic sharpnose and bonnethead sharks exemplify a “typical” small coastal shark. Pelagic sharks are large, with life history characteristics generally intermediate to those of the two other groups, which range widely in the upper reaches of the ocean and undertake extensive, sometimes transoceanic, migrations. Typical pelagic sharks are blue, shortfin mako, and thresher sharks. Prohibited species are a mixture of species once included in the other management groups and having coastal, pelagic, and coastal-pelagic habitat preferences.

They include some charismatic species, such as the white, whale, and basking sharks, and three species that have been proposed for listing under the Endangered Species Act (dusky, night, and sand tiger sharks). Prohibited species tend to be large and rare, and have life history characteristics that make them particularly vulnerable to overfishing. In some cases, however, they were included in this group to err on the side of caution because of a complete absence of biological data on the species (e.g., Caribbean sharpnose, smalltail, and Atlantic angel sharks). As a group, sharks exhibit low productivity (as compared to teleosts, for example), mainly owing to their reduced reproductive rates. We included 37 species of sharks in our analysis (Table 5).

Although shark production is relatively low compared to other marine resources, U.S. commercial and recreational shark fisheries are likely to account for more than $100 million annually, with the global shark fin trade alone being valued at close to $400 million (Clarke 2003). In addition to direct consumption and production of shark products, net benefits in the shark fishery are also derived from the existence value of sharks for non-consumptive user groups (Davis et al. 1997, Cardenas-Torres et al. 2007, Rowat and Engelhardt. 2007). While there are bottom longline and drift gillnet fisheries that target sharks in the United States, sharks are caught incidentally as bycatch in a variety of fisheries (e.g., gill net, pelagic longline and trawl fisheries), with the magnitude of this bycatch being poorly known in general. The commercial fishery is a limited access fishery with incidental retention limits, observer and reporting requirements, and a ban on finning. Sharks are also commonly caught in U.S. recreational fisheries, including private boats, charterboats, and headboats. Recreational regulations allow retention of one shark per vessel per trip, with a 4.5 ft (1.4 m) fork length minimum size requirement, and an additional allowance of one Atlantic sharpnose shark and one bonnethead shark per person per trip with no minimum size. In general, the U.S. Atlantic shark fishery is primarily a southeastern fishery extending from Virginia to Texas, although sharks are also landed in the states north of Virginia. All sharks fall under the jurisdiction of NMFS' Highly Migratory Species Division.

Both the quality and quantity of available biological and fishery data vary by species of sharks. While relatively good information is available for the most important species in the fisheries, basic biological information is lacking for the less common species. Analytical stock assessments are thus available for only a few species: sandbar and blacktip sharks (large coastal); Atlantic sharpnose, bonnethead, blacknose, and finetooth sharks (small coastal); blue and shortfin mako sharks (pelagic); and dusky sharks (prohibited).

The information used to score the productivity attributes was derived from a dedicated shark life history database maintained by NMFS (citations available upon request). The information used to score the susceptibility attributes was derived from various sources. The *area overlap* and *geographic concentration* attributes were scored using information from IUCN species distribution maps (pelagic shark species), HMS Essential Fish Habitat maps (large and small coastal sharks), ICCAT effort distribution maps (pelagic sharks), Coastal Fishery Logbook effort maps (large coastal sharks), and shrimp trawl effort distribution (small coastal sharks). For *vertical overlap*, we used mostly unpublished information from archival tags and published papers (a variety of species, mostly pelagic); for *morphology affecting capture,* we used data on size of animals caught in various scientific observer programs (U.S. pelagic longline observer program for pelagic sharks, bottom longline observer program for large coastal sharks, shrimp trawl observer program for small coastal sharks); for *survival after capture and release,* the data also came from the three observer programs referenced above. There was consistently no information for several attributes (*recruitment pattern, seasonal migrations,* and s*chooling/aggregation behavior*). Information for *F relative to M* and *SSB* was only available for those species for which stock assessments have been conducted.

The susceptibility aspect refers to the main fishery affecting each group: pelagic longline fishery for tunas and tuna-like species (pelagic sharks), bottom longline directed shark fishery (large coastal sharks), and bottom trawl shrimp fishery (small coastal sharks). Weights for each attribute were assigned by discussion and consensus between the two assessment scientists involved in the evaluation. For the productivity attributes, both scientists felt that the intrinsic rate of increase (r) was the most valuable quantitative measure of productivity and was assigned the highest weight of 4. *Measured fecundity* and *estimated natural mortality* were also viewed as important indicators and were assigned a weight of 3. The *recruitment* attribute, on the other hand, was assigned a weight of zero because it was felt it was not a good indicator for productivity of sharks as currently defined. For the susceptibility attributes, it was felt that the overlap between the distribution of the species and the fisheries (*areal overlap* and *vertical overlap*) and the probability of *survival after capture and release* were the most important attributes and were assigned a weight of 4. The remainder of the susceptibility attributes were given a default weighting of 2.

The productivity scores clearly separated the highly productive Atlantic sharpnose and bonnethead (small coastal) and the Caribbean sharpnose shark (prohibited, but note the low data quality) from the other species in the analysis (Table 5; Figure 5). The remaining species were grouped toward the lower end of the productivity scale, with scores ranging from 1.0 to 1.35. Within this grouping, the relatively higher productivity of species such as the tiger and nurse (large coastal) and blue (pelagic) sharks were reflected in the scoring; however, the overall scoring showed little contrast for over 50 percent of the stocks analyzed (22 of the 37 stocks had weighted productivity scores of 1.1 or less). While this level of detail may be appropriate for intertaxonomic comparisons, it would not be adequate for a PSA applied to sharks only for which the use of a continuous score, such as the intrinsic rate of increase (*r*) provides much more contrast (Cortés et al. 2008, Simpfendorfer et al. 2008). The susceptibility scores show more overall contrast than the productivity scores, with a range of 1.4 to 2.9. A number of ecologically different species have similar susceptibilities to the main fisheries, while several less common species (e.g., sixgill, sharpnose sevengill, bigeye sandtiger, and whale shark) show decreased susceptibility (but also note the lower data quality). It is interesting to note that 12 of the 14 species with the lowest susceptibility scores fall into the prohibited FMP group.

5.3 California Nearshore Groundfish Finfish Assemblage

The California nearshore finfish assemblage is a complex of 19 nearshore species, with a unique history of landings comprising a mix of heavy recreational and lucrative commercial fisheries. Most of the species in this fishery are rockfishes (family Scorpaenidae, with most of these of the genus *Sebastes*), but there are also two greenlings (family Hexagrammidae), one prickleback (family Stichaeidae), and one wrasse (family Labridae) (Table 5). The species are typically associated with nearshore rocky reef or kelp forest communities, and have a range of life histories. Most are relatively long-lived, slow-growing, and either live-bearing (*Sebastes*) or egg-guarding (cabezon, greenlings); there is also one protogynous hermaphrodite (California sheephead). By virtue of their life history characteristics and accessibility to a wide range of fishing types, most have been shown or are perceived to be vulnerable to overexploitation in the absence of effective management regimes (Gunderson et al. 2008). Although the total landings by volume tend to be small (only 224 tons landed commercially in California waters in 2006), many of the premium/live-fish fishery targets are highly lucrative, with ex-vessel values of up to $10 per pound (and net revenues of $2.2 million in 2006). Through the 1990s, as commercial landings in the major offshore fisheries sectors decreased, the live-fish fishery harvest began to represent a greater proportion of landings and revenue in California. For example, between 1989 and 1992 the nearshore, live-fish trap fishery developed in response to demand in high-end restaurants, increasing from 2 to 27 boats that landed over 52,000 lbs of live fish (Palmer-Zwahlen et al. 1993). Recreational fisheries consist largely of commercial passenger fishing vessels (CPFVs), an important activity in many coastal communities for which the economic contribution can be comparable to the landed value of the commercial catch. Private boats access, pier and jetty fishing, and spearfishing also contribute to the high recreational effort targeted at these species.

Most of the nearshore species are considered to be relatively data-limited, with relatively modest research done on their life history and little or no fishery-independent survey data available for monitoring trends in abundance. Only 5 of the 16 species managed by the Pacific Fisheries Management Council (gopher rockfish, black rockfish, blue rockfish, cabezon and California scorpionfish) have formally adopted stock assessments that included part or all of their California populations. An assessment also exists for sheephead, although the results have not been directly applied in management. An assessment for kelp greenling also exists for the Oregon population. Most of these assessments have been considered to have moderate to poor data availability, and a majority of the remaining nearshore species have even less available data for potential assessments, such that alternative means of monitoring of stock status and evaluating the vulnerability to overexploitation are key management priorities.

The average productivity and susceptibility scores for each of the 19 nearshore species are shown in Figure 6. These scores were produced using the default weighting of 2, as all attributes were viewed to be equally applicable. Susceptibility scores are similar for all species (average range between 2.0 and 2.4), with only the California scorpionfish scoring below 2. Considering the productivity axis, two primary clusters can be distinguished: one of relatively deeper-living, larger, and longer-lived rockfishes (though grass rockfish is one of the shallowest-living of the species considered), and the other mainly smaller, shorter-lived species with varying reproductive life histories. Combining the two axes, there is a loose but noticeable negative linear relationship between productivity and susceptibility. Of the species considered, brown, blue, China, copper, and quillback rockfish appear to be the most vulnerable, based on their relatively lower productivity and greater susceptibility; black, olive, and grass are also ranked as among the more vulnerable species. Interestingly, all of the most vulnerable species are

Sebastes, consistent with the perceived higher vulnerability of the slower-growing and longer-lived members of this genus relative to most other groundfish. Given that these are among the more valuable commercial targets, but are characterized by long lifespans and slow growth rates, these results are consistent with expectations (Table 5).

5.4 California Current Coastal Pelagic Species

The coastal pelagic species fisheries management plan (CPS FMP) on the U.S. West Coast includes four species of schooling pelagic fishes (Pacific sardine, northern anchovy, Pacific mackerel, and jack mackerel), market squid, and more recently two species of euphausiids declared prohibited due to their important role as forage. Euphausiids are not included in this assessment as the lack of any historical fisheries in the California Current, and the recent ban on future fisheries, gives us no ability to evaluate susceptibility. However, several additional coastal pelagic species, currently not managed under the CPS FMP, exhibit similar life history characteristics and trophic roles as the five above. Consequently, we considered Pacific herring, Pacific bonito, and Pacific saury as well. All of these species are characterized by rapid growth, relatively short lifespans, and significant short- and long-term variability in abundance, productivity, and distribution. These species also represent key energy pathways from planktonic communities to higher-trophic-level predators such as salmon, tunas, groundfish, sharks, seabirds, and marine mammals. Commercial fisheries for these stocks are typically high-volume and, despite moderate ex-vessel values, they are among the most economically significant fisheries in the California Current. Many of these species are also targeted by fisheries in both Mexico and Canada; however, there are no formal international management agreements in place for these partially shared resources.

The Pacific sardine (*Sardinops sagax*) fishery was the largest in the United States throughout the first half of the 20th century, with landings greater than 700,000 tons during its peak. Although the notorious collapse of the sardine stock in the 1950s led to several decades of low abundance and landings, the current stock biomass and fishery are again among the largest on the U.S. West Coast. The northern anchovy (*Engraulis mordax*) fishery was of considerable economic significance throughout the 1970s and early 1980s, but biomass levels have been relatively low since the early 1980s and the current fishery is negligible. Although not taxonomically related, both Pacific (*Scomber japonicus*) and jack (*Trachurus symmetricus*) mackerel are larger, have greater longevity (particularly *Trachurus*), and are higher-trophic-level components of this assemblage that have variously been important in the CPS fisheries in the California Current. The market squid (*Doryteuthis opalescens*) is a very short-lived and highly variable stock that has been a significant target of commercial fisheries for over 100 years and is frequently the largest (by volume) fishery in California waters. For the three species not in the CPS FMP, Pacific herring (*Clupea pallasii*) is a state-managed species of considerable economic importance in California and modest importance in the Pacific Northwest. Pacific bonito (*Sarda chiliensis*) is a larger piscivorous species rarely found north of Point Conception that is an occasional commercial target and a fairly important recreational target. Pacific saury (*Cololabis saira*) is a pelagic species of little commercial importance in the California Current but of considerable economic importance in the western Pacific.

These species are typical of the coastal pelagic community of upwelling ecosystems, which collectively account for as much as one-third of total global marine fish landings. The population dynamics of all of these species can be characterized as highly dynamic in space and time, with tremendous interannual and interdecadal variability in abundance, productivity and distribution. Although the mechanisms behind these fluctuations remain largely unknown, this variability is widely held to be a consequence of the dynamic nature of oceanographic features in coastal upwelling ecosystems over both interannual and interdecadal time scales (Bakun 1996, MacCall 1996, Schwartzlose et al. 1999). The current management regime for the federally managed CPS species includes threshold biomass levels because of the considerable importance of these species as forage to higher-trophic-level predators. Additionally, Pacific sardine are managed using a climate-based harvest control rule, in recognition of the significance of climate factors in driving productivity and abundance (PFMC 1998).

The productivity and vulnerability scores developed for these eight species are shown in Figure 7. All are estimated to range between moderate and high productivity (with the caveat that they routinely undergo extensive periods in which productivity declines to very low levels), with the species having the fastest growth rates and shortest lifespans (market squid, Pacific saury and northern anchovy) among the highest in their collective productivity scores. The relatively longer-lived Pacific and jack mackerel are characterized by lower productivity. The generally above-average susceptibility scores for these species are in part a consequence of relatively high susceptibility due to schooling behavior and the hyperstability of catch rates (Hilborn and Walters 1992). Higher scores for California market squid and Pacific herring reflect their current relatively high exploitation rates in fisheries that target spawning aggregations. In contrast, Pacific saury and jack mackerel are generally widespread, located in offshore waters, and effectively unexploited in the California Current, even though both stocks now may be at low levels of abundance due to climate factors.

Despite their rapid growth and relatively high natural mortality rates, high interannual and interdecadal recruitment variability tempers the higher productivity scores for all species. Such variability is significant with respect to assessing the vulnerability of these stocks to overexploitation, as the failure to recognize climate-driven changes in the productivity of coastal pelagics was a key factor behind the notorious collapse of the California sardine fishery in the 1950s and 1960s and of the largest historic fishery on the planet – Peruvian anchoveta (*Engraulis ringens*). Between 1971 and 1973, anchoveta landings fell from over 12 million tons per year to less than 2 million (Schwartzlose et al. 1999). Although this fishery also has recovered to the point where it is again the largest fishery by volume in the world's oceans, there is general agreement that coastal pelagic populations are highly vulnerable to overexploitation in the absence of effective monitoring and management systems.

5.5 Skates (Rajidae) of the Bering Sea and Aleutian Islands Management Area

The Bering Sea and Aleutian Islands (BSAI) fishery management plan contains 13 species of skate (Rajidae) that are incidentally caught by the commercial fisheries in this management area off Alaska. Although not targeted, these skate species are caught in substantial amounts by bottom trawl and longline vessels pursuing other species and are valued at $2 million (2006 NMFS commercial landing statistics). They are managed by the North Pacific Fishery Management Council as part of its "Other Species" group, which also contains sharks, squid, octopus, and sculpins (Ormseth and Matta 2007). An aggregate catch limit is established annually for this entire group.

Skates in the BSAI vary in size and other life history traits, as well as in abundance and distribution. The BSAI consists of three main regions: the eastern Bering Sea (EBS) shelf, which is quite broad; the EBS slope; and the Aleutian Islands (AI). The EBS shelf contains the vast majority of the skate biomass in the BSAI but has relatively low species diversity of skates, with the Alaska skate (*Bathyraja parmifera*) dominating the biomass. The skate communities of the EBS slope and the AI are much more diverse, and species are distributed unequally among the three areas. Because Alaska skate dominate the shelf, where fishing activity is strongest, they are the main species caught in commercial fisheries. Data quality is greatest for this species (Table 5).

Within our analysis, all attributes were weighted equally with the exception of recruitment pattern. Based on skate life histories and information available for *B. parmifera*, we concluded that skates have low recruitment variability and that year classes tend to be small but of consistent size. Because it was unclear how this pattern might affect productivity, particularly as the criteria are based on the frequency of successful year classes, we decided to reduce the weight to 1. Extensive life history data were available for only a subset of the species (*B. parmifera*, Aleutian, Bering, big, and longnose). For the remaining species, maximum size was the only attribute for which we had information. Other life history attributes for these species were assigned based on results for the better-known species, and were assigned a data quality score of 3.

During the scoring process, we identified some attributes that warranted further explanation, including breeding strategy, management strategy, areal overlap, and geographic concentration. We used Winemiller's (1989) index to estimate breeding strategy, but modified it somewhat for skates. When Winemiller mentions "parental protection of zygotes or larvae," it seems as if he has teleosts in mind and perhaps is thinking of nest-guarding behavior. For skates, there is no nest-guarding protection as such, but the spawners do produce a tough egg case that helps ward off predation for up to several years. We evaluated this as providing lengthy protection to the offspring, and gave a score of 4 for the "parental protection" portion of the index.

Regarding the attribute management strategy, all skate species received a score of 1 for this attribute, because a catch limit is set for the BSAI skate complex and catch is monitored weekly throughout the fishing season. However, because skate catch limits are managed in aggregate with a larger "Other Species" group, and identification of rarer skates can be problematic, there is more potential for inadvertent overfishing of skates than indicated by the attribute score. A data quality score of 2 was assigned to reflect this inconsistency.

We quantified *areal overlap* by examining the percentage of the stock distribution (based on survey data) that occurs within the depths of the trawl fishery. First, we examined the observed trawling effort (in minutes) by depth from the North Pacific Fishery Observer Program and noted that nearly all of the trawling effort occurs at depths less than 300 meters. Next, we quantified the proportion of the total CPUE data, per year, that exists at depths shallower than 300 meters. For each skate species in each year, we produced the cumulative distribution of CPUE as a function of depth, which gives the proportion of the sum of the CPUE data that occurs shallower than a given depth. From this distribution, we were able to identify the proportion of the CPUE data that occurred shallower than 300 meters, which we took as the maximum percentage areal overall with the fishery. Note that the actual overlap may be less because of spatial and/or temporal mismatches between the distributions of the fishery and the stock, so this is a conservative estimate of areal overlap. This technique was applied to the Aleutian Islands trawl survey and the Eastern Bering Sea slope trawl survey; the Eastern Bering Sea shelf survey occurs at depths less than 200 meters, so all CPUE from this survey would be less than 300 meters.

Lastly, we quantified *geographic concentration* as the area covered by 95 percent of the stock relative to the area covered by the survey using the method of Swain and Sinclair (1994) described in the Methods section.

Overall, all attributes received a score less than 2.0 for BSAI skates, because the species were considered highly susceptible to becoming overfished and their productivity was relatively low compared to other U.S. fish stocks. Many of the skate species were clustered close together in the PSA plot (Figure 8). This result is likely due to three factors: 1) most skates share similar life histories that tend toward low productivity; 2) BSAI skate species show similar susceptibility to trawl and longline fishing gear; and 3) similar attribute scores were assigned to many of the data-poor species. One species (longnose skate) stood out from the rest as a result of lower productivity, which in turn resulted from its larger size and longevity. Of the remaining 12 species, four (Aleutian skate, Bering skate, big skate, and butterfly skate) showed reduced susceptibility relative to the others. This resulted from differences in spatial distribution that reduced their susceptibility to fisheries. Data quality was highest for *B. parmifera* and lowest for the eight species for which life-history data were mostly unavailable. The lowest data quality score was 3: we had enough data to produce a score for each attribute. The results of this

PSA suggest that skates in the BSAI are vulnerable to fishing activity and should be carefully managed to reduce the likelihood of overfishing.

5.6 Hawaii-based Longline Fishery: A Comparison of the Tuna and Swordfish Sectors

The Hawaii-based longline fishery is a year-round pelagic fishery operating out of Hawaii that targets a range of pelagic finfish species with hook and line gear for the fresh fish market, and is comprised of approximately 125 active fishing vessels in a limited entry program (WPRFMC 2007). This is the largest commercial fishery in Hawaii in both landings (21.6 million pounds for 2006) and revenue ($54.4 million ex-vessel revenue for 2006). The Hawaii-based longline fishery began in 1917 using tuna fishing methods imported from Japan. The fishery underwent a substantial expansion from 1987 to 1993 due to the introduction of swordfish (*Xiphias gladius*) fishing methods using shallow set fishing gear (Boggs and Ito 1993). As this sector of the fishery became more heavily regulated (due primarily to interactions with sea turtles in the late 1990s) shallow set fishing effort decreased substantially with a corresponding expansion of the tuna sector of the fishery, which primarily targeted bigeye tuna (*Thunnus obesus*) with deep set gear. These two sectors of the fishery continue through present time; fishermen can either set shallow gear to target swordfish in the higher latitudes, or set deep gear to target tuna primarily in lower latitudes (Bigelow et al. 2006). Tunas are the largest component of the overall catch (59 percent for 2006), with bigeye tuna alone comprising 40 percent of the total longline landings for 2006. Billfish are the second largest component of the overall catch (22 percent for 2006), with swordfish alone composing 10 percent of the total longline landings for 2006. Both sectors are tightly regulated to reduce conflicts with recreational fishermen, to reduce protected species interactions, and to minimize risks of overfishing.

The Western Pacific Regional Fishery Management Council (WPRFMC) pelagics FMP includes 28 stocks or assemblages as pelagic management unit species (PMUS). This PSA considered 33 stocks, since two assemblages (oilfishes and pomfrets) were disaggregated to individual species (Table 5). These PMUS taxa can be aggregated into four general categories of tunas, billfishes, other bony fishes, and sharks (Table 5). A wide variety of data sources were examined to extract pertinent biological and fishery information for this PSA case study, and included published and unpublished scientific findings, webpage summaries, personal communications, and NMFS research finding from longline observer data, auction data, logbook data, and State of Hawaii commercial catch data (citations available upon request). The dual nature of the fishery necessitated that two separate PSA results be prepared – one for the shallow set swordfish fishery sector and one for the deep set tuna fishery sector. Productivity attributes were identical for the two PSA applications; however, susceptibility values can vary substantially between the sectors for the same species due to differences in the geographic fishing areas, seasonal patterns of fishing effort, vertical positioning of the fishing gear in the water column, and bycatch survival. Other gear-related issues involved in targeting of particular species are also important and are incorporated in the sector-specific susceptibility scorings.

