18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Can spawning closures allow more fishing capacity in the Torres Strait Prawn Fishery? : a simulation study

Mai Tanimoto, Michael O'Neill, and Clive Turnbull

Queensland Primary Industries and Fisheries
Department of Employment, Economic Development and Innovation
Email: Mai.Tanimoto@dpi.qld.gov.au

Abstract: The Torres Strait Prawn fishery is a multi-species fishery harvesting in the order of 1300t of brown tiger prawns (*Penaeus esculentus*) and blue endeavour prawns (*Metapenaeus endeavouri*) annually. The fishery is primarily controlled by total allowable effort. This was recently reduced from 13570 vessel nights to 9200, 75% of which is allocated to Australian vessels (6867 nights). With recent economic downturns the size of the active fleet has dropped from 74 to 37 vessels and the observed fishing effort from ~10000 to ~4000 nights. Industry has raised an urgent need for new spatial management to allow more fishing capacity without compromising biological as well as economical sustainability of the fishery.

A multi-species monthly spatially explicit simulation model (TSPFsim) was developed in order to investigate the feasibility and effectiveness of an alternate management strategy: a closure designed to protect spawning tiger prawns. This would close fishing in the deeper eastern sector of the trawl ground when effort reaches a trigger level of nights fished. The model divided the stock into multiple spatial regions and tracked the regional population dynamics by applying growth, mortality, recruitment and movement among these regions. Movement was implemented using a spatial transition matrix. The transition probabilities were estimated from tag-recapture data. Temporal and spatial levels of fishing effort were simulated based on a weighted combination of the historical fishing pattern and attractiveness ($ value per unit of effort) of fishing in each region.

A number of key uncertainties were considered including: temporal and spatial variations in recruitment and fishing pattern (process error); and less-than-certain likelihood that fishers use up their allocated nights. The latter, known as implementation error, was related to simple economic indicators of fuel cost and prawn market prices.

The performance of the management scenarios was evaluated in terms of the risk that biomass is reduced below the level that can support MSY (i.e. B_{MSY}). Results showed that the tiger spawner closure would have a minimal impact on reducing this risk. Possible reasons for this are: 1) the proportion of spawners protected by this closure was relatively small; 2) the additional effort re-allocated into other regions after the closure was introduced countered the number of spawners protected in closed region; and 3) the effort trigger points were only activated in the latter part of the fishing season when the fishing pressure was relatively low. The results also showed that the effort trigger points were unlikely to be activated unless 100% usage of total allocated effort was assumed (no implementation error; fishers use up all their nights). Fishers do not currently fully utilize all their allocated nights due to the current general market conditions of low prawn prices and high fuel costs. Unless this situation changes, the triggers will unlikely be activated.

The results inform the long-term harvest strategy for the prawn fishery by providing stakeholders with estimates of the risk of the stock biomass falling below sustainable level for a range of fishing effort.

Keywords: *Management Strategy Evaluation, spatial management, simulation, age-length-based structure model, Torres Strait Prawn Fishery*

1. INTRODUCTION

The Torres Strait Prawn Fishery (TSPF) operates in the international waters of the Torres Strait Protected Zone (TSPZ) between Australia and Papua New Guinea (PNG). The fishery primarily harvests the brown tiger prawn (*Penaeus esculentus*) and the less valuable blue endeavour prawn (*Metapenaeus endeavouri*). The fishery is managed by input controls; primarily a Total Allowable Effort (TAE) along with gear/vessel restrictions and spatial/seasonal closures.

In 2006 the TAE was reduced from 13570 vessel nights to 9200 (≈ E_{MSY}), 75% of which is allocated to Australian vessels (6867 nights). The other 25% is for allocation to PNG vessels. In recent years PNG vessels have fished in neither the PNG nor Australian jurisdictions of the TSPZ.

During this decade *active* effort, which has always been below the TAE, decreased from 10000 to 4000 vessel nights. This was due to the combined effect of the reduced allocation to Australian vessels, a down turn in the economics of prawn trawling (e.g. declining prawn market price and increasing fuel costs) and a decrease in the infrastructure (supply barges and air services) that support this remote fishery. This decrease in the effort resulted in the annual harvest dropping from the average of 1,800t per annum during the 1990s to less than 1,300t in recent years. These changes led to an urgent demand for new alternative management to ensure biological as well as economical sustainability of the fishery. In July 2005, the Alternative Management Workshop was held and a number of spatial and temporal management options were discussed. One of the options suggested by the industry was the tiger spawner closure which was designed to protect spawning tiger prawns by closing the deeper eastern side of the fishing ground (Figure 1) once the fishing effort reaches a certain trigger point. We evaluated the effectiveness of the spawner closure and different levels of TAE by developing an open-loop simulation framework named TSPFsim.

