The monkfish fishery and its management in the northeastern USA

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The domestic monkfish (*Lophius americanus*) fishery off the northeastern USA is described, along with the management response to the expansion of the fishery and the challenges posed to the management and scientific processes. The US fishery was virtually non-existent in the early 1980s, but it expanded rapidly over the next decade to the point that a management plan became necessary to regulate harvesting. By law, US fishery management plans must include measurable biological reference points based on maximum sustainable yield or a proxy; management plans must stop overfishing and rebuild overfished stocks. For monkfish, the limited biological and historical fisheries information presented significant challenges to science and management and resulted in the adoption of innovative approaches to comply with the law.

Keywords: biological reference points, fishery management, monkfish.

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Introduction

Expansion of domestic directed monkfish (*Lophius americanus*) fishing off the northeastern United States (USA) from the mid-1980s on was so rapid that, by the early 1990s, the industry asked that a fishery management plan (FMP) be developed. The plan was implemented in 1999, and because of a dearth of scientific information about the species, managers have had to rely on several different, innovative approaches to evaluate stock status and to limit fishing effort. Effort was limited through target total allowable catches (TACs). These are not "hard" TACs (quotas) that lead to fishery closures once they are reached. Instead, they are used to establish input control management measures, such as days-at-sea (DAS) and trip limits. Innovation and adaptation at the science/management interface have been, and continue to be, necessary because until the most recent stock assessment (summer of 2007), absolute estimates of spawning-stock biomass and fishing mortality were unavailable. As US fishery management legislation requires management to stop overfishing and to rebuild overfished stocks using objective, measurable, and scientifically based management reference points, the absence of absolute estimates of stock size and fishing mortality complicated this process and posed challenges in the management of the monkfish fishery.

Here, we briefly review the history of the fishery, then examine the science/management interface, detailing the evolution of biological reference points and associated management measures. We also describe future challenges facing the scientific and management processes for monkfish.

Overview of the fishery and management

The monkfish fishery in the northeastern USA extends from Maine to North Carolina (Figure 1), and seasonally from inshore waters out to the continental margin and deep-water basins. The fishery overlaps the areas of jurisdiction of both the New England Fishery Management Council (NEFMC) and the Mid-Atlantic Fishery Management Council (MAFMC). As a result, the fishery is jointly managed by the two Councils, with the NEFMC having the administrative lead. The Councils manage the fishery as two management units, the Northern Fishery Management Area (NMA) covering the Gulf of Maine and northern part of Georges Bank and the Southern Fishery Management Area (SMA) extending from the southern flank of Georges Bank through the Mid-Atlantic Bight to North Carolina.

This two-zone approach is more reflective of the differences in how the fishery is prosecuted in the two areas than of any distinct biological differences delimiting two stocks. Recruitment seems to have occurred mainly in the northern management area (NEFSC, 1997 *et seq.*), but this observation could be due to different recruitment patterns in the two management areas or to the existence of a nursery area in the northern management unit of single stock covering the two areas. Limited genetic studies have indicated no differences between monkfish sampled in the northern and southern management areas (Chikarmane *et al.*, 2000). Ongoing cooperative research projects, such as tagging and biochemical analysis, are expected to provide additional insight into the question of stock delimitation.

The monkfish fishery in the NMA is closely integrated with the multispecies groundfish fishery, and landings are predominantly (>70%) from otter trawlers fishing on groundfish trips. Although monkfish is a component of the mixed trawl catch, there is some evidence in observer data to suggest that vessels target monkfish on individual tows made during groundfish trips in the area. During the late 1980s and early 1990s, scallop dredge vessels accounted for 30–40% of total monkfish landings

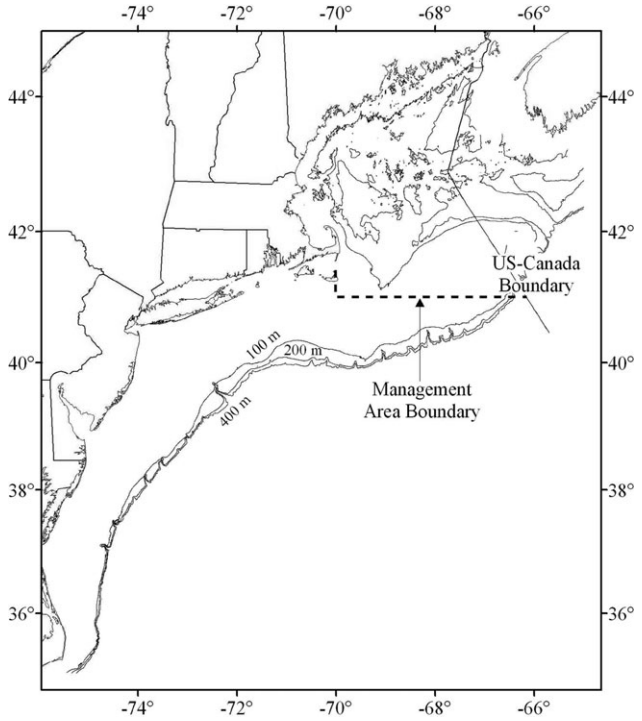

Figure 1. Map of northern and southern management areas for monkfish off the northeastern USA.

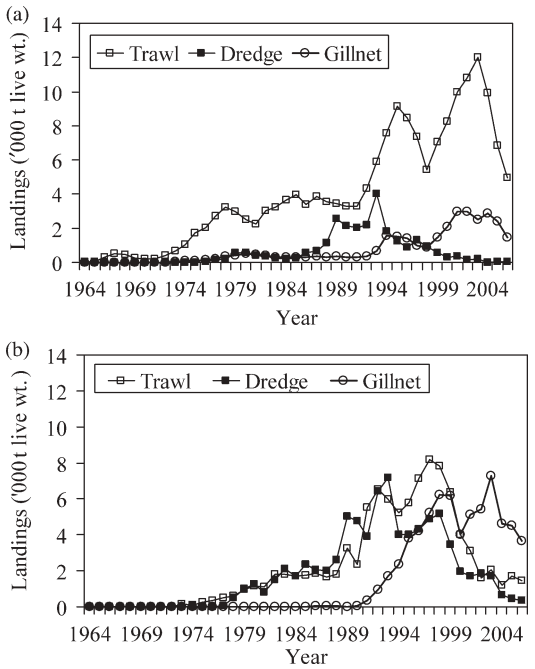

Figure 2. Reported commercial monkfish landings by gear from the US (a) northern and (b) southern management areas, 1964–2006 (after NEFSC, 2007).

from the NMA, but have since declined to <5%. The proportion of landings by gillnet vessels from the NMA has increased over the history of the fishery, accounting for 25–30% of the total (Figure 2).

