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Modeling marine fish landings and environment using VARX models

T.V. Sathianandan

MRC of C.M.F.R.I.,CIBA Campus, 75, Santhome High Road, R.A. Puram, Chennai – 600 028, India

Abstract

The relationship between monthly landings of oil sardine, mackerel, *Stolephorus* spp., elasmobranchs and environmental variables were used for developing multiple time series models of the type Vector Autoregressive model with environmental variables as exogenous variables (*VARX* model). Landings of these species/groups at Cochin Fisheries Harbour and environmental variables recorded at Cochin during 1988-97 were used for the study. Six different *VARX* models were fitted using the four landings time series as output vector and two environmental time series, one each to represent temperature and rainfall, as exogenous vector. The results revealed that an increase in highest rainfall is expected to cause increased landings of *Stolephorus* spp., increase in the values of highest and lowest temperatures and highest rainfall are not favourable for good landings of mackerel, the series on number of rainy days has significant negative effect on the series on elasmobranchs landings and increase in highest temperature is expected to cause reduction in oil sardine landings.

Keywords: Vector time series, *VARX* model, Marine fishery and environment

Introduction

Major objectives of analyzing a set of time series data together as vector time series is for estimating and describing the dynamic relationships among different time series and to use these additional information for developing improved forecast models. Analogous to the class of Autoregressive Moving Average (*ARMA*) models in univariate time series, the models that are becoming popular in multivariate time series is the Vector Autoregressive Moving Average (*VARMA*) type models including Vector Autoregressive model with exogenous variables (*VARX*). In this study, *VARX* models with environmental variables as exogenous variables are used to examine the relationship between marine fish landings and environment.

The expression for a general vector autoregressive model with exogenous variable of orders *p* and *r* denoted by *VARX*(p,r) is given by

$$\Phi(B)y_t = \delta+\beta(B)x_t+a_t$$

where $\Phi(B) = I - \Phi_1 B - \cdots - \Phi_p B^p$ and

$\beta(B) = \beta_0 + \beta_1 B + \cdots + \beta_{r-1} B^{r-1}$ are matrix polynomials of orders ***p*** and ***(r-1)*** respectively in the back shift operator *B*, $y_t = (y_{1t}, \cdots, y_{kt})'$ is the vector output series with ***k*** components, $x_t = (x_{1t}, \cdots, x_{mt})'$ is the exogenous vector series with *m* components, $\delta_t = (\delta_1, \cdots, \delta_k)'$ is a constant vector of size ***k***, $\Phi_1, \cdots, \Phi_p$ are $k \times k$ parameter matrices, $\beta_0, \beta_1, \cdots, \beta_{r-1}$ a are $k \times m$ parameter matrices and $a_t = (a_{1t}, \cdots, a_{kt})'$ is a vector of innovations that are assumed to be distributed independently and identically with zero mean vector and constant dispersion matrix Σ. The condition for stationarity of the model is that the determinantal polynomial det $(I - \Phi_1 z - \cdots - \Phi_p z^p) = 0$ have all its roots out side the unit circle.

Time series data on monthly landings of elasmobranchs, oil sardine, *Stolephorus* spp. and mackerel, at Cochin Fisheries Harbour during the period 1988-97, were used for developing suitable *VARX* models. These marine fish species/groups were selected based on their commercial importance and prey-predator or competitive type of biological interaction. The environmental variables considered were monthly means of maximum and minimum temperatures, lowest and highest temperatures recorded in the month, monthly total rainfall, highest rainfall recorded in the month and the number of rainy days in the month, all being recorded at Cochin.