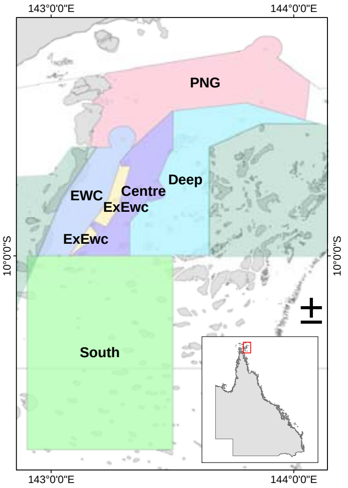

Figure 1 Six regions used in the simulation model: Region1 = East Warrior Closure (EWC); Region2= Extension of EWC (ExEwc); Region3= Centre; Region4=Deep; Region5=South; Region6=PNG. The outside of fishing ground was defined as Region7.

Table 1 Equations used in the operating model

Eq	Equations
(1)	$N_{l,a,r,sp,s}(1)=\{N^{*}{}_{l,a,sp,s}sNp_{r,sp}$
(2)	$N_{l,a,r,sp,s}(t)=\begin{cases}0.5R_{y,sp}P_{l,a,=A_{\min},sp,s}\Phi_{m,sp}sRp^{rnd}_{r,sp} & \text{for } a=A_{\min}\\ P_{l,l'}N_{l',a-1,r,sp,s}(t-1)e^{-(M+F_{r,sp})}T_{r,r'} & \text{for } a=A_{\min+1},\ldots,A_{\max}\end{cases}$
(3)	$R_{y,sp}=\begin{cases}\dfrac{E^{*}{}_{sp}}{\alpha_{sp}+\beta_{sp}E^{*}{}_{sp}} & \text{for } y=1\\ \dfrac{E_{y-1,sp}}{\alpha_{sp}+\beta_{sp}E_{y-1,sp}} & \text{for } y=2,\ldots,10\end{cases}$
(4)	$E_{y}=\sum_{m=7}^{12}\sum_{r=1}^{7}\sum_{l=L_{\min}}^{L_{\max}}\sum_{a=A_{\min}}^{A_{\max}}N_{l,a,r,sp,s=1}mat_{l,sp,m}fec_{l,sp}$
(5)	$bio_{sp}(t)=\sum_{s=1}^{2}\sum_{r=1}^{7}\sum_{l=L_{\min}}^{L_{\max}}\sum_{a=A_{\min}}^{A_{\max}}N_{l,a,r,sp,s}(t)W_{l,sp,s}$
(6)	$F_{r,sp}(t)=eff_{r}(t)q_{r,sp}(t)$
(7)	$q_{r,sp}(t)=\dfrac{q^{*}{}_{sp}\ fp^{rnd}{}_{y,sp}}{\dfrac{a_{r}}{A}}$ for $t=1,\ldots,120;\ A=\sum_{r=1}^{6}a_{r}$
(8)	$eff_{r}(t)=E^{TAE}err_{y}^{imp}\varphi_{m}^{rnd}(t)\varpi_{r}(t)$
(9)	$\varpi_{r}(\mathrm{t})=\begin{cases}eff_{r}^{hist} & \text{for } month(t)=Mar\\ \left[\theta eff_{r}^{hist}+(1-\theta)\Lambda_{r}(t-1)\right]\psi_{r}(\mathrm{t}) & \text{for } month(t)=Apr-Nov\end{cases}$
(10)	$\Lambda_{r}(t)=\sum_{sp=1}^{2}V_{r,sp}^{\$}(t)\Big/eff_{r}(t)$
(11)	$V_{r,sp}^{\$}(t)=\sum_{l=L\min}^{L\max}C_{l,r,sp}(t)p_{l,sp}^{\$}$
(12)	$C_{l,r,sp}(t)=\dfrac{F_{r,sp}}{F_{r,sp}+M}bio_{l,r,sp}\left(1-e^{-(M+F_{r,sp})}\right)$