PSA scorings for the two fishery sectors are shown in Table 5 and Figures 9 and 10. Generally, all stocks fell into the region characterized as moderate to low productivity and moderate to low susceptibility. Sharks and others were among the lower productivity stocks, while tunas and billfishes tended to be among the higher productivity stocks, when examined as broader taxonomic groupings (Table 5). Interestingly, it was observed that the productivity scores for blue, bigeye thresher, longfin mako, oceanic whitetip, silky, and the common thresher shark differed from those recorded in the Highly Migratory Atlantic Shark Complexes case study (Table 5, Appendix 2). These differences are likely related to intraspecific variations in life history patterns (Cope 2006), and the use of different weightings in the vulnerability analysis. Sharks and billfishes were among the lower susceptibility stocks, while tunas and others were among the higher susceptibility stocks. The swordfish sector exhibited an overall slightly reduced susceptibility when compared to the tuna sector, probably due to the higher level of targeting in this sector of the fishery. In fact, only five stocks had a higher susceptibility in the swordfish sector than the tuna sector (Figures 9 and 10). Therefore, ~85 percent (28 out of 33) of the stocks analyzed here had an equal or higher susceptibility in the tuna sector than the swordfish sector of the longline fishery. Further analysis is needed to fully understand the roles of spatio-temporal patterns of fishing gear deployment, gear specificity, catchability, and the biology of the individual stocks.

6.0 SYNTHESIS AND DISCUSSION

6.1 Range of Vulnerability Scores

The managed stocks evaluated in this report represent both targeted (*n* = 71; 44 percent) and non-targeted species (*n* = 91; 56 percent) that were included in FMPs to prevent overfishing and rebuild overfished stocks (see MSA §§ 303(a)(1)(A) & 303(b)(1)(A)). The stocks generally displayed vulnerability scores greater than 1.0 or, when plotted, are above the 2.0 isopleth (the distance should be measured from the origin, which in this case is 3,1; see Table 5 and Figure 2). The only exception to this observation was the Pacific saury, which received a susceptibility score of 1.91, a productivity score of 2.70 and a vulnerability score of 0.96.

Within any particular example application, the range of productivity and selectivity values can be restricted depending upon the characteristics of the species of interest. For example, the species in the Atlantic shark complex showed a wide range of susceptibility values, but 34 of the 37 species had productivity values between 1.0 and 1.5. Similarly, the 13 BSAI skate species had productivity scores between 1.0 and 1.5, and susceptibility scores between 1.5 and 2.0. In contrast, the species in the Hawaii longline fishery (both the tuna and swordfish sectors) showed an expanded range of productivity and susceptibility scores. The restricted range in some of the example applications may reflect the species chosen for these examples, and it is possible that a more expanded range would be observed if the PSA was applied to all species in a FMP. For example, BSAI skates are managed within the BSAI groundfish FMP which includes a range of life-history types, including gadids and flatfish, and the productivity and susceptibility scores for these species would likely show some contrast from those obtained for skates.

A restricted range of scores from a PSA might motivate some to modify the attribute definitions to produce greater contrast. However, it is important to recognize that the overall goal of the PSA is to estimate vulnerability relative to an overall standard appropriate for the range of federally managed species. Thus, a lack of contrast in vulnerability scores may simply reflect a limited breadth of species diversity. For example, examination of a subset of approximately 40 stocks in the West Cost Groundfish FMP indicates that none have a maximum age less than 10 years, and nearly 60% have a maximum age over 30 years (Figure 11). Similarly, over 80% of these stocks have natural mortality rates estimated to be less than 0.20, and half have a von Bertalanffy growth coefficient of less than 0.15. A similar lumping of values takes place for other attributes, including age at 50% maturity. Thus, it may be advantageous in some cases to redefine the attribute score definitions in order to increase the contrast within a given region or FMP, while recognizing that the vulnerability scores for that particular fishery no longer represent the risk of overfishing based on the original scoring criteria. Analyses that use modified attribute scoring definitions should be clearly labeled to avoid confusion with PSAs based on the scoring bins indentified in the report.

6.2 Relationship of Vulnerability to Fishing Pressure

In order to evaluate the effect of fishing pressure on vulnerability, we examined a subset (n = 50) of the example application stocks for which status determination criteria were available to determine if the stock had been overfished or undergone overfishing between the years of 2000 – 2008 (Figure 12; Appendix 11). Kruskall-Wallis tests indicated that there were significant differences in susceptibility ($P = 0.001$) and vulnerability ($P = 0.002$) scores between stocks that had been overfished or undergone overfishing in the past (i.e., New England Groundfish and Atlantic Shark Complexes) and those that had not. However, productivity scores were not found to be significantly different ($P = 0.891$). Stocks that had been overfished or undergone overfishing in the past generally had susceptibility scores greater than 2.3 and vulnerability scores greater than 1.8.

To further examine the effect of fishing pressure on PSA results, we evaluated four lightly fished non-target species in the South Atlantic-Gulf of Mexico Snapper/Grouper Bottom Longline fishery that were considered potential ecosystem component species (i.e., low vulnerability to overfishing/overfished) based on their average landings (< 5 mt/yr) and price/pound (< $1.00) (Table 5; Figure 2; Appendix 12). Three of the four non-target species received vulnerability scores less than 1.0, but the other stock (sand tilefish) received a vulnerability score of 1.1 due to its moderate productivity (2.1) and susceptibility (1.9). However, several other stocks that would not be considered ecosystem stocks had similar vulnerability scores. Though based on limited data, these *post hoc* results involving overfished and potential ecosystem component stocks indicate that although the PSA is capable of identifying low-, moderate-, and highly- vulnerable stocks, a fixed threshold for delineating between low and highly vulnerable stocks in all situations was not observed.

Determination of appropriate thresholds for low-, moderate-, and highly-vulnerable stocks will likely reflect upon the nature of each particular fishery and the management action to which it will apply. In some cases, the Council may prefer to use the results of the PSA in a qualitative manner to inform management decisions rather than as a basis for specifying rigid decision rules. When thresholds are desired, we recommend that Fishery Management Councils and their associated Science and Statistical Committees jointly determine appropriate thresholds on a fishery-by fishery basis.

6.3 Comparisons Between Target and Non-target Stocks

Comparisons of productivity and susceptibility between target and non-target stocks can be made in the Hawaii longline (tuna sector), Hawaii longline (swordfish sector), and the Atlantic shark complex (Table 5 notes which stocks were considered targets and non-targets). Kruskall-Wallis tests revealed that the productivity scores were significantly different between the target and non-target stocks in each of the two sectors of the Hawaii longline fishery ($P = 0.026$)(Figures 9 and 10, Table 6), whereas the susceptibility scores were significantly different ($P = 0.000$) in the Atlantic shark complex (Figure 5, Table 6). None of these cases showed significant differences in both axes, and no significant differences were observed in vulnerability. These results suggest that non-target stocks can be as vulnerable to overfishing as the target stocks of a fishery, and reinforce the need to carefully examine the vulnerability of non-target stocks when making management decisions.

6.4 Data Availability and Data Quality

Application of a PSA to data-poor stocks will very likely reveal missing data for one or more attributes. From our example applications, data availability was relatively high for the majority of the attributes evaluated, averaging 88% and ranging from 30 to 100% in scoring frequency (Table 7; Figure 3). However, the quality of this data was considered moderate (i.e., medium data quality scores 2 to 3), with an exception of the Northeast Multi-species Groundfish fishery (Table 5, Figure 3). The high degree of data quality for these targeted stocks reflects the relatively long time series of fishery and survey data. In general, a relationship between susceptibility and data quality is intuitive in that valuable stocks are likely the most susceptible due to targeting, and the priority placed upon the collection of data for valuable target fisheries. It is recommended that the data quality of vulnerability scores be considered in the decision-making process, and that the precautionary approach is employed if vulnerability scores were made with limited or poor data.

6.5 Degree of Consistency within Productivity and Susceptibility Scores

The degree of consistency within the productivity and susceptibility scores was determined from correlations of a particular attribute to its overall productivity or susceptibility score (after removal of the attribute being evaluated). In this analysis, susceptibility attributes related to management were separated from other susceptibility attributes. All but two of the attributes had relatively high correlation coefficients, averaging 0.43 and ranging from -0.21 to 0.80 (Table 7). The correlation coefficients for recruitment pattern (-0.21) and seasonal migration (0.06) were unusually low and could reflect the narrow range of observed recruitment patterns or seasonal migrations, as is evident from each attribute being scored 90% of time as a moderate risk. The restricted range observed for these attributes could also reflect the definition of scoring bins that were used. While these attributes were not informative for the majority of the stocks we examined here, it is anticipated that in some fisheries these attributes may prove to be more useful. As previously noted, in these cases the attribute weight can be adjusted to reflect its utility.

6.6 Correlations to Other Risk Analysis

The productivity scores obtained from our PSA analysis generally correspond to Musick's (1999) extinction risk analysis and vulnerability analysis of Cheung et al. (2005), which is integrated into the FishBase database (www.fishbase.org). In contrast to the PSA analysis which evaluates vulnerability to overfishing, these approaches aim to evaluate the risk of extinction as a function of stock productivity, trends in abundance, and life-history characteristics. As expected, scores from Musik (1999) and Cheung et al (2005) were highly correlated with our productivity scores and not correlated with our susceptibility scores (Table 8; Figures 13 and 14). Since vulnerability scores are dependent on productivity and susceptibility scores, correlations between our PSA vulnerability score and the other risk analyses were moderate (Table 8; Figures 13 and 14).

6.7 Cluster Analysis for Determining Stock Complex Groupings

The NS1 guidelines emphasize that when stock complexes are created to manage data-poor stocks, the stocks should be sufficiently similar in geographic distribution, life history, and vulnerabilities such that the impact of management actions on the stocks within the complex is similar (see § 600.310 (d)(8)). The NS1 guidelines also state that the vulnerability of stocks should be evaluated when determining if a particular stock complex should be established or reorganized, or if a particular stock should be included in a complex. To help determine the appropriate grouping of vulnerable stocks, it is recommended that a hierarchical cluster or discriminant function analysis be conducted.

7.0 CONCLUSIONS

While there are many qualitative risk analyses currently used by fisheries scientists and managers, a PSA is a particularly useful methodology for determining vulnerability because it evaluates both the productivity of the stock and its susceptibility to the fishery. Several modifications to previously published PSAs were developed to better evaluate U.S. fisheries and incorporate the principles described in the NS1 guidelines. The output from this relatively simple and straightforward tool provides the SSC and Council members an index of how vulnerable their managed stocks are to becoming overfished. It also provides guidance to help determine the needed strength of conservation measures and the degree of precaution to apply in management measures. The vulnerability of a stock should be considered when determining: 1) which stocks are fishery and ecosystem component stocks; 2) the appropriate grouping of data-poor stocks into stock complexes; and 3) appropriate buffers in either the ABC or ACT control rules.

Our analyses indicate that the PSA is generally capable of distinguishing the vulnerability of stocks that experience differing levels of fishing pressure, although fixed thresholds separating low, medium, and high vulnerability stocks were not observed. Due to differences in data quality and the manner in which FMPs were developed, it is recommended that Fishery Management Councils and their SSCs determine thresholds between low, medium, and high vulnerability stocks on a fishery-by-fishery basis.

Similar to Shertzer and Williams (2008), our example applications showed that current stock complexes exhibit a wide range of vulnerabilities (e.g., pomfrets and sharks). Therefore, the SSCs and Councils should consider reorganizing complexes that exhibit a wide range of vulnerabilities, or at least consider choosing an indicator stock that represents the more vulnerable stock(s) within the complex. If an indicator stock is found to be less vulnerable than other members of the complex, management measures need to be more conservative so that the more vulnerable members of the complex are not at risk from the fishery (see § 600.310(d)(9)).

Lastly, it is recommended that SSC or Council members consider using information on vulnerability to adjust the buffer either between OFL and ABC, or ACL and ACT, but not both in order to avoid "double-counting" of the vulnerability information. More specific guidelines about incorporating the vulnerability of stocks into control rules are being addressed by the ABC/ACT control rule working group (see Methot et al. *in prep*).

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TABLES AND FIGURES

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

Table 1 (continued).

Susceptibility Attribute	Ranking		
	Low (1)	Moderate (2)	High (3)
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.
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
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)
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.
Survival After Capture and Release	Probability of survival > 67%	33% < probability of survival < 67%	Probability of survival < 33%
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)
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

Table 2. Productivity attribute thresholds based on the empirical relationships between t_{max}, M, k, and t_{mat} (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).

		Productivity		
Attribute	**Source**	**Low**	**Moderate**	**High**
K	Modeling	<0.10	0.10 - 0.30	>0.30
	US 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
	US 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
	US Fisheries	>30	10 - 30	<10
	Threshold	>30	10 - 30	<10
t_{mat} (yrs)	Modeling	>9	3 - 9	<3
	US Fisheries	>4	2 - 4	<2
	Threshold	>4	2 - 4	<2
L_{max} (cm)	Modeling	-	-	-
	US Fisheries	>150	60 - 150	<60
	Threshold	>150	60 - 150	<60

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 (lbs)	< $500,000	$500,000 - $10,000,000	> $10,000,000
Recreational	% Retention	< 33%	34 - 66%	> 66%

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

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.	

Table 5. Data for example applications including identification numbers, common and scientific names, productivity, susceptibility and vulnerability and data quality scores. ID numbers are used to note stocks in summary x-y plots that include multiple fisheries, while group IDs are used in x-y plots for a particular fishery.

ID	Group ID	Fishery	Stock	Scientific name	Productivity	Susceptibility	Vulnerability	# of Productivity Attributes Scored	Productivity Data Qaulity	# of Susceptiblity Attributes Scored	Susceptibility Data Quality
1	1	Atlantic Shark Complexes	Sixgill shark*	*Hexanchus griseus*	1.1	1.4	2.0	9	2.7	7	3.0
2	2		Sharpnose sevengill shark*	*Heptranchias perlo*	1.1	1.4	1.9	4	4.1	6	3.4
3	3		Bigeye sandtiger shark*	*Odontaspis noronhai*	1.1	1.6	2.0	9	3.0	7	3.1
4	4		Whale shark*	*Rhincodon typus*	1.3	1.7	1.9	9	3.1	6	3.2
5	5		Caribbean sharpnose shark*	*Rhizoprionodon porosus*	1.8	1.6	1.4	9	2.9	6	3.4
6	6		Angel shark*	*Squatina dumeril*	1.3	1.6	1.8	9	3.0	6	3.5
7	7		White shark*	*Carcharodon carcharias*	1.1	1.7	2.1	9	2.5	6	3.3
8	8		Basking shark*	*Cetorhinus maximus*	1.0	1.8	2.1	9	2.9	7	2.9
9	9		Sandtiger shark*	*Carcharias taurus*	1.1	1.8	2.0	9	2.0	8	2.7
10	10		Blue shark*	*Prionace glauca*	1.3	1.9	1.9	9	1.8	10	1.9
11	11		Smalltail shark*	*Carcharhinus porosus*	1.3	1.8	1.9	9	2.5	6	3.4
12	12		Nurse shark	*Ginglymostoma cirratum*	1.3	1.8	1.9	9	2.4	7	2.7
13	13		Galapagos shark*	*Carcharhinus galapagensis*	1.2	1.9	2.0	9	2.6	6	3.3
14	14		Dusky shark*	*Carcharhinus perezi*	1.0	2.1	2.2	9	2.0	9	2.1
15	15		Porbeagle*	*Lamna nasus*	1.0	2.1	2.3	9	2.0	9	2.2
16	16		Common thresher shark*	*Alopias vulpinus*	1.1	2.3	2.3	9	2.0	7	2.7
17	17		Oceanic whitetip shark*	*Carcharhinus longimanus*	1.1	2.2	2.3	9	2.3	7	2.7
18	18		Blacknose shark	*Carcharhinus acronotus*	1.3	2.3	2.2	9	2.0	9	2.1
19	19		Lemon shark	*Negaprion brevirostris*	1.0	2.2	2.3	9	1.6	8	2.7
20	20		Shortfin mako shark*	*Isurus oxyrinchus*	1.0	2.3	2.4	9	2.0	9	2.1
21	21		Longfin mako shark*	*Isurus retroflexus*	1.1	2.3	2.3	9	2.5	7	2.8
22	22		Tiger shark	*Galeocerdo cuvier*	1.4	2.3	2.1	9	2.0	7	2.7
23	23		Smooth hammerhead shark	*Sphyrna zygaena*	1.1	2.3	2.3	9	2.6	7	2.7
24	24		Caribbean reef shark*	*Carcharhinus perezi*	1.0	2.4	2.4	8	3.0	8	2.7
25	25		Blacktip shark	*Carcharhinus limbatus*	1.2	2.4	2.3	9	2.0	10	2.0
26	26		Scalloped hammerhead shark	*Sphyrna lewini*	1.0	2.4	2.4	9	2.0	10	2.1
27	27		Sandbar shark	*Carcharhinus plumbeus*	1.0	2.4	2.4	9	2.0	10	2.0
28	28		Bigeye thresher shark*	*Alopias superciliosus*	1.1	2.4	2.4	9	2.4	7	2.7
29	29		Finetooth shark	*Carcharhinus isodon*	1.3	2.5	2.2	9	2.0	9	2.1
30	30		Night shark*	*Carcharhinus signatus*	1.1	2.5	2.4	9	2.4	7	2.7
31	31		Bignose shark*	*Carcharhinus altimus*	1.1	2.5	2.4	9	2.1	7	2.7
32	32		Bonnethead shark	*Sphyrna tiburo*	1.7	2.5	2.0	9	2.0	9	2.1
33	33		Spinner shark	*Carcharhinus brevipinna*	1.2	2.6	2.4	9	2.0	7	2.7
34	34		Bull shark	*Carcharhinus leucas*	1.1	2.6	2.4	9	2.0	7	2.7
35	35		Great hammerhead shark	*Sphyrna mokarran*	1.0	2.5	2.5	9	2.2	7	2.7
36	36		Atlantic sharpnose shark	*Rhizoprionodon terraenovae*	1.8	2.6	2.0	9	2.0	9	2.1
37	37		Silky shark	*Carcharhinus falciformis*	1.1	2.7	2.6	9	2.0	7	2.7
38	1	BSAI Skate Complexes	Alaska skate*	*Bathyraja parmifera*	1.4	1.9	1.8	10	1.3	10	2.0
39	2		Aleutian skate*	*Bathyraja aleutica*	1.3	1.6	1.8	9	1.5	10	2.5
40	3		Commander skate*	*Bathyraja lindbergi*	1.4	1.8	1.8	9	2.9	10	2.5
41	4		Whiteblotched skate*	*Bathyraja maculata*	1.4	1.8	1.8	9	2.8	10	2.5
42	5		Whitebrow skate*	*Bathyraja minispinosa*	1.4	1.8	1.8	9	2.9	10	2.5
43	6		Roughtail skate*	*Bathyraja trachura*	1.4	1.8	1.8	9	2.7	10	2.5
44	7		Bering skate*	*Bathyraja interrupta*	1.4	1.6	1.7	9	1.6	10	2.5
45	8		Mud skate*	*Bathyraja taranetzi*	1.4	1.8	1.8	9	2.8	10	2.5
46	9		Roughshoulder skate*	*Amblyraja badia*	1.4	1.7	1.8	9	3.0	9	2.8
47	10		Big skate*	*Raja binoculata*	1.3	1.6	1.8	9	1.6	10	2.5
48	11		Longnose skate*	*Raja rhina*	1.3	1.6	1.8	9	1.5	10	2.8
49	12		Butterfly skate*	*Bathyraja mariposa*	1.4	1.6	1.7	9	2.9	10	2.5
50	13		Deepsea skate*	*Bathyraja abyssicola*	1.4	1.8	1.8	9	2.9	10	2.2

Table 5. (continued).

