Supporting Information

Dichmont et al. 10.1073/pnas.0912091107

The model results presented in the main paper illustrate only a summary of the effects of the alternative assumptions on optimal fleet size, optimal catch levels, and associated levels of profit. More detailed results are presented here, along with a brief description of how the model was modified to run each scenario.

Modifications to the Model

The model and biological data used in this analysis are fundamentally the same as those developed and reported by Dichmont and colleagues (1). The economic data were updated after publication, and the updated economic data were used in setting the target effort levels. The updated analysis, undertaken in 2008, was used to set target effort levels in the fishery for 2008 and 2009, shown in Fig. S2. The updated economic data used in the analysis are given in Tables S1 and S2.

The model was used to estimate the optimal effort trajectory for each of 2 fleets that maximizes the net present values of profits over time. The fleets relate to 2 different fishing patterns that have been identified in the fishery, resulting in different catch compositions over the season. A constraint requested by the NPF management advisory committee was that the fishery should achieve MEY by 2014. In this case, MEY was interpreted as an equilibrium catch level, and the model was used to ensure that the optimal trajectory resulted in an equilibrium catch of each species by this period.

The original model considered only variable costs in the profit function, on the assumption that vessel numbers were fixed. For the purposes of the current analyses, the profit function was modified to enable the assumptions about quasi-fixed costs to be examined and also to allow for the possibility of new boats entering the fishery. The revised annual profits were given by

$$\pi_y = \sum_w \Big\{ \sum_k l\big[(1-c_L)v_{k,y} - c_M\big] Y_{k,w,y} - \sum_f (c_K + c_{F\,y}) E_{f,w,y} \Big\} - F_y V_y$$

where π_y is the profit in future year y, $v_{k,y}$ is the average price per kilogram for animals of species k in year y, c_L is the share cost of labor (labor costs are proportional of fishery revenue), c_M is cost of packaging and gear maintenance (assumed to be proportional to fishery catch in weight), $Y_{k,w,y}$ is the catch (in weight) of species k in week w of year y, c_K is the cost of repairs and maintenance per unit of effort, $c_{F\,y}$is the cost of fuel and grease per unit of effort during year y, $E_{f,w,y}$, is the total number of days fished by vessels in fleet f during week w of year y, and F_y is the average fixed costs associated with a vessel operating in year y, given by

$$F_y = W_y + (o+d)K_y$$

where W_y is the annual vessel costs (i.e., those not related to the level of fishing effort), o is the opportunity cost of capital (also equal to the discount rate), d is the economic depreciation rate, V_y is the number of vessels (either variable or fixed, depending on the simulation), and K_y is the average value of capital (vessel plus gear) in year y.

For the simulation treating gear and repair costs as fixed rather than variable, c_K was set to zero, and the annual gear and repair costs were included in the measure of W_y. For the simulations involving a maximum or minimum effort level, upper or lower bounds were placed on the value of $\Sigma_y E_{f,w,y}$. For the simulations involving variable fishing fleet size, the value of V_y was imputed by dividing the total effort by the average effort per vessel (assuming vessels were fully used).

More Detailed Results

Changes in effort by the fleet and the catch of each species over the transitional period (2008–2014) under the different scenarios are illustrated in Figs. S1–S7. The model is used to estimate effort from 2008 only.

1. Dichmont CM, et al. (2008) Beyond biological performance measures in management strategy evaluation: Bringing in economics and the effects of trawling on the benthos. *Fish Res* 94:238–250.