2. METHOD

2.1. General Structure

The structure of TSPFsim is similar to that of Management Strategy Evaluation (MSE) widely adopted in many fisheries (De Oliveira, Kell *et al.* 2008; Dichmont, Deng *et al.* 2006; Kell, Pastoors *et al.* 2005; Kell, Pilling *et al.* 2005; Pelletier and Mahevas 2005). It has an *operating model* which mimics the population dynamics of the stock, taking account of various source uncertainties; and a *fishery sub-model*, which dynamically simulates fishing behaviours. The main difference is that TSPFsim is an open-loop model which applies fixed management control throughout the simulation period, rather than allowing a model to alter harvest control rules depending on the management decision rules incorporated in the simulation loop (closed-loop simulation). Although TSPFsim incorporated potential fishing impact from PNG fleets, only Australian components are presented herein. The model was developed using MATLAB (Math Works 2008).

2.2. Operating Model

The key input parameters (catchability q, spawner-recruitment relationship) were estimated from a monthly age- and size-structured stock assessment model. The model was developed for each species separately (single-species model) and has no spatial component. Each model was fitted to the respective standardized catch rate data for 1980 to 2003. The model optimization was conducted by Bayesian estimation methods using a Monte Carlo Markov Chain (MCMC) algorithm. To incorporate parameter uncertainties 1000 combinations were sampled from their resulting posterior distributions and imported into TSPFsim.

Table 2 Definitions of symbols

Notation	Definition
a	Age class in months ($A_{\min}$,=6; $A_{\max}$ = 24)
l, l'	Size class in months ($L_{\min}$,=15; $L_{\max}$ =50)
s	Sex indices (1 = female, 2 = male)
sp	Species indices (1 =tiger 2 = endeavour)
r, r'	Region number {1,…,7}
$N^{*}_{l,a,sp,s}$	The initial number of prawns of age class *a* in size class *l* for each species and sex at the beginning of simulation. Estimated from the size and age structured model fitted to the historical data.
$sNp_{r,sp}$	The fraction of total abundance of species *sp* in region *r*. Estimated from the 2007 survey data.
$N_{l,a,r,sp,s}$	The number of prawns of age class *a* in size class *l* in region *r* for each species and sex
$P_{l,a=A\min,sp,s}$	the fraction of prawns in length class *l* for the first age class ($A_{\min}$) for species *sp* and sex *s*
$R_{y,sp}$	Annual recruitment of species *sp* in year *y*
$sRp^{rnd}_{r,sp}$	The fraction of prawns recruiting into region *r* for species *sp*
$P_{l,l'}$	the fraction of fish in size class *l'* that grow into size class *l* in one month
M	Instantaneous natural mortality (0.2 month^{-1}); Watson and Turnbull (1993)
$F_{r,sp}$	Instantaneous fishing mortality in region *r* for species *sp*
$T_{r,r'}$	The fraction of prawns in region *r*' moving into region *r* in one month time step
$\Phi_{m,sp}$	Monthly proportion of annual recruits in month *m* for species *sp*
α_{sp}, β_{sp}	Beverton-Holt spawner recruitment parameters for species *sp*
E^{*}_{sp}	The initial number of spawners for species *sp*. Estimated from the size and age structured model fitted to the historical data.
$E_{y,sp}$	Annual spawners of species *sp* in year *y*
$fec_{l,sp}$	Fecundity at length *l* for species *sp*; Dall *et al.* (1990)
$mat_{l,sp,m}$	Seasonal proportion mature at length *l* in month *m* for species *sp*
$W_{l,sp,s}$	Length-weight relationships for species *sp* and sex *s*
bio_{sp}	Monthly biomass (kg) of species *sp*
$eff_{r}(t)$	*Active* monthly effort used in region *r* at time *t*
$q_{r,sp}$	The catchability coefficient in region *r* for species *sp*
q^{*}_{sp}	The overall catchability coefficient for species *sp*
$fp^{rnd}_{y,sp}$	Fishing power for species *sp* in year *y*
a_{r}	Area in region *r*
A	Total fishing area (for *r* = 1,…,6)
E^{TAE}	Annual total allowable effort (TAE)
err^{imp}_{y}	fraction of TAE actually used by fishers in year *y*
$\varphi^{rnd}_{m}(t)$	Monthly proportion of fishing effort in time *t*
$\varpi_{r}(t)$	Fraction of monthly fishing effort spent in region *r* in time *t*
eff^{hist}_{r}	Fraction of historical fishing effort spent in region *r* based on the VMS data
θ	Weighting coefficient (= 0.5)
Λ_{r}	Attractiveness of region *r*
$\psi_{r}(t)$	the logical index vector defining regions open for fishing in time *t* (0 = closed, 1 = open)
$V^{\$}_{r,sp}$	Value of production of species *sp* in region *r*
$C_{l,r,sp}(t)$	Catch from length class *l* for species *sp* in region *r* at time *t*
$p^{\$}_{l,sp}(t)$	Market price of prawns ($ per kg) at length class *l* for species *sp*

