Providing management advice for deep-sea fisheries: lessons learned from Australia's orange roughy fisheries

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1. INTRODUCTION

All over the world, in marine and freshwaters, on continental shelves and in deepwater, fisheries have been found, established and overfished. Recent statistics indicate that 18 percent of the world's fisheries are overexploited and a further 10 percent are significantly depleted (FAO 2002). Deepwater fisheries seem particularly prone to a boom and bust cycle (Miller 1999, Moore 1999). Overfishing does not seem to be limited by the stage of a country's development, the political system or the level of scientific advice. Indeed many examples of overfishing have occurred in the world's most developed countries under the auspices of well-established management structures and in spite of high standards of stock assessment.

One of the core reasons why we have often failed to manage fisheries for sustainability is uncertainty. It is the objective of this paper to examine how scientific uncertainty and mistakes in judgement, combined with management and implementation shortcomings, led to the decline of the Australian orange roughy fisheries, and in particular the Eastern Zone fishery. This is not to suggest that this fishery is a unique example of uncertainty and mistaken judgement. Unfortunately, there is no reason to believe that similar shortcomings do not exist in the management of all fisheries, other natural resources and any endeavor where humans are required to predict future events and their part in controlling it.

2. ORANGE ROUGHY

Orange roughy is a long-lived species with a maximum age of over 100 years. It is distributed throughout the temperate regions of the world's oceans at depths of 450 to 1 800 m (Branch 2001). They form dense spawning and non-spawning aggregations on topographical features such as seamounts, but are also widely distributed at low densities in other areas. Commercial fishing for orange roughy first began in New Zealand in 1979 and now trawl fisheries for orange roughy occur in Australia, New Zealand, the North-East Atlantic, Namibia and Chile, as well as on the high seas (Branch 2001).

3. THE AUSTRALIAN FISHERIES

Australian orange roughy fisheries can be conveniently divided into the five following categories. The examples provided do not include all Australian orange roughy fisheries but are representative of the scientific, industry and management issues that are faced.

i. *Exploratory fisheries*, characterized by government subsidies and limited management controls, e.g. Sandy Cape 1986/87, Kangaroo Island 1988, Port Lincoln 1989, St Helens 1989–1992 (Figure 1).

ii. *Fishing for catch and reserve sustainability*, characterized by well-defined strategies and performance criteria to be achieved through controls on total allowable catch (TAC) (e.g. Eastern, southern and western management zones 1993 – until 2004 or fishery failure).

iii. *Recovery*, characterized by fishing at low levels to allow stock rebuilding while funding a well-defined monitoring strategy (proposed for St Helens 2004–?).

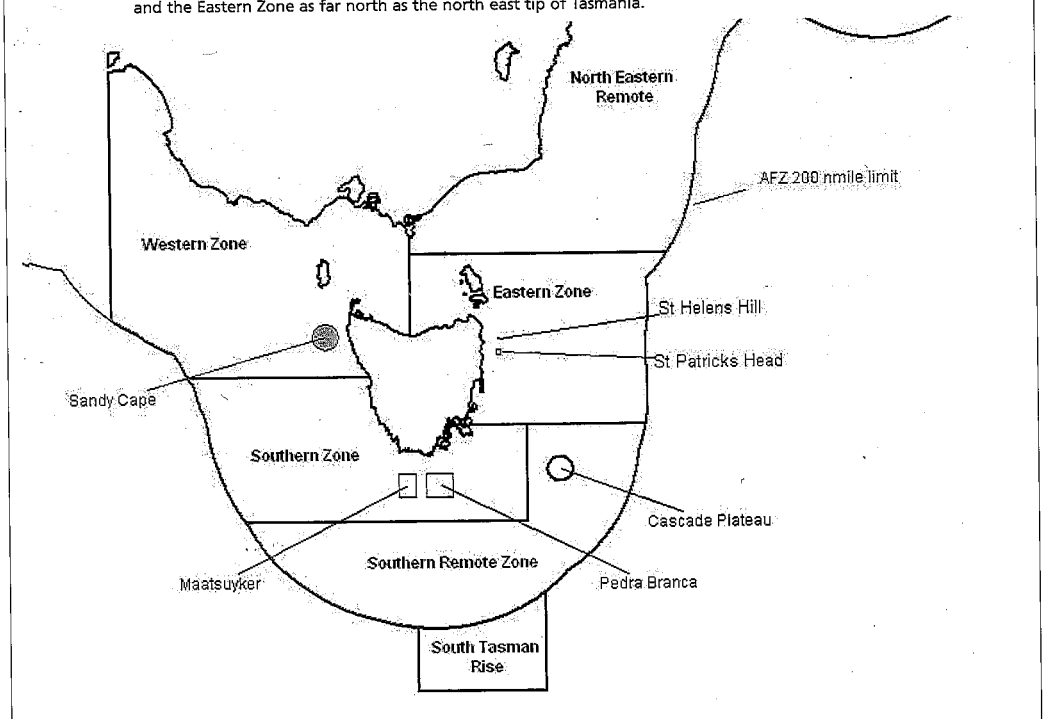
iv. *Precautionary management*, characterized by caps on total catch prior to the fishery and fishing at a level that is unlikely to lead to produce an unregulated fishdown (e.g. Cascade Plateau 1996–ongoing).

v. *Management under the 1982 United Nations Law of the Sea Convention (LOSC)*, characterized by internationally-agreed management of stocks that straddle national borders (e.g. South Tasman Rise 1997–ongoing).