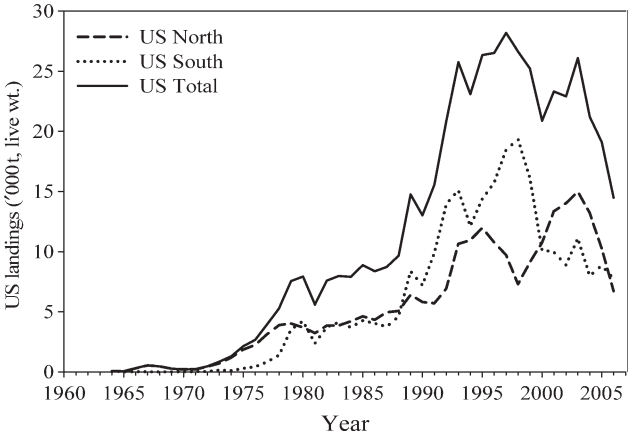

Figure 3. Reported commercial monkfish landings by area, and total from the US northern and southern management areas, 1964–2006 (after NEFSC, 2007).

In the SMA, the monkfish fishery is more of a directed fishery, because the groundfish fishery in the area is smaller scale, with fewer targeted species than in the NMA. Over the past 20 years, the proportion of monkfish landings by different gear types has shifted significantly in the SMA: in the 1980s, landings were fairly evenly split between trawl and dredge vessels, but during the 1990s the proportion of landings by gillnetters increased from <1 to 50%. With the implementation of the FMP, gillnets now account for ~65% of the total catch in the SMA, whereas the proportion of landings by dredge vessels has declined to 10% or less, and otter trawls to ~20–25% (Figure 2).

The proportion of landings from each area has fluctuated over the history of the fishery in response to recruitment events, management restrictions, and other factors. During the 1980s, landings from each area were equivalent. During the 1990s, annual landings from the SMA were 20–50% higher than those in the NMA. During the period 2001–2005, NMA landings were as much as 50% higher than those in the SMA. Recently, as NMA landings declined, landings from the two areas have again become roughly equivalent (Figure 3).

Pre-1980s

Until the 1980s, monkfish was an incidental catch in groundfish and sea scallop fisheries, but had little or no commercial value, and was allegedly discarded in significant quantity. In the 1960s domestic reported landings averaged <500 t, and revenues from monkfish were just a few hundred thousand dollars a year, as the price per pound, even for tails only, was <$0.10 in nominal dollars. Foreign landings from Subareas 5 and 6 reported to the International Commission for Northwest Atlantic Fisheries (ICNAF), the predecessor of the Northwest Atlantic Fisheries Organization (NAFO), averaged some 2500 t annually from 1964 to 1975, but essentially ended with the establishment in 1976 of the US Exclusive Economic Zone and the departure of foreign groundfish fishing vessels.

1980s and 1990s: directed fishery, scallop, and groundfish catches

From the mid-1970s to the mid-1980s, a tenfold increase in the price of tails led to a 17-fold increase in trips reporting landings, and in landings themselves, as gillnet and sea scallop fishers

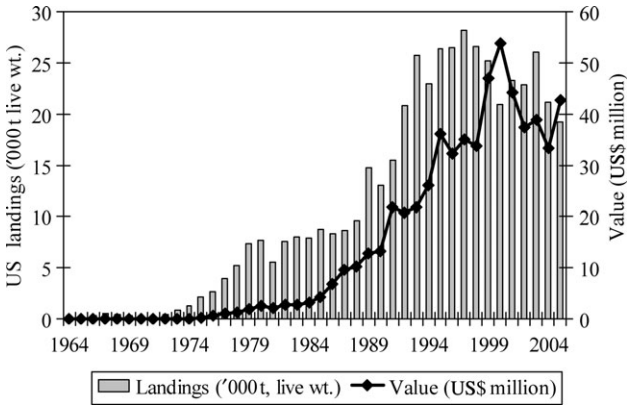

Figure 4. US monkfish landings ('000 t, live weight) and value (US$ million), 1982–2005 (after NEFMC Framework 4, 2007).

joined trawlers in recording landings (Figure 3). Growth in the demand from Europe for monkfish tails, and from Japan and South Korea for livers and whole fish, fuelled the growth of US dockside markets through the 1980s and into the 1990s. By 1995, total live weight landings exceeded 26 000 t. Monkfish tails averaged >$2.00 per pound, and livers $5.00 per pound (Figure 4).

In the early 1990s, fishers and fish dealers expressed concern to the New England and Mid-Atlantic Fishery Management Councils that the burgeoning fishery was beginning to show signs of overexploitation. They cited the increasing proportion of small fish being caught, as well as a greater frequency of gear conflicts, particularly with the offshore lobster fishery, as the directed trawl fishery expanded into areas not previously fished by groundfish vessels. Fishers' reports of biological stress were substantiated by fishery-independent survey data that showed declining abundance and average size of fish in surveys (Figures 5 and 6). The fishers urged the Councils to adopt an FMP to limit entry to the fishery, and to establish controls on fishing effort, including a minimum fish size and gear (mesh size) restrictions.

Science/management interface: the development and evolution of management reference points and associated catch limits

From the beginning, management of the monkfish fishery has suffered from poor data and a lack of basic scientific information. Not only are the historical catches uncertain (both landings and discards, especially from the early period when there was only a limited market), but most of the other elements necessary for a reliable assessment have been lacking. The NEFSC bottom trawl survey, which extends back to 1963, catches relatively few monkfish, making the survey indices for the species highly variable. This is due in part to the type of gear used, but is also thought to be a result of the distribution of monkfish relative to the survey strata, which do not extend into the deeper water inhabited by monkfish. There is also considerable uncertainty regarding natural mortality, growth rate, reproduction, and other important assessment model inputs. These factors have forced fishery managers to be creative and adaptive in translating the scientific information into an effective management programme. For a more detailed discussion of some of the scientific challenges with monkfish, the reader is referred to Richards *et al.* (2008), in this issue.

