A Retrospective Evaluation of Sustainable Yields for Australia's Northern Prawn Fishery

You-Gan Wang

Centre for Applications in Natural Resource Mathematics (CARM), School of Mathematics and Physics, The University of Queensland, Queensland 4072, Australia. E-mail: you-gan.wang@uq.edu.au

Na Wang

Centre for Applications in Natural Resource Mathematics (CARM), School of Mathematics and Physics, The University of Queensland, Queensland 4072, Australia

ABSTRACT: *The fundamental aim in fisheries management is to determine an optimal fishing effort for sustainably harvesting from a replenishable resource. The current management objective of Australia's Northern Prawn Fishery is to maximize the long-term net economic return following Australian government policy, resulting in an average recent catch of tiger prawn species of about 1,250 tons only. However, the maximum sustainable catch stated from different studies is around 3,000–4,700 tons. We also evaluated the net profit assuming that there was no buyback scheme in 2005 and the fishing fleet was kept at 89 vessels since 2005 and concluded that 40% more catch on average (2006–2009) and an additional total profit of A$17 million (excluding crew cost) could have been gained in addition to the many millions of dollars of savings in the buyback scheme. These findings have great implications for future management in Australia and elsewhere because there is a grave concern of overfishing worldwide.*

Evaluación retrospectiva de rendimientos sostenibles de la pesquería de camarón del norte de Australia

RESUMEN: El objetivo principal del manejo pesquero es determinar el esfuerzo óptimo que produzca la captura sostenible de un recurso renovable. El objetivo actual de manejo de la pesquería de camarón del norte de Australia es maximizar el retorno económico neto en el largo plazo bajo los términos de la política del gobierno australiano, tomando en cuenta que los niveles actuales de captura de camarón ascienden a 1,250 toneladas, cuando la máxima captura sostenible, de acuerdo a varios estudios, es de 3,000 a 4,700 toneladas. También se evalúa la ganancia neta bajo la suposición de que no existió un esquema de recompra en 2005 y que la flota pesquera se mantuvo en 89 embarcaciones desde 2005. Se concluye que se pudo haber ganado, en promedio, un 40% más de captura (2006-2009) y una ganancia adicional total de A$17 millones (excluyendo el gastos de la tripulación) con respecto a los muchos millones de dólares que se ahorraron con el esquema de recompra. Estos resultados tienen implicaciones importantes para el futuro manejo en Australia y en otros lugares dado que existe una preocupación a nivel mundial por la sobrexplotación pesquera.

INTRODUCTION

The Australian federal government is in the process of introducing maximum economic yield (MEY)-based management for 26 fish species. The Northern Prawn Fishery (NPF), one of Australia's most valuable fisheries in terms of gross production value, has been managed under the MEY objective since 2006. However, it is not clear whether the MEY objective is actually beneficial to Australia at all. Bromley (2009) has provided rigorous justification for why MEY is not the same as "making society better off." This article aims to present an NPF case study to support the claims of Bromley (2009) that other researchers (and politicians) might not expect.

As a multispecies fishery targeting mainly prawns, the NPF also takes scampi, squid, scallops, and bugs. The NPF prawn catch consists of nine prawn species, among which three species—brown tiger prawns (*Penaeus esculentus*), grooved tiger prawns (*Penaeus semisulcatus*), and banana prawns (*Penaeus merguiensis*)—account for almost 80% of the annual average catch (Wang and Die 1996). The catch and effort data recorded in the NPF are separated by commercial species groups (banana prawn, tiger prawn, endeavour prawn, and king prawn) and thus do not distinguish between the two species of tiger prawn. Much work was carried out using data from commercial catches, scientific trawls, and tagging experiments to study growth, mortality, and movement of these key species (Lucas et al. 1979; Somers and Wang 1997; Punt et al. 2009). In particular, Somers and Wang (1997) used a multispecies bioeconomic simulation model to evaluate different management strategies by incorporating factors such as seasonal effects in price and catchability, and the net revenue was estimated as $40–50 million in 1993 Australian dollar currency. There are two fishing seasons each year; the first season is from April to early June, when most banana prawns are caught, and the second season is from August to November, when most tiger prawns are caught. The seasonal closures were introduced to ensure good sizes at harvest and for protection of spawners of tiger prawns (Somers 1990; Somers and Wang 1997). Since 2006, the length of the banana prawn season has been set to depend on whether or not catches meet a predetermined decision rule (Hohnen et al. 2008). The banana prawn season was extended by 2 weeks in 2007 and was once again extended in 2008 and 2011 (Table 1).

