Development of methods and information to support the assessment of economic performance in Commonwealth fisheries

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The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the Federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

Designing and implementing measures of economic performance in Commonwealth fisheries has taken a number of years, starting with a series of FRDC sponsored workshops on economic efficiency in 2004 and 2005, and culminating in the recent successful establishment of maximum economic yield targets and productivity measures by Australian Fisheries Management Authority in a number of key fisheries.

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- Given the problems with open access resources and the effectiveness of modern fishing technology, there are few fisheries, if any, which will not be both biologically over-exploited and unprofitable unless they are managed effectively. For a fishery to be economically efficient requires setting correct management targets which are enforced effectively and delivered in a least-cost and incentive-compatible manner. An efficient outcome is important because it protects fish stocks and guarantees sustainability, and because it ensures resources will be correctly allocated to the fishery. That is, the cost of fishing at a given harvest level is minimised. Inefficient fisheries suffer low profits and excessive boat capital or fishing capacity, with the outcome of 'too many boats chasing too few fish'.

- Part of the solution to over-fishing and unprofitable fisheries is to adopt the right target level of effort, or catch, in the fishery. The correct target maximises profits regardless of changes in prices and the costs of fishing.

- Another important part of the solution is to use an instrument that gives industry a stake in protecting the future of the fishery to achieve the target. In other words, maximising economic efficiency requires catch and effort levels to be set appropriately and industry to have an effective property right to the harvest which removes the incentive for a wasteful and inefficient 'race to fish'.

- This report is part of a Fisheries Research Development Corporation (FRDC) project on the *Development of methods and information to support the assessment of economic performance in Commonwealth fisheries*. The project included two workshops and a number of presentations at the Australian Fisheries Management Authority (AFMA), the Australian Bureau of Agricultural and Resource Economics (ABARE), resource assessment groups (RAGs) and fisheries management meetings, along with specific implementation of efficiency measures in the northern prawn fishery, south east trawl fishery and the eastern tuna and billfish fishery. The northern prawn fishery has subsequently adopted maximum economic yield (MEY) as its target, and AFMA has now moved to provide economic efficiency measures, including MEY and other productivity indicators, for all of its fisheries where possible.

- The principal underlying the definition of economic efficiency used in this project is maximum economic yield (MEY). MEY is an effort or catch level that maximises the present value of current and future profits in the fishery, consistent with AFMA's mandate to conduct fishery management in a manner which maximises benefits to the Australian community. This target changes with changes in the price of fish and

the cost of fishing but, if appropriately set, will always imply that fishery profits are maximised. When the price of fish decreases or the cost of fishing increases, the target calls for larger fish stocks and less fishing effort. When the price of fish increases or the cost of fishing decreases it is appropriate to fish more intensively, with larger effort or catch levels. MEY generally involves fish stocks which are larger than stocks at maximum sustainable yield (MSY). In this sense, MEY is more 'conservationist' than MSY.

- For MEY to hold, vessel efficiency must be maximised. In other words, vessels must use the right amount and combination of inputs, including vessel capital, to minimise the cost of harvest at the MEY catch level. This will generally require fishery control instruments to encourage autonomous adjustment and allow fishers to freely combine inputs such as gear, engine size, crew and bait in proportions to minimise costs.

- MEY estimates in this project are applied to the Commonwealth managed northern prawn fishery (NPF) and the south east trawl fishery (SETF). In almost all cases, current stock levels are much smaller than stock levels at MEY, implying substantial losses in sustainable profits in the fishery. The NPF has now moved to a MEY target, and the SETF will move to a MEY-based target as part of the Commonwealth Fisheries Harvest Strategy Policy (Commonwealth of Australia 2007). Model results for the SETF also calculate optimal current total allowable catch (TAC) values as a transition to MEY. This generally requires considerable cuts in current harvests of most important species.

- Vessel-level efficiency studies have also been undertaken for the NPF and the SETF. The NPF introduced a MEY target but the instrument used in the fishery (input controls) still generates considerable efficiency losses. In the SETF the individual transferable quota (ITQ) instrument is rights-based and easily transferable (requirements to ensure vessel-level efficiency), but the target is not appropriate. Until recently, TAC was generally set far larger than MEY in this fishery, and in many cases TAC is far from binding. The efficiency studies in all cases show these fisheries are over capitalised. The recent structural adjustment package will partly address this concern, but only if the reduction in fishing capacity is accompanied by targets and policies that guarantee economic efficiency.

- Finally, the project developed alternative performance indicators, in particular productivity indexes and profit decompositions. Productivity measures are a basic indicator of the ratio of output to inputs. Often this measure is stock adjusted in a fishery to account for changes in abundance. Holding stock and inputs constant, an increase in output indicates an increase in productivity. If output falls under the same conditions, productivity falls. Profit decompositions, on the other hand, decompose profits into various components: for example, output, inputs and productivity. Profit decompositions allow the effects of changes in, for example, fuel prices, on profits to be determined. In this report profit

decompositions are applied to both the SETF and the eastern tuna and billfish fishery.

- The suite of performance indicators used in this project — MEY, vessel-level efficiency, productivity indexes and profit decompositions — provide AFMA with the required tools to measure and report fishery efficiency and economic performance. The indicators which would be appropriate for each AFMA managed fishery are also determined. Where the data allows indicators are being used to give a complete picture of fishery performance. In almost all cases, profit decompositions and basic index numbers will provide a benchmark of performance.

1 Introduction

The traditional command and control approaches to fisheries management which focus on input restrictions and total catch limits, fail to provide incentives for those who fish to do so efficiently and do not give industry a long-term stake in the future of the fishery (Grafton et al. 2006a).

These approaches often result in effort creep (increases in fishing power) and excessive and wasteful competition, with both inappropriate levels and combinations of inputs used to catch fish (Kompas et al. 2004). The negative consequences of input and output controls are illustrated by recent experience in Australia's Commonwealth fisheries.

In the past 10 years, the Australian Government has committed $90 million a year to fisheries research and development, undertaken buybacks of fishing effort, implemented detailed scientific fishery management plans which incorporate strong stakeholder involvement and expanded its National Representative System of Marine Protected Areas. Despite such strategies, substantial effort creep in input-controlled fisheries, and the inability to decrease total allowable catches (TACs) when necessary in output controlled fisheries, have contributed to a number of fish stocks managed by the Australian Government being assessed as overfished. Larcombe and Begg (2008) report 11 stocks managed by the Australian Government were assessed as overfished in 2007 and six stocks were assessed as subject to overfishing. The economics of many fisheries has also suffered. ABARE surveys have consistently shown close to zero net returns in most Commonwealth fisheries in the past several years (Kompas and Gooday 2005).

In Commonwealth fisheries the government holds title to the resource on behalf of the Australian community as a whole, meaning the government has primary responsibility for ensuring the net value of the resource to the Australian community is maximised. In the absence of government intervention, resources will not be allocated to fishing activities in an efficient manner by the market. As a result, governments have a specific role to play in preventing the market failures which occur in open access fisheries and lead to unsustainable harvests and the dissipation of economic returns.

This is in stark contrast to the role government plays in other sectors of the economy. For example, it would be possible for the government to artificially increase returns for a particular industry by limiting the supply

of a good to less than that demanded. However, while this intervention would benefit those producing the goods in question, there would be a loss to consumers through increased prices and a loss in economic efficiency because insufficient resources would be employed in producing the good in question. This is not the case with fisheries resources. Government intervention can eliminate unnecessary increases in fishing costs from 'race to fish' behaviour and constrain the resources used in the sector to an efficient level.

Any intervention to improve on the biological and industry profitability outcomes achieved under open access will effectively determine the potential profitability of the fishery. Requiring fishery managers to pursue economically efficient management ensures government intervention produces the largest benefits possible. In this sense it is important to note fisheries can be managed in an ecologically sustainable manner without producing net economic benefits, and in some cases produce net costs, to the Australian economy.

Management regimes will determine the net return the community receives from the use of its fishery resources by controlling the total level of harvests (by whatever means) and contributing to the incentive structure fishers operate within. In the absence of a fisheries royalty charge, the only return the community receives from the commercial use of fisheries resources is through the profits made by commercial fishers. Management regimes that do not effectively control fishing harvests and effort do not allow for the returns to be maximised from expenditure on fisheries management and research.

Part of the solution to over-fishing and unprofitable fisheries is to adopt the right target level of effort, or catch, in the fishery. The correct target maximises profits regardless of changes in prices and the costs of fishing. It is also necessary to implement this target with an instrument that gives industry a rights-based incentive to protect the fishery.

In other words, maximising economic yield requires setting catch and effort levels appropriately and for industry to have an effective property right to the harvest which removes the incentive for a wasteful and inefficient 'race to fish' and ensures the fishery is economically efficient. An efficient outcome is important because it protects fish stocks and guarantees sustainability, and also ensures resources will be allocated to the fishery in a way that minimises the cost of harvesting.

Finding the right target and the best instrument requires an assessment procedure, along with a set of tools to analytically determine the best economic approach to the fishery. An economically efficient outcome occurs when the sustainable catch or effort level for the fishery as a whole maximises profits, or creates the largest difference between discounted

total revenues and the total costs of fishing. This point is referred to as Maximum Economic Yield (MEY). This target changes with changes in the price of fish and the cost of fishing but, if appropriately set, will always imply that fishery profits are maximised. When the price of fish decreases or the cost of fishing increases, the target calls for larger fish stocks and less fishing effort. When the price of fish increases or the cost of fishing decreases it is appropriate to fish more intensively, with larger effort or catch levels.

For profits to be maximised, the fishery must also apply a level of boat capital and other resources in combinations that minimise the costs of harvest at the MEY catch level. In other words the fishery cannot be over-capitalised, and to minimise the cost of a given harvest, vessels must use the right combinations of inputs such as gear, engine power, fuel, hull size and crew.

There are a number of benefits to pursuing economic efficiency in a fishery. First, profits are maximised regardless of changes in the price of fish or the cost of fishing. Profits may be low when the price of fish is low or the costs of fishing are high (for example, because of an appreciation of the exchange rate in Australia or the rising price of fuel), but will still be maximised under this target.

Pursuing economic efficiency will also ensure the costs of harvesting are minimised, which improves the international competitiveness of domestic fisheries and the resilience of the industry to economic and environmental shocks. Also, an efficient level of catch at MEY is a sustainable harvest and as such is preferable to a biological target like maximum sustainable yield (MSY). Depending on prices and costs, profits can be zero or even nega-tive at MSY. If sustainability is the goal, as it should be, it makes sense to select a sustainable yield which guarantees the largest return from the use of the community's fish resources regardless of the circumstance. In addi-tion, at most biological growth rates, as well as practical discount rates and (stock dependent) harvesting costs, pursuing economic efficiency will imply an equilibrium stock of fish larger than that associated with MSY. In this sense the efficient level of harvest at MEY is more 'conser-vationist' than MSY, and provides additional environmental benefits and added resilience to unforeseen environmental shocks to the fishery. Finally, pursuing economic efficiency helps prevent over-capitalisation and ensures resources are allocated to the fishery at correct levels, with surplus vessel and fishing capital allocated to their next best alternative uses in the economy.

Along with MEY measures there are a number of other useful indicators, such as direct efficiency measures (eg. stochastic frontiers) and produc-tivity indicators. Stochastic frontiers measure vessel level efficiency to determine whether harvest is at its maximum level, given inputs, or whether the cost of fishing at a given harvest level is minimised.

This report discusses and illustrates the methods used in the assessment of fisheries and provides case studies to illustrate how these methods can be employed in specific Commonwealth fisheries. The focus is on MEY, productivity measures and stochastic cost and production frontiers.

2 Why regulate a fishery

Fisheries are regulated to protect the environment, ensure biological sustainability and to avoid problems associated with open access or common property resources — the so-called 'tragedy of the commons' (Hardin 1968).

This situation arises because fishers lack the right to exclude others from using (if not abusing) the resource. This lack of clearly defined property rights generates 'race to fish' behaviour, whereby individuals make investments in larger boats, bigger engines and better gear to gain a competitive edge over their fishing rivals. Some fishers are better off in this process, at least for some period of time, but as all fishers in the fishery attempt to capture a larger share of the harvest, the fishery becomes over-capitalised, resulting in excess effort and falling stocks of fish (Gordon 1954; Scott 1955). The final outcome to this process is zero profitability and, given the extent of the over-capitalisation, greater difficulty for the regulator who desires to 'wind back' the fishery.

The rationale for a 'tragedy of the commons' outcome is much like a 'prisoners dilemma' problem in a basic game situation (Gibbons 1992). If a single vessel decides to postpone its harvest, this benefits all other vessels in the fishery. In general, it would be in the interest of all those who fish to agree to a restricted catch in order to maximise returns. However, without some form of centralised control, it is difficult to enforce this outcome, and avoidance is likely. Each vessel has an incentive to 'free ride' once a deal has been struck, by increasing their harvest while others reduce theirs. All vessels are therefore prone to increase harvest, attempting to do so before others. Therefore, open access resources have one of the key properties of a public good, that of 'non-excludability' — it is not possible to prevent others from using the resource. Markets usually fail in these cases (the market outcome is not optimal from an economy-wide perspective) and indeed the open access nature of the fishery generates an additional 'stock externality' as a result because, as each vessel increases its catch, the costs of harvesting for all other vessels in the fishery rises because of stock depletion.

Governments have a specific role to play in preventing the market failures which occur with common-pool resources such as fisheries. In Commonwealth fisheries the government holds title to the resource, on behalf of the Australian community as a whole, meaning the government has primary responsibility to ensure the net value of the resource to the Australian

community is maximised. To do this requires avoiding a common-pool resource property or open access outcome. In this sense it is important to note that fisheries can be managed in an ecologically sustainable manner yet produce no net economic benefits, and in some cases produce net costs, to the Australian economy. Management regimes, through controlling the total level of harvests (by whatever means) and contributing to the incentive structure that fishers operate in, will determine whether the net value of the fish resources to the community is maximised — that is, whether the fishery is economically efficient. Management regimes that do not effectively control fishing harvests and effort do not allow for the returns from expenditure on fisheries management and research to be maximised.

To prevent problems of over-fishing and market failure, a number of control devices have been proposed and used, including limits on effort, area and seasonal closures, input restrictions, output or harvest controls, and output controls combined with individual transferable quotas. The goal of fishery regulation — finding the right target in terms of catch and effort and using the right instrument to implement this target — should be to maximise sustainable returns, as best as possible in an uncertain environment, to guarantee a sustainable stock of fish and secure property rights over a share of the catch for those who fish, and to allow for voluntary or autonomous adjustment in the size of the fleet given changes in the price of fish and the cost of fishing. It needs to be recognised that any intervention to improve on the outcome achieved under open access will effectively determine the potential profitability of the fishery. By requiring fisheries managers to pursue the goal of economically efficient management ensures that government intervention produces the largest benefits possible.

3 Economic efficiency and maximum economic yield in a fishery

From an economic perspective, the definition of economic efficiency in a fishery is straightforward; by concentrating on sustainable yields alone, economic efficiency occurs when the sustainable catch or effort level for the fishery as a whole maximises profits, or creates the largest difference between total revenues and the total costs of fishing. This point is referred to as Maximum Economic Yield (MEY). For profits to be maximised it must also be the case that the fishery applies a level of boat capital and other resources in combinations that minimise the costs of harvest at the MEY catch level. The fishery, in other words, cannot be over-capitalised and vessels must use the right combinations of such inputs as gear, engine power, fuel, hull size and crew to minimise the cost of a given harvest.

There are three things to note about MEY. For most practical discount rates and costs, MEY will imply the equilibrium stock of fish is larger than that associated with Maximum Sustainable Yield (MSY). In this sense the economic objective of MEY is more 'conservationist' than MSY and should in principle help protect the fishery from unforseen or negative stochastic environmental shocks which could diminish the fish population.

The catch and effort levels associated with MEY will vary, as will profits, with a change in the price of fish or the cost of fishing. This is as it should be. If the price of fish increases it pays to exploit the fishery more intensively, albeit at yields still less than MSY. If the cost of fishing rises, it is preferable to have larger stocks of fish and thus less effort and catch.

As long as the cost of fishing increases with days fished, as it generally will, MEY as a target will always be preferred to MSY and, of course, to any catch or effort level that corresponds to stocks that are smaller than those associated with MSY. This is because, regardless of what happens to prices and costs, targeting catch and effort at MEY will always ensure that profits are maximised. Profits may be relatively low when the price of fish is low and the cost of fishing is high, but profits will still be maximised.

However, with a biological target of MSY alone it is quite possible profits will be small or even zero. The fishery would thus be sustainable at MSY but may not be commercial, much less efficient. A target where the net economic returns to the community from fishing are zero cannot be a good target.

Illustrating maximum economic yield
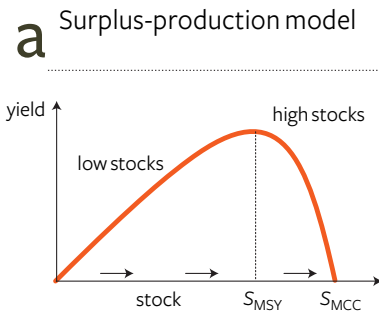
The management structure, stock level and nature and extent of fishing effort which generates MEY depend on a combination of biological and economic factors. In particular, it depends on the relationships between harvest, stocks and recruitment, and on the way in which fishing behaviour, revenue and costs relate to those factors. To understand these relationships the following discussion begins with some of the fundamental biological relationships of a fishery (see Grafton et al. (2006b) for a more complete discussion). Figure a describes a basic surplus-production model of a fishery, showing yield or net additions to the stock of fish on the vertical axis (which might include recruitment and cohort net weight growth) and the stock of fish on the horizontal axis. For this example, to eliminate all cohort effects, all fish are assumed to have the same length and age, whether they are new additions to the stock of fish or exiting members. Also, there is an assumption of no uncertainty about the state of nature.

Following Grafton et al. (2006b), the curved line in figure a shows the growth in the stock of fish, or yield, for every possible stock size, or what is normally referred to as density dependent growth. At low stocks, recruitment is small, since there are relatively few fish available to reproduce. Recruitment increases as the stock of fish increases, and then falls as the stock of fish begins to 'crowd' the environment and reaches a limit on such things as food supply. Stock at maximum carrying capacity (S_{MCC}) thus defines the maximum number of fish that the environment will support. With no fishing, the stock of fish will naturally increase (represented by the arrows moving in the right-hand direction) to this point. Sustainable harvest, on the other hand, occurs when harvest matches yield, or catch is just sufficient to capture new additions to the stock of fish, at any given stock level. In this sense, each point on the yield curve represents a point of potential sustainable harvest; with stock at maximum sustainable yield (S_{MSY}) generating the largest potential catch.

To translate figure a into familiar economic terms, assume the price of fish is given — as would be the case for a competitive fishing industry which faces given world prices for fish and substitution among different fish species— and, for convenience, set to one dollar. In this situation the yield curve, representing sustainable harvest levels, would simply measure the total revenue from each sustainable catch. Also, for the economist, it is usually more convenient to measure effort (as nominal days fished or trawl hours depending on the context) on the horizontal axis, rather than stock. To make this transformation, requires a recognition that increases in effort will result in a fall in stock. In other words, the two variables generally move in opposite directions. Accordingly, figure b measures total revenue (TR) in the fishery as a function of effort.

a Surplus-production model

Thus, the stock-yield diagram has been turned 180 degrees; the origin in this sense now represents stock at maximum carrying capacity and the intercept with the largest amount of effort corresponds to a zero stock of fish. Compared to figure a, a stock of fish that is plentiful, or 'high stocks', thus occurs on the left-hand side of the diagram and stocks that are thin, or 'low stocks', occur on the right-hand side.

In relation to the cost of fishing, assume that all fishing vessels are identical and that the total cost (TC) — including the cost of fuel, crew, bait, gear, etc — of fishing is just proportional to the amount of effort applied in the fishery; and that fixed costs are zero, so that at zero effort TC also equals zero. Assume as well that TC includes the opportunity cost of using vessel capital and all other inputs, or includes returns that could have been obtained in the next best employment (for example, the average return on a bank deposit). Total cost would thus account for the normal rate of return on investment. Figure c combines TR and TC together in one diagram. The result illustrates an important outcome, that of a Common Property Equilibrium (CPE). As illustrated, a CPE occurs at the point where total cost equals total revenue, or where economic profit (allowing for the opportunity cost of investment and thus distinct from accounting profit) is zero, at point B.

Why is a CPE an equilibrium, or resting point for the fishery? First, of course, it represents a sustainable harvest. Second, points to the right of effort levels at the CPE will necessarily imply that total costs are larger than total revenues, or that profits are negative (lower than the rate of return that can be obtained elsewhere). This must imply that it would be better for firms to employ their capital in their next best alternative use and in any case, with negative profits, firms will eventually fail and leave the fishery until point B is again obtained. In the case where vessels differ, those that are the least efficient, or have the highest cost of fishing, will clearly leave the industry first.

Points to the left of B are more interesting, and illustrate the proverbial 'tragedy of the commons' that is associated with every CPE. Begin, for example, at an initial effort level E_o, where profits are positive and measured by the distance DC. Profits are in fact large in this case because stocks are 'thick' and the cost of fishing is relatively low. Low in a real fishery for two reasons: first, since less time is spent fishing, fuel costs and all other variable costs will be low; and second, 'thick' stocks imply that the cost per unit of harvest will also be lower. With larger stocks, each cast of the net, so to speak, catches more fish.