The relationship between fishery and environmental variables has been examined by different research workers. Murty and Edelman (1966) related the long-term fluctuations in the Indian oil sardine fishery with the strength of summer monsoon over the peninsular region of India and found that certain range of monsoon intensity is unfavourable to the fishery and certain other range favourable. Pati (1984) studied the relationship between rainfall and coastal fishery in Indian waters and obtained significant correlations between the fluctuations in annual rainfall and landings from drift gillnet fishery, total rainfall and total catch rate and total rainfall and catch rate of plankton. Fogarty (1988) used Box-Jenkins transfer function models to analyse the relationship between water temperature and marine lobster catch and catch per unit effort and found the effect as vulnerability to capture increase with water temperature. Longhurst and Wooster (1990) studied the relationship between the abundance of oil sardine and upwelling on the south west coast of India and they found that the 0-group recruitment to the fishery begins towards the end of the summer monsoon and its success is statistically related to sea level at Cochin just prior to the onset of monsoon.

Materials and methods

Time series data on landings at Cochin Fisheries Harbour of the four marine fish species/groups were obtained from the "National Marine Living Resources Data Centre" (NMLRDC) of the Central Marine Fisheries Research Institute, Kochi. The environmental time series data were received from the India Meteorological Department, Pune. A 12-point moving average of these series were taken before analysis to remove seasonality present in the data.

Estimate of lag l cross correlation between i^{th} and j^{th} component series of a vector time series, based on a sample of size T is computed as

$$\hat{\rho}_{ij}(l) = \frac{\sum_{t=1}^{T-l}(Z_{it} - \bar{Z}_i)(Z_{j(t+l)} - \bar{Z}_j)}{\sqrt{\left\{\sum_{t=1}^{T-l}(Z_{it} - \bar{Z}_i)^2\right\}\left\{\sum_{t=1}^{T-l}(Z_{jt} - \bar{Z}_j)^2\right\}}}$$

where $\bar{z}_i$ the sample mean of the i^{th} component series. For large sample size, under white noise assumption, $\hat{\rho}_{ij}(l)$'s are expected to be distributed as normal with zero mean and approximate variance $1/T$ and to test the significance of individual sample cross correlations the two standard error limits $\pm 2/\sqrt{T}$ is used.

The method of estimation of parameter matrices in *VARX* model was derived following the procedure given by Spliid (1983). Let a sample of size T is available for the input and output vector series as $y_1, \cdots y_T$ and $x_1, \cdots x_T$ To avoid the problem of initial values for y_t and x_t we define the data matrices for the output and input series by $y = (y_{s+1}, \cdots, y_T)'$, $x = (x_{s+1}, \cdots, x_T)'$ and the innovation matrix by $a = (a_{s+1}, \cdots, a_T)'$ where $s = \max(p, r)$. These matrices will be of order $n \times k$, $n \times m$ and $m \times k$ respectively where $n = T - s$. Now define matrices

Y $= (By, B^2y; \ , B^p y)$ of order $n \times pk$
X $= (x, Bx; \cdots, B^{r-1}x)$ of order $n \times rm$ and
U $= (\underline{1}, Y, X,)$ is of order $n \times (pk+mr+l)$

where $\underline{1}$ is a column vector of size n with all elements unity.

Define $\alpha = (\delta, \Phi_1, \cdots, \Phi_p, \beta_0, \beta_1, \cdots, \beta_{r-1})'$ as the parameter matrix of order $(pk + mr + 1) \times k$. Then the general multivariate linear regression equivalent for the model is

$$Y = U\alpha + a$$

The model representation for the t^{th} row of this equation is

$$y_t' = \delta' + y_{t-1}'\Phi_1' + \cdots + y_{t-p}'\Phi_p' + x_t'\beta_0' + x_{t-1}'\beta_1' + \cdots + x_{t-r+1}'\beta_{r-1}' + a_t'$$

and transpose of this will yield the original model $\Phi(B)y_t = \delta + \beta(B)x_t + a_t$. Under this general multivariate linear regression model, the maximum likelihood estimate of the parameter matrix α is same as the least square estimate given by