The NPF gross value of catch has been the highest of any of the commonwealth fisheries in recent years. Over the period 1989–1999, the estimated gross values varied between $102 million and $149 million. There was a downward trend over the period 2000–2008, with the lowest value of $62.3 million in 2006 compared with the peak of $164.7 million in 2000 (Table 1). The currency unit used throughout the article is the Australian dollar. The reduction in gross revenue resulted from mainly the decrease in catch levels, as well as the drop in prawn prices due to prawn supplies mainly from farming and appreciation of the Australian dollar (Pascoe et al. 2011). The net revenue was around $20 million in the 1990s (Kompas et al. 2010) and dropped to −$13.9 million (a loss) for 2004–2005 due to increasing costs in labor and fuel. By 2007–2008, the net revenue had become positive at $8.1 million, which was largely due to the higher catches of banana prawns.

The NPF is a limited-entry, input-controlled fishery and is managed by the Australian Fisheries Management Authority (AFMA). The inputs under the NPF Plan 1995 are the number of vessels in the fishery, vessel size, and engine power. Under this plan, the NPF fishing fleet was assigned two classes of statutory fishing rights (SFRs): gear SFRs, which are based on vessel size and engine power, and B SFRs, which determine the number of vessels (Jarrett 2001). In 2000, gear SFRs were changed to be measured in terms of total headrope length for the fleet (Dichmont et al. 2006a). A system of individual transferable quota (ITQs) will be implemented in 2012 (Pascoe et al. 2011). For years, restriction of gear SFRs has been an important management tool in reducing fishing effort. In 2008, a 33% increase in total gear for the 2008 tiger prawn season was accepted by AFMA to help achieve MEY for the fishery. An increase of about 20% in vessel engine power in the long run was estimated by Pascoe et al. (2011) under expected price conditions, which suggests that larger vessels may appear under the new ITQ system.

Actions have also been taken with respect to Class B SFRs. Over the last decade, two vessel buyback schemes have reduced the fleet. The second buyback reduced the fleet from 89 vessels in 2005 to 55 (52 B SFRs) in 2009, mainly to achieve the MEY objective (Dichmont et al. 2006a; Pascoe et al. 2011). In 2004, a new target level of catch for MEY was accepted by the AFMA, replacing maximum sustainable yield (MSY) because MEY was regarded as a biologically more conservative target than MSY in this fishery (Larcombe 2008; Evans 2010; Kompas et al. 2010). This can be compared with the peak of about 300 vessels in the early 1980s.

Management of this fishery was based on results from yield-per-recruitment analysis until the stock–recruitment relationship (SRR) was established by Wang and Die (1996) for the two tiger prawn species (*P. esculentus* and *P. semisulcatus*). This has led to a significant development in managing this fishery because a framework was established in deriving the sustainable catches and efforts. Wang and Die (1996) obtained the MSY as 1,900 tons for *P. esculentus* and 2,200 tons for *P. semisulcatus* when assuming a 5% increase in fishing power. Because no SSRs were found for banana prawns, the total effort for the NPF could be adjusted based on the historical split between the tiger and banana prawns efforts (Wang and Die 1996; Kompas et al. 2010). The other reason for doing this is that effort cannot be practically controlled at species level or targeted on the banana prawn fisheries alone. The work of Wang and Die (1996) was further extended by Dichmont et al. (2003) using a Deriso-Schnute delay–difference model. A management strategy evaluation (MSE) framework was conducted to evaluate management strategies using input controls for the prawn

TABLE 1. Gross value of product, Class B SFRs (denoted by number of vessels [nv], fishing efforts [Ey], and corresponding fishing days [Ey/nv])for tiger prawn and banana prawn in the NPF, by financial year from 2000 to 2009.

Year	Gross Value of Product (A$, millions)	No. of Vessels	Fishing Effort of		Fishing Days for		
			Banana Prawns boat-days	Tiger Prawns boat-days	Banana Prawns	Tiger Prawns	Total
2000	164.7	121	3,697	12,736	31	105	136
2001	135	118	6,247	10,440	53	88	141
2002	82.5	114	4,148	8,718	36	76	113
2003	74	97	4,114	8,503	42	88	130
2004	65	96	3,985	7,793	42	81	123
2005	72.8	89	3,364	7,967	38	90	127
2006	62.3	77	3,283	6,983	43	91	133
2007	74	51	2,696	4,829	53	95	148
2008	73	52	3,347	4,556	64	88	152
2009	—	52	3,095	4,889	60	94	154
2000–2009 Average	—	87	3,798	7,741	44	89	133

fishery (Dichmont et al. 2006b). The MSY estimate was 1,418 tons for *P. esculentus* and 1,709 tons for *P. semisulcatus*. More recently, Punt et al. (2010) provided an extended bioeconomic study incorporating the two tiger species and the blue endeavour prawn (*Metapenaeus endeavouri*) and provided the MEY estimates for the three species. The MEY estimate for *P. esculentus* was 1,231 tons and for *P. semisulcatus* it was 1,447 tons.