However, in an unregulated or open access fishery, the existence of positive economic profits — over and above the average rate of return that can be obtained elsewhere — induces new fishing vessels to enter the industry and, those vessels already in the fishery, to expand effort and capture the extra

b The relationship between total revenue and effort
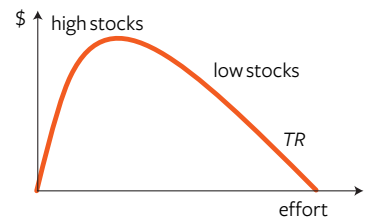
c Common property equilibrium (CPE)
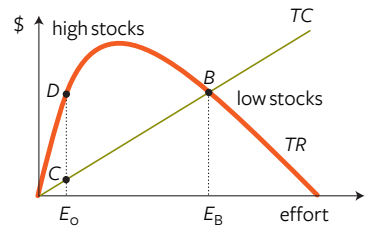
profit. As long as profits are positive, this will continue to occur until point *B*, where there is no further incentive to expand effort. This is the 'tragedy of the commons'. When all vessels act in this way, the stock of fish falls and the per unit cost of fishing rises until all profits are dissipated.

Indeed, the process is inevitable. If any one vessel decides to limit fishing effort and conserve stocks, while others do not, that vessel will be relatively worse off. All vessels, acting in their own interest, are induced to fish more, but since those vessels that increase effort do not take into account the effect of their fishing activity on other vessels in the fishery — including the increased cost of harvest as a result of stock depletion — therefore, eventually all vessels are worse off. Indeed, in this sense, point *B* is undesirable in two senses: first, because profits are zero and the cost of fishing is needlessly high and second, as drawn — and this does not necessarily have to be the case, depending on the level of the proportional cost of fishing — it would have been possible to obtain the same catch with less effort, lower costs and larger stocks at point *D*.

d Maximum economic yield (MEY)
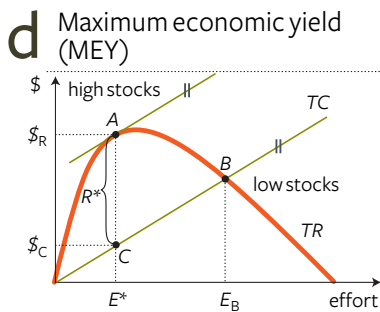
The case of a CPE makes it clear how profits can be maximised in a fishery, or how to find the point of MEY, assuming for the moment a zero discount rate. In figure d this occurs at the effort level E_{MEY} (E^* in figure d) and corresponding value of catch $\$_R$ that creates the largest difference between the total revenue and total cost of fishing, thus maximising profits, given by the difference between $\$_R$ and $\$_C$, or *R**.

MEY at point A in figure d is perhaps an easy case to make to industry. As drawn, the comparison of point *A* to *B* implies that not only are profits maximised at *A*, but the value of harvest (both yield in physical terms and the value of catch in terms of revenues) has also increased compared to the common property equilibrium. The reason that profits are now larger at point *A*, of course, is not only that *TR* has increased, but, given that stocks of fish are larger and the amount of days spent fishing is smaller, the cost of fishing has also fallen. In many fisheries this is often not the case. That is, the cost of fishing is already sufficiently high (simply rotate the *TC* curve closer to MSY, implying a fall in effort at MEY), so that moving from a CPE to MEY requires a fall in harvest and revenues.

Through a little redrawing of the diagram it should also be clear what the effects on MEY are from an exogenous change in the price of fish or the cost of fishing. An increase in the price of fish, for example, results in a shift upward of the *TR* curve at all effort levels, leaving the intercepts unchanged. For a given cost curve, the point of MEY moves closer to MSY. This is an intuitive result. The more valuable landed fish are, the more it pays to work the fishery harder, and thus decrease the equilibrium stock of fish. With an increases in costs, or a rotation leftward of the *TC* curve, MEY moves further away from MSY since with a more costly harvest it pays to have

larger stocks from which to catch. It follows that a fall in the price of fish and an increase in costs — common in Australia given the recent appreciation of the dollar and the rising cost of fuel over time — implies a smaller fishery in order to maximise profits, with lower harvest and less effort.

There is one final, important lesson in this context. The discussion of MEY underscores the undesirability of MSY (and other biological indicators) as a target, at least as long as having a commercially viable fishing industry is an objective. Pursuing MSY alone, in other words, can result in zero or even negative profits at that target level. Figure e illustrates the point.

In this case, given the high cost of fishing, effort at MSY implies that *TR* is less than *TC*. Of course, industry will not move beyond the common property equilibrium given by point *B* since profits would turn negative, although cases where average costs exceed average revenues for a period of time are common in poorly regulated fisheries. A target that can be consistent with negative profits cannot be a good target.

Indeed in this case, and as is always true of a CPE to the left of MSY, a regulatory environment that attempts to target and enforce MSY will result in a replication of a common property equilibrium, as if there was no regulation in place at all, save for the considerable amount of resources (financial and scientific) that are typically required to estimate MSY and implement a management regime.

This can often be the case in real fisheries, under both input and output controls: fishery regulation simply results in a CPE. The value of a MEY target (point *A* in figure e) is that regardless of prices and costs, profits will always be maximised. They will be low when prices are low and costs are high, but they will still be at their highest possible value.

Vessel-level efficiency

The examples presented have been silent on boat numbers. Indeed, the graphs basically assume all boats are the same and there is a rough correspondence between boats and effort or nominal days fished. In this context, it is natural to assume that a move from MSY to MEY would imply a decrease in boat numbers, with catch per boat increasing. It is also the nature of an optimal result that those fishers that lose from a reduction in boat numbers can be more than compensated for by the increased profits MEY generates, at least in principle. In any case, efficiency requires that at MEY the measure of effort corresponds to a total boat capital in the fishery that is just sufficient to obtain the required catch at minimum cost. Thousands of boats each fishing a day could generate effort at MEY but clearly that excess capacity would be inefficient.

e MEY with negative profits at MSY

For full efficiency to prevail it must also be the case that fishers combine fishing inputs in the correct proportions to minimise the cost of harvest. In general terms, the correct combinations of gear, engine power, boat size, gear length and crew (along with all of the other many inputs into fishing), depend not just on technical or engineering considerations, but also on the relative cost of employing each input. For example, if the price of an average member of crew increases, it may pay for the fisher to substitute an alternative technology that is labour saving. Likewise, if the price of fuel decreases it may be more profitable to use a larger engine or spend more time at sea, thus increasing (say) the proportion of engine power to other inputs. If markets are left to function normally, boat owner-operators will generally find the correct proportions of the various inputs to minimise costs, since it is simply good business practice to do so. However, in some cases, the management instrument prevents this from happening. A restriction on gear length, for example, changes the cost minimising proportions of inputs, and especially so if owner-operators substitute toward unregulated inputs in an effort to maintain catch. This is a common problem with effort controls in the form of input restrictions, such as limits on gear length or type, vessel size or engine power.

Three important caveats

There are three important qualifications to the previous discussion. First, the diagrams illustrating MEY, as they stand, presuppose a zero rate of discount, that the cost of fishing depends on stock size in a simple linear fashion, and that fishing costs rise proportionately with effort.

The discount rate is the interest rate at which future income or catches are valued today. A case can be made for a zero discount rate in common property resources, but it is accepted practice to assume some positive interest rate to account for the fact that a harvest some time in the distant future is worth less than a harvest today. If so, it implies a modified version of MEY is appropriate, in that a positive discount rate moves optimal effort and catch closer to MSY. In other words, if the current catch is valued more highly than a future harvest it pays to work the fishery harder today, with smaller equilibrium stocks of fish. It is even possible that if the discount rate is high enough, MEY will correspond to stocks that are smaller than that associated with MSY. It will generally depend on how strong is the stock effect in either the harvest or cost function.

In general terms, it is not difficult to demonstrate that if the discount rate becomes infinitely large, MEY will correspond to a CPE, and at a zero discount rate MEY will be exactly as portrayed in the diagrams above (Clark 1990). A positive discount rate will place MEY somewhere between these two extremes. In practice, for most productive fisheries, with reasonably large intrinsic rates of biological growth, and with discount rates that reflect normal rates of return (say 5 per cent or less), it will almost always be the case that this modified MEY will occur to the left of MSY in figure e, or at

stock sizes which are larger than those associated with MSY (Grafton et al. 2007). This is an important point. For practical fisheries and discount rates, MEY will normally be more 'conservationist' than MSY, or a comparable biological target. In principle this should help protect the fishery from unforseen or negative stochastic environmental shocks that may diminish the fish population.

This point is strengthened if relevant cost considerations are also taken into account. The implication of a cost of fishing that increases with stock depletion, at an increasing rate — what economists refer to as convex cost functions in terms of stock; ones that would probably characterize most fishing activity — is to move optimal catch and effort further to the left of MSY. If it is more costly to fish as stock decreases, and if this cost increases at an increasing rate, it pays to have even larger stock sizes than that depicted at MEY in the previous diagrams. This will partly offset (and in some cases even more than offset) the effect of the discount rate.

Second, the MEY diagrams also implicitly assume a single species fishery. Multi-species fisheries create complications in a number of ways; if species interact biologically this requires relatively complicated models, such as predator-prey models, where the notion of sustainability itself becomes difficult to define. If the interactions mostly occur 'above the water', so to speak, or in terms of the profitability of the boat, the bio-economic model must account for differing prices across species, the value of target versus by-catch species, effort split across target species, and the likelihood that the cost of fishing and specific cost functions vary across individual species. It is possible to model all this, but determining the value of MEY for each species becomes much more difficult. It should be noted that unless there is non-jointness across species (that is when a particular species is targeted, there is no catch of other species), costs would have to be allocated, and there are no firm and rigorous ways to allocate common and fixed costs across outputs when there is joint production.

Finally, the analysis in the previous sections assumed the population biology and all of the relevant economic functions and parameters were clear, as if drawn from a deterministic setting, or one with no uncertainty about the state of nature or the economics of the fishery. This of course will never be the case. One source of uncertainty is a lack of complete biological data and the nature of the stock-recruitment relationship (the yield curve in figure a) itself. In some cases natural variability in stocks may make it all but impossible to even estimate a yield curve, and thus the relationship between total revenue and effort. Natural variability implies that the *TR* curve shifts up and down in a hard to predict fashion. The calculation of MEY requires a specified stock-recruitment relationship and if there is uncertainty in that relationship, the measure of the standard deviation must also be known or estimated. Another source of uncertainty is the price of fish and the precise

cost of fishing. These must be forecasted and forecast errors are common. If these errors are systematic, then at least part of the efficiency gains from targeting MEY will be lost. With uncertainty taken into account, it is not unreasonable to approach an estimated MEY target in a slow way, with adaptive management responses to changes in prices, costs and the underlying biology of the fishery.

Why maximum economic yield?

MEY generates maximum profits, an outcome which is guaranteed regardless of the price of fish or the cost of fishing, and MEY is 'conservationist' in the sense that stocks will be larger than at MSY. This in itself can confer enormous benefits to the fishery and its ecosystem, and protect the fishery against large negative shocks to the fish population, since larger stock levels generally imply greater resilience in the face of these shocks.

Another compelling reason to pursue MEY is the issue of resource allocation. For example, effort levels larger than E_{MEY} would imply more boats, days at sea, gear, crew, bait and all of the other inputs used in fishing – resources that could be used instead in alternative employment. This is what economists mean by efficiency in general terms, for the economy as a whole. If too many resources are being expended in fishing, too little are being used elsewhere. Moreover, as long as the right instruments to facilitate adjustment are in place – instruments that allow for trade in secure and specific property rights, such as the right to a share of harvest – it follows that decreasing the size of an over-exploited fishery will make no one worse off and many better off by compensating those that leave the fishery for their lost income, while providing more profit for those that remain in the fishery. That is the nature of an optimal position given by MEY. It is noted that the focus here remains producer welfare rather than the net benefits to the nation.

Attempts to extend resource use and particularly employment well beyond MEY are common and often disastrous. Experience in Canada's Atlantic fisheries provides a striking example. Subsidies provided by the Canadian government - with a specific mandate to maximise employment levels in the industry - greatly extended the amount of resources applied to these fisheries. Indeed, even as early as 1970 it was "estimated that Canada's commercial catch in 1970 could be harvested by 40 per cent of the boats, half as much gear and half the number of fishers" (Atlantic Groundfish Fisheries, 1997:14/15). This is wasteful in itself, but dwindling stocks and the eventual collapse of the Atlantic fisheries, in large part because of over fishing, even further increased the government's burden to maintain incomes. In 1990, for example, self-employed fishers received $1.60 in unemployment insurance benefits for every dollar earned in the fishery, and the 'adjustment programs' associated with the collapse of the fisheries cost the Canadian

taxpayer more than \$3 billion (CDN) dollars in the 1990s alone (*Atlantic Groundfish Fisheries*, 1997:14/22).

Implementing maximum economic yield

If targeting E_{MEY} in figure e with input controls to obtain MEY is not effective or even desirable, the alternative is to target catch at the value $\$_R$. Setting effort creep aside, it should be noted that in a deterministic world (no uncertainty) there would be no difference in outcomes between a catch or effort control, as long as the correspondence between input restrictions and effort levels is known exactly and is perfectly enforceable. With uncertainty, and again setting effort creep aside, in cases where there is more variance in the stock-recruitment relationship than in catch per unit of effort (CPUE), effort controls will be preferred. If there is more variance in CPUE relative to the stock-recruitment relationship, then output or catch controls will dominate, generating less variance in profits. For the tiger prawn component of the NPF the latter is the case, where output controls are the preferred instrument (Kompas and Che 2004). A clear evaluation of all of the specific, or detailed, alternative fishery management instruments is contained in Gooday (2004).

Along with creating effective property rights to fish, ITQs confer a number of other related benefits. First, since these rights are tradeable, market forces will generally distribute quota among fishers which value the right most highly. Vessels which have lower marginal costs of fishing will therefore be willing to pay more for quota, with the resulting transfer of quota from high to low marginal cost producers increasing economic efficiency overall; essentially fishing inputs are distributed to those who use them best. In other cases, quota trade simply allows vessels to compensate for catches which are larger or smaller than planned or prior quota holdings. These efficiency gains, or what amount to cost reductions, can be substantial, even in fisheries where TAC is not binding in aggregate. In the Australian south east trawl fishery, for example, where TAC undoubtedly has not corresponded to MEY (Gooday 2004), the cost savings from quota trades are estimated to be 1.8-2.1 cents per kilogram for every 1 per cent increase in the volume of quota traded (Kompas and Che 2005).

Second, instead of investing in boat capacity to catch fish before others do, with a guaranteed harvesting right, boat owners can instead concentrate on investments which lower the per unit costs of fishing. This is a major benefit. With input controls, technological change (new boats, a better engine, more efficient gear, try nets, GPS, etc) can become harmful in the sense that the resulting effort creep through increased fishing power lowers fishery profits and endangers stocks. In some cases input restrictions are designed to prevent the adoption of such new technologies, which under other circumstances may be beneficial or efficiency enhancing. With output

controls and ITQs, alternatively, boat-specific technological change is desirable, in that it lowers the costs of fishing and increases profits, with no effect on stocks or the cost of fishing of any other vessel in the fleet which has not yet adopted the new technology.

A third benefit of ITQs is that a good number of area and seasonal closures, common to input controlled fisheries, can be eliminated. Spawning stocks must naturally be protected and marine reserves can almost always be justified even on economic grounds (Grafton et al. 2005), but area and seasonal closures used to simply limit effort are unnecessary under an ITQ system and often economically harmful in any case. By eliminating these controls, vessels can fish when the weather permits and, perhaps more importantly, match the harvest throughout the year to market conditions therefore generating the highest price for their catch. In general, unlike with input restrictions, output controls and ITQs allow fishers to choose the right mix of inputs and the time and manner to fish, all of which is cost reducing and efficient.

A final benefit of ITQs is that they allow for autonomous adjustment of the fishing fleet, with operators voluntarily able to 'cash out' by selling their quota to more profitable vessels. Indeed, if implemented correctly, an output control and ITQ system which targets MEY will generate the largest possible (marketable) asset value for those who have the right to fish, reflected in a high price for each unit of quota. Fishers are thus compensated for exiting the fishery without the need for government intervention.

For catch controls and ITQs to be successful there must be adequate monitoring and enforcement. This too can be costly, although there is no necessary reason for this cost to be a government responsibility. Under an ITQ system, fishers are keen to protect their secure property rights and it is not uncommon for monitoring to be at least partially funded by industry (Grafton et al. 2006a). Even when government pays for monitoring and enforcement, this cost is likely to be comparable to the cost of monitoring and enforcing effort controls, not to mention the cost of any resulting effort creep which goes with input restrictions.

Similar arguments can be made with respect to problems with high-grading and variations in stock abundance. With regard to high-grading, a key difference between input and output controls is in the relationship between the policy instrument and the policy objective. High-grading will most likely occur in long-lived or fast growing species where the price differential between high and low grade fish is relatively large.

For output controls, the possibility of high-grading means the policy instrument (TAC) may not always match the policy objective (a given level of mortality from fishing). However, high-grading occurs in only some circumstances which are often predictable.

As well, provided that high-grading can be estimated, the TAC can be matched with desired mortality. Unless the relationship between fishing costs and the price differential between grades changes substantially, the match will be valid over time. There can be no doubt that waste occurs through high-grading, but that is simply a cost of management to be assessed against other costs, as well as the benefit; and compared to the costs and benefits of other management instruments.

More importantly, the level of high-grading enters the management decision once only. Since the incentive to high-grade is a function of the cost of fishing and the price differential between grades, it is not something which increases over time in a way that erodes the practical meaning of a catch quota, or in that way in which effort creep subverts input controls (Rose and Kompas 2004).

With regard to variations in stock abundance, the traditional arguments against catch controls, and with it ITQs, are clear. With output controls, managers face a problem in setting the TAC when abundance varies between seasons and is unknown at the beginning of the season. By setting the TAC too high the manager runs the risk that fishing pressure on stocks will be excessive should a low abundance season occur. By setting the TAC more conservatively, the manager guarantees the loss of potential profits, should the season be one of high abundance. Indeed the problem is well recognised and is often cited as a primary reason for preferring input controls.

However, what is not so well recognised is that essentially the same problem affects the setting of input controls. To set effort at the optimal level, the manager needs information on abundance, catch per unit effort, the value of catch and the cost of effort. Setting input controls too tightly leads to a loss of potential profits in seasons of high abundance. Setting input controls too generously leads to excessive investment and effort and excessive catch. The long-term consequences are pressure on future stocks and dissipation of potential profit.

In principle, the type of information needed to make an efficient choice using input controls does not vary much from that needed to make the choice using output controls.

There is really no argument for input controls on this basis. Careful assessments of stock abundance, including where needed, fishery independent surveys, and pre- and in-season sampling, are mandatory under any management regime. If the cost of obtaining this information does vary under different regimes, or with different management instruments, a case has to be made in comparing these costs against all the other costs and benefits of alternative management systems.

Problems with input controls

For management of a fishery to be effective in the sense that catch and stocks are maintained at desired levels, there must be either direct or indirect control over catches. Management through output controls involves explicit catch targets and direct enforcement of those targets. Management through input controls also involves some implied catch target. The fact that the catch target is sometimes only vaguely defined is one of the reasons that input management regimes are often not successful.

However, the real problem is the inability of input controls to control effort in the first place. The moment control of a particular input becomes the policy instrument, operators have an incentive to substitute other inputs in a way which will change the relationship between effort and catch. Also, technological advance and improvements in knowledge provide other background reasons for the relationship to change constantly. A manager relying on input controls is in constant competition with the imagination, energy and inventiveness of each operator in the fishery and the full technological backup of a modern economy, with effort creep inevitable. In terms of figure e, attempting to target effort at MEY can only be successful in the very short term, with effort creep moving the fishery to the right and thus dissipating profits, or decreasing the distance between total costs and revenues.

More important to the general lack of success of input management regimes are two characteristics of the incentives that they provide for fishers. First, as outlined previously, controls on one or more inputs provide an immediate incentive for operators to substitute uncontrolled inputs for controlled inputs.

Second, input control regimes provide no sense of ownership or stewardship of the fisheries resource. There are no guarantees in any input control management regime except the right of access to the fishery under certain guidelines. Operators are encouraged by these rules to compete for catch within those guidelines, and if one operator refuses to expand effort while others do, that operator will be worse off. Unfortunately, if all operators increase effort, all are made worse off through a fall in profits and the fishery remains overexploited — the proverbial 'tragedy of the commons' as discussed earlier. The management response in this environment is to continuously and repeatedly find ways to cut effort (eg. gear reductions, area and seasonal closures, vessel buyback schemes, etc), 'winding the fishery down' over time to a small number of boats or days fished, all making zero (or near zero) profits.

All of this can be illustrated by examining the Commonwealth managed northern prawn fishery (NPF), which provides a good example of how input controls and the resulting 'race to catch' can generate inefficient outcomes.

Over the past 30 years the NPF has been managed by a series of input controls, including seasonal closures, a move from quad to twin nets, engine power and hull limits and, most recently, gear reductions and restrictions. In all cases the limits to fishing power have been temporary at best. Indeed, A-unit (a measure of hull capacity and engine power) limits in place in the 1990s resulted in a clear substitution toward unregulated inputs, specifically gear. This substitution is illustrated in figure f, where average headrope gear length clearly increased throughout most the 1990s, while A-units fell.

The implication of this counter-movement in A-units and gear is two-fold. First, restricting A-units in fact did not control effort, since boats simply increased effort by using other inputs, including gear, more intensively. Second, the forced change in input combinations, inducing boat owners to use different proportions of gear to A-units, resulted in considerable loss in boat-level efficiency throughout the NPF (Kompas and Che 2002). In the banana prawn section of this fishery, technical efficiency for the fleet as a whole fell from 75.1 per cent in 1994 to 68.2 per cent in 2000 (Kompas et al. 2004). For individual operators in the NPF, the aggregate response to input restrictions thus led to much lower profits than would otherwise have been realised.

Each of the changes made in the management regime in the NPF (seasonal and area closures, A-unit restrictions and most recently gear reductions) was made in recognition that the system it replaced had failed to constrain effective effort and the inevitable effort creep sufficiently to protect prawn stocks. Where effective effort was reduced by management change, the primary reduction was short-lived. This outcome, and one of the primary reasons for it, is illustrated in figure g. Fishing power, measured as the average catching ability of a boat in a day's fishing has risen rapidly and consistently over time. The rise in fishing power is the result of continuous improvements in technology, input combinations and knowledge. The acquisition of improved scientific knowledge of the fishery, along with the observation of declining catches has made it increasingly clear that prawn stocks need to be conserved and catches and effort are difficult to control.