FIGURE 1

Southeast Australia, the fishery management zones for orange roughy introduced in 1989 and main fishing grounds

Between 1984 and 1989 the South East Fishery was divided into three sectors, with roughy primarily being caught in the South West Sector that included, the Western, Southern, Southern Remote zones and the Eastern Zone as far north as the north east tip of Tasmania.



In this paper we first provide the background to the fishery – the Type 1 exploratory fisheries – and then concentrate on the eastern zone (including St Helens) for a discussion of the failure to fish for sustainability (Type 2). Development of a Type 3 fishery – as against a failed Type 2 fishery where the hard decision to close has not been taken – will not be discussed here. The Cascade Plateau is discussed briefly as an example of precautionary management (Type 4). Type 5 fishery management, under

the LOSC did not eventuate before 2001 because of lack of ratification by a requisite number of countries. This delay in ratification led to failure to cap South Tasman Rise catches with Australian vessels taking advantage of delays in the bilateral agreement to continue fishing. In 1999 the agreed bilateral TAC (between New Zealand and Australia) was exceeded by New Zealand vessels, while unregulated fishing occurred by two South African and one Korean vessels. The South Tasman Rise fishery has not recovered to date.

3.1 Management objectives, strategy and performance criteria

Up to the mid-1980s fisheries off Southeast Australia were managed by the states, primarily through input controls. In 1985, the Australian Fisheries Service (AFS), a division of the Department of Primary Industries, took over management of the fishery for the Commonwealth. The South East Trawl Management Advisory Committee (SETMAC), which has participants from industry, management, science and (more recently) the World Wildlife Fund for Nature (WWF), was established.

Principal Commonwealth objectives in the management plan for the southeastern trawl fishery were (Australian Fisheries, August 1984):

- ensuring through proper conservation and management measures, that the living resources of the Australian fishing zone are not endangered by over-exploitation and
- achieving the optimum utilization of the living resources of the Australian fishing zone.

There was no formal assessment group for the South East Fishery (SEF) and the Demersal and Pelagic Fisheries Research Group (DPFRG) – an unfunded research advisory group – was asked to take on this task. But perhaps the most significant aspect of the Commonwealth plan, as presaged by a ministerial announcement on 6 July 1981, was that the fishery would become closed to operators without a licence, effective on 31 March 1985; licence applications would be judged on "a demonstrated commitment to the fishery"(Australian Fisheries, August 1981). New licences would only be available for particular development or exploration programmes at least until 1987. However, restricted temporary licences would be provided to three large trawlers to determine viability of deepwater trawling off Tasmania; they would not be able to fish in other parts of the South East Fishery. This restriction did not last for long and by 1990, 67 vessels would report catches of orange roughy from the southwestern sector (Wayte and Bax 2002), while the number of tows in the sector trebled between 1986 and 1990 (Tilzey 1994).

In December 1991 management of the SEF changed from primarily input controls to output control in the form of an individual transferable quota (ITQ) system. Again, the AFS relied for control on the DPFRG to provide stock assessments prior to establishing TACs for the 16 species placed under quota. For orange roughy, different TACs apply to the zones in the fishery where substantial catches of orange roughy had been taken (Figure 1). In 1992, management of the fishery passed from the AFS to a statutory authority, the Australian Fisheries Management Authority (AFMA). In 1993 AFMA developed general management objectives, strategy and performance criteria for the South East Fishery and established formal assessment groups to provide scientific advice to managers. Specific objectives – a target reference point of 30 percent pre-fishery biomass and a limit reference point of 20 percent – for the orange fishery were developed in 1994 following input from the assessment group and were applied to manage the eastern, southern and western zones. The 30 percent target reference point was endorsed by an international review (Deriso and Hilborn 1994). In 1995, a time frame for recovery to 30 percent pre-fishery biomass of 5–10 years was established by the AFMA and this time frame was made even more specific in 1996 so that recovery was required by 2004 (i.e. 10 years from the first strategic plan; Bax 1995). At the same

time the action of closing the fishery, if the limit reference point of 20 percent was reached, was removed. Closure became an option for the assessment group to consider and there was no agreed management action if 20 percent was reached. Also, a 1993 performance criterion, that industry would generally accept the assessment and TACs, was removed by the AFMA, although it remained a unspoken rule for the assessment group (which was run on consensus) and became critical in delaying implementation of the results from the 1997 assessment.