In this article, we assess the economic effectiveness in relation to yield, revenue, and net revenue for tiger prawns in the NPF and demonstrate that a broader socioeconomic definition of the fishery should be considered for the purposes of calculating MEY. We also quantify the potential gain in this fishery if no buyback scheme had occurred in 2005. Our results indicate that there could be a gain if there had been no such fleet reduction scheme.

METHODS

The analysis is based on weekly catch and effort data. The biological year is assumed to range from week 40 until week 39 of the following year (Wang and Die 1996; Dichmont et al. 2006b). The sex ratio for each tiger prawn species is assumed to be 1:1. The estimates of annual recruitment and spawning stock indices are based on an age-structured population model (Wang and Die 1996; Somers and Wang 1997). The SRR, recruitment–spawning stock relationship (RSR), and catch–effort relationship are used to obtain the sustainable catch for a given fishing mortality. A broader revenue function was applied to assess the economic effectiveness of inputs (mainly the number of vessels) in relation to yield and net revenue.

The annual catch in tons, denoted as Y_y, is modeled using the catch–effort relationship (Somers and Wang 1997):

$$Y_y=a_3 R_y(1-exp(-b_3 F_y)),$$

where R_y is the recruitment number in year y, and F_y is the fishing mortality in year y (proportional to the effort, defined below). The SRR is modeled using Ricker's equation,

$$R_y=a_1 S_{y-1} exp(-b_1 S_{y-1}),$$

where S_{y-1} is the spawning stock index of previous year. The RSR is modeled by (Somers and Wang 1997):

$$S_y=a_2 R_y exp(-b_2 F_y).$$

The optimal F that maximizes the Y satisfies $F = AD/(1+D)$, where $A= log(a_1 a_2)/b_2$ and $D=b_2+b_3 exp(-b_3 F)/(1-exp(-b_3 F))$.

The fishing mortality, F_y, is expressed as

$$F_y=qE_y=q \times days \times n_v$$

where q is the catchability, E_y is the fishing effort of year y, $days$ is the number of fishing days, and n_v is the number of vessels.

By taking into consideration the impact due to technological changes, effective effort rather than nominal effort is applied to the tiger prawn fishery (Robins et al. 1998; Bishop et al. 2000). Two scenarios are set to measure the impact of changes in fishing efficiency over time based on the work of Robins et al. (1998) and Kompas et al. (2010). In scenario 1, we assume an annual increase of 2.5% for years before 1988 and after 1992 and 5% for 1988–1992. The significant improvement in fishing power from 1988 to 1992 was largely due to the usage of Global Positioning Systems (GPS) and plotters, and the measurements of the impact of GPS and plotters are based on the analysis of commercial catch data (Robins et al. 1998). In scenario 2, we allow an annual increase of 2.5% before 1988 and 5% for 1988–1992 and then variable effort creep (with an average of 1.5% annually) is applied to years after 1992 using values obtained from Kompas et al. (2010).

The economic status of the NPF is measured by the total revenue and the net revenue. Based on the economic parameters used by Somers and Wang (1997) and Punt et al. (2010) and assuming that the price is unaffected by the yield Y and a fixed number of fishing days per year, the annual net revenue for the NPF is approximately (Wang and Wang 2012)

$$R(Y)=PY-c_1 Y-c_2 E,$$

where P is the average price, \$19.85/kg; c_1 includes crew cost, 0.23P (\$/kg), and packaging cost, \$0.98/kg; and c_2 is the cost associated with each of the E vessels including repairs and fuel, annual permit cost, annual depreciation, and opportunity cost. In the case of NPF, the daily operating cost (repairs and fuel) is \$2,321 and the average fishing days is 135 days per year (Punt et al. 2010). The average capital cost per vessel is \$727,184. The opportunity cost is assumed to be 5% and the annual depreciation of the capital is 3.7%. There is also an annual fishing permit cost of \$56,116 per vessel. Therefore, we have $c_2 = 2{,}321 \times 135 + 727{,}184 \times (5\% + 3.7\%) + 56{,}116 = 432{,}716$ per vessel per year. More details are given in table 2 of Punt et al. (2010).