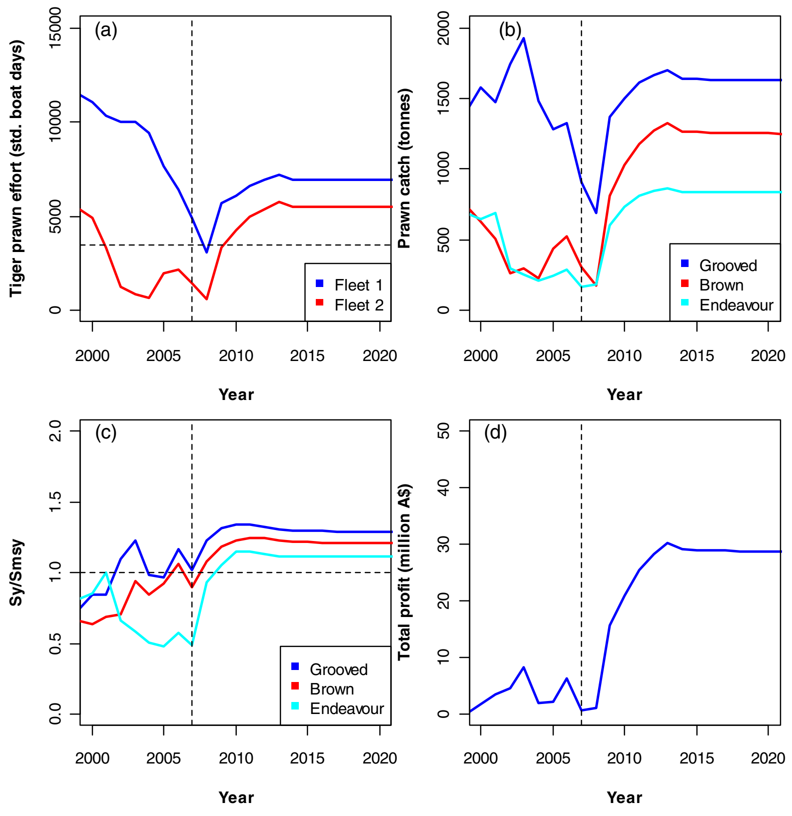

Fig. S1. The unconstrained model. No minimum or maximum effort has been set, and profits may become negative in any given year. The vertical dotted lines delineate the last year of actual data (2007). "Grooved" refers to grooved tiger prawn (*Penaeus semisulcatus*), "Brown" to the brown tiger prawn (*Penaeus esculentus*), and "Endeavour" to endeavor prawns (*Metapenaeus* spp.) as a group. (*A*) The recent past and projected tiger prawn fishery effort for the 2 fishing fleets. (*B*) The catch by prawn species. (*C*) The spawning stock size in a year relative to that at MSY. (*D*) Total annual profit.

