Incorporating Survey Data to Improve Space–Time Geostatistical Analysis of King Prawn Catch Rate

Ainslie Denham and Ute Mueller

Abstract Commercial fishing logbook data from the Shark Bay managed prawn fishery in Western Australia provide king prawn catch rate data densely informed and irregularly spaced in both the spatial and temporal domains. Space–time geostatistical analysis for the data from the 2001 to 2004 fishing seasons has shown that short term catch rate prediction is possible with the use of the product-sum covariance model and the subsequent kriging estimation process. However the operation of closure lines within the fishery makes it difficult to capture the high catch rate behaviour in areas as they first open to trawling. One of these regions is the Extended Nursery Area which usually opens in the first week of May. Analysis of the survey trawls from seasons 2001 to 2003 in this region in March and April shows there is a moderate positive correlation between the actual catch rate and the survey catch rate. By using the survey catch rate data as additional data in space–time geostatistical estimation of the catch rates for May 2004, the space–time behaviour of the king prawn catch rate data is more successfully captured.

1 Introduction

We consider king prawn logbook catch rate data from the Shark Bay Prawn Managed Fishery in Western Australia and incorporate catch rate data from survey trawls in the preceding months to more accurately reproduce the space–time behaviour of the prawn catch rate in the fishing region. The king prawn catch rate data are densely informed in both the spatial and temporal domains and involve varying locations at successive time instants. Space–time geostatistical analysis for king prawn catch rate data from the 2001 to 2004 fishing seasons, incorporating traditional time series modelling of annual king prawn catch rate trends, has shown that short term catch rate prediction is possible with the use of the product-sum covariance model and subsequent kriging. However, time-limited closure lines operate

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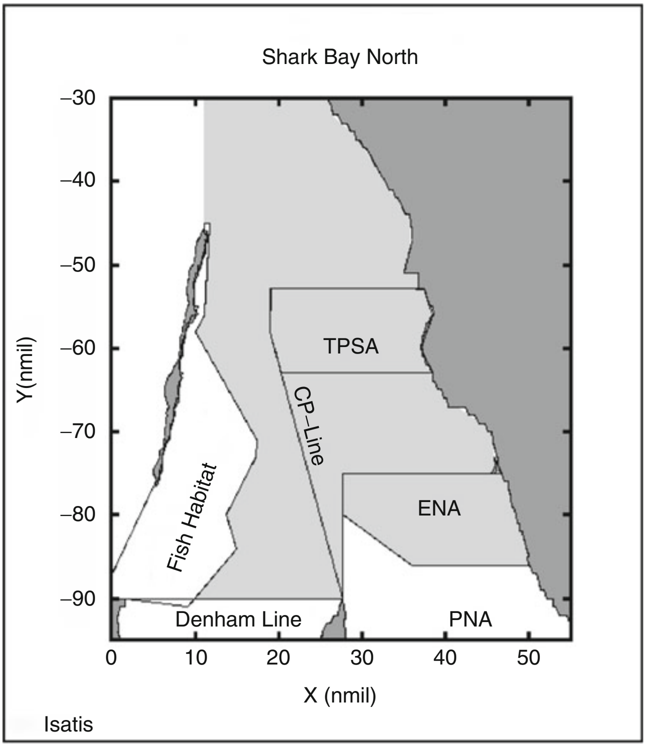

Fig. 1 Shark Bay North fishing region (*light grey*) and permanent and temporary closure lines for the fishery

in the fishery and the timing of the closures is dependent on the lunar phase and survey results. It is therefore difficult to capture successfully the high king prawn catch rate behaviour in areas as they first open to trawling.

Of particular importance is the opening of the extended nursery area (ENA) (Fig. 1) at the start of the last quarter in May producing high catch rates in the newly opened region. Using the catch rate logbook and survey data from the 2001 to 2003 seasons along with the logbook and survey catch rate data from the lunar months of March and April 2004, we investigate to what extent their use improves the reproduction of the catch rate data for the (lunar) month of May of season 2004. The ENA is surveyed in March and April of each season and analysis of data from seasons 2001 to 2004 shows that there is a moderate positive correlation between the actual catch rate and the survey catch rate from preceding months.