From a broader societal perspective, the labor cost (often related to yield/revenue) is actually income for crews; therefore, there is no cost or gain because the entities include both the vessel owners and crews. The license fee is also income for the government (which has great implications for research funds). Opportunity cost does not seem to apply here because the vessels have already entered this fishery; on the contrary, shadow profit (savings from government) should be considered because removal of a vessel (buyback) is costly (A\$400,000 per vessel), and government assistance may be needed for crews (three crews per vessel) if unemployed (A\$11,856 per person per year). We therefore adopt a broader revenue function (to reflect a broader societal perspective) that includes the shadow profits such as the potential unemployment benefit and exit benefit (assuming 5% of the buyback cost), c_2 = 2,321 × 135 + 727,184 × 3.7% − 11,856 × 3 − 400,000 × 5% = A$284,673 per vessel per year. The daily operating cost ($2,321/day for the first term in c_2) dominates the total cost, which makes accurate estimates of the other economic parameters relatively unimportant. Actually, the cost ($2,321/day) also includes normal profits by other sectors. More interesting discussion on this complex issue can be found in Christensen et al. (2011) and Bromley (2009).

When computing the catch losses due to underfishing, the new inputs are the number of fishing days and the number of vessels, which will result in changes in fishing mortality. To adjust for the impact on fishing mortality, we use

$$F_y^* = F_y\,(E_y^*/E_y) = F_y\,(days^* \times n_v^*)/(days \times n_v),$$

where *days* * and n_v^* are the hypothesised fishing days and number of vessels, E_y^* is the new estimated effort, and F_y^* is the new estimated fishing mortality. Accordingly, the spawning stock of the same year is adjusted using

$$S_y^* = S_y\,(R_y^*/R_y)\exp(-b_2F_y^* - b_2F_y),$$

and the number of recruits in the following year is consequently adjusted to

$$R_y^* = R_y\,(S_y^*/S_{y-1})\exp(-b_1S^*_{y-1} - b_1S_{y-1}),$$

The estimated catch in tons is finally calculated as

$$Y_y^* = Y_y\,(R^*_y/R_y)(1-\exp(-b_3F^*_y))/(1-\exp(-b_3F_y)).$$

Note that $R^*_y = R_y$ for the estimation for the first year.

RESULTS

Long-Term Yields—Optimal and Sustainable

The equilibrium yield estimates for *P. semisulcatus* and *P. esculentus* in the NPF for the two scenarios are shown in Figure 1. The peak of each curve indicates the MSY. Overfishing occurs when the effective fishing efforts exceed E_{MSY}, and rebuilding happens when the effective fishing efforts stay below the critical value.

For the period 2005–2009, the exploitation levels remain far lower than E_{MSY} for both species. It appears that the NPF has undergone an unnecessary rebuilding period over recent years from an MSY perspective. The status of the NPF is further illustrated by plotting the time series of estimated spawning index relative to S_{MSY} and adjusted effort relative to E_{MSY} for both tiger prawn species in the NPF (Figure 2).

Both *P. esculentus* and *P. semisulcatus* were previously judged as being overfished in 2002 (Dichmont 2006b), and stocks responded and rebounded to much higher levels due to substantial reduction in fishing effort within a few years, especially for *P. esculentus*. However, the status of both tiger prawn species appears to be quite healthy under scenario 2, which is deemed as most realistic. Based on this scenario, current level of fishing effort (52 vessels in 2009) could have been maintained at the 2005 level and the buyback scheme might be unnecessary.

We assume that each vessel fishes for 135 days per year and two thirds of these fishing days are spent on tiger prawn fishery (Punt et al. 2010). Then, the number of vessels (n_v) needed in the NPF is calculated as E_f /(135 × 2/3); E_f is the total fishing effort (in 2009 boat-day unit). The estimated optimal numbers

