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# Impact of a change in reporting systems in the Maryland blue crab fishery

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## Abstract

Reported landings of the blue crab (*Callinectes sapidus*) in the Maryland portion of Chesapeake Bay nearly doubled starting in 1981, coincident with a change from a self-reporting system for harvesters to an interview program with a randomized selection process. A peak in relative abundance as measured by a trapping survey in the Calvert Cliffs region also occurred in 1981 and persisted for several years. We developed time series models for the effects of abundance only (here referred to as transfer function models), the effects of the reporting requirement change (intervention models), and for both factors combined, on blue crab landings. Simple transfer models with consideration only of changes in abundance could not adequately account for changes in reported landings. Intervention models accounting for the change in reporting systems resulted in a considerable improvement in model performance relative to the simple transfer function model. A substantial improvement in fit was obtained with a model that included both transfer and intervention components. We conclude that the change in reporting methodology resulted in a major change in reported landings while changes in abundance account for a significant fraction of the fluctuations around the shift due to the change in statistical systems. The methods employed here provide an objective way of quantifying the effect of the reporting requirement change.

*Keywords:* Blue crab; Reporting systems; Transfer function models; Intervention analysis

## 1. Introduction

Accurate determination of the levels of removals as catch, discards, and landings is essential in any assessment of the impacts of harvesting on exploited fish and invertebrate populations (e.g. Pope, 1988; Shepherd, 1988). Landings are typically monitored using logbooks or dealer records in an attempt to obtain a complete census or by interviews and/or catch reports from randomly selected harvesters (Fabrizio et al., 1996). Estimates of catch and discard levels often involve the use of logs maintained by harvesters or by observers stationed on-board fishing vessels. Estimates of removals from the population play a central role in many analytical methods designed to estimate population size and exploitation rates. Accordingly, the compilation of consistent time series of losses attributable to fishing is essential in the development of management advice (National Research Council, 1998).

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The blue crab, *Callinectes sapidus*, currently supports the most valuable fishery in the Chesapeake Bay. Recent assessments of the status of blue crab in this region have been provided by Rugulo et al. (1998a,b) and Miller and Houde (1999). These assessments provide descriptors of trends in baywide landings, fishing effort, catch-per-unit-effort, population size, and exploitation rates based on both fishery-dependent and fishery-independent sources. Central to the conclusions drawn in these assessments is the interpretation of Maryland landings of blue crab, which increased abruptly by a factor of 2 in 1981 (Fig. 1), coincident with a change in statistical systems from a self-reporting system for harvesters to a probability-based interview system. A further change was instituted in 1994 with the transition to mandatory reporting using trip tickets by all commercial harvesters.

The increase in reported Maryland blue crab landings in 1981 also coincided with a peak in abundance in a fishery-independent trap survey conducted in the Calvert Cliffs region of western Chesapeake Bay (Abbe, 1983; Abbe and Stagg, 1996; see Fig. 1). Rugulo et al. (1998a) attributed the increase in landings to the apparent increase in abundance and did not adjust the landings series for reporting system changes. In contrast, Miller and Houde (1999) concluded that the change in reporting systems in 1981 was the dominant factor in the increase in reported landings based on an intervention analysis of the timing and magnitude of the change. Rothschild et al. (1996) had previously noted the change in Maryland blue crab landings starting in 1981 and advocated the development of separate time series models for the different stanzas in the landings series. In recognition of the potential bias introduced by not accounting for the reporting requirement change, Abbe and Stagg (1996) partitioned the series at the change point in the development of bivariate models relating the Calvert Cliffs series to landings and contrasted these with a model for the entire time series.

Here, we examine the joint impact of the change in the reporting system in 1981 and changes in relative abundance using multi-variable time series models (Box and Jenkins, 1976) to assess the potential importance of accounting for the reporting change. In the following, we have restricted our analysis to the period prior to 1994 because of the difficulty in assessing the effect of changes implemented near the end of the landings series using time series models. Accordingly, no attempt is made to determine the effect of the most recent reporting requirement change.