Space–time geostatistical estimation of king prawn catch rate for May 2004 is performed using the survey catch rate data as additional information. Multiplicative trend models are employed involving a polynomial trend model and (lunar) weekly seasonal indices obtained from classical decomposition. Spatio-temporal semivariograms of the combined detrended and deseasonalised data for 2001 to 2003 are computed and modelled using product-sum covariance models (De Iaco et al., 2001;

De Cesare et al., 2002). Cross-validation (Mueller et al., 2008) has shown that these semivariogram models capture the properties of the sample data and supports their use for estimation and smoothing of the king prawn catch rate data. We compare the estimates with those previously obtained using no survey data and with the actual catch data for 2004 and show that the space–time behaviour of the king prawn catch rate data is captured accurately with the use of the additional survey catch rate data in an area which has just opened to trawling.

2 Data Description

The data in this study are king prawn catch rate logbook and survey data from 2001 to 2004 from the Shark Bay North fishing region of the Shark Bay prawn fishery. For our analysis the catch locations were converted to nautical miles and a local coordinate system with origin at 24° southern latitude and 113° eastern longitude. Records without coordinates were eliminated from the data sets and the remaining records were aggregated to a single centroidal location for each vessel per night. This resulted in 90% of the data being used. The survey data consist of 17 locations across the study region sampled around the third moon phase in the months of March and April of each season. Spatial maps of the fishing locations for seasons 2001 to 2003, including the permanent closure lines for the fishery are shown in Fig. 2 along with the survey locations.

The means and medians of the daily king prawn catch rate are similar in 2001 and 2003 with 2002 showing a slightly larger mean and median (Table 1). The variance of the 2001 data set is considerably smaller than that of 2002 and 2003. The 2001 season also has a smaller range than the 2002 and 2003 seasons. The catch rate data for all three seasons have a moderate positive skew. The catch rate data were averaged over each lunar week to obtain a time series for each season to be used to model the temporal trend. These annual time series show similar means, medians and positive skewness to the corresponding daily data sets they were computed from (Table 1). Their variances, as expected by the averaging process, are smaller. Similarly, the minima/maxima of the averaged weekly data are larger/smaller than the corresponding daily data. Of the fishing weeks evident in each of the fishing seasons, there are a number of weeks for which there are no fishing data because of a closure period around the full moon of each month and also, in some weeks the fleet concentrates on the Denham Sound region.

3 Temporal Trend Modelling

Previous analysis (Harman, 2001; Mueller et al., 2008) has demonstrated that multiplicative classical decomposition models are appropriate for modeling the temporal trend in the king prawn catch rate data using the 4 week lunar cycle as the seasonal