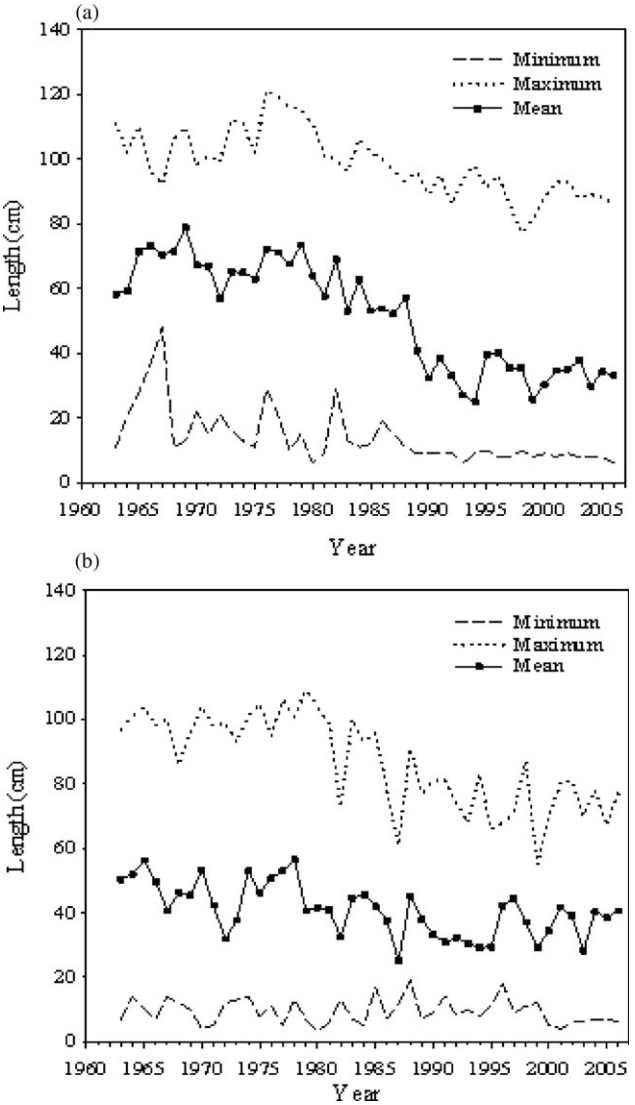

Figure 5. Monkfish minimum, mean, and maximum lengths from the NEFSC autumn bottom trawl survey for (a) northern and (b) southern management areas.

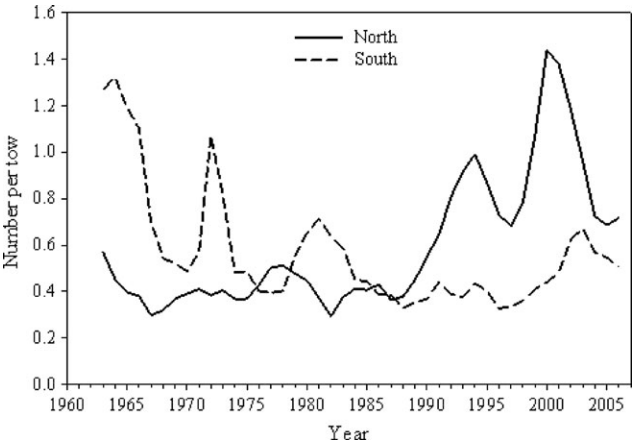

Figure 6. Monkfish smoothed (3-year running average) abundance indices from the NEFSC autumn bottom trawl survey, 1963–2006.

National Standard 1 of the US federal law, called the Magnuson–Stevens Act, requires FMPs to "prevent overfishing while achieving on a continuing basis, the optimum yield from each fishery". Optimum yield is defined in the Act as "the amount of fish which (a) will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems; (b) is prescribed as such on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor; and (c) in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the maximum sustainable yield in such fishery". To achieve this goal, FMPs must establish objective and measurable definitions of overfishing, as well as biomass targets that will produce maximum sustainable yield, or a proxy reference point, and a minimum biomass threshold reference point below which a stock is deemed to be "overfished".

The reference points, in conjunction with the stock status relative to those reference points, provide the basis for calculating target TACs. The target TACs are, in turn, used to set input controls, specifically, for the monkfish fishery, DAS, and trip limits. This process of setting reference points is relatively straightforward when a historical time-series of absolute estimates of biomass and fishing mortality is available, but it was more complicated for monkfish, for which only relative indices were available.

The science/management interface is the process of determining the stock status relative to the biological reference points, and translating that status (overfished, rebuilding, or rebuilt) into a target TAC and appropriate management measures. The target TAC represents either optimum yield from the fishery, while allowing for rebuilding if the stock is below the biomass target, or a reduction in fishing mortality, if fishing mortality (or its proxy) is above the overfishing threshold. For monkfish, there are sources of uncertainty throughout the process: in setting reference points, in determining stock status, in setting appropriate catch targets to achieve management goals, and in translating those catch targets into effective management measures.

Initial FMP science background, adoption of reference points

The NEFMC convened an Overfishing Definition Review Panel (OFD Panel) in 1997 to evaluate all the overfishing definitions, including those being considered for the monkfish plan that was under development at that time, and to develop recommendations for new definitions, as needed, to bring the FMP into compliance with the 1996 Magnuson–Stevens Act reauthorization, known as the Sustainable Fisheries Act (SFA). The OFD Panel recommended (NEFMC, 1999) to the Council overfishing definitions based on NMFS guidelines for SFA National Standard 1 (prevent overfishing and achieve optimum yield) and National Standard 2 (using the best scientific information available). The Councils adopted, with modification, the panel's recommendation for monkfish overfishing definitions, and these were incorporated in the original FMP in 1998.

The overfishing definitions developed by the OFD Panel had two basic parts; a stock-biomass component (B) and a fishing mortality rate (F) component. A stock is "overfished" when its biomass is less than the minimum biomass threshold ($B_{\text{threshold}}$), regardless of the reason for the biomass being below that threshold. The National Standards specify that "overfishing" is occurring when $F > F_{\text{threshold}}$. The $F_{\text{threshold}}$ has to be less than or equal to the rate of fishing mortality that can produce maximum sustainable yield (F_{MSY}). If biomass is $<B_{\text{threshold}}$, then $F_{\text{threshold}}$ is the F that allows the stock to rebuild to B_{MSY} in a rebuilding period, which is not to exceed 10 years.