Although the combination of recent policy changes appears to have tempo-rarily slowed the increase in fishing power as well as contributing to a rapid fall in total days fished, experience suggests this will only be temporary.

It took only four years for effort creep to overcome the initial fall in fishing power in response to the imposed move from quad to twin gear in 1987. The recent removal of A-unit restrictions in favour of gear reductions will logically imply, given the 'race to fish' incentive, that boat owners will now increase the size of their vessels and engine power, spurring more and deeper compensatory cuts in gear (or some other input) in the future. Inevitably the fishery 'winds down'.

f **Input substitution in the northern prawn fishery**

- - - average A-units per boat
— average gear length
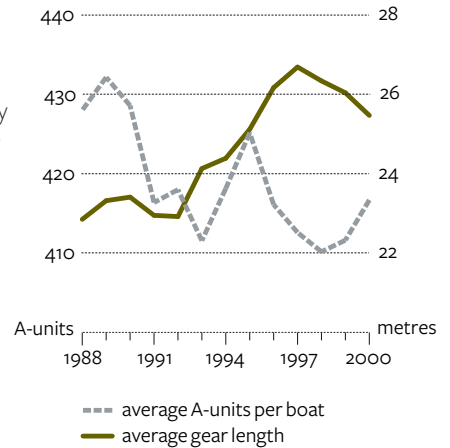
Note: The time-series are averages drawn from the AFMA logbook unbalanced panel data.

g **Fishing power and effective effort in the northern prawn fishery** effective 1970

- - - fishing power index (left axis)
— effective 1970 days fished (right axis)
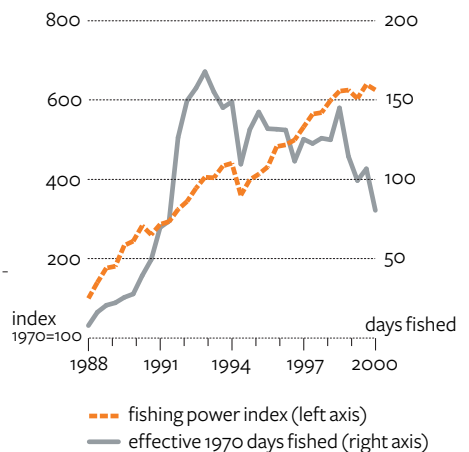
Note: The fishing power series assumes the 'basic high' case as designated by CSIRO (Dichmont et al. 2003a).

Total (nominal) days fished in 2002 are already 55 per cent of the 1998 level and far below the fishery peak in days in 1983 and the number of boats has fallen from more than 250 to less than 100 now. In fact, recent estimates show that MEY in the tiger prawn component of the NPF is roughly 60 and 30 per cent below actual days for 2000 and 2001 respectively, and about 28 per cent below actual days in the 2003 fishery. Even the recent shortening of the season and further large reductions in gear units have not yet been sufficient to ensure economic efficiency or MEY (Rose and Kompas 2004).

Rights-based fishing

It is important to recognise that aggregate catch controls can be just as ineffective as input controls, resulting in 'race to fish' behaviour. Even if the total amount of catch is fixed, there is still an incentive for boat owners to over-invest in fishing capacity to obtain a larger share of the catch, again moving the fishery past effort at MEY. With aggregate catch fixed, this amounts to an increase in the cost of fishing. The total cost of fishing, in other words, increases from TC_1 to TC_2 in figure h and zero profits (or total rent dissipation) at point A.

h Rent dissipation under a competitive TAC
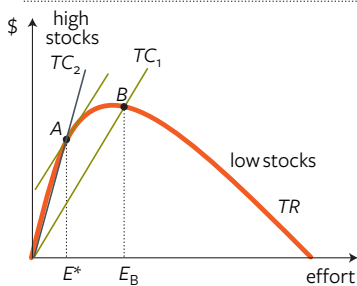
With effort creep an inevitable outcome of input controls in any circumstance, economists thus argue for catch controls combined with an ITQ system to obtain or implement MEY. ITQs confer an individual, transferable, harvesting right so that each vessel is guaranteed a share of the catch. The immediate impact of this is to remove any 'race to fish' incentive. Therefore, there is no reason for effort to increase beyond E_{MEY}, and MEY can be effectively targeted. The regulator simply needs to set total allowable catch (TAC) correctly. ITQs have been in place and worked well for decades in fisheries throughout the world, including New Zealand, Iceland, the USA, Australia and Canada (Hannesson 2004), generally establishing, as in the British Columbia halibut fishery, significant gains in cost savings and in enhanced revenues (Grafton et al. 2000).

It is important to note that the 'race to fish' incentive will not be always fully eliminated with ITQs. For example, in cases where fishing results in stock depletion over the course of the season, implying that even though there is a catch entitlement it will be less costly to catch 'earlier' in the season when stocks are more abundant, or ahead of other vessels. The problem is usually addressed by setting seasonal closures correctly or through quota dated by period (eg. weekly), with a market for trade across periods.

Finally, ITQs are ineffective if TAC is set incorrectly. The south east trawl fishery (SETF) provides a good example of this.

Until recently, catch levels in the SETF have rarely reached the TACs set for the species managed under the quota management system. While it is

unreasonable to expect all TACs should be completely filled in a particular year given the multi-species nature of the fishery, TACs should be set such that they are binding at some point (Squires et al. 1998). Over the period 1992-2005, the only TACs that have been largely filled are those for orange roughy in the eastern and cascade sectors. For most of the species currently assessed as over-fished, in that stocks are below the level that maximises sustainable yield, TACs have not been binding historically – silver trevally, redfish, orange roughy (west and south zones), gemfish (east) and blue warehou – and are often not even close to binding, with the harvest of some species caught as low as 30 per cent of TAC. For the most part, the SETF operates as a limited-user 'open access' fishery (Wilen 1979). Even when TAC is binding, or close to binding, it is not clear that it is set correctly.

The limited entry 'open access' character of the SETF is confirmed by estimating fishing effort, returns and biomass. Fishing effort in the SETF, measured as hours trawled, has increased over time, particularly since the introduction of ITQ management in 1992 (Elliston et al. 2004). Because trawling hours represent a measure of nominal effort, it is likely to under-state the real level of effort in the fishery as the adoption of new fishing technology has improved the effectiveness of each hour trawled over time. This increase in fishing effort can be explained in part by the expansion of the blue grenadier fishery and the general pattern of increasing TAC and catch levels for this species since 1992 (Elliston et al. 2004). However, at the same time that fishing effort has been increasing, the total value of catch in the SETF has declined in real terms (ABARE 2008a). As a result catch per hour trawled, measured either in tonnes or in inflation adjusted value terms, has declined since the mid-1980s. This result suggests that increasing effort in the SETF has been largely inefficient, dissipating the net returns to the fishery (Elliston et al. 2004). This is consistent with the findings of Galeano et al. (2004) which indicate persistently low net economic returns to the fishery.

4 Vessel-level efficiency and stochastic frontiers

Introduction

The concept of MEY is appropriate for a fishery level indicator of efficiency. At this target level however it must also be the case that individual vessels use inputs in levels and combinations that minimise the costs of harvest at the MEY level. To determine whether these conditions hold requires the use of stochastic frontiers. This basically amounts to determining vessel level efficiency.

Stochastic frontier production functions have been the subject of considerable econometric research during the past two decades, originating with a general discussion of the nature of inefficiency in Farrell (1957). In traditional economic theory, efficiency is generally assumed as an outcome of price-taking, competitive behaviour. In this context (and assuming no uncertainty) a production function shows the maximum level of output which can be obtained from given inputs and the prevailing technology. However, variations in maximum output can also occur either as a result of stochastic effects (eg. good and bad weather states), or from the fact that firms in the industry may be operating at various levels of inefficiency because of mismanagement, poor incentive structures, less than perfectly competitive behaviour or inappropriate input levels or combinations. The econometric technique used in this context, developed by Battese and Coelli (1988), allows for a decomposition of these effects and a precise measure of technical inefficiency defined by the ratio of observed output to the corresponding (estimated) maximum output defined by the frontier production function, given inputs and stochastic variation.

Recently, there has been widespread application of stochastic production frontiers to assess firm inefficiencies in various agricultural and industrial settings (eg. Battese and Coelli 1992, Coelli and Battese 1996 and Kong et al. 1999), but few studies have been directed toward renewable resource-based industries. For fisheries, Kirkley et al. (1995) and Sharma and Leung (1999) are among the few exceptions.

Conceptual framework

Farrell (1957) proposed that the efficiency of a firm consists of two components: technical efficiency and allocative efficiency. Technical efficiency reflects the ability of a firm to obtain the maximum output from a given set of inputs. Allocative efficiency reflects the ability of a firm to use inputs in optimal proportions, given their relative prices and the production tech-

nology. These two measures are then combined to produce a measure of total economic efficiency.

In figure *i*, it is assumed two inputs (x_1 and x_2) are used to produce one output (y), under the assumption of constant returns to scale. The production technology of a fully efficient firm is represented by the curve *SS'*. *SS'* represents the minimum combinations of x_1 and x_2 that can be used to produce a unit of output. If a given firm uses quantities of x_1 and x_2, defined by point *P* to produce a unit of output, the technical inefficiency of that firm can be measured by the distance *QP*, which is the amount by which all inputs could be proportionately reduced without a reduction in output. This is usually expressed in percentage terms by the ratio *QP/OP*; the percentage by which all inputs need to be reduced to achieve technical efficiency. The technical efficiency of a firm is measured as:

$$TE_i = OQ/OP$$

which is equal to one minus the measure of technical inefficiency (*QP/OP*). The technical efficiency indicator will take a value from o to 1. A value of 1 indicates that the firm is fully technically efficient.

The measurement of the allocative efficiency of a firm requires considering the choice of input mix given input prices. The slope of the line *AA'* represents the relative price of the two inputs x_1 and x_2. Any input combination along *AA'* has the same total cost. It can be seen that the cost minimising way of producing a unit of output (being on *SS'*) is with the input mix indicated by *Q'*. The distance *RQ* represents the reduction in production costs that would occur if production were to occur at the allocatively (and technically) efficient point *Q'* instead of the technically efficient, but allocatively inefficient, point *Q*. Allocative efficiency is defined by the ratio:

$$AE_i = OR/OQ$$

Total economic efficiency is defined by the ratio:

$$EE_i = OR/OP$$

The distance *RP* can be interpreted as a cost reduction from moving from point *P* to the technically and allocatively efficient point *Q'*. Note that:

$$EE_i = AE_i . TE_i$$

The measures of technical, allocative and total efficiency defined here all take values from o to 1.

In more formal terms, estimation requires a specific functional form.

i   Input measure of efficiency
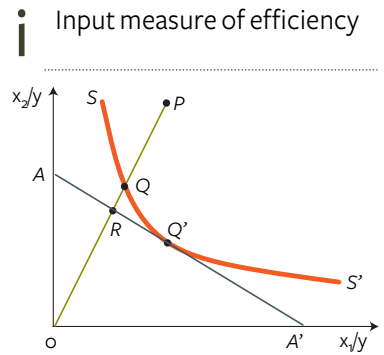
Following Grafton et al. (2006b), begin with the addition of a random error term, v_i.

$$4.1 \qquad y_i = f(x_i; \beta) \cdot e^{v_i} \cdot TE_i$$

The i subscript denotes observation or vessel i where $i = 1,2,...$, is observed output, x_i is observed input and TE_i is technical efficiency of vessel i. The common deterministic production frontier is given by $f(x_i; \beta)$ where the β represents the vector of parameters we need to estimate to construct this unknown deterministic frontier, while the stochastic production frontier is given by $f(x_i; \beta) e^{v_i}$ which includes the random error term v_i.

Using equation 4.1, an individual measure of technical efficiency for vessel i is the ratio of observed output to maximum feasible output given the random error, so that:

$$4.2 \qquad TE_i = \frac{y_i}{f(x_i; \beta) \cdot e^{v_i}}$$

The predicted and deterministic frontier output is obtained from estimating a production frontier using observed inputs and outputs for all vessels in a given sample. The inputs, given by x_i, are assumed to influence the deterministic production frontier, but are also assumed to be uncorrelated with either the random term v_i, or technical efficiency. In other words, the observed inputs determine the deterministic production frontier, but not the technical inefficiency or the random effects associated with fishing. Deviations from the actual output and the predicted deterministic frontier output occur because of, one, random events that can be positive or negative and given by v_i and two, technical inefficiency which is typically defined as u_i. There are several software packages that allow calculation of technical inefficiencies using Stochastic Frontier Analysis (SFA) from observations of output and inputs. Some of these packages also allow the use of different distributions for u_i to test the sensitivity of our results to the distributional restrictions.

Predicting technical inefficiencies for vessels provides valuable information as to what vessel characteristics (types, home port, size, etc.) may be affecting efficiency. If we have data on observed inputs and outputs over multiple periods we can also test whether changes in fisheries management at a particular point in time influence technical efficiency. Determining what factors may be affecting technical efficiency, and their size and significance, is the major reason analysts use SFA in fisheries. This hypothesis testing (such as to test whether large vessels are more technically efficient than small vessels) is accomplished by estimating, in addition to the stochastic frontier, a technical inefficiency model of the following form:

4.3
$$lny_i = f(ln\mathbf{x}_i;\boldsymbol{\beta}) + v_i - u_i$$

and:

4.4
$$u_i = g(z_i;\boldsymbol{\alpha}) + \boldsymbol{\omega}_i$$

where u_i is estimated technical inefficiency for vessel *i* and z_i is a vector of individual vessel and environmental characteristics for vessel *i* that influences observed output *indirectly* through effects on technical inefficiency.

In 4.4 the term $\boldsymbol{\alpha}$ is a vector of parameters to be estimated using the sample data and typically would include an intercept term, while $\boldsymbol{\omega}_i$ is an additional random error term that may be included depending on the estimation procedure. In current practice, the stochastic frontier model and the technical inefficiency model are combined in one estimation procedure which allows for the possibility of the z_i to be in the predicted production frontier, and also in the predicted technical inefficiency model. The choice of whether a variable belongs in the production frontier or the technical inefficiency model depends on our a *priori* understanding as to whether it affects the production frontier directly, or determines technical inefficiency, or both. For example, we should include some measure of fish stock size or abundance when estimating a stochastic frontier because it is likely to affect the production frontier.

The choice of what frontier to estimate depends on data availability and the research question. For instance, if the analyst wishes to obtain estimates of allocative efficiency then either a cost frontier must be estimated directly, or it must be constructed from estimates of a production frontier. When a cost frontier is directly estimated the technical inefficiency term is added to the random error, *i.*e., $\varepsilon_i = v_i + u_i$. In other words, the inefficiency term defined by $u_i \geq 0$, *increases* costs and places vessels above the minimum cost frontier.

5 Productivity measures and profit decompositions

General context

Productivity measures are a basic indicator of the ratio of output to inputs. Often this measure is stock adjusted in a fishery to account for changes in abundance. Holding stock constant, as well as inputs, implies that an increase in output indicates an increase in productivity. If output falls, productivity falls. Profit decompositions, on the other hand, decompose profits into various components: for example, output, inputs and productivity. The measure allows one to determine the effect of exact changes in (say) fuel prices on profits.

Productivity and profit decompositions

The approach used to decompose relative profits and analyse productivity changes is described in detail in Fox at al. (2003). It offers important advantages over traditional measures of productivity in fisheries (Squires 1992) in that it provides individual firm-level measures and quantifies the contribution of productivity, inputs and outputs to relative profits. It provides an easy way to assess both firm and industry performance at a point in time, and over time.

Following Fox et al. (2006), we briefly review the profit decomposition approach using index numbers. We define the relative profits of an arbitrary firm b, π^b, relative to the restricted profits of another reference firm a, π^a, by:

5.1
$$\theta^{a,b} \equiv \frac{\pi^b}{\pi^a}$$

A productivity index between firms b and a, denoted by $R^{a,b}$, is defined as:

5.2
$$R^{a,b} \equiv \left(\theta^{a,b}/P^{a,b}\right)/K^{a,b}$$

where the numerator is an implicit output index (Allen and Diewert 1981), $P^{a,b}$ is a price index of output and variable input prices, where variable inputs are treated as negative outputs and $K^{a,b}$ is a fixed input quantity index. Productivity defined by 5.2 is the difference in the output quantity index that cannot be explained by differences in input utilisation. By rearranging Equation 5.2, the following profit decomposition is obtained:

5.3
$$\theta^{a,b} = P^{a,b} \cdot R^{a,b} \cdot K^{a,b}$$

Using 5.3, the firms' relative profits can be defined in terms of contributions from output prices ($P^{a,b}$), productivity ($R^{a,b}$), and the fixed input quantity index ($K^{a,b}$) without making any behavioural assumptions or restrictions on the specific form of the technology used by firms.

To apply the decompositions, we first define $p^b = p^b_1, ..., p^b_M$ as a price vector for vessel b of netput prices specified for M variable 'netputs', denoted by $y^b = y^b_1, ..., y^b_M$. In the netput vector, if $y^b > 0$ the good is an output, but if $y^b < 0$ the good is a variable input. The vector of (quasi-) fixed input prices for vessel b is $r^b = r^b_1, ..., r^b_N$ where there are N fixed inputs, denoted by $k^b = k^b_1, ..., k^b_N$. Both price vectors satisfy the requirement that each element is positive.

As shown by Fox et al. (2003), the Törnqvist index has a number of useful properties for constructing the price and fixed-input indexes for use in 5.3. Using the Törnqvist index, $P^{a,b}$ and $K^{a,b}$ in 5.3 can be denoted as netput price and quantity indexes and are defined by 5.4 and 5.5, where $s_m = (p_m y_m)/(\Sigma p_m y_m)$ is the profit share of netput m and $s_n = (r_n k_n)/(\Sigma p_m y_m)$ is the profit share of fixed input n, i.e.

5.4
$$ln P^{a,b} \equiv \sum_{m=1}^{M} \frac{1}{2} \left(s^b_m + s^a_m \right) ln \left(p^b_m / p^a_m \right)$$

5.5
$$ln K^{a,b} \equiv \sum_{n=1}^{N} \frac{1}{2} \left(s^b_n + s^a_n \right) ln \left(k^b_n / k^a_n \right)$$

The multiplicative nature of the Törnqvist index allows us to decompose the aggregate price and fixed-input indexes between vessels a and b into a product of individual price and input differences, i.e.,

5.6
$$P^{a,b} = \prod_{m=1}^{M} P^{a,b}_m$$

and

5.7
$$K^{a,b} = \prod_{n=1}^{N} K^{a,b}_n$$

where the index for each netput m and fixed-input n is itself a Törnqvist index. In this manner, equations 5.3, 5.6 and 5.7 collectively represent a detailed decomposition of profits between firms a and b. Using these profit decompositions, individual measures of relative profits over time and the contributions to relative profits from input and output prices, vessel size and productivity can be derived. This is a multilateral index, and the comparison is to a specific vessel, which would give transitivity in comparisons.

Where there is only one (quasi-) fixed input, profits are all attributed to that input ($s_n = 1$), and the (quasi-) fixed quantity index defined by (5.5) reduces to the following:

5.8
$$K^{a,b} = \frac{k^b}{k^a}$$

Variable inputs in the fishery are fuel and labour. From equations 5.3 , 5.6 and (5.7), our decomposition of the profit ratio between vessel *a* and vessel *b*, $\theta^{a,b}$ is given by:

5.9
$$\theta^{a,b} = R^{a,b} \cdot PO^{a,b} \cdot PL^{a,b} \cdot PF^{a,b} \cdot K^{a,b}$$

In this profit decomposition, the performance of vessel *b* relative to vessel *a* can be decomposed into differences because of productivity ($R^{a,b}$), output ($PO^{a,b}$), variable inputs ($PL^{a,b}$ and $PF^{a,b}$) and vessel capital ($K^{a,b}$).

An important issue to consider is the effect of changes in fish stocks on both profits and productivity. Stock changes can be accounted for by calculating a resource-adjusted measure of efficiency (Fox et al. 2003). The stock-adjusted profit decomposition between any arbitrary vessel *b* and the reference vessel *a*, is:

5.10
$$\theta_s^{a,b} = \theta^{a,b} \cdot \left(\frac{stock^a}{stock^b} \right)$$

where *stock^a* and *stock^b* are the values of the overall stock index for reference vessel *a* and an arbitrary vessel *b*. Combining all equations gives a stock adjusted measure of productivity, and allows a decomposition of profits in terms of various key components.

6 Case study: the northern prawn fishery

The case study for the northern prawn fishery includes the MEY analysis for the tiger prawn component of the fishery and the stochastic production frontier estimated for the banana prawn component of the fishery. An overview of the fishery is discussed in the first section.

Overview of the northern prawn fishery

The northern prawn fishery (NPF), first established in the late 1960s, is one of Australia's most valuable fisheries. The fishery occupies an area of 771 000 square kilometres off Australia's northern coast, extending from the low water mark to the outer edge of the Australian Fishing zone (AFZ) along approximately 6000 kilometres of coastline between Cape York in Queensland and Cape Londonderry in Western Australia (see map 1).

