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Supplementary Material

Appendix S1. The biological component of the operating model

The dynamics of each stock of each prawn species are governed by the equation

$$\underline{N}_{k,v,y,w+1,s} = \mathbf{X}_{k,s}\mathbf{H}_{k,v,y,w}\underline{N}_{k,v,y,w,s} + 0.5\,\underline{R}_{k,v,y,w+1}, \quad \text{(S1)}$$

where $N_{k,v,y,w,s,l}$ is the number of prawns of sex *s* and size class *l* (1-mm size classes between lengths of 15 and 55 mm) in stock *v* of species *k* alive at the start of week *w* of year *y* ($\underline{N}_{k,v,y,w,s}$ denotes the vector of numbers by length), $\mathbf{H}_{k,v,y,w}$ is the survival matrix for stock *v* of species *k* during week *w* of year *y* (a diagonal matrix with $e^{-Z_{k,v,y,w,l}}$ on the diagonal), $\mathbf{X}_{k,s}$ is the size-transition matrix (the probability of an animal of species *k* and sex *s* in size class *i* growing into size class *j*) during a week, $\underline{R}_{k,v,y,w}$ is the vector by length of recruitment to stock *v* of species *k* during week *w* of year *y* (the sex ratio of the recruits is assumed to be 50 : 50 in the absence of data to the contrary).

$$R_{k,v,y,w,l} = \begin{cases} \alpha_{k,w}\, R_{k,v,\tilde{y}(y,w)} & \text{if } l = 15\text{mm} \\ 0 & \text{otherwise} \end{cases} . \quad \text{(S2)}$$

$\alpha_{k,w}$ is the expected fraction of the annual recruitment for species *k* that occurs during week *w*, $R_{k,v,\tilde{y}}$ is the recruitment to stock *v* of species *k* during 'biological year' $\tilde{y}$, and $\tilde{y}(y,w)$ is the biological year corresponding to week *w* of year *y*, as follows:

$$\tilde{y}(y,w) = \begin{cases} y & w < 40 \\ y+1 & \text{otherwise} \end{cases} . \quad \text{(S3)}$$

The operating model considers five regions (see fig. 5 of Dichmont et al. 2006*a*). However, the abundance of the various species spatially is such that only four regions are considered for each species so each stock is associated with a region, except when the region contains none of the species concerned. It is assumed that prawns do not move among the regions.

Total mortality, $Z_{k,v,y,w,l}$, on animals of stock *v* of species *k* in size class *l* during week *w* of year *y* is given by

$$Z_{k,v,y,w,l} = M_k + F_{k,v,y,w,l}, \quad \text{(S4)}$$

where M_k is the average (over week) weekly instantaneous rate of natural mortality for species *k* (assumed to be independent of sex, length and time), and $F_{k,v,y,w,l}$ is the fishing mortality on prawns of species *k* in size class *l* during week *w* of year *y*. Equation S3 implies that the biological year ranges from week 40 (roughly the start of October) to week 39 (roughly the end of September), whereas Eqn S2 implies that recruitment contributes only to the first size class in the model. Growth is assumed to be time-invariant (seasonally and annually), and the seasonal recruitment pattern (defined by $\alpha_{k,w}$) is assumed to be the same each year in the absence of data to parameterise seasonal growth and within-year recruitment patterns.

The spawner-stock size index for stock *v* of species *k* during calendar year *y*, $\tilde{S}_{k,v,y}$, accounts for the contribution to egg production integrated over the year, accounting for the proportion of prawns that spawn each year, and is computed using the equation

$$\tilde{S}_{k,v,y} = \sum_w \beta_{k,w} \sum_l \omega_{k,l} \frac{1-\mathrm{e}^{-Z_{k,v,y,w,l}}}{Z_{k,v,y,w,l}} N_{k,v,y,w,\mathrm{fem},l}, \quad \text{(S5)}$$

where $\beta_{k,w}$ is proportional to the quantity of spawning by individuals of species *k* during week *w*, and $\omega_{k,l}$ is the proportion of females (fem) of species *k* in size class *l* that are mature.