## 2. Methods

Our analyses are based on blue crab landings data and the Calvert Cliffs abundance index provided by Rugulo et al. (1998a) and updated by the Chesapeake Bay Blue Crab Technical Subcommittee (D. Orner, NOAA Chesapeake Bay Office, pers. commun.). To examine the relative effects of changes in abundance

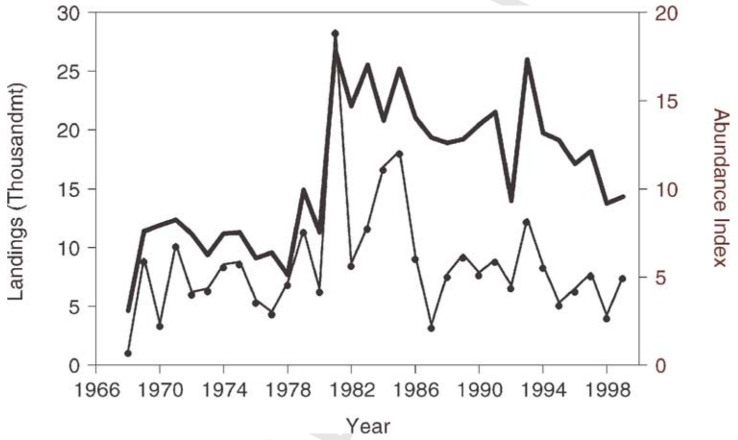

Fig. 1. Reported Maryland blue crab landings 1968−2001 (heavy solid line) and Calvert Cliffs trap-based abundance index (circles and thin solid line). Changes in reporting systems occurred in 1981 and 1994.

and in reporting systems, we sequentially fit time series models for the period 1968–1993 including (1) a transfer function model relating reported Maryland landings to the Calvert Cliff abundance index, (2) an intervention model for landings as a function of the change in reporting systems in 1981 and (3) a combined model incorporating the abundance index and an intervention term for the reporting changes. The distinction between the transfer and intervention models (a special class of transfer function models) is that the input term in the former is a continuous random variable (relative abundance) while the indicator variable in the latter essentially is a binary switch for the reporting requirement change. We also developed an intervention model for the period 1945–1993 to provide a possible tool for adjusting the longer time series of landings data (see also Miller and Houde, 1999).

Model parameters were estimated by the method of maximum likelihood using the Box–Jenkins iterative approach of model identification, estimation, and diagnostic checking. Time series were checked for stationarity prior to analysis. The abrupt change in landings in 1981, coincident with the change in the reporting system, complicates interpretation of stationarity of this series. In particular, if the shift in level is due to the change in reporting systems, adjusting the series by taking differences could obscure this important effect. To overcome this problem, we analyzed the landings series separately for the periods 1945–1980 and 1981–1993 and concluded that it was not necessary to make adjustment for secular trends in the development of intervention models because landings were stationary prior to, and following, the change in reporting systems. We transformed both the catch and relative abundance data to natural logarithms to stabilize the variance prior to analysis. The transformation results in a multiplicative model structure and changes in landings can be represented as the product of the (retransformed) coefficients and the input terms (relative abundance and/or the intervention variable).

The model for landings as a function of the transformed relative abundance series ($x_t$) and the intervention ($I_t$) can be written as:

$$y_t = \Theta_0 + \beta(B)x_t + \omega(B)I_t + \eta_t$$

where $y_t$ is the transformed landings series at time $t$, $\Theta_0$ a constant, $\beta$ and $\omega$ are the coefficients, and $B$ the so-called backward shift operator where:

$$z_{t-m} = B^m z_t$$

The backshift operator provides a convenient way of representing lagged values (of order $m$) of the random variable $z$. The error component $\eta_t$ can be represented as an autoregressive moving average process (Box and Jenkins, 1976):

$$\eta_t = \frac{\theta_i(B)}{\phi_i(B)} a_t$$

where $a_t$ is the random shock (Box and Jenkins, 1976), $\phi_i$ the autoregressive parameters, and the $\theta_i$ the moving average parameters. A model with more complicated intervention terms is possible to reflect a graduated change in the system but was not necessary in this analysis. The model can be generalized to account for additional input terms as:

$$y_t = \Theta_0 + \sum_{j=1}^{r} \beta(B)x_{j,t} + \sum_{k=1}^{s} \omega_k(B)I_{k,t} + \frac{\theta_i(B)}{\phi_i(B)} a_t$$

where the subscripts $j$ and $k$ represent different abundance and intervention series, respectively (Kendall and Ord, 1990). As more data accrue, the impact of the 1994 reporting requirement change can be assessed using the generalized model with the inclusion of an additional intervention term.