Although there are more than fifty species of prawn that inhabit Australia's tropical northern coastline, only about nine species are caught. Three species (the white banana prawn *Fenneropenaeus merguiensis*, the brown

map **1**   Area of the Northern Prawn Fishery
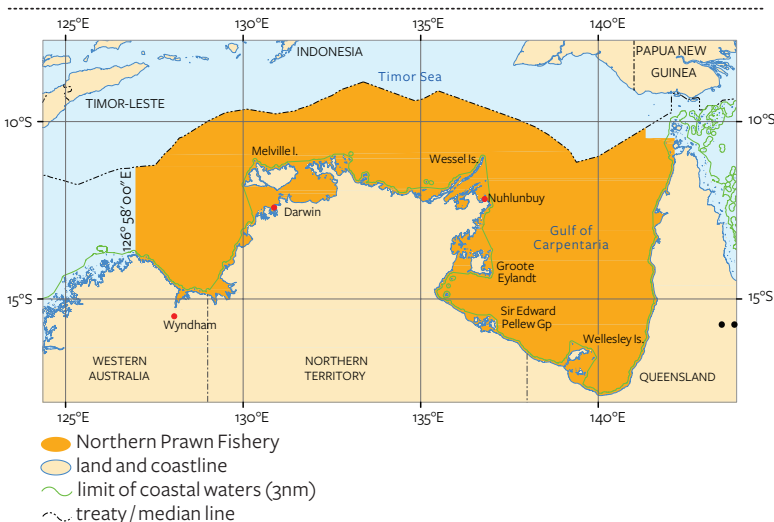
Source: Australian Fishery Management Agency 2008. http://www.afma.gov.au/

tiger prawn *Penaeus esculentus*, and the grooved tiger prawn *P. semisulcatus*) account for almost 95 per cent of the total annual landed catch weight from the fishery (ABARE 2008a). Endeavour prawns (*Metapenaeus endeavouri* and *Metapenaeus ensis*) and the red-legged banana prawns (*F. indicus*) form most of the remainder of the catch. Other commercial catch includes the giant tiger prawn (*P. monodon*), western king prawn (*Melicertus latisulcatus*) and the red spot king prawn (*Melicertus longistylus*) (AFMA 2002).

The gross value of prawn production in the NPF in 2006-07 is estimated to be A$64 million with a total harvest of about 5100 tonnes. Nearly 90 per cent of all prawn output is exported to Japan and Asia (ABARE 2008a).

In 2007-08, 52 vessels actively participated in the NPF. All vessels are purpose built twin-gear otter trawls and generally range in size from 14 to 29 meters, with the most common boat size between 18 and 25 meters (AFMA 2008a). Most boats operate between 80 and 90 per cent of the time available for fishing, with breakdowns and unloading (to mother-ships) accounting for much of the remaining time. The fleet is technologically advanced, employing modern packing and freezing capabilities and sophisticated fishing aids such as echo sounders and satellite global positioning systems and plotters.

The banana prawn fishery is primarily located in the eastern waters of the Gulf of Carpentaria, in isolated grounds along the Arnhem Land coast and in Joseph Bonaparte Gulf. Annual catches since 1983 range from 2200 to 6600 tonnes per year (Caton and McLoughlin 2000 and ABARE 2008a). The white banana prawn accounts for more than 80 per cent of all banana prawn catch. The spawning of banana prawns generally occurs in offshore areas, while recruitment of prawns to the fishery usually takes place in late spring. Banana prawns form dense aggregations (boils), which are easily spotted, allowing for rapid harvesting. The fishing season (with mostly daytime catch) starts around April and lasts only a few weeks. Single aggregations of prawns usually contain four to 180 tonnes, but can be as high as 400 tonnes. Highest seasonal catches generally follow higher than average rainfall during the preceding summer (see Staples and Vance 1986). Given the ease in harvesting, trawls for banana prawns are typically of a short, 10 to 20 minute duration.

Total effort attributed to the fishery in 2006-07 was approximately 11 100 boat days, comprising 7400 and 3700 boat-days for tiger and banana prawns respectively (estimated from the NPF Surveys carried out by ABARE in 2008). Although it is clear that potential catch is highly dependent on weather patterns, the relationship between catch and future stock size for banana prawns is not. As yet, there is still no conclusive evidence that effort affects future stock abundance in this fishery (see Staples and Maliel 1994), although very recent catches below expectations have caused concern. In

fact, the maximum sustainable yield for banana prawns is estimated to be 4000 tonnes, which is roughly equivalent to the average catch over the past decade (Taylor and Die 1999).

The fishery has historically been managed with input controls such as gear and vessel restrictions, limited entry, area closures and seasonal closures. A brief history of the management arrangements in the fishery is outlined in table 1. Since 2000, the main management tool has been input controls in the form of restrictions on the length of net headrope allowed to be towed in the fishery. Gear units allocated to each operator specify the length of headrope allowed and operators are free to buy, sell or lease these gear units.

Seasonal closures in the fishery create two distinct fishing seasons, a banana prawn season and a tiger prawn season. In 2006, the banana prawn season was open from 9 April to 21 May and the tiger prawn season was open from 1 August to 15 November. In recent years the fishery has been closed during August. However in 2005, AFMA agreed to include August in the tiger prawn season to minimise catches of tiger prawn in the banana prawn season.

Initially, management efforts were confined to limiting entry and imposing controls on boat replacement through the 1977 and 1980 three year plans. Adoption of A-units as the measure of capacity and B-units as the effective right for a boat to fish in 1984 was part of an attempt to control the increasing effort that resulted from replacement of old boats with new (AFMA 1999). In 1986, data compiled by CSIRO showed a serious decline in brown tiger prawn stocks in the western Gulf of Carpentaria. A Voluntary Adjustment Scheme, involving buy back of A-units, was developed largely in response to that finding and a consequent CSIRO proposal for an immediate 25 per cent cut in effort to protect pre-spawning tiger prawns (Pownall 1994). Initially the intent was to reduce total A-units in the fishery to 70 000 by the start of the 1990 season. Any shortfall would be met by a compulsory acquisition at the start of the 1990 season. However, industry opposition and eventual Senate rejection eliminated the compulsory element of the buy back. The voluntary element was extended to acquisition of B-units, so effectively buying out the right to operate a boat in the fishery.

The voluntary buy back scheme was refinanced and extended in 1990. An initial target of 50 000 A-units by the beginning of 1993 was set, later being amended to 53 844. If the target was not reached through voluntary buy back, the residual was to be met by a proportional surrender of A-units. The target was met by a combination of voluntary and compulsory acquisition, with 53 844 A-units and 132 B-units remaining in the fishery on April 1, 1993. Those units were rolled over as Class A and Class B Statutory Fishing Rights (AFMA 1999).

Throughout the period of the Voluntary Adjustment Scheme a series of other policy changes was implemented, in part in recognition of limited effectiveness of a slowly proceeding reduction in A-units. Those changes included the introduction of gear restrictions and both a daylight trawling ban and mid season closure for tiger prawns. Since 1993, two major changes in management have been implemented. In 1999 the basis for input constraint was changed from boat size and power (A-units) to headrope length (gear units), with a concurrent reduction in gear units of 15 per cent. In 2002 gear units were reduced by a further 25 per cent and the tiger prawn season length was further reduced. Further reductions followed in 2005. A new target level of catch of maximum economic yield (MEY) to replace maximum sustainable yield (MSY) was accepted by the AFMA Board in 2004 after being recommended by the Northern Prawn Fishery Management Advisory Committee (NORMAC) (AFMA 2004b, NORMAC 2004). This objective implies that the fishery be managed so that effort, catch and thus stock biomass are at levels that allow net economic returns to be maximised.

Several things are notable about the sequence of management regimes in the fishery. Each of the changes was made in recognition that the system it replaced had failed to constrain effective effort sufficiently to protect prawn stocks. Where effective effort was reduced by management change, the primary reduction appeared to be short lived. This effect, and one of the primary reasons for it, is illustrated in figure g. Fishing power, measured as the average catching ability of a boat in a day's fishing has risen rapidly and consistently over time. The rise in fishing power is the result of continuous improvements in technology, input combinations and knowledge. The acquisition of improved scientific knowledge of the fishery, along with the observation of declining catches has made it increasingly clear over the past few years that prawn stocks are not being conserved and catches are not being controlled.

The combination of policy changes in 1999 and 2002 appears to have temporarily slowed the increase in fishing power as well as contributing to a rapid fall in total days fished. Total days fished in 2002 were 55 per cent of the 1998 level, probably as a result of a combination of policy change and significant falls in prawn prices since 1998. A return to the average annual rate of growth in fishing power that applied from 1970 to 1998, more than 6.7 per cent, would see effective fishing days return to the 1998 level in less than 9 years, even if no other adaptations were made. It is evident from figure g that the effects of input policy change on fishing power are never more than temporary.

1 History of management changes in the northern prawn fishery

1971	Seasonal closures for banana prawns introduced (Rose and Kompas 2004).
1977 & 1980	Controls on boat replacement (Rose and Kompas 2004).
1984	Unitisation of fishery introduced: Class A Units (fishing right) and Class B Units (boat hull volume and engine power allowance) (NORMAC 2001) .
Mid-1980s	Buyback scheme implemented to reduce effort according to a target of 70 000 units in the fishery (NORMAC 2001) .
1987	April opening date to target market sized prawns and a mid-season closure to reduce catch of spawners introduced (Caton and McLoughlin 2004).
1989	20 810 Class A units sold under the above scheme but falls short of target (NORMAC 2001) .
1990	Further restructuring through a voluntary buy-back scheme and a 30 per cent compulsory reduction in units across the board with a target of 53 844 units. Target achieved and vessel numbers reduced from 216 to 132 by 1993 (NORMAC 2001).
1995	New management plan and Statutory Fishing Rights (SFRs) introduced to replace Class A and B units (Caton and McLoughlin 2004).
1999	First season shortened by 14 days and second season by 18 days (Caton and McLoughlin 2004).
2000	New management system based on control of gear units according to head-rope length of fishing nets (Caton and McLoughlin 2004). First season shortened by 5 days and second season by 5 days (Caton and McLoughlin 2004).
2002	Effort cut by 40 per cent. This was achieved through a 25 per cent reduction in total allowable headrope length (Caton and McLoughlin 2004) and a shortening of the first season by 14 days and the second season by 7 days (Caton and McLoughlin 2004).
2004	Maximum economic yield (MEY) defined as target level of catch (Roberts 2004).
2005	25 per cent reduction in total allowable headrope length (Roberts 2004). Tiger prawn season extended to include August (Larcombe and McLoughlin 2007)
2006	Structural adjustment package resulted in a 45 per cent reduction in vessel SFRs and 34 per cent reduction in gear SFRs (Abetz 2006). The limit on towing only two nets was removed for the start of the 2006 season subject to a 10 per cent penalty on gear SFRs if operators chose to use other gear configurations (Larcombe and McLoughlin 2007).

Maximum economic yield analysis for the northern prawn fishery

This analysis constructs MEY estimates for the tiger prawn component of the northern prawn fishery, illustrating the importance of MEY and fleet size. The theoretical context is a bioeconomic model calibrated by specific fishery parameters. The exercise also nicely illustrates the construction of standard bioeconomic models of a fishery. Kompas and Che (2004) and Rose and Kompas (2004) provide a more detailed analysis.

This section provides the biological model, and in particular the relationship between spawning stock-recruitment and spawning stock-biomass as well as the effect of fishing harvest and mortality.

Biological model

The spawning stock-recruitment relationship is modelled according to Ricker's equation (Ricker 1954) or:

6.1
$$R_t = \alpha_1 \hat{S}_{t-1} e^{\beta_1 \hat{S}_{t-1}} + \xi_1$$

where R_t is the total number of recruits produced in year t and $\hat{S}_{t-1}$ is the spawning stock of the previous year (estimated as the number of prawns), and where α_1 and β_1 are parameters that determine the relationship between recruitment and the spawning number of the previous year. The measure ξ_1 reflects uncertainty or the stochastic behaviour of the spawning stock-recruitment relationship.

Spawning stock is taken as a proportion (γ) of the total female stock, assuming that female prawns constitute half of the total stock of prawns, so that:

6.2
$$\hat{S}_{t-1} = (\gamma S_{t-1})/2.$$

Following Penn et al. (1995) and Wang and Die (1996) the spawning stock $\hat{S}_t$ is the result of annual recruitment R_t and fishing effort, defined as:

6.3
$$\hat{S}_t = \alpha_2 R_t e^{-\beta_2 (F_t + m)}$$

where F_t is fishing mortality at year t and m is the annual natural mortality rate.

Following Wang and Die (1996) fishing mortality at year t is defined by:

6.4
$$F_t = q \cdot E_t = q \cdot B_t \cdot N_t$$

where q is the 'catchability coefficient' and E_t is fishing effort at year t. Fishing effort is determined as total 'standard' boat days in the fishery, which is a multiple of total 'standard' boats (B_t) and nominal fishing days in the season (N_t). In this study one unit of fishing effort is defined as the daily effort of a 'standard' boat. A standard boat is used to avoid the problem of equating boat day units between large and small vessels. In practical terms, this capacity can be measured by boat engine power and a measure of hull units or the length or the weight of boat. In this study boat capacity is measured in terms of A-units, or a simple linear combination of a kilowatt of engine power and a cubic metre of hull. The measure of boat capacity used here is the same as that used to specify A-units in the NPF up until the intro-duction of gear units in July 2000. Define a standard boat size as A units so that the total standard boat numbers at year t is given by

6.5
$$B_t = \sum_{i=1}^{M} \frac{A_{it}}{\overline{A}}$$

where M is the number of boats in the fishery, and A_{it} is the capacity of boat i in year t. With technological change, fishing mortality at year t is simply given by:

6.6
$$F_t = q \cdot E_t = q \cdot TEC_t \cdot B_t \cdot N_t$$

where TEC_t is the variable that measures the change in technology at year t.

Following Wang and Die (1996) the annual catch h_t in tonnes is approxi-mately defined as:

6.7
$$h_t = \alpha_3 R_t \left(1 - e^{-\beta_3 (F_t + m)}\right).$$

Catch increases asymptotically to a maximum of $\alpha_3 R_t$ as fishing effort tends to infinity (Wang and Die 1996).

Based on equation 6.7 the catch per unit of effort ($CPUE$) is given as

6.8
$$CPUE_t = \frac{h_t}{E_t} = \left(\alpha_3 R_t \left(1 - e^{-\beta_3 (F_t + m)}\right)\right)/(E_t) + \xi_2$$

where ξ_2 represents stochastic error in $CPUE$. For input controls random error in CPUE is generally captured by variance in fish harvest. For output controls the error is generally captured by variance in fishing effort (E_t).

Bioeconomic model

Annual total revenue of the fishery is defined as the multiple of annual fish harvest and the annual (average) price of fish, so that

6.9
$$TR_t = p_h h_t$$

where p_h is the price of fish drawn from an inverse demand curve. Following Danielsson (2002) and Campbell, et al. (1993) this price is determined by

6.10
$$P_h = P_o \left(H_o/h_t\right)^{1/\varepsilon}$$

where ε is the elasticity of demand for catch and P_o is the unit price of the catch when the volume of the catch is H_o.

Annual total cost is assumed to be the sum of labour, material, capital and other costs. Labour costs generally include a share of total fish revenue and packaging and gear maintenance expenditures directly correspond to total fish revenue. Capital costs are defined by the cost of capital calculated as a sum of depreciation cost and the annual opportunity cost of boat capital value. Capital costs and other costs (of which fuel is a major component) are assumed to depend on fishing effort so that total costs can be expressed as:

6.11
$$TC_t = \alpha + c_L h_t p_h + c_M p_h h_t + c_K E_t + c_O E_t$$

c_L and c_M is the share cost of labour and materials per each Australian dollar of output respectively; and c_K and c_O is the average capital and other costs per unit of effort respectively. The average capital cost of a unit of effort (c_K) is estimated by dividing total capital costs by total effort. Average other costs (c_O) per unit of effort is estimated by dividing total other costs by total fishing effort. The value of α represents a fixed cost component.

Annual fishery profit is defined by subtracting annual total cost from annual total revenue. From equations 6.9 and 6.11 annual profit is expressed as

6.12
$$\Pi_t = p_h h_t - (x + c_L p_h h_t + c_M p_h h_t + c_K E_t + c_O E_t)$$

Fishing effort is defined as total 'standard' boat-days with the number of 'standard' boats (B_t) as computed in equation 6.5.

An objective of a fishery is to maximise aggregated profits over time. Although seasonal and area closures are important in almost every fishery, including the NPF, the main concern here is the choice between input and output controls. Under input controls the fishery authority targets overall effort levels through a combination of input restrictions, limits on technology and limitations on days fished. With output controls the authority sets a catch quota with vessels free to adjust their effort levels to meet total allowable catch. Assuming that effort levels are observable and enforceable, the problem for an input control regime is to maximise:

6.13
$$\max_{E_t} \sum_{i=1}^{T} \Pi_t = \sum_{i=1}^{T} \left[p_h h_t(E_t) - (x + c_L h_t(E_t) p_h + c_M h_t(E_t) p_h + c_K E_t + c_O E_t \right.$$

through a choice of or variations in effort. The choice of the control variable E_t is set by the length of time or nominal days fished. Introducing discounting and substituting 6.6, 6.7 and 6.1 into equation 6.13, gives

6.14
$$\max_{E_t} \sum_{i=1}^{T} \hat{\Pi}_t = \sum_{i=1}^{T} \left(\frac{1}{(1+\delta)^i} \right) \left((p_h - c_L - c_M) \, \alpha_3 \alpha_1 \hat{S}_{t-1} \, e^{\beta_1 \hat{S}_{t-1}} (1 - e^{-\beta_3 (qE_t + m)}) - c_K E_t - c_O E_t \right)$$

for δ the discount rate and where $\hat{\Pi}_t$ is the net present value of profit at year t.

For output controls the problem is to maximize

6.15
$$\max_{h_t} \sum_{i=1}^{T} \hat{\Pi}_t = \sum_{i=1}^{T} \left(\frac{1}{(1+\delta)^i} \right) (p_h h_t - (c_L h_t p_h + c_M h_t p_h + c_K E_t + c_O E_t))$$

through a choice of harvest (h_t) and where $\hat{\Pi}_t$ is the net present value of profit at year t.

A solution requires substituting from equations using equations 6.1, 6.6 and 6.7 to ensure that equation 6.15 is a function of catch or harvest only. Larger stock values clearly lower the costs of fishing or the amount of effort required to meet a catch quota. Solving equation 6.15 also requires that spawning stock at the period o ($\hat{S}_o$) be known. In all cases the appropriate transversality condition at time $t=T$ is that the value of profits is zero (Clark 1990).

Optimal solutions and maximum economic yield analysis

Parameters used in the model are indicated in Kompas and Che (2005), for base year 2000. Details of these parameters and their sources are discussed below. The initial spawning stock ($\check{S}_o$) for brown and grooved tiger prawns in the year 2000 is estimated from spawning stock indexes provided by CSIRO (2002a). The conversion from indexes to millions of prawns was done by using a coefficient linking spawning stock in terms of indexes at 1993 (CSIRO 2002a) with the spawning stock in terms of millions of prawns indicated by Wang and Die (1996). The recruitment of prawns is estimated from the initial spawning stocks following equation 6.1.

Parameters α_1, β_1 and α_2, β_2 for the biological relationship described in equations 6.1 and 6.3 are provided by Wang and Die (1996). The annual mortality rate (m) follows Wang (1999) and Wang and Die (1996). The sex (male and female ratio) is 1:1, following Wang (1999), Wang and Die (1996) and Dichmont et al. (2003b). The value of γ for brown tiger and grooved tiger prawns is computed as the average of the monthly percentage of female spawning over the 'biological year', from August to March (Crocos 1987a and 1987b).

Parameters for the catch, stock and effort relationship (α_3 and β_3) as defined in equation 6.7 are provided by Wang and Die (1996). The coefficient of effort distribution between brown and grooved tiger prawn fishing follows research by Dichmont et al. (2003b). The actual number of vessels operating in the year 2000 was 120 (AFMA 2002). Standard vessel fishing capacity is 400 A-units, the average obtained from CSIRO (2002b). The catchability rate of one unit of fishing effort is obtained from Wang (1999). This catchability rate is given for 1993 with a natural mortality rate of 0.045. For the year 2000 this number is adjusted to account for effort creep and technological change, based on Dichmont et al. (2003a). For the cases of 'basic high' and 'spatial high' it is estimated that fishing power has increased at around 2 to 2.4 per cent per annum. Therefore in this study the adjustment to the catchability parameter at 2000 is 19 per cent higher than in 1993. For years subsequent to 2000 it is assumed that there is no effort creep.

The initial price of tiger prawns is computed from ABARE (2008a). The initial catch and price of tiger prawns or $H(0)$ and $p(0)$ is based on values at year 2000. Based on statistics for catches and prices (ABARE 2008a), and given that 90 per cent of tiger prawns are exported to Japan, the coefficient of flexibility between supply and price is estimated at 15. This number is based on the empirical relation between prawn supply and demand in Australia (based on ABARE 2008a). The proportion of revenue share by labour, materials and other costs are based on data collected in economic surveys of the NPF carried out by ABARE.

The average capital cost per unit of fishing effort is computed from total capital cost and total fishing effort. The value of vessel capital is the market value at year 2000 of vessel, hull, engine and onboard equipment as of July during the survey years. Capital costs are defined by the user cost of capital calculated as a sum of depreciation cost, the annual opportunity cost of the total capital value and the difference in boat value between season opening and closing time in a given year. Vessel depreciation is based on the 'discrete diminishing value' approach. The opportunity cost for vessel capital was derived as the multiple of the nominal interest rate and vessel capital.

The average of 'other costs' per unit fishing effort is computed from total other costs (mainly fuel costs) and total fishing effort. Both average capital and other costs per unit of fishing effort are measured in real prices, base year 2000. The Consumer Price Index was obtained from the DOL (2008).

Using a genetic algorithm the optimal solutions described in equations 6.14 and 6.15 are obtained and reported in table 2. The choice variable for output controls is harvest or catch, for input controls, effort. Several models are solved. The first is a base model, assuming no uncertainty in effort or catch, setting the variance in stock and CPUE equal to zero. The second model obtains results based on the actual variance in stock and CPUE in the NPF,

using the variance in the residuals from the estimates above. Finally, the case of discounting is considered.