Catch is a function of weekly stock size, the level of fishing effort expended each week, the relative fishing power of the fleet in that year (fishing power measures relative changes in the efficiency of the fleet over time), the relative availability of each species in each week, the size selectivity of the fishing gear and the catchability of the species. The fishing mortality on animals of species *k* in size class *l* during week *w* of year *y*, $F_{k,v,y,w,l}$, is given by

$$F_{k,v,y,w,l} = A_{k,w}\, \gamma_{y,w}\, S^F_{k,l}\, (q^G_k E^G_{v,y,w} + q^B_k E^B_{v,y,w}), \quad \text{(S6)}$$

where $E^G_{v,y,w}$ and $E^B_{v,y,w}$ are the levels of effort in the region in which stock *v* is found during week *w* of year *y* targeted at *P. semisulcatus* (*G*) and *P. esculentus* (*B*), respectively, q^G_k and

q_k^B are the catchability coefficients for species *k* for the fishing strategies targeting *P. semisulcatus* and *P. esculentus*, respectively, $A_{k,w}$ is the relative availability of animals of species *k* during week *w*, $\gamma_{y,w}$ is the relative efficiency of the two fishing strategies during week *w* of year *y*, and $S_{k,l}^F$ is the selectivity of the fishery on animals of species *k* in size class *l*.

The catch (kg) of prawns of species *k* and size class *l* during week *w* of year *y* ($Y_{k,v,y,w,l}$) is given by

$$Y_{k,v,y,w,l} = \sum_s \tilde{w}_{k,s,l} \tfrac{F_{k,v,y,w,l}}{Z_{k,v,y,w,l}} N_{k,v,y,w,s,l}(1-\mathrm{e}^{-Z_{k,v,y,w,l}}) \quad , \text{(S7)}$$

where $\tilde{w}_{k,s,l}$ is the mass of an animal of species *k* and sex *s* in size class *l*.

Historical (i.e. pre-2010) recruitment is estimated when fitting the operating model to the data (see Punt *et al*. 2010 for details), whereas future recruitment is generated from a Ricker stock-recruitment relationship, i.e.

$$R_{k,v,\tilde{y}} = \tilde{\alpha}_{k,v}\, \tilde{S}_{k,v,y} e^{-\tilde{\beta}_{k,v}\tilde{S}_{k,v,y}} e^{\varepsilon_{k,v,y}-\sigma^2_{k,v,y}/2}$$

$$\varepsilon_{k,v,y} = \rho_{k,v}\varepsilon_{k,v,y-1} + \sqrt{1-\rho^2_{k,v}}\eta_{k,v,y} \quad \eta_{k,v,y} \sim N(0;\sigma^2_{k,v,y})$$

$$\varepsilon_{k,v,y} = \rho_{k,v}\varepsilon_{k,v,y-1} + \sqrt{1-\rho^2_{k,v}}\eta_{k,v,y} \quad \eta_{k,v,y} \sim N(0;\sigma^2_{k,v,y}) \quad , \text{(S8)}$$

where $\tilde{\alpha}_{k,v}, \tilde{\beta}_{k,v}$ are the parameters of the stock-recruitment relationship, $\sigma_{k,v,y}$ determines the extent of variation about the stock-recruitment relationship, and $\rho_{k,v,y}$ determines the extent of temporal auto-correlation in the deviations about the stock-recruitment relationship.

The values for the parameters of the operating model (Table S1) are either pre-specified on the basis of auxiliary information or sampled from a posterior distribution obtained by fitting the operating model to the data for each stock of each species. Punt *et al*. (2010) listed the likelihood function and penalty terms on which the estimation is based. Owing to lack of data for some regions, the survey and fishery selectivity patterns, along with the size-transition matrix are not estimated for each region, but are rather set to the size-transition matrix and selectivity patterns obtained by fitting the operating model to data aggregated over the entire NPF.

