

**Gulf of Mexico Red Grouper:
A Review of the Scientific Advice
and its Management Implications**

prepared by

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Note

Following the presentation of this document to the Reef Fish Committee of the Gulf of Mexico Fisheries Management Council, a member of that Council's Reef Fish Stock Assessment Panel pointed out that, in this report, I had misinterpreted the Panel's conclusion that the ABC could be as low as zero. Apparently, the RFSAP's intention was not to imply that the value of the ABC could lie anywhere within the reported ranges (e.g. 0 to 3.5 million pounds), as it appeared to be from the wording of the RFSAP report, but rather that it was biologically acceptable for the catch to be limited to levels below the estimated optimum (e.g. 3.5 million pounds).

While this interpretation removes any grounds for suggesting that the RFSAP's report violated the *Technical Guidelines*, it does not require any changes to the conclusions of this report. It does leave a gap in the logical argument presented here. I have not, however, amended the text nor made other changes since this was presented to the Reef Fish Committee, save for the addition of this note and the substitution of colour figures for the black-and-white ones in the printed version.

1 Introduction

Red grouper (*Epinephelus morio*) is the principal grouper in U.S. catches from the Gulf of Mexico and is a very important component of the reef-fish catch from the waters off Florida. Recorded catches have exceeded 15 million pounds per year in the past, though more recently they have been about one third of that peak level. The U.S. Gulf landed catch in 1997, the most recent year for which full data are available, is estimated to have been 5.2 million pounds (Schirripa *et al.* 1999). The species is primarily a commercial fish, though a not-insignificant fraction of the landed catch is taken by recreational fishermen. The commercial fishery is currently subject to a 20-inch minimum-size limit and to a combined annual quota of 9.8 million pounds (gutted weight) of “shallow-water groupers” – a group that includes red grouper and seven other species. Recreational fishing is subject to the same minimum size as applies to the commercial fleet and also to an aggregate daily bag limit of five groupers from a list of thirteen species which includes red grouper.

In June 1999, Schirripa *et al.* (1999) produced a new assessment of the red grouper resource in U.S. Gulf waters, concluding that it is over-fished. They also concluded that, under some assumptions, the resource may be unable to rebuild to the legislated MSY target level within ten years, even if the total catch (including bycatch and fish discarded dead) could be reduced to zero. Schirripa *et al.* (1999) did not explicitly recommend any management measures in response to their assessment. In September 1999, however, their work was reviewed by the Gulf of Mexico Fishery Management Council’s Reef Fish Stock Assessment Panel (RFSAP) which strongly recommended that a rebuilding strategy be based on a constant rate of fishing mortality¹, rather than a constant catch. Even with the rebuilding period stretched to the maximum that could be justified under current legislation (spanning 2000 to 2018), the recommended catch for Year 2000 under the RFSAP’s suggested strategy was only 1.5 million pounds. The Panel, apparently with an eye to the inevitable uncertainties of fisheries assessments, actually recommended a range for the Allowable Biological Catch (ABC) which extended downwards from the 1.5 million-pound calculated estimate all the way to zero.

Even an ABC of 1.5 million pounds, if adopted by the Gulf Council, would likely require the effective closure of directed red grouper fishing. Recreational fisheries might continue on a catch-and-release basis, since post-discard survival is thought to be high in the shallow waters frequented by the recreational sector. Survival appears low, however, if fish of this species are released after being caught at the depths more typical of the commercial fishery. Thus, achieving a red grouper ABC as low as 1.5 million pounds might require severe restrictions on the remainder of the commercial reef-fish fisheries,

¹ Meaning that the fishery would take a steady annual percentage of the resource during its recovery period. Catches would therefore start out very low but would increase as the red grouper rebuilt. A constant fishing mortality rate is equivalent to constant fishing effort.

since substantial incidental catches of red grouper seem unavoidable. Such management measures would have serious social and economic consequences, for many people in the west-coast Florida fishing industry in particular.

Faced with this situation, the Southeastern Fisheries Association contracted Gadus Associates to undertake a review of Schirripa *et al.*'s (1999) red grouper assessment in order to determine whether severe restrictions on the fishery were indeed necessary. No specific instructions were given, simply a requirement to uncover the true status of the resource, to the degree that that is possible. In preparing this review, I have not attempted to verify the data used by Schirripa *et al.* (1999) but have only examined the uses they made of the material available to them, while also considering the RFSAP's review of their assessment². I have not attempted to review the biology of red grouper. Dr. Mark Tupper is preparing a summary of existing knowledge of the species, on behalf of the Southeastern Fisheries Association, but his conclusions were not available in time for inclusion here. Most importantly, this review is confined to information held by scientists. Grouper fishermen will have additional knowledge which, alone or in combination with that of scientists, might provide a more precise picture of the current status of the red grouper resource. Fishermen's knowledge is not available to me, however, and should be sought direct from those in the industry.

Reviews necessarily stress criticisms of the work reviewed. Before doing so, I would emphasize that Schirripa *et al.* (1999) have undertaken a high-quality, state-of-the-art assessment of red grouper. While I have a few specific reservations about the methods they chose to use and a general doubt about the precision of their approach, those should not be taken as a broad condemnation of their work. If it is possible, at this time, to prepare a more accurate "best estimate" of the state of the resource than Schirripa *et al.* (1999) provided, I am certainly not capable of doing so. While I would encourage NMFS and the Council to explore some options for further refining last June's assessment before making final management decisions, I would also suggest that Schirripa *et al.*'s (1999) assessment, as interpreted and amended by the RFSAP, currently constitutes the "best available science" relating to the status of red grouper in the Gulf of Mexico.

That being said, the information-base on which any red grouper assessment must be built is sadly weak and, in consequence, such an assessment can only be imprecise and perhaps even speculative. Schirripa *et al.* (1999) followed a complex approach, relying in part on new models and considerable computing power, to construct conclusions from the weak foundations provided by the limited existing data. Such conclusions must necessarily be simultaneously unreliable and yet as trustworthy as any others which might be developed at the present time – as the RFSAP appears to have recognized. Thus, my review does not question the scientific advice provided to the Council by its RFSAP but it does emphasize

² The assessment and the RFSAP's report on it have been reviewed by the Council's Science and Statistics Committee. I did not have access to that Committee's formal conclusions at the time of preparing this document.

the imprecision of Schirripa *et al.*'s (1999) quantitative conclusions and then discusses the application of the uncertain advice to the management of the Gulf red grouper fisheries.

2 Data Sets

The central problem faced by any assessment of red grouper is that the available data base is very weak indeed. Aside from basic information on population biology [summarized by Schirripa *et al.* (1999) and by Tupper (in prep.)], there are only highly-uncertain data on catches, fishing efforts and the sizes of fish caught, plus three questionable fishery-independent indices of abundance. All else must be built on this sadly deficient foundation, with the aid of whatever framework can be constructed from theories of fisheries dynamics.

2.1 Catch Data

One of Schirripa *et al.*'s (1999) lasting contributions was the compilation of catch data from all of the various fishery sectors which have taken red grouper in U.S. waters of the Gulf of Mexico in the past half century. However, given the complex of incomplete data sets dealing with different periods, areas, fleets and gears, any such compilation must require multiple value judgements and thus will always carry a degree of uncertainty. Up to 1986, for example, grouper catches were not recorded separately by species and thus assumptions must be made of the proportions of them that were red grouper – assumptions which can differ by area and fishery sector. Thus, Schirripa *et al.*'s (1999) estimates of the landed catch may very well be the best that will ever be compiled but they cannot be considered exact.

Indeed, for the years up to 1976, those estimates are very heavily influenced by the recorded Cuban catches – that nation's fleet being active to the west of Florida until the Magnuson Act extended U.S. jurisdiction out to 200 miles from shore. The Cuban fishery developed through the 1940s and produced high recorded landings (over 10 million pounds per year) from 1948 to 1958. Their recorded landings then declined precipitously until they were negligible in 1964 (Schirripa *et al.* 1999). While the cause of this decline cannot be certain, it is notable that the Cuban Revolution began in March 1958, while the Castro regime reached the nadir of its international relationships with the Missile Crisis of 1962. The coincidence in the dates suggests that disruption within Cuba either curtailed fishing effort in the waters west of Florida or perhaps resulted in severe under-

reporting of that effort and its grouper catches³. If the latter was the case, Schirripa *et al.*'s (1999) combined catch data would be massively wrong for the 1960s.

The recorded Cuban landings recovered somewhat in the later 1960s and were about 5 million pounds per year through the 1970s. They ended abruptly in 1977, however, when the U.S. excluded foreign vessels from its newly-claimed waters (Schirripa *et al.* 1999). The Cuban data from that latter period may, perhaps, be assumed to be consistent in its errors across time, though whether it can be directly compared with the pre-revolutionary data must be doubtful.

Schirripa *et al.*'s (1999) figures for U.S. catches, while clearly not exact, can perhaps be considered tolerably accurate, at least in comparison to the Cuban data. There is no obvious reason why the records should have been subject to the sorts of massive misreporting of catches that some quota-limited fisheries have seen⁴.

2.2 Effort and Catch-Rate Data

In the available data sets, the only credible indicators of red grouper biomass are the catch rates in various fisheries. Those are subject to all of the imperfections of the catch data from which they are calculated as well as those of the equally-unreliable, and considerably more limited, data on fishing effort. Catch rates are, in any case, notoriously unreliable indices of trends in resource biomass. In the case of red grouper, it is hard to give them any credence at all since this fish is only taken in mixed-species fisheries and hence small changes in fishermen's targeting practices may have produced major shifts in catch rates even in the absence of real changes in the biomass of the species of interest.

Were any alternative measure of red grouper status available, I would strongly recommend ignoring the catch rate indices. Since none is, they must be used. That use should, however, be accompanied by a clear understanding of the imprecise, and potentially grossly misleading, nature of these catch rates.

³ A biological cause for the decline in Cuban catches cannot be ruled out, though it should be noted that U.S. catches rose slowly as the Cuban ones declined (Schirripa *et al.* 1999), suggesting that the causes lay with the Cubans, rather than with the fish.

⁴ There is an additional anomaly in Schirripa *et al.*'s (1999) compilation of these catches. Their text and Figures 23 to 25 indicate that Cuban landings data are available for the years from 1950 onwards while U.S. commercial data are available from 1962 to date. Yet their Table 54 provides such data back to 1940 and their Figure 33, summarizing their estimate of the overall catches, begins at the same date. In their text (pp. 24–25), they explain how they projected their recreational catch estimates back that far but nowhere do they state the source of the commercial landings figures. The estimated catches in the 1940s will have had a considerable impact on the fits of the ASPIC and ASAP models (see below) and if the undocumented sources of those estimates contained substantial errors, they could have had severe effects on Schirripa *et al.*'s (1999) final conclusions.

2.2.1 1940-1980

For the years prior to 1980, there are only two sets of fishing effort data from which catch rates can be calculated. The first, for the U.S. commercial fleet in 1950–1997, is actually the number of documented handline fishing vessels based on the west coast of Florida. Naturally, a count of vessels (particularly one which excludes the large number of non-documented boats) falls very far short of being a reliable measure of fishing effort. Even the recorded numbers look suspect: According to Schirripa *et al.*'s (1999) Table 54 and Figure 43, the fleet fell from 361 vessels in 1950 to 79 in 1953. Thereafter, it grew relatively steadily until 1994 (when it took a sudden jump from 591 to 794 in 1995). However, the steady trend was interrupted by a near-tripling of the fleet from 1958 to 1959, followed by a halving the next year. Such sudden changes in real fleet size, while not exactly impossible, are highly unlikely. Unless some factor can be identified that would explain the simultaneous movement of large numbers of fishing vessels into and out of the reef-fish fisheries of the eastern Gulf of Mexico, I would suggest that it is a great deal more likely that these apparent sudden shifts resulted from changes in the ways that the fleet size was recorded, if indeed they are not simply errors in the data.

It can usually be supposed that the amount of effective effort exerted per vessel rises over time (as larger and more powerful boats enter the fleet, while fishermen work harder and smarter). However, in the multi-species reef-fish fisheries the relationship between fleet size and the effort exerted on one particular species, such as red grouper, is far less clear. Thus, it is possible that the real level of fishing effort exerted on the red grouper resource remained steady or even fell during the long period (1953–1995) when the number of documented vessels in the handline fleet rose, though it is also possible that that real effort level rose faster than did the size of the fleet.

The other available fishing-effort data set, covering the years from 1940 to 1976, constitutes the days fished per year by the Cuban handline and longline fleets (the data being separated by gear type). These data come closer to providing measures of fishing effort than do the U.S. vessel numbers but they are otherwise subject to all of the doubts surrounding the latter data set. In addition, use of the Cuban figures involves an assumption that the accuracy of fishery statistics is not significantly degraded when the government which compiles them is replaced through a violent revolution, with accompanying general social upheaval. Such an assumption is, at best, highly speculative.