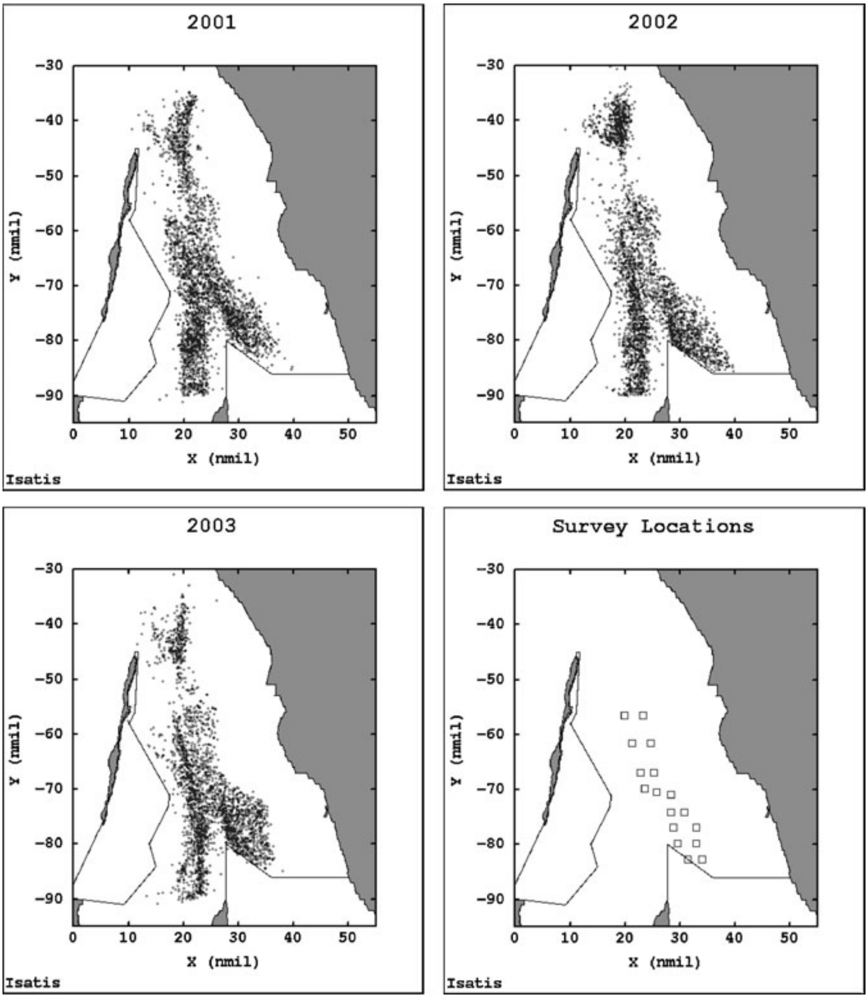

Fig. 2 Fishing locations in Shark Bay North for seasons 2001 to 2003, and survey locations

factors. Classical decomposition was performed on the weekly averaged king prawn catch rate data for seasons 2001 to 2003. A four point centred moving average was used to remove the annual effects of the 4 week lunar cycle and to identify underlying trends in the data (Fig. 3). As a function of the number of weeks the catch rate trend first increases until a maximum is reached, and then is a decreasing function of time. This pattern was also evident in the research on previous king prawn catch rate data in Harman (2001). This trend is modelled later by fitting a polynomial to the deseasonalised data, for which we must first calculate the seasonal factors.

The weekly average data were divided by the centred moving average to obtain the seasonal index component which was used to determine the seasonal factors for

Table 1 Summary statistics of daily and average weekly King Prawn catch rate for seasons 2001 to 2003

	Daily data			Average weekly data		
Season	2001	2002	2003	2001	2002	2003
Mean	28.03	34.25	29.43	24.69	28.24	23.48
Median	23.68	26.65	22.62	22.87	24.25	19.04
Variance	304.59	661.30	581.50	119.88	231.24	246.99
Skewness	1.78	3.13	2.92	1.28	1.65	2.75
Minimum	1.07	0.92	1.08	11.50	12.00	9.68
Maximum	146.07	440.32	266.63	56.99	72.13	83.86
Count	3,346	3,276	2,892	30(31)	29(31)	27(31)

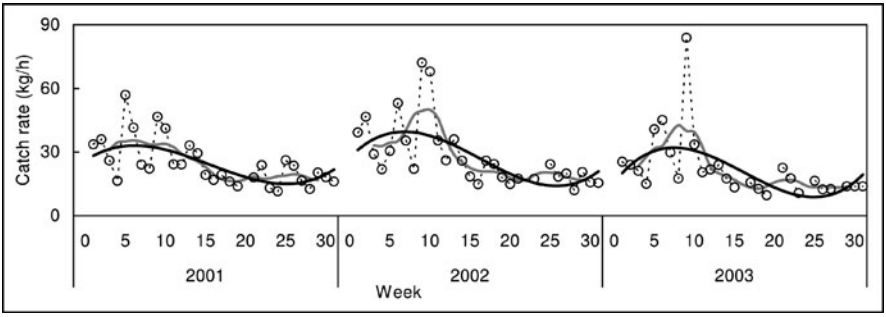

Fig. 3 Average weekly king prawn catch rate for seasons (*white circles*), centred moving average (*solid grey line*) and fitted deseasonalised trend (*solid black line*) for seasons 2001–2003

each of the four lunar phases. The Classical Decomposition seasonal factors for the king prawn catch rate for each season (Fig. 4) are similar between years. For all years the factor for the last quarter moon week is largest whilst the lowest annual factors are for the full moon period when the fishery is closed for 3 to 7 days due to the expected low catch rate (Sporer et al., 2007). The last quarter moon and new moon week factors are greater than one for all seasons whilst the full moon and first quarter moon week factors are below one for all seasons. Due to the similarity of factors across the three seasons we also compute average factors obtained by averaging across the three seasons (Fig. 4) for use in an average classical decomposition model for all three seasons.