The 1993/95 strategies and performance indicators remain unchanged despite their being impossible to achieve with the 2002 eastern zone biomass being estimated at 7–13 percent of the prefishery biomass (Wayte and Bax 2002) – there appears to be no formal mechanism to change them. In 2003 the AFMA Board asked SETMAC why the eastern zone orange roughy fishery should remain open. This is a difficult question to answer in the absence of achievable management objectives. While international reviewers recommended the formal evaluation of management procedures to identify one that has a high probability of stock rebuilding – i.e. one that is robust to data and model uncertainty (Francis and Hilborn 2002) – there is no funding for this work. In lieu of this, the assessment group provided estimated time to a detectable increase or recovery of the fishery under different assumptions and TACs and provided a plan that would monitor recovery on a three-yearly interval, while providing semi-quantitative monitoring in the other years so that any further precipitous decline would be detected (Wayte and Bax 2002). It was agreed that monitoring would be funded by industry based on the success that the orange roughy industry had had with industry-funded research and assessment for the Cascade Plateau fishery, and given that other funding sources were no longer available for ongoing monitoring. The strategies and indicators for this approach have not been defined.

3.2 Exploratory fisheries

The exploratory period of orange roughy fishing in Australia extended from the mid-1970s to 1992. It was a time of significant changes for the South East Trawl (SET) fishery. Starting in the mid-1970s, and especially since the declaration of the 200-mile exclusive economic zone in November 1979, the Commonwealth Government developed a range of policies to provide Australians with increased opportunities to exploit fishery resources. These ranged from boat building subsidies to exploratory fishing programmes, particularly in the SW Sector (Eastern, Southern, Southern Remote and Western zones, shown in Figure 1) where, following the New Zealand experience, it was hoped orange roughy aggregations would be found (Commonwealth Minister for Primary Industry, Peter Nixon in Australian Fisheries, October 1982). Fishers were well aware that quotas were being used in New Zealand to protect orange roughy stocks from overexploitation. Many would have concluded that they had better be seen to be in at the beginning of any promising new fishery if they were to be assigned quota later. Meanwhile, new research catches of orange roughy produced headlines in Australian Fisheries (e.g. Wilson 1982a). The first promising catches of orange roughy were taken off western Tasmania by the **R.V. Challenger** in late 1981 (Wilson 1982b). Using commercial and survey data, Wilson (1984) estimated the orange roughy resource to be 51 600 t with an annual yield of 4 125 t ± 1 300 t.

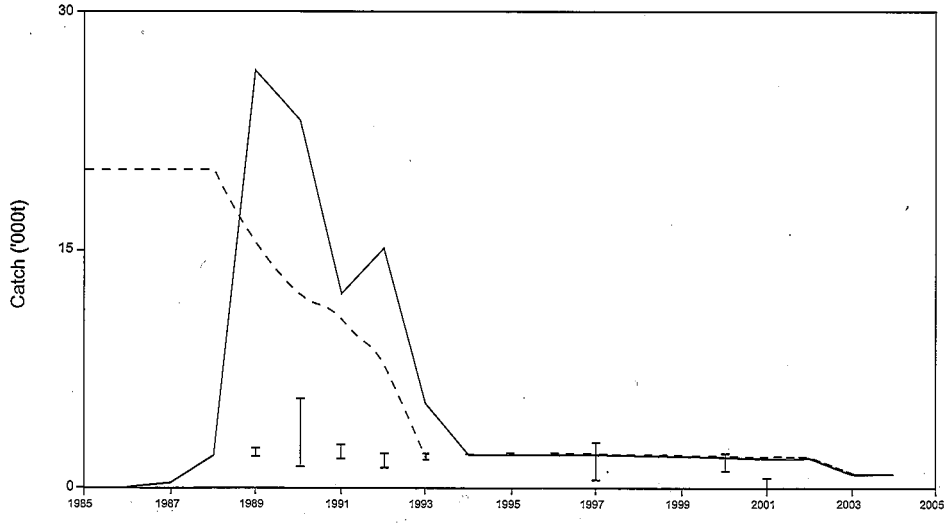
Exploratory commercial fishing for orange roughy commenced in 1982. Increased effort was produced by the granting of three restricted temporary licences to large trawlers (>32 m long) to encourage greater exploratory activity in the SW Sector (Tilzey 1994).The first substantial catches of orange roughy were taken off Sandy Cape, western Tasmania, in 1986 when a non-spawning aggregation was found (Figure 2). Several other non-spawning aggregations were found in this area and fished from 1986 to 1988. The number of shots increased by 50 percent over the same period as vessels moved in to the SW Sector from other areas of the SEF where overall the

number of tows declined 5 percent (Tilzey 1994). Based on area-swept methods it was concluded that 16 percent of the Sandy Cape and about 50 percent of the Beachport aggregations were removed in one year (Anon. 1988). These aggregations did not reappear a second year. Together with catches of dispersed orange roughy, landings ranged between 4 200 and 8 500 t per annum between 1986 and 1988. Early Australian catches were compared favourably with early New Zealand catches and the deepwater fishery was seen as entering a particularly "exciting phase"(Williams 1987). Scientific biomass estimates of hundreds of thousands to millions of tonnes in a small part of the area (Harden Jones 1987, Kenchington 1987) that would later be found to be mistaken can only have fueled the speculative fervor.