$$\hat{\alpha} = (U'U)^{-1}U'y$$

The unbiased estimate of innovation covariance matrix Σ is given by

$$\hat{\Sigma} = \frac{1}{(T-m)}(Y - U\hat{\alpha})'(Y - U\hat{\alpha})$$

and the maximum likelihood estimate of Σ is

$$\tilde{\Sigma} = \frac{T-m}{T}\hat{\Sigma}$$

The covariance matrix of the estimated parameter matrix can be estimated as

$$\hat{Cov}(\hat{\alpha}) = \hat{\Sigma} \otimes (U'U)^{-1}$$

For identification of suitable orders p and r of $VARX(p,r)$ type models, order selection criteria AIC, BIC and HQ were followed by evaluating them for different values of p and r ranging from 1 to 5. The Akaike's (1972) information criterion is approximated by $AIC_r \approx \log(|\tilde{\Sigma}_r|) + \frac{2r}{T} + c$, the Baysean information criterion given by Schwarz (1978) is $BIC_r = \log(|\tilde{\Sigma}_r|) + \frac{r\log(T)}{T}$ and the criterion proposed by Hannan and Quinn (1979) is $HQ_r = \log(|\tilde{\Sigma}_r|) + \frac{2r\log(\log(T))}{T}$ where $\tilde{\Sigma}_r$ is the maximum likelihood estimate of the innovation dispersion matrix Σ, r is the number of parameters estimated, T is the sample size and c is a constant. The orders that yield minimum value for these criteria are selected as the required order for the model.

Results and discussion

The relationships between the four landings series and environmental variables were initially examined by computing cross correlations up to lag 24 of each of the landings series with different environmental time series. Based on the cross-correlation analysis, two environmental time series variables, namely mean maximum temperature and total rainfall, were excluded from modeling as their influence was comparatively less on all the four landings series. For developing *VARX* models, the four time series sequences on landings formed the output vector $\boldsymbol{y}_t$ and two time series sequences, one each to represent temperature and rainfall, formed the exogenous vector $\boldsymbol{x}_t$. This resulted in six different models with same set of output vector and different pairs of environmental time series sequences as components for the exogenous vector.

For all the six models the *BIC* and *HQ* criteria yielded the *VARX(1,1)* model where as the *AIC* criterion suggested higher order models. The *VARX(1,1)* model and the higher order models suggested by *AIC* criterion were all estimated and evaluated for comparison. Though the higher order models explained the variation in the output landings series slightly higher (less than 2%) than the *VARX(1,1)* model, they had too many parameters most of which were not significant. Hence for parsimony the models suitable for all the cases were taken as *VARX(1,1)* model. The expression for *VARX(1,1)* model is $y_t = \delta + \Phi_1\, y_{t-1} + \beta_0\, x_t + \varepsilon_t$. The estimate of variance covariance matrix of the output vector time series $\{\boldsymbol{y}_t\}$ consisting of landings of the four species/group was

$$\begin{pmatrix} 301.9829 & 899.1459 & -254.3888 & -1411.6567 \\ 899.1459 & 27435.8854 & -5554.9400 & -10480.0057 \\ -254.3888 & -5554.9400 & 2482.9746 & 568.2350 \\ -1411.6567 & -10480.0057 & 568.2350 & 27487.8107 \end{pmatrix}$$

Estimates of parameter matrices of the *VARX(1,1)* models, with standard errors in parenthesis, for the six different cases are given in Tables 1 to 6. From the fitted vector models, individual models for each of the four component catch series having significant coefficients for the exogenous environmental time series variables are

(i) *Elasmobranchs*

$$y_{1t} = -62.2340 + 0.9509\, y_{1,t-1} - 0.0016\, y_{2,t-1} + 0.0072\, y_{3,t-1} + 0.0047\, y_{4,t-1} + 2.2443\, x_{1t} - 1.1346\, x_{2t} + \varepsilon_{1t}$$

with significant coefficients for $y_{1,t-1}$, $y_{4,t-1}$ and x_{2t} (number of rainy days).