Table 1 lists the equations used in the operating model; the parameter definitions are listed in Table 2. Simulation was initialized by allocating the total prawn abundance (estimated in the last year of the age-length structured model) into each region (Eq (1)). Note that prawn biomass was above B_{MSY} for both species at the start of future projection. The dynamic of the population followed Eq (2). Monthly recruitment was calculated by the product of the within-fishing-year recruitment pattern ($\Phi_{m,sp}$) and the total number of prawns recruiting in the fishing year (R_y) (Dichmont, Haddon *et al.* 1999), which is calculated from the Beverton-Holt recruitment function (Eq (3)). The spawning stock numbers E_y were calculated as the sum of the products of the number of mature females and the fecundity index across the size and effective spawning months (Eq (4)). The model assumed the winter-spring spawners (July – Dec) are the major contributor to the recruitment for the following year. The proportion of mature females in each length class ($mat_{l,sp,m}$) varied seasonally, which was estimated from the survey data collected in 2007 (unpublished). The growth of prawns older than the recruitment age of six months was determined by a size-transition matrix ($\mathbf{P}_{l,l'}$), which was calculated from a normal probability density function for a prawn in size class *l'* growing into size *l* over one month period (Sadovy, Punt *et al.* 2007). The monthly movement between each region was governed by the movement transition matrix ($\mathbf{T}_{r,r'}$) which was estimated from the tag-recapture data collected in 1987, 89 and 90 (Mellors 1990; Watson and Turnbull 1993). The transition matrix allowed prawns to move from/to outside of the fishing ground (Region 7). Due to the limited tag-recapture data for endeavour prawns (n = 125 endeavour, n = 2433 for tiger), the movement transition matrix was estimated from species-pooled data (n = 2558).

2.3. Fishery Sub-Model

The fishery sub-model governs the temporal and spatial allocation of annual fishing effort and simulates instantaneous fishing mortality in each region. The regional monthly instantaneous fishing mortality was calculated as the product of monthly fishing effort allocated to each region and the respective regional catchability coefficient (Eq (6)). Note that fishing only occurs in Regions 1 – 6. The catchability coefficient was increased in each region by dividing overall q^*_{sp} (which was estimated from the non-spatial stock assessment model) by the proportion of area in each region (Eq (7)). This assumes a homogeneous distribution of prawns and fishing effort within each region. It was also adjusted for future increase in fishing power based on the forward projection of the historical fishing power trend (O'Neill and Turnbull 2006).

To distribute fishing effort in each month and region, the TAE was first multiplied by the implementation uncertainty err_y^{imp}, which is defined as the proportion of annual effort *actually* used by fishers (Section 2.4). This *active* effort was then allocated into each month and region by the temporal and spatial fishing patterns, φ_m^{rnd} and ϖ_r, respectively (Eq (8)). The temporal effort pattern was randomly simulated from the historical monthly effort trend between 2000 and 2007. The regional effort pattern was defined by the weighted combination of the historical regional fishing pattern (eff_r^{hist}) and attractiveness of fishing area (Λ_r) observed from the previous month (Eq (9)). These were weighted equally in the simulation ($\theta = 0.5$). The attractiveness of each region was defined as value per unit of effort accommodating the range of prawn price by size (Eq. (10); Table 3). The tiger spawner closure was triggered by the logical index vector Ψ_r. The resulting pattern was normalised to 1 (ϖ_r (t)/sum(ϖ_r (t)). At the opening of the fishing season (March), the fishing effort was allocated into each region solely based on the historical fishing pattern as there is no attractiveness estimates available during the seasonal closure (Dec – Feb).