The revolution may have had other and more direct effects on the relationship between real and recorded Cuban effort. If, for example, many owners of larger, more powerful and more capital-intensive vessels opted to flee to Florida while most operators of smaller boats remained in Cuba and fished under the new regime, it would have had the effect of greatly reducing the average catchability of the fleet and thus depressing the real effort relative to the recorded number of boat-days used to take the catch.

When each of these fishing-effort data sets is used with the appropriate recorded catches to calculate a catch-rate series, they produce trends across time which could be interpreted as being similar or as markedly different. The Cuban catch rates (Figure A) were variable but high in the 1940s and 1950s, reaching a peak in 1949 and a lesser one in 1957 but hovering around 800 pounds per boat-day. They then fell steadily from 1957 to 1966, by which time they were about a third of their peak values (Schirripa *et al.* 1999). This fall in measured catch rates paralleled the simultaneous decline in recorded catches, though the recorded effort by the Cuban fleet also fell at the same time, so that its catches fell faster than its catch rates. As noted above, this downward trend might relate to resource biology but, besides all of the usual doubts surrounding catch-rates, its dates are suspiciously similar to those during which social and governmental disruption would be expected to have caused dislocation of both the fishery and the recording of data on its performance. To suppose that the trend exclusively tracked a decline in the red grouper resource through the late 1950s and early 1960s would be a bold assertion indeed.

From 1965 to 1976 (the final full year of the Cuban fishery west of Florida), the measured catch rates were remarkably steady at about 350 pounds per boat-day (Schirripa *et al.* 1999). I would not wish to suggest that this apparent constancy demonstrates that red grouper biomass was stable over the years in question but one might suppose that at least the quality of data recording by the Havana government had stabilized after its decay turning the preceding turbulent years. Hence the resulting numbers may be as indicative as catch rates can be.

The U.S. time series (expressed as catch per documented vessel in the fleet in western Florida) is much affected by the sharp changes in recorded fleet size during the 1950s. Schirripa *et al.* (1999, p. 33) read the U.S. trend as following the Cuban one but the sharp decline between two periods of stability, which is so clear in the Cuban trend, is not visible in the U.S. one. When the latter's extreme variability is reduced by applying a median-smoothing routine (Figure B), it shows a long, gradual decline with some periods of stability, as in the mid- to late 1960s and the early to mid-1980s.

In short, the available data can be used to calculate red grouper catch rates which show a pronounced decline starting in the late 1950s and continuing to date. It is, however, far from certain that there has been any such trend in the biomass of the resource. The Cuban data, which dominates the early years, is highly unreliable for the period 1958-1965. The decline in measured U.S. catch rates in the 1970s is clear enough. However, those rates were calculated using an uncertain measure of fleet size, which has only a tenuous connection to the amount of fishing effort actually exerted on red grouper to produce the recorded catches.

2.2.2 1980–1997

From 1980 onwards, the U.S. catches-per-documented-vessel can be supplemented with a number of alternative, and perhaps more precise, catch rate measures. The longest run (1981-1997) comes from the MRFSS survey of private and charter recreational boats. Schirripa *et al.* (1999) calculated a catch-rate index from the survey data on red grouper landings⁵. That index varied with little trend over nearly two decades (Schirripa *et al.* 1999, Figure 49). One might see in it stability, a general decline from 1985 to date or else one only from 1994 to 1997 – though it is unlikely that statistical analysis would be able to detect any significant trend in any direction. The MRFSS provides data on discarded fish as well as those landed, Schirripa *et al.* (1999) also calculated an equivalent index based on the total catch. Since recreational grouper discarding practices have been heavily affected by changes to minimum-size and bag-limit regulations, that second index is likely to be a much better indicator of resource biomass than is the one based on landings data. It shows (Figure C) a strong and rather steady increase from 1980 to 1991, followed by a pronounced decline from 1991 to 1997 (Schirripa *et al.* 1999, Figure 49)⁶.

Additional data are available from a survey of headboats, though Schirripa *et al.* (1999) judged that only the data from ten boats (which together took half of the red grouper caught by the entire headboat fleet and seemed to specialize in such fishing) should be used to construct a catch-rate index and then only for the years 1986 to 1997. The available data from this sector does not allow for the tracking of discards and thus the landings-per-trip from before 1990 (when the minimum size was increased to 20 inches) cannot be compared to those of later years. For the period 1990–1997, the resulting index (Schirripa *et al.* 1999, Figure 49) shows either a general decline, confused by some random variation, or else stability from 1990 to 1995 followed by a sudden decline (Figure C). The suddenness of the latter interpretation would be consistent with the effects of assorted artifacts (of management measures, fishing practices, erroneous data etc.) but not with the likely biology of red grouper⁷.

For 1990 to 1997, Schirripa *et al.* (1999) also had commercial fishing-effort data from the Reefish Logbook Program⁸. Those allowed the calculation of landings-per-hook-hour for

⁵ Schirripa *et al.* (1999) did not simply divide catches by efforts to obtain catch-rates but rather subjected to the data to more powerful, but potentially more misleading, calculations.

⁶ Schirripa *et al.*'s (1999) speculations as to the effects on these catch rates of regulatory changes and, particularly, of supposed resulting changes in biomass (their p. 36) seem, to me, to place too much credence in the irregular and largely random changes seen in any catch-rate time series.

⁷ The catch rate for these headboats, as presented in Schirripa *et al.*'s (1999) Table 55 and their Figure 49 does not correspond to the data supposedly used in its calculation as presented in their Table 53. Similar discrepancies can be seen in their calculations of catch rates from commercial logbook data (see below).

⁸ Schirripa *et al.*'s (1999) account of these commercial catch rates is inconsistent and confusing. The version given in the present text is drawn from Schirripa *et al.*'s (1999) text (pp. 33–35) and its accompanying figures. However, their Table 55, which presents their graphed numbers in tabular form, suggests that the longline catch rate was actually calculated as catch per day at sea and that of the trap fleet as catch per trap-day. Their Table 55 also indicates that the tabulated and graphed catch rates for handliners

and longliners were multiplied by 1,000, though that for traps was not. In reality, it probably was so expanded since Schirripa *et al.*'s (1999) numbers, taken at face value, suggest a catch per hook-hour with a handline of a pound or more of red grouper (a believable number) and of a few hundred pounds of red grouper per day at sea for a longliner (again a reasonable number) but of nearly a ton per trap-day, which is beyond reasonable belief.

Moreover, the summary of the logbook data in Schirripa *et al.*'s (1999) Tables 48 to 50 does not accord with the numbers given as mean values in their Table 55 (the latter being the source for their figures and so for the summary presented in the text above). In their text, they do correctly quote some figures from their Tables 48 and 49, suggesting that the discrepancy is not simply a matter of the wrong table having been inserted into their document by mistake. However, if the handline catch per hook-hour is calculated from the numbers in Table 48, it provides a radically different time trend to that shown in Table 55 and Figure 45. The longline data (Tables 49 and 55, Figure 46) have a closer correspondence but are not identical, while the trap data (Tables 50 and 55, Figure 47) again show no marked similarity. Some of the deviation may result from incomplete data sets, such that the mean number of hooks set (for example) is calculated from a slightly different selection of trips to that used in calculating the mean catches presented in Tables 48 to 50. That cannot, however, come close to accounting for the observed discrepancy. Rather, Schirripa *et al.* (1999) must have done something other than applying their stated equations to the data summarized in Tables 49 to 50 in order to produce the means in their Table 55 and Figures 45 to 47. [They also calculated more complex indices which roughly followed, but did not correspond with, their means. Errors in such indices cannot be detected from the information Schirripa *et al.*'s (1999) document alone.]

The data summarized in Tables 48 to 50 seem, in any case, to be erroneous or at least not to represent what they appear to do. Schirripa *et al.* (1999) noted in their text that the number of hooks per handline increased from about two in 1990 to reach nearly nine in 1994 before declining to three in 1997 – a trend that they could not explain. Yet Table 48 shows the maximum number of hooks rising from 20 to 2318 before falling to 100. One hundred hooks is an enormous number to work on a single line and may represent a lone captain mistakenly reporting the sum of the hooks on his four or five lines. 2318 hooks, however, is an impossible total for a handliner and suggests that some longline data has been improperly coded as though it came from handlining. Since the years of high mean numbers of hooks per line (1992-1995) are also those with extraordinary maximum numbers, it may be that blocks of longline data were miscoded. If so, and if Schirripa *et al.* (1999) did not apply some unstated corrections, the resulting catch-rate index will clearly be grossly in error. [It seems in any case that the data are from a mixture of red grouper and red snapper trips. Red grouper fishermen typically use two hooks per bandit, whereas 10 to 50 are used in red snapper fishing (Mr. R.Spaeth, Southern Offshore Fishing Association, personal communication). The increase in average hook numbers from 1990 to 1997 may therefore represent an increasing proportion of snapper trips in the data set used, which will naturally have depressed the red grouper catch-per-hook-hour relative to the trend in the biomass of that species.]

Schirripa *et al.* (1999) did note that the tabulation of hours per longline set in their Table 49 had been corrupted by a change in recording practices in 1993 and thus they did not use those data. Perhaps fortunately, they also did not use the tabulated number of lines (averaging about 30) or the hooks per line (averaging around 1,000). The combination, 30,000 hooks per set, is an achievable total for a small longliner but only if the gear is baited ashore and taken to sea for a single trip – which is not the normal practice of Gulf of Mexico grouper longliners, which average ten-day trips. Only a large longliner with auto-baiter gear could set 30,000 hooks a day repeatedly and such vessels do not exist in the Florida fleet. It therefore seems more likely that the tabulated number of “lines” was really the number of sets (two to three per day) made during a trip and the “hooks / line” the number of hooks per set.

Table 50 likewise presents numbers of traps per line (labelled “hooks / line”) which are not believable when combined with the numbers of lines set presented in the same table. It may be that the tabulated numbers of “lines” are really those of traps carried while the “hooks / line” are the numbers of trap-hauls made during a trip. Nor is the average number of hours given in Table 50 (about 15) reasonable.

It is possible that Schirripa *et al.* (1999) made allowances for these various problems in producing the catch rates in their Table 55 and that those adjustments account for the discrepancies among their tables.

the handline fleet, of landings-per-hook-day for the longline fleet and of landings-per-trap-hour for the trap fishery, all apparently being based on data from the Florida fleet fishing in the Gulf of Mexico and solely on those trips which landed some red grouper⁹. In addition to catch rates calculated as simple averages of the data, more complex indices were developed incorporating adjustments for changes in the seasons and areas of fishing. Each of these various indices (Figure C) suggests general stability from 1990 to 1997, though one might see in them a slow decline in handline catch rates, an equally-slow increase in those from the longline fleet and stability in trap catch rates.

Alongside these various catch-rate measures, the time series of landings per documented vessel (extending from 1940 to 1997) shows quasi-stability from 1980 to 1989, followed by a sharp drop as the new minimum-size limit came into force in 1990. It seems to have been stable thereafter until 1995 but has since shown a decline (Figure C).

With one catch-rate index rising from 1980 to 1991 and then falling to 1997, two others perhaps stable from 1990 to 1995 and then dropping, while three more show stability (or very slight and contradictory trends), it would be impossible to draw any firm conclusions as to recent trends in the red grouper resource even if the individual indices could be deemed reliable, which they cannot be. Perhaps the six could be summarized as giving a highly uncertain indication that there may have been a slight decline in the red grouper resource through the mid-1990s.

However, they did not indicate their awareness of the problems in their data, let alone what they may have done to resolve those.

⁹ For a catch rate to be at all reliable as an index of resource biomass, it should be calculated from data on trips directed towards the species of interest or at least those trips directed towards a stable mix of species including the one of interest. In the case of the reef-fish fisheries, however, there are no solid indications of fishermen's intentions and Schirripa *et al.* (1999) had few alternatives other than to select data on the basis of whether or not red grouper were caught on each trip. However, it is hard to accept the resulting catch rate as scientifically sound.

Among the factors which may have distorted the logbook data, the local shark fishery is said to have been developed by grouper longline fishermen. When the shark fleet was placed under restrictive trip limits, some captains resorted to mixed shark/grouper trips, resulting in grouper catches-per-trip substantially lower than those on purely reef-fish trips (Mr. R.Spaeth, Southern Offshore Fishing Association, personal communication). Meanwhile, it is thought that some charter-boat operators who also hold commercial permits sell their grouper catch (illegally) after landing and file the data under the Reefish Logbook program. Their one-day trips may account for the logbook-average duration of a handliner trip being only four days, when typical commercial handliners work seven to twelve-day trips (Mr. R.Spaeth, Southern Offshore Fishing Association, personal communication). A relative increase over time in the proportion of such trips in the logbook data would, of course, give the impression of a falling catch rate if all else was constant.