(ii) *Oil sardine*

$$y_{2t} = 874.9945 + 0.4413\, y_{1,t-1} + 0.9517\, y_{2,t-1} - 0.0557\, y_{3,t-1} - 0.0187\, y_{4,t-1} - 26.8017\, x_{1t} + 1.1548\, x_{2t} + \varepsilon_{2t}$$

with significant coefficients for $y_{1,t-1}$, $y_{2,t-1}$ and x_{1t} (highest temperature).

(iii) *Stolephorus* spp.

$$y_{3t} = -274.2013 - 0.1911\, y_{1,t-1} - 0.0251\, y_{2,t-1} + 0.9237\, y_{3,t-1} - 0.0299\, y_{4,t-1} + 8.3518\, x_{1t} + 0.4992\, x_{2t} + \varepsilon_{3t}$$

with significant coefficients for $y_{1,t-1}$, $y_{2,t-1}$, $y_{3,t-1}$, $y_{4,t-1}$ and x_{2t} (highest rainfall).

(iv) *Mackerel*

$$y_{4t} = 1962.3127 - 0.1611\, y_{1,t-1} + 0.0179\, y_{2,t-1} + 0.1622\, y_{3,t-1} + 0.9060\, y_{4,t-1} - 55.7698 x_{1t} - 1.8047 x_{2t} + \varepsilon_{4t}$$

with significant coefficients for $y_{4,t-1}$ and x_{1t}, x_{2t} (highest temperature and highest rainfall).

$$y_{4t} = 1534.6473 - 0.2760\, y_{1,t-1} + 0.0118\, y_{2,t-1} + 0.1864\, y_{3,t-1} + 0.9359\, y_{4,t-1} - 57.9377\, x_{1t} - 2.0518\, x_{2t} + \varepsilon_{4t}$$

Table 1. *Estimates of parameter vector and parameter matrices, with standard errors in parenthesis, of the VARX(1,1) model fitted with landings time series of elasmobranchs, oil sardine,* Stolephorus *spp. and mackerel as out put vector and highest temperature series and highest rainfall series as components of exogenous vector.*

$$\hat{\delta} = \begin{pmatrix} -66.5073 & 870.5186 & -274.2013 & 1962.3127 \\ (39.9554) & (447.6489) & (175.4848) & (729.5187) \end{pmatrix}'$$

$$\hat{\Phi}_1 = \begin{pmatrix} 0.9491 & 0.0019 & 0.0070 & 0.0016 \\ (0.0187) & (0.0025) & (0.0081) & (0.0021) \\ 0.4410 & 0.9498 & -0.0645 & -0.0165 \\ (0.2098) & (0.0277) & (0.0906) & (0.0231) \\ -0.1911 & -0.0251 & 0.9237 & -0.0299 \\ (0.0822) & (0.0109) & (0.0355) & (0.0091) \\ -0.1611 & 0.0179 & 0.1622 & 0.9060 \\ (0.3419) & (0.0451) & (0.1477) & (0.0377) \end{pmatrix} \quad \hat{\beta}_0 = \begin{pmatrix} 1.9336 & 0.0446 \\ (1.2132) & (0.0453) \\ -25.7190 & -0.3239 \\ (13.5918) & (0.5071) \\ 8.3518 & 0.4992 \\ (5.3282) & (0.1988) \\ -55.7698 & -1.8047 \\ (22.1502) & (0.8263) \end{pmatrix}$$

$$\hat{\Sigma} = \begin{pmatrix} 7.3700 & 4.4179 & -2.1791 & 23.7713 \\ 4.4179 & 925.1074 & -34.3015 & 261.4268 \\ -2.1791 & -34.3015 & 142.1662 & 87.3555 \\ 23.7731 & 261.4268 & 87.355 & 2456.9138 \end{pmatrix}$$