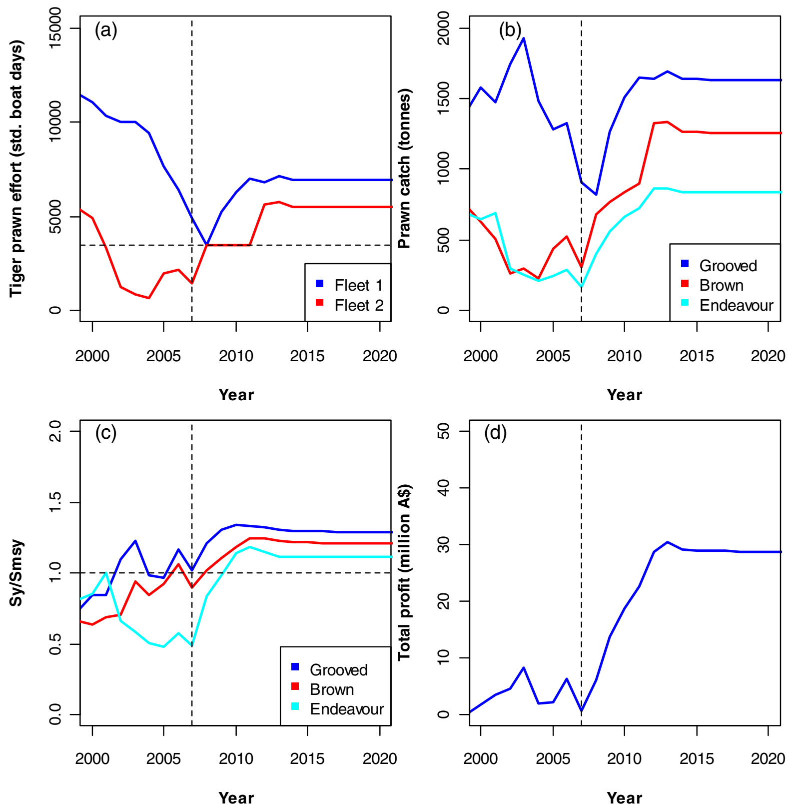

Fig. S2. A constraint on minimum effort. The minimum effort level was based on industry recommendations about what was thought to be a viable minimum. The vertical dotted lines delineate the last year of actual data (2007). "Grooved" refers to grooved tiger prawn (*Penaeus semisulcatus*), "Brown" to the brown tiger prawn *(Penaeus esculentus*), and "Endeavour" to endeavor prawns (*Metapenaeus* spp.) as a group. (*A*) The recent past and projected tiger prawn fishery effort for the 2 fishing fleets. (*B*) The catch by prawn species. (*C*) The spawning stock size in a year relative to that at MSY. (*D*) Total annual profit.

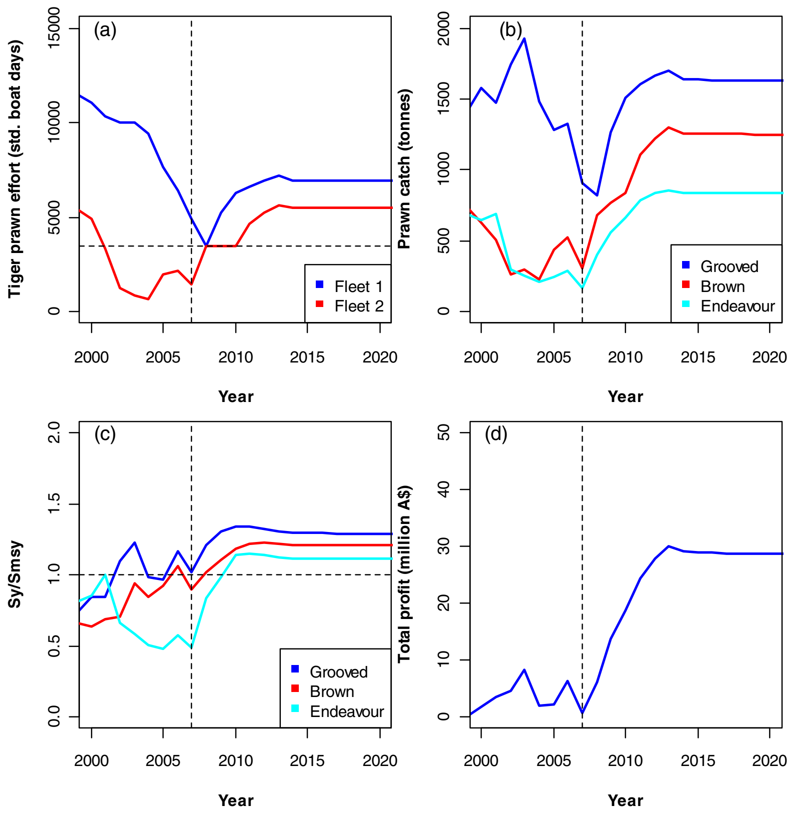

Fig. S3. A constraint to ensure annual profits were nonnegative. This model is an alternative to the minimum effort level but also ensures short-term viability of the fleets during the transition period. Because the fixed costs include an opportunity cost of capital component, nonnegative profits ensure that the vessels earn at least a "normal" return on their investment. The vertical dotted lines delineate the last year of actual data (2007). "Grooved" refers to grooved tiger prawn (*Penaeus semisulcatus*), "Brown" to the brown tiger prawn (*Penaeus esculentus*), and "Endeavour" to endeavor prawns (*Metapenaeus* spp.) as a group. (*A*) The recent past and projected tiger prawn fishery effort for the 2 fishing fleets. (*B*) The catch by prawn species. (*C*) The spawning stock size in a year relative to that at MSY. (*D*) Total annual profit.