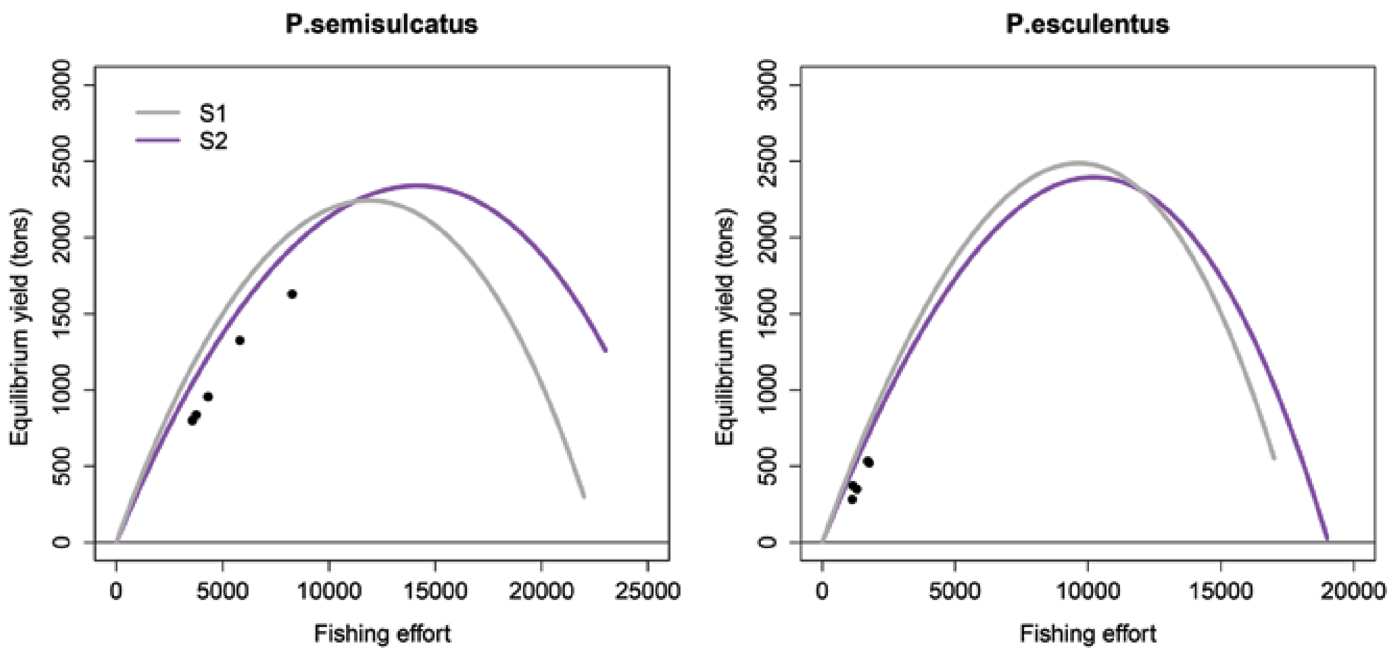

Figure 1. Estimated equilibrium yields for two tiger prawn species in the NPF under the two scenarios. Fishing effort is in 2009 boat-day unit. Dark points show the landings and corresponding effective fishing efforts for the recent 5 years (2005–2009).

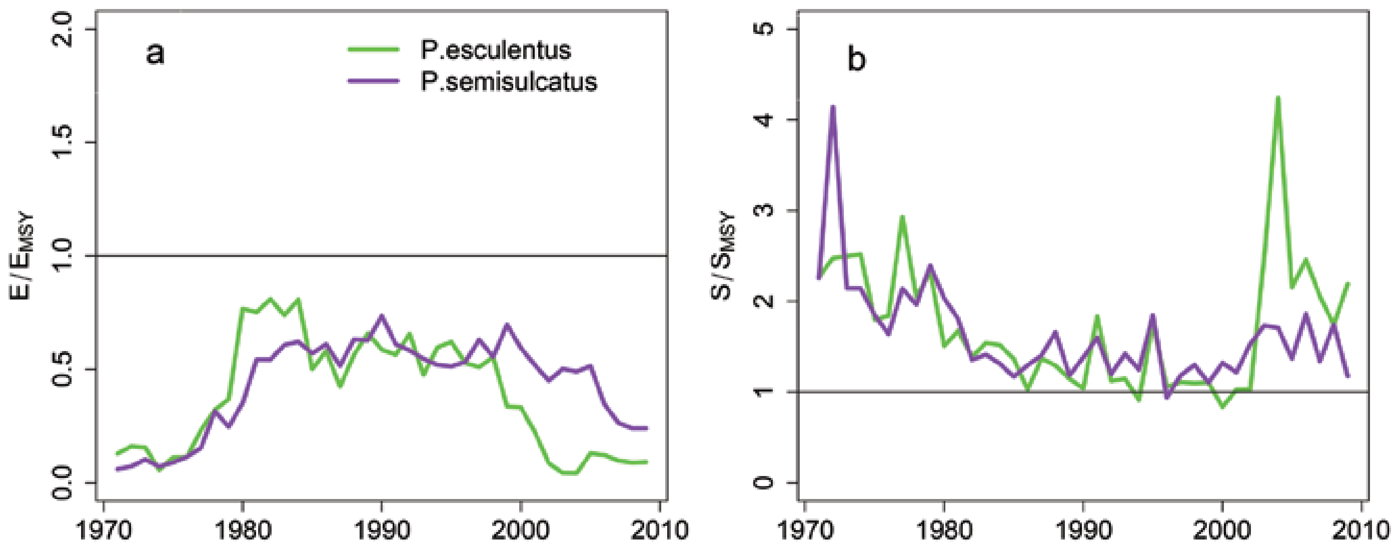

Figure 2. Time series of (a) effective fishing effort relative to E_{MSY} and (b) estimated spawning index relative to S_{MSY} for both tiger prawn species in the NPF for scenario 2.

of vessels under different scenarios as well as other target levels are shown in Table 2.