Such problems could be reduced, if not eliminated, in the catch rate indices by using a more stringent filter on the data than simply one of selecting all trips from which there was at least some recorded red grouper landing. The minimum landing for a qualifying "red grouper trip" might be set at some hundreds of pounds or else the analyses might be confined to a data from a few specialized boats, much as Schirripa *et al.* (1999) did with the headboat data.

2.3 Fishery-Independent Indices

In addition to the catch-rate series, Schirripa *et al.* (1999) also used three fishery-independent measures of the abundance of red grouper. Two were surveys, respectively using video and trap gear, that were run from 1992 to 1997. They produced one indication of a substantial increase in abundance and another showing near-stability interrupted by an anomalously-high value (Figure C) and thus added little to the sum of knowledge of resource status. In evident contrast to Schirripa *et al.* (1999, p. 38), I see no reason to give either of these data sets more credibility than the other, though the limited amount of sampling may indicate that both should be down-played relative to the catch-rate information, even though the surveys should avoid some of the biases inherent to the commercial and recreational data sets.

Schirripa *et al.*'s (1999) other fishery-independent index was based on data from a tagging study conducted by Mote Marine Laboratory. It showed a continuous decline in abundance (apparently of sub-legal sized red grouper) from 1991 to 1997 (Figure C). This index was derived from estimates of the fishing mortality rate developed by Legault *et al.* (1999), which were combined with an estimate of the corresponding catch and an assumed rate of natural mortality to derive an index of abundance, using the conventional catch equation. However, with the number of tags recovered annually being only 1 to 179 and with unsupported assumptions about the rates of natural mortality, tag loss, emigration from the study area and unreported recaptures, Legault *et al.*'s (1999) estimates of fishing mortality rates must be regarded as very highly imprecise. Indeed those authors specifically stated that “these Z^* values incorporate many factors besides just fishing mortality and should not be interpreted as the actual fishing mortality rate in the fishery”. Although they then proceeded to standardize their figures in an attempt to examine time trends, the standardization they used will not have produced an index suitable for Schirripa *et al.*'s (1999) calculations. Nor can a localized tagging study primarily focused on fish below the minimum legal size provide much indication of fishing mortality rates on the overall Gulf red grouper population¹⁰. In all, I would strongly suggest that Legault *et al.*'s (1999) mortality estimates not be used in assessing this resource.

2.4 Grouper Sizes

Schirripa *et al.* (1999) also presented the extensive available data on the sizes of red grouper landed, some of which dates from 1981 for the recreational fishery and 1984 from the commercial sector. Those data show a number of features of which the ones of immediate interest are a pronounced upward shift in the smallest sizes landed following the introduction of the 20 inch minimum-size limit in 1990 and a gradual reduction in the

¹⁰ Though Schirripa *et al.* (1999) may have applied the tag-based mortality estimates to the abundance of juvenile fish only, yielding them some approximation to a measure of the abundance of pre-recruit red grouper. If so, they did not make that fully clear in their document.

abundance of larger fish (above about 25 or 30 inches) through the 1990s. This latter trend was not seen in the trap catches (which always included relatively few large red grouper) but it was in both the handline and longline landings, as well as in samples from the recreational catches. It was not evident in the south (roughly south of Fort Myers) but was to the north of Tampa.

It is difficult to be certain whether this reduction in the proportion of large fish represents a change in the resource, a change in the catches only (perhaps due to a market-driven change in targeting or a move towards a different mix of target species, which is more concentrated in areas where large red grouper are less common) or even merely an artifact of sampling. The latter is not impossible – fisheries sampling is rarely randomly spread across the fleet, while each individual fishermen will have his own practices that tend to give him a fractionally-different mix of fish sizes in his catch than others do. When those are combined with small sample sizes and irregular human behaviour, biases will enter fish-size data. It is also clear that the “8 lb. and up” grade of red grouper (roughly equivalent to 25 inches and longer) remains common in some fishermen’s catches (Mr. R.Spaeth, Southern Offshore Fishing Association, personal communication).

Even if the observed shift in the data represents a real change in the population, fish size distributions can shift towards smaller sizes for various reasons, including a prolonged period of strong recruitment introducing many small fish and so reducing the proportion of large ones. Nevertheless, a first and precautionary reading of the red grouper size frequencies would suggest that large fish are becoming scarcer in the Gulf. That in turn hints at a resource that is slowly declining under high fishing pressure.

This reduction in the number of larger fish seems, to me, to be the strongest available evidence that points towards a decline in the red grouper resource. It would be well for the data set to be examined very closely to see whether other explanations for the observed trend can be eliminated and a decline left as the only explanation.

2.5 Catch-at-Age

For some of their modelling, Schirripa *et al.* (1999) also needed the catches-at-age of the red grouper. There has never been a routine ageing program for this resource, however, and they were obliged to re-create the missing information from estimates of catches-at-length, built from the length data. The lengths were converted to ages using an estimated growth (or length-at-age) curve, which itself was based on both age readings from otoliths and on data on the change in length of tagged fish between the times of release and re-capture (Schirripa *et al.* 1999).

This process had obvious, but unavoidable, uncertainties, particularly concerning the precision of the growth curve and the possibility that true growth rates differ from place to place and year to year. Another uncertainty, which may be less obvious, is that

Schirripa *et al.*'s (1999) approach cannot allocate the fish caught to their correct age-classes if there is a succession of strong and weak year-classes in the data set. If, hypothetically, there was a large class of five year olds one year, with poor numbers at ages four and six, a substantial proportion of the fish caught at a size typical of Age 4 would in fact be slow-growing five year-old individuals, while the fast-growing ones of the same year-class would be the length typical of six year-olds and might exceed the numbers of fish that were actually Age 6. It is not obvious what effects this sort of error might have on the "ASAP Model" in which Schirripa *et al.* (1999) employed their catch-at-age estimates. Nor indeed is it known how variable, from year-to-year, the year-class strengths of red grouper are. Thus the magnitude of the problem remains unknown but it must clearly introduce considerable uncertainty into the assessment results¹¹.

Besides having to resort to such uncertain approaches for the lack of anything better, Schirripa *et al.* (1999) made one surprising, and perhaps erroneous, calculation with their catches-at-age. They wished to adjust their estimates to include those discards that did not survive, rather than simply the landed catch – a very necessary adjustment to make. To do so, they assumed that the "selectivities" (actually partial recruitments: a related but very different concept) were age-related rather than size-related, which is improbable but not unreasonable. That is to say, they assumed that the young fish became available to the fisheries as they grew older rather than as they grew larger, the difference between those two depending on the varied growth rates of individual fish. Schirripa *et al.* (1999) then used to Goodyear's (1997) model to estimate the proportion of the fish above the minimum size limit (and which were thus landed) that were of young ages – Goodyear's (1997) method being such that the total catch at a given length can be partitioned among various age-classes based on assumptions about the among-individuals variations in growth rates. From the assumed distribution of sizes at those young ages and the number of fish landed (all of which were above the legal minimum and so at the upper range of the distribution for their ages), they estimated the number of sub-legal ones that were caught and then discarded.

There are massive uncertainties involved in that process, which result from using a poorly-estimated growth curve (and unsupported assumptions about the among-individuals variability in that rate) for the estimation of large numbers from uncertain estimates of landings-at-age in the tail of distributions of lengths-at-age. The assumption

¹¹ Schirripa *et al.* (1999) used Goodyear's (1997) "probabilistic" method for assigning ages from the length data, rather than simply reading them from a length-at-age curve. Goodyear's (1997) method has the potential to correct for the effect of variable year-class strengths if information on past recruitments is introduced to the calculations. However, the necessary data are not available for red grouper and Schirripa *et al.* (1999), properly, made no attempt at such a correction. Goodyear's (1997) method does allow for intense fishing depleting older age-classes, which has the effect of making a higher proportion of the big fish caught fast-growing younger individuals (rather than slower-growing, older ones), though that correction does not take account of size-selective fishing within each year-class – another significant complication. Schirripa *et al.*'s (1999) text is not entirely clear but it seems that they did not use this capability either but instead set the fishing mortality rate to 0.2 throughout.

that the partial recruitments are age- rather than size-related is highly dubious also. However, beyond all of those uncertainties, Schirripa *et al.*'s (1999) approach violates its own assumption and thus is internally inconsistent. That is: If the partial recruitments ("selectivities") truly were age-related, then young fast-growing fish would not be caught and all of the 20 inch red grouper in the catches would be older, slower-growing fish or at least four year-olds of average growth rate, rather than a mix of ages (from two years upwards) as estimated by Goodyear's (1997) model and as used in Schirripa *et al.*'s (1999) calculations. It is simply not logical to use an assumption that the length compositions of the landed catches are a result of size-selective fishing but then to use those compositions to estimate the number of discards under an assumption that the fishing was age-selective, which is in effect what Schirripa *et al.* (1999) did.

This internal inconsistency in their work will (most likely but not certainly) have massively inflated their estimates of the numbers of young fish discarded. Indeed, for 1997, they estimated that the longline fleet discarded 537,432 red grouper while landing only 346,365 (Schirripa *et al.* 1999, Table 58), making the discards 60% by number of the catch – an extraordinary percentage. Experienced reef-fish longline captains report that their red grouper discard rate is variable, with time and place, but that the average is certain to be below 20% (Mr. R.Spaeth, Southern Offshore Fishing Association, personal communication), which seems much more likely. This provides one indication of the magnitude of the likely over-estimation provided by Schirripa *et al.*'s (1999) calculation.

For commercial vessels other than longliners, the equivalent estimates were 132,962 red grouper discarded and 256,879 landed in 1997, while the figures for the recreational fishery were 289,317 and 95,642 respectively (Schirripa *et al.* 1999, Table 58). Since Schirripa *et al.* (1999) assumed that the survival rates of released fish were 10% for longline-caught red grouper, 67% for those caught by other commercial gear and 90% for those caught recreationally¹², their method for estimating the number of discards, particularly that from the longline fishery, will (most probably) have had a very substantial effect on their estimates of the total losses to fishing mortality (landings plus non-surviving discards).

¹² Schirripa *et al.* (1999) quoted these survival rates (which they present as the converse, mortality rates) as proportions but I assume that they intended them as percentages rather than as instantaneous mortality rates. They supported their figures with a citation of Wilson and Burns (1996). I can find nothing in that paper which leads to the rates used by Schirripa *et al.* (1999), though Wilson and Burns (1996) did find that about 90% of red grouper caught in 44 m depth survived for a prolonged period following return to the water, whereas none caught at 75 m depth did so. The longline fishery is confined to areas deeper than 20 fathoms (37 m) and operates down to about 50 fathoms (90 m). However, the proportion of sub-legal fish in the catch is likely higher when fishing near the shallow limit. Thus, a 10% survival rate of discards from longlining may be a rather low estimate as an overall figure (leading to an over-estimate of the fishing mortality imposed by the longlines). Otherwise, Schirripa *et al.*'s (1999) chosen survival rates can perhaps be seen as reasonable assumptions, even though they do not seem to be directly based on field data.

As explained below, the ASAP model in which Schirripa *et al.* (1999) used their estimates of catches-at-age is impenetrable and it is not possible to say how large an effect this over-estimation of discards will have had on the final results of the assessment. Indeed, I cannot even say whether it will have biased those results upwards or downwards. I would, however, caution that this one questionable approach may have resulted in a very considerable distortion of the ASAP results.

3 Model Fisheries

3.1 ASPIC Model

3.1.1 The Model

Building on their compiled and assembled data sets, Schirripa *et al.* (1999) fitted two models of the red grouper fisheries. The first, termed “ASPIC”, was originally developed by Prager (1994). It is a general production model, meaning that the production of the red grouper resource is assumed to depend solely on its biomass at the time, rather than on the mix of ages (or sizes) of fish in the population. Such models have a long history, dating at least to the work of Graham (1935) and for a few fisheries they can be very useful. Their inadequacies for others are well known and well documented, however. Prager’s (1994) particular variant of the surplus-production family uses the straightforward “logistic function” first recommended for the purpose by Graham (1935) but allows for the calculation of (model) biomasses and catches year by year, both hindcasting and projecting into the future, rather than just the estimation of particular equilibrium points, such as MSY (as more conventional general production models do) – though those can be calculated also. The model’s outputs can be directly compared with observed data (as by comparing the model biomass with catch rates based on real data) and alternative starting values tried until a model is produced which gives the best match to the data. This approach to fitting Graham’s (1935) model has a number of advantages over the classic one developed by Schaeffer (1957), particularly in that multiple series of catch and effort data, from different fisheries for the same resource, can be used in fitting the model, as can fishery-independent measures of biomass. ASPIC also avoids a non-equilibrium problem that has long troubled the builders of surplus production models¹³, while providing the capability for projecting the future trajectory of resource re-building under various possible management measures.