Table S1. Parameters of the population model for each species

Parameter	Treatment
Recruitment and spawning	
Relative weekly recruitment, α_w	Estimated (by month)
Relative weekly spawning, β_w	Based on auxiliary analyses (see fig 2*a* of Punt *et al*. 2011)
Maturity-at-length, κ_l	Based on auxiliary analyses (see fig. 2*b* of Punt *et al*. 2011)
Stock–recruitment relationship parameters, $\tilde{\alpha}$, $\tilde{\beta}$	Estimated
Temporal correlation in recruitment, ρ_r	Estimated
Variance in recruitment, σ_r	Estimated
Effort – fishing-mortality related	
Catchability, *Penaeus semisulcatus* strategy, q^G ($\times 10^{-5}$)	8.8, 0.792, 8.320[A]
Catchability, *P. esculentus* strategy, q^B ($\times 10^{-5}$)	1.0648, 8.8, 20.4996[A]
Relative weekly availability, A_w	Based on auxiliary analyses (see fig. 2*c* of Punt *et al*. 2011
Relative efficiency, $\gamma_{y,w}$	Based on auxiliary analyses (see fig. 2*d* of Punt *et al*. 2011)
Biological parameters	
Growth-curve parameters	Estimated
Length–weight regression	Based on auxiliary analyses (see fig. 2*e*, *f* of Punt *et al*. 2011)
Natural mortality, M	0.045 week^{-1}
Selectivity	
Fishery	Estimated (logistic function of length)
Recruitment survey	Estimated (logistic function of length)
Spawning survey	Estimated (logistic function of length)

[A]*P. semisulcatus*, *P. esculentus*, *M. endeavouri*.

Appendix S2. Generation of future data

The data potentially available for assessment purposes include catch and effort by week and region, survey indices of abundance (spawning and recruitment), the size composition of the survey data, data on growth increments from tagging, and the size composition of the catch. Data on prices and costs are needed to apply the bio-economic model. The catch and effort data are assumed to be known exactly (no measurement error) and it is assumed that there will be no additional tagging data in the future (the last tagging program took place during the 1980s).

The future recruitment and spawning survey indices are assumed to be computed for the entire NPF and are generated using the equation

$$I^S_{k,y} = q^S_k \sum_v \sum_l S^S_{k,l} \frac{1-\mathrm{e}^{-Z_{k,v,y,w,l}}}{Z_{k,v,y,w,l}} N_{k,v,y,w,l}\, e^{\varepsilon^S_{k,y}} \qquad \varepsilon^S_{k,y} \sim N(0;\tilde{\sigma}^2_{k,y}) \quad \text{(S9)}$$

where $I^S_{k,y}$ is the survey index for species k during year y (where the survey takes place during week w), $\tilde{\sigma}^S_{k,y}$ the standard error of the logarithm of $I^S_{k,y}$, i.e. $\tilde{\sigma}^2_{k,y} = (\sigma^E_k)^2 + (\sigma^S_{k,y})^2$,

$\sigma^S_{k,y}$ the standard error of the logarithm of $I^S_{k,y}$ attributable to sampling error, σ^E_k a measure of the variation caused by sources other than sampling for species *k*, q^S_k is the survey catchability for species *k*, and $S^S_{k,l}$ is the selectivity of the survey gear on prawns of species *k* in size class *l*.

The size-composition data (fishery and survey) are assumed to be multinomially distributed about the operating model values. The survey size-composition data relate to the weeks during which the surveys are assumed to occur (weeks 6 and 34 of the year), whereas catch size-composition data are assumed to be collected during weeks 34, 38 and 41. Table S2.1 lists the effective sample sizes for the survey and fishery size-composition data (set to 55% of the average actual sample size – Punt *et al*. 2010).