Table 2. *Estimates of parameter vector and parameter matrices, with standard errors in parenthesis, of the VARX(1,1) model fitted with landings time series of elasmobranchs, oil sardine,* Stolephorus *spp. and mackerel as out put vector and lowest temperature series and highest rainfall series as components of exogenous vector.*

$$\hat{\delta} = \begin{pmatrix} -15.7106 & -106.7808 & -17.0096 & 1084.6822 \\ (28.6981) & (323.0731) & (126.0997) & (525.3455) \end{pmatrix}'$$

$$\hat{\Phi}_1 = \begin{pmatrix} 0.9469 & 0.0027 & 0.0082 & 0.0012 \\ (0.0203) & (0.0027) & (0.0082) & (0.0021) \\ 0.5569 & 0.9507 & -0.0759 & -0.0095 \\ (0.2286) & (0.0307) & (0.0919) & (0.0233) \\ -0.2113 & -0.0230 & 0.9283 & -0.0319 \\ (0.0892) & (0.0120) & (0.0359) & (0.0091) \\ -0.2685 & -0.0286 & 0.1183 & 0.9161 \\ (0.3717) & (0.0499) & (0.1494) & (0.0378) \end{pmatrix} \quad \hat{\beta}_0 = \begin{pmatrix} 0.5740 & 0.0482 \\ (1.2915) & (0.0463) \\ 6.0319 & -0.4618 \\ (14.5398) & (0.5210) \\ 0.7675 & 0.5262 \\ (5.6751) & (0.2034) \\ -43.1766 & -1.7360 \\ (23.6430) & (0.8472) \end{pmatrix}$$

$$\hat{\Sigma} = \begin{pmatrix} 7.5296 & 1.9674 & -1.4487 & 19.8071 \\ 1.9674 & 954.2572 & -44.4546 & 338.8185 \\ -1.4487 & -44.4546 & 145.3757 & 67.1437 \\ 19.8071 & 338.8185 & 67.1437 & 2523.2135 \end{pmatrix}$$

with significant coefficients for $y_{4,t-1}$ and x_{1t}, x_{2t} (mean minimum temperature and highest rainfall).

$$y_{4t} = 1169.7475 - 0.2680\, y_{1,t-1} - 0.0647\, y_{2,t-1} + 0.1795\, y_{3,t-1} + 0.9400\, y_{4,t-1} - 48.7001\, x_{1t} - 6.0903\, x_{2t} + \varepsilon_{4t}$$

Table 3. *Estimates of parameter vector and parameter matrices, with standard errors in parenthesis, of the VARX(1,1) model fitted with landings time series of elasmobranchs, oil sardine,* Stolephorus *spp. and mackerel as out put vector and mean minimum temperature series and highest rainfall series as components of exogenous vector.*

$$\hat{\delta} = \begin{pmatrix} -48.8707 & 486.5004 & -251.9278 & 1534.6473 \\ (38.6195) & (435.2963) & (168.9213) & (709.0073) \end{pmatrix}'$$

$$\hat{\Phi}_1 = \begin{pmatrix} 0.9525 & 0.0021 & 0.0062 & 0.0006 \\ (0.0200) & (0.0025) & (0.0082) & (0.0021) \\ 0.4257 & 0.9466 & -0.0605 & -0.0048 \\ (0.2257) & (0.0279) & (0.0928) & (0.0236) \\ -0.1654 & -0.0243 & 0.9185 & -0.0348 \\ (0.0876) & (0.0108) & (0.0360) & (0.0092) \\ -0.2760 & 0.0118 & 0.1864 & 0.9359 \\ (0.3676) & (0.0455) & (0.1512) & (0.0385) \end{pmatrix} \quad \hat{\beta}_0 = \begin{pmatrix} 1.8927 & 0.0531 \\ (1.5891) & (0.0453) \\ -19.0042 & -0.4334 \\ (17.9113) & (0.5101) \\ 10.4015 & 0.5372 \\ (6.9507) & (0.1980) \\ -57.9377 & -2.0518 \\ (29.1738) & (0.8309) \end{pmatrix}$$

$$\hat{\Sigma} = \begin{pmatrix} 7.4456 & 3.0941 & -1.9678 & 21.7650 \\ 3.0941 & 945.9179 & -38.8645 & 297.8737 \\ -1.9678 & -38.8645 & 142.4466 & 82.2113 \\ 21.7650 & 289.8737 & 82.2113 & 2509.4863 \end{pmatrix}$$

