APPENDIX

Assessment methodology[1]

Yimin Ye
Senior Fishery Resources Officer
Marine and Inland Fisheries Service
FAO Fisheries and Aquaculture Department
E-mail: yimin.ye@fao.org

ASSESSMENT APPROACH FOR THIS REVIEW OF STOCK STATUS

The objective of the FAO assessment is to provide a global overview of the state of world marine fishery resources to help with policy formulation and decision-making for the long-term sustainability of marine fisheries. Fish stock status is normally assessed based on the relationship between stock abundance and productivity. For example, the United Nations Convention on the Law of the Sea (UN, 1982), the United Nations Fish Stocks Agreement (UN, 1995), and the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) require maintaining fish stocks at the biomass that can produce MSY. Such a relationship is often established through a formal stock assessment process. However, because of the high data demands of classical stock assessment methods, only a limited number of fish stocks have been assessed. These species account for 17–25 percent of the global catch (Trevor *et al*., 2011), and most are caught by fisheries in developed countries. To balance the global representativeness of the assessment results and the goal of using the best available information, the FAO uses a wide spectrum of data and methods to extend its assessment to the fish stocks that account for the majority (80 percent) of the global catch (FAO, 2005).

There are three recognized types of overfishing: biological (Hilborn and Walters, 1992), economic (Clark, 1976) and ecosystem overfishing (Murawski, 2000). This review focuses on biological overexploitation as it is the key reference point of most fishery-related international treaties (UN, 1982, 1995; FAO, 1995). In this review, fish stocks/species are classified into three categories: non-fully exploited, fully exploited and overexploited. The criteria corresponding to each category are listed in Table DA1. As discussed below, the approach in this report differs from the previous FAO assessments that used five separate status categories. In this report, the classification uses four major indicators, whose use varies according to their availability. These are: stock abundance, spawning potential, catch, and size/age composition. Stock abundance is the fundamental attribute on which the three categories of stock status have been defined in this review.

Stock abundance

Fully exploited refers to the situation where the current stock is at 40–60 percent of the unfished level (Table 1). This definition originated from the concept of surplus production of fish stocks and assumes that MSY is the goal of fishery management (UN, 1982, 1995; FAO, 1995). The most commonly used Schaefer model assumes that

[1] The assessment methods described here were used as guidelines for the assessment of marine fish stock status in the preparation of this review report. A series of meetings and consultations were held within the Marine and Inland Fisheries Service of the FAO Fisheries and Aquaculture Department, and external reviews were carried out by world renowned experts to further improve the methods. Therefore, they are the results of collective contributions and decisions of the whole Service, rather than the author's personal opinion.

MSY occurs at 50 percent of the virgin stock. However, the stock biomass associated with MSY (B_{MSY}) varies with assessment models. For example, the Pella-Tomlinson model allows for MSY to range from 25 to 63 percent of pristine biomass (B_0) when parameter *n* varies from 0.25 to 4 (with *n*=2, the Pella-Tomlinson model becomes a Schaefer's model; Quinn and Deriso, 1999). The range in these models reflects the uncertainty about the value of B_{MSY} in reality. For example, Thompson (1992) shows that MSY occurs at B < 50 percent B_0 when a stock has a Beverton-Holt spawner–recruit relationship. Hilborn (2010) concluded that 80 percent of the MSY can be obtained over a range of 20–50 percent B_0. However, Dick and MacCall (2011) argue that there is no objective reason that actual populations are restricted to B_{MSY} < 50 percent B_0, with practical evidence of $B_{MSY} > 0.5B_0$ (Taylor and DeMaster, 1993; MacCall, 2002). It seems clear that the real B_{MSY} may lie within a range of stock biomass, depending on the characteristics of the fish species concerned. Moreover, the use of a single reference point to define B_{MSY} may cause unnecessary difficulties in practical management of stocks that show strong interannual fluctuations in abundance. Selection and application of models needs to take these differences and variability into account. The estimates of stock biomass derived from different data sets and different models can also vary because of the uncertainties involved in data and models.