ID	Group ID	Fishery	Stock	Scientific name	Productivity	Susceptibility	Vulnerability	# of Productivity Attributes Scored	Productivity Data Qaulity	# of Susceptiblity Attributes Scored	Susceptibility Data Quality
51	1	CA Nearshore Groundfish	California sheephead	*Semicossyphus pulcher*	1.9	2.2	1.7	10	1.6	12	1.6
52	2		Cabezon	*Scorpaenichthys marmoratus*	2.0	2.2	1.6	10	1.7	12	1.5
53	3		Kelp greenling	*Hexigrammos decagrammus*	2.0	2.1	1.4	10	2.1	12	1.5
54	4		Rock greenling	*Hexigrammos lagocephalus*	2.0	2.1	1.5	10	2.3	12	1.9
55	5		California scorpionfish	*Scorpaena guttata*	2.0	1.8	1.3	10	2.1	12	1.5
56	6		Monkyface prickelback	*Cebidichthys violaceus*	1.8	2.0	1.6	10	2.3	12	2.0
57	7		Black rockfish	*Sebastes melanops*	1.4	2.2	2.0	10	1.9	12	1.5
58	8		Black-and-yellow rockfish	*Sebastes chrysomelas*	1.9	2.3	1.7	10	1.9	12	1.8
59	9		Blue rockfish	*Sebastes mystinus*	1.5	2.3	2.0	10	1.9	12	1.5
60	10		Brown rockfish	*Sebastes auriculatus*	1.7	2.4	1.9	10	2.2	12	1.9
61	11		Calico rockfish*	*Sebastes dallii*	1.8	2.0	1.5	10	2.4	12	1.9
62	12		China rockfish	*Sebastes nebulosus*	1.6	2.5	2.0	10	2.2	12	1.9
63	13		Copper rockfish	*Sebastes caurinus*	1.3	2.3	2.2	10	2.0	12	1.9
64	14		Gopher rockfish	*Sebastes carnatus*	2.0	2.2	1.6	10	2.4	12	1.6
65	15		Grass rockfish	*Sebastes rastrelliger*	1.6	2.2	1.8	10	2.1	12	1.9
66	16		Kelp rockfish	*Sebastes atrovirens*	1.9	2.0	1.5	10	2.2	12	1.9
67	17		Olive rockfish	*Sebastes serranoides*	1.5	2.2	2.0	10	2.1	12	1.9
68	18		Quillback rockfish	*Sebastes maliger*	1.3	2.4	2.3	10	2.0	12	1.9
69	19		Treefish rockfish	*Sebastes serriceps*	1.9	2.3	1.7	10	2.2	12	1.9
70	1	CA Current Pelagics	Pacific sardine	*Sardinops sagax*	2.5	2.1	1.2	10	2.7	11	2.3
71	2		Northern anchovy	*Engraulis mordax*	2.8	2.1	1.2	10	2.8	11	2.4
72	3		Pacific mackerel	*Scomber japonicus*	2.2	2.2	1.5	10	2.5	11	2.6
73	4		Jack mackerel	*Trachurus symmetricus*	2.1	1.9	1.3	10	2.7	11	3.1
74	5		Market squid	*Doryteuthis opalescens*	2.6	2.3	1.4	10	2.8	11	3.2
75	6		Pacific herring	*Clupea pallasii*	2.4	2.5	1.6	10	2.7	11	2.9
76	7		Pacific bonito	*Sarda chiliensis*	2.5	2.1	1.3	10	3.2	11	3.6
77	8		Pacific saury	*Cololabis saira*	2.7	1.9	1.0	10	3.5	11	3.1
78	1	NE Groundfish	Gulf of Maine cod	*Gadus morhua*	2.3	2.5	1.7	10	1.5	12	1.5
79	2		Georges Bank cod	*Gadus morhua*	2.3	2.6	1.7	10	1.5	12	1.5
80	3		Gulf of Maine haddock	*Melanogrammus aeglefinus*	2.0	2.4	1.7	10	1.5	12	1.5
81	4		Georges Bank haddock	*Melanogrammus aeglefinus*	2.0	2.5	1.8	10	1.5	12	1.5
82	5		Redfish	*Sebastes marinus*	2.5	2.3	1.4	10	1.5	12	1.5
83	6		Pollock	*Pollachius virens*	2.3	2.4	1.5	10	1.5	12	1.5
84	7		Cape Cod/Gulf of Maine yellowtail flounder	*Limanda ferruginea*	2.1	2.6	1.8	10	1.5	12	1.5
85	8		Georges Bank yellowtail flounder	*Limanda ferruginea*	2.1	2.5	1.8	10	1.5	12	1.5
86	9		Southern New England yellowtail flounder	*Limanda ferruginea*	2.1	2.6	1.8	10	1.5	12	1.5
87	10		American plaice	*Hippoglossoides platessoides*	2.2	2.3	1.5	10	1.5	12	1.5
88	11		Witch flounder	*Glyptocephalus cynoglossus*	2.2	2.5	1.7	10	1.5	12	1.5
89	12		Gulf of Maine Winter flounder	*Pseudopleuronectes americanus*	2.0	2.5	1.8	10	1.5	12	1.5
90	13		Georges Bank Winter flounder	*Pseudopleuronectes americanus*	2.0	2.5	1.8	10	1.5	12	1.5
91	14		Southern New England/Mid-Atlantic winter flounder	*Pseudopleuronectes americanus*	2.0	2.5	1.8	10	1.5	12	1.5
92	15		Gulf of Maine/Georges Bank windowpane	*Scophthalmus aquosus*	2.0	2.2	1.6	10	1.7	12	1.9
93	16		Southern New EnglandMid-Atlantic windowpane	*Scophthalmus aquosus*	2.0	2.2	1.6	10	1.7	12	1.9
94	17		Ocean pout	*Zoarces americanus*	2.5	2.3	1.4	10	1.8	12	1.9
95	18		White hake	*Urophycis tenuis*	2.5	2.4	1.5	10	1.5	12	1.5
96	19		Atlantic halibut	*Hippoglossus hippoglossus*	2.6	2.6	1.6	10	1.6	12	1.9
97	1	HA Pelagic Longline - Swordfish	Albacore	*Thunnus alalunga*	1.9	2.0	1.5	10	2.5	11	1.9
98	2		Bigeye tuna	*Thunnus obesus*	1.9	2.1	1.5	10	2.2	11	1.9
99	3		Black marlin*	*Makaira mazara*	1.8	1.8	1.5	10	2.3	9	3.4
100	4		Bullet tuna	*Auxis rochei rochei*	2.3	1.8	1.0	10	3.2	9	3.9

Table 5. (continued).

ID	Group ID	Fishery	Stock	Scientific name	Productivity	Susceptibility	Vulnerability	# of Productivity Attributes Scored	Productivity Data Qaulity	# of Susceptiblity Attributes Scored	Susceptibility Data Quality
101	5	HA Pelagic Longline - Swordfish	Pacific pomfret*	*Brama japonica*	2.3	1.6	1.0	9	3.2	9	3.3
102	6		Blue shark*	*Prionace glauca*	1.5	1.7	1.7	10	2.0	11	1.9
103	7		Bigeye thresher shark*	*Alopias superciliosus*	1.4	1.7	1.8	10	3.0	9	3.1
104	8		Blue marlin*	*Makaira nigricans*	1.8	1.8	1.4	10	2.2	11	2.2
105	9		Dolphin fish (mahi mahi)*	*Coryphaena hippurus*	2.3	1.9	1.1	10	1.4	9	2.4
106	10		Brilliant pomfret*	*Eumegistus illustris*	1.7	2.1	1.7	4	4.4	9	3.8
107	11		Kawakawa*	*Euthynnus affinis*	2.3	1.7	1.0	10	2.2	9	3.8
108	12		Spotted moonfish*	*Lampris guttatus*	1.5	2.0	1.8	6	3.7	9	3.1
109	13		Longfin mako shark*	*Isurus paucus*	1.4	1.5	1.7	10	2.9	9	3.8
110	14		Salmon shark*	*Lamna ditropis*	1.2	1.9	2.0	8	3.5	9	3.4
111	15		Striped marlin*	*Tetrapturus audax*	2.0	2.0	1.4	10	1.9	10	2.2
112	16		Oilfish*	*Ruvettus pretiosus*	2.0	1.8	1.2	10	3.7	9	2.8
113	17		Northern bluefin tuna*	*Thunnus orientalis*	1.7	2.2	1.7	10	2.3	11	2.9
114	18		Roudi escolar*	*Promethichthys prometheus*	2.1	1.7	1.1	10	3.5	9	2.8
115	19		Pelagic thresher shark*	*Alopias pelagicus*	1.5	1.5	1.6	10	2.6	9	3.8
116	20		Sailfish*	*Istiophorus platypterus*	1.9	1.8	1.3	10	2.1	9	3.4
117	21		Skipjack tuna	*Katsuwonus pelamis*	2.4	1.9	1.0	10	1.8	11	2.6
118	22		Shortfin mako shark*	*Isurus oxyrinchus*	1.4	1.5	1.6	10	2.6	9	2.8
119	23		Shortbill spearfish*	*Tetrapturus angustirostris*	2.2	1.8	1.2	10	2.8	9	2.8
120	24		Broad billed swordfish	*Xiphias gladius*	1.8	1.7	1.3	10	1.5	11	1.9
121	25		Flathead pomfret*	*Taractichthys asper*	1.7	1.5	1.3	4	4.4	9	3.8
122	26		Dagger pomfret*	*Taractichthys rubescens*	1.5	1.7	1.7	4	4.4	9	3.4
123	27		Sickle pomfret*	*Taractichthys steindachneri*	1.8	2.1	1.6	5	4.5	9	2.8
124	28		Wahoo*	*Acanthocybium solandri*	2.3	2.0	1.2	10	1.8	9	3.1
125	29		Yellowfin tuna	*Thunnus albacares*	2.3	1.9	1.2	10	1.2	11	2.2
126	30		Oceanic whitetip shark*	*Carcharhinus longimanus*	1.3	1.4	1.7	10	3.2	9	3.1
127	31		Silky shark*	*Carcharhinus falciformis*	1.3	1.5	1.7	10	3.3	9	3.4
128	32		Common thresher shark*	*Alopias vulpinus*	1.7	1.7	1.5	3	4.7	9	3.4
129	33		Escolar*	*Lepidocybium flavobrunneum*	2.0	1.8	1.3	10	3.6	9	2.8
130	1	HA Pelagic Longline - tuna	Albacore	*Thunnus alalunga*	1.9	2.1	1.6	10	2.5	11	1.9
131	2		Bigeye tuna	*Thunnus obesus*	1.9	2.1	1.6	10	2.2	11	1.9
132	3		Black Marlin*	*Makaira mazara*	1.8	2.0	1.5	10	2.3	9	3.4
133	4		Bullet tuna	*Auxis rochei rochei*	2.3	1.8	1.0	10	3.2	9	3.9
134	5		Pacific pomfret*	*Brama japonica*	2.2	1.9	1.2	9	3.2	9	3.0
135	6		Blue Shark*	*Prionace glauca*	1.5	1.6	1.6	10	2.0	11	1.9
136	7		Bigeye thresher shark*	*Alopias superciliosus*	1.4	1.5	1.7	10	3.0	9	2.8
137	8		Blue marlin*	*Makaira nigricans*	1.8	1.9	1.5	10	2.2	11	2.2
138	9		Dolphin fish (mahi mahi)*	*Coryphaena hippurus*	2.3	1.9	1.2	10	1.4	9	2.4
139	10		Brilliant pomfret*	*Eumegistus illustris*	1.7	2.3	1.8	4	4.4	9	3.1
140	11		Kawakawa*	*Euthynnus affinis*	2.3	1.7	1.0	10	2.2	9	3.8
141	12		Spotted moonfish*	*Lampris guttatus*	1.5	2.2	1.9	6	3.7	9	2.4
142	13		Longfin mako shark*	*Isurus paucus*	1.4	1.9	1.8	10	2.9	9	3.1
143	14		Salmon shark*	*Lamna ditropis*	1.2	1.7	1.9	8	3.5	9	3.4
144	15		Striped marlin*	*Tetrapturus audax*	2.0	1.8	1.3	10	1.9	10	1.9
145	16		Oilfish*	*Ruvettus pretiosus*	2.0	1.8	1.3	10	3.7	9	2.8
146	17		Northern bluefin tuna*	*Thunnus orientalis*	1.7	2.0	1.7	10	2.3	11	2.9
147	18		Roudi escolar*	*Promethichthys prometheus*	2.1	1.9	1.3	10	3.5	9	3.1
148	19		Pelagic thresher*	*Alopias pelagicus*	1.5	1.9	1.7	10	2.6	9	3.1
149	20		Sailfish*	*Istiophorus platypterus*	1.9	1.9	1.4	10	2.1	9	3.1
150	21		Skipjack tuna	*Katsuwonus pelamis*	2.4	2.0	1.2	10	1.8	11	1.9

Table 5. (continued).

ID	Group ID	Fishery	Stock	Scientific name	Productivity	Susceptibility	Vulnerability	# of Productivity Attributes Scored	Productivity Data Qaulity	# of Susceptiblity Attributes Scored	Susceptibility Data Quality
151	22	HA Pelagic Longline - tuna	Shortfinned mako shark*	*Isurus oxyrinchus*	1.4	1.9	1.8	10	2.6	9	2.8
152	23		Short bill spearfish*	*Tetrapturus angustirostris*	2.2	1.8	1.1	10	2.8	9	2.4
153	24		Broad billed swordfish*	*Xiphias gladius*	1.8	1.6	1.3	10	1.5	11	1.9
154	25		Flathead pomfret*	*Taractichthys asper*	1.7	1.6	1.4	4	4.4	9	3.1
155	26		Dagger pomfret*	*Taractichthys rubescens*	1.5	1.7	1.7	4	4.4	9	2.8
156	27		Sickle pomfret*	*Taractichthys steindachneri*	1.8	2.2	1.6	5	4.5	9	2.4
157	28		Wahoo*	*Acanthocybium solandri*	2.3	2.1	1.3	10	1.8	9	2.4
158	29		Yellowfin tuna	*Thunnus albacares*	2.3	2.0	1.2	10	1.2	11	1.9
159	30		Oceanic whitetip shark*	*Carcharhinus longimanus*	1.3	1.6	1.8	10	3.2	9	2.8
160	31		Silky shark*	*Carcharhinus falciformis*	1.3	1.7	1.8	10	3.3	9	2.8
161	32		Common thresher shark *	*Alopias vulpinus*	1.7	1.9	1.6	3	4.7	9	3.4
162	33		Escolar*	*Lepidocybium flavobrunneum*	2.0	1.8	1.3	10	3.6	9	2.9
163	1	South Atlantic and Gulf of Mexico Longline	Sand tilefish*	*Malacanthus plumieri*	2.1	1.5	1.1	10	3.4	9	3.4
164	2		Rock sea bass*	*Centropristis philadelphica*	2.7	1.7	0.7	10	3.6	9	3.6
165	3		Margate*	*Haemulon album*	2.4	1.8	1.0	10	3.3	9	3.1
166	4		Bar jack*	*Caranx ruber*	2.1	1.4	0.9	10	2.9	9	3.4

* Non-target stocks

Table 6. Non-parametric statistical analysis of targeted versus non-targeted species among productivity (VEP), susceptibility (VES), and vulnerability (VE) scores.

		Kruskall-Wallis P Values		
Fishery	**Number**	**VEP**	**VES**	**VE**
Hawaii Longline - Tuna Sector	33	0.026	0.373	0.072
Hawaii Longline - Swordfish Sector	33	0.026	0.153	0.058
Atlantic Shark Complexes	37	0.150	0.000	0.380
Combined	**103**	**0.752**	**0.000**	**0.160**

Table 7. Summary of the productivity and susceptibility scoring frequencies and correlations to its overall factor/category score. Correlations were based on stock attributes scores (1 – 3) compared to a modified categorical score for the stock, which did not included the related attribute score.

Category	Number Scored	Frequency Scored	Pearson Correlation Coefficient	P Value
Productivity				
r	128	96%	0.596	0.000
Maximum Age	126	95%	0.674	0.000
Maximum Size	128	96%	0.592	0.000
von Bertalanffy Growth Coefficient (k)	129	97%	0.656	0.000
Estimated Natural Mortality	127	95%	0.785	0.000
Measured Fecundity	126	95%	0.509	0.000
Breeding Strategy	133	100%	0.568	0.000
Recruitment Pattern	84	63%	-0.211	0.054
Age at Maturity	125	94%	0.802	0.000
Mean Trophic Level	132	99%	0.439	0.000
Susceptibility				
Management				
Management Strategy	133	100%	0.154	0.077
Fishing rate relative to M	79	59%	0.510	0.000
Biomass of Spawners (SSB) or other proxies	78	59%	0.389	0.000
Survival After Capture and Release	126	95%	0.201	0.024
Fishery Impact to EFH or Habitat in General for Non-targets	133	100%	0.286	0.001
Catchability				
Areal Overlap	123	92%	0.333	0.000
Geographic Concentration	133	100%	0.345	0.000
Vertical Overlap	133	100%	0.772	0.000
Seasonal Migrations	49	37%	0.058	0.692
Schooling/Aggregation and Other Behavioral Responses	87	65%	0.340	0.001
Morphology Affecting Capture	132	99%	0.319	0.000
Desirability/Value of the Fishery	133	100%	0.504	0.000

Table 8. Regression and correlation analysis of our vulnerability analysis compared to (A) fuzzy logic vulnerability assessment (FishBase.org source) and (B) AFS' vulnerability scores (Musick 1999).

(A)

		Coefficent of Determination (R^2)			Pearson's Correlation Coefficent		
Case Study	**Number**	**VEP vs. FB**	**VES vs. FB**	**VE vs. FB**	**VEP vs. FB**	**VES vs. FB**	**VE vs. FB**
Coastal Pelagics	8	0.505	0.012	0.103	-0.709	-0.110	0.313
Hawaii Longline - Tuna Sector	33	0.398	0.014	0.356	-0.631	-0.117	0.599
Hawaii Longline - Swordfish Sector	33	0.398	0.043	0.343	-0.631	-0.208	0.586
Northeast Groundfish	19	0.512	0.013	0.440	-0.716	0.114	0.665
Atlantic Shark Complexes	37	0.353	0.015	0.093	-0.594	-0.121	0.302
California Nearshore Groundfish	19	0.445	0.398	0.559	-0.667	0.631	0.742
Bering Sea/Aleutian Islands Skates	13	0.137	0.001	0.010	-0.035	0.307	0.307
All Case Studies Combined	**162**	**0.459**	**0.028**	**0.234**	**-0.674**	**-0.163**	**-0.484**

(B)

		Coefficent of Determination (R^2)			Pearson's Correlation Coefficent		
Case Study	**Number**	**VEP vs. AFS**	**VES vs. AFS**	**VE vs. AFS**	**VEP vs. AFS**	**VES vs. AFS**	**VE vs. AFS**
Coastal Pelagics	8	NA	NA	NA	NA	NA	NA
Hawaii Longline - Tuna Sector	33	0.815	0.145	0.682	0.903	0.319	-0.827
Hawaii Longline - Swordfish Sector	33	0.815	0.102	0.682	0.903	0.380	-0.826
Northeast Groundfish	19	0.756	0.023	0.425	-0.279	-0.220	0.103
Atlantic Shark Complexes	37	0.848	0.003	0.439	-0.040	0.120	0.105
California Nearshore Groundfish	19	0.468	0.234	0.468	0.642	-0.296	-0.568
Bering Sea/Aleutian Islands Skates	13	NA	NA	0.000	-0.072	-0.196	-0.196
All Case Studies Combined	**162**	**0.494**	**0.000**	**0.354**	**0.737**	**-0.005**	**-0.596**

Figure 1. 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).

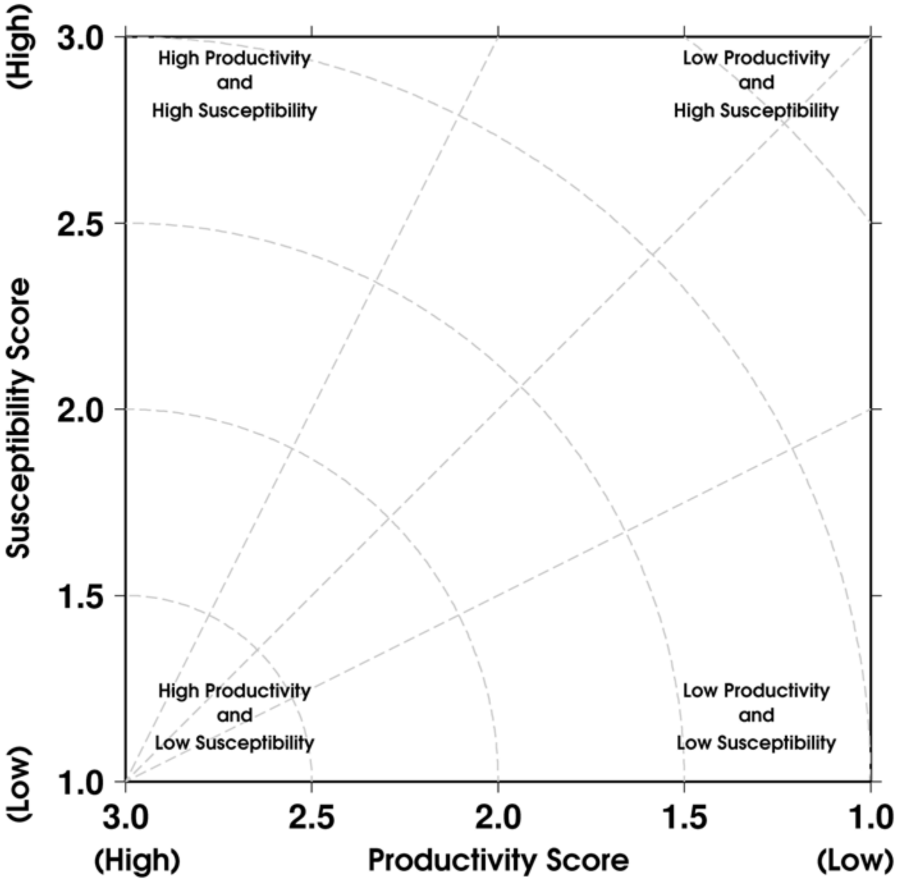


Figure 2. Overall distribution of productivity and susceptibility x-y plot for the 166 stocks evaluated in this study, as well as the associated data quality of each datum point (see Table 5 for reference IDs).

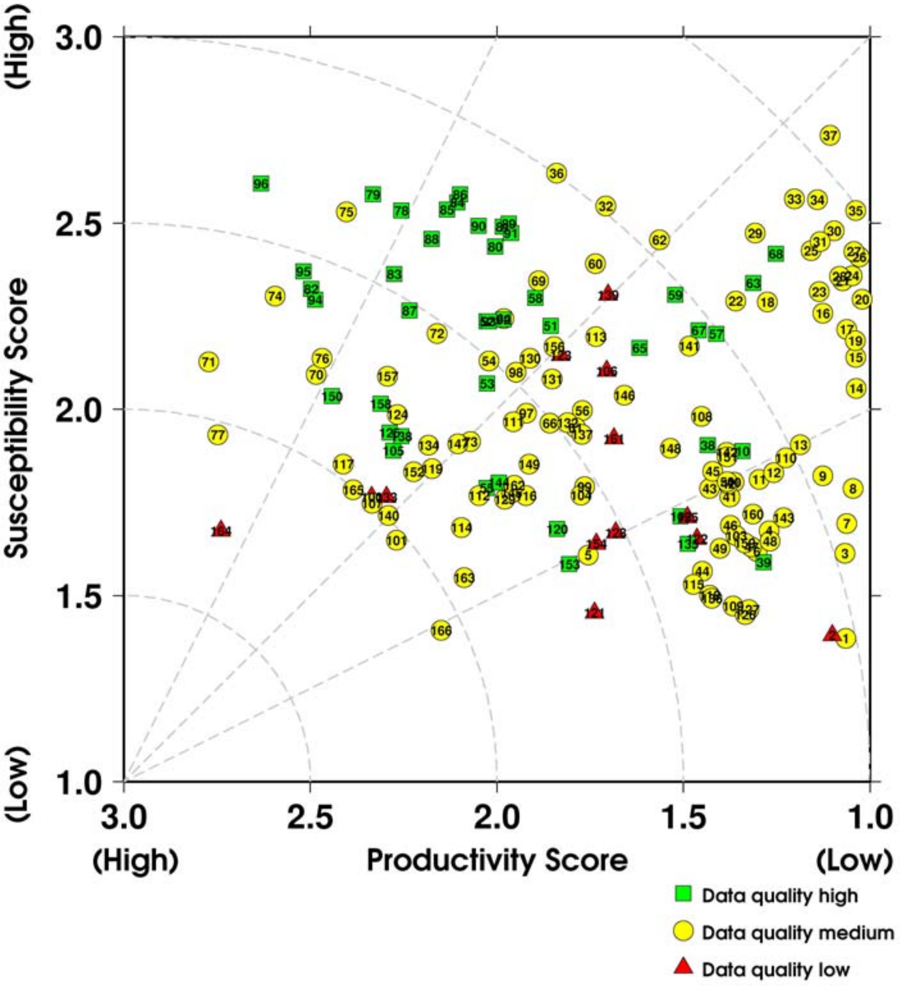


Figure 3. Overall distribution of data quality scores for the productivity and susceptibility factors, noting the number of attributes used for each stock (see Table 5 for reference IDs).