Table 4. *Estimates of parameter vector and parameter matrices, with standard errors in parenthesis, of the VARX(1,1) model fitted with landings time series of elasmobranchs, oil sardine,* Stolephorus *spp. and mackerel as out put vector and highest temperature series and series on number of rainy days as components of exogenous vector.*

$$\hat{\delta} = \begin{pmatrix} -62.2340 & 874.9945 & -301.2467 & 2056.4514 \\ (38.2658) & (448.4893) & (179.0007) & (741.5303) \end{pmatrix}'$$

$$\hat{\Phi}_1 = \begin{pmatrix} 0.9509 & -0.0016 & 0.0072 & 0.0047 \\ (0.0179) & (0.0026) & (0.0076) & (0.0022) \\ 0.4413 & 0.9517 & -0.0557 & -0.0187 \\ (0.2102) & (0.0306) & (0.0894) & (0.0258) \\ -0.1991 & -0.0146 & 0.9041 & -0.0381 \\ (0.0839) & (0.0122) & (0.0357) & (0.0103) \\ -0.1335 & -0.0176 & 0.2321 & 0.9335 \\ (0.3475) & (0.0506) & (0.1479) & (0.0427) \end{pmatrix} \quad \hat{\beta}_0 = \begin{pmatrix} 2.2443 & -1.1346 \\ (1.1567) & (0.3438) \\ -26.8017 & 1.1548 \\ (13.5596) & (4.0293) \\ 9.3537 & 2.2413 \\ (5.4108) & (1.6082) \\ -59.5120 & -7.3777 \\ (22.4149) & (6.6621) \end{pmatrix}$$

$$\hat{\Sigma} = \begin{pmatrix} 6.7549 & 4.6305 & -0.0922 & 16.6624 \\ 4.6305 & 927.8973 & -41.0585 & 285.4104 \\ -0.0922 & -41.0585 & 147.8105 & 66.0920 \\ 16.6624 & 285.4104 & 66.0921 & 2536.6093 \end{pmatrix}$$

with significant coefficients for $y_{4,t-1}$ and x_{1t} (lowest temperature).

The fitted models indicate that mackerel landings series have significant lagged positive effect on elasmobranchs landings. Elasmobranchs own lagged values showed significant positive effect on it where as oil sardine and *Stolephorus* spp. landings series did not have

Table 5. *Estimates of parameter vector and parameter matrices, with standard errors in parenthesis, of the VARX(1,1) model fitted with landings time series of elasmobranchs, oil sardine,* Stolephorus *spp. and mackerel as out put vector and lowest temperature series and series on number of rainy days as components of exogenous vector.*

$$\hat{\delta} = \begin{pmatrix} -20.3774 & -80.2955 & -42.0427 & 1169.7475 \\ (20.3727) & (323.0121) & (128.3342) & (531.5191) \end{pmatrix}'$$