Therefore, there is no clear consensus or precise estimates of suitable thresholds for defining status of stocks. However, the FAO definition is centred on stock biomass (abundance) and is loosely based on the standard Schaefer model. As a result, "fully exploited" is defined as a biomass within a band of 40–60 percent of the virgin stock, taking into account various uncertainties. As a result, stocks above 60 percent of the unfished biomass are classified as non-fully exploited, and those under 40 percent as overexploited (Table 1).

This classification of stock status is primarily based on stock abundance, but any other information or indicator that can linearly reflect changes in stock abundance can also be used as surrogates in the diagnosis of stock status. There would be clear advantages to also including an index of the current relative fishing mortality (e.g. overfished, or fished at F_{MSY}) as is currently done in several national and regional assessments. However, this more-demanding information is not available for many of the stocks covered by the FAO assessment.

Spawning potential

A fundamental goal of fishery management is to protect the reproductive potential of fish stocks for maximum yield and sustainability. The relative value of spawning stock biomass per recruit in comparison with the unfished situation is often used to measure the impact of fishing on the potential productivity (Goodyear, 1993). Many fisheries are managed based on reference points of fishing mortality that can maintain the spawning stock biomass per recruit at a certain level, instead using reference points that are associated with stock biomass (e.g. in the EU [ICES, 2010]; the United States of America (NMFS, 2010), and Australia (Wilson *et al.*, 2009]). In this review, the spawning stock biomass per recruit is, therefore, used as another indictor. A stock is considered to be overfished when its spawning stock biomass per recruit falls below 20 percent, and non-fully exploited if this value is above 40 percent of the unfished biomass. Stocks with values between 20 and 40 percent are referred to as fully exploited.

Catch

Catch represents the extent of biomass removal from a fish stock, and the development process of a fishery is usually accompanied by temporal changes in landings. Landings often initially increase and then decrease as species abundance decreases when no regulations over fishing effort are implemented (Grainger and Garcia, 1996). A drop in landings is often a symptom of overfishing. Grainger and Garcia (1996) diagnosed

TABLE 1
Criteria for the classification of fish stock status

Category	Characteristics
Overexploited	**1. Stock abundance** • Estimates of current stock biomass are < 40 percent of the estimated unfished stock size. • Catch rates (CPUE) are < 40 percent of the initial levels. • Survey abundance indices are < 40 percent of the initial values. **2. Spawning potential** • Spawning stock biomass is < 20 percent of the unfished biomass. **3. Catch trend** • Catches have dropped significantly from a peak without a clear cut in fishing effort. • Current catch is < 50 percent of the maximum after a 5-year smoothing. **4. Size/age composition** • Size/age composition unstable (excessively affected by recruitment, too few size classes in the exploited population given a species' life history). • Trends in size/age compositions are evident that indicate increasing (and/or excessive) fishing mortality.
Fully exploited	**1. Stock abundance** • Estimates of current stock biomass are between 40 and 60 percent of the estimated unfished stock size. • Catch rates (CPUE) are between 40 and 60 percent of the catch rates of the initial fishery stage. • Survey abundance indices are between 40 and 60 percent of the initial values. **2. Spawning potential** • Spawning stock biomass is between 20 and 40 percent of the unfished biomass. **3. Catch trend** • Catches have stabilized at or close to the peak values in the last 5–10 years although there may be interannual fluctuations. **4. Size/age composition** • Size/age composition is stable (not excessively affected by recruitment, enough age or size classes in the exploited population given a species' life history).
Non-fully exploited	**1. Stock abundance** • Estimates of current stock biomass are > 60 percent of the estimated unfished stock size. • Catch rates (CPUE) are > 60 percent of the initial catch rates. • Survey abundance indices are > 60 percent of the initial values. **2. Spawning potential** • Spawning stock biomass is > 40 percent of the unfished biomass. **3. Catch trend** • Catches increased over time when fishing effort has increased. **4. Size/age composition** • Size/age composition of the catch has been stable and has not shown large changes in comparison with that of the initial stage of the fishery.

the development status of a fishery by analysing the trend in landings over time. Pauly (2007) assessed stock status by comparing the current landings with the maximum historical catch. However, Trevor *et al.* (2011) show that this method has the potential to overestimate the status of stocks that are overfished when such a simple catch-only method is used. Moreover, low catches or declines in catch can be caused by management regulations. Connecting catch trends to stocks status is difficult when only catch data are available. However, fisheries that have only catch data usually have insufficient data to undertake any formal stock assessment and, consequently, rarely have management in place. For such fisheries, catch trend analyses may provide useful information on stock status if they are used together with other informal information and data.