The time horizon for the optimal process used in this study is 50 years, long enough to guarantee that optimal results are sufficiently close to their steady state values before diverting to meet a terminal condition in year 50. The terminal condition is such that the value of profits at year 50 goes to zero. The issue of what discount rate should be used in a Commonwealth fishery is contentious. Firms in the industry would prefer a rate that reflects the opportunity cost of investment in vessels and fishing capacity. The fishery manager would likely prefer a more 'conservationist' approach, or even a zero discount rate. For a Commonwealth resource some rates in between may be the most appropriate. In this study the case of zero discounting and a 3 per cent discount rate is used and compared.

The optimal solutions for the case with a discount rate of 3 per cent are reported in table 2. Both cases indicate more catch earlier in the planning horizon and consequently smaller 'near' steady state stocks than in cases without discounting.

In the case of stochastic recruitment and CPUE, optimal results show output controls dominate effort controls in the NPF for tiger prawns (there is no difference in a deterministic setting). Fishery profits are larger under output controls and the variance in profits is considerably smaller. Since there is less variance in stock relative to CPUE it is easier to control stocks by targeting catch, maintaining stock size, lowering its variance relative to the use of effort controls and thus decreasing the overall costs of fishing. The difference in profits between output and input controls is of course smaller under discounting since future gains from stock recovery and control in the future are worth less today. The issue of the appropriate rate of discount (if any) in a Commonwealth fishery is a subject for future research.

The comparison between MSY and MEY is most important. Using a constant number of boats at 120, shows that the ratio of stock at MEY to stock at MSY is roughly 1.42, indicating substantial overfishing in the NPF. Optimal effort levels in table 2 are roughly 60 per cent of current levels.

Finally, it should be noted that all results are obtained under the assumption of no effort creep or losses from high-grading. In cases where effort controls are used, effort creep can be considerable resulting in falls in fishery profits and the need to periodically measure 'true' fishing effort and thus adjust optimal target effort levels. This also involves costs in fleet restructuring and administrative and negotiating cost with new management arrangements. In cases where output controls are used, high-grading is often a concern since it may pay to discard low value catch, although in the NPF, with relatively homogenous stocks and catch this may be less of a problem.

2   Optimal solutions of the base and stochastic models for the northern prawn fishery (discount rate = 3 per cent)

	unit	output control	input control
Base model			
Total Expected Profit (mean value)	A$m	365	365
Mean values at steady state			
Total stock size	millions	302	302
Stock size of brown tiger prawns	millions	203	203
Stock size of grooved tiger prawns	millions	99	99
Annual harvest	tonnes	2 350	2 350
Number of boats in a year	boats	120	120
Fishing day per boat per year	days	77	77
Total boat days per year	boat-day	9 240	9 240
Average values per year			
Total stock size	millions	298	298
Stock size of brown tiger prawns	millions	196	196
Stock size of grooved tiger prawns	millions	102	102
Annual harvest	tonnes	2 250	2 250
Number of boats	boats	120	120
Fishing days	days	73	73
Total boat days	boat-day	8 760	8 760
Stochastic recruitment and CPUE model			
Total Expected Profit (mean value)	A$m	328	316
Standard of deviation	A$m	21	79
Mean values at steady state			
Average stock size	millions	329	322
Stock size of brown tiger prawns	millions	223	217
Stock size of grooved tiger prawns	millions	106	105
Annual harvest	tonnes	2 080	2 120
Number of boats in a year	boats	120	120
Fishing day per boat per year	days	63	64
Total boat days per year at the steady state	boat-day	7 560	7 680
Average values per year			
Total stock size	millions	320	315
Stock size of brown tiger prawns	millions	216	208
Stock size of grooved tiger prawns	millions	104	105
Annual harvest	tonnes	2 020	2 060
Number of boats	boats	120	120
Fishing days	days	61	63
Total boat days	boat-day	7 320	7 560

A stochastic production frontier analysis for the northern banana prawn fishery

This second case study summarises the results of a stochastic production frontier analysis for the NPF, specifically for the banana prawn fishery, by estimating equations comparable to 4.3 and 4.4. This approach allows for vessel level measures of economic efficiency and gives an assessment of the efficiency implications of the use of input controls for the fishery as a whole. A more elaborate description of the model and results is contained in Kompas et al. (2004).

Data sources and variables

The unbalanced panel data used to estimate the stochastic frontiers for the NPF comes from two different data sets. Data on a larger set of variables is available for an unbalanced panel of 853 observations for 138 vessels over the period 1990 to 2000. The vessels included in the data harvested almost 40 per cent of the total catch of banana prawns each year and are drawn from surveys and statistics for the NPF fleet carried out and compiled by ABARE and the CSIRO. The data includes measures of output by species (banana, brown and grooved prawn), crew size, revenue, boat variable costs (not available by species), capital costs, nominal fishing days for banana prawns and vessel characteristics (hull units, engine power, A-units, gear length, boat size). The vessel characteristics, landings of banana prawns and nominal fishing days for banana prawns are provided from the CSIRO surveys for the fishery.

Generalised likelihood ratio tests are used to help confirm the functional form and specification of the estimated models. The correct critical values for the test statistic come from a mixed chi-squared distribution (at the 5 per cent level of significance). A translog specification was initially estimated, but a pre-test with the null hypothesis of the Cobb–Douglas as the correct functional form could not be rejected (Kompas et al. 2004).

Maximum likelihood estimates of the model were obtained, following a three-step procedure. OLS estimates are first obtained, followed by a grid search that evaluates a likelihood function for values of gamma between zero and one, with adjustments to OLS estimates. All other values of beta are restricted to be zero in this step. Finally, the best likelihood values selected in the grid search are used as starting values in a quasi-Newton iterative procedure to form maximum likelihood estimates at a point where the likelihood function obtains its global maximum.

Estimated results and efficiency analysis

Results for the model are reported in table 4, and a description of inputs in table 3. All input variables in the stochastic frontier production function are significant, except crew number, as are time trend and year-dummy variables. Estimates also show that inputs for banana prawn output in order of importance are fishing effort (boat days), fuel (as a proxy for engine size and power), headrope gear length and crew number. All input share coefficients sum to 0.75. Results of OLS estimates are also reported and as expected vary from frontier estimates for all input variables.

j Average technical efficiency of the northern prawn fishery

fishing power
effective 1970 days fished

Note: An index value of 1 indicates complete technical efficiency.
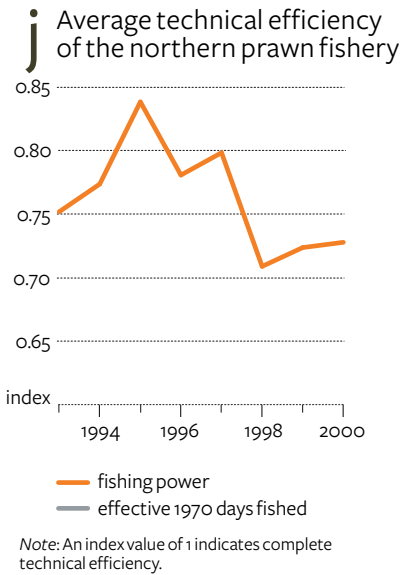
Results for the technical inefficiency model indicate that A-units and gear length are both significant. A-units have a significant negative effect on technical inefficiency (hence a positive effect on technical efficiency) and gear length has a positive effect on inefficiency. The hire of a skipper estimates as non-significant but has the expected sign. Incentive effects for owner-operated boats should likely result in an increase in technical efficiency relative to a hired skipper. The estimated results of the average technical efficiency are reported, showing the decreasing trend during the study period (see figure j).

Although banana prawn catch is highly dependent on seasonal weather effects, the relationship between catch and future stock abundance, as mentioned earlier, is not clear. In fact, it is argued that future stock size seems to be largely independent of the amount of fishing effort on adult stock, with the escape of spawners highly resilient to recruitment overfishing (Staples and Maliel 1994). Nevertheless, catches below expectations have generated concern that stock size may be falling.

3 Description of inputs and vessel specific variables in the northern prawn fishery
(138 vessels for the period 1994-2000)

variables	description
Output	Output of banana prawns (kg)
Fishing effort	Nominal fishing days for banana prawns (days)
Hull units	Under deck volume (m³)
Engine power	Registered engine power (kW)
Vessel A-unit	The sum of one A-unit for every cubic meter of hull volume and one A-unit for each kilowatt of engine power
Gear length	Headrope length of gear (meters)
Boat size	Vessel length (meters)

Sources: Statistics from CSIRO (2003).

Table 4 shows two important results of input controls in the northern prawn fishery. First, controls on A-units (hull and engine size) by the regulator has had the net effect of reducing technical efficiency (or raising technical inefficiency) because the estimated coefficient in the technical inefficiency model is statistically significant and negative. In other words, for the average vessel an increase in A-units lowers technical inefficiency (raises technical efficiency). Second, Kompas et al. (2004) found that because of controls on A-units in the 1980s fishers have tended to substitute to increased headrope length so as to increase their fishing power. Unfortunately, the technical inefficiency model indicates that such input substitution has raised technical inefficiency (lowered technical efficiency) because its estimated coefficient is positive and statistically significant. Table 4 shows this effect in terms of the average measure of technical efficiency over time in the NPF. It falls considerably. The reason is clear. On average the ratio of A-units to gear in the fishery falls over time. Given the estimates this must imply efficiency falls as well.

4   Estimated results of the NPF frontier analysis (1990-2000)

	coefficient			asymptotic T-ratio
Stochastic production frontier				
Constant	4.65	b	(0.43)	10.79
Effort	0.72	b	(0.03)	23.74
Engine power	0.38	b	(0.09)	4.01
Head rope length of gear	0.44	b	(0.14)	3.19
Year 1994	−0.62	b	(0.04)	17.89
Year 2000	−0.38		(0.04)	9.70
Technical inefficiency model				
Constant	11.00	b	(2.81)	3.91
Head rope length of gear	2.20	a	(1.16)	1.88
Hull units	−1.59	b	(0.61)	2.52
Fishing effort	−1.27	b	(0.37)	3.42
Engine power	−1.15	b	(0.49)	2.37
Sigma-squared	0.68		(0.21)	3.27
Gamma	0.91		(0.03)	33.63
Ln (likelihood)	348.54			
Mean Technical Efficiency (1990-2000)	74.40%			

a Denotes statistical significance at the 0.05 level b Denotes statistical significance at the 0.01 level.
Note: Numbers in parentheses are asymptotic standard errors.

The efficiency analysis indicates that input controls on hull size and engine power and the substitution to unregulated inputs, such as headrope length, have reduced technical efficiency in the NPF. Such an outcome runs counter to the stated objective of the fishery regulator to both maximise economic efficiency and ensure the sustainability of the resource.

7 Case study: the south east trawl fishery

The case study for the south east trawl fishery (SETF) includes MEY analysis and the analysis of profit decomposition and productivity for the south east trawl fishery.

Overview of the south east trawl fishery

The southern and eastern scalefish and shark fishery, which includes the Commonwealth trawl, Great Australian Bight trawl, gillnet hook and trap and east coast deepwater trawl fisheries, has been established since the early 1900s and is the largest tonnage source for fresh fish supply in the domestic Australian market. In 2006-07 the fishery had a gross value of production of around A$96 million, of which the trawl sector accounts for around 56 per cent (estimated from ABARE 2008a). The fishery is a complex, multispecies, trawl and non–trawl fishery situated off the south east coast of Australia, targeting about 118 species of finfish and deepwater crustaceans. Some species are caught in a few metres depth (eg. flathead, school whiting); while others (eg. orange roughy and dories) comprise some of the world's deepest commercial trawl fisheries extending down to 1300 metres. As a result, a number of different fishing methods and vessels have been operating simultaneously in the fishery.

The trawl sector accounts for a large proportion of the fishery, which extends southward from Barrenjoey Point in New South Wales around Victoria and Tasmania and west to Cape Jervis in South Australia (see map 2). The SETF is located in Australia's 200 nautical mile exclusive economic zone (EEZ). The fishery's 100 or so harvesters employ trawls (otter board, Danish seine and mid-water trawl) and harvest more than one hundred different types of species. Overall, the SETF accounts for about one-fifth of the landed value of Commonwealth fisheries, or about A$54.5 million in 2006-07 (ABARE 2008a). The most important species are orange roughy, blue grenadier, tiger flathead, spotted warehou and ling, accounting for 60 to 70 per cent of total GVP of the trawl sector. The harvest and the GVP of these species over 1997-2007 are indicated in figure k and l. It can be observed that the catch and GVP of orange roughy had been decreasing over the last decade.

Over recent decades, the participants in the fishery have increased their vessel size and capacity. In part, these investments have been made to access deeper water and further offshore fisheries, such as the orange roughy, but they have also occurred as a result of the 'race to fish' incentive.

k Total landings, by species
south east trawl fishery

- blue grenadier
- orange roughy
- spotted warehou
- tiger flathead
- ling
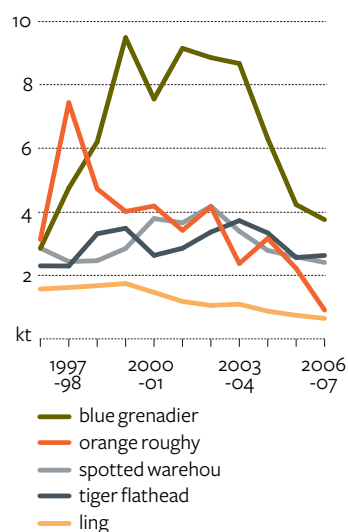
Gross value of landings, by species
south east trawl fishery

- blue grenadier
- orange roughy
- spotted warehou
- tiger flathead
- ling
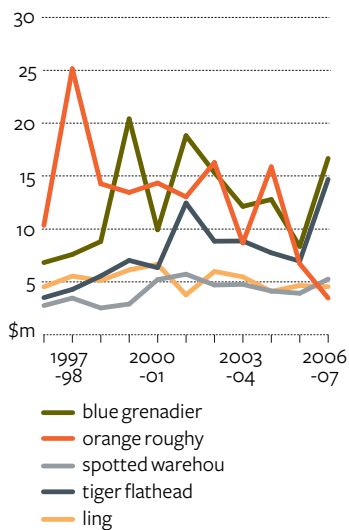
Because of concerns about over-capitalisation, input controls were introduced in 1986 that established vessel 'unitisation' whereby every boat was registered in terms of its hull and engine size, defined as boat units. Owners wishing to upgrade their vessels were required to purchase registered units from other operators with an "offset" amount to prevent overall increases in fishing power.

Vessel unitisation and input controls failed to prevent an increase in the capital employed in the fishery. To help prevent further increases in capacity, AFMA introduced individual transferable quotas (ITQs) in 1992 that encompassed 16 of the major commercial species in the fishery. The initial allocation of ITQs was contentious as some fishers considered their allocations as insufficient compensation for their loss of previous fishing entitlements associated with their boat units. The introduction of ITQs also failed to bring about the hoped for reduction in the number of vessels operating in the fishery with very low levels of quota traded in the first five years of the ITQ program. To address these concerns an industry assisted quota brokerage service was established in 1997 that greatly increased the level of lease quota trading relative to the period 1992-96. As a consequence, average yearly lease quota trades increased by more than 50 per cent to 26 000 tonnes in the period 1997-2000 compared to the preceding five years (see Kompas and Che 2007).

Acrimony from the initial allocations, and a concern that ITQs had not delivered the expected benefits to all fishers, led the regulator to also institute a permit or license buyback in 1997. The buyback had a dual purpose: to remedy the acrimony over the initial allocation and its associated uncertainty and litigation and to reduce the perceived overcapacity in the fishery. In total, about A$4 million was spent in the buyback that included A$2.35 million of targeted assistance to 18 fishers designed to avoid further legal action over the initial quota allocation. The sum of A$1.7 million was used to buy back the fishing licenses of 27 fishers (AMC Search Ltd 2000), with seven fishers receiving both a buyback of their licenses and targeted financial assistance.

The license buyback removed 14 active licenses and 13 dormant or latent licenses from the fishery. Overall, the buyout reduced the number of active fishing vessels from 108 to 94 and vessel capital worth approximately A$7 million (AMC Search Ltd 2000). The buyout was taken up by vessels that were mainly '...small scale with annual turnover of less than A$1 million' (AMC Search Ltd 2000). The net effect was to increase the expected profitability in the fishery, as reflected in the increase in the value of a boat license to participate in the fishery from A$60 000 to A$85 000 immediately following the license retirement.

There is significant latent effort in the fishery. FERM (2004) reports that soon after their introduction, TACs and catch for many species had increased by nearly 50 per cent and by 1998 were nearly 65 per cent above

Southern and eastern scalefish and shark fishery
Commonwealth trawl sectors and South Australian coastal waters sector

- east coast deepwater trawl sector
- trawl exclusion zone (closed by permit conditions)
- Commonwealth GAB trawl sector
- Commonwealth trawl sector
- South Australia coastal waters sector
- limit of coastal waters (3nm)
- limit of Australian fishing zone (200nm)
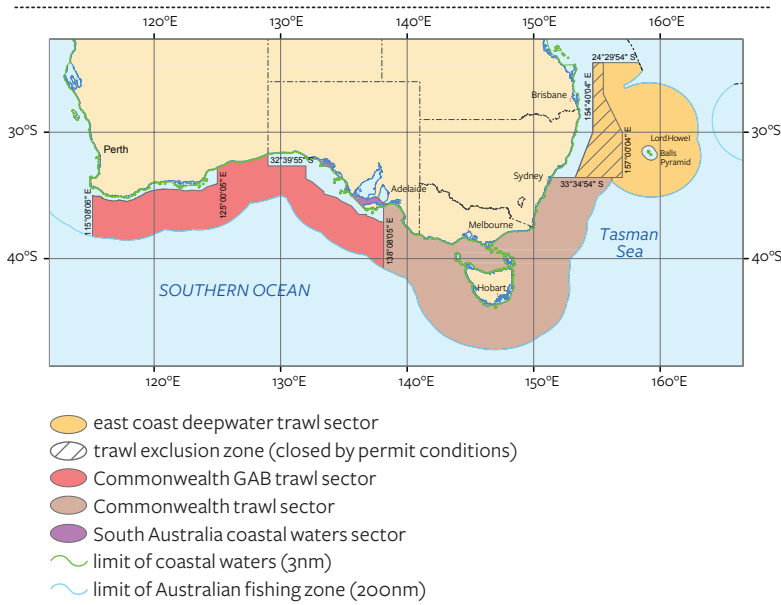
Source: Australian Fishery Management Agency 2008. http://www.afma.gov.au/

the 1992 level. While it is not expected that all quotas bind every season in a multi-species fishery, no species' quota was met in 2007, and only two species had 95 per cent or more of the available quota used. Overall, almost a third of available TAC remained uncaught in 2007. Of more concern is that the TACs for many species that are classified as overfished or uncertain were not close to being filled (figure m). For example, in 2007, 28 per cent of available redfish quota, 49 per cent of silver trevally quota, and 45 per cent of oreo quota were caught. Effort in the fishery will gravitate to the open access equilibrium when TACs are set too high (and hence are nonbinding). Elliston et al. (2004) conclude that the available evidence suggests that settings in the fishery have not allowed returns to be maximised — rather the fishery appears to have operated as a regulated open access fishery.

Nonbinding TACs affect the rate of autonomous adjustment in the fishery. Autonomous adjustment is the process of effort gravitating to the most efficient operators. One reason that it has not been observed on a large scale in the fishery is that controls on catch are rarely binding. This makes the quota price for many species relatively low and unlikely to offset the transaction costs of trading. Another hurdle to autonomous adjustment is that the market value of many vessels in the fishery is probably very low, so operators have an incentive to continue fishing until their vessel is due for a major overhaul.

50

m Catch as a percentage of average TAC in the southern and eastern scalefish and shark fishery, by species, 1 January 2007 –30 April 2008 [a]
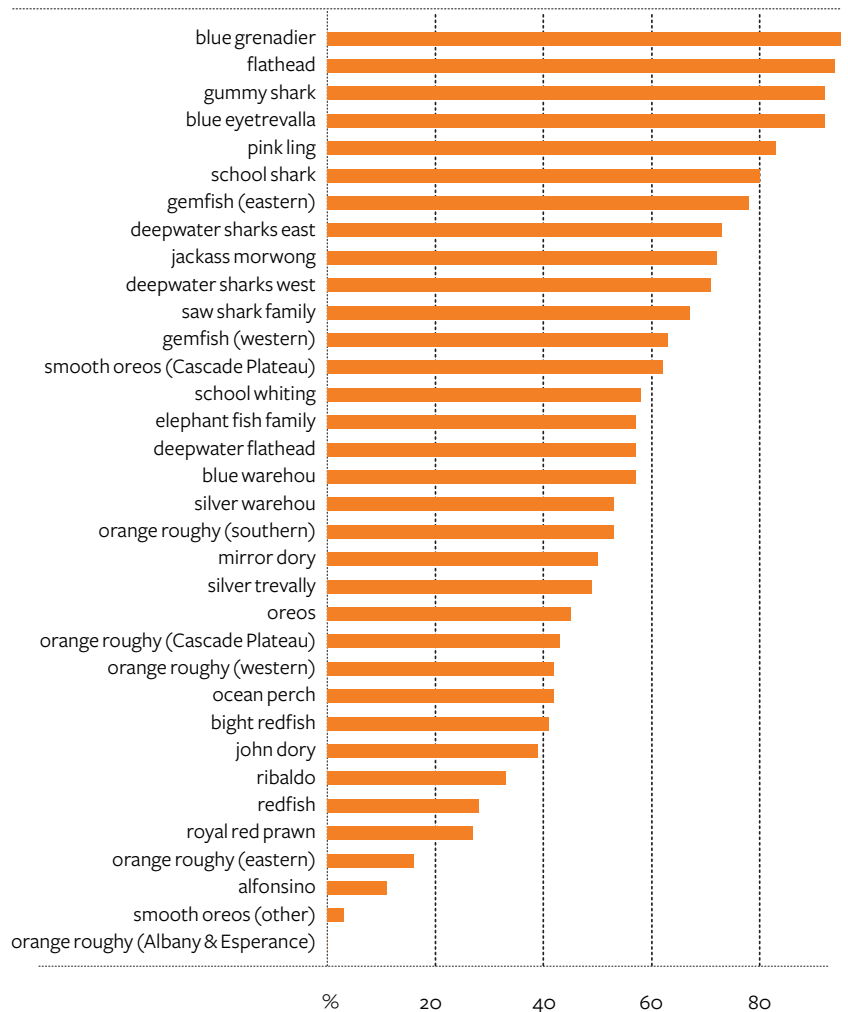
[a] Species Smooth oreo, Smooth oreo cascade and Oreo include Spikey, Warty, Black and Rough Oreo.
Source: AFMA (2008e).