The Councils' monkfish overfishing definition adopted into the FMP (NEFMC, 1998, p. 19) stated: "Monkfish in the northern and southern management areas are defined as being overfished when the three-year moving average autumn survey weight per tow falls below the 33rd percentile of the time series, 1963–1994, or when fishing mortality exceeds $F_{\text{threshold}}$. Monkfish are in danger of becoming overfished when the three-year moving average autumn survey weight per tow falls below the median of the three-year moving average during 1965–1981 and when fishing mortality is between F_{target} and $F_{\text{threshold}}$".

"For the northern and southern areas, $F_{\text{threshold}}$ is based on conditions of stock stability at high abundance, calculated at the rate of fishing mortality that prevailed during the period 1970–1979. F_{target} for the southern area is $F_{0.1}$. For the northern area, F_{target} is currently undefined".

The OFD Panel evaluated this definition and commented (NEFMC, 1999, p. 24) that "It is not known whether fishing at a level that prevailed during 1970 to 1979 would produce MSY, or that the biomass during that time period approximates B_{MSY}. Also unknown is whether fishing at $F_{0.1}$ would allow rebuilding to occur within 10 years or less".

The OFD Panel expanded this evaluation later in the report: (NEFMC, 1999, p. 144) to say that "The existing overfishing definition has many characteristics that comply with the Sustainable Fisheries Act and the proposed guidelines. The target biomass and fishery mortality rates were based on a period of stability when the stock had a healthy age-structure. This management strategy appears to be sustainable and would, in the long-term, approximate MSY. The biomass and fishing mortality thresholds also appear to satisfactorily define an overfished condition and overfishing, respectively".

"Unfortunately, the catch history for monkfish in the 1960s and 1970s is unreliable, making the results of a surplus production model unreliable. As an acceptable proxy for B_{MSY}, the panel recommends revising the biomass targets, so they are more equivalent to the MSY-based reference points that the proposed guidelines require. A suitable proxy for B_{MSY} is one-half the maximum survey value in the time series (4.9 kg/tow in the north, 5.8 kg/tow in the south). This strategy treats the maximum survey value as an approximation of the carrying capacity of monkfish. Based on reference points chosen for more resilient stocks, the control law strategies apply F_{min} when stock biomass is below $\frac{1}{4}B_{\text{MSY}}$. [Note: F_{min} is defined as the minimum achievable fishing mortality rate caused by reducing fishing activity to as close to zero as practicable.] The panel, therefore, recommends that the biomass thresholds be set at $\frac{1}{4}$ of the maximum survey value, a level equivalent to $\frac{1}{2}B_{\text{MSY}}$. Table 1 gives the survey values for the existing biomass thresholds and targets".

The following excerpts from the original Monkfish FMP provide the Councils' perspective on the overfishing definitions: (NEFMC, 1998; Monkfish FMP, p. 16): "The only data available to support a definition based on a minimum stock level are from fishery-independent surveys. A few state-supported surveys exist, but the most comprehensive are the bottom surveys conducted by NMFS. There are problems because the surveys do not encompass the entire range of the monkfish resource. No samples are taken offshore of the Continental Shelf edge where

Table 1. Biomass reference points for the monkfish overfishing definition and for MSY-based proxy values adopted in the original Monkfish FMP for the northern and southern fishery management areas (NMA and SMA).

Parameter	NMA	SMA
Biomass threshold (kg tow^{-1}) 33rd percentile, 1963 – 1994	1.460	0.750
Biomass target (kg tow^{-1}) median, 3-year average, 1965 – 1981	2.496	1.848
Maximum value for 3-year moving average (kg tow^{-1})	4.887	5.878
25% ($\frac{1}{4}$) of the maximum survey value (kg tow^{-1})	1.222	1.470
50% ($\frac{1}{2}$) of the maximum survey value (kg tow^{-1})	2.443	2.939

monkfish are known to occur. These surveys do, however, provide a reasonable estimate of stock abundance for that portion of the population occurring in coastal and shelf areas".

"This method utilizes relative abundance to define when a stock is overfished. The survey data is the most complete source of information currently available. A measure of a minimum number or biomass is an attractive definition. On the downside, fishermen often distrust survey data and the survey is subject to inter-annual changes in availability. The latter may not be problematic for monkfish given its wide range and the extent of the survey, but it does argue for a longer-term approach than action based on one year of survey data".

At the time the FMP was under development, the 3-year moving averages of the survey biomass index were 1.01 kg tow^{-1} for the northern area, and 0.41 kg tow^{-1} for the southern area. These values were below the minimum biomass threshold adopted in the overfishing definition (1.45 kg tow^{-1} in the northern area and 0.75 kg tow^{-1} in the southern area), prompting the Councils to adopt a 10-year rebuilding programme in the FMP. Target TACs were calculated to reduce current catches for the two areas based on a phased reduction in fishing mortality over 3 years, and the elimination of the directed fishery in Year 4, allowing only limited incidental catch of monkfish in other fisheries (Table 2).

Table 2. TACs corresponding to the fishing mortality objectives for the northern and southern fishery management areas (NMA and SMA).

Fishing year	Objective	NMA TAC (t)	SMA TAC (t)
1995 – 1996	Baseline	12 739	14 667
1 May 1998 to 30 April 1999	Partial implementation	Undefined	Undefined
1 May 1999 to 30 April 2000	Mortality reduction	5 673	6 024
1 May 2000 to 30 April 2001	Mortality reduction	5 673	6 024
1 May 2001 to 30 April 2002	Mortality reduction	5 673	6 024
1 May 2002 to 30 April 2003	Stop overfishing	4 047	3 252
1 May 2003 to 30 April 2004 and subsequent fishing years	Rebuilding	4 047	2 224

The Councils adopted a limited entry programme and a monkfish rebuilding plan in 1999, with the adoption of the Monkfish FMP. As noted above, the original FMP contained a 4-year implementation of management measures to reduce fishing effort and to rebuild the stocks within 10 years or less. Based on the target TACs, the Councils allocated 40 monkfish DAS for the first 3 years, 0 DAS in Year 4 (starting 1 May 2002), and adopted an array of trip limits, based on gear and area. The FMP also established incidental catch limits for most other gears and fisheries, to minimize the discards and to prevent increased effort targeting monkfish in those other, less selective fisheries. The directed fishery trip limits would be reduced to the incidental catch limits in Year 4, when DAS were to be reduced to zero. In the northern area, however, monkfish vessels fishing on a multispecies DAS had no monkfish trip limit, because monkfish was viewed as a component of the mixed trawl catch and the Councils felt that a trip limit would simply result in monkfish discards while vessels were fishing for other groundfish species. Therefore, the original monkfish FMP implied limited control on monkfish fishing in the northern area except as a consequence of restrictions being imposed under the multispecies FMP rebuilding programme.