$$\hat{\Phi}_1 = \begin{pmatrix} 0.9534 & -0.0001 & 0.0089 & 0.0044 \\ (0.0195) & (0.0028) & (0.0077) & (0.0022) \\ 0.5460 & 0.9474 & -0.0638 & -0.0096 \\ (0.2301) & (0.0325) & (0.0913) & (0.0262) \\ -0.2136 & -0.0109 & 0.9090 & -0.0405 \\ (0.0914) & (0.0129) & (0.0363) & (0.0104) \\ -0.2680 & -0.0647 & 0.1795 & 0.9400 \\ (0.3787) & (0.0534) & (0.1502) & (0.0431) \end{pmatrix} \qquad \hat{\beta}_0 = \begin{pmatrix} 1.4538 & -1.1662 \\ (1.2307) & (0.3513) \\ 3.3484 & 0.6139 \\ (14.5225) & (4.1459) \\ 2.2053 & 2.2805 \\ (5.7699) & (1.6472) \\ -48.7001 & -6.0903 \\ (23.8969) & (6.8221) \end{pmatrix}$$

$$\hat{\Sigma} = \begin{pmatrix} 6.9012 & 1.6133 & 0.7538 & 13.4059 \\ 1.6133 & 961.0046 & -53.0893 & 366.8509 \\ 0.7538 & -53.0893 & 151.6954 & 44.6009 \\ 13.4059 & 366.8509 & 44.6009 & 2602.1089 \end{pmatrix}$$

Table 6. *Estimates of parameter vector and parameter matrices, with standard errors in parenthesis, of the VARX(1,1) model fitted with landings time series of elasmobranchs, oil sardine,* Stolephorus *spp. and mackerel as out put vector and mean minimum temperature series and series on the number of rainy days as components of exogenous vector.*

$$\hat{\delta} = \begin{pmatrix} -56.7753 & 469.2078 & -191.1021 & 1318.7337 \\ (36.8410) & (436.5616) & (173.4347) & (726.3920) \end{pmatrix}'$$

$$\hat{\Phi}_1 = \begin{pmatrix} 0.9581 & -0.0016 & 0.0055 & 0.0036 \\ (0.0192) & (0.0026) & (0.0077) & (0.0022) \\ 0.4252 & 0.9491 & -0.0483 & -0.0073 \\ (0.2272) & (0.0310) & (0.0918) & (0.0260) \\ -0.1869 & -0.0140 & 0.9003 & -0.0423 \\ (0.0903) & (0.0123) & (0.0365) & (0.0103) \\ -0.2031 & -0.0220 & 0.2544 & 0.9599 \\ (0.3780) & (0.0516) & (0.1527) & (0.0432) \end{pmatrix} \qquad \hat{\beta}_0 = \begin{pmatrix} 2.8816 & -1.2260 \\ (1.5433) & (0.3502) \\ -20.0571 & 1.6271 \\ (18.2872) & (4.1496) \\ 8.3264 & 2.0192 \\ (7.2653) & (1.6485) \\ -51.4190 & -6.0321 \\ (30.4290) & (6.9045) \end{pmatrix}$$

$$\hat{\Sigma} = \begin{pmatrix} 6.7718 & 3.3401 & 0.2575 & 14.3194 \\ 3.3401 & 950.8867 & -48.3813 & 332.8231 \\ 0.2575 & -48.3813 & 150.0754 & 51.3407 \\ 14.3194 & 332.8231 & 51.3407 & 2632.5698 \end{pmatrix}$$

any significant effect on this series. The only environmental variable found to have significant effect on elsamobranchs landings was the number of rainy days and it had negative effect. Lagged vales of elasmobranchs and oil sardine series had positive effect on oil sardine landings series and the only environmental variable that had significant effect on oil sardine series was highest temperature with negative effect. Lagged values of elasmobranchs, oil sardine and mackerel series had significant negative effect on *Stolephorus* spp. landings and its own lagged values had positive effect on *Stolephorus* spp. landings. Among the environmental variables considered, highest rainfall had significant positive effect on *Stolephorus* spp. landings. Mackerel landings had positive effect by its own lagged values and none of the other landings series had significant effect on this series. Environmental time series variables that were found to have significant influence on mackerel landings are highest temperature, lowest temperature, mean minimum temperature and highest rainfall. All this time series variables had positive effects on mackerel landings.

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