The price data consist of estimates of prices for the current year and forecasted prices. The approach used to account for errors when estimating prices assumes that the estimates of price for the most recent year are most precise, whereas forecasted prices are subject to ever-increasing amount of uncertainty, i.e.

$$v^{obs}_{k,y,w,l} = v_{k,y,w,l} e^{\zeta_y - \sigma^2_\xi/2} e^{\xi_y (y-y_c)} \quad \zeta_y \sim N(0;\sigma^2_\zeta); \xi_y \sim N(0;\sigma^2_\xi) , \quad \text{(S10)}$$

where $v^{obs}_{k,y,w,l}$ is the predicted average price per kg for animals of species *k* in size class *l* during week *w* of year *y* (i.e. that used when computing the TACs), σ_ξ quantifies the extent of error for the prices in the first year of the forecast, σ_ζ quantifies the extent to which errors when predicting prices change depending on the length of the forecast, and y_c is the first forecast year (see Table S3). A similar approach is used to forecast cost parameters.

Table S2. Effective sample sizes when generating future length-composition data

Survey type	Fishery	Spawning survey	Recruitment survey
Effective sample size	131	262	230

Table S3. Variability of the economic-input parameters used when computing total allowable catches in the bio-economic model (ABARE data; Sean Pascoe, pers. comm.)

Parameter	CV of price	CV of price trend	CV of cost	CV of cost trend
Values	0.137	0.195	0.131	0.305