Table 3 Price of prawns in each grade and equivalent size range (as of November 2008).

Grade	Tiger prawns		Endeavour prawns	
	CL (mm)	Price($/kg)	CL(mm)	Price($/kg)
U10	> 36	19.5	-	NA
10/20	29 - 36	17.5	> 29	9.5
21/30	23 - 28	14	25 - 28	7
30+	-	NA	20 - 24	6

2.4. Uncertainties

Key uncertainties that were considered in the analysis include: temporal and spatial variations in recruitment and fishing pattern (process error); uncertainties associated with management input control (TAE) and actual effort used by fishers (implementation uncertainty); and parameter uncertainties (*q*, spawner-recruitment parameters). Implementation uncertainty was important as the TSPF has never used all the allocated nights and the proportion of TAE actually used by the industry has been variable particularly in recent years. Since 2001 the *active* effort used by the industry has declined to less than 6000 nights per year in the last three years. The proportion of TAE used also declined to a low of 44% in 2005, but has increased to about 64 – 70% in 2006 and 2007 due to the reduction in TAE (from 13570 nights to 6867 for Australian vessels). The Torres Strait Prawn Fishery appears to be very sensitive to the market prawn price and fuel cost due to the remoteness of the fishing ground. There was a strong positive and negative correlation between the *active* fishing effort and tiger prawn price (ρ = 0.75) and fuel price (ρ = -0.89), respectively.

The implementation uncertainty was estimated by fitting a logistic regression model to the proportion of TAE fished between 1997 and 2007 and the respective average fuel and tiger

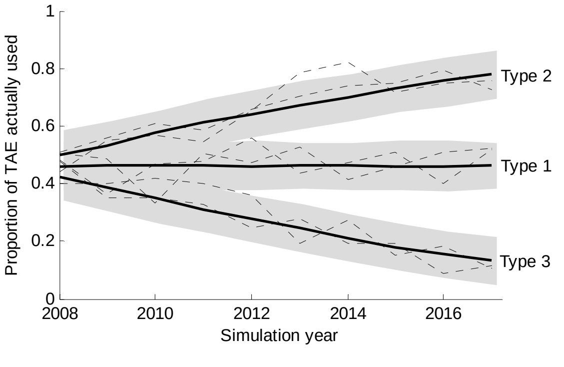

Figure 2 Three types of implementation uncertainty tested in TSPFsim. Each uncertainty was signified by the median (solid lines), two simulation replicates (broken lines), and 5th and 95th percentiles (shaded area). The fuel and tiger prawn price in 2017 was set to be: 142c, $14 (Type 1); 95c, $21 (Type 2); and 211c, $9 (Type 3), respectively. The error was based on TAE = 12000 nights.

prawn market prices. We then conducted 10-year future projections based on three hypothetical scenarios: 1) maintain fuel and tiger prawn price in 2007 (status quo); 2) fuel price goes down by 4% every year and prawn price up by 4% (optimistic); and 3) fuel up by 4% but prawn down by 4% (pessimistic) (Figure 2). The model allowed a 5% variation for each error type (~ 1900 nights).

2.5. Management Scenarios & Performance Measure

The management scenarios tested in TSPFsim are summarised in Table 4. Scenarios 1 – 4 were run for the risk analyses testing the impact of different levels of fishing effort on prawn stocks. Scenarios 5 and 6 apply the tiger spawner closure when effort reaches the trigger point of 9200 and 7000 nights respectively, but allows fishers to continue operating in outside the closure until effort reaches 2nd trigger point (12000 nights). Scenarios 1 - 6 assumed 100% effort usage. Implementation uncertainty was included in Scenario 7 - 9 with trigger effort at 7000 nights. We evaluated the performance of each management strategy in terms of: biomass ratio (B_{2017}:B_{MSY}); the probability that the biomass falls below B_{MSY} in the last year of the simulation projection (Pr($B_{2017}<B_{MSY}$)); median total harvest and median annual catch rate of the 10–year simulation period.

Table 4 Nine management scenarios tested in TSPFsim.