Size/age composition

Finally, fishing is often a selective removal process. With the increase in fishing intensity, the size composition of the catch will shrink. Different size-based indicators can be used to detect the impact of fishing (Jennings and Dulvy, 2005). FAO's assessment uses no numeric length-based reference points, but includes some general judgements as supplementary information when required and when suitable size information is available. It should be borne in mind that changes in size composition can only be detected in the medium term rather than annually.

Synthesizing the information

Spawning potential, catch trend and size composition data are not directly linked with stock biomass. They should be used together with other supplementary information when abundance (biomass) data are absent or believed to be unreliable. Classification of stock status should be undertaken by integrating all the sources of information available. There is no simple rule to follow for such integration in data-poor fisheries. Informal and innovative approaches may need to be adopted, which may vary in accordance with assessors' personal experience and the specific circumstances of the stock concerned. To ensure the quality and objectiveness of the assessment, FAO relies on two measures. One is close consultation with local and regional experts on the fishery, and the other is seeking supplementary information when the assessment is based on limited information, qualitative methods or unpublished information.

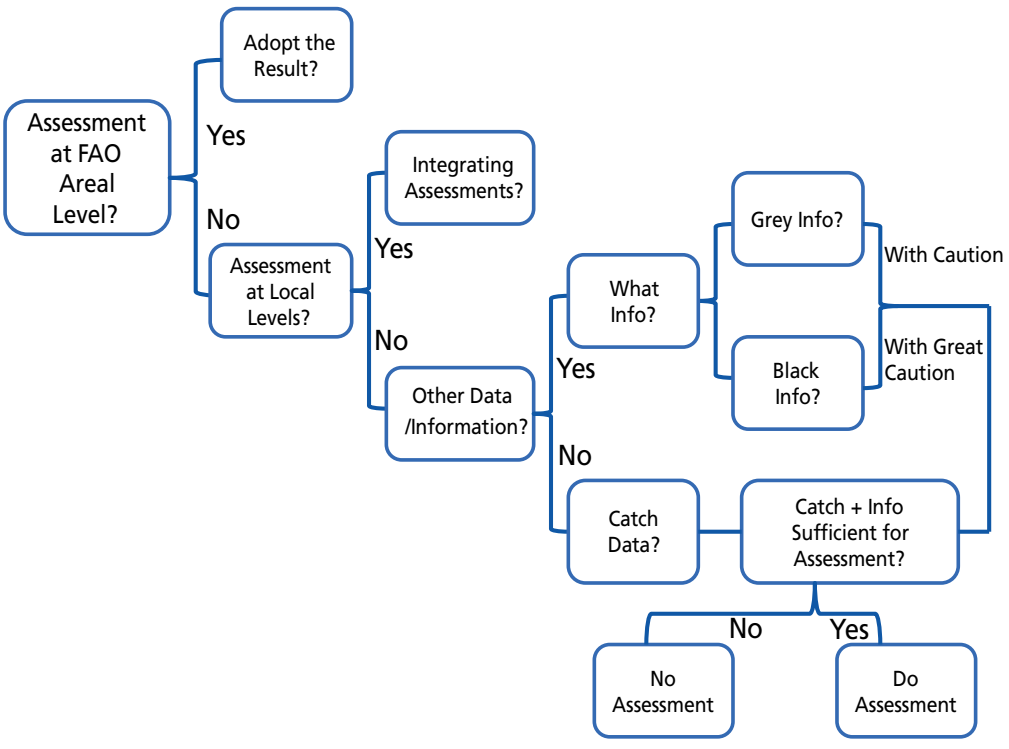
ASSESSMENT PROCEDURES

Assessment of status

The fish stocks that FAO has monitored since 1974 represent a wide spectrum of data availability, ranging from data-rich and formally assessed stocks to those that have very little information apart from catch statistics and those with no stock assessment at all. For the purposes of using the best available data and information and maintaining consistency among stocks and assessors, the following procedures have been used (Figure 1).