What if there had been no buyback?

Now we let the number of vessels be fixed at 89 for the period 2005–2009 to assess the effect on fishery status in relation to catch (tons) and net revenue (A$, millions). The simulated vessels are supposed to be, on average, identical to those that remained in the fishery in terms of headrope length and other characteristics. The recruitment and spawning indices of each year were recalculated corresponding to the new changed fishing mortality. The results are shown in Table 3. Roughly speaking, there would be an additional 2,000 tons of catches from 2006 to 2009. This 40% potential additional catches represent quite a substantial gain in terms of food and employment opportunities.

DISCUSSION

The general perception of trawling (which is the case in the NPF) is that it has a devastating effect on the ecosystem. Roughly 30% of world fisheries are overexploited (Branch et al. 2011). However, this does not necessarily mean that all fisheries need to greatly reduce fishing effort, especially for those regarded as having a healthy status. In this short article, we have provided a quick assessment of the NPF. The method is simple and calculation is straightforward. These estimates should be sufficient to draw the conclusions, although more accurate estimates may be sought that would require incorporation of more relevant information. The results are not contrary to those in Punt et al. (2010) and Norman-López and Pascoe (2011). In Norman-López and Pascoe (2011), the net profit was evaluated at a baseline and the MEY level. For example, our calculation indicates that their net profit could go even higher if fishing effort were set at 10% more than their MEY level. If the crew cost is revenue share based, the increased profit in our hypothesized case (without buyback in 2005) is more than the corresponding

TABLE 2. Estimated optimal efforts expressed as number of vessels under different scenarios for the tiger fishery and the whole NPF (after adjusting for banana fishery). The MSY and MEY (in tons) are yields from the tiger prawns only. Effort unit is Year 2009 boat-days, and 135 fishing days per year, and a proportion of two-thirds fishing days for tiger prawns are assumed.

		Tiger Fishery Only				NPR (Tiger and Banana Fisheries)	
		MSY	MEY	E_{MSY}	E_{MEY}	E_{MSY}	E_{MEY}
Wang and Die (1996)		4,100	—	112	—	168	—
Dichmont et al. (2003)		3,127	—	98	—	147	—
Dichmont et al. (2010)		—	2,905	—	—	—	—
Punt et al. (2010)		—	2,678	—	71	—	107
Scenario 1	Narrow	4,730	3,089	182	75	272	112
	Broader	—	4,330	—	129	—	194
Scenario 2	Narrow	4,734	3,102	180	74	271	111
	Broader	—	4,336	—	128	—	193

TABLE 3. Actual estimates of catch (tons) and difference in profit (A$, millions), assuming a fixed number of 89 vessels in the years 2006–2009 for the two scenarios. Fishing days of each year are the same as recorded.

Year	Real Status of		Simulation Model		Added Value of		
	Catch (tons)	Effort (boat-days)	Catch (tons)	Effort (boat-days)	Catch (tons)	Catch (A$, millions)	Profit (A$, millions)
Scenario 1							
2006	1,856	7,095	2,072	8,200	215	4.3	1.7
2007	1,304	5,402	1,994	9,427	690	13.7	4.5
2008	1,120	4,792	1,629	8,202	509	10.1	2.4
2009	1,171	4,730	1,749	8,096	578	11.5	3.8
Total	5,452	22,019	7,444	33,925	1,992	39.5	12.5
Scenario 2							
<2006	1,856	6,618	2,085	7,649	228.5	4.5	2.1
2007	1,304	5,157	2,049	8,999	744.4	14.8	5.9
2008	1,120	4,682	1,694	8,014	574.1	11.4	3.8
2009	1,171	4,730	1,826	8,096	654.6	13.0	5.3
Total	5,452	21,187	7,653	32,758	2,202	43.7	17.1

increased crew share (around A$9 million) in the two scenarios (cf. Table 3). Our results show that this additional catch would lead to higher sustainable yield, which is arguably beneficial to the fishing industry and the society. An interesting question is whether this additional 40% of food (averaged over the last 4 years) should be caught. Society may demand less environmental effect on a fishery, and any effort reduction is therefore welcome (and the society may gain from a less disturbed environment; Christensen and Walters 2004; Christensen and Maclean 2011). This is especially true in a prawn trawl fishery where the bycatch component is large (such as in the NPF).