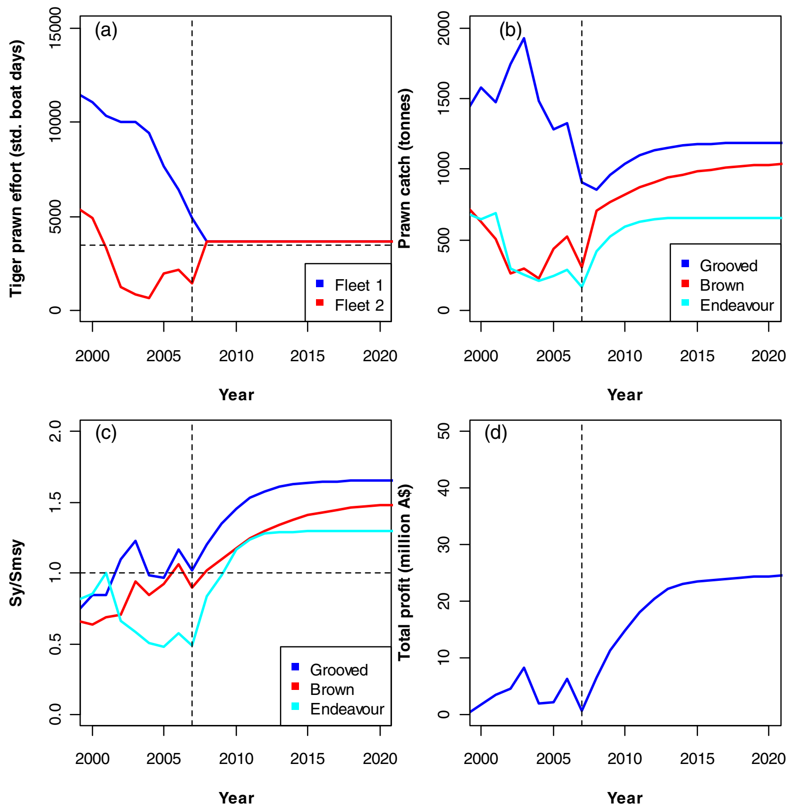

Fig. S4. Nonnegative profit constraint with a maximum effort constraint. This constraint ensured that vessels could not produce more days than possible given the existing season lengths. The vertical dotted lines delineate the last year of actual data (2007). "Grooved" refers to grooved tiger prawn (*Penaeus semisulcatus*), "Brown" to the brown tiger prawn *(Penaeus esculentus*), and "Endeavour" to endeavor prawns (*Metapenaeus* spp.) as a group. (*A*) The recent past and projected tiger prawn fishery effort for the 2 fishing fleets. (*B*) The catch by prawn species. (*C*) The spawning stock size in a year relative to that at MSY. (*D*) Total annual profit.