The deseasonalised data for seasons 2001 to 2003 were calculated by dividing the catch rate data by the seasonal factors obtained for the individual seasons, and then modeled using polynomial trend lines (Fig. 3). The equations and accuracy measures are shown in Table 2. For all years a cubic function was appropriate for modelling the trend. The model for 2001 has the largest R^2 value of 0.717 indicating a large correlation with the deseasonalised data. It also shows the smallest mean error, mean percentage error and mean absolute deviation across the three seasons. The models for seasons 2002 and 2003 have slightly smaller R^2 values, still showing moderate correlation with the deseasonalised data. As the shapes and equations of

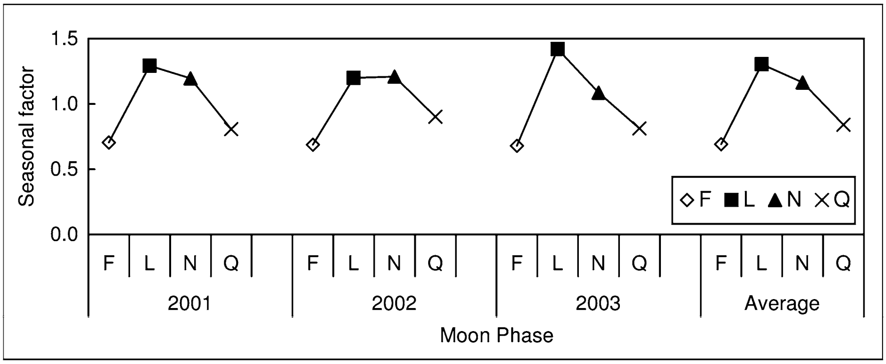

Fig. 4 Seasonal factors for seasons 2001 to 2003 based on moon phase

Table 2 Equations of fitted third order polynomial deseasonalised trend models, 2001–2003 and average model and accuracy measures

	Equation	Mean error	Mean % error	Mean abs. deviation	R^2
2001	$0.005t^3 - 0.251t^2 + 2.476t + 26.071$	0.002	−0.508	3.214	0.717
2002	$0.007t^3 - 0.365t^2 + 3.923t + 27.437$	−0.002	−1.114	5.530	0.612
2003	$0.009t^3 - 0.425t^2 + 4.879t + 15.687$	0.071	−2.598	5.200	0.566
Average	$0.007t^3 - 0.347t^2 + 3.760t + 23.065$	–	–	–	–

the trends were similar for the three seasons, an average model was computed by averaging the polynomial coefficients across the three seasons.

Multiplicative classical decomposition models for seasons 2001 to 2003 were obtained by multiplying the deseasonalised trend by the relevant (lunar) seasonal factor. Individual classical decomposition models were calculated for each season along with an average model using the average polynomial trend and average seasonal factors (Fig. 5). These models replicate the catch rate time series well. The noticeable differences exist for peaks evident in the data in weeks 5 and 9, which correspond to the opening times of two closure lines near the nursery areas. The Carnarvon-Peron line opened in week 5 in season 2001 and 2003 and in week 6 in season 2002 whilst the ENA opened in week 9 for all three seasons.

Accuracy measures for the classical decomposition models (Table 3) show the errors of the average models are greater in magnitude than their corresponding individual model, with the exception of the mean percentage error for season 2001. The large mean percentage error of the 2003 average model is due to the contribution of the first 3 weeks where the model is significantly higher than actual values. The R^2 values of the average models are only slightly smaller than their corresponding