Appendix S3. Supplementary figures

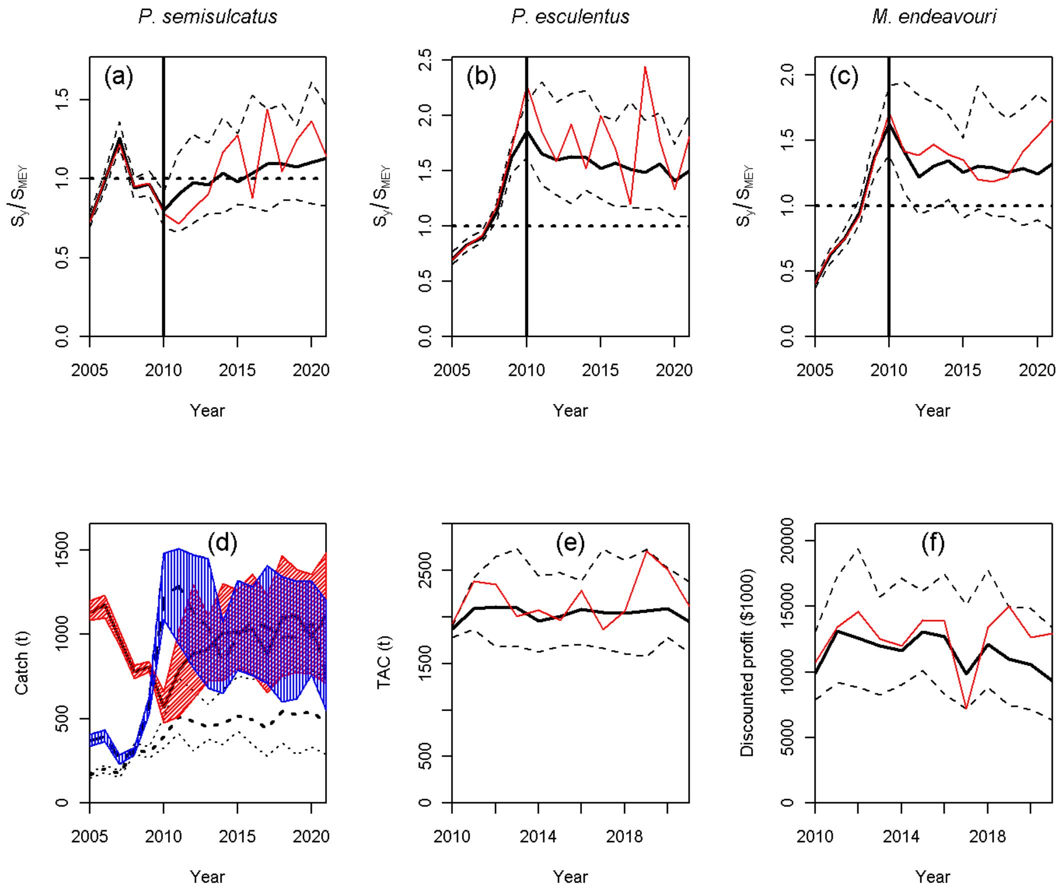

Fig. S1. Time trajectories (medians, 90% intervals and 5th replicate in grey/red) of spawning-stock size relative to S_{MEY} (see text for definition) by species (*a*, *b*, *c*), time trajectories of catch (*d*, red/angled, blue/vertical and blank-shaded areas represent *Penaeus semisulcatus*, *P. esculentus* and *Metapenaeus endeavouri*, respectively), total allowable catches (*e*) and discounted profit (*f*). The results in this figure are based on Scenario B (see text for definition).