In June 1987, the AFS announced a 20 000 t catch limit, proposed a quota system and made an urgent request for an assessment of the resource. A preliminary ("inspired guesswork") assessment, critically based on fishers' observations and theoretical assumptions of packing density, suggested a biomass of 500 000 to 700 000 t between Sandy Cape and Cape Grim (Kenchington 1987). But because it was also assumed that roughy were more likely to be slow growing and long-lived (maximum age of 150 years; natural mortality = 0.03), and recognizing that the biomass could be off by a factor of 10 in either direction, Kenchington (1987) recommended an annual quota of 2 500 t and cautioned that optimum yield could be less than 1 000 t or more than 10 000 t. He recommended that the South East Trawl Management Advisory Committee (SETMAC) consider limiting catches during the fishing down phase[1], rather than having to face the disruption of a 90 percent reduction in quotas in five years time when the biomass built up over many years had been reduced and the fishery was reduced to the sustainable yield. He did however conclude that "this (limiting catches) is not a matter for biological analysis." Kenchington's 1987 assessment would never have an impact as after 5 000 t of roughy was taken from the Sandy Cape ground, primarily during a 90-day period in the summer of 1986/87, when catch rates remained at over 10–15 t/hr for 40 days (Merryl Williams in Anon. 1988). The fish did not return in numbers the following year and catch rates never went above the 1 t/hr background level.

FIGURE 2

Estimated total catch (solid line), Total Allowable Catch (dashed line) and assessment group recommendation (given as range) for Australian orange roughy fisheries (Data from Wayte and Bax 2002)



[1] It may be symptomatic of the optimism of the time, that Kenchington (1987) used the term "fishing up phase" to denote the practice of removing the non-productive biomass to maximize long-term sustainable yield.

Further orange roughy 'hotspots' were discovered in the Great Australian Bight. In 1988, seven vessels fished the Kangaroo Island aggregation; next year 27 vessels fished the Port Lincoln aggregation. Fishers experienced a short duration of good catch rates and depressed prices and the approach was characterized as a "gold rush" (Australian Fisheries, July 1989). Orange roughy catches in the entire Great Australian Bight have rarely reached a quarter of the 1988/89 catches since 1990 (Wayte and Bax 2002).

Australian scientists reviewing the small early fisheries off Sandy Cape and Beachport (the latter was rapidly fished down following a research vessel getting higher than average catch rates during a scientific survey (Anon. 1988) expressed concern that apparently significant fractions of the virgin biomass had been removed and that the current fishing process could be expected to rapidly deplete an unproductive population. "The management implications of this should be examined in more detail" (Anon. 1987). Scientists went on to recommend that a further build up of catching power during this period of transient high catches was to be avoided making the point that, given the low mortality rates, "very little catch is forgone by slow development of the fishery"(original emphasis, Anon. 1988). A feedback management policy was suggested to quickly recognize signals from the fished resource and modify management actions accordingly.

By 1989 the expected large sustained catches had not eventuated, leading the Australian Bureau of Agricultural and Resource Economics (ABARE) to conclude that the rapid increase in fishing capacity, resulting from industry expectations of a greater sustainable yield than had so far been justified, was likely to remain a major long-term problem with fish stocks put under greater fishing pressure than could be sustained (Smith 1989).

The situation changed rapidly and six months later it became clear that the fishery was just beginning. The discoveries of non-spawning aggregations on hills off southern Tasmania and a major spawning aggregation on a seamount off St Helens on the east coast of Tasmania led to a dramatic increase in catches to 37 000 t in 1989 and 58 600 t in 1990 (catches corrected for misreporting and loss) (Figure 2). It was heralded as an "orange roughy bonanza" (Australian Fisheries December 1989), and represented the first aggregations in Australia that were not fished out in the first year (Lyle *et al.* 1989). Catches were substantially higher than the 20 000 t limit introduced in 1987, and the 15 000 t TAC introduced as an interim management strategy by the AFS in 1989 (Tilzey 1994) for which there was no Commonwealth monitoring or enforcement. Following intervention by the Tasmanian minister for primary industry, and amid concerns over the apparent fragile biology of this deep-sea species, management controls on orange roughy fishing were introduced by the AFS. The Government Industry Technical Liaison Committee (GITLC) was established to promote closer cooperation between industry and scientists and in so doing to develop a stock protection strategy (Ross and Smith 1997). Further increases in catch were then prevented by the creation of the Eastern and Southern Management Zones (Figure 1) and associated TACs.

Catches in the Eastern Zone were 'limited' by a 15 000 t TAC in 1989 which was designed to achieve a "safe fishing-down rate (5 percent of the initial stock size per annum)."(SETMAC 20, 9 November 1989). Unfortunately the biomass estimate of 300 000 t used to set the TAC was unsupported by either scientific opinion or GITLC, although it did result in a TAC approximately equal to the catch taken that year. The TAC was reduced to a contingency level of 12 000 t in 1990 (until further scientific information became available). Scientists did not consider this to be biologically conservative given that yields for south eastern Australia were likely to be substantially less than New Zealand's total sustainable yield estimates of 15 000–20 000 t and unlikely to exceed 8 000–10 000 t (DPFRG 1990a). However, the 12 000 t limits caused some controversy with many fishermen concerned that their decreased share of the TAC due to more boats entering the fishery and low prices might make it impossible to keep

their boats at sea (Australian Fisheries June 1990). The number of boats landing orange roughy in Australia had increased 50 percent from 44 in 1988 to 67 in 1990 (Wayte and Bax 2002). In the same Australian Fisheries article, fisheries managers defended the TACs as being far better to 'err on the side of conservatism'.