Maximum economic yield analysis for the south east trawl fishery

The MEY analysis presented in this section is an example of a bio-economic model for a multi-species fishery. A bioeconomic model for the southern and eastern scalefish and shark fishery (SESSF) is constructed in order to determine optimal harvest and stock sizes at MEY. Technical details can be found in Kompas and Che (2006).The model is specified for six fish resources in the SESSF: orange roughly (in the cascade and eastern zones),

spotted warehou, ling, flathead and gummy shark. These species together cover the bulk of the gross value of production (GVP) in the SESSF, and all are targeted, with different vessels and fishing methods in the fishery.

The model includes five fishing methods: offshore trawl, inshore trawl, Danish seine, auto longline and gillnet. In the Commonwealth trawl sector, demersal trawling (both offshore trawl and inshore trawl) and Danish seining are the dominant fishing methods. The gillnet, hook and trap sector includes methods such as gillnetting, droplining, demersal longlining, trapping and purse seine. In 2006, there were 90 vessels operating in the Commonwealth trawl sector of the fishery (four offshore trawl, 69 inshore trawl and 17 Danish seine). In 2006 in the gillnet hook and trap sector of the fishery there were nine autolongline vessels and 61 gillnet vessels (AFMA 2008b).

Biological model

Bio-economic models must be based on an underlying stock assessment and a stock-recruitment relationship. For the SETF, both a Schaefer (1957), or a logistic growth or surplus-production growth model, and a Beverton and Holt (1957) model are relevant.

Surplus-production models map the relationship between the growth or net additions to the stock of fish, as a function of existing stock size. The key parameters are the intrinsic rate of growth r and 'maximum carrying capacity'. In a continuous-time model of population growth, without fishing behaviour included, a Schaeffer model is given by:

7.1
$$\frac{dB}{dt} = rB_t(1\text{-}B_t/B_o)$$

where B_t is the biomass of the stock and B_o is virgin biomass, or stock at time zero, defined as maximum carrying capacity.

In discrete time, the relevant relationship is:

7.2
$$B_{t+1} = \left[B_t + rB_t(1\text{-}\frac{B_t}{B_o}) \right] e^{\varepsilon_2} \text{-} h_t$$

where h_t is the catch rate. The measure ε_2 captures random behaviour in biomass recruitment and the harvest relationship in 7.2. Harvest is generally assumed to be a function of the biomass and fishing effort at time t.

In the SETF a Beverton-Holt model is typically used for orange roughy. Based on Beverton and Holt (1957) a simple density-dependent mortality model to determine N_t (the number of fish) is given by:

7.3
$$\frac{dN_t}{dt} = -m_t N_t$$

given that:

7.4
$$m_t = \mu_1 + \mu_2 N_t$$

where m_t is the rate of natural mortality and μ_1, μ_2 are parameters.

On this basis, Beverton and Holt (1957) established a stock recruitment relationship model, a solution to 7.3 and 7.4, given by:

7.5
$$R_t = \frac{\mu_3 B_{t-1}}{1 + \dfrac{\mu_4 B_{t-1}}{B_o}} e^{\xi_1}$$

where R_t is the recruitment at year t as a result of the spawning stock at the previous time; B_o is the virgin biomass; and μ_3 and μ_4 are parameters. The measure ξ_t reflects random behaviour in the spawning stock-recruitment relationship.

In its simplest form, the change in the biomass at year t is a sum of fish growth from the surviving stock from the previous year (because of fishing and natural mortality), plus new recruits. Based on Clark (1976) and Bjorndal (1988), the dynamic interactions among recruitment, fish stock, fishing mortality and natural mortality can be expressed by a delay-difference equation of the form:

7.6
$$B_{t+1} = (B_t - h_t)e^{\delta_t} + R_t$$

where h_t is harvest at time t and:

7.7
$$\delta_t = g_t - m$$

where g_t is the instantaneous net growth rate and m is the natural mortality rate.

It is clear there will be relatively more food (or 'environmental capacity') available to a small stock than to a larger one, or that the natural growth rate depends on a biomass density at time t, represented as the ratio between the current biomass over the virgin biomass (Bjorndal 1988). Natural mortality may also be density dependent, for example, if the effectiveness of predation depends on stock size. In a general form, the relationship between the instantaneous net growth rate and biomass density can be expressed as:

7.8
$$\delta_t = \delta_o \left(\frac{B_t}{B_o}\right)^\eta$$

where δ_o and η are parameters. At maximum carrying capacity, it can be shown that δ_o must be negative. In order to maintain the negative relationship between the instantaneous net growth rate and the biomass density, it also can be seen that η must be positive.

The growth models presented above should be measured consistently either in terms of fish numbers or fish weight. The fish population of a species consists of a number of different year-classes or cohorts, one resulting from each annual spawning and subsequent recruitment. Following Clark (1990), assume that $t=0$ corresponds to the time of recruitment of the first cohort (or the time at which the cohort first becomes available for fishing). At any time t the total biomass of the cohort is:

7.9
$$B_t = N_t w_t$$

where N_t is the number of fish of the cohort alive at time t and w_t is the average weight of fish at t.

Since the stock recruitment relationship is analysed in terms of fish numbers, but harvest is usually in terms of weight, a conversion is required. In this report the conversion between fish numbers and fish weight is obtained from the growth in length and length-weight relationship. Based on the von Bertalanffy formula (1938) growth in fish length is given by:

7.10
$$l_t = l_\infty \left[1 - e^{-k(t-t_0)} \right]$$

where l_∞ defines an asymptotic or maximum body size, l_∞ is called the Brody growth coefficient and defines growth rate toward the maximum, and t_0 shifts the growth curve along the age axis to allow for apparent nonzero body length at age zero. The length-weight relationship is:

7.11
$$w_t = w_\infty \left[1 - e^{-k(t-t_0)} \right]^{b_i}$$

where w_∞ is maximum weight.

Bioeconomic model

Bio-economic models combine the relevant biology given by the stock assessment, and associated stock-recruitment relationship, with a harvest function, total revenue and the total costs of fishing. In a multi-species, multi-fleet model, effort allocation, or the allocation of harvest across vessels and species must also be specified.

The harvest function of vessel type j for species i at time t is given by:

7.12
$$h_{jit} = q_{ji}^{\circ} E_{jit}^{\alpha_{ji}} B_{it}^{\beta_{ji}}$$

where q_{ji}° is a catchability rate of vessel type j to species i; E_{jit} is the fishing effort of vessel type j to species i at time t; B_{it} is the biomass stock of species i at time t; and α_{ji} and β_{ji} are the parameters in the harvest function of vessel type j targeting species i (assumed to be constant over time). From 7.12 the fishing effort of vessel type j to fish species i is thus given as:

7.13
$$E_{jit} = \left(\frac{h_{jit}}{q_{ji}^{\circ} B_{it}^{\beta_{ji}}} \right)$$

where:

7.14
$$h_{it} = \sum_{j=1}^{n} h_{jit} = h_{it}$$

and:

7.15
$$E_{jt} = \sum_{i=1}^{m} E_{jit}$$

such that h_{it} is the TAC for species i at time t and E_{jt} is the fishing effort of vessel type j at time t.

Denote the harvest share of vessel type j for species i at time t in TAC of that species as θ_{itj}, so that the harvest h_{jit} can be expressed as:

7.16
$$h_{jit} = \theta_{jit} h_{it}$$

where it is understood that shares must sum to one, or $\sum_{j=1}^{n} \theta_{jit} = 1$.

Substitution gives:

7.17
$$E_{jit} = \left(\frac{1}{q_{ji}^{\circ}} \frac{h_{it} \theta_{jit}}{B_{it}^{\beta_{ji}}} \right)^{1/\alpha_{ji}}$$

as effort, indicating the relationship between biomass and TAC on the effort allocated to species i.

Annual total revenue of vessel type j at time t (TR_{jt}) is defined as a sum of revenue of all targeted species landed by that vessel, which is calculated as the multiple of harvest and the annual (average) price of each species of fish, or:

7.18
$$TR_{jt} = \sum_{i=1}^{m} TR_{jit} = \sum_{i=1}^{m} h_{ijt} p_{it}$$

where p_{it} is the price of species i at time t. In many cases the price of fish (p_{it}) can be determined from an inverse demand curve. Following

Danielsson (2002) and Campbell et al. (1993) this price is determined by:

7.19
$$p_{it} = p_{it}^{\circ} \left(H_i^{\circ} / \sum_{j=1}^{n} h_{ijt} \right)^{1/\varepsilon_i}$$

where ε_i is the elasticity of demand for catch for species i and p_i° is the unit price of catch when the volume of the catch is H_i°.

Total revenue of the fishery at time t (TR_t) is defined as a sum of revenue of all vessel types at that time, or:

7.20
$$TR_t = \sum_{j=1}^{n}\sum_{i=1}^{m} p_{it} h_{ijt}$$

Assume that fishing costs (including labour, material, capital and all other costs) are a function of fishing effort and biomass or stock. Fishing costs for vessel type j for species i at time t (C_{jit}) depends on a fixed cost component and variable costs which depend on the fishing effort of vessel type j on species i (E_{jit}), or:

7.21
$$C_{jit} = \gamma_{jt}^{\circ} + \gamma_{jt}^{1} E_{jit}$$

where γ_{jt}° is the fixed cost parameter of vessel type j and γ_{jt}^{1} is the variable cost share parameter. It is assumed that γ_{jt}° and γ_{jt}^{1} are both positive.

Substitution from 7.17 for effort gives:

7.22
$$C_{jit} = \gamma_{jt}^{\circ} + \gamma_{jt}^{1} \left(\frac{h_{it}\theta_{jt}}{q_{jt}^{\circ} B_{it}^{B_{ji}}} \right)^{1/\alpha_{ji}}$$

where the smaller is the stock the larger is the cost of fishing. Total fishing costs of vessel type j (c_{jt}) are thus given by:

7.23
$$C_{jt} = \sum_{i=1}^{m} C_{jit}$$

The total fishing cost for the fishery as a whole is a sum of total fishing costs of all vessel types in the fishery.

Annual fishery profit of vessel type j for specie i at time t (Π_{jit}) is defined by subtracting annual total cost from annual total revenue, so that:

7.24
$$\Pi_{jit} = p_{it} h_{it}\theta_{it} - \left[\gamma_{jt}^{\circ} + \gamma_{jt}^{1} \left(\frac{h_{it}\theta_{jt}}{q_{jt}^{\circ} B_{it}^{\beta_{ji}}} \right)^{1/\alpha_{ji}} \right]$$

and total profit in the fishery across vessels and species at time t (Π_t) is given by:

7.25
$$\Pi_t = \sum_{i=1}^{m} p_{it} h_{it} - \sum_{j=1}^{n}\sum_{i=1}^{m} \left[\gamma_{jt}^\circ + \gamma_{jt}^1 \left(\frac{h_{it}\theta_{jit}}{q_{jt}^\circ B_{it}^{\beta_{ji}}} \right)^{\gamma/\alpha_{ji}} \right]$$

The optimisation problem is to maximise the aggregate profit over a period of time *T* through choice of the harvest (TAC) for each species and the harvest share allocated among vessel types. In other words, the problem is to:

7.26
$$\max_{h_{it},\theta_{jit}} \Pi_t = \sum_{t=0}^{T} \left(\frac{1}{(1+\delta)^t} \right) \left\{ \sum_{i=1}^{m} p_{it} h_{it} - \sum_{j=1}^{n}\sum_{i=1}^{m} \left[\gamma_{it}^\circ + \gamma_{jt}^1 \left(\frac{h_{it}\theta_{jit}}{q_{jt}^\circ B_{it}^{\beta_{ji}}} \right)^{\gamma/\alpha_{ji}} \right] \right\}$$

where δ is the discount rate. Solving equation 7.26 also requires that virgin biomass at time *0* for each species is known.

Optimal solutions and maximum economic yield analysis

Model results are summarized in table 5. All results are preliminary in the sense that the model may require further calibration based on more recent biological studies and economic data, obtained from consultation with biologists and industry stakeholders. Model output comes into two forms: a calculation of the harvest at MEY, after convergence, and a measure of the optimal initial TAC consistent with a move to MEY. This value of TAC will change from its initial value to gradually approach the harvest rate at MEY. TAC in 2007 and actual harvest are also listed, along with the target of BMEY/BMSY.

5   Results for optimal harvest strategy and optimal stocks in the south east trawl fishery

species	BMEY/BMSY	*h* MEY	*h* optimal initial TAC	*TAC* 2007	*h* actual harvest 2007
Trawl fishery					
Orange roughy in the eastern	1.20	1200	340	76	12
Orange roughy in the Cascade	1.53	690	500	485	151
Spotted warehou	1.10	4100	3100	4512	1931
Ling (trawl)	1.29	1300	800	1538	932
Flathead	1.06	3880	2990	4197	2782
Gillnet, hook and trap fishery					
Ling (longline)	1.18	500	450		
Gummy shark (gillnet)	1.22	1500	1110	2509	1586
School shark (gillnet)	1.20	200	150	360	169

Notes: Harvest amounts are in tonnes. Sources of TAC and current harvest are provided from AFMA 2008b; TAC for ling includes both trawl and non-trawl sector; orange roughy catch is for both the eastern and the cascade zones.

In all cases the ratio BMEY/BMSY is greater than one, implying a substantial 'stock effect' in either the harvest function or the cost of fishing. However, this value varies from 1.06 for flathead to 1.53 or orange roughy. Also, in all cases, optimal initial TAC (ie. the TAC value that is consistent with convergence to MEY) is less than harvest at MEY, implying the need for stock rebuilding, or lower harvests on the path to MEY. With stock rebuilding the cost of fishing will fall in the future and profits will rise. In all cases except orange roughy optimal initial TAC is less than TAC in 2007, although not necessarily less than actual harvest in 2007.

Pursing MEY does imply positive amounts of harvest in the orange roughy fishery, both at MEY and in terms of the optimal initial TAC. As expected the time to convergence is very long, in the order of 70 years or more to reach within 5 per cent of MEY. The plan for harvest in 2008 in these fisheries, however, was to set TAC at zero given the substantially depleted stocks of orange roughy. This may be perfectly justifiable given environmental factors and the possibility of collapse if stock sizes for orange roughy (in some cases less than 15 per cent of virgin biomass) are too small. The MEY model does not allow for such 'depensation effects'.

Analysis of profit decompositions and productivity for the south east trawl fishery

This section illustrates the use of productivity indexes and profit decompositions in the SETF. A complete analysis is contained in Fox et al. (2006). The profit decomposition method is applied to the SETF using vessel-level data on the implicit output price, fuel price, price for labour and a capital measure represented by vessel tonnage.

Data sources and variables

The sample data were obtained by ABARE and AFMA, and are an unbalanced panel of 47 vessels over the period 1997-2000, giving a total of 131 observations. Because of data inconsistencies, 11 observations were dropped leaving a total of 120 observations to calculate the profit decompositions. Summary statistics are provided in table 6.

Individual prices per species per vessel are not available for the fishery. Consequently, the vessel output price is defined as the total value of landings of fish divided by the total weight of the fish landed for each vessel. This data limitation prevents us from assessing the relative profit contributions of the different fish species, but does not restrict us from assessing the overall effect of fish returns on individual and industry performance. Nor does it prevent us from applying the profit decomposition to assess the contribution of harvests to relative profits.

6 Summary Statistics
data on the south east trawl fishery

		mean	std. deviation	min.	max.
All Years					
Revenue	$	485 730	453 259	86 110	2 467 011
Landings	kg	229 164	182 048	22 266	1 171 634
Price	$/kg	2.13	0.71	1.12	4.47
Crew hours	trawling hours	3 562	2 391	128	14 095
Labor price	$/trawling hours	74	104	15	668
Fuel quantity	L	1 175	1 135	64	5 312
Fuel price	c/L	70.00	6.00	63.00	81.00
Vessel tonnage	GVT	82	92	13	670
1997					
Revenue	$	390 518	378 994	116 996	2 110 863
Landings	kg	215 714	191 165	31 531	1 051 230
Price	$/kg	1.88	0.69	1.12	4.45
Crew hours	trawling hours	4 129	2 963	1 276	14 095
Labor price	$/trawling hours	42	24	15	131
Fuel quantity	L	1 056	1 008	111	4 078
Fuel price	c/L	68.00	0.00	68.00	68.00
Vessel tonnage	GVT	63	48	13	196
1998					
Revenue	$	426 822	383 243	86 110	2 094 586
Landings	kg	229 111	205 366	38 389	1 171 634
Price	$/kg	1.91	0.55	1.22	4.47
Crew hours	trawling hours	3 654	2 404	128	11 829
Labour price	$/trawling hours	68	99	19	531
Fuel quantity	L	1 065	1 001	107	4 349
Fuel price	c/L	63.00	0.00	63.00	63.00
Vessel tonnage	GVT	73	52	13	196
1999					
Revenue	$	571 656	526 541	98 993	2 467 011
Landings	kg	241 148	181 019	22 266	889 694
Price	$/kg	2.39	0.77	1.44	4.45
Crew hours	trawling hours	3 197	1 965	360	7 245
Labour price	$/trawling hours	97	128	16	509
Fuel quantity	L	1 329	1 296	98	4 521
Fuel price	c/L	68.00	0.00	68.00	68.00
Vessel tonnage	GVT	94	123	13	670
2000					
Revenue	$	568 177	510 214	105 770	2 336 295
Landings	kg	231 226	149 968	27 093	615 403
Price	$/kg	2.38	0.69	1.24	3.90
Crew hours	trawling hours	3 223	2 073	360	7 038
Labour price	$/trawling hours	93	129	19	668
Fuel quantity	L	1 274	1 260	64	5 312
Fuel price	c/L	81.00	0.00	81.00	81.00
Vessel tonnage	GVT	94	124	13	662

The (implicit) price for labour is defined as the ratio of total vessel labour payments per vessel over the number of trawling hours and then multiplied by the number of crew. Thus the measure of productivity is not independent of the crew share that is normally paid as a proportion of a vessel's net revenue. That means in this study labour remuneration is endogenous. The price of fuel is the recorded price for each of the vessels, and capital is the vessel gross registered tonnage.

Profit is defined as 'net gain' from fishing activity, which equals total boat cash income minus capital cost (*i.e*, repairs and maintenance), labour cost and material costs. For comparative purposes, a reference firm (*a*) must be chosen. Using a benchmark that is an observed firm or vessel helps fishers to better assess those factors that are constraining profits that are under their control (such as productivity) from factors that are not (such as fuel prices). A natural benchmark vessel is one that maximises profit, adjusted for stock size, relative to all other vessels and over all periods. This corresponds to the vessel denoted by observation 26 in the year 2000.

SETF profit decomposition and productivity analysis results

The results of the profit decompositions are presented in table 7 for the years 1997-2000. When comparing the index values, if an index takes a value greater (less) than one, it contributes by expanding (contracting) the stock-adjusted profit ratio defined by θ_s .

A value of less than one for the output price index indicates that the contribution of the output price to profit is less than in the benchmark firm. Only five observations have an output price index (*PO* in table 7) greater than unity, and most vessels have values considerably less than unity. This suggests that an important factor contributing to the profits of the bench-mark vessel was the price it received for its harvest. A value greater than one for the input indexes for all vessels does not imply that the input prices are greater than for the benchmark vessel. Rather, it indicates that the contribution of that input price to the profit ratio is greater than for the benchmark vessel. This could arise if the input price for the given vessel is less than that of the reference firm as an increase in the input price reduces profits. If the input price for a given vessel is identical to the benchmark vessel, the corresponding price decomposition index will be unity.

Observation of the profit decompositions reveals a number of insights about vessel performance in the fishery. Scatter plots (see Fox et al. 2006) of the index suggest that the contribution to profits from the implicit output price is higher for larger vessels and that its importance for all vessels rises over time. Part of the reason for this difference across vessel sizes is that larger vessels are able to harvest in deeper waters much further

offshore and, thus, are able to target some very high priced species, such as orange roughy, which cannot be harvested by the smaller inshore vessels. Both small and large vessel classes (defined relative to average vessel size) however, experienced increases in the contribution to relative profits from rising output prices. For instance, table 7 shows that the geometric mean of the output price index for all vessels rose from 0.199 and 0.238 in 1997 and 1998 to 0.374 and 0.360 in 1999 and 2000. No consistent trend is apparent for the variable inputs (*PF* in table 7) across vessel sizes or over time, but the contribution of labour to profits declines over the period. The trend in the relative contribution of labour to profits is consistent with an increase in the value of landings over the period that raised crew remuneration.

Our results suggest that since 1997 profit performance in the fishery has improved. The extent to which this improvement is attributable to the combined license buyback and industry assisted brokerage services, however, is not immediately clear. The profitability of both small and large vessels improved over the period 1997-2000 because of a rise in output prices, but this was independent of the buyback because the fishery has been managed by ITQs since 1992. A possibility exists, however, that the establishment of limited brokerage services for trading quota in 1997 might have stimulated increases in output prices by allowing fishers to adjust their harvests to better suit market conditions and their catches. Such an outcome is supported by the fact that annual lease quota trades increased by more than 50 per cent for the period 1997-2000 compared to the period 1992-96.