We first developed separate models for the transfer and intervention elements to provide insights into the relative importance of these individual components and then constructed the combined model. To develop the transfer function model, we first tested for stationarity and autocorrelation in the log-transformed Calvert Cliffs series. This analysis indicated that the abundance index was stationary and could best be described as a white noise stochastic process. Further filtering (or pre-whitening, Box and Jenkins, 1976) of this series was therefore unnecessary prior to estimation of the cross-correlation function and subsequent model fitting.

We used the akaike information criterion (AIC) for model selection. The AIC is a robust information-theoretic measure (Burnham and Anderson, 1998) that explicitly addresses the issue of model parsimony. Models with a greater number of parameters are assessed a penalty. The model with the lowest AIC score is deemed the most appropriate model among those

Table 1
Parameter estimates for time series models fit to the Maryland blue crab landings series

| Model type | Parameter estimates | Residual error | AIC |
|---|---|---|---|
| Transfer with white noise errors | $\Theta_0 = 1.711$ (0.194)<br>$\beta_0 = 0.624$ (0.118) | 0.309 | 15.320 |
| Transfer with ARMA errors | $\Theta_0 = 1.957$ (0.269)<br>$\beta_0 = 0.442$ (0.085)<br>$\phi_1 = 0.924$ (0.105)<br>$\theta_1 = 0.499$ (0.249) | 0.232 | 4.717 |
| Transfer with differencing | $\Theta_0 = -0.698$ (0.198)<br>$\beta_\eta = 0.466$ (0.121) | 0.316 | 16.451 |
| Intervention | $\Theta_0 = 2.314$ (0.066)<br>$\omega_0 = 0.746$ (0.093) | 0.237 | 1.495 |
| Combined | $\Theta_0 = 1.840$ (0.108)<br>$\beta_\eta = 0.359$ (0.074)<br>$\omega_0 = 0.570$ (0.076) | 0.17 | −14.318 |

Standard errors of the parameter estimates are provided in parentheses. The adjusted akaike information criterion (AIC) is used to assess model performance.

tested based on the same series. Due to the relatively small number of observations available for analysis, we employed the adjusted form:

$$\mathrm{AIC} = -2\log_{\mathrm{e}}[\mathcal{L}(\hat{\Phi}\,|x)] + 2K + \frac{2K(K+1)}{n-k-1}$$

where the first term in brackets is the likelihood function, $\hat{\Phi}$ the vector of estimated parameter values, $K$ the number of parameters, and $n$ the number of observations (Burnham and Anderson, 1998).

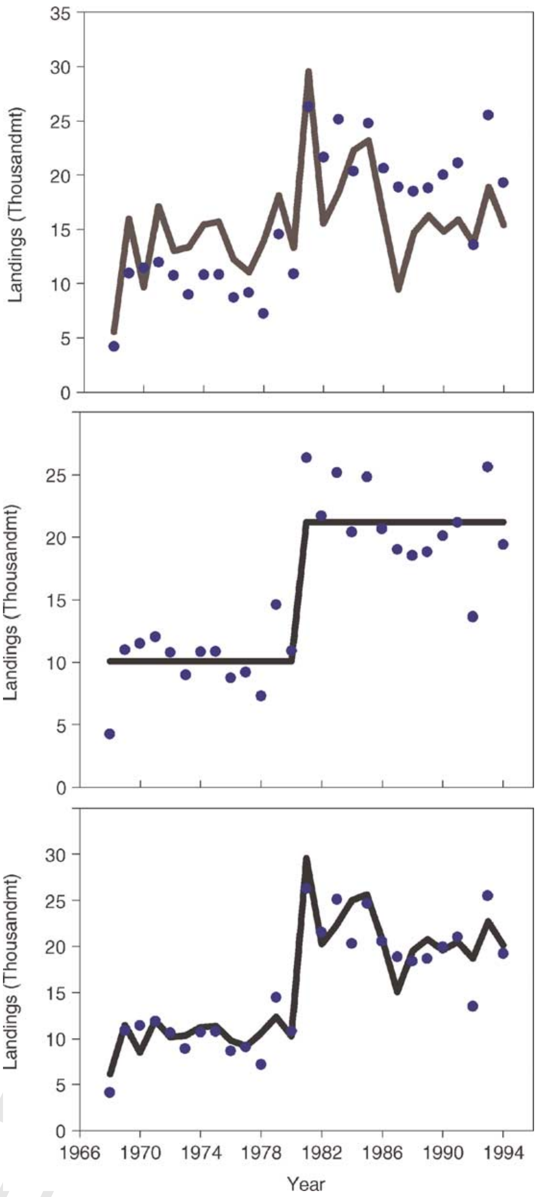

Fig. 2. Comparison of observed (circles) and predicted (lines) for simple transfer function model with no ARMA component (upper), an intervention model (middle) and combined model (lower).