Scenario No.	Effort	Imp_error type	Trigger effort
1	4500	N/A	N/A
2	6867	N/A	N/A
3	9200	N/A	N/A
4	12000	N/A	N/A
5	12000	N/A	9200
6	12000	N/A	7000
7	12000	1	7000
8	12000	2	7000
9	12000	3	7000

2.6. Model Verification

The spatial and temporal distribution of total population and number of spawners simulated from TSPFsim was verified against the available monthly survey data collected in May, July, September and November 2007. Spatial interpolation analyses ("TopoToRaster" function in ArcView, ESRI) were conducted on the point survey data to estimate a spatial distribution of prawn abundance and spawning stocks. Prawn abundance and spawning stocks were estimated in terms of average catch rates (as number of prawns) and the number of ripe female per net, respectively.

3. RESULTS

Table 5 Relative performance measures for each species from the 10 year forward projection of each scenario. Harvest and annual CPUE were shown as relative proportion scaled to 1 at status quo (Scenario 2). Values within brackets indicated 90th percentiles.

Scenario	Tiger prawn				Endeavour prawn			
	Bratio (B_{2017}:B_{MSY})	Risk Pr($B_{2017}<B_{MSY}$)	Harvest	CPUE	Bratio (B_{2017}:B_{MSY})	Risk Pr($B_{2017}<B_{MSY}$)	Harvest	CPUE
1	1.37 (0.97:1.88)	0.07	0.91	1.24	1.51 (1.08:2.07)	0.02	0.85	1.22
2	1.1 (0.74:1.54)	0.36	1	1	1.25 (0.87:1.74)	0.15	1	1
3	0.91 (0.58:1.3)	0.65	1.02	0.84	1.05 (0.72:1.49)	0.42	1.07	0.83
4	0.74 (0.45:1.11)	0.87	1	0.69	0.85 (0.57:1.24)	0.77	1.08	0.67
5	0.74 (0.44:1.1)	0.87	1	0.68	0.85 (0.56:1.23)	0.78	1.08	0.67
6	0.74 (0.44:1.1)	0.87	1	0.68	0.84 (0.56:1.22)	0.78	1.08	0.67
7	1.23 (0.86:1.71)	0.17	0.96	1.13	1.38 (0.97:1.94)	0.06	0.93	1.11
8	0.92 (0.59:1.32)	0.62	1.01	0.93	1.06 (0.73:1.51)	0.4	1.04	0.94
9	1.88 (1.36:2.58)	0	0.75	1.39	1.91 (1.37:2.64)	0	0.66	1.34

As expected, prawn biomass in the last year of simulation (i.e. B_{2017}) was higher when effort was low and the risk of biomass falling below B_{MSY} increases as effort increases (Table 5). At 12000 nights of effort (Scenarios 4 - 6) there is no increase in tiger prawn harvest compared to status quo (Scenario2) whereas endeavour prawn harvest increased by 8%.

When a TAE of 12000 nights was fully fished every year of the virtual future projection (10 years), it was highly likely that the tiger prawn biomass in 2017 would be below B_{MSY}. However, if we consider the likelihood of industry utilising all of the TAE under current economic situation (Scenario 7), the risk of overfishing reduced significantly from 87% to 17%. If the economic situation becomes favourable to fishers in the future (continuous increase in prawn market price and decrease in fuel price; Scenario 8), the risk of overfishing increased every year with increasing *active* effort, reaching 62% probability in 2017. In contrast, under the most pessimistic situation (decline in prawn price and increase in fuel price), there was no risk of overfishing for both species (Scenario 9) as the median annual effort applied over 10 year projection was small (i.e. 3100 nights). As the *active* annual effort was always less than the trigger effort, the spawner closure was never implemented in Scenarios 7 and 9.

The risk curve and performance measures indicated that the endeavour prawn stock was relatively more resilient to the fishing pressure than tiger prawns (Table 5; Figure 3).

The performance measures estimated in Scenarios 4–6 were almost identical, indicating that the spawning closure had little effect on both tiger and endeavour prawn population dynamics (Table 5). When the trigger point was set to 9200 nights (Scenario 5), the deep water area (Region 4) was closed for fishing in August for 72% of the simulations and for 100% in September. When the trigger point was set at 7000 nights, the spawner closure was activated in June for about 31% of the simulations and for 100% in July. The number of tiger spawners in Region 4 compared to the spawner abundance estimated under no spatial management (Scenario 4) was 5% and 9% higher with 9200 and 7000 night trigger points respectively. On the regional scale, spawners in Region 4 contributed 12 – 13% of total spawners.