What Prager’s (1994) model cannot do, nor can any other general-production model, is to take account of the year-to-year differences in production (after allowance for differences

¹³ Schaeffer (1957) worked with the short-lived tuna, in which the biomass of the resource may be affected by the amount of fishing this year but not directly by that in previous years. When his model was applied to long-lived species, it was necessary to compare the biomass in one year with some measure of the fishing effort exerted over a number of previous years equivalent to the exploited lifetimes of the fish being caught.

in the biomass) that result from the advent and subsequent disappearance of strong year-classes. When a resource is depleted and the incoming recruits thus comprise a substantial fraction of the total biomass, these inter-annual differences can be very considerable. It is this deficiency which often leads general production models to wildly erroneous results and Schirripa *et al.*'s (1999) application is as vulnerable to its effects as Schaeffer's (1957) was four decades ago.

Nor, without additional complications, can any general production model take account of factors affecting resource biomass other than fishing and the intrinsic rate of increase of the resource population. The model simply assumes that no other factors, such as environmental change, can have any effect and thus forces itself to match the data so that the recorded catches explain all of the estimated trends in the biomass, whether or not the resulting fit bears any resemblance to reality¹⁴. This is a particular problem for red grouper since it utilizes estuarine and other seagrass areas as a juvenile.

In fisheries stock assessment, it is all too obvious that short data sets lack sufficient information to provide reliable answers. What is slowly becoming clear as runs of high-quality data extend, however, is that common assumptions about environmental stability (with year-to-year changes represented as, at most, random variability) are not tenable over periods of decades. By compiling catch data back to 1940 and using it in their modelling, Schirripa *et al.* (1999) have encountered the effects on the red grouper resource of inter-decadal environmental change, which is well known to have been profound in the inshore and estuarine waters of the Gulf of Mexico during the last half-century. The urban development of estuaries, channelization of waterways and the extraction of water from drainage basins for human use will have materially altered the productivity of the red grouper nursery grounds, yet the effects of such changes are necessarily ascribed to fishing by Schirripa *et al.*'s (1999) use of Prager's (1994) model.

Offshore, the balance of predator/prey relationships and of competition between red grouper and a range of similar species is also likely to have been disturbed by the effects of fishing, by expanded "dead zones" driven by terrestrial run-off and indeed by the slow processes of global environmental change. Together, these trends since 1940 may have had substantial effects on red grouper. Yet all of these factors are assumed out of existence by general production models. It is, of course, always possible to force any model to fit a data set, as Schirripa *et al.* (1999) have done. However, conclusions drawn from such a fit are unlikely to provide a usefully-close representation of reality unless the model itself is appropriate to the situation.

¹⁴ Prager's (1994) model could, in fact, be modified quite easily to incorporate the effects of factors correlated to some environmental index (such as the rate of run-off in rivers emptying to the Gulf). Schirripa *et al.* (1999) made no such elaboration.

3.1.2 Model Application

Schirripa *et al.* (1999) fitted the ASPIC model using catch data from 1940 to 1997, with the longline catches (both U.S. and Cuban) being treated as coming from a separate fishery from all of the others, which were themselves lumped together. As measures of the abundance of the resource, they used, firstly, a combination of eight indices¹⁵ standardized by their means, and secondly a combination of Cuban longline catch rates, U.S. longline catches-per-vessel and U.S. longline catch rates from logbook data similarly standardized. It is not clear how Schirripa *et al.* (1999) standardized the various indices in each group using their means when the various data sets spanned different years (sometimes non-overlapping ones) and thus should have had different mean values after standardization.

When fitting the ASPIC model, or any similar one, to such data, the output values will be primarily controlled by contrasts in the data – long runs of years with steady catches and catch rates do not provide much information for the statistical calculations to follow in finding the best fit. Since the major cycles in both red grouper catches and catch rates were caused by variations in the recorded Cuban catches in the years before 1977, Schirripa *et al.*'s (1999) fit is, to a considerable degree, determined by the Cuban data. Thus, besides all of its other assumptions, this model (as applied) assumes the validity of fishery statistics compiled by the Batista and Castro regimes – an assumption that, I suggest, few in the United States would be willing to make if stated as such.

From their fit of the ASPIC model, Schirripa *et al.* (1999) concluded that the red grouper biomass in 1997 was about 20% of that which would support MSY while the fishing mortality rate in 1997 was slightly over twice F_{MSY} . According to the model, fishing mortality had reached a similar level by 1957 and has fluctuated widely but without any long-term trend ever since. Biomasses are modelled to have dropped below one half of B_{MSY} by 1960 and to have declined slowly and irregularly ever since. Thus, the model suggests that Gulf red grouper have been overfished more or less steadily for forty years – a rather surprising but not impossible contention. Schirripa *et al.* (1999) ran projections with this model, estimating that the resource might reach B_{MSY} in approximately ten years if all directed fishing for red grouper ceased and if the deaths of released fish could be kept sufficiently low.

Considering the erroneous assumptions built into this model and its heavy reliance on highly-suspect data, I would recommend that its conclusions be set aside, as indeed the RFSAP decided to do – though that Panel proceeded to draw some support for its own final conclusions from Schirripa *et al.*'s (1999) ASPIC fit. Prager's (1994) ASPIC may have its virtues in the assessment of other fishery resources but, in my judgement, it is not a suitable model to use with red grouper.

¹⁵ Cuban handline catch rate, U.S. handline catch-per-vessel, U.S. logbook catch rates for handline and trap gear, three fishery-independent indices and the MRFSS catch rate, including discards.

3.2 ASAP Model

3.2.1 The Model

Schirripa *et al.* (1999) also fitted a model named “ASAP”, very recently developed by Legault and Restrepo (1999), to two data sets. ASAP involves a different conceptual approach to fisheries assessment from the familiar ones developed in the 1950s through to the 1970s and relies on modern computational power for calculations that were unthinkable in even the recent past. This new approach involves constructing a simulation model of the fishery, comparing its output with the available field data, then amending the starting values of the simulation and continuing until the values which gives the best fit to the data are found¹⁶. (To that extent, ASAP is similar to ASPIC.)

The ASAP model was first presented last year (see Legault and Restrepo 1999) and then only briefly. It can certainly be regarded as “state-of-the-art”, though whether that is a desirable characteristic in an assessment model is another matter: It took many years before the defects in Schaeffer’s (1957) surplus production model were fully understood and just as long for the weaknesses of Sequential Population Analyses to be properly considered. ASAP may likewise have problems that are not yet known to those using it.

ASAP considers the various age-classes in the resource population separately (in contrast to ASPIC), while also allowing for multiple “fleets” fishing for the same resource. The number of fish entering each year-class, as recruits, is derived from the modelled biomass of spawners through a stock/recruit model. Once recruited, the number decreases each year through the combined effects of fishing- and natural mortality, following the conventional equations used by fisheries dynamicists. The fishing mortality rate applied is a sum of those caused by the various fleets and, for each fleet and each age-class, is a multiple of (effectively) the fleet’s fishing effort in a given year with a form of partial recruitment (called “selectivity” by Legault and Restrepo and modelled in a non-conventional way) which has different values for fish of different ages. From the numbers, fishing mortality rates and the weights-at-age of the fish, the annual catches by each fleet can be straightforwardly calculated. All of this allows the simple production of an internally-consistent simulated fishery.

In order to fit the simulation to data, the computer must estimate (besides a set of values representing the starting population): the fishing efforts by each fleet each year, the “selectivities” by fleet and fish age-class, a “catchability” coefficient relating the model biomass to each abundance index in the data, and the parameters of the stock/recruitment

¹⁶ I am not competent to judge whether or not Schirripa *et al.* (1999) correctly formulated their likelihood functions (which are critical to the process of fitting the model to data). I assume that that aspect of their work was fully valid.

model used (Legault and Restrepo 1999)¹⁷. The computer seeks that combination of values of all of these parameters which, together, make the model fit the data most closely.

The basic mathematics of this model are straightforward and unobjectionable, though it does make many of the assumptions common to most fishery-dynamic models (such as the resource population being homogeneous and not made up of a series of semi-discrete local populations). More seriously, like ASPIC, it supposes that increases and reductions in resource biomass result only from the intrinsic characteristics of the population and/or the effects of fishing. The model can make no allowance for trends in the environment affecting either recruitment, growth or the rate of natural mortality – a potentially-fatal flaw. In particular, the supposition that the number of recruits each year is directly determined by the spawning biomass, through a simple curve relating the two quantities, flies in the face of several decades of solid experience showing the high degree of environmentally-controlled year-to-year variation in year-class strengths¹⁸.

3.2.2 Simulation Models and Uncertainty

My major concern, however, does not relate directly to specific deficiencies in the model or the data to which it is fitted but rather to the manner of that fitting and the potentially misleading appearance of accuracy that it carries. That Schirripa *et al.*'s (1999) application of the ASAP model produces an interesting and internally-consistent simulation of a grouper fishery is beyond doubt. Whether that simulated fishery bears more than a passing resemblance to the real red grouper fishery of the Gulf of Mexico is another matter entirely. Yet the model is so advanced, so complex and capable of generating such reams of output that it becomes impenetrable. Unless he has the full model and data sets on a computer where he can experiment with them, even an experienced assessment scientist is unable to judge which parts of the output may be unreliable or how they might be affected by various imperfections in the data. That makes ASAP a very dangerous thing to release into the fisheries-management arena.

In fitting complex models to data, it is always important to remember that any model can fit (almost) any data set, though some may fit very badly. If the models are complex and the number of data points are few, even bizarre models can fit very well indeed. It is, for example, always possible to draw a perfect circle through any three points but that does not mean that the circle has any relevance to the locations of the points in question.

¹⁷ Legault and Restrepo's (1999) brief paper is not entirely clear but it seems that their model actually estimates more parameters than this. The catchabilities, for example, seem variable (rather than fixed), though it is not clear how that is possible without over-parameterizing the model.

¹⁸ Legault and Restrepo's (1999) trial application of their model, to bluefin tuna, produced estimates of recruitment that did not follow a simple stock/recruit curve and were, in any case, discussed in terms of model outputs rather than input parameters. It is not clear in their paper how their model could produce such estimates, though that is doubtless a defect of the presentation, not the model.

Likewise, models containing a hundred unknown “parameters” (to be selected by the computer in an effort to match the data) can usually be forced to fit exactly through several dozen data points – a condition known as being “over-parameterized”. Sufficiently complex models, in which the values of some parameters are constrained by the values of others, may not fit perfectly to even small data sets. However, the general principle still applies: Simply by adjusting the parameter values, a model with well over 1,000 parameters, such as Schirripa *et al.*’s (1999) ASAP, can be fitted reasonably well to any data set with the 1,500 or so observations¹⁹ that they used, whether or not the structure of the model has any relevance to the system from which the data were drawn. The inevitability of a good fit prevents the suitability of the model from being judged by its agreement with the field data. The good fit does not, however, make conclusions drawn from the fitted model in any way relevant to the real system being modelled.

Such complex models also cannot be fitted directly by statistical calculations that determine the parameter values which would give the best agreement. Rather, they must be fitted by an iterative process in which the model is run, its deviation from a perfect fit is calculated, a new set of parameter values are selected that will give a better fit and the model is run again. That process is continued until no further improvement in the fit can be found. There are a number of computer algorithms which can efficiently undertake this process by judging how to change the parameters at each step in order to move the solution rapidly towards the best fit, which is to say the least achievable deviations from the data. The whole system resembles an attempt to get to the bottom of a valley, in which greater height represents a greater deviation of the model from the data, by always facing down hill and jumping forward (Figure D).

One problem with this approach is that many complex models do not yield the sort of simple “hill” shown in Figure D but rather an intricate surface (Figure E). In such cases, the computer will often find a solution which comes to rest in a minor “valley” (technically known as a “local minimum”), with very different parameter values from those of the best fit. The approved method for avoiding such problems is to re-run the simulation with very different starting values, in the hope that at least one route down from the “hills” will lead the computer into the deepest “valley”. Schirripa *et al.* (1999) did not indicate that they had done anything of the sort but the rather-similar fits that they obtained in six different ASAP runs (see below) suggest that their models did not get lost in any local minima.

Surfaces analogous to that in Figure E introduce a further complication, however. Once a model has been fitted to data, straightforward concepts of the precision of the fit would be based on the “shape” of the “valley” that the computer finds. A steep, V-shaped hollow would mean that small changes in the parameter values would considerably increase the discrepancies between the model and the data. Thus, only a narrow range of

¹⁹ Including input values calculated from raw observations.

values would give a good fit and that fit would be judged to be precise. (A wider, flatter “valley” would give a less precise estimate of the ideal parameter values.) Yet, in Figure E, there are a number of “valleys” located at widely different parameter values, the bottoms of which are at about equal heights – making them equally probable. Thus, while one might find a single “best” fit of such a model and that fit might appear quite precise, there could be a considerable number of other possible, and almost equally probable, fits with very different parameter values. Short of running the ASAP model for a wide range of values of each of its 1,000 parameters and mapping the resulting probabilities, it is impossible to know whether there are potential fits, far different from the “best” ones reported by Schirripa *et al.* (1999), that are close enough in probability to be considered as within the range that should be considered by the Council.