The first quantitative acoustic estimates of the St Helens spawning aggregation were obtained in 1990 by CSIRO (Kloser, Koslow and Williams 1996). The spawning aggregation was estimated at 57 000 t (range 30 000 to 150 000 t), with an annual production of 2 700 t (range 1 300 to 5 500 t). Scientific advice was that the fishdown was almost complete (DPFRG 1990b). The group stressed the need for caution as only 1 to 3 percent of the adult virgin biomass might be able to be taken on a sustainable basis. The group drew attention to the severe depletion of the Challenger Plateau in New Zealand and consequent reduction in catches, and reiterated the need for caution in setting TACs, especially considering that TACs set too high would lead to collapse of the stock, while TACs set too low would result only in deferral of catch with little overall loss due to the long-lived nature of the species. TACs were reduced slightly to 10 700 t in 1991.

The 1990 acoustic survey result was reinforced by the 1991 survey and an independent egg-production estimate (Koslow *et al.* 1995). Survey results were independently reviewed at industry's request and led to the conclusions that the stock was depleted to between 34–67 percent of the initial biomass (i.e. potentially already below the then target level of 50 percent unfished biomass) and that the sustainable yield was likely to be in the range of 1 700 to 2 600 t (DPFRG 1991). The Group reiterated the need for caution given the long time required to recover from overfishing, whereas fish not taken this year would remain in the stock for many years. The 1992 TAC was reduced further to 7 423 t. This ended the exploratory stage of this fishery. The 1991 acoustic and egg production surveys of the St Helens spawning stock were repeated in 1992. The acoustic target strength estimate was revised downwards following advice from the independent reviewer, and the backscatter estimation algorithm adjusted following advice from the manufacturer. At the same time the area of the survey was increased to include fish echoes received away from the St Helens hill. The acoustic backscatter from other species was removed based on their abundance in a trawl survey and estimated target strength. Together, these four adjustments led to an overall 37 percent decline in the previous years' St Helens biomass estimates. An acoustic survey also took place in the Southern Zone (DPFRG 1992). Maximum likelihood stock reduction analysis models were developed based on Mace and Doonan (1988). These would later develop into a full Bayesian approach, which theoretically can take into account the full range of uncertainties related to models and parameter values, and enables the application of a formal decision-analysis approach to fishery management (Punt and Hilborn, 1997). Biomass for the Eastern Zone was estimated at 24–40 percent of pre-fishery biomass and sustainable yield at 1 200–1 500 t. If the fish in the Eastern and Southern zones were considered one stock then biomass was reduced to 12–40 percent pre-fishery biomass and sustainable yield to 2 100–3 000 t. The Group concluded that the 50 percent fishdown target that they had recommended for orange roughy in 1990 (DPFRG 1990b) had already been exceeded at St Helens.

Subsequent analyses of the catch data and discussion with industry suggested that catches (including that with burst nets, discarding and misreporting) for the four years 1989–1992 were 26 236, 23 200, 12 159 and 15 119 t, or 68 percent higher than the TACs (Wayte and Bax 2002). Subsequent analyses would also show that the fishing down target of 50 percent of virgin biomass repeatedly recommended by scientists had been exceeded. For example, at the end of 1992 the Eastern Zone biomass was 25–30 percent of prefishery biomass. The Australian Fisheries Management Authority (AFMA), a statutory authority, replaced the Australian Fisheries Service, a division of the Commonwealth Department of Primary Industries, in 1992. SETMAC remained the

management advisory committee responsible for orange roughy. An AFMA-appointed advisory group – often named the Orange Roughy Assessment Group (ORAG) – was initiated and included scientific, management and industry members. DPFRG, an independent group that had specifically excluded management and industry members, reverted to the review and coordination of research in 1993 – its original objective. One of AFMA's first objectives for Australia's South East Fishery was to ensure continuation of a sustainable fishery.

3.3 Management for sustainable yield

Eastern zone TACs were reduced markedly in 1993 to what was the upper range of the estimated sustainable yield – 1 500 t. Sustainable yields were less than had been previously estimated following downwards revision of the acoustically-derived biomass estimates. Allocated TACs would be a third higher after accounting for carryovers (uncaught TAC) from the previous year. This decrease in eastern zone TAC was substantially compensated by starting an "adaptive management experiment" or pulse fishdown in the southern zone, following the recommendations of the industry consultant. This resulted in a combined TAC of 13 000 t in comparison to a recommended sustainable yield of 2 100 to 3 000 t. The adaptive management experiment would ultimately prove unsuccessful because of misreporting of where catches were taken and the lack of a monitoring programme capable of tracking the fishdown, but southern zone TACs would remain well above the estimated sustainable yield for three years. The high TACs decided upon for the southern zone also ignored the risk that the fish in the eastern and southern zones were a single stock. As of 1993, the advice was that there was some mixing between zones, and a single stock could not be ruled out. The estimated catch in 1993 from the eastern zone was three times the estimated maximum sustainable yield and agreed TAC (Figure 2).