Framework 1

During the first 3 years of the FMP, several events caused the Councils to adjust the management strategy. The 3-year average of the biomass indices doubled in the southern area and tripled in the northern area. Landings declined in the southern area, but continued to rise in the north, owing to a combination of good recruitment and a lack of direct control on monkfish fishing effort. In the northern area, as noted above, the management system for the monkfish fishery relied mostly on effort controls (DAS) in the multispecies FMP, and there were no monkfish trip limits. There was also considerable pressure from industry to develop an alternative to the anticipated closure of the directed fishery planned for Year 4, particularly given the positive signs shown in the survey. The Year 3 review resulted in Framework 1 (implemented by NMFS through a temporary emergency action) which delayed the default measures for one year so that the Councils could complete a more comprehensive adjustment to the FMP. (The management system provides for a relatively abbreviated process, 6 months to 1.5 years, for making certain changes to the management system, known as a "framework adjustment".).

The rationale for the action proposed in Framework 1 (delay the scheduled closure of the directed fishery) was based on an evaluation of the best available scientific information on stock status and trends in the fishery. First, the assumptions about recruitment and natural mortality used to calculate initial fishing mortality reference points in the 1997 stock assessment [Stock Assessment Workshop (SAW) 23; NEFSC, 1997] were invalidated by two more recent SAWs (SAW 31; NEFSC, 2000; and SAW 34; NEFSC, 2002). Application of updated data and a more scientifically defensible set of assumptions resulted in unfeasible (negative) estimate of the fishing mortality threshold in the NMA. This finding also indicated that the rates of fishing mortality estimated using length composition data from the NEFSC surveys were not reliable estimates of absolute fishing mortality exerted on monkfish and should not be used to set TACs. In autumn 2001, the Monkfish Monitoring Committee concluded that the TACs in the FMP for FY2002 (fishing year 2002) were inadequate targets on

Table 3. Monkfish target TACs for fishing year 2002/2003, northern and southern fishery management areas (NMA and SMA).

NMA	SMA	Total (OY)
11 674 t	7 921 t	19 595 t

which to measure fishery performance relative to the management objectives.

Second, SAW 31 (terminal year of data 1999, before the FMP took effect) concluded that estimates of F could not be estimated reliably, but it also stated that estimates of total mortality (Z) indicated that overfishing was occurring. SAW 34 (terminal year of data 2000) came to the same conclusion about fishing mortality (F could not be estimated reliably, but based on estimates of Z, overfishing was occurring), but observed that the biomass index in the north was increasing, whereas in the south it was fluctuating around the time-series low. SAW 34 recommended that the fishing mortality threshold be set at $F_{max} = 0.2$ (from the yield-per-recruit analysis), but there were insufficient data to conduct short-term projections to set TACs.

Third, the relative exploitation index (catch divided by biomass index) based on FY landings and the autumn survey index declined substantially from FY1999 to FY2000. Seasonal landings patterns suggested that even without further restrictions, fishing mortality for calendar year 2001 was lower than that for calendar year 2000. Although not conclusive, the decline in the relative exploitation index provided some evidence that the management programme was having its intended effect and that closure of the directed fishery was not required.

Fourth, in the SMA, although the 3-year running average of the survey abundance index remained below the FMP threshold, the 2001 index rose for the third consecutive year to its highest since 1986. In the NMA, the 3-year average moved above the threshold in 2001, indicating that the NMA was no longer overfished. Upon review of the analysis and public comment, the Councils recommended, and NMFS adopted, revised target TACs for Year 4 (Table 3).

Framework 2

In 2002, as the Councils were developing Framework 2 (NEFMC, 2003) to replace the Framework 1/temporary emergency rules (under the US law, temporary rules expire after 180 d, but may be extended under certain circumstances to not more than 365 d), NMFS informed the Councils that the minimum biomass threshold reference point, although approved by the agency, was not compliant with the National Standard 1 Guidelines and needed to be revised to $\frac{1}{2}B_{target}$, or the minimum stock size at which rebuilding to B_{target} would be expected within 10 years if the stock were exploited at $F_{threshold}$. Because of data limitations and an inability to make reliable projections of monkfish rebuilding, the second approach was not practicable. In fact, the unreliability of F estimates, and the inability to project stock rebuilding under various scenarios of F, caused the Councils to adopt an innovative approach to setting TACs in Framework 2, to achieve the 10-year rebuilding goals.

In Framework 2 (68 FR 22325, 28 April 2003), the Councils adopted the revised fishing mortality threshold reference point of F_{max} as the proxy for the rate of fishing mortality that would achieve maximum sustainable yield from a rebuilt stock. SAW 34 recommended using F_{max} as $F_{threshold}$, and NMFS incorporated that change into the 2002 emergency rule implementing the measures in Framework 1. SAW 34 calculated F_{max} to be $F = 0.2$. The Councils also revised the minimum biomass threshold, below which a stock is deemed to be in an overfished condition, to $\frac{1}{2}B_{target}$, or 1.25 kg tow^{-1} for the northern area and 0.93 kg tow^{-1} for the southern areas. These adjustments to the reference points did not, however, change the rebuilding plan adopted under the original FMP, which required rebuilding to B_{target} by 2009.

The Councils' Monkfish Monitoring Committee was faced with the task of setting annual TACs that would result in rebuilding monkfish in both management areas in the remaining 7 years of the programme, in the absence of a reliable estimate of F and an inability to project stock rebuilding under various target TACs. The Committee created an index- and landings-based method for setting TACs that compared current 3-year average biomass index values with annual index targets based on ten equal increments from the 1999 index (the start of the rebuilding programme) to the 2009 biomass target (the proxy for maximum sustainable yield biomass). The ratio of observed annual index values (3-year average) to the annual index targets was then applied to the previous year's landings to calculate the target TACs for the upcoming year. For example, if the observed biomass index was 10% below the target in a given year (observed index/target index = 0.90), then the target TAC for the subsequent year would be set at 10% below the previous year's landings.