Furthermore, the process of fitting the model assumes that the data is a reliable reflection of reality, perhaps with some random variation thrown in. The computer fits the model to the data – not to the real world. Yet, as has been stressed above, the available data on red grouper are anything but reliable and several of the inputs to Schirripa *et al.*'s (1999) ASAP had to be constructed as much on assumptions as on the fallible field data itself. Thus, there is another level of complication under which the probability surface (here represented diagrammatically as Figures D or E) would shift and change if other assumptions or corrections were applied to the data before the model was fit. Yet further change would be expected if the model was given additional terms to represent environmental trends over the past decades. Thus, the complete range of parameter values yielding reasonably-probable fits to one or more plausible sets of inputs could be expected to be very wide indeed.

In summary, Schirripa *et al.* (1999) fitted the ASAP model and produced one plausible set of parameters which constituted the “best fit” to the input data which they provided. (They actually made six runs and produced six sets of parameters: see below.) For lack of any alternative, the conclusions drawn from the model when run with those parameters can be considered the “best available scientific” picture of the current status of the red grouper resource. However, they did not place any confidence limits or bounds of uncertainty around their best estimate, as scientific advice requires. The width of the real confidence limits cannot be determined without very extensive computations, repeatedly running the model with a range of plausible data inputs. However, for all of the reasons discussed above, it seems likely that that range would be very wide indeed. Used in the calculation of ABCs, it might very well yield values ranging from zero to greater than the highest red grouper catches yet seen in the Gulf of Mexico²⁰.

²⁰ Legault and Restrepo's (1999) trial application of their ASAP model to bluefin tuna data did include a number of alternative fits using different assumptions about input data. The outputs showed fishing-mortality-at-age changing in apparently-meaningless ways, while the pattern of purse seine “selectivities” reversed for no obvious reason. These are examples of the sorts of instabilities that fits of such models can produce.

3.2.3 Model Application

Schirripa *et al.* (1999) made a total of six fits of the ASAP model, one using data from 1940–1997 and the other five only from 1986–1997. For the whole of the latter period, recorded grouper catches were separated by species while catch-at-length data were available for all sectors of the fishery and thus the level of uncertainty in the data was somewhat reduced. The model as used was slightly modified from that outlined by Legault and Restrepo (1999) in that it incorporated estimated discards, as well as data on the landed catch (though the discard information was derived from the flawed process discussed above). The “selectivities” for most age-classes were fixed, with only those for ages up to ten years being estimated by the model. The annual recruitments were derived as deviations from a stock/recruitment curve²¹. The fishery was modelled as having three fleets: longline, other commercial and recreational. The catches and (where available) catches-at-age were used as input. All of the available catch-rate and fishery-independent indices of biomass were used to test the quality of the model’s fits. The rate of natural mortality was set at 0.2 throughout (Schirripa *et al.* 1999), which is rather low for a species not normally expected to reach the age of 30. No attempt was made to extend the model to take into account the effects of long-term environmental change.

When this model was fitted to the long data series, the stock/recruitment curve was determined by the mathematics. There was not enough range in modelled biomasses to do that with the short data series, however, and thus the model was fit to the 1986–1997 data set five times using different fixed values of the key parameter of such a curve – the true value presumably lying within the range tried (Schirripa *et al.* 1999).

All of the ASAP fits showed sharply increasing fishing mortality rates in recent years, the long data series producing an estimate of 1997 “F” of nearly 0.9, whereas the five fits to the 1986–1997 data led to values of about half that. All fits also showed declining spawning biomass in recent years, a pattern that closely follows some of the recent biomass indices but conflicts with others. The 1997 fishing mortality rate was estimated by the six fits to be between 1.38 and 3.21 times F_{MSY} , while the spawning biomass that year was estimated at 19% to 60% of SS_{MSY} . Projections calculated on an assumption that

²¹ How this was done is not clear from either Schirripa *et al.*’s (1999) account or Legault and Restrepo’s (1999) explanation of their model. Restrepo and Legault (1998) did, however, outline a procedure embedded in a similar model which they may have carried forward to ASAP without explicitly stating that that was done. In their earlier work, they recognized that the model would be over-parameterized if it was allowed to find a separate and independent value of recruitment for each year and thus they constrained it to following a particular stock/recruitment curve plus or minus a lognormally-distributed deviation. That approach seems well suited to building theoretical models of fish populations but its relevance to time series of data from real populations (which are subject to specific recruitment strengths in particular years, not to ones chosen by a random-number generator) is difficult to understand. In stock assessment applications, age-structured models must either be given input estimates of annual recruitments (data for which are not available in the case of red grouper) or else the models must estimate such recruitments. The latter will often lead to over-parameterization, as Restrepo and Legault (1998) noted. It is not clear to me how, or whether, the ASAP model as applied by Schirripa *et al.* (1999) avoids these pitfalls.

fishing mortality was reduced to zero effective from 2000 showed recovery to the MSY target in as short as two years by one fit, within eight years by most of the fits but not until 2013 and 2022 by the two most pessimistic. Under current legislated standards, management plans must rebuild the resource by 2009 if possible but otherwise (as for the two most pessimistic fits) by one generation time after they could be rebuilt under zero fishing; the operative dates being 2022 and 2031 respectively. Schirripa *et al.* (1999) estimated that rebuilding within these target dates could be achieved while taking constant annual catches of 1.30 to 4.70 million pounds per year, depending on the fit in question.

It should be noted that the biomass and fishing-mortality targets used in these projections were themselves calculated from the model results. They are as subject to uncertainty as are the estimates of the current status of the resource, while there is no guarantee that any errors will cancel (such that B/B_{MSY} and F/F_{MSY} would be correct even if B and F are not).

Of this complex of fits and results, the RFSAP opted to use only the fit to the long data set, apparently because it allowed the estimation of a stock/recruitment curve. The Panel's report does not indicate whether its members considered the relative benefits of estimating such a curve from a model known to be erroneous (from its use of dubious historical data and its assumption that there had been no significant environmental change in the past half-century) *versus* not estimating one at all. Their decision fixed the estimate of the 1997 Fishing Mortality rate at more than three times the F_{MSY} target, while the 1997 biomass was estimated at 26% of that which would support MSY – the conclusions that Schirripa *et al.* (1999) had derived from their fit to the 1940–1997 data set.

The Panel then generated a selection of recommended harvest levels for the rebuilding period, depending on whether the legislated requirement should be interpreted as requiring rebuilding in ten years or allowing an extension by one generation time to 2018. However, where Schirripa *et al.* (1999) had calculated that rebuilding could be achieved by 2010 under a constant catch of 1.30 million pounds per year (assuming the fit to the long data set preferred by the RFSAP), the Panel opted for “0 to 1.5 million” and “0 to 1.6 million” pounds – its report text and its summary conflicting with one another. Stretching to 2018 would, in the Panel's judgement, require a constant catch of “0 to 3.5 million pounds”. The source of these estimates is not stated, though it is likely that they represent an attempt to express the uncertainty in Schirripa *et al.*'s (1999) assessment plus an implicit recommendation to set the ABC below the “best estimate” produced by the ASAP model.

The RFSAP also strongly recommended a strategy of fishing at a constant fishing mortality rate of $F = 0.1069$ for rebuilding by 2010 or $F = 0.2275$ for rebuilding by 2018. These rates would imply catches in 2000 of 0.7 and 1.5 million pounds respectively, if the preferred ASAP fit were followed. Curiously, however, the Panel did not recommend either figure but instead suggested a catch range of zero to 1.5 million pounds. Once

again, its report gives no indication of why a zero catch might be necessary and it can only be supposed that that was intended as a precautionary and conservative approach to the “best estimate”.

4 Discussion and Conclusions

4.1 The Scientific Advice

A number of conclusions can be drawn from the above discussion. One is that, whatever its flaws (such as with the estimation of the number of discards, the assumption that there has been no significant long-term trend in the environment and the use of some highly-dubious data sets), Schirripa *et al.*'s (1999) assessment, as modified by the RFSAP, provides the best currently-available estimate of the state of the red grouper resource in the Gulf of Mexico. By that best estimate, the resource could rebuild to the legislated targets within the required period while subject to a constant catch in the range of 1.0 to 3.5 million pounds per year or else under a constant fishing mortality rate of either 0.11 or 0.23, depending on interpretations of the required duration of the recovery phase. A number of modifications or developments of Schirripa *et al.*'s (1999) approach might usefully be attempted before management actions are implemented in response to it. Those aside, however, nothing in this document should be interpreted as disputing that their figures represent the current “best available science” on the status of red grouper.

What is argued here is that a wide range of equally-good, or near equally-good, estimates of resource status could be developed by using alternative assumptions when compiling the data or by introducing other factors, such as long-term environmental change, to the models. Thus, Schirripa *et al.*'s (1999) numbers should not be seen as precise estimates but rather as points within a very wide range of near-equally probable estimates. Nor should the more probable of those different estimates be seen as being clustered close to the best estimate. Rather, I would suggest that possible answers both near to Schirripa *et al.*'s (1999) and far from it are almost equally likely²².

Although it has not explained its logic in its report, the RFSAP seems to have drawn a similar conclusion. At least, in addition to reporting Schirripa *et al.*'s (1999) results (or modifications of them to suit a different perspective on the required rebuilding time and/or a constant-effort rebuilding strategy), the Panel also recommended ranges of possible ABCs which extended from the calculated values downwards to zero. They thus implied that the uncertainties around the best estimates are very wide.

²² In statistical terms, I am arguing that the probability density function of possible outcomes approximates to a multi-dimensional analogue of the Cauchy distribution, rather than of the familiar Gaussian distribution.

With the greatest respect to the members of the Panel, however, their particular advice confounded their proper role, scientific review, with that of the Reef Fish Committee, which is responsible for formulating management advice. Speaking scientifically, the best estimate of resource status (as developed by Schirripa *et al.*) cannot also be an upper bound on the range of probable values. Rather, the best estimate must lie somewhere towards the centre of the range. Indeed, where stock assessment results are concerned, ABCs cannot be less than zero. That unavoidable truncation at the lower end can mean that the upper bound of probable values lies further from the best estimate than the lower one can (see Figure F). Moreover, it often seems that stock-assessment results have highly skewed confidence intervals, such that if the “worst case” result is one third the best estimate then the most optimistic, probable outcome is three times the best estimate. Either or both of these factors may be important in a particular case but, together or separately, they usually result in a pronounced asymmetry in the range of results that should be considered by fisheries managers, with the upper bound lying further above the best estimate than the lower lies below it.

The RFSAP’s contrary recommendation that management limits be set exclusively below Schirripa *et al.*’s (1999) best estimate thus cannot be a strictly scientific conclusion. Rather, it appears to be a laudable, if misplaced, attempt to “err on the side of conservation”. If so, it involved a dangerous confusion of the different roles, within the fisheries-management process, of the scientific-review and decision-making committees²³. This aspect of the RFSAP’s advice should, therefore, be set aside.

Since the RFSAP recommended an ABC for Year 2000 of between 1.5 and 3.5 million pounds as its best estimate, while setting a lower bound at zero, the proper scientific advice would have also stated an upper bound at least as high above the best estimate as zero is below it and probably a good deal higher. Thus, I would argue that the best scientific advice available to the Council is to be found by combining Schirripa *et al.*’s (1999) numerical conclusions (as modified and interpreted by the RFSAP) with a confidence interval extrapolated from the Panel’s advice. If the Council should aim to rebuild the red grouper resource with a target date of 2018, as suggested by the RFSAP, the appropriate constant-catch ABC might then be stated as 3.5 million pounds, plus or minus at least 3.5 million pounds. Perhaps more usefully, the ABC could be stated as lying somewhere between zero and at least 7 million pounds²⁴.

²³ In the *Technical Guidance on the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act*, Restrepo *et al.* (1998, p.11) specifically cautioned scientists against adding non-transparent conservatism into their estimations, using as an example of what should not be done a case of confusing best estimates with precautionary ones similar to the RFSAP’s apparent action. Both Pearse and Walters (1992, p.171) and Francis and Shotton (1997, pp. 1711f) have made equivalent recommendations, though without the particular relevance to Councils operating under the MSFCMA.

²⁴ As is usually seen with the very wide confidence intervals surrounding scientific estimates of resource status, more precise estimates of the ABC may well be found by combining the calculated values with other indications, drawn from fishermen’s knowledge or management experience.