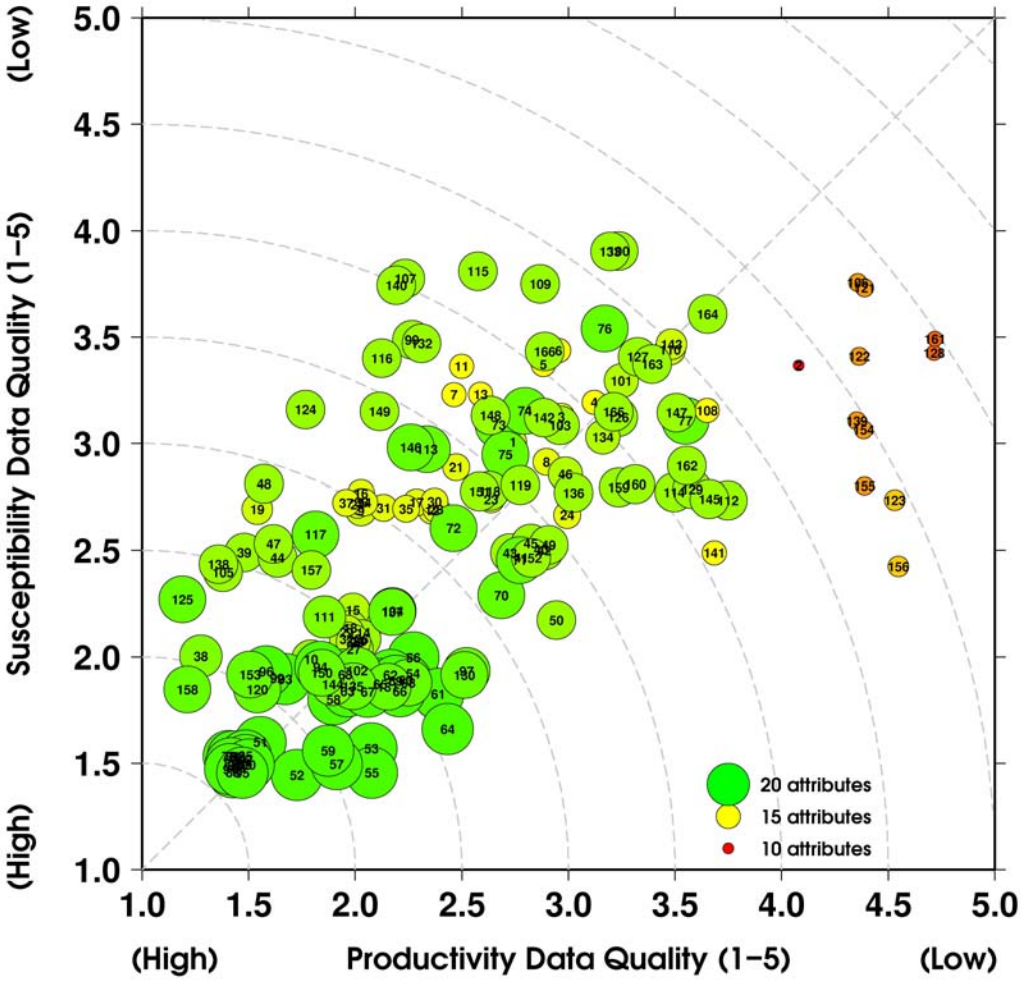


Figure 4. Northeast Groundfish Multispecies Fishery productivity and susceptibility x-y plot (see Table 5 for reference group numbers).

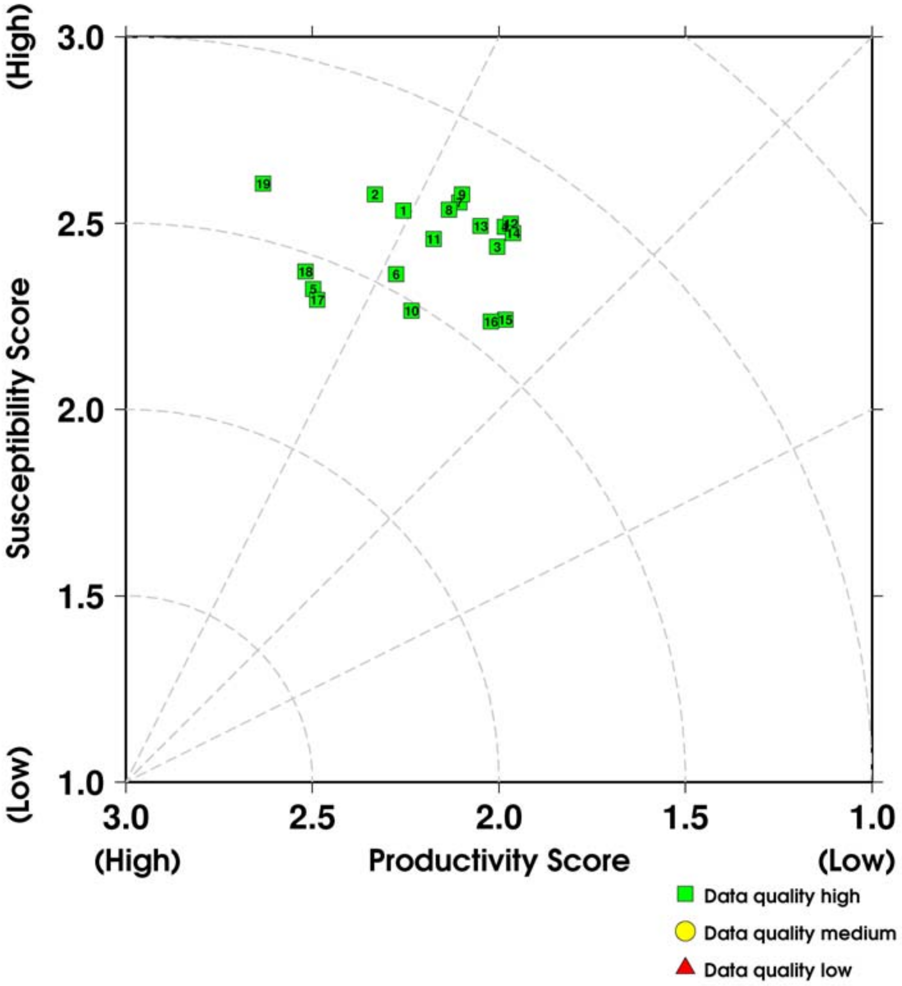


Figure 5. Highly Migratory Atlantic Shark Complex productivity and susceptibility x-y plot (see Table 5 for reference group numbers).

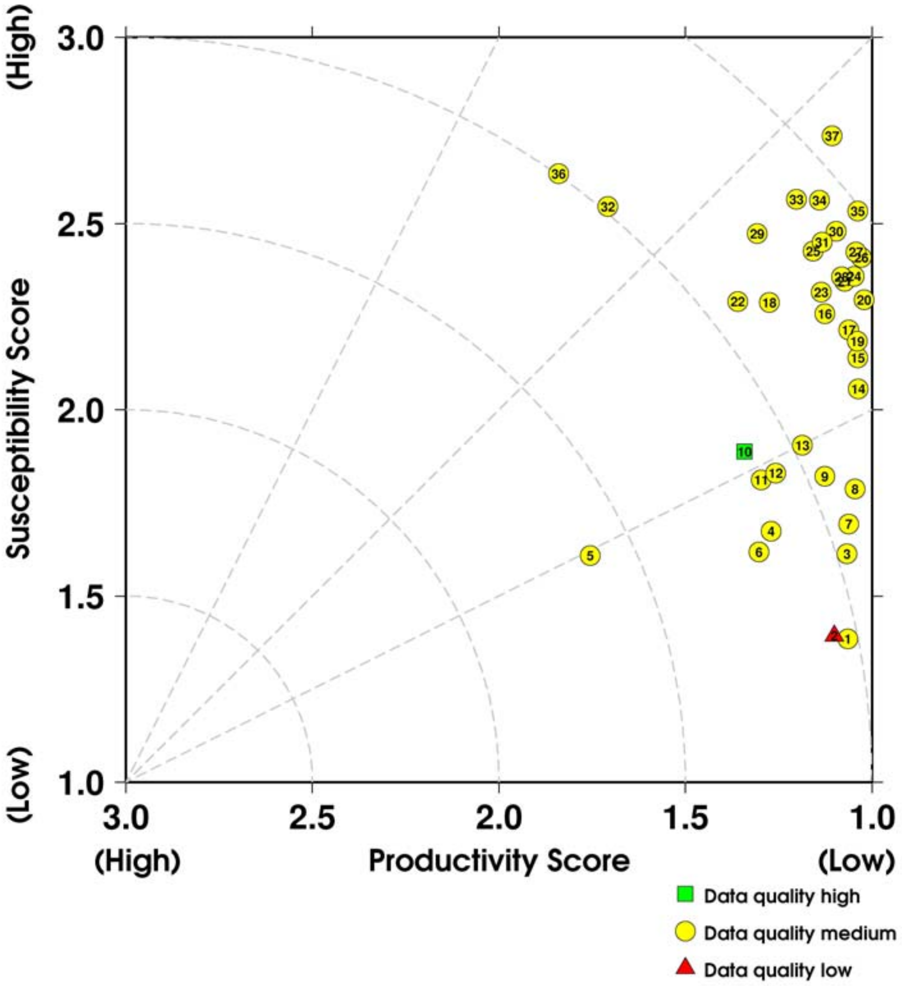


Figure 6. California Nearshore Groundfish Finfish Assemblage productivity and susceptibility x-y plot (see Table 5 for reference group numbers).

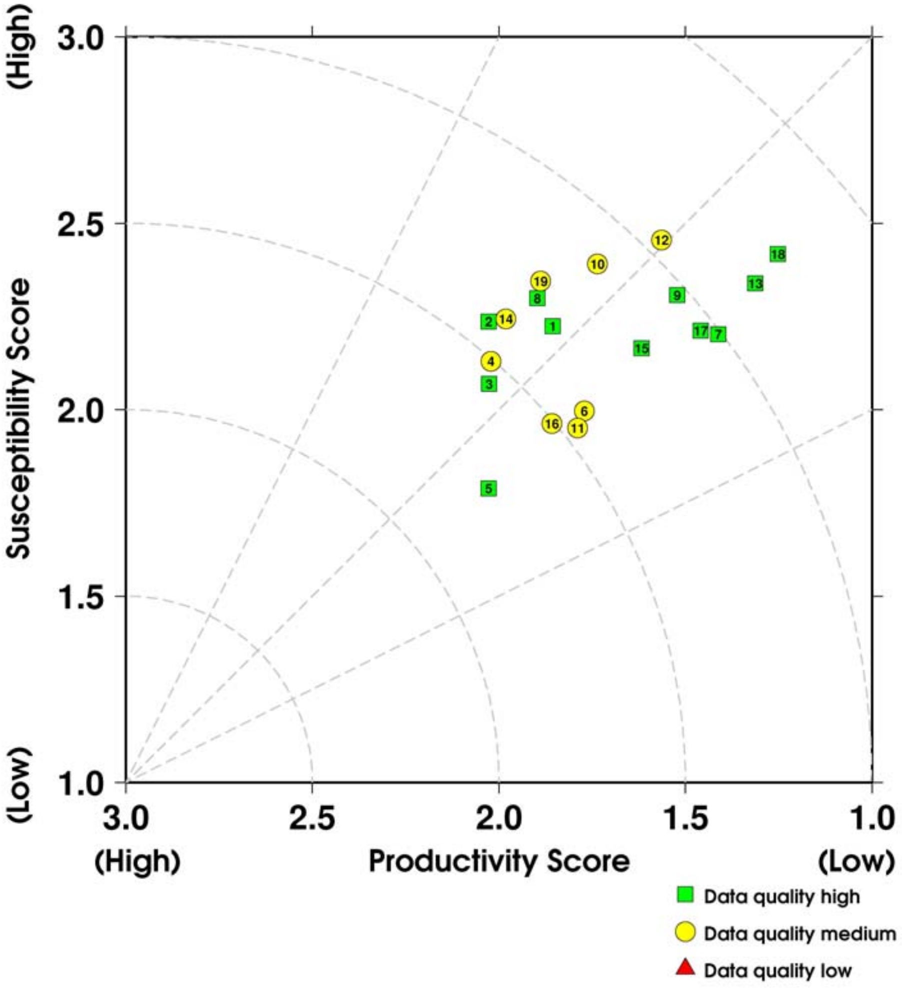


Figure 7. California Current Coastal Pelagic Species productivity and susceptibility x-y plot (see Table 5 for reference group numbers).

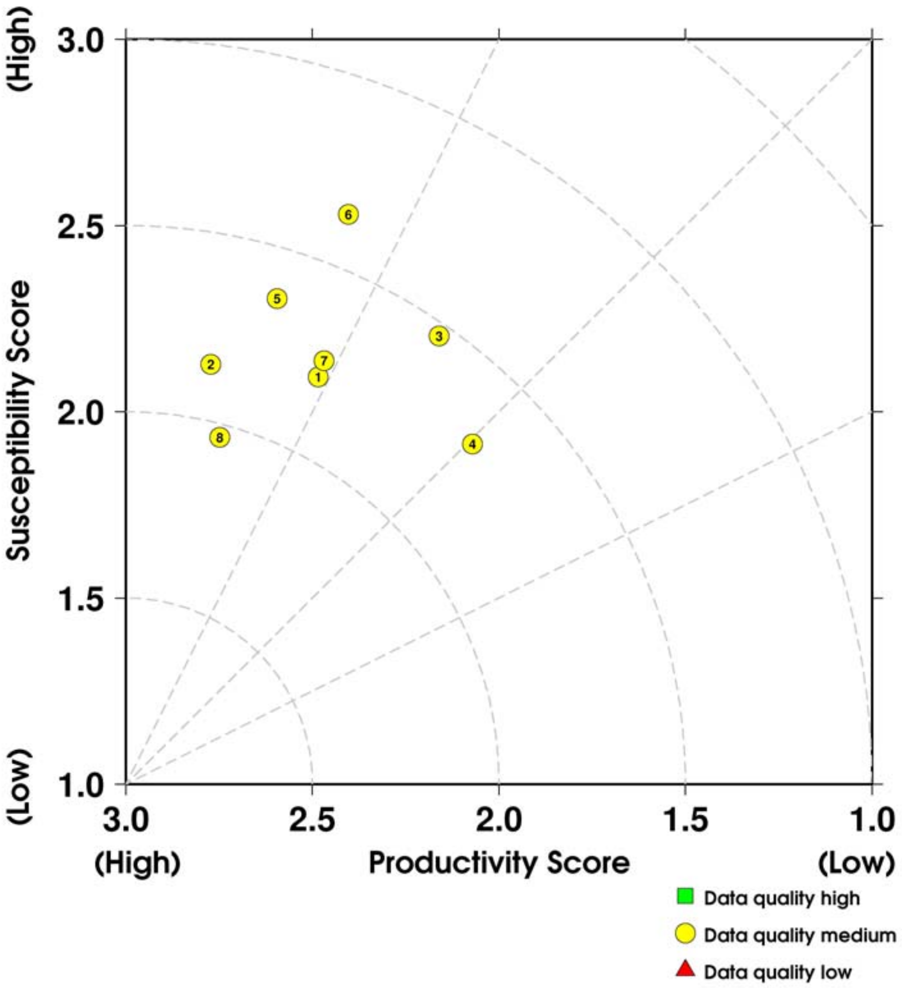


Figure 8. Skates of the Bering Sea and Aleutian Islands Management Area productivity and susceptibility x-y plot (see Table 5 for reference group numbers).

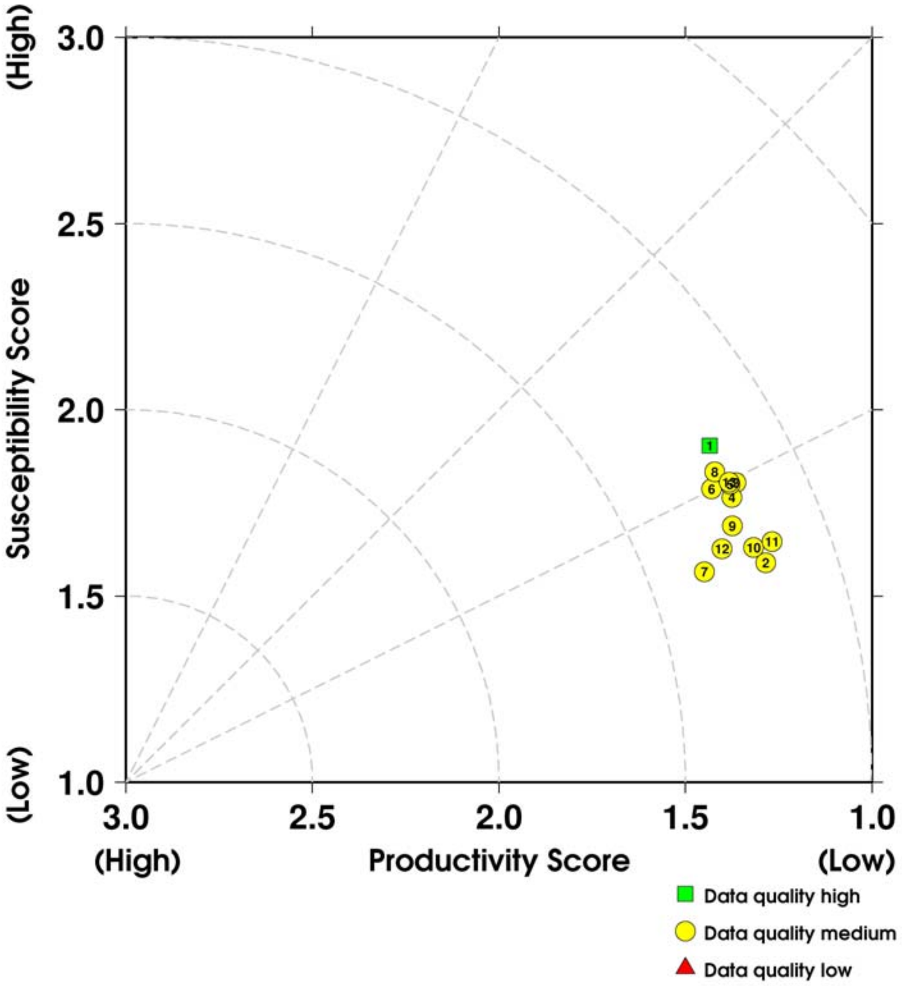


Figure 9. Hawaii-based Tuna Longline Fishery productivity and susceptibility x-y plot (see Table 5 for reference group numbers).

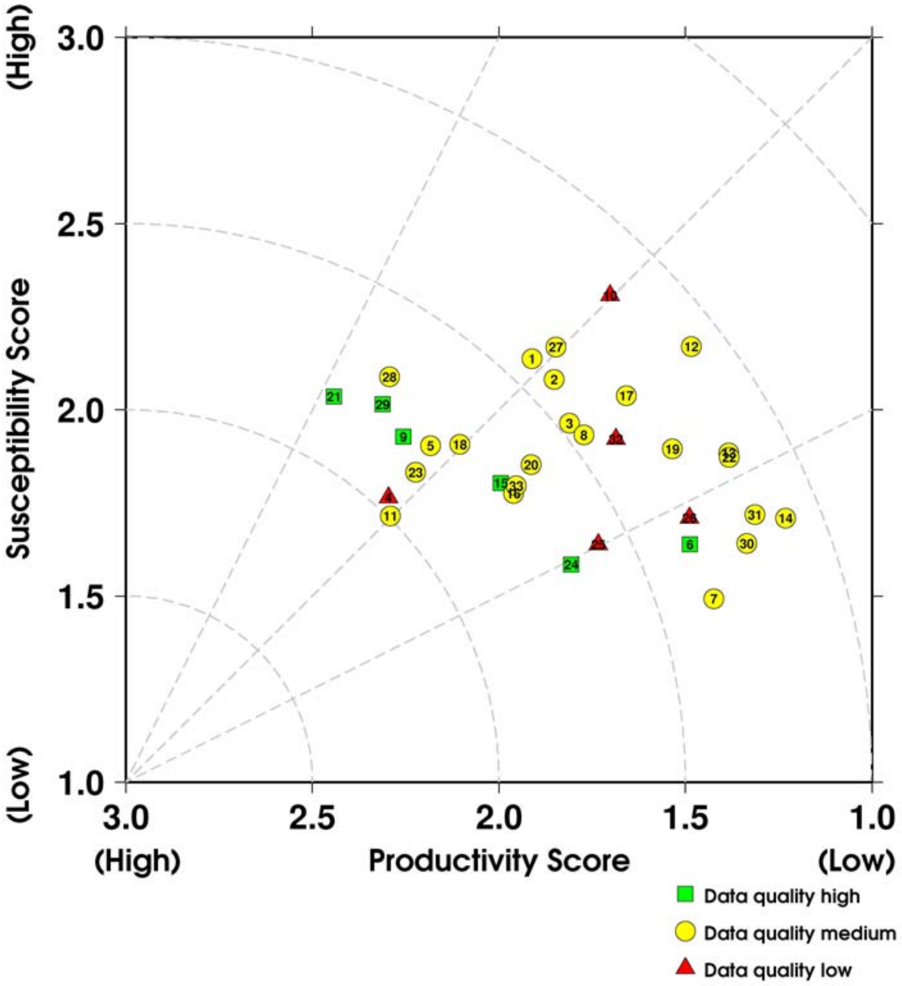


Figure 10. Hawaii-based Swordfish Longline Fishery productivity and susceptibility x-y plot (see Table 5 for reference group numbers).