1. For stocks that have formal assessment at the FAO Statistical Area level (e.g. stocks assessed by the ICES, the FAO fishery commissions or RFMOs), these assessment results should be simply adopted. However, the following adjustments may be necessary in practice:
   a. The classification of stock status should follow the criteria listed in Table 1 if an estimate of current biomass of a stock relative to B_{MSY} is available.

FIGURE 1
Diagram of the decision tree for the classification of fish stock status



b. If existing assessments are not fully updated (with a gap of 1–3 years), other formal or informal information and the catch data extracted from the FAO database may be used to extend the previous assessment to the year of the current assessment.

2. For stocks that have no formal assessment at the FAO Statistical Area level, stock status assessments at regional, national or even finer scales should be used where available. FAO's assessment of stock status is about the overall condition of fish stocks/species. If a stock/species consists of several stocks or substocks, the following rules should be followed:
   a. The overall stock status should be the average of the status of the substocks weighted by their biomasses. Where no biomass data are available, the averages of the five consecutive years of the largest catches for each substock should be used as weighting factors.
   b. In cases where the above approach a) is not applicable, the state of exploitation in the summary table should list all the substocks if there are three or fewer substocks as "F, O, N", indicating one substock "fully exploited", one "overfished" and the other "non-fully exploited", or the three substocks that have the largest catches if there are more than three substocks.
   c. Any information that may have influenced the determination of stock status should be reflected in the text.
3. For stocks that do not have assessment at all, effort should be made to collect data/information that may exist in the "grey literature" or "black literature",[2] which may not always be about stock status. However, it may contain other relevant information such as length frequency data, survey abundance indices or fishing mortality estimates in selected years. Classification of these stocks should follow the rules below:
   a. Where data/information, such as intermittent CPUE data from the fishery or a sector of the fishery, survey abundance indices or ad hoc indicators are available in working papers or reports of local governments, RFMOs and projects (grey information), stock status may be classified following the criteria related to stock abundance in Table 1. This should be done in combination with other information or methods such as catch trend analysis; in the meantime:
      - some extrapolation may be necessary to bring the assessment up to date based on surrogate data/information from the fishery;
      - the catch trend should be analysed based on the data extracted from the FAO statistics database and stock status should be classified following the criteria in Table 1.
      - integration of different information or assessment results may be done informally or based on expert experience.
   a. Where no grey data/information are useful for determining stock status, information from personal communications or informal channels, such as views/opinions of local experts working on the fish species or fisheries, reports of local meetings or newspapers (black information), may also be incorporated in the classification. In addition, a catch trend analysis should also be carried out based on the data extracted from FAO's database.
      - When a clear drop can be identified and the black information is consistent with the catch trend analysis, the stock should be classified following the criteria listed in Table 1.

[2] "Grey literature" refers to working papers and reports of local governments, RFMOs and projects, and "black literature" means personal communications, reports of local meetings, newspapers, etc.

- If the catch trend analysis does not give a conclusive solution about stock status or the black information is not consistent with the results of the catch trend analysis, educated judgement that includes best knowledge from experts on the stock and/or region may be adopted to classify the stock.

a. For stocks that have neither grey nor black information available and for which the time series catch data does not support a clear judgement about stock status, no classification should be made.

Estimating and reporting uncertainty

4. Caution should be exercised with all the qualitative diagnostics that use the grey or black data/information mentioned above.
5. All stock status classifications involve uncertainty, and awareness of the level of such uncertainty can help readers to determine how to make better use of the assessment results. Therefore, a score of uncertainty involved in the classification is provided and listed in the last column of the state of exploitation tables. They are measured by three levels:
   a. Low uncertainty – formal stock assessment at the FAO Statistical Area level or at the regional and national levels forms the foundation of the classification.
   b. Intermediate uncertainty – grey data/information and a catch trend analysis provide the basis for classification.
   c. High uncertainty– black data/information and a catch trend analysis together with other qualitative assessment were used for the classification.
6. If the resulting status assessment of a stock differs from the last assessment, effort should be made to understand the reasons why and to explain the change in the text.
7. Recording briefly how the conclusion of stock status has been reached. This information is not reported here in the report, but retained for internal uses for future assessment and increasing transparency.