It should be clearly understood that, whether the “true” ABC is ten million pounds or zero, the red grouper resource is not in any imminent danger of collapse – even if a “collapse” is a potential outcome for a grouper population. Much of the available evidence suggests that this resource has been stable through the 1990s, the few pointers to on-going, slow declines being balanced by alternative indices suggesting increases, perhaps as a slow response to the minimum size limit increase in 1990. Schirripa *et al.*'s (1999) models did show continuing declines but, even if those are not simply dismissed as artifacts of questionable data, the suggested downward trend is slow.

Thus, any appearance that the red grouper resource has slid into an overfished condition since it was last assessed, in 1995, is erroneous. Rather, the change in its nominal status is very largely an artifact of Congressional decisions: The Sustainable Fisheries Act pushed the red grouper into an overfished condition by changing the criteria for “overfishing”, while Schirripa *et al.*'s (1999) results suggest that the resource has actually been in its current “overfished” state (as that is now defined) for some decades²⁵. Its apparently dire condition, supposedly requiring near or total closure of the fishery in order to meet the legislated rebuilding target, is nothing more than a side effect of the short period (relative to the species' generation time) allowed for that rebuilding. Thus, whatever action the Council might take and whenever that might come into effect, the red grouper is not on the verge of disaster. Drastic, emergency actions are not required.

4.2 Optimal Management in the Face of Uncertainty

The primary question now confronting the Council is what management measures should be adopted in response to the RFSAP's, necessarily uncertain, scientific advice. In doing so, it faces a new challenge that has rarely been handled, in any explicit manner, by any fisheries managers. It is a problem compounded of limited fish resources, strict legislated requirements, scientific uncertainty and the economic realities of the fishing industry.

Although it is often discussed in terms of “biological” targets or optimal management of fish resources, fisheries management (as distinct from nature conservation in aquatic ecosystems) is really a process of maximizing human benefits, however those may be defined, subject to the constraints of biological sustainability. Thus, it is a task requiring the Council to find a bio-economic, or perhaps bio-socio-economic, optimum. The SFA introduced an extra difficulty into that task by setting explicit targets for rebuilding fisheries resources but did not explicitly state an equivalent target for either the fishing fleets or the broader seafood industry. Thus, too a literal reading of the current revision of

²⁵ Another source of the new “overfished” designation is the change in assessment approaches used by Schirripa *et al.* (1999). Even if those were seen as improvements that raised accuracy over the methods previously used, which I could not unreservedly do, they would only show a continuing condition of overfishing, not a decline into that state from a more desirable one a few years earlier.

the MSFMCA could lead to the red grouper being rebuilt by 2018, when it would be capable of sustainably supporting the OSY, but to there being by that date no grouper fishery capable of taking such a catch. That, however, was clearly not the intention of the Act, as shown by its stated purposes, and the Council must balance the required rebuilding with measures to ensure that the abundant grouper of the future are matched by a fishery of appropriate size.

Maintaining such a fishery through the next decade may not be trivial, in light of the RFSAP's recommendation that the ABC be set at very low levels. It is common in theoretical studies to assume that the cost of down-sizing a fishery is proportional to the reduction in the catch. That is clearly untrue for individual fishermen and fishing companies, who see a percentage reduction in their net earnings far larger than that in their gross turnover and who must also bear a social cost over and above immediate economic losses. However, when taken to extremes, the assumption of simple proportionality between catch reductions and costs will also fail for entire sectors of the fishing industry and hence for the coastal communities of which they are parts. That is to say, if downsizing cuts deeply enough, it can terminate the industry sectors that were dependent on the resources in question.

Such a *de facto* closure does not only involve short-term social and economic costs. If the objective is to reach 2018 with both grouper and a grouper fishery capable of producing OSY, then shutting the industry down in the meanwhile would involve major re-activation costs. It would not take many years of a closure, or near closure, for the fleet to be dispersed, wharves and waterfront areas turned over to recreational uses, markets lost to foreign imports and the experienced workforce scattered. Restoring all of those, if it could be done at all, would be massively expensive. Were a closure required to prevent imminent disaster to the resource, that future expense would simply have to be accepted. It would, however, be grievously sub-optimal to impose such costs on the regional economy in pursuit of one interpretation of the legally-mandated rebuilding targets for a resource that is not in such danger and, indeed, may already be increasing.

Before the SFA was passed in 1996, it is unlikely that any fisheries managers, anywhere in the world, had to face this dilemma. It would, perhaps, have been better if that had been done but in practice no government attempted to squeeze a fishery to the point of failure in order to rebuild resources that were already stable. Thus, the Gulf Council and the other Councils are facing this new challenge with little or no past experience, nor even theoretical studies, to offer guidance on how to proceed.

4.2.1 Standards of Proof

There is nothing new about making decisions in the face of uncertainty, which everyone does daily in one context or another. When the decision is a matter of public policy or the consequences are important, however, the choices are best guided by established

standards of how to act when the outcomes cannot be fully predicted – standards which must be adapted to the issue at hand: criminal law requires that a verdict be found beyond a reasonable doubt, whereas cases under civil law are often decided by a simple balance of probabilities. In a different context, medical practitioners are generally called upon to do no harm, even if that harm could lead to benefits which more than balanced it. In the case of fisheries management, no equivalent standards have yet clearly emerged. For some decades, the problem was avoided by simply ignoring the uncertainty – scientists reported their best estimates and managers used those as though they were accurate. The error in that approach has been known since the 1970s (e.g. Doubleday 1976) and efforts have been made, particularly in the 1990s, to develop something better, though with limited success.

One proposal has been to apply the Precautionary Principle, in its strict sense as originally developed for uncertainties surrounding the effects on human health of toxic chemicals. This Principle requires, partly in the name of inter-generational equity, that action be taken when there is a risk of severe and irreversible damage even in the absence of full scientific proof that such damage would occur, while the burden of proof is reversed and laid on those who contend that there would be no impact. As Garcia (1995) has argued, however, the Precautionary Principle in that strict sense is not applicable to most questions facing fisheries managers since fisheries typically have only measured and reversible impacts on marine ecosystems. For that reason, the Principle has been rejected by most nations as a basis for fisheries management and is not incorporated into any relevant international agreements²⁶.

What has now been adopted in a number of cases is the milder Precautionary Approach. While not all commentators distinguish between the two, the Approach differs from the Principle in a number of essentials, not least that the former requires explicit consideration of the social and economic implications of decisions made on uncertain evidence in order to ensure (a) that they do not put undue strain on present generations, and the fishing sector specifically, by shifting the balance too strongly towards non-fishery uses and the interests of future generations and (b) that necessary short-term costs to the fishery are mitigated and equitably shared (Garcia 1995, p.9). The United Nations Conference on Environment and Development (UNCED, Rio de Janeiro, 1992) thus spoke only of not using scientific uncertainty to delay “cost-effective” measures to address serious or irreversible damage. An alternative wording, more directly applicable to fisheries issues, was provided by the U.N.’s *Straddling Stocks Agreement*. Article 7(2) of that document calls on States to be “more cautious when information is uncertain. The

²⁶ The Precautionary Principle seems, nevertheless, to be supported by some interest groups. Indeed, some would apparently wish that catches be limited low enough as reduce to zero the chance of exceeding the unknown best level – a requirement which, if applied, would require that nearly all of the world’s fisheries be closed. Such a standard, while appropriate to human health under the medical principle of “do no harm”, has little relevance to the practice of fisheries management in the face of uncertainty.

absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures.”

When attempts have been made to turn these brief definitions into working guidelines for international application (e.g. FAO 1995), most of what passes for a “precautionary approach” is nothing more than what, in the United States, would be seen as normal management measures. More specific references to recommended actions in response to uncertainty include the recognition that:

- a. all fishing activities have environmental impacts, and it is not appropriate to assume that these are negligible until proven otherwise;
- b. although the precautionary approach to fisheries may require cessation of fishing activities that have potentially serious adverse impacts, it does not imply that no fishing can take place until all potential impacts have been assessed and found to be negligible;
- c. [...]
- d. the standard of proof to be used in decisions regarding authorization of fishing activities should be commensurate with the potential risk to the resource, while also taking into account the expected benefits of the activities (FAO 1995, pp. 4-5).

Thus, in its application to fisheries management, the Precautionary Approach is taken to mean something more than simply managing on the basis of the best available scientific estimates of the optimal yield but also something less than the presumption (until proven otherwise) that each fishery should be cut back to levels below those best estimates. Its exact import varies depending on the circumstances of particular fisheries and requires consideration of the benefits from the fishing, along with risks to the fish resources.

These foreign definitions and guidelines may provide useful guidance to the Council but they are clearly not binding. Nor, in legal terms²⁷, are the *National Standards Guidelines* which provide the only explicit direction to the Councils to adopt the precautionary approach – there being no mention of such an idea in the MSFMCA itself. Those *Guidelines* call for the approach to be applied when specifying Optimum Yield (OY) for

²⁷ *Magnuson-Stevens Fishery Conservation and Management Act* as amended through October 11, 1996, Sec.301 National Standards for Fishery 16 U.S.C. 1851 (b) “GUIDELINES. The Secretary shall establish guidelines (which shall not have the force and effect of law), based on the national standards, to assist in the development of fishery management plans.”

a particular fishery²⁸, and direct that the “precautionary approach”, in that context, means setting OY safely below the relevant limit reference point. By Schirripa *et al.*'s (1999) best estimate, however, the red grouper resource is currently ten years or more away from reaching OY (however conservatively that might reasonably be defined) and the *National Standards Guidelines* give little guidance on how the Council should address uncertainty in the interim. Section 600.310(f)(5)(ii) does suggest that a stock which is depressed below the level that would support MSY should be fished at a lower fishing mortality rate than if it were above that target level but that suggestion, while in fact the reverse of the technically-correct advice, is also not applicable to the red grouper situation in which all of the suggested alternatives assume a low fishing mortality rate that will permit rather rapid rebuilding.

Although they give no more specific advice applicable to the red grouper situation, the *Guidelines* appear to be approaching, without quite explicitly stating, the notion that the Councils should not select management measures that would be optimal if the best available scientific advice was strictly accurate but rather ones that are optimal given that the advice is uncertain – which has been good advice to fisheries managers for at least two decades now.

The accompanying *Technical Guidance* document (Restrepo *et al.* 1998) is no more forthcoming. It makes no mention whatever of the particular situation of the red grouper fishery, with its presumed requirement to severely cut catches in order to rebuild the resource from a stable, if depressed, state. Indeed, the authors of the document made clear that its content was “provided essentially for those aspects of scientific fishery management that have biological underpinnings” (Restrepo *et al.* 1998, p. 1). In practice, that seems to have meant that they approached the bio-socio-economic optimization problem, which is central to management in the face of uncertainty, by using an advanced understanding of resource dynamics coupled to extremely simplistic (and unstated) assumptions of the costs and benefits to mankind of both fishing and conservation. The result is guidance which consistently errs towards the only truly-biological optimum, zero fishing, without regard to the real objectives of fisheries management.

4.2.2 Management Theory

If official definitions and guidelines provide little useful advice for the immediate management of the red grouper fishery, existing theory is no better. Both population dynamicists and fisheries economists studying management in the face of uncertainty have concentrated on long-term optima (rather than the routes by which such levels should be approached) or else on the major management problems faced in the past (such as newly-developing fisheries or those with rapidly-declining resources) rather than the

²⁸ *Magnuson-Stevens Act Provisions – National Standard Guidelines – Final Rule*, 50 CFR Part 600.310(f)(5).

unique challenges posed by the SFA's rebuilding criteria. There has also been a tendency to look at situations with rather limited uncertainty, rather than the massive doubts which surround the ABC estimates for red grouper (and most of the world's other fisheries resources).

Many studies have nevertheless been undertaken over the last quarter century, producing conclusions that both pre-date and go far beyond the crude notions of "precaution" that were introduced to the fisheries-management world from environmental arenas during the 1990s. One of the first lessons from this research (e.g. Doubleday 1976) was that fisheries systems have asymmetry of risk as a result of both the population dynamics of the fish and the non-malleability of fisheries capital and labour. The costs of recovering from an overfished state exceed the losses involved in keeping a fishery smaller than it could be and thus optimal management involves setting OY at a level below, and B_{OY} at a level above, the best estimates of MSY and B_{MSY} for the resource in question. Numerous econometric studies have made elaborate examinations of this general point and, for most situations, they confirm the common-sense view that management should "err on the side of conservation", setting allowable catches safely below the best estimates of their maximum-sustainable value.