Precision of scientific advice improved slightly in 1993 with an extra year's acoustic survey and inclusion of an egg production survey (Koslow *et al.* 1995). The 1994 TACs allocated for the eastern zone fell within the estimated yield. However a special orange roughy workshop in early 1994 (CSIRO and TDPIF 1996) detailed the uncertainties associated with the assessment and industry requested an external review of the 1994 assessment. This occurred later the same year (Deriso and Hilborn 1994). The reviewers suggesting some improvements, but overall concluded that "the methods used to measure abundance and calculate stock trajectories are consistent with the best methods used elsewhere in the world" and the assessment itself was "much less ambiguous" than orange roughy assessments elsewhere (as all indices and assessments were consistent). Importantly, the new AFMA strategy of maintaining the stock at 0.3 of virgin biomass was found to be "consistent with what is known of ecologically sustainable development" and the reviewers recommended that the AFMA adopt a policy that would be expected to keep the stock above the 0.3 level 50 percent of the time in a five-to-ten year time horizon. This led to the codification of the management strategy of there being a ≥ 50 percent chance that the biomass was above 30 percent of the original spawning biomass, which later was refined to providing a 50 percent chance that the biomass would be above 30 percent of the original biomass in five-to-ten years (1995 assessment, Bax 1995), subsequently tightened to a 50 percent chance by 2004 (1996 assessment, Bax 1996). This was a significant departure from the original DPFRG advice that the target biomass should be "not less than half the virgin biomass", but appeared to have some support in the fisheries literature, which suggested that a limit reference point of 20 percent was not unreasonable (FAO 1993). Importantly, industry agreed to the assessment after this review, accepting in the process the much lower TACs than had been set at the start of the fishery. The concerted exploration of new areas, such as the Cascade Plateau, was triggered by the reduced TACs for the eastern and southern zones.

In 1994, following on from the new management strategy the assessment group estimated the catch levels that would give a 50 percent probability of being above 30 percent pre-fishery biomass in 2004. The catch level of 2 000 t recommended by the assessment group for the eastern zone was adopted by AFMA as the 1995 TAC, while the combined-zones TAC remained double the recommended level, being still part of the, by now, discredited adaptive management experiment. By 1995 it was estimated that there was a 73–75 percent probability of the stock being below the 30 percent of prefishery biomass target (if the fish in the two zones were one stock). TACs in both the southern and eastern zones were set at the level required to reach the target biomass in 2004.

The 1996 assessment process raised further uncertainties. The industry consultant attending the meetings questioned the values of natural mortality being used in the assessment, especially as there appeared to be some bimodality in the only catch at age curves available. The assessment group could not determine which of the two natural mortality rates was correct (0.045 or 0.064) and henceforth it was decided that both would be reported in assessments. This had the unfortunate effect that under one scenario, reduction in the combined eastern and southern zones TAC to 2 800 t was essential if the strategic objectives were to be met, while under the other scenario no reduction from the 1996 TAC of 6 000 t was acceptable. The southern zone TAC 1997 was reduced to 4 000 t, above the 3 200 level recommended by the assessment group.

There was increased concern among scientists during the 1997 assessment that the 2004 target could not be met (Bax 1997). These concerns were due to a recently completed study on otolith shape, which added to the probability that fish from the eastern and southern zones were from a single stock (Robertson *et al.* unpublished ms). In addition, refinement of earlier acoustic abundance estimates, due to a redefined survey area (based on improved topography), manufacturer calibration error, and corrections to inconsistent assumptions of acoustic deadzone height for the earlier surveys led to reduced biomass estimates in recent years, but a higher biomass estimate for 1990 (Bax 1997). Further complicating the assessment was the apparent redistribution of fish between St Helens (the traditional main ground), and the nearby St Patricks Head so that catch and effort at the two areas was approximately equal (Figure 1). This cast doubt on the 1996 acoustic biomass estimate of the fish at St Helens derived from the first acoustic biomass estimate since 1992. Future population projections were no longer provided for the eastern zone alone and under the assumption of a lower rate of natural mortality a reduction in catches of more than 50 percent was required to meet management goals for the combined zones. Estimates using the higher rate of natural mortality indicated that no decrease in catch levels was necessary. Industry disagreed with the 1997 assessment results and included a separate position statement in the annual assessment report (Bax 1977). As a result, eastern zone TACs would not be reduced until 2001. Southern zone TACs were reduced to 1000 t but remained far above the catches taken.