7 Decomposition of Profit Ratios in the south east trawl fishery

obs	no.	θ	R	PO	PF	PL	K
All years	120	0.085	0.271	0.279	1.044	3.955	0.318
Small	73	0.057	0.304	0.261	1.037	4.058	0.201
Large	47	0.156	0.226	0.309	1.056	3.800	0.648
1997	30	0.055	0.211	0.199	1.057	5.643	0.303
Small	19	0.037	0.201	0.187	1.049	6.368	0.203
Large	11	0.108	0.229	0.221	1.073	4.581	0.602
1998	33	0.074	0.283	0.238	1.068	4.117	0.306
Small	20	0.047	0.280	0.221	1.059	4.435	0.195
Large	13	0.151	0.288	0.263	1.082	3.670	0.608
1999	29	0.113	0.307	0.374	1.047	3.105	0.337
Small	17	0.083	0.417	0.359	1.034	2.913	0.204
Large	12	0.174	0.198	0.395	1.064	3.398	0.686
2000	28	0.117	0.297	0.360	1.000	3.313	0.331
Small	17	0.081	0.390	0.336	1.000	3.078	0.202
Large	11	0.205	0.195	0.399	1.000	3.713	0.709

Note: The arithmetic mean is used to average over the profit values, while the geometric mean is used to average over the indexes. Vessel tonnage (K) is used to split up observations into "small" and "large" vessels. Small vessels are defined as those being lighter than the sample average (K < 0.318), and large vessels are defined as those being heavier than the sample average (K > 0.318). "No." denotes the number of vessels in each year/size category.

If the vessel buyback and increased quota trading combined did have a positive economic benefit to fishers, it should also have raised overall vessel productivity. The evidence from the profit decompositions is that productivity rose over the period 1997-2000, but only for small vessels. This difference explains why the gap in the mean of profit ratio for large and small vessels narrowed substantially in the period between 1997-1998 and 1999-2000.

Both vessel classes experienced a productivity jump in 1998 with the productivity contribution (R in table 7) to profits rising by 39 per cent for small and 26 per cent for large vessels. Such gains, in part, occurred because the total allowable catch for all quota species was non-binding prior to 1997. Thus, despite the existence of individual harvesting rights, the removal of capacity helped to increase the landings of the fishers who remained. Individual landings rose because the 27 licence holders that were bought out from the SETF with the 1997 buyback were obliged to sell their quota-holdings, thereby allowing remaining fishers to optimise their scale of production and raise productivity. Such quota trading is likely to have provided greater benefit to smaller vessels that have less flexibility than larger vessels to substitute between inputs and, thereby, increase efficiency (Grafton, et al. 2000).

Further support for the buyback and increased quota trading as the causes for the productivity increases is that such gains were simultaneous with a decline in catch per unit of effort for seven of the 16 quota species over the period 1997-1998 (AMC Search Ltd 2000) and a *decline* in the overall stock index. Changes in fish stocks, however, may help to explain the subsequent decline in productivity of large vessels since 1998. In particular, orange roughy, which is an important species for large vessels, has declined in abundance over this period (Kompas and Che 2008).

Overall, the empirical evidence provides support for the hypothesis that the combined license buyback and the establishment of a brokerage service instituted in the fishery in 1997 have had a positive impact on profitability via productivity improvements. Unlike vessel or license buybacks implemented in other fisheries, such as British Columbia's salmon fishery or the US northeast multi-species fisheries (Holland, et al. 1999), it has occurred within a fishery managed by individual and transferable output controls. Thus the SETF offers a unique 'natural experiment' where a buyback, coupled with ITQs, appears to provide on-going benefits to fishers.

The payoffs of the combined buyback and brokerage service do not appear to have diminished over time which might otherwise have been the case if the fishery had been managed by only input controls — a type of fisheries management that can result in both input substitution (Dupont 1991) and rent dissipation (Dupont 1990). Indeed, increasing productivity gains for small vessels in 1998, and again in 1999, is suggestive that increased quota

trading has helped smaller vessels to better optimise their scale of production and raised productivity. In other words, because the SETF is managed by individual harvesting rights, with an effective quota trading system since 1997, it appears to have avoided the incentive for fishers to increase fishing effort that often follows buybacks (Campbell 1989; Weninger and McConnell 2000).

The results indicate a large range in the relative profits and productivities of vessels within the fishery and measurable differences across vessel sizes. In the three years following the buyback and the establishment of an industry assisted quota brokerage service, all vessels have benefited from a rise in output prices. The results also indicate a substantial increase in mean stock-adjusted productivity for both small and large vessel classes the year immediately following the license buyback and establishment of the quota brokerage service. Smaller vessels, which may lack the flexibility of large vessels to substitute across inputs, appear to have benefited the most from the buyback and increased quota trading with the mean contribution of productivity to profits almost doubling from 1997-98 to 1999-2000.

The findings suggest that the buyback, coupled with individual tradeable harvesting rights and greater quota trading through the establishment of a quota brokerage service, have been successful at improving economic performance. Such a desirable outcome is in direct contrast to the unfavourable long-term outcomes often associated with vessel and license buyback in fisheries managed exclusively by input controls.

A stochastic cost frontier analysis for the south east trawl fishery

Stochastic cost frontier model

This case study constructs a cost frontier. Since our concern is with a panel data set (time series and cross sectional data), index vessels by i and time periods by t. In general terms, the stochastic cost frontier takes the form:

7.27
$$lnC_{it}=C(Q_{it},w_{it};\beta)+v_{it}+u_{it}$$

where C is the cost of harvest, Q is the volume of output produced, w input prices and β parameters to be estimated. The term v represents a random stochastic variable, with the usual properties, or $v \sim N(0,\sigma_v^2)$ accounting for effects on costs beyond vessel control. The term u is a non-negative cost inefficiency effect, assumed to be drawn from a normal distribution truncated at zero. In the case where $u_{it}=0$ across all vessels and time periods, equation 7.27 reverts to standard (minimum) cost function implying that

all vessels are fully efficient. For any $u_{it} > 0$ costs are larger and harvest inefficient. The value u_{it} can be further restricted by:

7.28
$$u_{it} = u(z_{it}; \delta)$$

where z accounts for the effects of fishery and vessel-specific terms that influence efficiency and δ are parameters to be estimated. Equation 7.28 can also include a random stochastic variable. The measure of efficiency E_{it} is given by:

7.29
$$E_{it} = e^{-u_{it}}$$

and is clearly bounded between zero and one. In more specific terms, for a production function in log-linear form:

7.30
$$lnQ_{it} = lnA + n\sum_{j=1}^{n}\alpha_j lnx_{ijt}$$

for inputs x (indexed by j) and resulting factor demand equations, the cost frontier takes the form:

7.31
$$lnC_{it} = \alpha_o + \frac{1}{r}lnQ_{it} + \sum_{j=1}^{n}\frac{\alpha_j}{r}lnp_j + \frac{1}{r}(v_{it} + u_{it})$$

for input prices p and:

7.32
$$r = \sum_{j=1}^{n}\alpha_j$$

is a measure of returns to scale. Equation 7.32 is bounded below by the case in which $u_{it} = 0$ for all vessels and years and thus represents the minimum possible cost of harvesting fish given input prices. The complications of a systems estimate with first order conditions for optimal imput use by a factor of production are avoided in this paper. Thus, a decomposition between so called technical and allocative efficientcy is not possible (see Coelli et al. 1998).

Although total input payments for each factor of production are listed in the data set, exact input price data is not available for the SETF. However, when constant returns to scale holds, equations 7.27 and 7.31 can be transformed to give a cost function of the form:

7.33
$$C_{it} = \alpha_o Q_t \left[\Pi_j \left(\frac{p_{ijt}x_{ijt}}{Q_{it}} \right)^{\alpha_i} \right] e^{(v_{it} + u_{it})}$$

accounting for total payments to inputs, or in log-linear form equation 7.31 for $r = 1$. In log form, parameter estimates for 7.33 are obtained through maximum likelihood estimates (MLE), where the maximum likelihood

function is based on a joint density function for the error term $v_{it} + u_{it}$ (Stevenson, 1980). Efficiency can be calculated for each individual firm or vessel per year by:

$$7.34 \qquad E\left[\exp(u_i){:}v_{it}+u_i\right]=\frac{1-\phi(\alpha_a+\gamma(v_1+u_i/\sigma_a)}{1-\phi(\gamma(v_1+u_i/\sigma_a)}\exp\left[\gamma(v_1+u_i)+\sigma_a/2\right]$$

for $\sigma_a=\sqrt{\gamma(1-\gamma\sigma^2)}$, $\sigma^2\equiv\sigma_u^2+\sigma_v^2$, $\gamma\equiv\sigma_u^2/\sigma^2$ and $\phi(.)$ the density function of a standard normal random variable (Battese and Coelli 1988). The value of when there are no deviations in costs due to inefficiency and $\gamma = 1$ implies that no deviations in costs result from stochastic random effects with variance σ_v^2.

Data sources and variables

The unbalanced panel data set used in this paper consists of 47 vessels over the period 1997 to 2000, or 131 observations with 57 missing observations. The original database was drawn from annual surveys and statistics for the SEFT fleet carried out and compiled by ABARE and AFMA. The raw database includes measures of output (value and quantity of total fish landed), type of fishing (otter trawl and Danish seine), length of vessels, under-deck tonnage, engine power, fishing hours, boat composition (wood, steel etc.), boat value, boat depreciation, average number of crew onboard, labour costs, fuel costs, gear costs, material costs (including costs for oil, grease, boat and gear repair, bait, ice, and packing materials). Fishing logbook data obtained from AFMA includes data for all vessels for the period 1997-2000, including the number of fishing hours (effort) and other vessel characteristics. Of the roughly 103 vessels operating in the SETF during the sample period, the 47 vessels in the unbalanced panel data set represent more than 50 per cent of the total catch of fish in the fishery each year.

A summary list of all specific variables is contained in table 8. All values are in 2000 prices. Output variables are available for both quantity and value. Total fish volume sold for all species was provided from ABARE surveys. The value of fish landed or total income from fish sold was derived as the difference between the total value of fish sold and the expenditures for fish marketing and transportation. Based on raw cost variables, cost expenditure components were derived, including those for four major groups: capital, labour, fuel, gear and materials. The value of boat capital is the market value of boat, hull, engine and onboard equipment (excluding quota and endorsement values) as of July during the survey year. Capital costs are defined by the user cost of capital calculated as a sum of depreciation cost (depending on the life time of the vessel, usually 10-15 years), annual opportunity cost of the total capital value (5 per cent a year) and the difference in boat value between season opening and closing time in a given year.

8 Description of outputs, inputs and vessel-specific variables in the south east trawl fishery

47 vessels for the period 1997-2000

variables	description	sources
Q	Total fish volume sold (kg)	ABARE
Y	Gross value from fish sold ($)	ABARE
TYPE	Type of fishing operation: Trawl =1; Danish = 0	AFMA Log Book
TIME	Year of observation 1997=1; 1998=2; 1999=3; 2000=4	
SIZE	Vessel length (meters)	AFMA Log Book
WEIGHT	Under deck tonnage	AFMA Log Book
POWER	Registered engine power (kW)	AFMA Log Book
EFF	Fishing hours (hours)	AFMA Log Book
HULL	Boat material, eg., wood, steel, aluminium	AFMA Log Book
K	Boat value ($)	ABARE
DK	Boat depreciation ($)	ABARE
LAB	Average number of crew on boat (no.)	ABARE
LCOST	Labour costs ($)	ABARE
FCOST	Fuel costs ($)	ABARE
GCOST	Gear costs ($)	ABARE
MCOST	Other costs including costs for oil grease, repairs for boat, cost gear, bait, packing materials, ice and other materials ($)	ABARE

Vessel depreciation is based on the discrete diminishing value approach. The opportunity cost for vessel capital was derived as the multiple of the nominal interest rate and vessel capital value. Fuel cost was calculated as total fuel expenditures used for fishing for the financial year. Gear cost was calculated as total expenditures for gear (purchasing, maintaining and repairing) used for fishing each year. Material costs are calculated as a sum of the costs for boat repairs (the most important part of material costs), bait and ice, packing materials and other material costs. The factor price for capital, labour and fuel is derived as the cost required to produce a dollar value of output. Since gear and material costs generally depend on fish volume harvested (regardless of the value of fish) this measure is derived as the cost required for harvesting a kilogram of fish. Expenditures for labour (crew and skipper) are obtained from ABARE surveys and generally include both wage and share payments.

Estimated results and efficiency analysis

Prior to testing the cost frontier estimations, a production function for the SETF was estimated to test for returns to scale. Coefficients for capital, labour, gear, material inputs and gear are 0.01, 0.65, 0.044, 0.11, 0.16 (table 9). A Wald test with a null hypothesis of no constant returns to scale is rejected, with critical value 39.0 > 16.07. With constant returns to scale, an estimate of equation 7.33 for the SETF is thus specified by:

9 Parameter estimates of the production function in the south east trawl fishery

	coefficient		asymptotic T-ratio
Constant	1.69	***	3.48
Capital	0.01		0.34
Labour	0.65	***	12.32
Fuel	0.16	***	4.49
Material	0.11	***	3.26
Gear	0.04	**	1.73

*Notes: *, ** and *** denote statistical significance at the 0.10 level, 0.05 and 0.01 level respectively.*

7.35 $\quad lnC_{it} = \beta_o + \beta_1 lnQ_{it} + \beta_2 lnp^k_{it} + \beta_3 lnp^l_{it} + \beta_4 lnp^f_{it} + \beta_5 lnp^m_{it} + \beta_6 lnp^g_{it} + (v_{it} - u_{it})$

for C and Q costs and output (or harvest) and input prices p^k, p^l, p^f, p^m and p^g for capital, labour (total labour costs including skipper), fuel, materials and gear per unit of output, all indexed for each vessel i and time period t. The inefficiency model, or equation 7.28, is given by

7.36 $\quad u_{it} = \delta_o + \delta_1 ln_i qt + \delta_2 trawl + \delta_3 lnweight + \omega_{it}$

where qt is the volume of lease quota traded, $trawl$ is the type of trawl method used (a binary variable with zero for Danish seine and one for inshore and offshore otter trawlers), $weight$ is vessel weight and ω_{it} is a random stochastic variable for $\omega_{it} \sim N(0, \sigma^2_w)$. Since this is a 'share payment' fishery various values for payments to labour are trialled, ranging from reported ABARE data (which includes all payments to labour and skipper, composed of standard wages and share payments for labour per unit of output sold on each vessel) to cases where total labour costs, including skipper costs, are arbitrarily divided by 2, 2.5, and 3 to account for a potential difference between wage and share payments. A precise decomposition is not reported in the data set. The estimated results for the stochastic frontier and inefficiency models are reported in table 10.

The specification given by equations 7.35 and 7.36 was determined on the basis of generalized likelihood ratio tests, with the relevant test statistic given by

7.37 $\quad LR = -2\{ ln[L(H_o)] - ln[L(H_1)]\}$

where $L(H_o)$ and $L(H_1)$ are the values of the likelihood function under the null and alternative hypotheses. The null hypotheses of a translog cost function and a time trend in either the cost frontier or inefficiency model were both rejected at the 5 per cent level of significance. Additional likelihood ratio tests show the critical values for the test statistic drawn from a mixed χ-squared distribution as reported in Kodde and Palm (1986). The null hypothesis that technical inefficiency effects are absent ($\gamma = \delta_o + \delta_1 = \delta_2 = \delta_3 = 0$) and that vessel-specific effects do not influence technical inefficiencies ($\delta_1 = \delta_2 = \delta_3 = 0$) in equation 7.28 are both rejected as is $\delta_o = \delta_1 = \delta_2 = \delta_3 = 0$). Finally, the null hypothesis that $\gamma = \sigma_u / (\sigma_v + \sigma_u) = 0$, or that inefficiency effects are not stochastic, is also rejected. All results indicate the stochastic and inefficiency effects matter so that usual OLS estimates are not appropriate in this study.

The maximum likelihood estimates for the stochastic cost function 7.35 and the inefficiency model equation 7.36 are reported in table 10 for the case of wages that include all share payments (model 1) and the case in which

10 Parameter estimates of the stochastic cost frontier and technical inefficiency models in the south east trawl fishery

	model 1			model 2		
	coefficient		T-ratio	coefficient		T-ratio
Stochastic cost frontier						
Constant	1.18***	(0.059)	19.86	1.30***	(0.08)	15.25
Output	1.00***	(0.005)	209.35	1.00***	(0.075)	132.35
Capital price	0.08***	(0.008)	9.29	0.11***	(0.086)	12.33
Labour price	0.51***	(0.02)	27.97	0.33***	(0.020)	16.36
Fuel price	0.12***	(0.007)	16.66	0.17***	(0.010)	16.60
Material price	0.20***	(0.012)	16.15	0.27***	(0.013)	20.55
Gear price	0.04***	(0.004)	9.44	0.05***	(0.005)	8.92
Technical inefficiency model						
Constant	7.34**	(3.34)	2.19	14.10**	(5.599)	2.52
Quota traded	-1.05**	(0.45)	2.30	-1.70***	(0.66)	2.56
Type of trawl	0.70**	(0.36)	1.94	0.69**	(0.273)	2.51
Boat weight	0.47***	(0.16)	2.87	0.45***	(0.153)	2.95
Sigma-squared	0.10***	(0.04)	2.49	0.117***	(0.042)	2.78
Gamma	0.997***	(0.001)	673.80	0.995***	(0.003)	3.77

*Notes: *, ** and *** denote statistical significance at the 0.10 level, 0.05 and 0.01 level respectively. Figures in parenthesis are asymptotic standard errors.*

half of the wage rate is assumed to be a share payment and thus excluded from costs (model 2). In both cases the largest component of costs in the stochastic cost frontier is the price of labour although (not surprisingly) its value falls from 0.51 to 0.33 in model 2. The price of materials and fuel are the next largest components. All estimates are significant at the 1 per cent level, with standard errors in parentheses. Coefficients in the stochastic cost frontier roughly correspond to those given in the estimates of the production function for the SETF, as expected. The results for the estimates of the cost and production frontiers were confirmed using a 'random coefficients approach', following Kalirajan and Obwona (1994), allowing for the possibility of non-neutral shifts in the frontiers. Estimated coefficients varied little from those reported in table 9 and table 10 and all efficiency rankings remain unchanged.

Of particular interest in the inefficiency model is the estimated coefficient on the volume of quota traded. In both models, the sign on this coefficient is negative indicating that an increase in the volume of quota traded (in tonnes of fish) results in enhanced efficiency and a consequent decrease in costs. Again, not surprisingly, this value rises from -1.05 to -1.70 in model 2 since adjusted wage rates are now half of their previous value. Positive values for coefficients on trawl and boat weight indicate that inshore and offshore otter trawlers are larger boats and less cost efficient. The reason for this is clear in the SETF. Offshore otter trawlers, which are typically made of steel, fish more than 50 kilometres offshore, principally targeting orange roughy, eastern gemfish and blue warehou. More recently, these otter

trawlers have moved to the inshore sector.

However, stocks of these fish are thought to have declined considerably indicating longer fishing trips and higher costs for offshore vessels. Danish seine vessels are typically smaller vessels made of wood and target closer to shore on species that are relatively more abundant. The value of $\gamma = \sigma_u / (\sigma_v + \sigma_u)$ is high in both models indicating that differences in efficiency dominate stochastic random effects, a likely characteristic of an ITQ fishery where fishing days can be reserved for favourable weather conditions and the specific targeting of each species depending on quota holdings. Mean technical efficiency is also roughly the same in both models but rises from 90.42 (89.29) in model 1 (model 2) in 1997 to 92.12 in both models in the year 2000, reflecting the efficiency gains from increased trades in quota.

Sensitivity results (Kompas and Che 2005) for different values of labour costs confirm expectations. The lower are the labour costs (and hence the higher are potential share payments) the lower is the estimated coefficient on the price of labour and the larger is the coefficient on the volume of quota traded. Removing potential share payments from labour costs thus increases the measure of efficiency or the cost savings from having trades in quota. Model 3 is the case where labour costs are divided by 2.5 and in model 4 by 3 (models 3 and 4 are not described in table 10; see Kompas and Che (2005) for details). The coefficient on the volume of quota traded ranges from -1.05 to -2.02. The impact on cost savings for the surveyed fishery from trade in ITQs is substantial.

Table 10 indicates total fishing costs and cost savings per kilogram of fish landed that result from a one per cent increase in the total volume of quota traded, for the years 1997 to 2000. Depending on the amount of total payments to labour, cost savings range from 1.8 to 3.5 cents per kilogram. Even in the case where total payments for labour are not adjusted for potential share payments (model 1), cost savings range from 1.8 to 2.1 cents per kilogram, or 1 to 2.4 per cent of total variable costs, with total cost savings (based on actual catch) to the surveyed fishery in 1999, for example, of $110 000. In all four models, cost savings fall slightly from 1998 to 2000. The reason for this is unclear, although it is possible that either efficiency gains are dissipating over time as the volume of quota trade increases or there are unknown falls in the stock of fish.

This final case study provides an analysis of the eastern tuna and billfish fishery as an application of the profit decomposition and productivity index number approach.

8 Case study: the eastern tuna and billfish fishery

Overview of the eastern tuna and billfish fishery

The eastern tuna and billfish fishery is a complex fishery system involving multiple species and fishing methods. There is also a significant recreational sector targeting the same stocks. The commercial fishery includes longline and minor line fishing methods; and the non-longline sector, which uses purse seine and pole fishing methods.