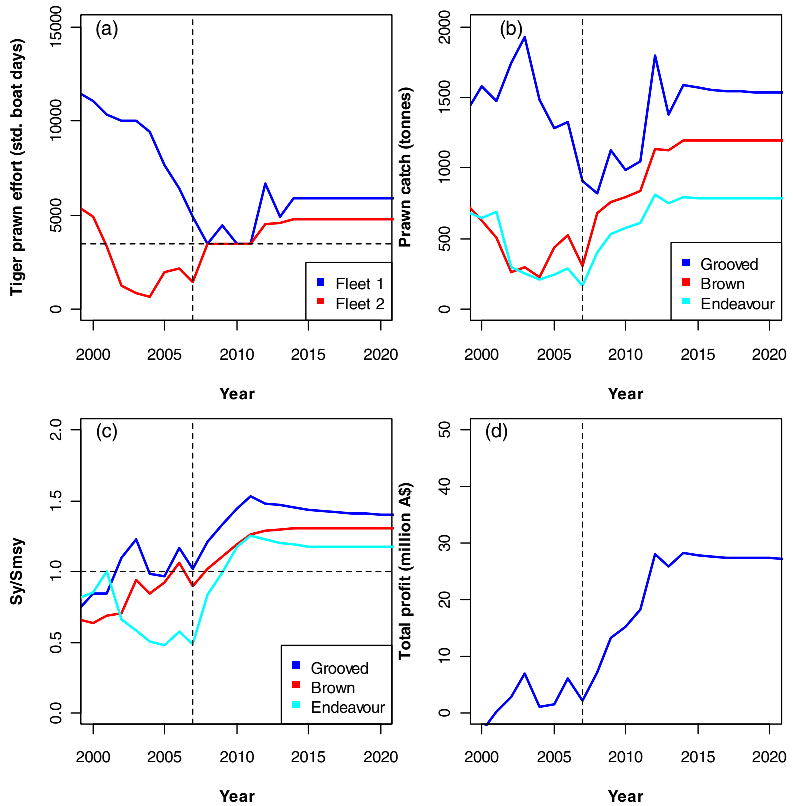

Fig. S5. Nonnegative profit constraint allowing vessel numbers to vary over the transition period. This model allows the fleet to overcome the maximum effort constraint by introducing additional vessels to the fleet. This option currently is not available to the industry, given the limit on the number of vessel licenses, but illustrates the potential benefits of issuing (or auctioning) additional licenses. The vertical dotted lines delineate the last year of actual data (2007). "Grooved" refers to grooved tiger prawn (*Penaeus semisulcatus*), "Brown" to the brown tiger prawn (*Penaeus esculentus*), and "Endeavour" to endeavor prawns (*Metapenaeus* spp.) as a group. (*A*) The recent past and projected tiger prawn fishery effort for the 2 fishing fleets. (*B*) The catch by prawn species. (*C*) The spawning stock size in a year relative to that at MSY. (*D*) Total annual profit.

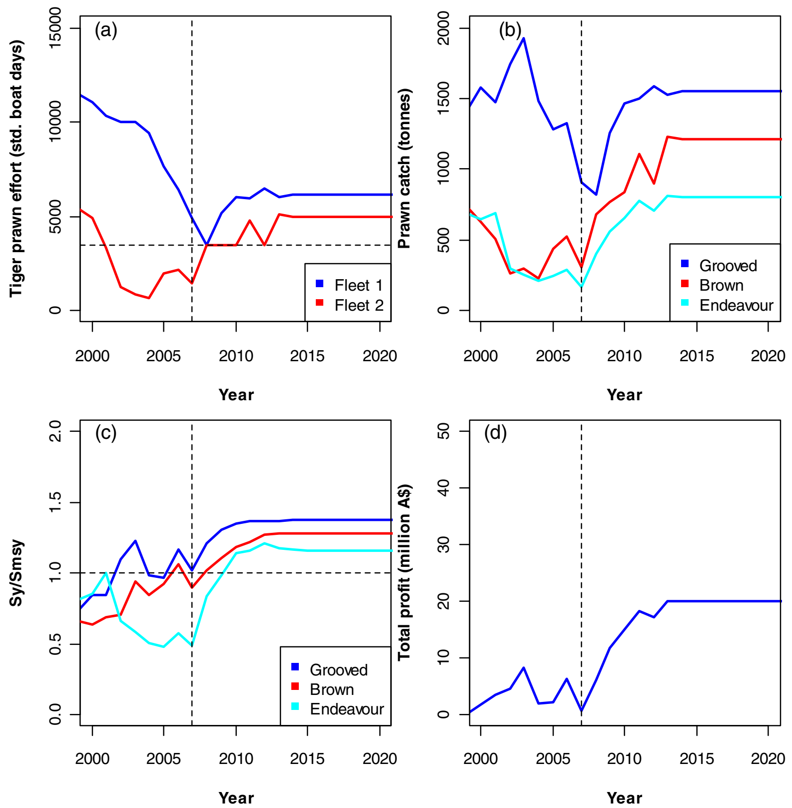

Fig. S6. Nonnegative profit constraint assuming costs and prices are constant. By not using forecasted cost and prices, the estimated effort levels, profits, and catches are lower than otherwise might occur. Ignoring expectations about changes in prices and costs therefore may lead to suboptimal management. The vertical dotted lines delineate the last year of actual data (2007). "Grooved" refers to grooved tiger prawn (*Penaeus semisulcatus*), "Brown" to the brown tiger prawn *(Penaeus esculentus*), and "Endeavour" to endeavor prawns (*Metapenaeus* spp.) as a group. (*A*) The recent past and projected tiger prawn fishery effort for the 2 fishing fleets. (*B*) The catch by prawn species. (*C*) The spawning stock size in a year relative to that at MSY. (*D*) Total annual profit.