DIFFERENCES BETWEEN CURRENT AND PREVIOUS APPROACHES

In FAO's previous assessments, the status of a fish stock/species was classified in one of six categories. The details of this classification are listed in Table 2 (FAO, 2005). The approach used in the current latest assessment differs from previous assessments in the following three important aspects:

- As explained above, only three categories of stock status have been used compared with the six used in previous assessments. This simplification has been undertaken

TABLE 2
Criteria for the classification of fish stocks status in previous assessments

Stock status	Symbol	Description
Underexploited	U	Underexploited, undeveloped or new fishery. Believed to have a significant potential for expansion in total production.
Moderately exploited	M	Stocks are exploited with a low level of fishing effort. Believed to have some limited potential for expansion in total production.
Fully exploited	F	The fishery is being exploited at or close to an optimal yield level, with no expected room for further expansion.
Overexploited	O	The fishery is being exploited at above a level that is believed to be sustainable in the long term, with no potential room for further expansion and a higher risk of stock depletion/collapse.
Depleted	D	Catches are well below historical levels, irrespective of the amount of fishing effort exerted.
Recovering	R	Catches are again increasing after having been depleted or a collapse from a previous high.
Unknown	? or blank	Not known or uncertain. Not much information is available for assessment and stock status cannot be determined.

to reflect the underlying uncertainty in many of the assessments. This means that there is a high risk of error in attempts for a more precise assessment into six categories. It is important to note that the three categories used here are not new but are simply the result of aggregating overexploited, recovering and depleted into the one category overexploited, and the categories of moderately exploited and underexploited into the single group non-fully exploited. Therefore, the use of the three categories in this assessment should not in itself have led to any change in the percentages of stocks within the broad categories of overexploited, fully exploited and non-fully exploited.

- There are large differences in the types of fisheries, nature of the stocks and the data and information available from region to region. Therefore, it would be impractical to attempt to impose a rigid and identical framework across all regions. In previous assessments, the choice of approaches was largely left to the responsible authors to use their individual judgement on which data and information to use and how to use them. The process summarized in Figure 1 has been implemented in the current assessment in order to try to obtain greater standardization. Thus, it should improve comparability between the different individuals and groups undertaking the different regional assessments, while still recognizing the need to allow flexibility. The elements and options within the process do not differ significantly from those used in previous assessments. While it should have led to greater standardization and consistency in assessments, the process should not in itself have resulted in any change in percentages of stocks across the different categories.
- The individuals responsible for assessing each region were asked to review the stocks conventionally assessed in their region. They had to consider whether any changes were required to improve the representativeness or quality of the overall regional assessment. Some stocks might have been assessed in the past, but are now omitted because of the inadequate data available. Some stocks that were not fished historically may have been assessed recently owing to their increasing production and socio-economic importance in the region. This may have been because of changes in fish species composition of marine ecosystems or in targeting by fishing fleets.

Overall, the changes to the assessment approach applied for this review are expected to have improved the accuracy of the results and the comparability across regions. This is despite substantial uncertainty inevitably remaining, in particular as a result of the poor information quality for many stocks. It is the opinion of the contributors to the review that the new approach would not have significantly biased the assessment compared with earlier reports. The approach should not have generated either a more negative or a more positive view on the global status of the world's marine fishery stocks. Therefore, the results should be comparable with previous assessments, taking into account the wide confidence intervals that result from high levels of uncertainty.

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Wilson, D., Curtotti, R., Begg, G. & Phillips, K. 2009. *Fishery status reports – status of fish stocks and fisheries managed by the Australian government*. Canberra, Bureau of Rural Sciences and Australian Bureau of Agriculture and Resources Economics.

This publication presents an updated assessment and review of the current status of the world's marine fishery resources. It summarizes the information available for each FAO Statistical Areas; discusses the major trends and changes that have occurred with the main fishery resources exploited in each area; and reviews the stock assessment work undertaken in support of fisheries management in each region. The review is based mainly on official catch statistics up until 2009 and relevant stock assessment and other complementary information available until 2010. It aims to provide the FAO Committee on Fisheries and, more generally, policy-makers, civil society, fishers and managers of world fishery resources with a comprehensive, objective and global review of the state of the living marine resources.

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