This optimal response does not extend to seeking to avoid almost all risk: Holding a fishery below the maximum that could be achieved has a cost in terms of lost opportunities for economic activity. Some of that cost is balanced by the higher catch rates expected with the elevated biomasses which result from low catches. More can be seen as a price paid to reduce pressure on non-resource components of the ecosystem. The remainder, however, is the cost to the national economy of avoiding the risk of overfishing. Optimal management requires that a reasonable balance be drawn between that cost and that risk – not that huge costs (in terms of forgone catch) should be paid in order to reduce the risk to inconsequential levels.

These concepts are clearly applicable when a long-term OY is being determined. The human side of the fishery needs to be brought into balance with the resources and that balance should be a precautionary one. They also define the optimum approach in situations where new fisheries are expanding towards OSY and should be kept small until more information is gathered, rather than allowed to grow past the true OSY such that they need to be downsized. Furthermore, these ideas provide the right approach to use when there is evidence that a fishery resource is declining quickly and is at risk of severe depletion, with failure of the fishery that depends on it. In that setting, prompt action to cut the catch below the limit that the resource can support, with some substantial safety margin, is certainly needed. Otherwise the rising costs of probable future resource rebuilding would rapidly out-strip the immediate costs of possibly-unnecessary down-sizing.

The current situation for the red grouper, as with many other U.S. fisheries in the wake of the SFA, is quite different, however. It is one in which an over-expanded but stable fishery must be reduced or, perhaps more accurately, in which a possibly over-expanded but apparently-stable fishery may need to be reduced. The uncertainty relates to how far the current catch, or the current fishing effort, needs to be cut in order to reach OSY within an acceptable time – with the ever-present possibility that no cut is necessary. This situation has not drawn much (if any) attention from econometricians but the broad outline of the optimal path can be deduced without a requirement for their complex models.

In general summary, if a fishery is thought to be too large but nobody can be sure by how much it is too large, the most cautious strategy is to prevent its further expansion, maybe limit its catches to a little less than they have been but not to cut it back substantially until further information is available. That approach causes the fishery to carry excessive risk of overfishing relative to the costs of forgone catch (as in the above explanation). However, the social and economic costs of down-sizing a fishery are so great that cutting one by more than is known to be necessary are almost never acceptable. Indeed, as already noted, those very great social and economic costs account for much of the asymmetry of risk in setting OSY and thus drive the need for precautionary approaches in fisheries management. Once an over-expanded fishery exists, part of the asymmetry reverses, placing a great cost on any under-estimation of the optimum (though the biological asymmetry remains unchanged and thus helps to balance the social and economic ones). The advice to not cut until the size of the cut necessary is known must clearly be modified if the upper bound on the plausible values of ABC is below the present catch. In such a setting, one would expect to cut to the catches to match highest likely ABC value if not further.

4.2.3 Application to Red Grouper

If some degree of down-sizing is deemed necessary, managers must be aware that the costs of cuts are not linear. Limited reductions can impose costs, on regional and national economies, that are proportional to the value of the foregone catch. Such proportionality has been assumed (or at least the catch has been taken as a measure of benefits to humanity from the fishery, which amounts to much the same thing) in a number of theoretical studies (e.g. Rosenberg & Brault 1991; Francis & Shotton 1997). However, as suggested above, major downsizing approximating to total closure would impose disproportionate costs, not only on individuals but on fishing communities and the region in general. Whether the Council decided upon a formal closure or simply reduced the allowable catches to levels at which continued fishing became financially impossible for most participants, those costs would appear in the short term as bankruptcies of fishing and fish-processing businesses, with the consequential social disruption on many levels. In the longer term, there would be substantial additional costs to re-establish the industry, its workforce, its infrastructure and its markets once the resource was rebuilt. Indeed, in

Florida early in the 21st century, it seems improbable that the commercial sector could be re-established at all. Waterfront property values can be so high as to be prohibitive for investors seeking to establish a fishing enterprise from the ground up (without access to existing boats or manpower). One might also question whether the political climate would be conducive to establishing a “new” grouper fishery in 2015 or 2020. In short, one cannot simply “switch off” and “switch on” a fishery as biologically-oriented analyses of its resources dictate.

If a major down-sizing of the red grouper fishery was known to be necessary, these costs would obviously have to be borne in the short term in order for the long-term national optimum to be achieved – doubts over the re-establishment of a once-closed fishery notwithstanding. Given the inevitable uncertainty, however, it cannot be known whether such cuts in the red grouper fisheries really are required. Their enormous costs, linked to the risk that they are unnecessary, means that major down-sizing carries a very high “expected loss” (the multiple of the probability of an undesirable outcome with its cost if it should come to pass). Maintaining catches near their current level, on the other hand, would carry some moderate risk that the legislated rebuilding targets would not be achieved by the intended time. The cost of such an event (composed of lost future opportunities for catches plus the cost to the environment of some continued depression of the grouper population) would be small, however, thus the expected loss from allowing catches somewhat above the (unknown) ideal level is likely to be relatively small.

The balance between these concerns can be illustrated by a simple graphical model, as in Figure G²⁹. In this model, it is supposed that the ABC could be set at any value over a wide range, extending down to zero, while the available scientific advice is unable to say which ABC values within that range are more probable than others. (In Figure G, the range of possible ABC values is scaled from zero to one but any other values could be substituted.) For any ABC, there is some risk that future management targets will not be achieved on schedule – an outcome that has some cost to the nation. Clearly, higher ABCs in the short term will carry higher risks of such failure and hence higher expected losses. Meanwhile, moderate restrictions on the ABC are assumed to impose a cost on mankind proportional to the value of the catch but, for the reasons outlined above, deeper cuts see sharply-accelerating increases in the cost to the nation. In Figure G, it is assumed that both these fishery-related costs and the ABC at which they would accelerate are known exactly, thus their probabilities are all equal to one and the curve of costs is also the curve of expected losses. (Real uncertainties in those values could be represented in a more complex diagram by multiple cost lines combined into a single curve of expected loss.)

²⁹ This model is not an analytical one which can give specific guidance on the management of red grouper. Rather, it is intended to assist in thinking about the issues that must be balanced by that management.

Optimum management of this simple system, while ignoring all other complexities (which real-world management must not do), would involve selecting that ABC level which minimized the sum of the “resource” and “fishery” expected losses – that being the lowest overall loss (multiplying its probability by its cost) for the nation. Because of the sharp change in slope where costs to the fishery begin to be counted as more than proportional to the reduction in catch, this minimum will invariably lie at an ABC value slightly below that at which the slope changes.

If applied to red grouper, this conceptual model would suggest that the optimum response to the massive uncertainties over stock status is to restrict catches to such a level that the fisheries approach, but do not quite reach, the point of general business failure. In simple terms, it would pay to “trim the fat” from the fishery in the interests of reducing the risk of delayed rebuilding but further reductions in that risk would not justify “cutting to the bone”. (Whether there is any “fat” to be trimmed in the red grouper fishery and, if so, how deep that layer may be are not matters on which I can comment.) That would not, of course, constitute “erring on the side of conservation” but it would be a cautious approach, balancing the risks of slow rebuilding against those of unnecessarily deep cuts.

These same considerations argue against the RFSAP’s recommendation to adopt a constant-effort (rather than constant-catch) rebuilding strategy. Constant-effort strategies, involving steady rates of fishing mortality but catches that fluctuate with resource biomass, are generally preferable for multiple reasons. However, with the current low perceived level of the red grouper resource, a constant-effort strategy would require very low catches in Year 2000. It would be extremely sub-optimal to drive the fishery into failure now in an attempt to rebuild its resources quickly at first and more slowly later, when a constant-catch option (providing for slower rebuilding at first but faster later, so as to reach the same target at the same time) is also available. The RFSAP’s advice, while correct in most situations for most fisheries, is erroneous for red grouper at the present time (or would be if reducing the ABC to 1.5 million pounds is tantamount to closing the fishery, as seems likely).

The Council should also be aware that the only credible indices of red grouper abundance are drawn from catch rates. The three available fishery-independent measures have not only yielded unconvincing results to date but their time series are very short so far. If the ABC were to be reduced to zero, there would be no catches and so no information on whether the intended rebuilding was progressing or not – except for the MRFSS data on discards from recreational fishing aboard private and charter boats. Even major reductions in catches, short of closure, are certain to cause substantial changes in targeting patterns of the various fisheries (such as causing fishermen to redirect their effort towards other species) and thus would change the catchability of red grouper and so invalidate the catch rates as indices of resource biomass. The year following such reductions, for example, could well see “severe” declines in catch rates of that species, even as its biomass began to rebuild swiftly. It would not be appropriate to keep the red

grouper fisheries open simply to generate data from which their effect on the resource could be judged. However, the loss to management of that essential information should be considered as an additional cost of deep regulatory reductions in the catch³⁰.

4.3 Conclusion

In this paper, I have argued two major points. The firstly is that the best available scientific advice on the status of red grouper is highly uncertain. I have raised a number of specific issues, some of which could be addressed in the short term and might serve to somewhat reduce this uncertainty, but much of it will remain simply because the existing data sets are too weak for any analysis to produce precise results. My second point is that the optimum management response to that uncertainty is not to “err on the side of conservation”, let alone to apply the strictures of the Precautionary Principle in its most rigid senses. Rather, I have suggested, the Council needs to find a point of balance between the risks and costs of cutting the fishery more deeply than is needed and those of not achieving the legislated rebuilding targets.

This is a novel requirement but not a fanciful one. It is driven by the new resource-rebuilding requirements set out in the Sustainable Fisheries Act, which has created new challenges for the Councils – and so requires equally new solutions. While my final suggestion has some parallels to those short-term self interests of the fishing industry which drove fisheries management in the past (and too often drove resources into depletion), my arguments have been built from the national interest which primarily guides the Council.

If those arguments are accepted, it will remain to determine what allowable catch would be optimal, which is closely related to deciding how deeply the catch can be cut without widespread devastation to all sectors of the reef-fish fishery. Some support for that decision may be provided by stakeholders’ evidence presented to the Council and also by formal socio-economic surveys of the fishery. It might also, however, be worthwhile to subject the case presented in this paper to economic analysis.

Even should such analyses be extended to quantitative modelling, there will still be a wide margin of uncertainty around the results. Ultimately, only the Council, after listening to all of the evidence, is in a position to make a balanced decision as to the optimal course of red grouper management in the coming years, seeking in the face of that uncertainty how best to /achieve the national objectives laid down by Congress.

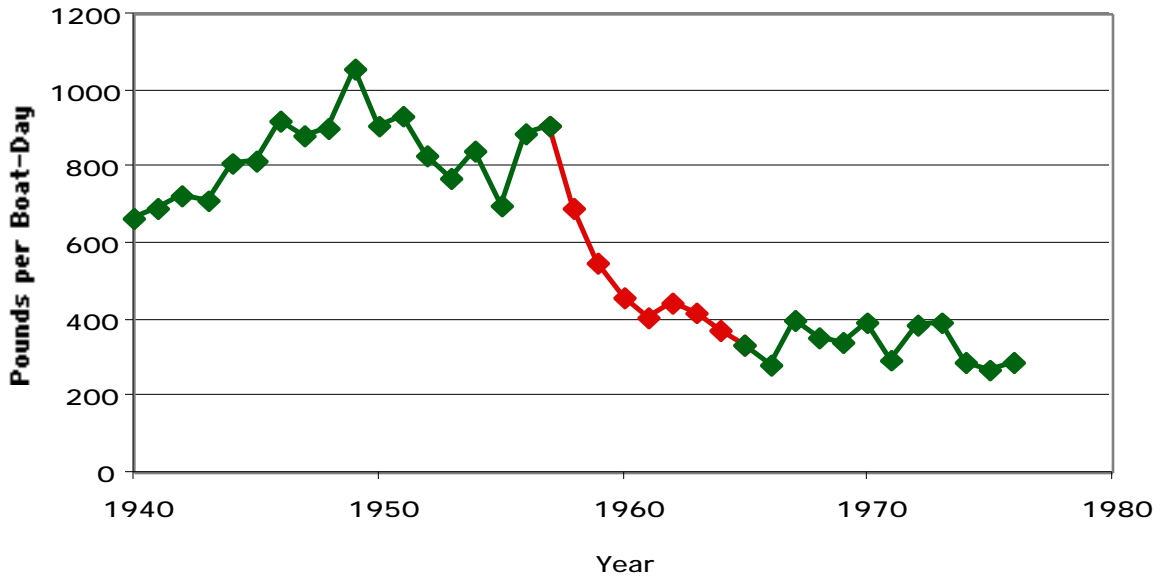
³⁰ Lane and Palsson (1996) have discussed the advantages of keeping a small fishery open as a means of obtaining necessary monitoring data even when low biomasses call for closure. I disagree with parts of their argument, since a small fishery cannot provide data comparable to that from earlier years when fishermen were free to use more expansive fishing strategies. However, they were correct to point out the costs of forgoing the data that fishing provides.