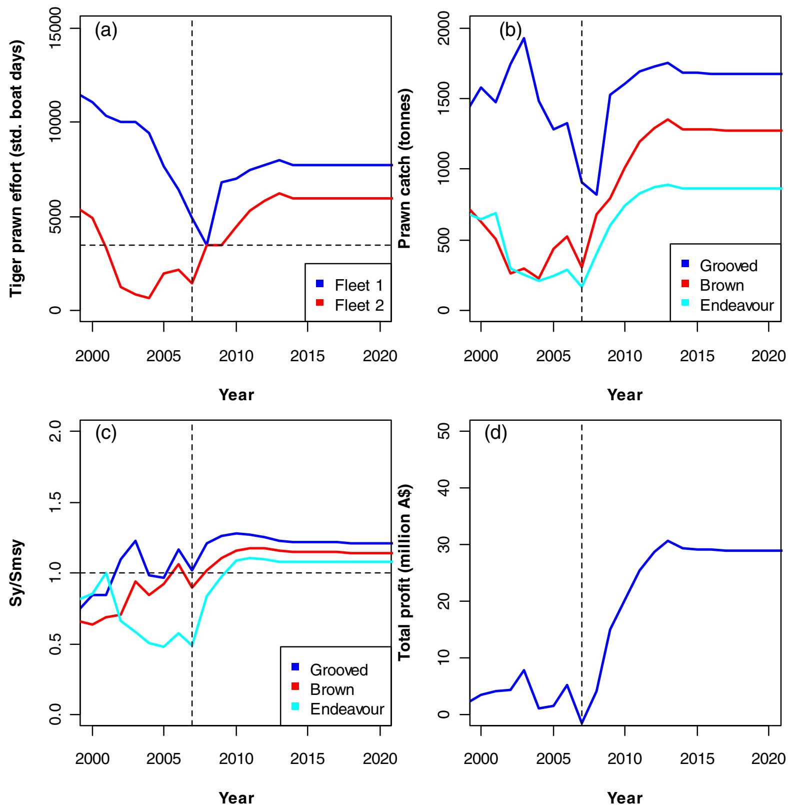

Fig. S7. Nonnegative profit constraint with quasi-fixed costs treated as fixed rather than variable. This model reduced the cost per day fished but increased the total fixed costs. The vertical dotted lines delineate the last year of actual data (2007). "Grooved" refers to grooved tiger prawn (*Penaeus semisulcatus*), "Brown" to the brown tiger prawn *(Penaeus esculentus*), and "Endeavour" to endeavor prawns (*Metapenaeus* spp.) as a group. (*A*) The recent past and projected tiger prawn fishery effort for the 2 fishing fleets. (*B*) The catch by prawn species. (*C*) The spawning stock size in a year relative to that at MSY. (*D*) Total annual profit.

Table S1. The parameters of the profit equation

Parameter	Unit	Value
Average price of Tiger prawns (grooved and brown)	\$/kg	19.85
Average price of Endeavor prawns	\$/kg	12.80
Labor share of revenue, c_L	rate	0.23
Unit cost of other costs, c_M	\$/kg	0.98
Unit cost of repairs, maintenance ,and gear, c_K	\$/day	497
Base unit cost of fuel, c_F	\$/day	1,824
Annual vessel costs, W_y	\$/vessel	56,116
Annual cost of repairs, maintenance, and gear	\$/vessel	89,831
Average of value of capital, K_y	S/vessel	727,184
Opportunity cost of capital, *o*	rate	0.05
Economic depreciation rate, *d*	rate	0.037

All monetary values are in Australian dollars and relate to 2008.

Table S2. Forecasted changes in real prawn prices and fuel costs (2008 values)

Year	Fuel cost ($/day)	Price index
2008	1,833	1.000
2009	1,650	1.021
2010	1,619	1.042
2011	1,565	1.068
2012	1,525	1.093
2013	1,517	1.116
2014	1,517	1.120

Real fuel prices were assumed to follow a pattern similar to the Australian Farm Fuel Price index (1). Real price forecasts for prawns over the period 2008–2014 were based on an otherwise standard autoregressive moving average model, in which the main drivers were the exchange rate forecasts (1) and projected increases in world output (including aquaculture supplies in Asia). The price index was assumed to apply equally to all prawn species.

1. Australian Bureau of Agricultural and Resource Economics (2008) *Australian Commodity Statistics 2007* (Australian Bureau of Agricultural and Resource Economics, Canberra, Australia).