Once the target TAC was calculated, using the method described above, it was then used to calculate DAS and trip limits using a formula established in the framework. As a precautionary measure, the Councils also set limits on potential increases in the target TAC, if the observed biomass index value was above the annual biomass index target. Under that scenario, the TAC would be increased from the previous year's landings by 50% of the ratio of the observed to target index values, up to a maximum of 20%. This approach was vetted through the New England Council's Scientific and Statistical Committee, which concluded that the procedure had the virtue of simplicity and clarity and was a reasonable proposal in concept for developing a rebuilding schedule.

In the second year of this new target TAC-setting procedure, however, a flaw prompted the Regional Administrator of NMFS to express the agency's concerns in a letter to the Council. In the method adopted in Framework 2, the target TAC for the next year is calculated by multiplying the previous (complete) year's landings by the ratio of the observed survey to the target survey index in the current year. The flaw is that if the previous year's landings are sufficiently high, the method would result in an increase in next year's target TAC from the current year landings, even when a reduction should have occurred. In other words, even if the stock was below its annual biomass target index, the TAC could increase because the calculation is based on the previous year's landings, because landings for the current year are not available when the calculations are made. Coincidentally, the upwards trend in biomass indices had slowed (in the SMA) or reversed (in the NMA), raising the urgency to revise the management programme. This was the basis for the Council undertaking in 2006 the development of Framework 4, to implement management measures for the remaining 3 years of the rebuilding programme.

Framework 3

The Council implemented Framework 3 in November 2006 as a joint action with the Multispecies FMP Framework 42. This adjustment modified the ability for vessels on restricted Multispecies DAS (so-called "B" days) to target monkfish. Although marginally reducing the ability of vessels to target monkfish when on a multispecies DAS, this action did not modify the allocation of monkfish DAS, nor did it address any science/management interface matters.

Framework 4

Following adoption of Framework 2 in May 2003, the Northeast Fisheries Science Center completed another monkfish stock assessment (SAW 40 in Autumn 2004). The data used in the 2004 assessment included NEFSC research survey data through 2003, data from the 2001 and 2004 Cooperative Monkfish Surveys, commercial fishery data from vessel trip reports, dealer landings records, and observer data. In summary, the Stock Assessment Review Committee concluded: "Based on existing reference points, the resource is not overfished in either stock management area (north or south). Fishing mortality rates (F) estimated from NEFSC and Cooperative survey data are currently not sufficiently reliable for evaluation of F with respect to the reference points" (NEFSC, 2005, p. 8).

With respect to recruitment, the report noted evidence of increased recruitment in the NMA during the 1990s, particularly for the 1999 year class. Conversely, the SAW 40 report noted that in the SMA, recruitment appeared to have fluctuated without trend during the 1990s. However, there were some indications that the 2002 year class in the SMA was above average.

The 2005 autumn survey indices were again below the minimum biomass threshold for both management areas, which implied that monkfish was deemed "overfished" (Figure 7). To meet the rebuilding objectives, the biomass indices would need to double over the remaining 3 years of the rebuilding programme. Although such growth appeared unlikely, equivalent or higher increases in the indices had already been observed during the first 3 years of the FMP, despite relatively high monkfish landings during that period. Nevertheless, the task before the Councils' Monkfish Plan Development Team (PDT), identifying management measures that would rebuild monkfish within the remaining time of the FMP, was even more formidable than that in Framework 2, given the short-time remaining in the rebuilding programme and the lack of improvement in the scientific information that would form the basis of the effort. In reaction to the new information, the Councils initiated work on Framework 4 (NEFMC, 2007).

Given the absence of an analytical assessment and the inability to conduct projections of stock rebuilding under various scenarios of fishing mortality rates, the PDT used several approaches for estimating the fixed target TACs to be used for the rest of the rebuilding period (Table 4). The TACs were estimated either by comparing the relative exploitation generated by various TACs to time-series of relative exploitation (Figures 8 and 9), or by comparing the TAC with a time-series of landings (Figures 10 and 11). In these analyses, relative exploitation is defined as catch, in kg, divided by the relative biomass index from the NEFSC trawl survey, in kg tow^{-1}. The resulting units, therefore, represent the number of standardized tows that would be needed to achieve the total catch in each year. (Note that the

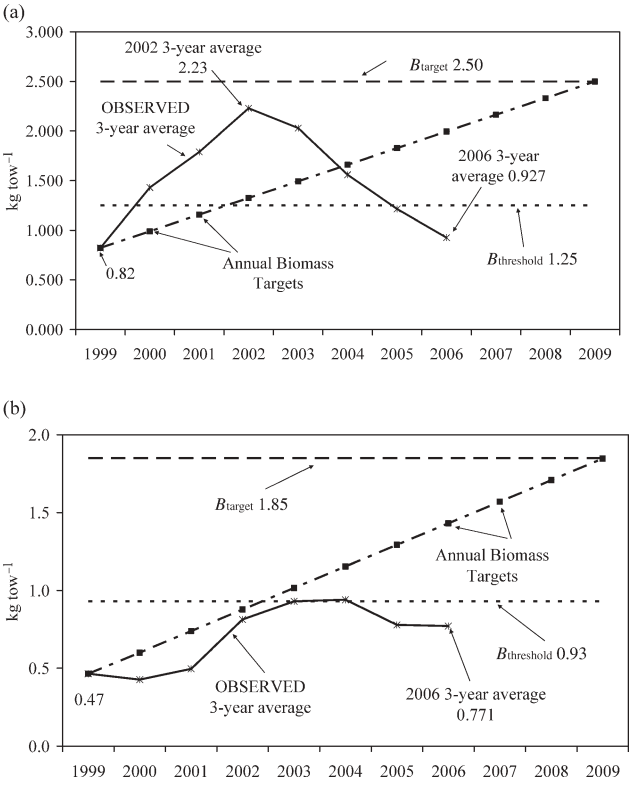

Figure 7. Monkfish biomass rebuilding programme targets (annual and final), and observed autumn bottom trawl indices (3-year average) for (a) northern and (b) southern management areas.

methods, M1–M9, referenced in the explanatory captions to Figures 8–11 are described in Table 4.).