## 3. Results

A simple transfer function model under the assumption of a white noise error structure is equivalent to the ordinary least-squares regression model. If the model accurately reflects the underlying process, model residuals should be randomly distributed about the predicted response. We first fit a simple transfer function with uncorrelated errors and found that all residuals but one were negative prior up to and including 1981 and all but one were positive after 1981. This pattern indicates that temporal changes in the landings series are not a simple linear function of changes in abundance as measured by the Calvert Cliff series. Further diagnostic checking indicated that first-order autoregressive (AR) and moving average (MA) terms were necessary to account for the residual pattern (Table 1). Inclusion of these terms resulted in a large decrease in the $\mathrm{AIC_c}$, indicating

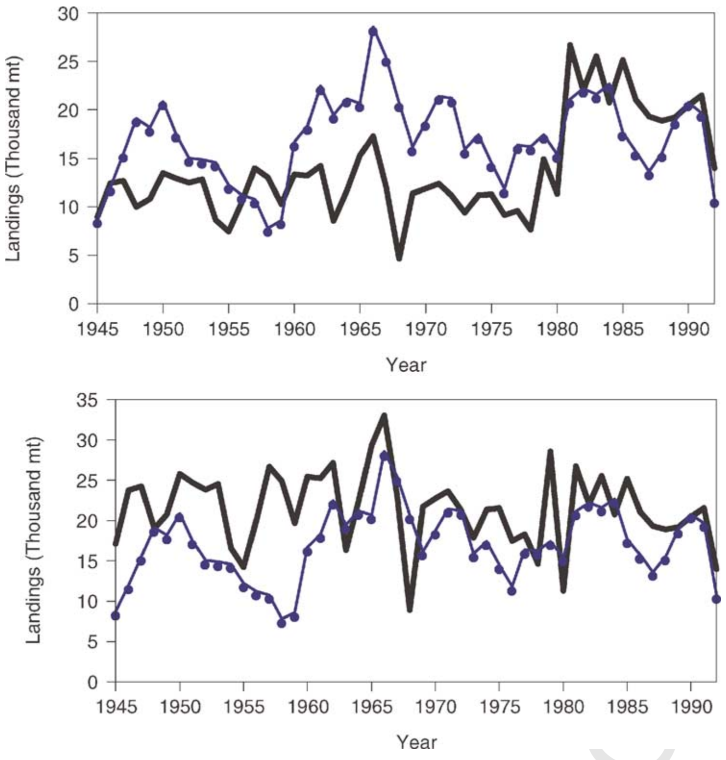

Fig. 3. Comparison of Maryland (heavy solid line) and Virginia (circles and thin solid line) blue crab landings for unadjusted (upper panel) and adjusted (lower panel) Maryland data.

a substantially improved fit (Table 1; Fig. 2). The autoregressive parameter was, however, close to the bounds of stationarity for this system indicating possible further model deficiencies. We therefore examined an alternative model based on the first-differenced landings series. The residuals of this model did not differ significantly from white noise following specification of a simple model including only the Calvert Cliffs abundance index. The AIC was slightly higher for this model than for the transfer function model with a white noise error structure (Table 1) and substantially higher than that for the transfer model with autoregressive and moving average terms.

It is instructive to note that had ordinary least-squares regression analyses has been used to evaluate the relationship between abundance and landings without careful analysis of residual patterns, it would have been concluded that the change in landings was strongly influenced by changes in abundance ($F_{1,30} = 20.46$; $P < 0.0001$; $R^2 = 0.41$). The nominal significance levels noted above would have been very misleading, however, because of the strong autocorrelation and distinct pattern in the residuals which indicate deficiencies in the model specification.

Development of a model including only an intervention term for the change in reporting systems in 1981 indicated a significant effect due to the change in reporting methods. Examination of model residuals indicated that no further terms were required (i.e. the residuals followed a white noise stochastic process). Based on the AIC scores, the intervention model resulted in a substantially better fit than the simple transfer function model with uncorrelated errors and indicated an improved fit when compared with the more complex transfer function models (Table 1; Fig. 2).