Because the buyback program had already been carried out (2006–2008), it would be too costly to reestablish the fishery with 89 vessels. The other option is to extend the fishing seasons at both ends (earlier opening and later closure) as much as possible. However, an extended tiger season would also have a negative effect in protecting the spawners. An extended banana season implies that the smaller banana prawns would be caught from earlier opening days and smaller tiger prawns will be caught from later banana season because substantial effort on the tiger prawn species is deployed during banana prawn season. On the other hand, because excessive fishing is often the key contributing factor to collapse of fisheries globally (Worm et al. 2009), overcaution may have been a reasonable choice. It should be noted that setting appropriate ITQ requires objective functions with appropriate parameter values. We therefore strongly encourage being more careful in using the economic parameters in the gain function and fully investigating the implications of different choices.

Finally, is the fishery's economic gain at society's expense? The answer is yes, because all parts of our society are connected and maximizing one single component will be at the cost of suboptimality of the others (Christensen 2010). The MEY approach is not to maximize the resource rent but the economic rent. The subtle difference was well explained by Bromley (2009). The difference between resource rent and economic rent is clear; for example, the license fees are part of the resource rent for the Australian government but a cost in the MEY approach, which allows excess profit accrual to the lucky firms remaining in the fisheries. The economic loss due to buyback scheme since 2005 would be much larger if we considered beyond 2009 and multiplied the effects. Management strategies based on maximizing the net profit for the fishery alone would lead to undesirable social consequences when potential opportunities for other relevant sectors are ignored. In our objective functions, we have excluded employment costs because we see them as labor opportunities.

On the other hand, some might argue that such expense was well spent as a premium cost for ensuring sustainability. The lower the fishing effort, the easier it will be to ride out spawning/recruitment falls in bad years. Nevertheless, it is debatable whether the extra 40% catch is worthwhile when factoring in all the other costs, such as opportunity loss and ecosystem impacts, because dredging is quite damaging to the sea bottom and the bycatch/by-product is always quite substantial, which cannot be ignored. Because the catch comprises mixed sizes, and the prawn price is size dependent, more careful studies using a multispecies approach and biological and environmental impacts are still needed. Nevertheless, our illustration of the NPF clearly shows there may be great potential benefits when taking account of the whole of society's interest. Perhaps there is a need to move from MEY/MSY to a society–ecosystem approach in fisheries management. This will further enlarge our inference domain to balance between the diverse societal objectives and maintaining healthy statuses of all components in the affected marine ecosystems. Research toward quantifying the impacts of fishing on degradation of ecosystems would be a great step forward (Christensen and Maclean 2011). Alternatively, one can consider spatial/temporal closures to complement the ecosystem and catches (Zhou et al. 2010; Little et al. 2011).

ACKNOWLEDGMENTS

We are grateful for the referees' very constructive comments, which led to a much improved article.

REFERENCES

Bishop, J., D. Die, and Y.-G. Wang. 2000. A generalized estimating equations approach for analysis of fishing power in the Australian Northern Prawn Fishery. Australian and New Zealand Journal of Statistics 42:159–177.

Branch, T. A., O. P. Jensen, D. Ricard, Y. Ye, and R. Hilborn. 2011. Contrasting global trends in marine fishery status obtained from catches and from stock assessments. Conservation Biology 25: 4, 777–786.

Bromley, D. W. 2009. Abdicating responsibility: the deceits of fisheries policy. Fisheries 34:280–290.

Christensen, V. 2010. MEY = MSY. Fish and Fisheries 11:105–110.

Christensen, V., and J. Maclean. 2011. Ecosystem approaches to fisheries—a global perspective. Cambridge University Press, Cambridge, UK.

Christensen, V., J. Steenbeek, and P. Failler. 2011. A combined ecosystem and value chain modeling approach for evaluating societal cost and benefit of fishing. Ecological Modelling 222:857–864.

Christensen, V., and C. J. Walters. 2004. Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modelling 172:109–139.

Dichmont, C. M., A. R. Deng, A. E. Punt, W. Venables, and M. Haddon. 2006a. Management strategies for short lived species: the case of Australia's Northern Prawn Fishery: 2. Choosing appropriate management strategies using input controls. Fisheries Research 82:221–234.

Dichmont, C. M., A. R. Deng, A. E. Punt, W. Venables, and M. Haddon. 2006b. Management strategies for short-lived species: the case of Australia's Northern Prawn Fishery: 1. Accounting for multiple species, spatial structure and implementation uncertainty when evaluating risk. Fisheries Research 82:204–220.

Dichmont, C. M., S. Pascoe, T. Kompas, A. E. Punt, and R. Deng. 2010. On implementing maximum economic yield in commercial fisheries. Proceedings of the National Academy of Sciences 107:16–21.

Dichmont, C. M., A. E. Punt, A. Deng, Q. Dell, and W. Venables. 2003. Application of a weekly delay–difference model to commercial catch and effort data for tiger prawns in Australia's Northern Prawn Fishery. Fisheries Research 65:335–350.