Stock assessments were halted in 1998 and 1999 while the available assessment group resources were redirected to address industry concerns over the 1997 assessment. There was a continued shifting of effort to St Patricks Head and since 1999 catches there have been double those on St Helens (Wayte and Bax 2002). The assessment in 2000 had the agreement of industry that all that could be done had been done to address their concerns. However the assessment did not indicate the resource was in any better condition than estimated in 1997. Assuming natural mortality of 0.048, a zero catch (combined zone) or a maximum of 1 000 t (eastern zone alone) was all that could be taken. Under the higher rate of natural mortality (0.064) the existing catch of 2 000 t (eastern zone) or 2 350 t (combined zones) would meet the agreed management goals for the fishery. TACs for 2001 remained unchanged at 2 000 t for the eastern zone and 2 700 t for the combined zones.

Some of the ambiguity from reporting on two possible levels of natural mortality was reduced in 2001 by fitting the assessment model to the age composition data and, with catches being maintained at the same level as previous years, the outlook became steadily worse. While under some scenarios it was still possible that strategic objectives could be met, overall it was "increasingly unlikely that AFMA's performance indicator can be met without a substantial reduction in the Eastern Zone TAC" (Wayte and Bax 2001). TACs for the following year were reduced by 10 percent following a SETMAC policy of not reducing TACs by more than 10 percent to reduce disruptions to industry and concerns over what effect displaced effort, especially from the larger vessels, would have on other already fully or over-exploited inshore fish species.

An additional age composition sample taken in 2001 further reduced assessment ambiguities (M was now estimated at between 0.039 and 0.042, instead of the range of 0.045 to 0.064 that had been used since 1996) and the 2002 assessment made it clear that, with less than 15 percent of prefishery biomass remaining, "the AFMA performance criterion for this fishery will not be met even with a zero catch."(Wayte and Bax 2002). Additional modelling indicated that the eastern zone performance criterion would not be met for 6–17 years even with a zero catch, or 9–27 years with continued catches of 800 t. The 2002 TAC was set at 800 t, but notice was given that this would not necessarily be continued. Given the implications for industry of the 2002 assessment, a second international review was requested (this time by the assessment group). While the reviewers had specific recommendations on how the assessment could be improved, overall they found the assessment to be "consistent with world best practice", and the stock to be "at a level of biomass that most biologists would consider too low"(Francis and Hilborn 2002). The reviewers gave support to 40 percent of prefishery biomass being a commonly accepted target biomass level, but stressed that what was most important was that the stock be demonstrated to be in the process of rebuilding.

Between 1993 and 2003, scientists had recommended that in aggregate between 10 000 and 18 000 t could be caught if AFMA's performance criteria were to be met. Resulting TACs were always closer to the upper end of the range than the lower end. Over the same period, aggregate TAC was 20 000 t and actual catch 3 000 t higher.

3.4 Precautionary management

The Cascade Plateau is a rocky seamount 125 nm ESE of Hobart, Tasmania that has been fished consistently since 1996. A 1 000 t precautionary quota had been set for this fishery by SETMAC before consistent fishing began. As TACs for eastern and southern zones declined, a few operators (with larger vessels) started to explore the Cascade Plateau. In 1996 863 t were caught and in 1997 the 1 000 t trigger was reached by late April. AFMA closed the fishery and requested that the assessment group consider the Cascade Plateau stock status. In May of the same year a research and fishing proposal was developed by ORAG and submitted to AFMA to support development of a long-term management strategy for this fishery.

The research and fishing proposal was designed to be precautionary, in effect requiring demonstration that fishing on the Cascade Plateau would be 'safe' for the stock, instead of scientists having to prove that it would have an adverse effect. It was proposed that a controlled level of ongoing commercial fishing would be allowed monitored closely by scientific observers. A levy base was established to support a range of scientific studies leading to an acoustic or egg production biomass estimate of the spawning aggregation (e.g. Prince and Diver 1999, Prince and Diver 2001). Given this cooperative research approach, the 1 000 t trigger was increased to a 1 600 t TAC. To increase knowledge on the dynamics of orange roughy on the Plateau, the 1 600 t TAC was divided into four 400 t quarterly TACs providing year-round information and reducing the potential for fishing to concentrate on the spawning aggregation if the fishery were to start to decline.

From 1998 to 2003, the 1 600 t TAC has been caught, the spawning aggregation defined and delimited and a type of acoustic monitoring by industry vessels developed. Acoustic biomass estimation was not practical with the equipment available, although estimates of school volume gave some reassurance to ORAG that the aggregation was not in precipitous decline (Wayte and Bax 2002). As increasingly sophisticated acoustic equipment became used in the fishery, an acoustic estimate of the spawning biomass was made in 2003 using methods comparable to earlier scientific surveys in other Australian fisheries. The results of that survey will be available before the 2005 Cascade Plateau TAC is set.

4. DISCUSSION

Exploitation of Australia's orange roughy fisheries has been characterized by uncertainty in stock structure, standing stock and sustainable exploitation rates. Looking forwards, uncertainty is a somewhat benign and intellectually stimulating, if sometimes frustrating aspect of interacting with complicated systems. Looking backwards, uncertainty is error, misjudgment and wishful thinking.