The full model including both abundance and intervention terms resulted in a dramatic improvement in the model fit over the alternatives as measured by the AIC criterion (Table 1; Fig. 2), indicating the impor-

Table 2
Parameter estimates and associated standard errors for an intervention model applied to Maryland blue crab landings data for the period 1945–1993

| Coefficient | Parameter estimates | S.E. |
|---|---|---|
| $\Theta_0$ | 2.411 | 0.039 |
| $\omega_0$ | 0.648 | 0.074 |

tance of changes in both apparent abundance and in reporting systems.

Development of the models including both intervention and abundance terms can only be applied for the period, since 1968. The clear indication of the importance of the changes in the reporting system in 1981 suggests the utility in developing an intervention model for the full catch time series to provide a broader historical perspective on stock status. We therefore constructed an intervention model for the landings series for the period 1945–1993. The intervention term for the change in reporting systems in 1981 was significant and examination of the residuals indicated that no further terms were required for the noise component (see Table 2). The intervention model can be used to develop an estimate of the earlier landings if it can be assumed that the degree of under-reporting was roughly constant during 1945–1980. Comparison of Maryland and Virginia blue crab landings both adjusted and unadjusted for the change in Maryland reporting requirements using the coefficients derived from the intervention analysis on the 1945–1993 landings data show a much stronger coherence for the adjusted data (Fig. 3), again suggesting that calibration for the reporting change is justified.

## 4. Discussion

Our analysis indicates that changes in the reporting system for blue crab in Maryland in 1981 substantially affected the catch statistics for this species. It can be inferred that the change to a probability interview system resulted in an approximate doubling in landings relative to those under the previous self-reporting system. There is no reason to believe that the probability interview scheme could have resulted in an upward bias by a factor of 2. However, it would not be uncommon to have a downward bias in the self-reporting systems of the type employed prior to 1981, because of harvester's concerns related to income reporting and taxation. The change in reporting systems was in fact motivated by concerns that the mail census method employed prior to 1981 was providing a substantial underestimate of landings because of inaccurate reporting and because all gear sectors were not represented (Summers et al., 1983a,b). We therefore conclude that an upward adjustment is necessary for the pre-1981 landings series. The methods employed here provide a means of quantifying the magnitude of the change while accounting explicitly for the time series nature of the data.

The combined intervention-transfer model does indicate that changes in abundance account for a significant component of the variation in landings. We suggest that changes in abundance and/or availability are most appropriately viewed as contributing to fluctuations in landings superimposed on the larger-scale changes attributable to the switch in reporting systems (see Fig. 2).

If adjustments for the reporting system change are accepted, profound implications for the presumed stock status follow. In particular, the inference that population levels increased markedly during the early 1980s and remained at high levels until recently is not tenable. The adjusted long term catch series rather shows relatively stable landings levels until the mid-late 1990s. Any evaluation of stock status relying on trends in landings-per-unit-effort or on statistical catch-at-age methods would be strongly influenced by use of the unadjusted catch series. The consequences of not adjusting for the change in reporting systems in terms of risk to the resource are substantial in this instance.

Transfer function and/or intervention models have proven useful in evaluating factors affecting landings in other crustacean stocks (e.g. Noakes, 1986; Fogarty, 1988, 1989). In the present case, the availability of fishery-independent information is especially valuable in separating the effects of statistical reporting requirements from changes in underlying population levels. The Calvert Cliffs abundance index has previously been shown to provide critical insights into changes in abundance and demographic characteristics of blue crab in the Maryland portion of Chesapeake Bay (Abbe, 1983; Abbe and Stagg, 1996; Rugulo et al., 1998b; Miller and Houde, 1999).

The time series methods employed here provide a useful approach to assessing the impacts of reporting system changes in the absence of other information for inter-calibration of reporting methods. It should be noted that the time series available for analysis are relatively short and some caution must be exercised in interpretation. The large contrast in the landings data following the switch to the probability sampling scheme, however, does appear to permit valid statistical inference concerning the effects of the change. It would have been instructive to have a period of overlap between the old and new reporting systems to fully evaluate the implications of the switch in reporting requirements and we recommend that where possible, changes in reporting methodologies be accompanied by calibration studies to assess impacts. The combined information derived from landings trends and fishery-independent monitoring programs, however, provides sufficient evidence of an impact of the change in reporting system. Accordingly, we recommend that adjustment for the change in the Maryland reporting system be used in stock assessment and the development of management advice for the blue crab in Chesapeake Bay.

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