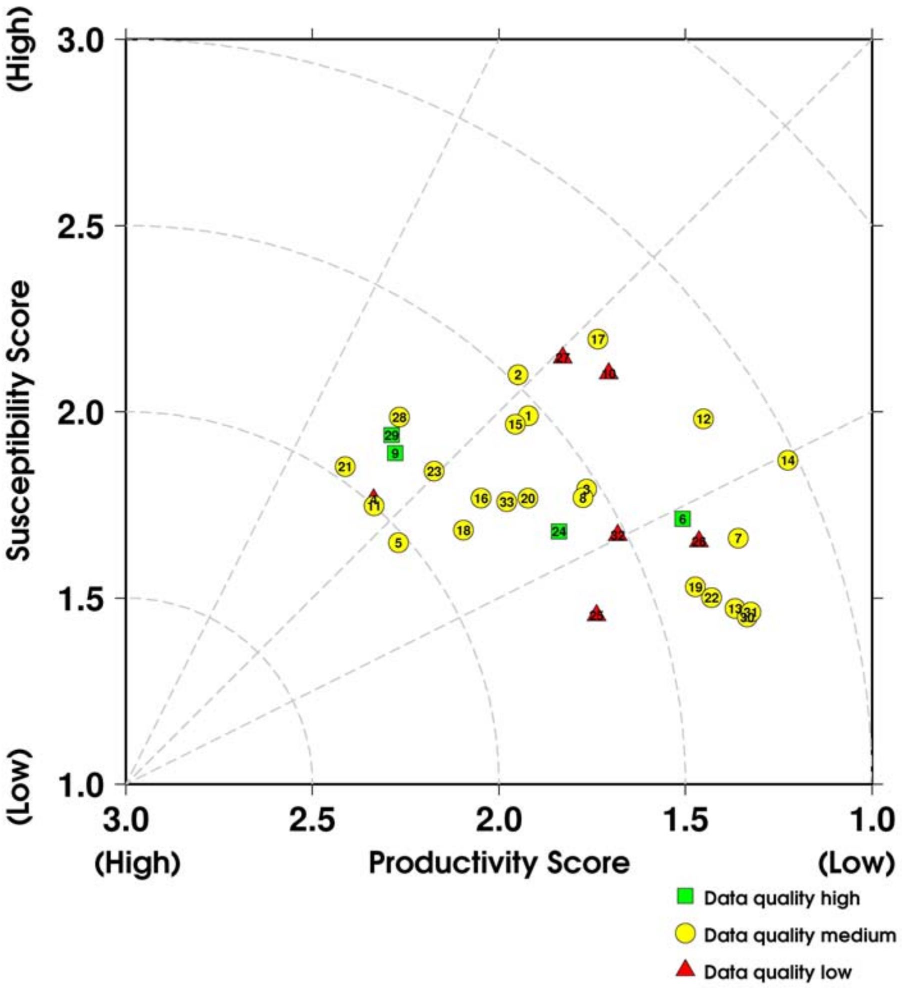


Figure 11. Differences in productivity observed in a subset of forty stocks from the West Coast Groundfish Fishery Management Plan, including nearshore (black) and shelf (grey) species.

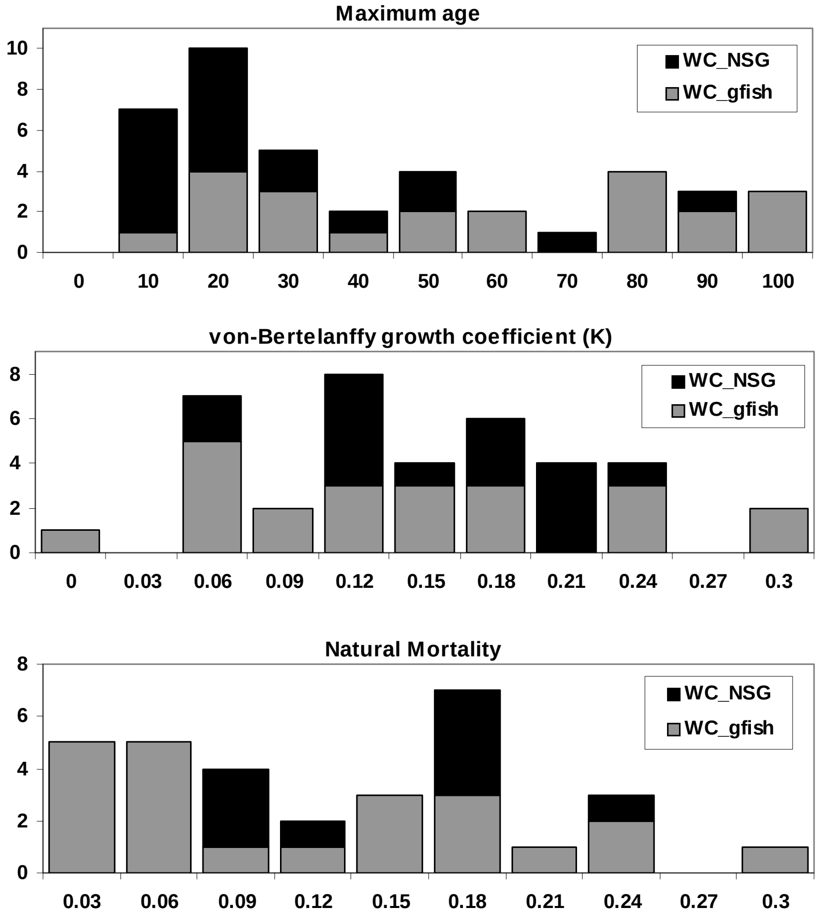


Figure 12. A subset of the stocks from the example applications (n = 50) for which the status (either overfished or undergoing overfishing) could be determined between the years of 2000 and 2008. The dashed line references the minimum vulnerability scores observed among the 162 stocks evaluated in the example applications.

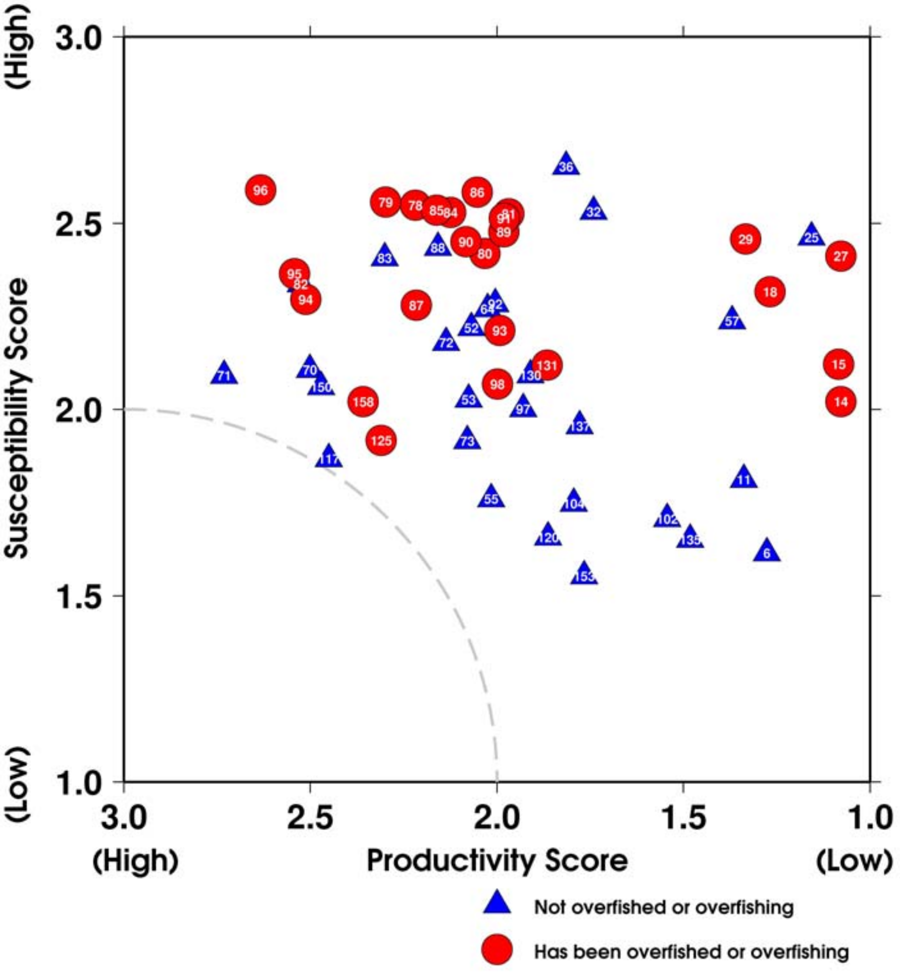
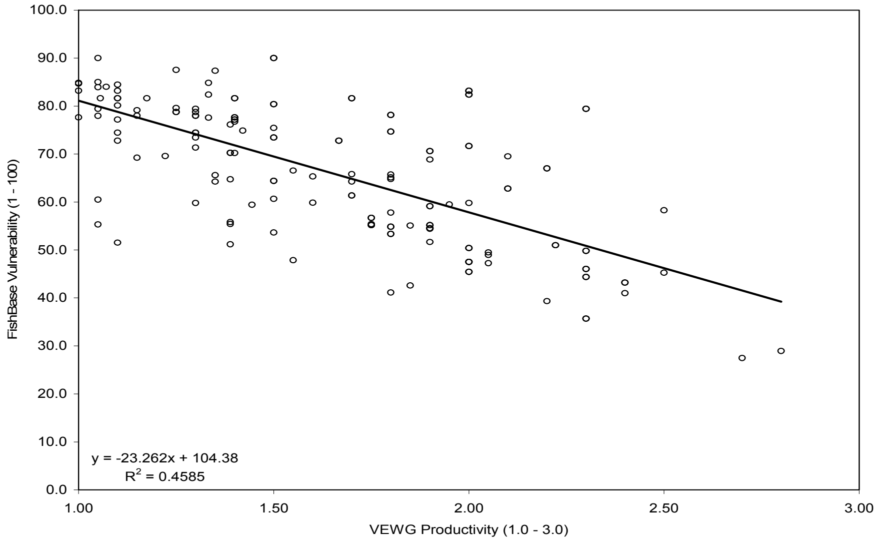
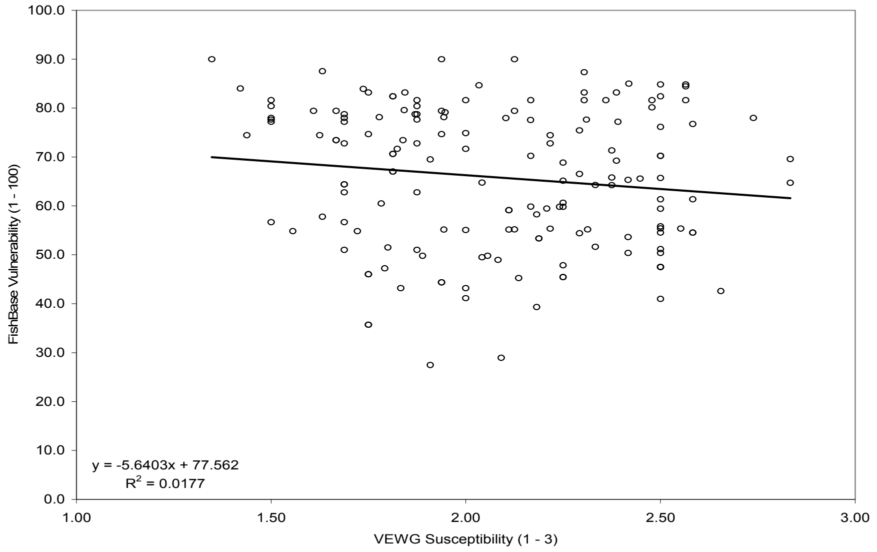


Figure 13. VEWG vulnerability (A), productivity (B), and susceptibility (C) scores compared to FishBase vulnerability (Cheung et al. 2005).


FishBase Vulnerability (1 - 100)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
y = -23.262x + 104.38
R^2 = 0.4585
1.00
1.50
2.00
2.50
3.00
VEWG Productivity (1.0 - 3.0)


FishBase Vulnerability (1 - 100)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
y = -5.6403x + 77.562
R^2 = 0.0177
1.00
1.50
2.00
2.50
3.00
VEWG Susceptibility (1 - 3)

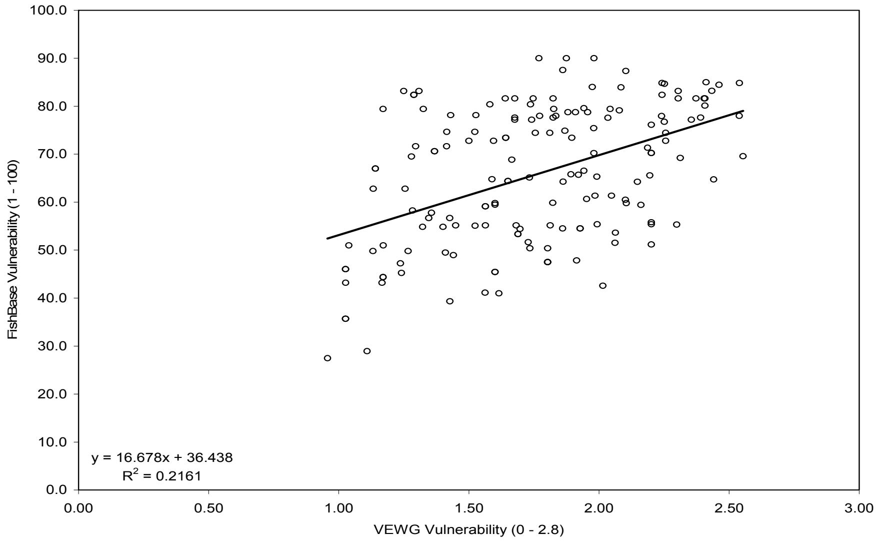
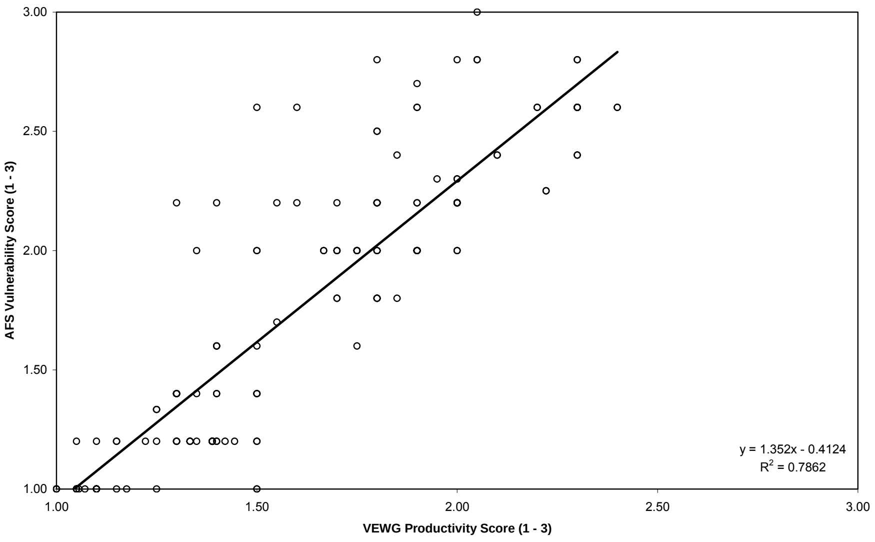
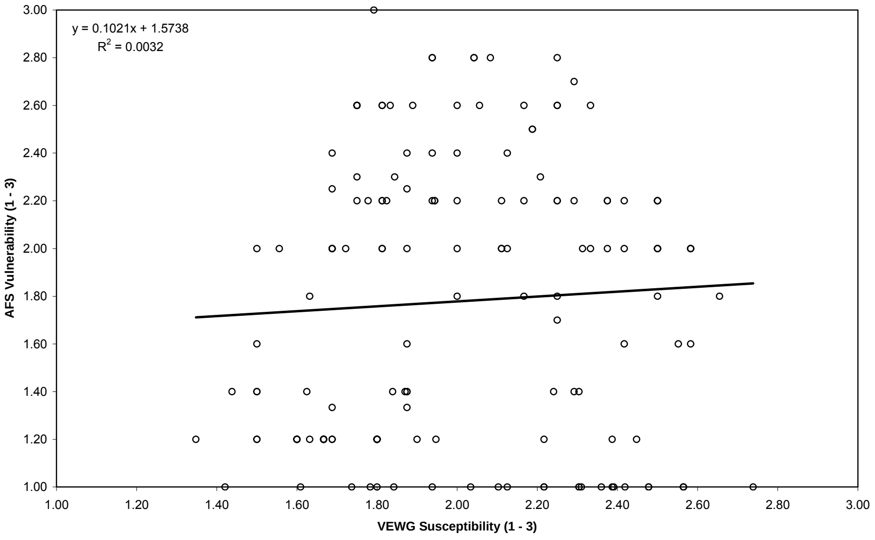
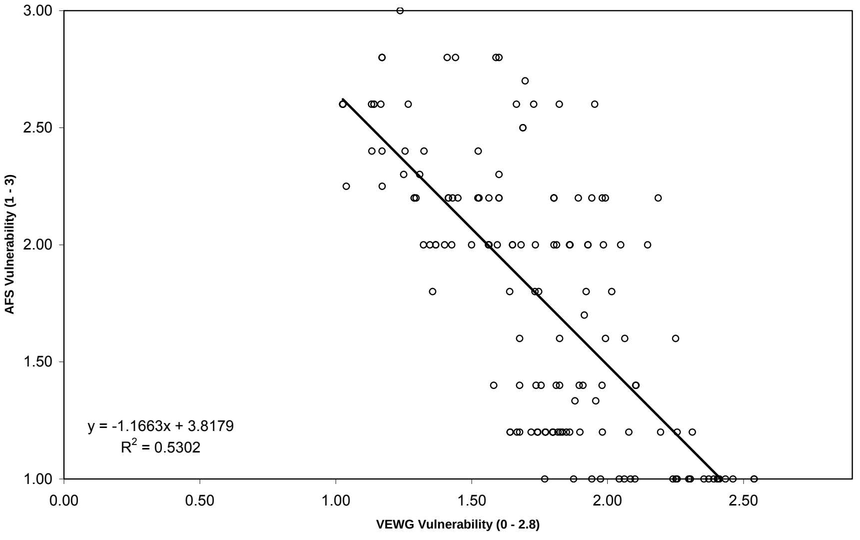

FishBase Vulnerability (1 - 100)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
y = 16.678x + 36.438
R^2 = 0.2161
0.00
0.50
1.00
1.50
2.00
2.50
3.00
VEWG Vulnerability (0 - 2.8)

Figure 14. VEWG vulnerability (A), productivity (B), and susceptibility (C) scores compared to American Fisheries Society's (AFS) vulnerability (Musick 1999).


AFS Vulnerability Score (1 - 3)
3.00
2.50
2.00
1.50
1.00
1.00
1.50
2.00
2.50
3.00
VEWG Productivity Score (1 - 3)
y = 1.352x - 0.4124
R^2 = 0.7862


AFS Vulnerability (1 - 3)
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
2.80
3.00
VEWG Susceptibility (1 - 3)
y = 0.1021x + 1.5738
R^2 = 0.0032


AFS Vulnerability (1 - 3)
3.00
2.50
2.00
1.50
1.00
0.00
0.50
1.00
1.50
2.00
2.50
VEWG Vulnerability (0 - 2.8)
y = -1.1663x + 3.8179
R^2 = 0.5302

APPENDICES

Appendix 1. The list of marine fish stocks that were considered to be representative of U.S. fisheries, and used to help define scoring bins for the following productivity attributes: maximum age, maximum size, growth coefficient, natural mortality, and age at maturity.

Number	Family Name	Scientific Name	Common Name
1	Acanthuridae	*Acanthurus bahianus*	Ocean Surgeonfish
2	Alopiidae	*Alopias superciliosus*	Bigeye thresher shark
3	Anguillidae	*Anguilla rostrata*	American eel
4	Anoplopomatidae	*Anoplopoma fimbria*	Sablefish
5	Balistidae	*Balistes ventula*	Queen triggerfish
6	Bramidae	*Brama japonica*	Pacific Pomfret
7	Bramidae	*Eumegistus illustris*	Brillant Pomfret
8	Bramidae	*Taractes asper*	Flathead/Rough Pomfret
9	Bramidae	*Taractichthys steindachneri*	Sickle Pomfret/Monchong
10	Carangidae	*Caranx crysos*	Blue Runner
11	Carangidae	*Seriolda lalandi*	Amberjack
12	Carangidae	*Seriola zonata*	Banded rudderfish
13	Carangidae	*Trachinotus carolinus*	Florida Pompano
14	Carcharhinidae	*Prionace glauca*	Blue Shark
15	Carcharhinidae	*Carcharhinus longimanus*	Oceanic Whitetip Shark
16	Carcharhinidae	*Carcharhinus falciformis*	Silky Shark
17	Cheatodontidae	*Chaetodon ocellatus*	Spotfin Butterflyfish
18	Clupeidae	*Sardinops sagax*	Pacific Sardine
19	Clupeidae	*Clupea harengus harengus*	Atlantic Herring
20	Clupeidae	*Alosa sapidissima*	American shad
21	Clupeidae	*Alosa aestivalis*	Blueback Herring
22	Coryphaenaidea	*Coryphaena hippurus*	Mahi Mahi/Dolphin Fish
23	Cottidae	*Scorpaenichthys marmoratus*	Cabezon
24	Engraludae	*Engraulis mordax*	Northern Anchovy
25	Ephippidae	*Cheatodipterus faber*	Atlantic Spadefish
26	Gadidae	*Gadus morhua*	Atlantic Cod
27	Gadidae	*Melanogrammus aeglefinus*	Haddock
28	Gadidae	*Pollachius virens*	East Coast Pollock
29	Gadidae	*Theragra chalcogramma*	Alaska Pollock
30	Gempylidae	*Ruvettus pretiosus*	Oilfish
31	Gempylidae	*Promethichthys prometheus*	Roudi Escolar
32	Haemulidae	*Haemulon plumierii*	White Grunt
33	Haemulidae	*Anisotremus surinamensis*	Margate
34	Hexagrammidae	*Hexagrammos decagrammus*	Kelp Greenling
35	Hexagrammidae	*Hexagrammos lagocephalus*	Rock Greenling
36	Hexagrammidae	*Ophiodon elongatus*	Lingcod
37	Holocentridae	*Holocentrus rufus*	Longspine Squirrelfish
38	Istophoridae	*Makaira indica*	Black Marlin
39	Istophoridae	*Makaira nigricans*	Blue Marlin
40	Istophoridae	*Istiophorus platypterus*	Sailfish
41	Istophoridae	*Tetrapturus angustirostris*	Short Bill Spearfish
42	Labridae	*Semicossyphus pulcher*	California Sheephead
43	Labridae	*Bodianus rufus*	Spanish Hogfish
44	Lamnidae	*Isurus paucus*	Longfin Mako
45	Lamnidae	*Lamna ditropis*	Salmon Shark
46	Lamnidae	*Isurus oxyrinchus*	Shortfinned Mako
47	Lampridae	*Lampris guttatus*	Spotted Moonfish
48	Loliginidae	*Loligo opalescens*	Market quid
49	Lophiidae	*Lophius americanus*	Pacific Squid
50	Lutjanidae	*Lutjanus campechanus*	Red Snapper

Appendix 1 (continued).