Evans, S. K. 2010. Northern Prawn Fishery data summary 2009. NPF Industry Pty Ltd., Canberra, Australia.

Hohnen, L., R. Wood, P. Newton, N. Jahan, and S. Vieira. 2008. Fishery economic status report 2007. ABARE. Canberra, Australia.

Jarrett, A. E. 2001. Initial allocation of unitisation (boat/engine units) as harvesting rights in Australia's northern prawn fishery. In Shotten, R. (ed.), Case studies on the allocation of transferable quota rights in fisheries. FAO Fisheries Technical Paper. No. 411. Rome, Italy.

Kompas, T., C. M. Dichmont, A. E. Punt, A. Deng, T. N. Che, J. Bishop, P. Gooday, Y. Ye, and S. Zhou. 2010. Maximizing profits and conserving stocks in the Australian Northern Prawn Fishery. Australian Journal of Agricultural and Resource Economics 54:281–299.

Larcombe, J. 2008. Northern Prawn Fishery. Pages 25–38 in J. Larcombe and G. Begg, editors. Fishery status reports 2007: status of fish stocks managed by the Australian government. Bureau of Rural Sciences, Canberra, Australia.

Little, L. R., R. Q. Grafton, T. Kompas, D. M. Smith, A. E. Punt, and B. D. Mapstone. 2011. Complementarity of no-take marine reserves and individual transferable catch quotas for managing the line fishery of the Great Barrier Reef. Conservation Biology : The Journal of the Society for Conservation Biology 25(2):333–340.

Lucas, C., G. Kirkwood, and I. F. Somers. 1979. An assessment of the stocks of the banana prawn Penaeus merguiensis in the Gulf of Carpentaria. Australian Journal of Marine and Freshwater Research 30:639–652.

Norman-López, A., and S. Pascoe. 2011. Net economic effects of achieving maximum economic yield in fisheries. Marine Policy 35:489–495.

Pascoe, S., S. Vieira, C. M. Dichmont, and A. E. Punt. 2011. Optimal vessel size and output in the Australian northern prawn fishery: a restricted profit function approach. Australian Journal of Agricultural and Resource Economics 55:107–125.

Punt, A. E., Buckworth, R. C., Dichmont, C. M., and Y. Ye. 2009. Performance of methods for estimating size—transition matrices using tag—recapture data. Marine and Freshwater Research 60:168–182.

Punt, A. E., R. A., Deng, C. M. Dichmont, T. Kompas, W. N. Venables, S., Zhou, S. Pascoe, T. Hutton, R. Kenyon, T. van der Velde, and M. Kienzle. 2010. Integrating size-structured assessment and bioeconomic management advice in Australia's northern prawn fishery. ICES Journal of Marine Science 67:1785–1801.

Robins, C. M., Y.-G. Wang, and D. Die. 1998. The impact of Global Positioning Systems and plotters on fishing power in the northern prawn fishery, Australia. Canadian Journal of Fisheries and Aquatic Sciences 55:1645–1651.

Somers, I. F. 1990. Manipulation of fishing effort in Australia's penaeid prawn fisheries. Marine and Freshwater Research 41:1–12.

Somers, I., and Y.-G. Wang. 1997. A simulation model for evaluating seasonal closures in Australia's multispecies northern prawn fishery. North American Journal of Fisheries Management 17:114–130.

Wang, Y.-G., and D. Die. 1996. Stock–recruitment relationships of the tiger prawns (Penaeus esculentus and Penaeus semisulcatus) in the Australian northern prawn fishery. Marine and Freshwater Research 47:87–95.

Wang, Y.-G., and N. Wang. 2012. Implications of gain functions in fisheries management. Reviews in Fisheries Science 20(2):103–109.

Worm, B., R. Hilborn, J. K. Baum, T. A. Branch, J. S. Collie, C. Costello, M. J. Fogarty, E. A. Fulton, J. A. Hutchings, S. Jennings, O.P. Jensen, H.K. Lotze, P.M. Mace, T.R. McClanahan, C. Minto, S.R. Palumbi, A.M. Parma, D. Ricard, A.A. Rosenberg, R. Watson and D. Zeller. 2009. Rebuilding global fisheries. Science 325:578–585.

Zhou, S., A. D. M. Smith, A. E. Punt, A. J. Richardson, M. Gibbs, E. A. Fulton, S. Pascoe, C. Bulman, P. Bayliss, and K. Sainsbury. 2010. Ecosystem-based fisheries management requires a change to the selective fishing philosophy. Proceedings of the National Academy of Sciences USA 107:9485–9488.