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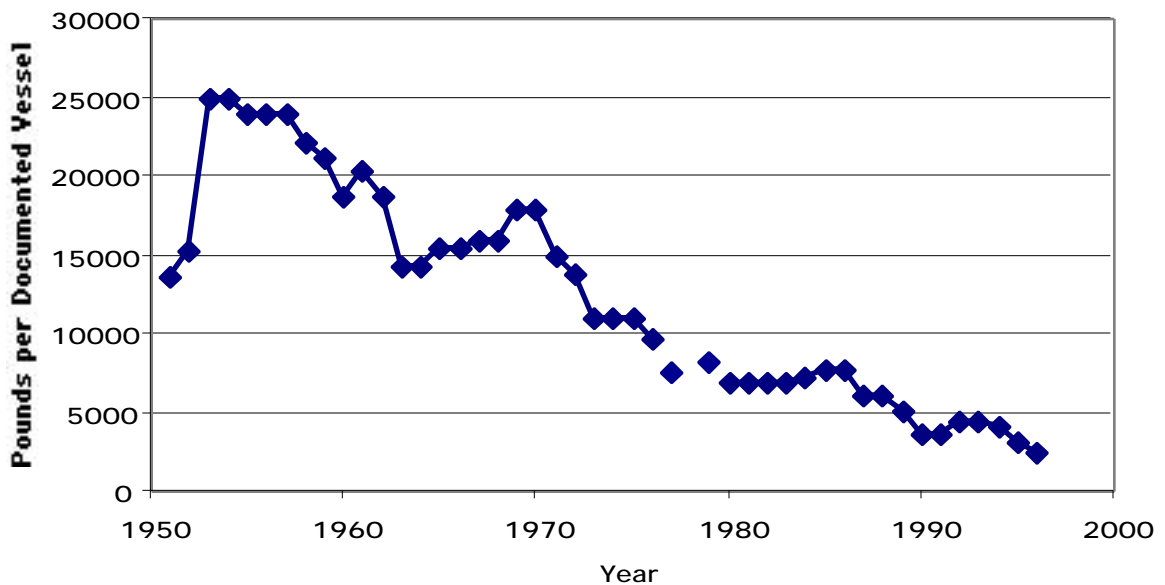
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Figure A: Catch Rate of Cuban Fleet



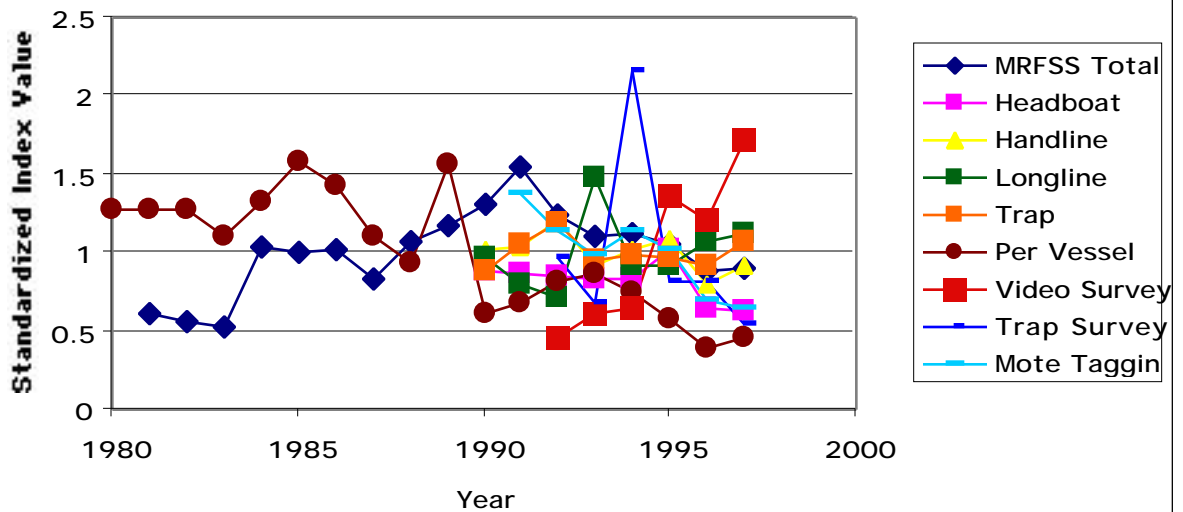
Data from Schirripa et al. (1999) Table 54.
Contrast shading indicates period from start of Cuban revolt
resumption of indirect diplomatic contact with the U.S.

Figure B: Smoothed U.S. Catch Rate



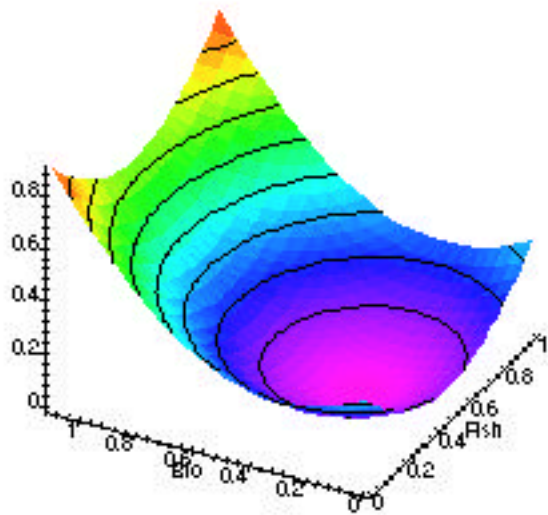
Data from Schirripa et al. (1999) Table 54.
Smoothed by taking three-point running median.
Isolated points are unsmoothed values around a single missing data point.

Figure C: Biomass Indices Since 1980

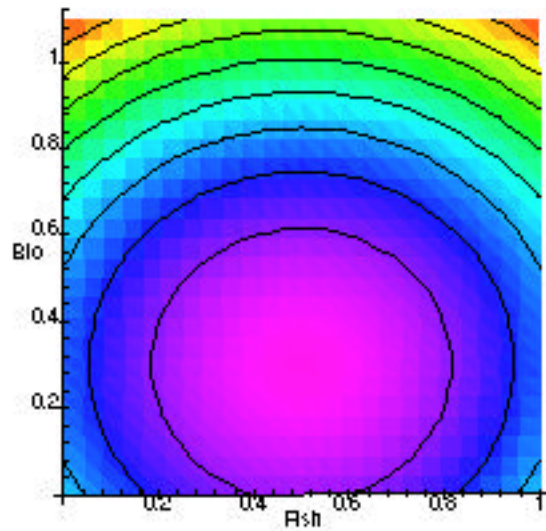


Data from Schirripa et al. (1999) Tables 54 & 55, Figure 53. All series to standardized to average of one.

Figure D: Diagrammatic Representation of a Simple Probability Surface from a Hypothetical Model with Two Parameters: Biomass and Fishing Mortality

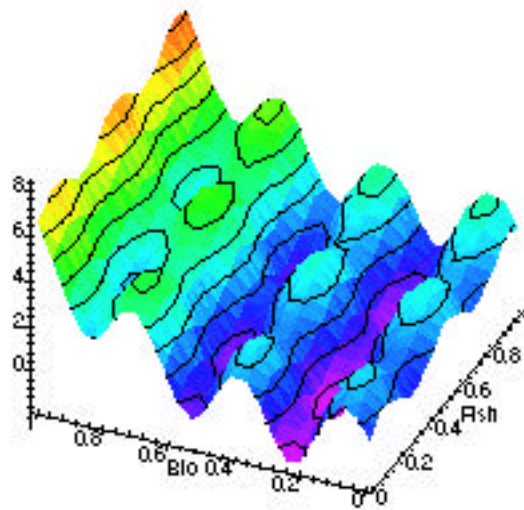


Three-Dimensional Oblique View

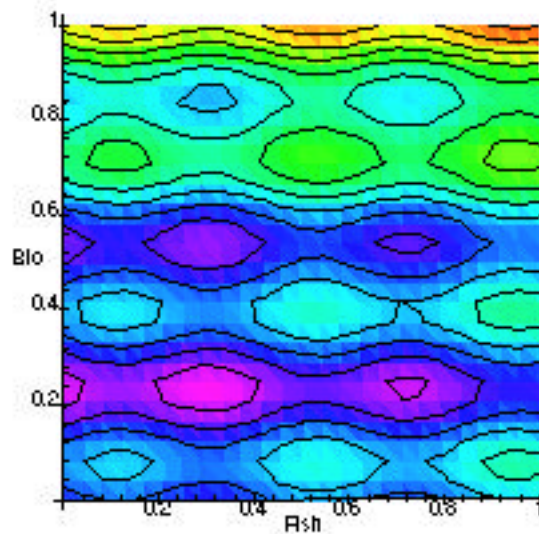


Contour Plot

Figure E: Diagrammatic Representation of a Complex Probability Surface from a Hypothetical Model with Two Parameters: Biomass and Fishing Mortality



Three-Dimensional Oblique View



Contour Plot

Figure Fi: Effect of Truncating Confidence Interval at Zero (theoretical diagram only)

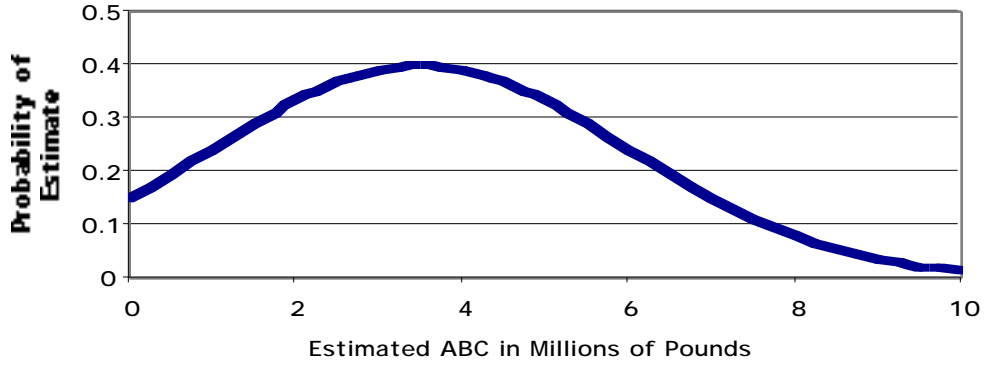


Figure Fii: Effect of Geometric Confidence Interval (theoretical diagram only)

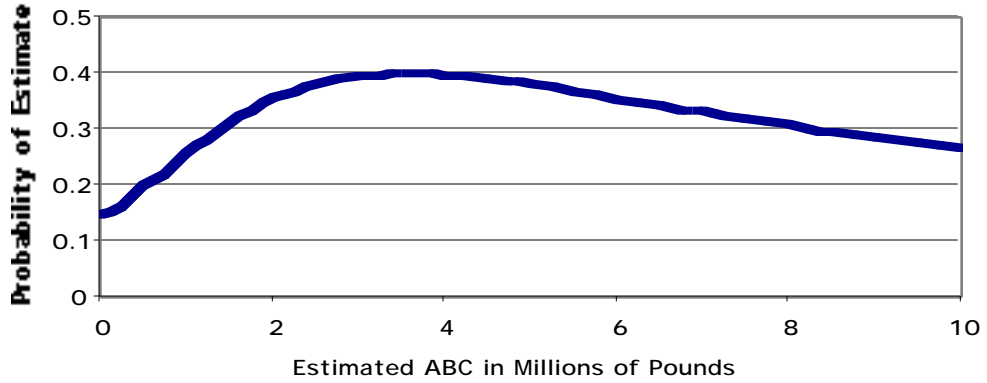


Figure Fiii: Effect of High Uncertainty (theoretical diagram only)

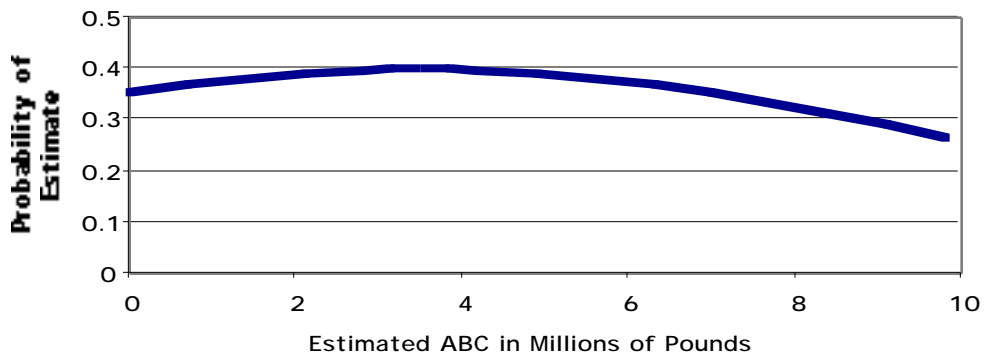


Figure G: Hypothetical Model of Costs of Various ABC Levels