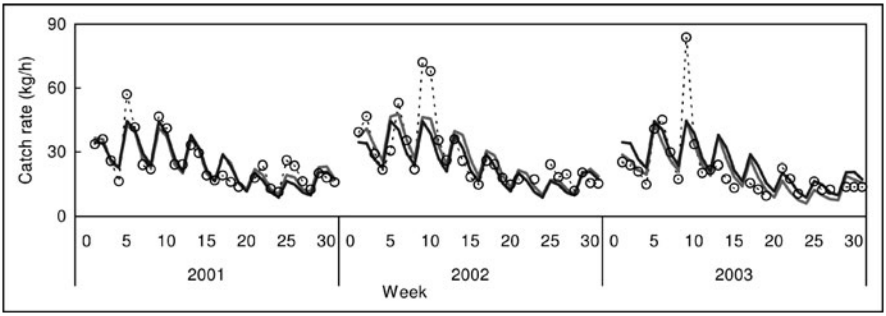

Fig. 5 Individual season classical decomposition model (*solid grey line*), average classical decomposition model (*solid black line*) and weekly king prawn catch rate (*circles*) for seasons 2001 to 2003

Table 3 Accuracy of classical decomposition models (individual and average), 2001–2003

	2001		2002		2003	
	Individual	Average	Individual	Average	Individual	Average
Mean error	−0.065	−0.281	−0.256	−3.480	−0.353	3.147
Mean % error	2.969	0.663	4.671	−7.177	5.704	25.790
Mean abs deviation	3.474	3.797	5.850	6.418	5.976	6.969
R-squared	0.813	0.794	0.696	0.675	0.610	0.567

individual model. Therefore, the average model was chosen to remove the temporal trend from the king prawn catch rate data to obtain the adjusted king prawn catch rate data.

4 Variography

Space–time semivariograms were computed for the adjusted king prawn catch rate data for the individual seasons 2001 to 2003. Although there was slight evidence of anisotropy in the spatial direction, it was regarded as an artifact of the shape of the fishing region and so disregarded in the modelling. For all three seasons the structure in both the temporal and spatial directions is similar and so a model was computed for the combined 2001 to 2003 seasons. The marginal spatial and temporal experimental semivariograms along with their fitted models are shown in Fig. 6. The spatiotemporal experimental semivariogram and its fitted semivariogram model are shown in Fig. 7. A generalized product-sum model was used (De Iaco et al., 2001) and the semivariogram model parameters are shown in Table 4. The marginal spatial semivariograms consist of a nugget effect and a long range spherical structure. The marginal temporal semivariogram consists of a nugget effect, a short range spherical structure and a long range spherical structure. The global sill of the spatiotemporal semivariogram is fitted to the data variance.

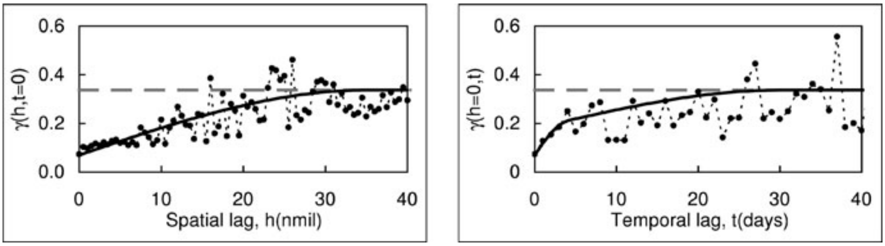

Fig. 6 Experimental marginal spatial semivariogram (*left, black circles*) and marginal temporal semivariogram (*right, black circles*) with fitted models (*solid black line*) and data variance (*grey dashed line*) for adjusted king prawn catch rate data of combined seasons 2001 to 2003

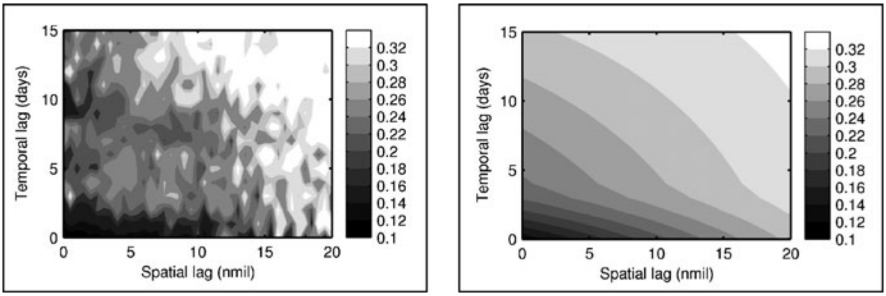

Fig. 7 Space–time semivariogram for seasons 2001 to 2003, experimental (*left*) and fitted model (*right*)