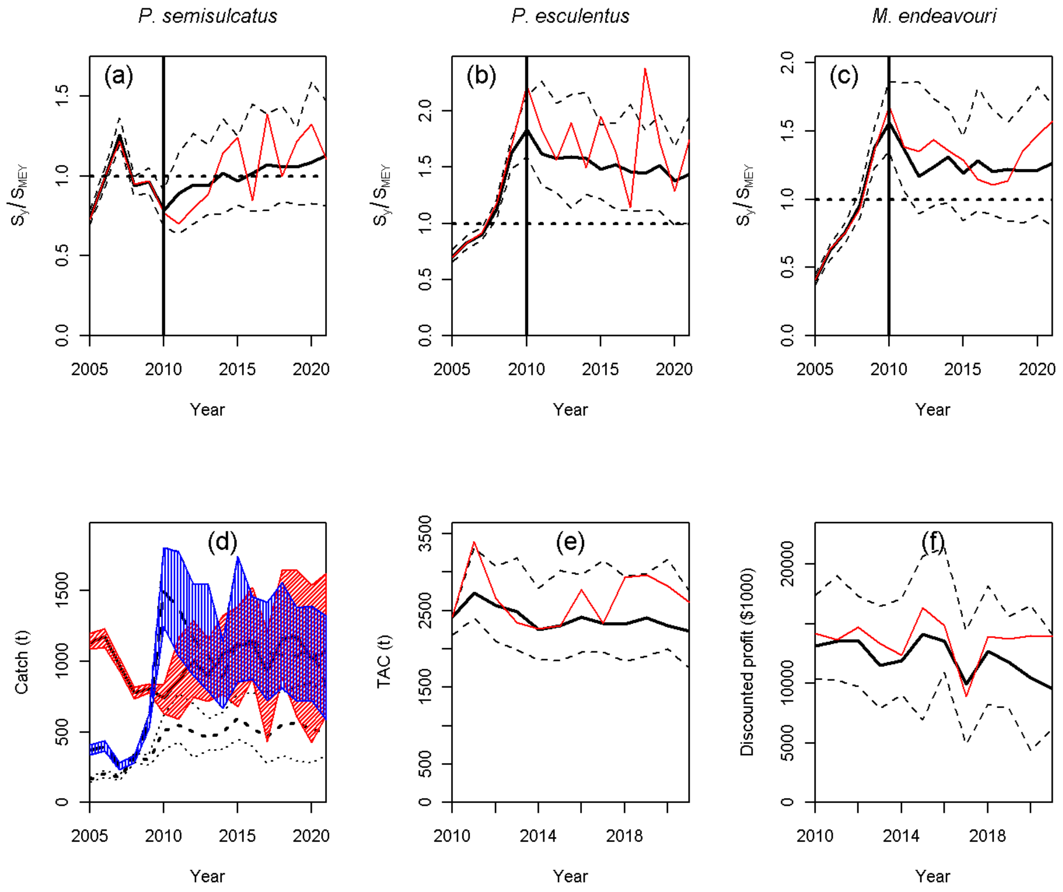

Fig. S2. Time trajectories (medians, 90% intervals and 5th replicate in grey/red) of spawning-stock size relative to S_{MEY} (see text for definition) by species (*a*, *b*, *c*), time trajectories of catch (*d*, red/angled, blue/vertical and blank-shaded areas represent *Penaeus semisulcatus*, *P. esculentus* and *Metapenaeus endeavouri*, respectively), total allowable catches (*e*) and discounted profit (*f*). The results in this figure are based on Scenario C (see text for definition).

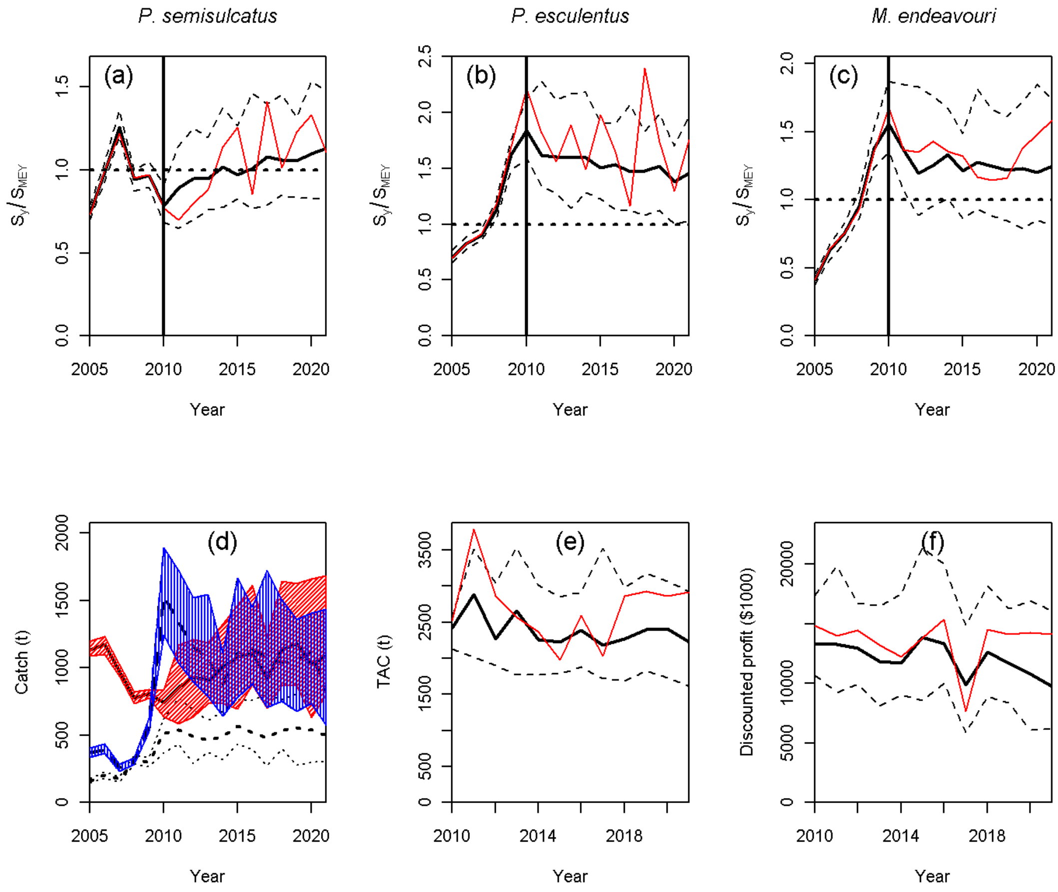

Fig. S3. Time trajectories (medians, 90% intervals and 5th replicate in grey/red) of spawning-stock size relative to S_{MEY} (see text for definition) by species (*a*, *b*, *c*), time trajectories of catch (*d*, red/angled, blue/vertical and blank-shaded areas represent *Penaeus semisulcatus*, *P. esculentus* and *Metapenaeus endeavouri*, respectively), total allowable catches (lower centre panel) and discounted profit (lower right panel). The results in this figure are based on Scenario D (see text for definition).