Number	Family Name	Genus species	Common Name
51	Lutjanidae	*Rhomboplites aurorubens*	Vermillion Snapper
52	Lutjanidae	*Ocyurus chrysurus*	Yellowtail Snapper
53	Lutjanidae	*Lutjanus analis*	Mutton Snapper
54	Lutjanidae	*Lutjanus synagris*	Lane Snapper
55	Lutjanidae	*Lutjanus apodus*	Schoolmaster
56	Lutjanidae	*Pristipomodies filamentosus*	Opakapaka/Pink Snapper
57	Lutjanidae	*Etelis cornuscans*	Onaga/Flame Snapper
58	Lutjanidae	*Etelis carbunculus*	Ehu/Ruby Snapper
59	Lutjanidae	*Aprion virescens*	Uku/Grey Snapper
60	Malacanthidae	*Lopholatilus chamaeleonticeps*	Golden Tilefish
61	Megalopidae	*Megalops atlanticus*	Tarpon
62	Merluccidae	*Merluccius productus*	Pacific Whiting
63	Moronidae	*Morone saxatilis*	Striped Bass
64	Mugilidae	*Mugil cephalus*	Striped Mullet
65	Mullidae	*Mullodichthys martinicus*	Yellow Goatfish
66	Osmeridae	*Osmerus mordax mordax*	Rainbow Smelt
67	Phycidae	*Urophycis tenuis*	White Hake
68	Pleuronectidae	*Limanda ferruginea*	Yellowtail Flounder
69	Pleuronectidae	*Hippoglossoides platessoides*	American Plaice
70	Pleuronectidae	*Glyptocephalus cynoglossus*	Witch Flounder
71	Pleuronectidae	*Pseudopleuronectes americanus*	Winter Flounder
72	Pleuronectidae	*Scophthalmus aquosus*	Windowpane Flounder
73	Pleuronectidae	*Paralichthys dentatus*	Summer Flounder
74	Pleuronectidae	*Hippoglossus hippoglossus*	Halibut
75	Pleuronectidae	*Atheresthes stomias*	Arrowtooth Flounder
76	Pleuronectidae	*Microstomus pacificus*	Dover Sole
77	Pleuronectidae	*Eopsetta jordani*	Petrale Sole
78	Pleuronectidae	*Platichthys stellatus*	Starry Flounder
79	Polyprionidae	*Polyprion americanus*	Wreckfish
80	Pomacanthidae	*Holacanthus ciliaris*	Queen Angelfish
81	Pomacanthidae	*Pomacanthus arcuatus*	Gray Angelfish
82	Pomatomidae	*Pomatomos saltatrix*	Bluefish
83	Rachycentridae	*Rachycentron canadum*	Cobia
84	Rajiidae	*Bathyraja parmifera*	Alaska Skate
85	Rajiidae	*Bathyraja aleutica*	Aleutian Skate
86	Rajiidae	*Bathyraja interrupta*	Bering Skate
87	Rajiidae	*Raja eglanteria*	Clearnose Skate
88	Rajiidae	*Dipturus laevis*	Barndoor Skate
89	Salmonidae	*Salmo salar*	Atlantic Salmon
90	Salmonidae	*Oncorhynchus tshawytscha*	Chinook Salmon
91	Salmonidae	*Oncorhynchus keta*	Chum Salmon
92	Scaridae	*Scarus guacamaia*	Rainbow Parrotfish
93	Scaridae	*Scarus coelestinus*	Midnight Parrotfish
94	Scaridae	*Sparisoma viride*	Stoplight Parrotfish
95	Scieanidae	*Sciaenops ocellatus*	Red Drum
96	Scieanidae	*Micropogonias undulatus*	Atlantic Croaker
97	Scieanidae	*Leiostomus xanthurus*	Spot
98	Scorpaeinidae	*Scorpaena guttata*	California Scorpionfish
99	Scrombridae	*Scomber japonicus*	Pacific Mackerel
100	Scrombridae	*Trachurus symmetricus*	Jack Mackerel

Appendix 1 (continued).

Number	Family Name	Genus species	Common Name
101	Scrombridae	*Thunnus thynnus*	Northern Bluefin Tuna
102	Scrombridae	*Katsuwonus pelamis*	Skipjack Tuna
103	Scrombridae	*Acanthocybium solandri*	Wahoo
104	Scrombridae	*Thunnus albacares*	Yellowfin Tuna
105	Scrombridae	*Scomberomorus cavalla*	King Mackerel
106	Scrombridae	*Thunnus alalunga*	Albacore
107	Scrombridae	*Thunnus obesus*	Bigeye Tuna
108	Scrombridae	*Auxis rochei rochei*	Bullet Tuna
109	Scrombridae	*Euthynnus affinis*	Eastern Little/Mackerel Tuna
110	Sebastidae	*Sebastes maliger*	Quillback Rockfish
111	Sebastidae	*Sebastes caurinus*	Copper Rockfish
112	Sebastidae	Sebastes mystinus	Blue Rockfish
113	Sebastidae	*Sebastes melanops*	Black Rockfish
114	Sebastidae	*Sebastes carnatus*	Gopher Rockfish
115	Sebastidae	*Sebastes atrovirens*	Kelp Rockfish
116	Sebastidae	*Sebastes viviparus*	Redfish
117	Sebastidae	*Sebastes flavidus*	Yelloweye Rockfish
118	Sebastidae	*Sebastes paucispinis*	Bocaccio Rockfish
119	Sebastidae	*Sebastes crameri*	Darkblotched Rockfish
120	Sebastidae	*Sebastes jordani*	Shortbelly Rockfish
121	Sebastidae	*Sebastes goodei*	Chilipepper Rockfish
122	Sebastidae	*Sebastes levis*	Cowcod
123	Sebastidae	*Sebastolobus altivelis*	Longspine Thornyhead
124	Sebastidae	*Sebastes alutus*	Pacific Ocean Perch
125	Serranidae	*Centropristis striata*	Black Sea Bass
126	Serranidae	*Cephalophols cruentata*	Graysby
127	Serranidae	*Epinephelus itajara*	Jewfish
128	Serranidae	*Epinephelus striatus*	Nassau Grouper
129	Serranidae	*Epinephelus adscensionis*	Rock Hind
130	Serranidae	*Epinephelus quernus*	Hapuupuu/Hawaiian grouper
131	Serranidae	*Mycteroperca veneosa*	Yellowfin Grouper
132	Sparidae	*Stenotomus chrysops*	Scup
133	Sparidae	*Lagodon rhomboides*	Pinfish
134	Sparidae	*Diplodus holbrookii*	Spottail Pinfish
135	Sparidae	*Archosargus probatocephalus*	Sheepshead
136	Sparidae	*Pagrus pagrus*	Red Porgy/Common Seabream
137	Sparidae	*Calamus bajondao*	Jolthead Porgy
138	Stichaenidae	*Cebidichthys violaceus*	Monkyface Prickleback
139	Stromateidae	*Pepriuls triacanthus*	Butterfish
140	Xiphiidae	*Xiphias gladius*	Broad Billed Swordfish
141	Zoarcidae	*Gymnelus viridis*	Ocean Pout

Appendix 2. Scoring of the productivity attributes for the example applications.

Fishery	Stock	r	Maximum Age	Maximum Size	von Bertalanffy Growth Coefficient (k)	Estimated Natural Mortality	Measured Fecundity	Breeding Strategy	Recruitment Pattern	Age at Maturity	Mean Trophic Level
Atlantic Shark Complexes	Shortfin mako	1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Blue shark	2.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Common thresher	1.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Porbeagle	1.0	1.5	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Oceanic whitetip	1.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Bigeye thresher	1.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Longfin mako	1.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Sixgill shark	1.0	1.0	1.0	1.5	1.0	1.0	1.0		1.0	1.0
	Sharpnose sevengill shark			1.5			1.0	1.0			1.0
	Sandbar shark	1.0	1.5	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Blacktip shark	1.0	2.0	1.0	1.5	1.0	1.0	1.0		1.0	1.0
	Spinner shark	1.0	2.0	1.0	1.0	1.5	1.0	1.0		1.0	1.0
	Silky shark	1.0	2.0	1.0	1.5	1.0	1.0	1.0		1.0	1.0
	Bull shark	1.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Tiger shark	2.0	2.0	1.0	1.5	1.0	1.0	1.0		1.0	1.0
	Nurse shark	2.0	1.0	1.0	2.0	1.0	1.0	1.0		1.0	1.0
	Lemon shark	1.0	1.5	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Scalloped hammerhead	1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Great hammerhead	1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Smooth hammerhead	1.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Dusky shark	1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Caribbean reef shark	1.0	1.5	1.0		1.0	1.0	1.0		1.0	1.0
	Night shark	1.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Bignose shark	1.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Galapagos shark	1.0	2.0	1.0	1.5	1.0	1.0	1.0		1.0	1.0
	Sandtiger shark	1.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Bigeye sandtiger shark	1.0	1.5	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	White shark	1.0	1.5	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Basking shark	1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	2.0
	Whale shark	1.0	1.5	1.0	1.0	1.0	2.0	1.0		1.0	2.0
	Atlantic sharpnose shark	2.0	2.5	2.0	3.0	2.0	1.0	1.0		2.0	1.0
	Bonnethead shark	2.0	2.5	1.5	3.0	1.5	1.0	1.0		2.0	1.0
	Blacknose shark	1.0	2.0	1.0	2.0	1.0	1.0	1.0		2.0	1.0
	Finetooth shark	1.0	2.5	1.5	2.0	1.5	1.0	1.0		1.0	1.0
	Angel shark	1.0	2.0	1.5	2.0	1.5	1.0	1.0		1.0	1.0
	Smalltail shark	1.0	2.5	1.5	1.0	1.5	1.0	1.0		1.0	1.0
	Caribbean sharpnose shark	2.0	2.0	2.0	3.0	2.0	1.0	1.0		2.0	1.0
BS/AI Skate Complex	Alaska skate	2.0	2.0	2.0	1.0	1.0	1.0	1.0	3.0	1.0	1.0
	Aleutian skate	2.0	2.0	1.0	1.0	2.0	1.0	1.0		1.0	1.0
	Commander skate	2.0	2.0	2.0	1.0	1.5	1.0	1.0		1.0	1.0
	Whiteblotched skate	2.0	2.0	2.0	1.0	1.5	1.0	1.0		1.0	1.0
	Whitebrow skate	2.0	2.0	2.0	1.0	1.5	1.0	1.0		1.0	1.0
	Roughtail skate	2.0	2.0	2.0	1.0	1.5	1.0	1.0		1.0	1.0
	Bering skate	2.0	2.0	2.0	1.0	2.0	1.0	1.0		1.0	1.0
	Mud skate	2.0	2.0	2.0	1.0	1.5	1.0	1.0		1.0	1.0
	Roughshoulder skate	2.0	2.0	2.0	1.0	1.5	1.0	1.0		1.0	1.0
	Big skate	2.0	2.0	1.0	1.0	2.0	1.0	1.0		1.0	1.0
	Longnose skate	2.0	2.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
	Butterfly skate	2.0	2.0	2.0	1.0	1.5	1.0	1.0		1.0	1.0
	Deepsea skate	2.0	2.0	1.0	1.0	2.0	1.0	1.0		1.0	1.0
California Nearshore Groundfish	California sheephead	2.0	2.0	2.0	1.0	2.0	1.0	3.0	2.0	1.0	2.0
	Cabezon	2.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	1.0
	Kelp greenling	2.0	2.0	3.0	2.0	2.5	2.0	1.0	1.0	2.0	2.0
	Rock greenling	2.0	2.0	3.0	2.0	2.5	2.0	1.0	1.0	2.0	2.0
	California scorpionfish	2.0	2.0	3.0	1.0	1.0	2.0	2.0	2.0	2.5	2.0
	Monkyface prickelback	2.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0
	Black rockfish	1.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0
	Black-and-yellow rockfish	1.0	2.0	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0
	Blue rockfish	1.0	1.0	3.0	1.5	1.0	1.0	1.0	2.0	1.0	2.0
	Brown rockfish	1.0	1.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	1.0
	Calico rockfish	1.0	2.0	3.0	1.0	2.0	2.0	1.0	2.0	2.0	2.0
	China rockfish	1.0	1.0	3.0	2.0	1.0	1.0	1.0	2.0	1.0	2.0
	Copper rockfish	1.0	1.0	1.0	1.5	1.0	1.0	1.0	2.0	1.0	2.0
	Gopher rockfish	1.0	2.0	3.0	2.5	2.0	1.0	1.0	2.0	2.0	2.0
	Grass rockfish	1.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0
	Kelp rockfish	1.0	2.0	3.0	3.0	2.0	1.0	1.0	2.0	1.5	2.0
	Olive rockfish	1.0	1.0	2.0	1.5	1.0	1.0	1.0	2.0	1.5	2.0
	Quillback rockfish	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0
	Treefish rockfish	1.0	2.0	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0
Coastal Pelagics	Pacific sardine	2.0	2.5	3.0	3.0	2.5	3.0	2.5	1.5	2.5	2.5
	Northern Anchovy	2.5	3.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0	2.5
	Pacific mackerel	1.5	2.0	2.5	3.0	3.0	3.0	2.5	1.0	2.0	1.5
	Jack mackerel	2.0	2.0	2.0	1.0	2.0	3.0	3.0	1.0	3.0	2.0

Appendix 2. (continued).

Fishery	Stock	r	Maximum Age	Maximum Size	von Bertalanffy Growth Coefficient (k)	Estimated Natural Mortality	Measured Fecundity	Breeding Strategy	Recruitment Pattern	Age at Maturity	Mean Trophic Level
Coastal Pelagics	Market squid	3.0	3.0	3.0	3.0	3.0	2.5	2.5	1.0	3.0	2.0
	Pacific herring	2.0	2.0	2.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0
	Pacific bonito	2.0	3.0	2.0	3.0	3.0	3.0	3.0	2.0	3.0	1.0
	Pacific saury	2.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0	2.0
Hawaii Longline Fishery - Both Sectors	Albacore	2.0	2.0	2.0	2.0	2.0	3.0	1.0	2.0	2.0	1.0
	Bigeye Tuna	2.0	3.0	1.0	2.0	2.0	3.0	1.0	2.0	2.0	1.0
	Black Marlin	3.0	3.0	1.0	1.0	1.0	3.0	1.0	2.0	2.0	1.0
	Bullet Tuna	3.0	3.0	2.0	3.0	3.0	3.0	1.0	2.0	2.0	1.0
	Pacific Pomfret	3.0	3.0	2.0	2.0	3.0		1.0	2.0	3.0	1.0
	Blue Shark	2.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0	1.0	1.0
	Bigeye thresher shark	2.0	2.0	1.0	1.0	2.0	1.0	1.0	2.0	1.0	1.0
	Blue Marlin	3.0	2.0	1.0	2.0	1.0	3.0	1.0	2.0	2.0	1.0
	Dolphin Fish	3.0	3.0	1.0	3.0	3.0	3.0	1.0	2.0	3.0	1.0
	Brilliant Pomfret				2.0			1.0	2.0		2.0
	Kawakawa	3.0	3.0	2.0	3.0	3.0	3.0	1.0	2.0	2.0	1.0
	Spotted Moonfish		2.0	1.0		2.0		1.0	2.0		1.0
	Longfin Mako Shark	2.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	1.0	1.0
	Salmon Shark	2.0		1.0	1.0	1.0	1.0	1.0	2.0		1.0
	Striped Marlin	1.0	3.0	1.0	3.0	3.0	3.0	1.0	2.0	2.0	1.0
	Oilfish	3.0	2.0	1.0	3.0	3.0	3.0	1.0	2.0	1.0	1.0
	Northern Bluefin Tuna	2.0	2.0	1.0	1.0	2.0	3.0	1.0	2.0	2.0	1.0
	Roudi Escolar	3.0	2.0	3.0	2.0	3.0	3.0	1.0	2.0	1.0	1.0
	Pelagic Thresher Shark	3.0	2.0	1.0	1.0	2.0	1.0	1.0	2.0	1.0	1.0
	Sailfish	3.0	2.0	1.0	1.0	3.0	3.0	1.0	2.0	2.0	1.0
	Skipjack Tuna	3.0	3.0	2.0	3.0	3.0	3.0	1.0	2.0	3.0	1.0
	Shortfinned Mako Shark	2.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	1.0	1.0
	Short Bill Spearfish	3.0	3.0	1.0	3.0	3.0	3.0	1.0	2.0	2.0	1.0
	Broadbill Swordfish	2.0	2.0	1.0	3.0	2.0	3.0	1.0	2.0	1.0	1.0
	Flatheat Pomfret				2.0			1.0	2.0		2.0
	Dagger Pomfret				2.0			1.0	2.0		1.0
	Sickle Pomfret	3.0			2.0			1.0	2.0		1.0
	Wahoo	3.0	3.0	2.0	2.0	3.0	3.0	1.0	2.0	3.0	1.0
	Yellowfin Tuna	3.0	3.0	2.0	3.0	3.0	3.0	1.0	2.0	2.0	1.0
	Oceanic Whitetip Shark	2.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0
	Silky Shark	2.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0
	Common Thresher Shark	2.0						1.0	2.0		
	Escolar	3.0	2.0	2.0	2.0	3.0	3.0	1.0	2.0	1.0	1.0
NE Groundfish	GM Cod	2.0	3.0	3.0	2.0	2.0	1.0	3.0	2.0	2.0	3.0
	GB Cod	2.0	3.0	3.0	2.0	2.0	1.0	3.0	2.0	2.0	3.0
	GM Haddock	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	GB Haddock	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Redfish	3.0	3.0	2.0	3.0	3.0	1.0	3.0	2.0	3.0	2.0
	Pollock	2.0	3.0	3.0	2.0	2.0	1.0	3.0	2.0	2.0	3.0
	CC-GM Yellowtail Flounder	2.0	3.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	2.0
	GB Yellowtail Flounder	2.0	3.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	2.0
	SNE Yellowtail Flounder	2.0	3.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	2.0
	American Plaice	2.0	3.0	2.0	2.0	2.0	1.0	3.0	2.0	3.0	2.0
	Witch Flounder	2.0	3.0	2.0	2.0	2.0	1.0	3.0	2.0	3.0	2.0
	GM Winter Flounder	2.0	2.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	2.0
	GB Winter Flounder	2.0	2.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	2.0
	SNE-MidA winter Flouder	2.0	2.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	2.0
	GM-GB Windowpane	2.0	2.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	2.0
	SNE-MA Windowpane	2.0	2.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	2.0
	Ocean Pout	2.0	3.0	3.0	2.0	2.0	2.0	3.0	3.0	2.5	2.0
	White Hake	3.0	3.0	3.0	2.0	2.0	1.0	3.0	2.0	3.0	3.0
	Halibut	3.0	3.0	3.0	2.0	3.0	1.0	3.0	2.0	3.0	3.0
SA/GOM Bottom Longline Fishery	Sand Tilefish	3.0	2.0	2.0	1.5	2.0	3.0	3.0	2.0	1.0	1.0
	Bar Jack	3.0	2.0	2.5	1.5	2.0	3.0	3.0	2.0	1.5	1.0
	Rock Sea Bass	3.0	3.0	3.0	3.0	3.0	2.5	3.0	2.0	2.5	2.0
	Margate	3.0	2.5	2.5	2.0	2.0	3.0	3.0	2.0	2.0	2.0

Weights
Atlantic Sharks - 4, 2, 1, 2, 3, 3, 2, 0, 2
BS/AI Skates - 2, 2, 2, 2, 2, 2, 2, 1, 2, 2
California Nearshore Groundfish - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
Coastal Pelagics - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
Hawaii Longline - Both Sectors - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
NE Groundfish - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
SA/GOM Snapper-Grouper Bottom Longline - 4, 2, 2, 2, 2, 2, 2, 2, 3, 2

Appendix 3. Scoring of the susceptibility attributes for the example applications. .

Fishery	Stock	Management Strategy	Areal Overlap	Geographic Concentration	Vertical Overlap	Fishing rate relative to M	Biomass of Spawners (SSB) or other proxies	Seasonal Migrations	Schooling-Aggregation and Other Behavioral Responses	Morphology Affecting Capture	Survival After Capture and Release	Desirability-Value of the Fishery	Fishery Impact to EFH or Habitat in General for Non-targets
Atlantic Shark Complexes	Shortfin mako	2.0	2.0	1.0	3.0	2.0	2.0			3.0	3.0	3.0	1.0
	Blue shark	2.0	2.0	1.0	3.0	1.0	1.0	2.0		3.0	1.0	3.0	1.0
	Common thresher	2.0	3.0	1.0	3.0					3.0	2.0	1.0	1.0
	Porbeagle	2.0	2.0	2.0	3.0	1.0	3.0			3.0	1.0	3.0	1.0
	Oceanic whitetip	2.0	2.0	1.0	3.0					3.0	2.0	3.0	1.0
	Bigeye thresher	1.0	3.0	2.0	3.0					3.0	2.0	3.0	1.0
	Longfin mako	1.0	3.0	1.0	3.0					3.0	2.0	3.0	1.0
	Sixgill shark	1.0	3.0	1.0	1.0					1.0	1.0	1.0	1.0
	Sharpnose sevengill shark	1.0	3.0	1.0	1.0					1.0		1.0	1.0
	Sandbar shark	1.0	3.0	1.0	3.0	2.0	2.0	3.0		3.0	3.0	3.0	1.0
	Blacktip shark	2.0	3.0	1.0	3.0	2.0	1.0	3.0		3.0	3.0	3.0	1.0
	Spinner shark	2.0	3.0	1.0	3.0					3.0	3.0	3.0	1.0
	Silky shark	2.0	3.0	3.0	3.0					3.0	3.0	3.0	1.0
	Bull shark	2.0	3.0	1.0	3.0					3.0	3.0	3.0	1.0
	Tiger shark	2.0	2.0	2.0	3.0					3.0	2.0	3.0	1.0
	Nurse shark	2.0	2.0	1.0	2.0					3.0	1.0	3.0	1.0
	Lemon shark	2.0	2.0	1.0	2.0					3.0	3.0	3.0	1.0
	Scalloped hammerhead	2.0	3.0	1.0	3.0	2.0	1.0		3.0	3.0	3.0	3.0	1.0
	Great hammerhead	2.0	3.0	1.0	3.0					3.0	3.0	3.0	1.0
	Smooth hammerhead	2.0	1.0	2.0	3.0					3.0	3.0	3.0	1.0
	Dusky shark	1.0	3.0	1.0	3.0	1.0	1.0			3.0	2.0	3.0	1.0
	Caribbean reef shark	1.0	1.0	3.0	3.0				3.0	3.0	3.0	3.0	1.0
	Night shark	1.0	3.0	1.0	3.0					3.0	3.0	3.0	1.0
	Bignose shark	1.0	3.0	1.0	3.0					3.0	3.0	3.0	1.0
	Galapagos shark	1.0	1.0	1.0	3.0					3.0		3.0	1.0
	Sandtiger shark	1.0	3.0	1.0	2.0				3.0	1.0	1.0	3.0	1.0
	Bigeye sandtiger shark	1.0	1.0	3.0	1.0					3.0	1.0	3.0	1.0
	White shark	1.0	1.0	1.0	2.0					3.0		3.0	1.0
	Basking shark	1.0	1.0	1.0	3.0					3.0	1.0	3.0	1.0
	Whale shark	1.0	1.0	1.0	3.0					1.0		3.0	1.0
	Atlantic sharpnose shark	2.0	3.0	1.0	3.0	3.0	3.0			3.0	3.0	3.0	1.0
	Bonnethead shark	2.0	3.0	1.0	3.0	2.0	3.0			3.0	3.0	3.0	1.0
	Blacknose shark	2.0	3.0	1.0	3.0	1.0	1.0			3.0	3.0	3.0	1.0
	Finetooth shark	2.0	3.0	1.0	3.0	3.0	3.0			1.0	3.0	3.0	1.0
	Angel shark	1.0	3.0	1.0	1.0				1.0			3.0	1.0
	Smalltail shark	1.0	1.0	3.0	3.0					1.0		3.0	1.0
	Caribbean sharpnose shark	1.0	1.0	1.0	3.0					1.0		3.0	1.0
BS/AI Skate Complex	Alaska skate	1.0	1.0	3.0	1.0	3.0	3.0			1.0	2.0	1.0	3.0
	Aleutian skate	1.0	1.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Commander skate	1.0	3.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Whiteblotched skate	1.0	3.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Whitebrow skate	1.0	3.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Roughtail skate	1.0	3.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Bering skate	1.0	1.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Mud skate	1.0	3.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Roughshoulder skate	1.0		1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Big skate	1.0	1.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Longnose skate	1.0		1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Butterfly skate	1.0	1.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0
	Deepsea skate	1.0	3.0	1.0	1.0	2.0	3.0			1.0	2.0	1.0	3.0

Appendix 3 (continued).