Table 4 Semivariogram model parameters for adjusted king prawn catch rate, seasons 2001–2003

			First spherical structure		Second spherical structure	
Season	Semivariogram	Nugget	Range	Sill	Range	Sill
2001	Spatial	0.05	35.0	0.15	–	–
	Temporal	0.05	1.5	0.04	30.0	0.11
2002	Spatial	0.07	35.0	0.28	–	–
	Temporal	0.07	1.5	0.04	30.0	0.24
2003	Spatial	0.07	35.0	0.29	–	–
	Temporal	0.07	1.5	0.04	30.0	0.25
2001–2003	Spatial	0.07	35.0	0.26	–	–
	Temporal	0.07	4.0	0.11	30.0	0.15

5 Opening of Extended Nursery Area

There are a number of closure lines implemented in the fishery. The ENA closure is one such closure line that opens just before the last quarter moon phase in May in all three seasons. This corresponds to the peak seen in May (Week 9) in previous

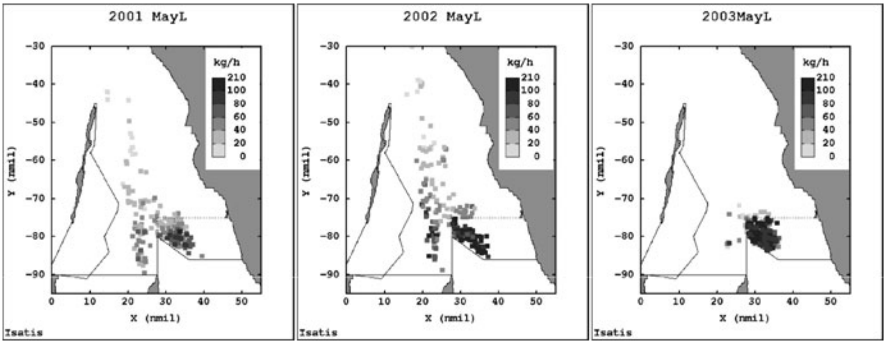

Fig. 8 Logbook catch rates for week of last quarter moon phase in seasons 2001–2003, ENA shown by dotted line

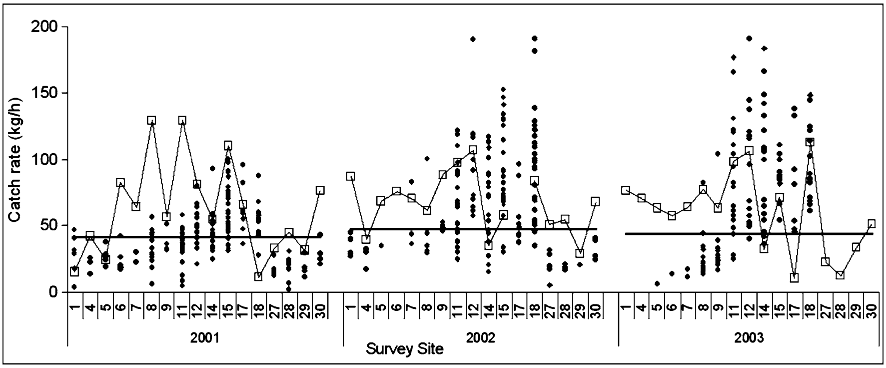

Fig. 9 Average survey catch rates (*white squares*), logbook catch rates at survey locations (*black circles*) and classical decomposition model fit (*solid line*) for week of last quarter moon phase in season 2001–2003

plots. Spatial maps of the catch rate data for this week in seasons 2001 and 2003 are shown in Fig. 8. The catch rates in the ENA are relatively high compared to those further away from the ENA and they are significantly higher than the estimate of the classical decomposition model (Fig. 9). The March and April survey data for seasons 2001 to 2003 showed similarities with the actual catch rates within the ENA in the first week it is open. It was decided that the average of the 2 months was the most reasonable indicator of the catch rate values in the ENA (Fig. 9) and the use of the average survey data in the estimation process would help to reproduce the high catch rate behaviour in the ENA.