The eastern tuna and billfish fishery extends along Australia's entire eastern seaboard from the tip of Cape York to the southern most point of the Australian Fishing Zone. It includes Commonwealth waters off Queensland, New South Wales, Victoria and Tasmania out to the 200 nautical mile limit of the Australian Fishing Zone and includes waters around Norfolk Island (map 3). The fishery has been commercially exploited since the early 1950s when the Japanese began pelagic longlining off the east coast of Australia. Major ports used by the fleet include Cairns, Mooloolaba, Coffs Harbour and Hobart (AFMA 2008c). In 2006-07 the gross value of production (GVP) of the entire fishery was around $32 million, of which the longline sector accounted for over 99 per cent (ABARE 2008a).

Australian longline and minor line fishers catch over seventy species of fish in the eastern tuna and billfish fishery. However, the principal catches are yellowfin tuna (Thunnus albacares), bigeye tuna (Thunnus obesus), broadbill swordfish (Xiphias gladius), albacore tuna (Thunnus alalunga), and skipjack tuna (Katsuwonus pelamis) (Larcombe and McLoughlin 2007). In 2005-06 these species accounted for 80 per cent of the total gross value of production of the fishery (ABARE 2008a). Many other species are caught as byproducts, such as striped marlin, pelagic sharks, longtail tuna, rudder fish, black oilfish, dolpinfish, rays bream, moonfish and wahoo. Incidental catches of blue and black marlin occur, but these must be returned to the sea under a legislative amendment that came into effect in July 1998, in recognition that these species are the key target species of the game fishing sector.

Tuna and billfish are highly migratory species. The link between fish caught in Australian waters and the large stocks of the central and western Pacific is poorly understood, and is the subject of ongoing research because of its obvious management implications. Approximately, 2 million tonnes of tuna are taken annually in the central and western Pacific Ocean. International

map 3   Area of the eastern tuna and billfish fishery

- eastern tuna and billfish fishery
- area of High Seas
- land and coastline
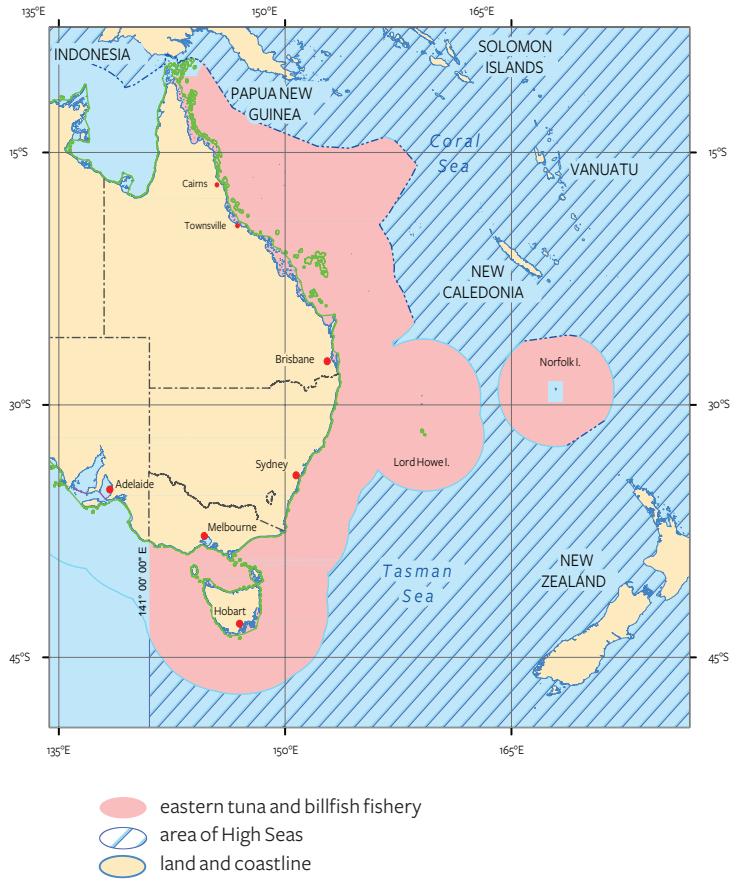
stock assessment advice indicates that these levels are generally sustainable, although concern is beginning to emerge about the status of bigeye and yellowfin tuna stocks.

Overall, ETBF catches show high inter-annual variability. It is thought that catch variability is influenced by oceanographic factors (eg. El Niño), which influences the migration of tuna to and within the fishery, particularly as the southern half of the AFZ is at the extreme migration range for many of these species.

Commercial fishing for major tuna and billfish species in the ETBF is regulated by the Commonwealth government through the *Eastern Tuna and Billfish Fishery Management Plan 2005*, which was adopted in October 2005. Under the plan, annual fishing permits are to be replaced by statutory fishing rights (SFRs) (AFMA 2005). Longline SFRs will restrict the number of

branchline clips (hooks) available to operators using longline methods on a yearly basis and minor line SFRs will define the maximum number of lines that may be used at any one time by minor line operators. Operators in both sectors will also need an additional permit to operate in the Coral Sea Zone, formerly referred to as Zone E. All other management zones in the fishery have been removed under the new management plan.

Until SFRs are granted, the fishery continues to be managed by annual fishing permits (through transitional arrangements under the Management Plan). Species specific arrangements are also in place for operators targeting southern bluefin tuna, broadbill swordfish and albacore.

During the 1990s the ETBF expanded rapidly, particularly in northern Queensland waters where catch rates of yellowfin and bigeye were high. In late 1997, many longliners began to fish out of southern Queensland ports, such as Mooloolaba, to target both bigeye tuna for sashimi markets and swordfish for markets in the United States (AFMA 2004a).

Effort in the ETBF increased steadily throughout the 1990s before peaking at 12.7 million hooks in 2002-03. Since then effort has decreased significantly to 8.9 million hooks in 2006-07 (figure n and table 11). The number of active vessels had also decreased from around 143 in 2001-02 to 113 vessels in 2004-05 and 71 vessels in 2006-07.

In contrast, average effort per vessel has increased sharply (figure n) from 90 thousand hooks in 2001-02 to 101 thousand hooks in 2005-06 and 125 thousand hooks in 2006-07. The number of hooks per set has also increased, from around 900 hooks per set during 1998-99 to 2001-02 to around 1,200 hooks in 2006-07 (computed from AFMA 2008d and Campbell 2007).

Catches of yellowfin, bigeye and broadbill swordfish are shown in figure o. Swordfish catches grew strongly until 2001-02 when they peaked at 3129 tonnes before falling to 1633 tonnes in 2006-07. Similarly, catches of yellowfin peaked at 3394 tonnes in 2002-03, fell to 1385 tonnes in 2005-06 before recovering slightly to 1800 tonnes in 2006-07. In contrast, catches of albacore have increased from 632 tonnes in 2004-05 to 2814 tonnes in 2006-07 (ABARE 2008a).

In line with the trend in catch, the gross value of production (in 2006-07 dollars) for the fishery declined from $78 million dollars in 2001-02 to $28 million dollars in 2005-06 and back to about $32 million dollars in 2006-07 (with a significant contribution from the albacore fishery). The GVP of the major species, including yellowfin, bigeye and billfish, has all fallen dramatically in recent years (figure p).

n Effort in the eastern tuna and billfish fishery, 1991-92 to 2006-07
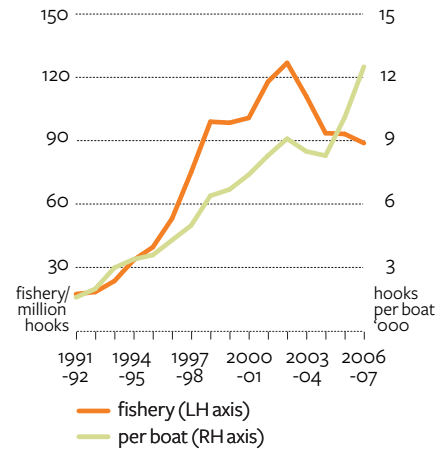
Source: Australian Fisheries Management Authority (2008c).

**o** Harvest (longline and minor line), by major species
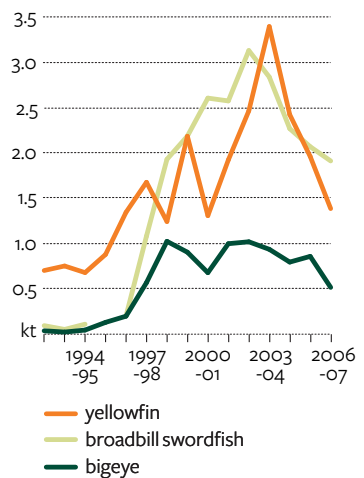
11 Effort statistics of the eastern tuna and billfish fishery

year	hooks millions	sets	hooks per set	active vessels
1986/87	0.29	760	377	62
1987/88	1.07	1 618	664	68
1988/89	1.09	2 099	520	94
1989/90	0.79	2 300	345	98
1990/91	1.56	2 864	543	101
1991/92	1.76	3 252	541	109
1992/93	1.86	2 975	625	91
1993/94	2.38	3 664	650	79
1994/95	3.37	4 509	747	98
1995/96	3.98	5 552	717	112
1996/97	5.33	7 645	698	123
1997/98	7.53	9 270	812	150
1998/99	9.91	10 762	921	156
1999/00	9.86	11 070	891	147
2000/01	10.09	11 529	875	136
2001/02	11.8	12 874	916	143
2002/03	12.69	13 535	938	140
2003/04	11.11	11 766	945	131
2004/05	9.37	9 869	950	113
2005/06	9.33	8 976	1 039	92
2006/07	8.9	7 315	1 217	71

Source: AFMA (2008d).

p Gross value of production (longline and minor line), by major species

- yellowfin
- billfish
- bigeye
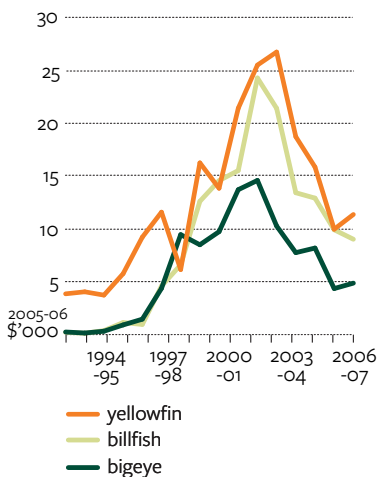
The harvest and gross value of production of albacore has increased substantially in recent years and is shown in figure q. In 2006-07 albacore accounted for around 18 per cent of the total gross value of production of the fishery.

Profit decomposition and productivity in the eastern tuna and billfish fishery

Individual prices per species per vessel are not available for the fishery. Consequently, the vessel output price is defined as the total value of landings of fish divided by the total weight of the fish landed. This data limitation prevents relative profit contributions of the different fish species being assessed, but allows the overall effect of fish returns on individual and industry performance to be assessed. Profit decompositions can also be used to assess the contribution of harvests to relative profits.

Profit is defined as net gain from fishing activity, which equals total boat cash income minus capital cost (repairs and maintenance), labour cost and material costs. Net gain from fishing in this report is different than boat cash profit in Vieira et al. (2007). The differences are in terms of measured

labour costs, repairs and maintenance costs and material costs. In Vieira et al. (2007) cash costs include administration, bait, crew costs, freight and marketing expenses, fuel, insurance, interest paid, license fees and levies, packaging, repairs and maintenance and other costs. Labour cost (usually the highest cash cost) includes wages and an estimated value for owner and partner, family and unpaid labour.

In terms of total revenue, vessel owners assert that total income before packaging, recorded in the ABARE surveys, is lower than the true income (ETBF RAG meeting, 14-15 July 2007). Without taking into account income after packaging, many vessels may show false losses. In addition, labour cost in ABARE surveys may reflect share payments in profits. The 'true' labour costs for crew may thus be lower.

Fishing effort is measured as number of hooks (AFMA logbook data 2007). For the longline fisheries in the Western Central Pacific Ocean, the fishing cost is usually measured by dollars per hook (Kompas and Che 2006). For the ETBF study, the fishing cost and the labour cost per hook is not available, therefore it is estimated based on total effort (number of hooks) (AFMA logbook data 2007), average hooks per fishing day (Campbell 2007), average number of crew on board (ABARE survey data), and average wage per day for agriculture and fishing (DOL 2008).

The number of fishing days is computed by dividing total effort (number of hooks) by average hooks per day. The labour quantity is defined as the multiplication of the average number of crew on board (ABARE survey data) and fishing days (defined by dividing total number of hooks by average hooks set per day). To calibrate, a time series for wage labour is also computed from the average wage per day for agriculture and fishing during 2000-2005 (DOL 2008).

Since fuel is the most important material in fishing costs, a fuel price index is used as a proxy for the material price index. The fuel price index is computed from the average diesel price from ABARE (2008b). The quantity of fuel is computed by dividing fuel and gear costs (surveyed at boat level) by fuel price. Capital cost is measured as a sum of the repair costs and maintenance and a charge for the opportunity cost of capital (6 per cent per year).

q Harvest and gross value of production of albacore, 1991-92 to 2006-07
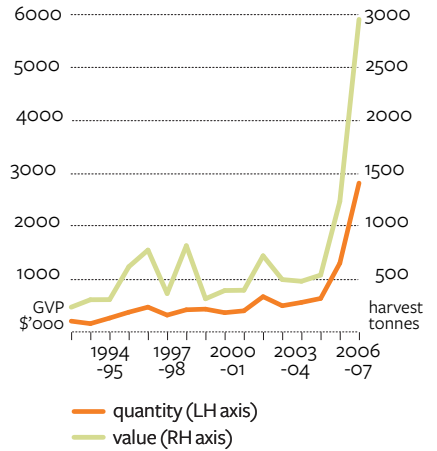
Source: Estimated from ABARE 2008.

Estimated results and profit, productivity analysis

The relevant decomposition takes the form (see section 5 above):

$$(8.1) \qquad \theta^{a,b} = R^{a,b} \cdot PO^{a,b} \cdot PF^{a,b} \cdot PL^{a,b} \cdot K^{a,b} \frac{S_a}{S_b}$$

so that the performance of vessel a relative to vessel b can be decomposed into differences because of productivity ($R^{a,b}$), output ($PO^{a,b}$), variable inputs ($PL^{a,b}$ and $PF^{a,b}$) and vessel fishing power ($K^{a,b}$). In constructing the index in (8.1) $PL^{a,b}$ and $PF^{a,b}$ are treated as negative outputs. In this study vessel fishing power is measured as total number of hooks.

For comparative purposes, a reference firm (a) must be chosen. Using a benchmark that is an observed firm or vessel helps fishers to better assess those factors that are constraining profits under their control (such as productivity) from factors that are not (such as fuel prices). The reference vessel is the arithmetic average vessel in 1999. In 1999, profit and capital were high and stable and during that year the average TFP was also highest. All value variables are in 2004-05 prices. The profit decompositions are presented in table 12 for the years 1989-90 to 2004-05.

12 Decomposition of Profit Ratios in the longline eastern tuna and billfish fishery

				indexes				
		profit	productivity	output price	fuel price	labor price	capital	stock
	Obs	θ	R	PO	PF	PL	K	S
1989-90	22	0.80	1.14	0.95	0.95	0.96	0.18	2.18
1990-91	25	0.85	1.07	0.92	0.95	0.97	0.28	1.45
1991-92	32	0.47	0.74	0.96	0.97	0.97	0.32	1.49
1992-93	34	0.69	1.00	0.96	0.97	0.98	0.35	1.53
1993-94	27	1.00	1.21	0.90	0.96	0.98	0.48	1.21
1994-95	33	1.03	1.06	1.06	0.99	0.99	0.54	1.21
1995-96	25	0.75	0.87	1.16	1.00	0.99	0.50	1.31
1996-97	27	1.13	1.07	1.15	1.02	0.99	0.56	1.25
1997-98	20	1.44	1.00	1.17	0.97	1.00	0.84	1.14
1998-99	32	2.14	1.57	1.00	1.00	1.00	1.00	1.00
1999-2000	25	2.13	1.36	1.20	1.17	1.00	0.96	0.95
2000-01	37	2.31	1.24	1.32	1.16	1.00	1.17	0.99
2001-02	42	2.72	1.20	1.34	1.16	1.01	1.18	1.21
2002-03	31	1.62	0.80	1.09	1.18	1.01	1.15	1.13
2003-04	16	1.89	0.99	0.79	1.19	1.01	1.04	1.13
2004-05	20	2.33	1.20	1.30	1.14	1.01	1.06	1.13

Note: The geometric mean is used to average over the indexes. The results for 1989-90 to 2002-03 are extracted from Kompas and Che (2007). All value are in 2004-05 prices.

During 1989-90 to 2002-03 the stock component of the productivity decomposition shows that the contribution of the fish stock to profit in the ETBF has been falling steadily since 1990. However, the profit index had increased during this time because of higher output prices and a larger contribution from vessel capital to profits. During 2000-02, higher output prices contributed relatively more to profit relative to the reference year (1999), as did higher productivity and additional capital investment. However, during that period higher fuel costs had a negative impact on profits. Note: all values are in 2004-05 prices.

The profit level in 2002-03 decreased dramatically from an index value of more than 2 in the previous four years (1998-99 to 2001-02) to 1.62. However, in 2003-04 and 2004-05 there is improvement in profit. The profit index increased from 1.62 in 2002-03 to 1.89 and 2.33 in more recent years (see figure r). The improvement in profitability is because of higher productivity (see figure s), higher relative output prices, and a fall in the capital cost index.

The increase in productivity can be partly explained by two main factors. First, the tendency of over capitalisation detailed in an earlier report (Kompas and Che 2007) seems to have been partially resolved, undoubtedly because of a number of 'highly expensive' vessels leaving the fishery. Average vessel capital decreased from about $1.5 million in 2002-03 to $1.3 million, and $1.1 million in 2003-04 and 2004-05. In terms of fishing power (measured as number of hooks), the average hooks per vessel also decreased from about 120 000 hooks in 2002-03 to about 110 000 hooks per boat in 2004-05. Also, the number of operating boats decreased from 150 in 2002-03 to 116 in 2004-05. Typically, those vessels that exit a fishery are the least productive, leaving on average higher efficiency vessels operating in the fishery.

Along with the higher productivity in 2004-05, the higher profit index in 2004-05 can also be explained by lower fishing costs (number of hooks per vessel had decreased), and higher output price index. In addition, it is argued that the increase in the albacore catch also added to profits, especially in 2004-05 (Kompas 2008). In the sample, the catch of albacore increased by roughly 50 per cent from 2003 to 2005 (or from an average 4.8 tonnes to almost 7.0 tonnes per vessel). The average contribution of albacore to GVP per vessel increased to more than A$9000 in 2004-05.

Compared with the period 1998-99, in 2004-05 the output price index had increased, indicating that the relative contribution of the output price to profit has increased. The increase of the output prices and the profit in 2004-05 is because of higher share of harvest in yellowfin and bigeye tuna, with higher values (higher fish prices) in total GVP. The changes in fuel and labour price indexes are negligible (see table 12).

r Profit index for the longline eastern tuna and billfish fishery
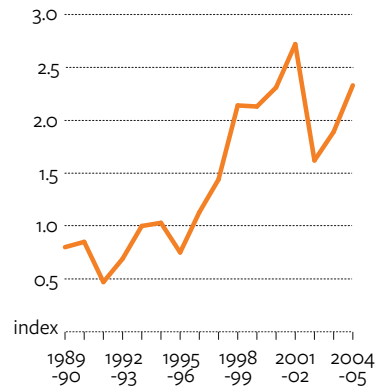
S Productivity index for the longline eastern tuna and billfish fishery

Though this study only covers the period to 2004-05, it is likely that 2005-06 profit may be lower than over the period 2000-01 to 2004-05, because of the decrease in share of high value catch (yellowfin and bigeye). Overall, there appears to be little trend in productivity, a characteristic of 'limited open access' fisheries.
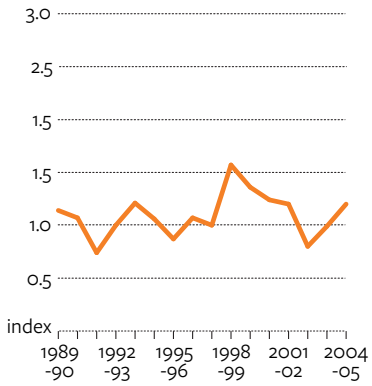
9 Efficiency and performance measures for other Commonwealth fisheries

The preceding case studies have focused on three of the main Commonwealth fisheries: the eastern tuna and billfish fishery, the northern prawn fishery and the south east trawl fishery. However, these methods can be applied to a number of other fisheries as well. Table 13 (constructed in conjunction with AFMA) indicates which methods are appropriate for each of the candidate fisheries. MEY is 'maximum economic yield'. This usually requires a stock-recruitment relationship and key parameter values for the price of fish and the cost of fishing. INPD refers to index number and profit decomposition methods. This requires data on all outputs and inputs, in quantity and value terms. 'Efficiency' refers to stochastic cost and production frontiers. Since this is an econometric exercise, this is the most data intensive of all methods, requiring detailed output and input data over a large number of boats and time periods. All considered, table 13 indicates the potential for broad coverage, in terms of performance indicators, for Commonwealth fisheries.

AFMA is now implementing a number of these performance measures in selected Commonwealth fisheries, with plans to include more.

13 Potential performance indicators for Commonwealth fisheries

	MEY	INPD	Efficiency
Northern prawn fishery		√	√
Banana (common)	√	√	√
Banana (red leg)	√	√	√
Tiger/endeavour	√	√	√
Southern and eastern scalefish and shark			
South east trawl fishery (multiple species)	√	√	√
Orange roughy	√	√	√
Flathead (Danish seine)	√	√	√
Gummy shark	√	√	√
School shark	√	√	√
Non trawl sector	√	√	√
Otter trawl	√	√	√
Great Australian Bight (Redfish and flathead)	√	√	√
Auto longline	√		
Heard, McDonald	√	√	√
Eastern billfish fishery			
Tuna (excluding albacore)	√	√	√
Swordfish	√	√	√
Albacore	√	√	√
Western tuna			
Skipjack/ SBT	√	√	
Torres strait prawn	√	√	√
Torres strait rock lobster	√		
Coral sea (line fishing)		√	
North-west slope		√	√

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