Fishery	Stock	Management Strategy	Areal Overlap	Geographic Concentration	Vertical Overlap	Fishing rate relative to M	Biomass of Spawners (SSB) or other proxies	Seasonal Migrations	Schooling-Aggregation and Other Behavioral Responses	Morphology Affecting Capture	Survival After Capture and Release	Desirability-Value of the Fishery	Fishery Impact to EFH or Habitat in General for Non-targets
California Nearshore Groundifsh	California sheephead	2.0	3.0	1.0	3.0	2.0	3.0	2.0	3.0	3.0	1.0	2.0	2.0
	Cabezon	1.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0	3.0	1.0	2.0	2.0
	Kelp greenling	1.0	3.0	3.0	3.0	1.0	1.0	2.0	2.0	3.0	1.0	2.5	2.0
	Rock greenling	2.0	3.0	3.0	3.0	1.0	1.0	2.0	2.0	3.0	1.0	2.0	2.0
	California scorpionfish	1.0	3.0	3.0	3.0	1.0	1.0	2.0	2.0	2.0	1.0	1.5	1.0
	Monkyface prickelback	2.0	3.0	3.0	3.0	2.0	1.0	2.0	1.0	3.0	1.0	1.5	2.0
	Black rockfish	1.0	3.0	3.0	3.0	2.0	1.0	2.0	3.0	3.0	2.0	1.0	2.0
	Black-and-yellow rockfish	2.0	3.0	3.0	3.0	1.0	1.0	2.0	3.0	3.0	2.0	2.5	2.0
	Blue rockfish	1.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0	3.0	2.5	1.0	2.0
	Brown rockfish	2.0	3.0	3.0	3.0	2.0	1.0	2.0	3.0	3.0	2.0	2.5	2.0
	Calico rockfish	2.0	3.0	3.0	3.0	1.0	1.0	2.0	2.0	1.0	3.0	1.0	2.0
	China rockfish	2.0	3.0	3.0	3.0	2.0	1.0	2.0	3.0	3.0	2.5	2.5	2.0
	Copper rockfish	2.0	3.0	3.0	3.0	2.0	1.0	2.0	3.0	3.0	2.5	2.0	2.0
	Gopher rockfish	1.0	3.0	3.0	3.0	1.0	1.0	2.0	3.0	3.0	2.0	2.5	2.0
	Grass rockfish	2.0	3.0	3.0	3.0	2.0	1.0	2.0	1.0	3.0	1.0	3.0	2.0
	Kelp rockfish	2.0	3.0	3.0	3.0	1.0	1.0	2.0	1.0	2.0	1.5	2.5	2.0
	Olive rockfish	2.0	3.0	3.0	3.0	2.0	1.0	2.0	3.0	3.0	2.0	1.0	2.0
	Quillback rockfish	2.0	3.0	3.0	3.0	2.0	1.0	2.0	3.0	3.0	2.5	2.0	2.0
	Treefish rockfish	2.0	3.0	3.0	3.0	1.0	1.0	2.0	3.0	3.0	2.0	3.0	2.0
Coastal Pelagics	Pacific sardine	1.0		2.0	3.0	1.5	2.0	2.0	3.0	3.0	3.0	2.0	1.0
	Northern Anchovy	2.0		2.0	3.0	1.0	2.0	2.0	3.0	3.0	3.0	1.0	1.0
	Pacific mackerel	1.0		2.0	3.0	2.0	2.0	2.0	3.0	3.0	3.0	2.0	1.0
	Jack mackerel	2.0		2.0	2.0	1.0	1.0	2.0	3.0	3.0	3.0	1.0	1.0
	Market squid	2.0		2.0	3.0	2.5	2.0	3.0	3.0	3.0	2.0	2.0	1.0
	Pacific herring	2.0		2.0	3.0	2.5	3.0	3.0	3.0	3.0	3.0	2.0	1.0
	Pacific bonito	2.0		2.0	3.0	2.0	2.0	1.0	3.0	3.0	3.0	2.0	1.0
	Pacific saury	2.0		2.0	2.0	1.0	2.0	2.0	3.0	2.0	3.0	1.0	1.0
Hawaii Longline Fishery - Swordfish Sector	Albacore	1.0	1.0	1.0	2.0	3.0	1.0		2.0	3.0	3.0	2.0	1.0
	Bigeye Tuna	1.0	1.0	1.0	2.0	3.0	2.0		2.0	3.0	3.0	3.0	1.0
	Black Marlin	1.0	1.0	1.0	2.0				2.0	2.0	3.0	1.0	1.0
	Bullet Tuna	2.0	1.0	1.0	2.0				2.0	1.0	3.0	1.0	1.0
	Pacific Pomfret	2.0	1.0	1.0	2.0				2.0	3.0	2.0	1.0	1.0
	Blue Shark	1.0	1.0	1.0	3.0	3.0	1.0		2.0	3.0	1.0	1.0	1.0
	Bigeye thresher shark	2.0	1.0	1.0	2.0				2.0	3.0	2.0	1.0	1.0
	Blue Marlin	1.0	1.0	1.0	2.0	2.0	1.0		2.0	3.0	3.0	1.0	1.0
	Dolphin Fish	1.0	1.0	1.0	2.0				2.0	3.0	3.0	2.0	1.0
	Brilliant Pomfret	2.0	1.0	3.0	2.0				2.0	3.0	3.0	2.0	1.0
	Kawakawa	2.0	1.0	1.0	2.0				2.0	1.0	3.0	1.0	1.0
	Spotted Moonfish	1.0	1.0	1.0	2.0				2.0	3.0	3.0	2.0	1.0
	Longfin Mako Shark	2.0	1.0	1.0	2.0				2.0	3.0	1.0	1.0	1.0
	Salmon Shark	2.0	1.0	1.0	2.0				2.0	3.0	3.0	1.0	1.0
	Striped Marlin	1.0	1.0	1.0	2.0	3.0			2.0	3.0	3.0	2.0	1.0
	Oilfish	2.0	1.0	1.0	2.0				2.0	3.0	2.0	2.0	1.0
	Northern Bluefin Tuna	1.0	1.0	1.0	3.0	3.0	2.0		2.0	3.0	3.0	2.0	1.0
	Roudi Escolar	2.0	1.0	1.0	2.0				2.0	3.0	2.0	1.0	1.0
	Pelagic Thresher Shark	2.0	1.0	1.0	1.0				2.0	3.0	2.0	1.0	1.0
	Sailfish	1.0	1.0	1.0	2.0				2.0	3.0	3.0	1.0	1.0
	Skipjack Tuna	1.0	1.0	1.0	2.0	1.0	1.0		2.0	3.0	3.0	2.0	1.0
	Shortfinned Mako Shark	2.0	1.0	1.0	2.0				2.0	3.0	1.0	1.0	1.0
	Short Bill Spearfish	1.0	1.0	1.0	2.0				2.0	3.0	3.0	1.0	1.0

Appendix 3 (continued).

Fishery	Stock	Management Strategy	Areal Overlap	Geographic Concentration	Vertical Overlap	Fishing rate relative to M	Biomass of Spawners (SSB) or other proxies	Seasonal Migrations	Schooling-Aggregation and Other Behavioral Responses	Morphology Affecting Capture	Survival After Capture and Release	Desirability-Value of the Fishery	Fishery Impact to EFH or Habitat in General for Non-targets
Hawaii Longline Fishery - Swordfish Sector	Broadbill Swordfish	1.0	1.0	1.0	2.0	1.0	1.0		2.0	3.0	3.0	1.0	1.0
	Flatheat Pomfret	2.0	1.0	1.0	2.0				2.0	3.0	1.0	1.0	1.0
	Dagger Pomfret	2.0	1.0	1.0	2.0				2.0	3.0	2.0	1.0	1.0
	Sickle Pomfret	2.0	1.0	1.0	3.0				2.0	3.0	3.0	2.0	1.0
	Wahoo	1.0	1.0	1.0	2.0				2.0	3.0	3.0	2.0	1.0
	Yellowfin Tuna	1.0	1.0	1.0	2.0	2.0	1.0		2.0	3.0	3.0	2.0	1.0
	Oceanic Whitetip Shark	1.0	1.0	1.0	2.0				2.0	3.0	1.0	1.0	1.0
	Silky Shark	2.0	1.0	1.0	2.0				2.0	3.0	1.0	1.0	1.0
	Common Thresher Shark	2.0	1.0	1.0	2.0				2.0	3.0	2.0	1.0	1.0
	Escolar	2.0	1.0	1.0	2.0				2.0	3.0	2.0	1.5	1.0
Hawaii Longline Fishery - Tuna Sector	Albacore	1.0	1.0	1.0	3.0	3.0	1.0		2.0	3.0	3.0	2.0	1.0
	Bigeye Tuna	1.0	1.0	1.0	2.0	3.0	2.0		2.0	3.0	3.0	3.0	1.0
	Black Marlin	1.0	1.0	1.0	3.0				2.0	2.0	3.0	1.0	1.0
	Bullet Tuna	2.0	1.0	1.0	2.0				2.0	1.0	3.0	1.0	1.0
	Pacific Pomfret	2.0	1.0	1.0	3.0				2.0	3.0	2.0	1.0	1.0
	Blue Shark	1.0	1.0	1.0	3.0	3.0	1.0		2.0	3.0	1.0	1.0	1.0
	Bigeye thresher shark	2.0	1.0	1.0	2.0				2.0	3.0	1.0	1.0	1.0
	Blue Marlin	1.0	1.0	1.0	3.0	2.0	1.0		2.0	3.0	3.0	1.0	1.0
	Dolphin Fish	1.0	1.0	1.0	2.0				2.0	3.0	3.0	2.0	1.0
	Brilliant Pomfret	2.0	1.0	3.0	3.0				2.0	3.0	3.0	2.0	1.0
	Kawakawa	2.0	1.0	1.0	2.0				2.0	1.0	3.0	1.0	1.0
	Spotted Moonfish	1.0	1.0	1.0	3.0				2.0	3.0	3.0	2.0	1.0
	Longfin Mako Shark	2.0	1.0	1.0	3.0				2.0	3.0	2.0	1.0	1.0
	Salmon Shark	2.0	1.0	1.0	2.0				2.0	3.0	2.0	1.0	1.0
	Striped Marlin	1.0	1.0	1.0	3.0	3.0			2.0	3.0	1.0	2.0	1.0
	Oilfish	2.0	1.0	1.0	1.0				2.0	3.0	3.0	2.0	1.0
	Northern Bluefin Tuna	1.0	1.0	1.0	2.0	3.0	2.0		2.0	3.0	3.0	2.0	1.0
	Roudi Escolar	2.0	1.0	1.0	3.0				2.0	3.0	2.0	1.0	1.0
	Pelagic Thresher Shark	2.0	1.0	1.0	3.0				2.0	3.0	2.0	1.0	1.0
	Sailfish	1.0	1.0	1.0	2.0				2.0	3.0	3.0	1.0	1.0
	Skipjack Tuna	1.0	1.0	1.0	3.0	1.0	1.0		2.0	3.0	3.0	2.0	1.0
	Shortfinned Mako Shark	2.0	1.0	1.0	3.0				2.0	3.0	2.0	1.0	1.0
	Short Bill Spearfish	1.0	1.0	1.0	2.0				2.0	3.0	3.0	1.0	1.0
	Broadbill Swordfish	1.0	1.0	1.0	1.0	1.0	1.0		2.0	3.0	3.0	1.0	1.0
	Flatheat Pomfret	2.0	1.0	1.0	3.0				2.0	3.0	1.0	1.0	1.0
	Dagger Pomfret	2.0	1.0	1.0	3.0				2.0	3.0	1.0	1.0	1.0
	Sickle Pomfret	2.0	1.0	1.0	3.0				2.0	3.0	3.0	2.0	1.0
	Wahoo	1.0	1.0	1.0	3.0				2.0	3.0	3.0	2.0	1.0
	Yellowfin Tuna	1.0	1.0	1.0	3.0	2.0	1.0		2.0	3.0	3.0	2.0	1.0
	Oceanic Whitetip Shark	1.0	1.0	1.0	3.0				2.0	3.0	1.0	1.0	1.0
	Silky Shark	2.0	1.0	1.0	3.0				2.0	3.0	1.0	1.0	1.0
	Common Thresher Shark	2.0	1.0	1.0	3.0				2.0	3.0	2.0	1.0	1.0
	Escolar	2.0	1.0	1.0	2.0				2.0	3.0	2.5	1.5	1.0
NE Groundfish	GM Cod	2.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
	GB Cod	2.0	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0	3.0	3.0
	GM Haddock	2.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
	GB Haddock	2.0	3.0	2.0	3.0	2.0	3.0	2.0	2.0	2.0	3.0	3.0	3.0
	Redfish	2.0	3.0	2.0	3.0	2.0	1.5	2.0	2.0	2.0	3.0	2.0	3.0
	Pollock	2.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0	3.0
	CC-GM Yellowtail Flounder	2.0	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0	3.0	3.0

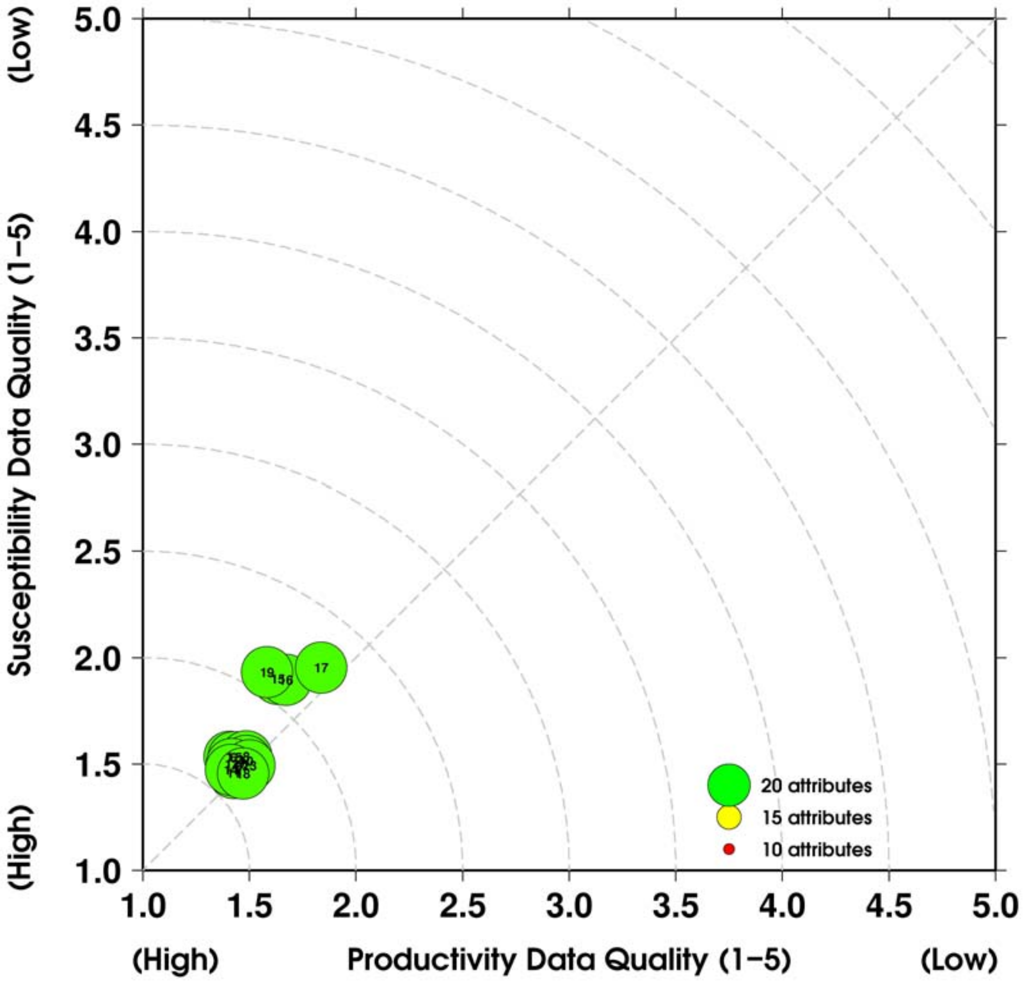
Appendix 3 (continued).

Fishery	Stock	Management Strategy	Areal Overlap	Geographic Concentration	Vertical Overlap	Fishing rate relative to M	Biomass of Spawners (SSB) or other proxies	Seasonal Migrations	Schooling-Aggregation and Other Behavioral Responses	Morphology Affecting Capture	Survival After Capture and Release	Desirability-Value of the Fishery	Fishery Impact to EFH or Habitat in General for Non-targets
NE Groundfish	GB Yellowtail Flounder	2.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
	SNE Yellowtail Flounder	2.0	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0	3.0	3.0
	American Plaice	2.0	3.0	2.0	3.0	2.0	1.0	2.0	2.0	2.0	3.0	2.0	3.0
	Witch Flounder	2.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
	GM Winter Flounder	2.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
	GB Winter Flounder	2.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
	SNE-MidA winter Flouder	2.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
	GM-GB Windowpane	2.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	3.0	1.0	3.0
	SNE-MA Windowpane	2.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	3.0	1.0	3.0
	Ocean Pout	2.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	3.0	1.0	3.0
	White Hake	2.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	3.0	2.0	3.0
	Halibut	2.0	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0	3.0	3.0
SA/GOM Snapper-Grouper Bottom Longline	Sand Tilefish	3.0	1.0	1.0	1.0				2.0	2.0	2.5	1.0	1.5
	Bar Jack	3.0	1.0	1.0	1.0				2.0	1.5	2.5	1.0	1.5
	Rock Sea Bass	3.0	1.0	1.0	1.0				2.0	2.0	3.0	1.0	1.5
	Margate	3.0	1.0	1.0	2.0				2.0	2.0	3.0	1.0	1.5

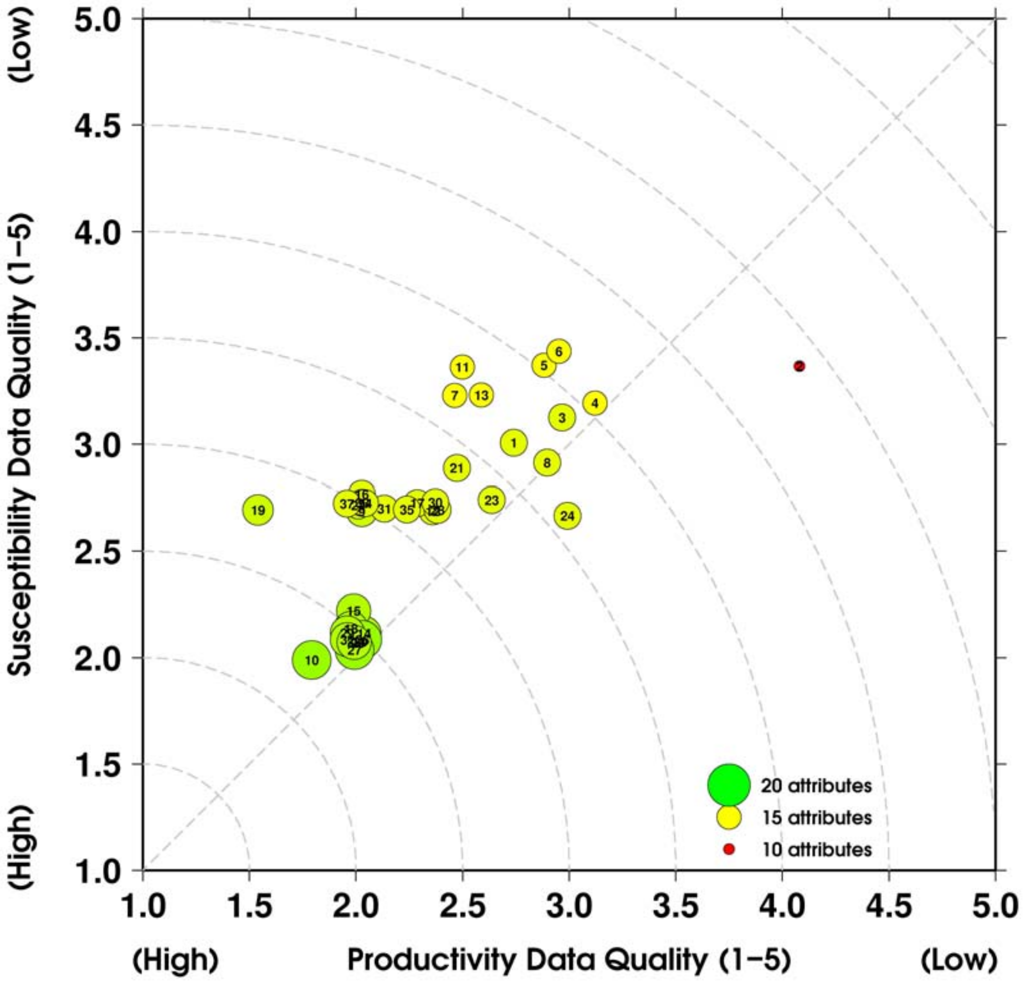
Weights

Atlantic Sharks - 2, 4, 2, 4, 3, 3, 2, 2, 3, 4, 2, 2
BS/AI Skates - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
California Nearshore Groundfish - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
Coastal Pelagics - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
Hawaii Longline - Both Sectors - 1, 2, 1, 3, 1, 1, 0, 2, 1, 3, 2, 1
NE Groundfish - 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
SA/GOM Snapper-Grouper Bottom Longline - 2, 4, 2, 3, 2, 2, 1, 2, 2, 2, 2, 1