6 Estimation

Short term catch rate prediction is possible with the use of the product-sum covariance model and the subsequent kriging estimation process. We predict the king prawn catch rate data for the (lunar) month of May 2004 by space–time geostatistical estimation using the March and April logbook catch rate data and the spatiotemporal semivariogram model obtained from the 2001 to 2003 fishing seasons. Grid catch rate estimates for the fishing region and jacknife estimates for the actual logbook catch rate data locations are shown in Fig. 10 for the week of the last quarter moon phase of May as the ENA is opened to trawling. It is evident that this method does not adequately capture the relatively high catch rates in the ENA.

As the average of the March and April survey data give a good indication of the catch rate levels seen in the ENA, we re-estimated the catch rates in May 2004 including the average survey data in the kriging process as additional data along with the March and April logbook catch rate data. The survey data were detrended and deseasonalised using the trend and seasonal index for the last quarter moon phase of May, but were allocated a date from the preceding week to enable its use in the estimation process which was directly affected by the short temporal range of the semivariogram model. Estimates over the fishing region and jacknife estimates for the actual logbook catch rate data locations in Fig. 11 demonstrate the ability to better capture the high catch rates in the ENA.

While inclusion of the survey data improved the estimation for the last quarter, this was not the case for the weeks of the new moon and first quarter moon phase of May 2004. The relatively high catch rates are much fewer in these weeks and the estimates involving the survey data are much higher than those evident in the actual catch rates (Fig. 12). The estimates involving no survey data are more representative of the actual catch rates. Accuracy measures for the jacknife estimates (Table 5) support the use of the survey data to estimate for the last quarter moon week. Estimation using the survey data decreases the magnitude of the errors for the week of

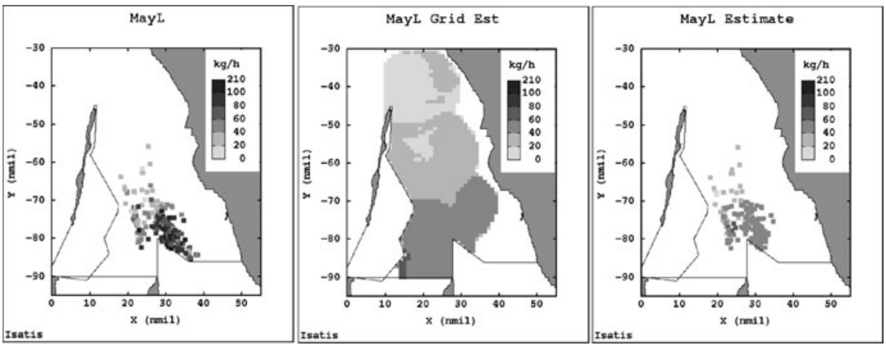

Fig. 10 Logbook catch rates (*left*), grid estimates (*centre*) and jacknife estimates (*right*) of the king prawn catch rate for the week of last quarter moon phase of May 2004

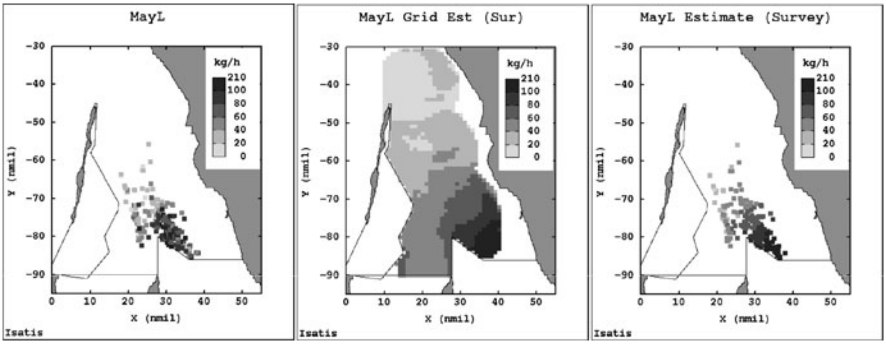

Fig. 11 Logbook catch rates (*left*), grid estimates (*centre*) and jacknife estimates (*right*) of the king prawn catch rate using average survey data for the week of last quarter moon phase of May 2004