The PDT then selected the median value of the results of these nine methods as the recommended TACs for each area. As shown in Figures 8–11, the nine estimates were relatively tightly clustered. The PDT estimates of target TACs were 5000 t for the northern management area and 5100 t for the southern management area (Table 4) for the remaining years of the FMP. The PDT concluded that these target TACs should reduce exploitation for the northern management area, and maintain exploitation near recent values for the southern management area. These TACs are similar to landings observed during the mid-1980s for both management areas. Although the recommended target TACs could not be analysed to determine whether they would in fact result in the needed rebuilding, they represented the PDT's best estimates of target catches that could facilitate stock building and maintain a limited directed fishery, consistent with Framework 4 objectives.

The National Marine Fisheries Service delayed approval of Framework 4, pending the results of a special stock assessment to be made available in August 2007 (Northeast Data Poor Stocks Assessment Working Group, NEFSC, 2007). A number of assessment approaches [index-based, mortality estimates using various methods, general production models, catch-survey analysis (also known as a "Collie–Sissenwine Analysis")] were used, but a statistical catch-at-length model (SCALE), incorporating several sources of information (landings, length composition of the landings, surveys, length composition of the surveys, etc.), was considered the most appropriate basis to provide management

Table 4. A range of monkfish TAC values for the northern and southern management areas.

Method	Source/method for calculating TAC	TAC ('000 t)	
		Northern management area	Southern management area
Label	FY 2006 *status quo*	7.7	3.7
M1	Median relative exploitation (1963–2005) × 3-year average of exploitable biomass index (2003–2005)	2.7	3.3
M2[a]	Average relative exploitation (1963–2005) × 3-year average of exploitable biomass index (2003–2005)	6.0	9.4
M3	75% of average catch 1963–2005	4.3	5.0
M4	75% of average catch for 1970–2005	5.0	5.7
M5	Median catch (1963–2005)	4.3	4.6
M6[b]	*Status quo* method	5.9	5.2
M7	0.75 × median of sensitivity analysis TAC	3.9	3.8
M8	Median of sensitivity analysis TAC	5.2	5.1
M9	1.25 × median of sensitivity analysis TAC	6.5	6.3
	Median of all TACs calculated in M1–M9	5.0	5.1

"Relative exploitation" is calculated as the catch divided by the NEFSC survey biomass index. This table describes the methods referenced in the legends for Figures 8–11.

[a]Relative exploitation rates for the southern management area were extremely high in 1993 and 1996 as a result of high landings and an extremely low exploitable biomass index. These years are considered outliers and were not included in the calculation of the average for the southern management area.

[b]Estimate of 2005 FY landings based on May 2004–January 2005 landings pro-rated to a full year using the ratio of landings in FY2004 to May 2003–January 2004 landings. Assumes that the 3-year average survey biomass does not change.

advice. New reference points were also suggested based on age-structured yield-per-recruit for fishing mortality (as before, but with a different assumption for *M*, the rate of natural mortality, which increased from 0.20 to 0.30), and on SCALE for biomass reference points. Existing and proposed reference points, with 2006 values, are summarized in the Table 5.

According to the existing reference points (in place at the time of the assessment), monkfish was overfished in both areas, but in the absence of reliable estimates of fishing mortality, status could not be determined with respect to whether or not overfishing was occurring. According to the new assessment model, monkfish is not overfished in either area and exceeds the biomass targets, meaning that monkfish in both management areas would now be considered "rebuilt". In fact, the new assessment suggests that the biomass never decreased below the biomass threshold in either area. The new assessment also concluded that fishing mortality is below the threshold, and, therefore, that overfishing

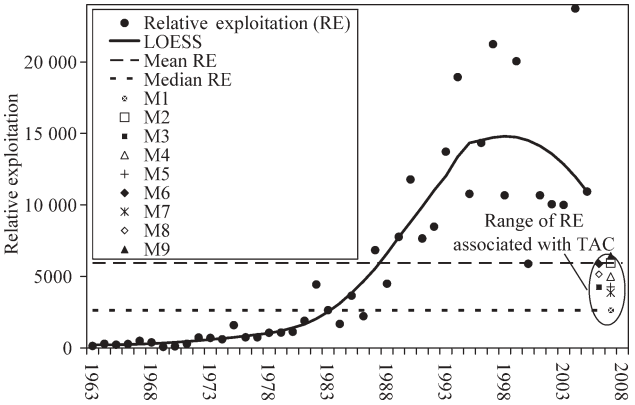

Figure 8. Time-series of the northern management area's relative exploitation (catch divided by survey biomass index) and relative exploitation associated with various TACs. Methods M1–M9, referenced in the explanatory caption, are described in Table 4.

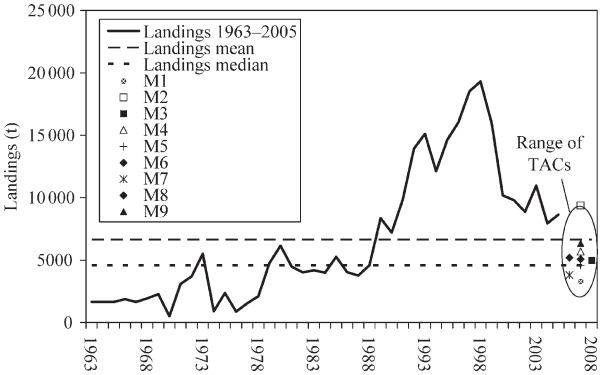

Figure 9. Southern area monkfish landings for the period 1963–2005 and the range of TACs estimated using various methods. Methods M1–M9, referenced in the explanatory caption, are described in Table 4.

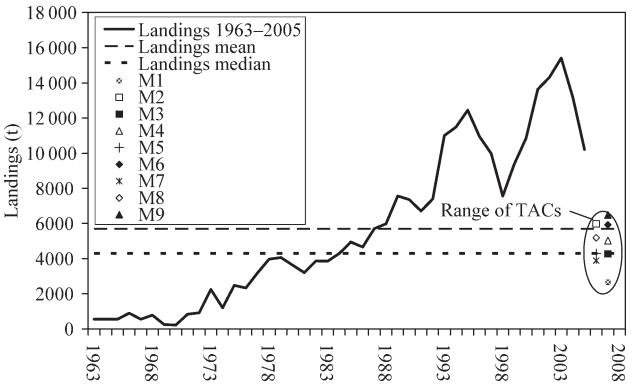

Figure 10. Northern monkfish landings for the period 1963–2005 and the range of TACs estimated using various methods. Methods M1–M9, referenced in the explanatory caption, are described in Table 4.

is not occurring in either area. In the northern management area, fishing mortality was above the target during 1993–2005, and above the threshold from 1994 to 1998. In the southern