Fishing effort allocated in Region 4 was about 17% (2000 nights) each year with no spatial closure, 12% (1400 nights) for a 9200 trigger point closure, and 11% (1300 nights) with a 7000 trigger point closure. The fishery sub-model reallocated the majority of the redundant effort into Region 3 (45 – 60%) and Region 5 (30%).

The spatial and temporal trends of prawn density (prawn abundance per unit of area) were a closer fit to the survey data for tiger prawns than for endeavour prawns (Figure 4). The correlation between the prawn densities simulated in TSPFsim and estimated from the survey data was 0.91 for tiger prawns and 0.64 for endeavour prawns. In contrast, the spatial and temporal trends of simulated spawner density were relatively different from that of survey data, with correlation of 0.22 for tiger and 0.33 for endeavour prawns. In terms of the total number of spawners (density × area), however, TSPFsim spawner trends were highly correlated to the survey data for both species ($\rho = 0.88$ for tiger, $\rho = 0.85$ for endeavour prawns).

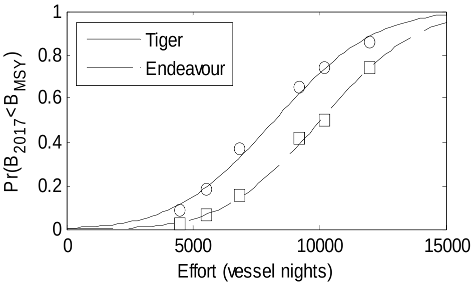

Figure 3 Risk of overfishing with different levels of fishing pressure.

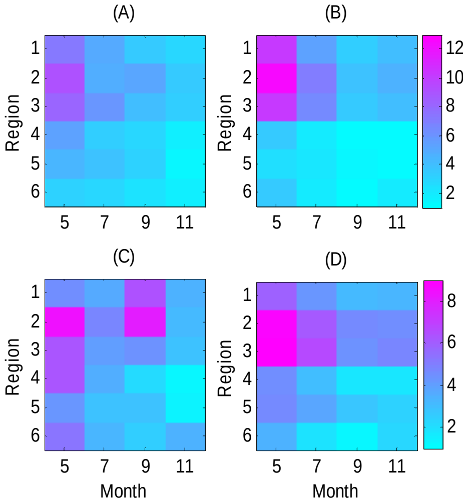

Figure 4 Temporal and spatial distribution of prawn density estimated from: (A) survey07, tiger; (B) TSPFsim, tiger; (C) survey 07, endeavour ; and (D) TFPFsim, endeavour. Values indicate percentage (%) of abundance per a unit area in each month and region over the sum of monthly abundance in May, Jul, Sep and Nov. Note that the simulation results were based on Scenario 4 (no spatial management).

4. DISCUSSION

TSPFsim is an open-loop MSE that can explicitly test the effectiveness of the spatial and temporal management of the fishery. One of the biggest challenges of model development was to simulate the movement of prawns between regions. The comparison of temporal and spatial distribution of prawn abundance between TSPFsim and the survey indicated that the overall movement of tiger prawn was relatively well captured by the movement transition matrix. It is important to note that the proportion of prawns moved from one region to others were constant for both species every month and for all size/age classes. This means that we assumed: a) tiger and endeavour prawns move identical; b) there was no seasonal difference in the prawn movement; and c) the smallest size class prawn moved at the same rate as the oldest size class prawns. These assumptions may not reflect reality; for example, the discrepancy between the simulated endeavour prawn abundance and observations from the survey indicates that the movement of endeavour prawn is different from that of tiger prawns. The spatial distribution of the tiger prawn was better captured than for the endeavour prawn as the majority of the tag-recapture data, from which the movement transition matrix was estimated, were tiger prawn records. One of the possible reasons for the poor correlation between simulated and surveyed spawning stock (per unit of area) was the variable movement between size/age classes (Die and Watson 1992) and different growth rates between regions. Another reason related to temporal discrepancy, is that the seasonal maturity trend included in TSPFsim may not have fully captured temporal variation in the seasonal spawning pattern.