Uncertainty is often understood as implying that there is range of possible values around the best estimate, and that this range is somewhat symmetrical, although not perhaps on an arithmetic scale. For this fishery, uncertainty has been characterized almost uniformly by overly optimistic interpretations of the present and future states of the fishery. Looking back at the history of scientific advice during the exploratory stage of the fishery, starting with Kenchington (1987) for the Sandy Cape fishery through to DPFRG for the St Helens fishery (DPFRG 1990a) catches of several thousand tonnes were recommended. TACs were set an order of magnitude higher and were either not enforced or failed to take into account lost and discarded fish, so catches were considerably higher.

At various and repeated, times during the exploitation of these fisheries fishery scientists and managers have made mistakes on where we were, where we were going, and how we were going to get there. In the exploratory stage of the fishery, misinterpretation of bottom features as fish shoals, taken together with high short-term catch rates, and a goldrush mentality to fishing in an almost unregulated fishery, led to unrealistic expectations and excessive transfer of capital into the fishery. This was no doubt influenced by the large orange roughy stocks that had been previously found and fished in New Zealand, declining catches elsewhere in the South East Trawl fishery and by the understanding among fishers that if quotas were introduced they would be based on catch history, so there was no time to lose in getting into their orange roughy fishery. Subsequently, during what should have been the sustainable fishery – after industry had agreed to much lower, but sustainable TACs – errors in acoustic biomass estimates and new data on stock structure and age composition led to recommendations for further decreases in TACs, that were implemented only after several years' delay.

The assessment group responsible for providing orange roughy advice still does not know where it is going with this fishery. At the start of the fishery, scientific advice was clear that biomass should not be reduced below 50 percent of prefishery biomass (DPFRG 1990b). This limit was soon passed and in 1994, AFMA, acting on advice from the assessment group, determined that 30 percent of prefishery biomass was the target, which was subsequently endorsed by international reviewers (Deriso and Hilborn 1994) and a timeframe to reach it was established (for fisheries already below 30 percent). Following revised scientific advice and the failure to manage to this target level, a rebuilding target of 40 percent of initial biomass was put forward by the assessment group and again endorsed by international reviewers (Francis and Hilborn 2002). This target has yet to be accepted by AFMA.

Last, even if there was agreement on a rebuilding target, there has been doubt about how to get there. Total allowable catches have been consistently set at, or above, the highest levels recommended by scientists and estimated catches consistently exceeded the TAC at the start of the Eastern Zone fishery. In addition, and despite DPFRG concluding that the "greatest danger to the resources and industry is... from a build up of catching power during the transient period of high catches" (Anon. 1988), there seems to have been no restriction on permits given to develop the orange roughy fishery and the number of shots trebled between 1986 and 1990 (Tilzey 1994). Scientists expressed their concern that their advice was often seen as overconservative, while Australia's record on managing fish resources at the time did not seem overly conservative given that most resources were maximally exploited and some had collapsed (Kearney 1989). Either the scientists had not been conservative enough, or else managers, because of the uncertainty in advice, had not accepted that short-term gains or stability should be sacrificed in the interest of long-term resource conservation (Kearney 1989).

Part of the process of delivering effective management advice is to ensure that decision makers recognize the full range of uncertainty before they make decisions. Scientific uncertainty is just one component of epistemic uncertainty that incorporates the perceptual, intellectual, and linguistic processes by which knowledge and understanding are achieved and communicated. It is an important part of the process of how scientific advice (and associated uncertainty) on the status of a fishery gets translated into management action. Fisheries management is not unique in the difficulty of making reliable predictions. A recent paper spells out a story for business executives that will be only too familiar to those involved in managing the world's fisheries:

> *"When forecasting the outcomes of risky projects, executives all too easily fall victim to what psychologists call the planning fallacy. In its grip, managers make decisions based on delusional optimism rather than on a rational weighting of gains, losses, and probabilities. They overestimate benefits and underestimate costs. They spin scenarios of success while overlooking the potential for mistakes and miscalculations. As a result, managers pursue initiatives that are unlikely to ... ever deliver the expected returns"*
> (Lovallo and Kahneman 2003).

It might be considered unrealistic to believe that we are able to predict the future with any accuracy – at least if we base our predictions solely on our own understanding of the local system. One way to bring in additional information and potentially improve our accuracy could be to bring in information from outside sources. In providing stock assessment advice, this could involve basing forecasts on how successful similar forecasts (by species, region or jurisdiction) have been in the past. In fisheries management, a precautionary approach would be to take best (unbiased) estimates from stock assessments and then adjust them on the basis of how successful others' best estimates have been in the past. How would the history of Australia's orange roughy fisheries have been different if we had taken the New Zealand prior experience in overfishing orange roughy, decided that their assessment science was not dissimilar to our own and therefore concluded that we should be more conservative than our best science recommended? Unfortunately this outside view is rarely popular, often being viewed as a crude analogy to superficially similar instances and is usually rejected in favour of the inside view which is seen as a serious attempt to come to grips with the complexities of a unique challenge. Neither approach can be expected to be perfect, however the outside view has repeatedly been shown to be more accurate in systematic research (Lovallo and Kahneman 2003). Looking towards the future we recommend that both the inside and outside views be used in providing management advice for deep-sea fisheries. In this way we can learn from the costly lessons that constitute much of our history in deep-sea fisheries management.

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THEME 4

Technology requirements