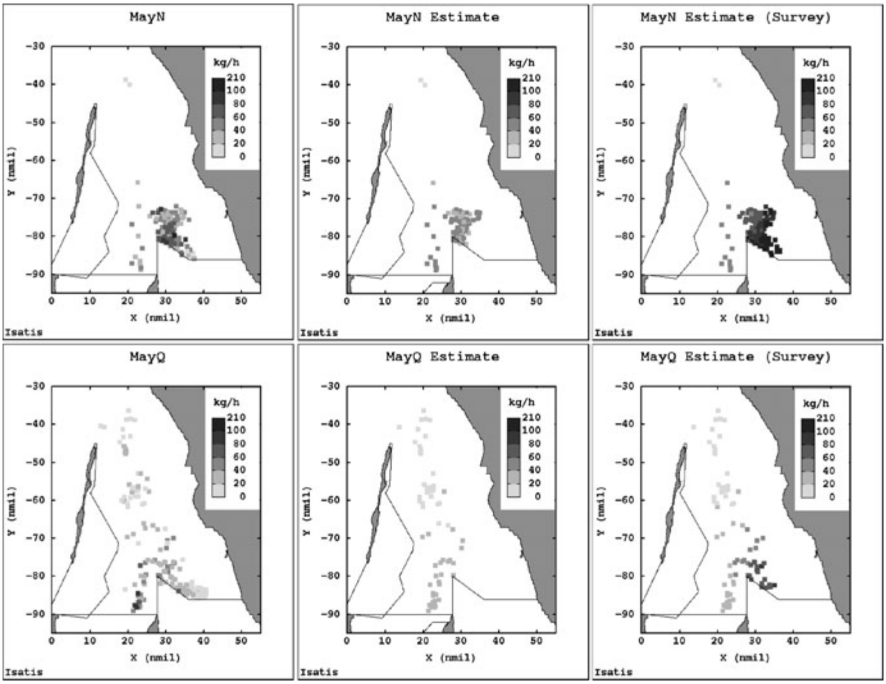

Fig. 12 Logbook catch rates (*left*), grid estimates (*centre*) and jacknife estimates (*right*) of the king prawn catch rate using average survey data for the week of new moon (*top*) and first quarter moon phase (*bottom*) of May 2004

the last quarter moon phase but increases the magnitude of the errors for the weeks of the new moon and first quarter moon phase. The R^2 value of the estimates using survey data increases for the last quarter moon phase week but decreases for the weeks of the new moon and first quarter moon phase.

Table 5 Accuracy measures for jacknife estimates, with and without survey data, May 2004

	Jacknife estimates			Jacknife estimates (average survey)		
	MayL	MayN	MayQ	MayL	MayN	MayQ
Mean error	−21.65	−4.48	−11.13	11.22	34.27	4.61
Mean % error	−17.77	0.70	−23.00	15.45	100.41	36.68
Mean abs deviation	27.72	10.90	12.60	23.47	36.23	18.00
R^2	0.22	0.13	0.66	0.30	0.002	0.09

7 Discussion

We have shown that it is possible to predict the king prawn catch rates for May 2004 using a spatiotemporal geostatistical model obtained using the data of seasons 2001 to 2003, along with the logbook catch rate data of March and April 2004. However, this method does not adequately capture the relatively high catch rates in the first week of May as the ENA opens to trawling. The accuracy of the estimates can be increased by using the April survey catch rate data, which are a good indicator of the catch rate values in the ENA. However, including the survey data does not improve the estimates for the subsequent weeks in May. The estimates computed using no survey data are more indicative of the actual catch rate behaviour in these weeks.

The use of the survey data compensates for the absence of data in the ENA and more specifically for the absence of significantly high catch rates in the preceding week for use in estimation. Thus, they provide a more realistic estimate than just using the ordinary kriging mean. An alternative to using the survey data might be to use a multiplicative factor in the temporal trend model for the week where the ENA opens. This multiplicative factor could be isolated to the ENA region so as not to affect estimates throughout the entire fishing region. The peak associated with the opening of the Carnarvon-Peron Line may also be addressed in this manner.

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