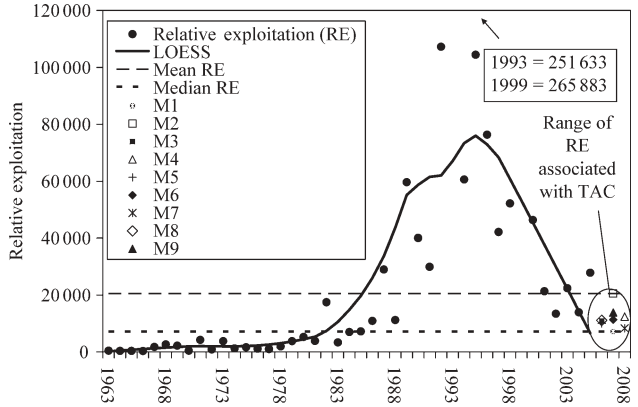

Figure 11. Time-series of the southern management area's relative exploitation (catch divided by survey biomass index) and relative exploitation associated with various TACs. Methods M1–M9, referenced in the explanatory caption, are described in Table 4.

management area, fishing mortality was above the target in 1996–1998, but it never exceeded the threshold.

This assessment, however, relies on a new analytical model and is reported with a number of caveats. Needless to say, this complete reversal of status determination (from overfished to rebuilt) poses a challenge to the management process in the near term, as a sufficiently precautionary management regime is developed for the next several years. [Note: At the time of the original drafting of this article, NMFS had not approved the new reference points as part of the FMP. On 28 April 2008, NMFS approved Framework 5, which contained the new biomass reference points.].

Future challenges at the science/management interface

In addition to the ongoing uncertainty about monkfish biology, improvements notwithstanding, several events and circumstances in the science arena are contributing to a changing, and very challenging, environment for managing the monkfish fishery in the next few years. New scientific information from a number of ongoing cooperative research projects may provide important insight into the stock structure, basic biology, and population dynamics of monkfish. These improvements could have important implications for managing the monkfish fishery. As new scientific information is incorporated into future stock assessments, the view of stock status and biological reference points will likely be revised, as uncertainty is reduced.

In addition, the National Marine Fisheries Service is replacing the primary fishery-independent survey vessel, the RV "Albatross IV", with a new vessel, the RV "Bigelow". This transition will require significant calibration work to adapt the new time-series of data to the 44-year series collected on the RV "Albatross IV". Calibration work was conducted in 2007 and 2008. Despite the tremendous effort and priority placed on this calibration work, it is unclear at this time whether the results will be robust enough to extend the RV "Albatross IV" time-series forward or if a new series will begin with the introduction of RV "Bigelow". This situation presents yet another challenge to the science behind monkfish fishery management.

Whatever the outcome of these events, one thing is certain: the management of the monkfish fishery in the northeastern US will have to evolve and adapt as new scientific information becomes available. The challenge for the management process will be to incorporate this new information in a way that does not impose dramatic changes on the industry in different directions with each new piece of information.

Discussion

The development of the monkfish fishery and of its management off the northeastern USA provides a striking example of the difficulties of fisheries management in a data-poor environment. As fishing effort expanded and signs of heavy exploitation were detected, participants asked for a management plan. Given the paucity of information on monkfish biology and population dynamics, as well as on trends in stock sizes and exploitation rates, available information from fishery-independent surveys was used. At the time, in the absence of a reliable way of combining all available information into a modelling framework, the results of the autumn NEFSC survey were considered to best represent trends in stock size. The length composition in both the survey and the fishery was used to estimate the values of total mortality. These analyses led to the adoption of the original FMP in 1999, which anticipated that the monkfish-directed fishery would be closed in Year 4 of the plan.

Whether attributable to the implementation of management measures or to increased recruitment as a consequence of favourable environmental conditions, or both, the survey indices for monkfish increased rapidly during the late 1990s and early 2000s, which led in Year 3 to the withdrawal of the closure of the directed fishery planned for Year 4, and the adoption of a TAC-setting mechanism based on the previous year's landings and the ratio of the current 3 year average of the survey to the target survey index. Because the method to set the target TAC for the next year relied on the previous year's landings, rather than the current year landings which are not available when the decision has to be made, the target TAC could end up increasing, when the survey results indicated that it should be decreased. In addition, scientific analyses indicated that the method used to calculate fishing mortality from the survey and

Table 5. Summary of existing and proposed reference points based on the new assessment model (SCALE).

Area	Reference point	Existing	2006 value	Proposed	2006 value
North	B_{target}	2.6 kg tow^{-1}	1.10 kg tow^{-1}	92 200 t	118 700 t
	$B_{threshold}$	1.3 kg tow^{-1}		65 200 t	
	$F_{threshold}$	0.2		0.31	0.09
South	B_{target}	1.84 kg tow^{-1}	0.87 kg tow^{-1}	122 500 t	135 500 t
	$B_{threshold}$	0.92 kg tow^{-1}		96 400 t	
	$F_{threshold}$	0.2		0.40	0.12

Existing biomass reference points based on a 3-year running average of NEFSC autumn survey biomass index. $F_{threshold}$ is based on F_{max}. Note: "Proposed" reference points at the time of the original drafting of this article were adopted into the FMP as of 1 May 2008.

fishery length compositions was unreliable and could no longer be used.

Population estimates based on survey indices from 2002 to 2006 remained stable or declined, failing to increase as needed to meet rebuilding goals. Although the Monkfish PDT offered reasonable target TACs and management measures in Framework 4, the NMFS was considering more drastic measures to try to meet the rebuilding targets by 2009. The assessment results released in August 2007 suggest that this will not be necessary, because monkfish is not overfished in either management area nor is overfishing occurring.

Large changes in the perception of the status of the stock, or its exploitation, are not unique to monkfish off the northeastern USA. In fact, most stocks assessed for more than 15 years will have gone through at least one large change in perception attributable to changes in either the methodology, the data used, or the assumptions. For monkfish, the new assessment appears to be superior to previous ones, because it makes better use of more data. However, there remain considerable unknowns about the behaviour of the model and many of the input data. Users of the assessment results should, therefore, not be surprised if future assessments differ from the current one. This suggests that fishery managers should react with caution to the assessment results (that is, not immediately remove existing controls on the fishery) and be receptive to future assessment results that may differ markedly from previous ones, particularly when the methodology has changed.

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