Although the spawner closure resulted in a 5 - 9% increase in the number of spawners in Region 4, it did not contribute to the overall number of spawners for a number of reasons. Firstly, only 12 – 13% of annual spawners were contributed from Region 4. Secondly, there was a slight reduction in the number of spawners outside Region 4 due to the additional effort re-allocated into other regions after the closure was introduced. This reduction countered the number of spawners protected in Region 4. Lastly, TSPF fishers generally use almost 50% of their allocated fishing effort in the first three month of the fishing season (March – May). The spawner closure was generally triggered in the later part of the season when the fishing pressure was relatively low.

We conclude that the proposed tiger spawner closure would have a minimum benefit for the fishery in terms of reducing the risk of overfishing the tiger prawn stock and maximising the productivity of the fishery. It should be noted that this conclusion was based on the assumption that the model accurately estimated the abundance of spawners in Region 4. Further research and modification of the model, particularly on prawn movement and its size/age dependence, and on the temporal spawning pattern, will be require to better quantify the benefits of spatial closures suggested for the Torres Strait Prawn Fishery. It is unlikely that the spawner closure would be activated under the current economic conditions. The results will inform the long-term harvest strategy for the prawn fishery by providing stakeholders with estimates of the risk of the stock biomass falling below sustainable levels for a range of fishing effort.

ACKNOWLEDGMENTS

This research is funded by the Department of Agriculture, Fisheries and Forestry. We thank Simon Vieira and Laura Hohnen from ABARE for supplying the prawn market price data. We thank our DPI&F staff, particularly Alex Campbell for providing useful modelling advice and Carissa Fairweather for collecting the survey data.

REFERENCES

Dall W, Hill BJ, Rothlisberg PC, Staples DJ (1990) 'The Biology of the Penaeidae.' (Academic Press, Harcourt Brace Jovanovich, Publishers: London)

De Oliveira JAA, Kell LT, Punt AE, Roel BA, Butterworth DS (2008) Managing without best predictions: the Management Strategy Evaluation framework. In 'Advances in fisheries science: 50 years from Beverton and Holt'. (Eds A Payne, J Cotter and T Potter) pp. 104-134. (Blackwell Publishing: Oxford)

Dichmont CM, Deng A, Punt AE, Venables W, Haddon M (2006) 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 CM, Haddon M, Yeomans K, Kelly K (1999) 'Proceedings of the South-East Queensland Stock Assessment Review Workshop.' Department of Primary Industries, QC99003, Brisbane.

Die D, Watson RA (1992) A per-recruit simulation model for evaluating spatial closures in an Australian penaeid fishery. *Aquatic Living Resources* **5**, 145-153.

Kell LT, Pastoors MA, Scott RD, Smith MT, Van Beek FA, O'Brien CM, Pilling GM (2005) Evaluation of multiple management objectives for Northeast Atlantic flatfish stocks: sustainability vs. stability of yield. *ICES J. Mar. Sci.* **62**, 1104-1117.

Kell LT, Pilling GM*, et al.* (2005) An evaluation of the implicit management procedure used for some ICES roundfish stocks. *ICES J. Mar. Sci.* **62**, 750-759.

Math Works (2008) MATLAB The Language of Technical Computing. In. (The Math Works Inc: Natick, Massachusetts)

Mellors JE (1990) 'Torres Strait prawn project: a review of research 1986 - 88.' Queensland Department of Primary Industries, Brisbane.

O'Neill MF, Turnbull CT (2006) 'Stock assessment of the Torres Strait tiger prawn fishery (*Penaeus esculentus*).' (Department of Primary Industries and Fisheries: Queensland)

Pelletier D, Mahevas S (2005) Spatially explicit fisheries simulation models for policy evaluation. *Fish and Fisheries* **6**, 307-349.

Sadovy Y, Punt A, Cheung W, Vasconcellos M, Suharti S, Mapstone B (2007) 'Stock assessment approach for the Napoleon fish, *Cheilinus undulatus*, in Indonesia. A tool for quotasetting for data-poor fisheries under CITES Appendix II Non-Detriment Finding requirements.' FAO Fisheries Circular 1023, Rome.

Watson RA, Turnbull CT (1993) Migration and growth of two tropical penaeid shrimps within Torres Strait, Northern Australia. *Fisheries Research* **17**, 353-368.