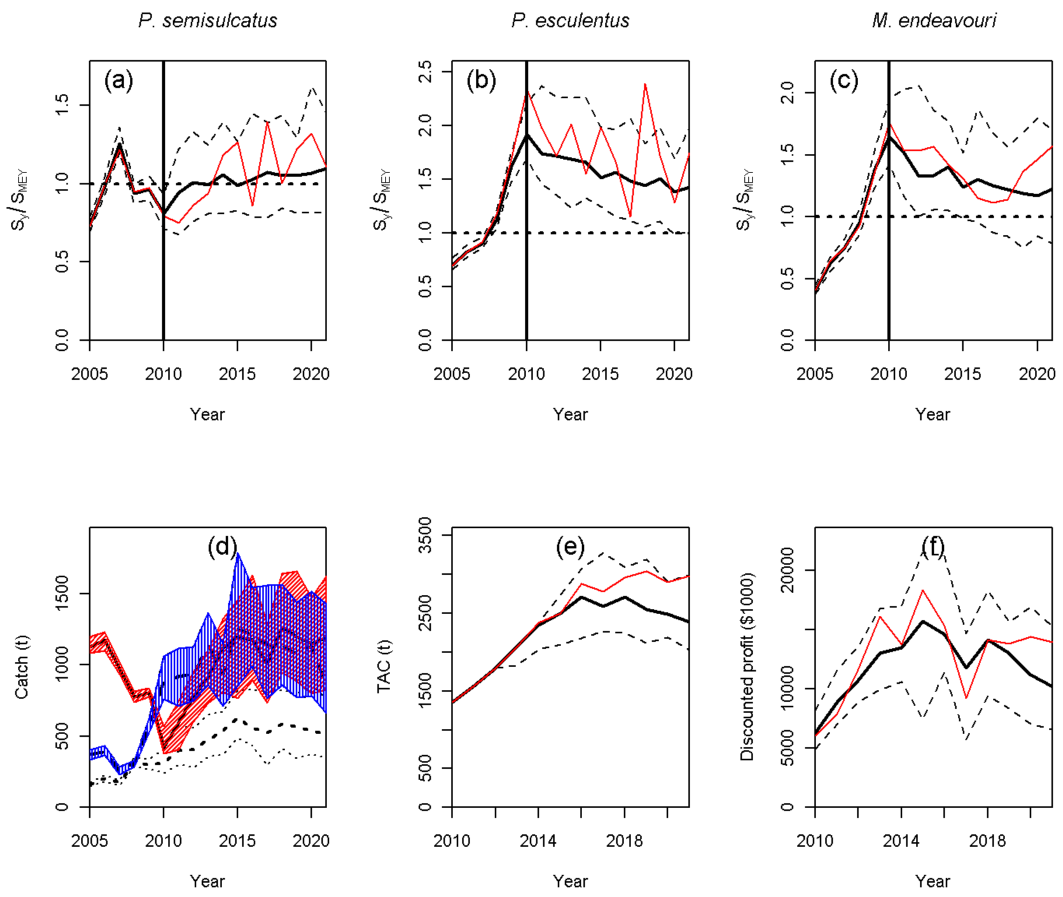

Fig. S4. Time trajectories (medians, 90% intervals and 5th replicate in grey/red) of spawning-stock size relative to S_{MEY} (see text for definition) by species (*a*, *b*, *c*), time trajectories of catch (*d*, red/angled, blue/vertical and blank-shaded areas represent *Penaeus semisulcatus*, *P. esculentus* and *Metapenaeus endeavouri*, respectively), total allowable catches (*e*) and discounted profit (*f*). The results in this figure are based on Scenario E (see text for definition).