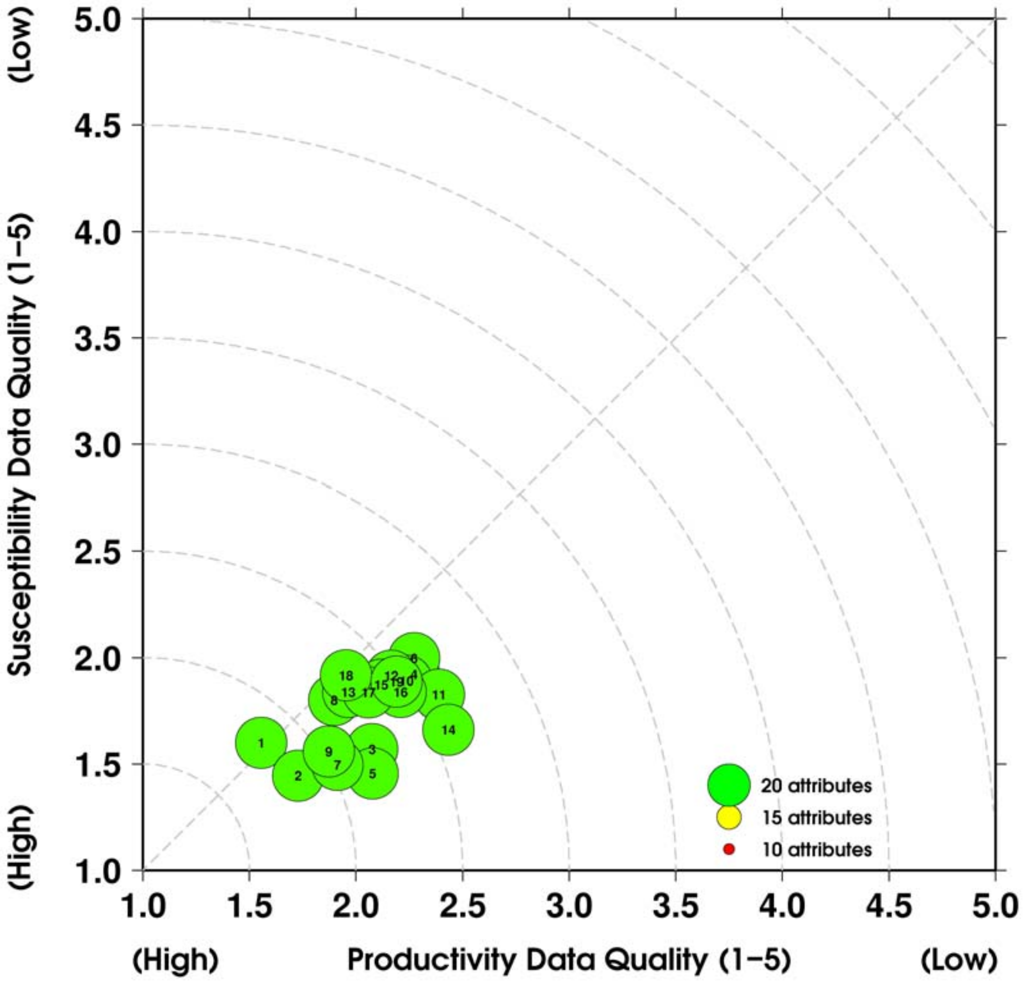
Appendix 4. Data quality plot for the Northeast Groundfish Multispecies Fishery.



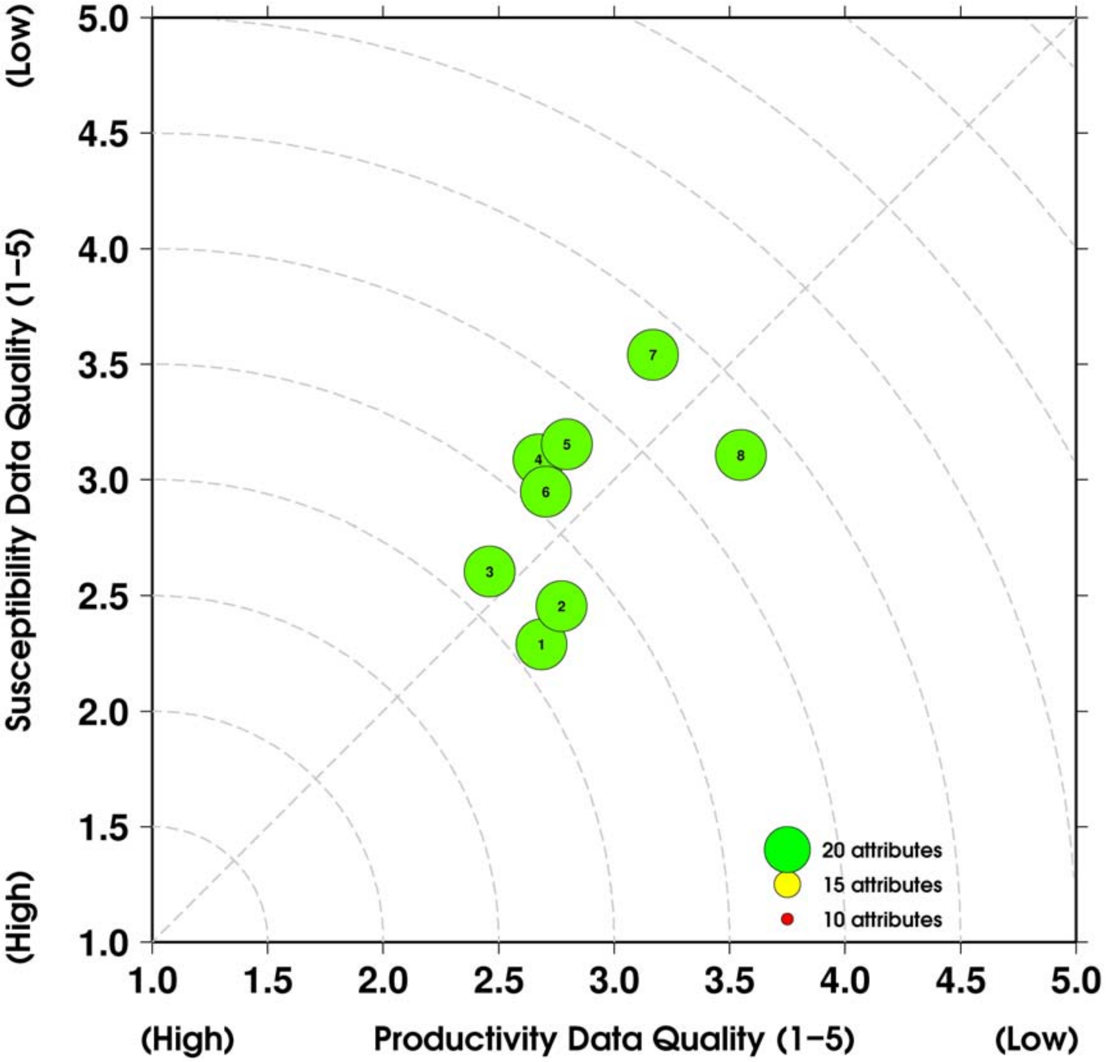
Appendix 5. Data quality plot for the Highly Migratory Atlantic Shark Complex.



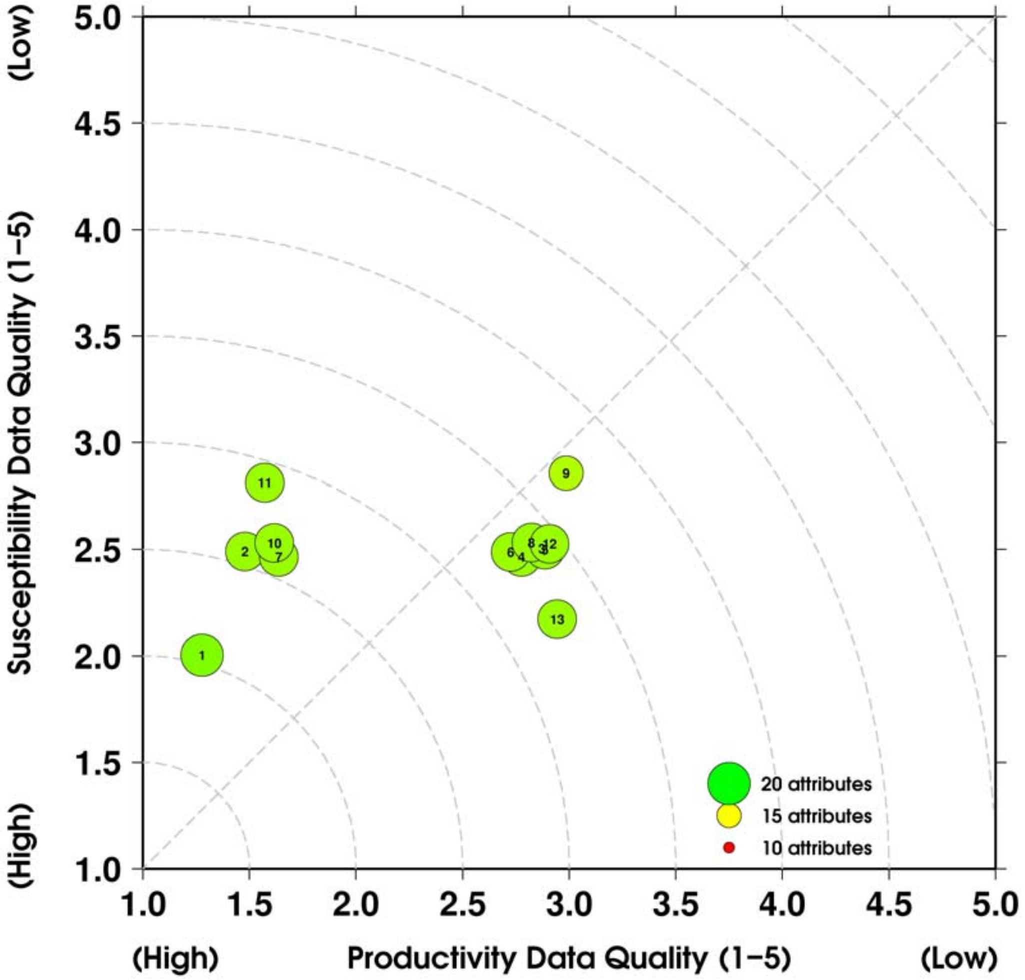
Appendix 6. Data quality plot for the California Nearshore Groundfish Finfish Assemblage.



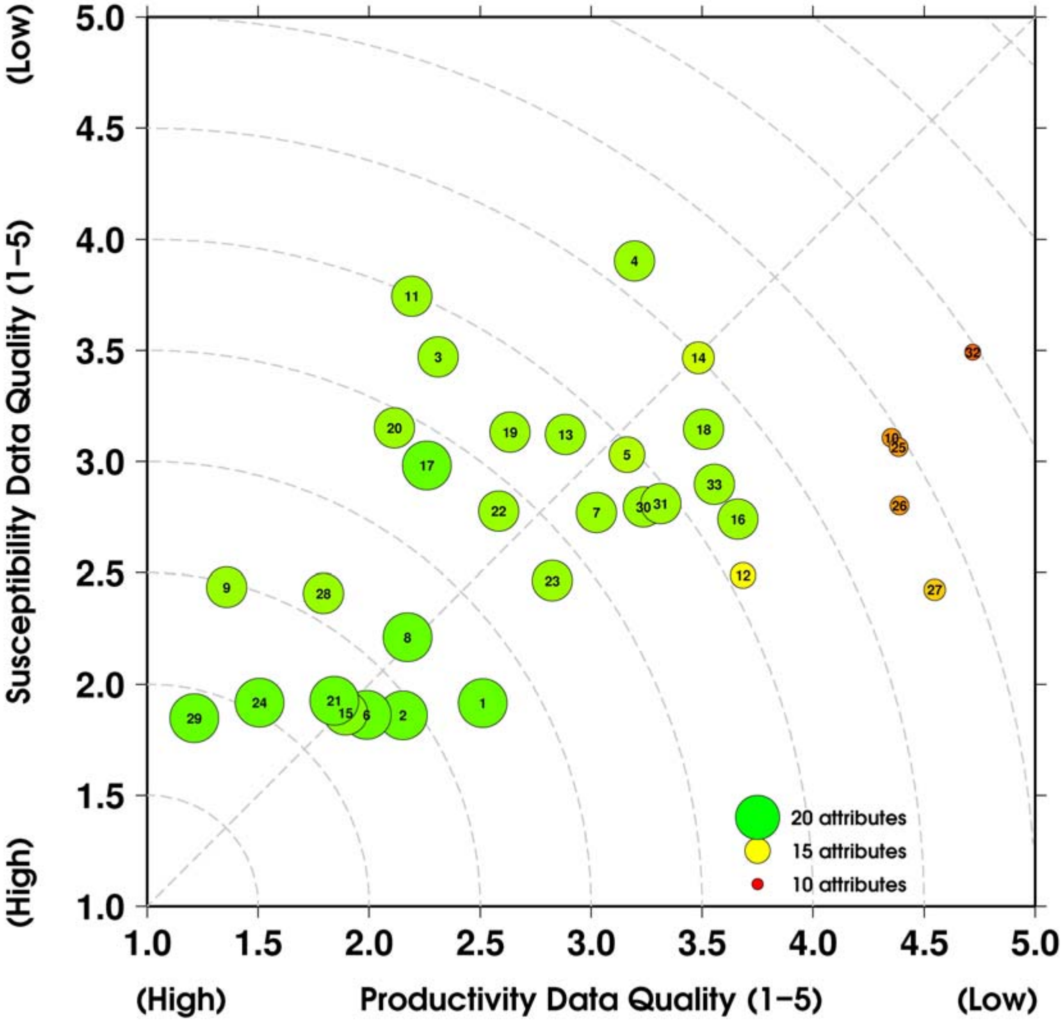
Appendix 7. Data quality plot for California Current Coastal Pelagic Species.



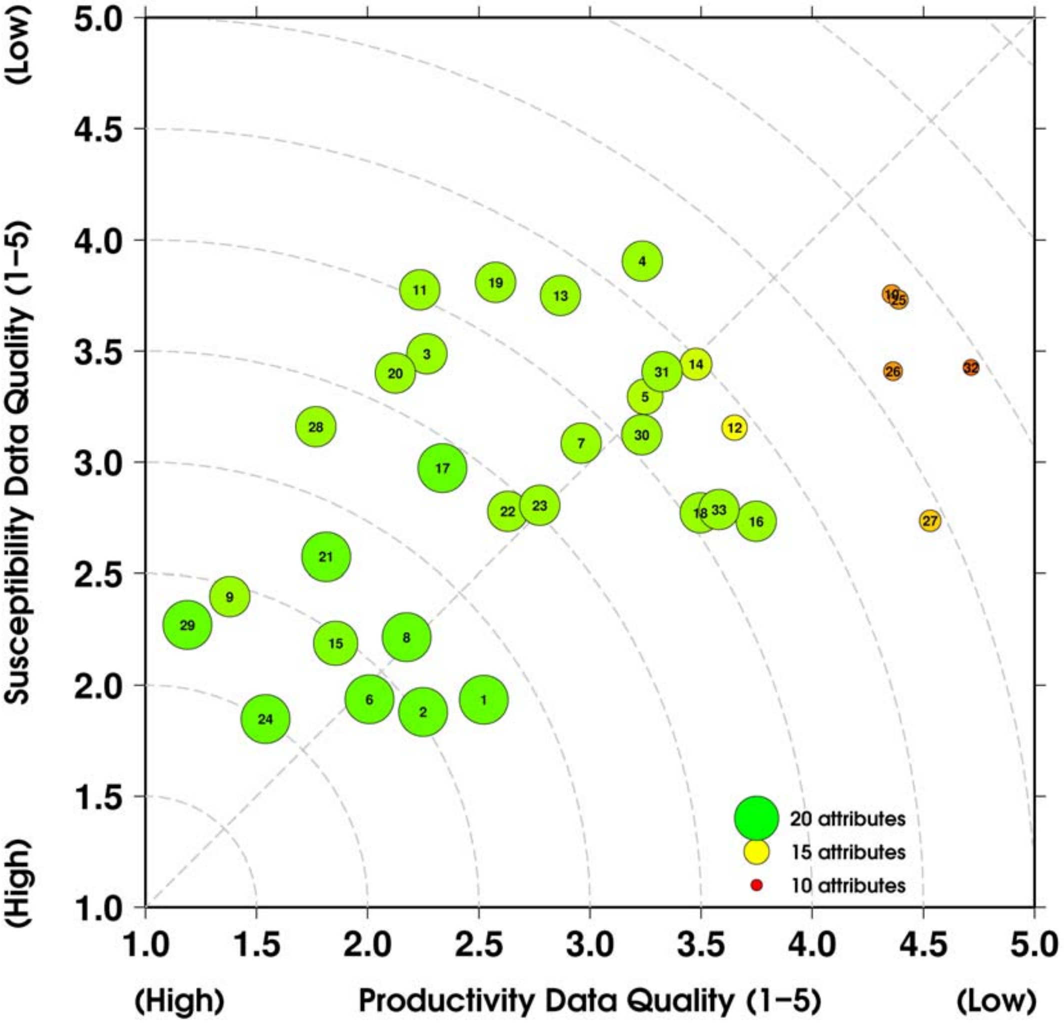
Appendix 8. Data quality plot for the Skates of the Bering Sea and Aleutian Islands Management Area.



Appendix 9. Data quality plot for the Hawaii-based Tuna Longline Fishery.



Appendix 10. Data quality plot for the Hawaii-based Swordfish Longline Fishery.



Appendix 11. A subset of the stocks from the example applications for which status determinations could be made between the years of 2000 and 2008.

						2000 - 2008 Stock Status	
ID	Fishery	Stock	Productivity	Susceptibility	Vulnerability	Overfishing	Overfished
14	Atlantic Shark Complexes	Dusky shark	1.04	2.06	2.23	Y	Y
15		Porbeagle	1.04	2.14	2.27	N	Y
18		Blacknose shark	1.28	2.29	2.15	Y	Y
25		Blacktip shark	1.16	2.43	2.33	N	N
27		Sandbar shark	1.04	2.42	2.42	Y	Y
29		Finetooth shark	1.31	2.47	2.24	Y	N
32		Bonnethead shark	1.71	2.55	2.01	N	N
36		Atlantic sharpnose shark	1.84	2.63	2.00	N	N
52	CA Nearshore Groundfish	Cabezon	2.03	2.24	1.57		N
53		Kelp greenling	2.03	2.07	1.45	N	N
55		California scorpionfish	2.03	1.79	1.25		N
57		Black rockfish	1.41	2.20	1.99	Y	N
64		Gopher rockfish	1.98	2.24	1.61		N
70	CA Current Pelagics	Pacific sardine	2.48	2.09	1.21	N	N
71		Northern anchovy	2.77	2.13	1.15	N	
72		Pacific mackerel	2.16	2.20	1.47	N	N
73		Jack mackerel	2.07	1.91	1.30	N	
78	NE Groundfish	Gulf of Maine cod	2.26	2.53	1.70	Y	Y
79		Georges Bank cod	2.33	2.58	1.71	Y	Y
80		Gulf of Maine haddock	2.01	2.44	1.75	N	Y
81		Georges Bank haddock	1.98	2.49	1.80	N	Y
82		Redfish	2.50	2.32	1.42	N	N
83		Pollock	2.28	2.36	1.54	N	N
84		Cape Cod/Gulf of Maine yellowtail flounder	2.11	2.56	1.79	Y	Y
85		Georges Bank yellowtail flounder	2.13	2.54	1.76	Y	Y
86		Southern New England yellowtail flounder	2.10	2.58	1.82	Y	Y
87		American plaice	2.23	2.26	1.48	N	Y
88		Witch flounder	2.18	2.46	1.67	N	N
89		Gulf of Maine Winter flounder	1.97	2.50	1.82	Y	N
90		Georges Bank Winter flounder	2.05	2.49	1.77	Y	N
91		Southern New England/Mid-Atlantic winter flounder	1.96	2.47	1.80	Y	Y
92		Gulf of Maine/Georges Bank windowpane	1.98	2.24	1.60	N	N
93		Southern New EnglandMid-Atlantic windowpane	2.02	2.24	1.58	N	Y
94		Ocean pout	2.49	2.29	1.39	N	Y
95		White hake	2.52	2.37	1.45	Y	Y
96		Atlantic halibut	2.63	2.61	1.65		Y
97	HA Pelagic Longline - Wwordfish	Albacore	1.92	1.99	1.46	N	N
98		Bigeye tuna	1.95	2.10	1.52	Y	N
102		Blue shark	1.51	1.71	1.65	N	N
104		Blue marlin	1.77	1.77	1.45	N	N
117		Skipjack tuna	2.41	1.85	1.04	N	N
120		Broad billed swordfish	1.84	1.68	1.35	N	N
125		Yellowfin tuna	2.29	1.94	1.18	Y	N

Appendix 11 (continued).

ID	Fishery	Stock	Productivity	Susceptibility	Vulnerability	2000 - 2008 Stock Status	
						Overfishing	**Overfished**
130	HA Pelagic Longline - Tuna	Albacore	1.91	2.14	1.57	N	N
131		Bigeye tuna	1.85	2.08	1.58	Y	N
135		Blue Shark	1.49	1.64	1.64	N	N
137		Blue marlin	1.77	1.93	1.54	N	N
150		Skipjack tuna	2.44	2.04	1.18	N	N
153		Broad billed swordfish	1.81	1.58	1.33	N	N
158		Yellowfin tuna	2.31	2.01	1.23	Y	N

Appendix 12. Data quality plot for the four non-target species captured in the South Atlantic/Gulf of Mexico Snapper-Grouper Bottom Longline Fishery.