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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.

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**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 ob-

tain 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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47 The blue crab, *Callinectes sapidus*, currently sup- 78  
 48 ports the most valuable fishery in the Chesapeake 79  
 49 Bay. Recent assessments of the status of blue crab 80  
 50 in this region have been provided by Rugulo et al. 81  
 51 (1998a,b) and Miller and Houde (1999). These as- 82  
 52 sessments provide descriptors of trends in baywide 83  
 53 landings, fishing effort, catch-per-unit-effort, pop- 84  
 54 ulation size, and exploitation rates based on both 85  
 55 fishery-dependent and fishery-independent sources. 86  
 56 Central to the conclusions drawn in these assessments 87  
 57 is the interpretation of Maryland landings of blue 88  
 58 crab, which increased abruptly by a factor of 2 in 89  
 59 1981 (Fig. 1), coincident with a change in statistical 90  
 60 systems from a self-reporting system for harvesters 91  
 61 to a probability-based interview system. A further 92  
 62 change was instituted in 1994 with the transition to 93  
 63 mandatory reporting using trip tickets by all commer- 94  
 64 cial harvesters. 95

65 The increase in reported Maryland blue crab land- 96  
 66 ings in 1981 also coincided with a peak in abun- 97  
 67 dance in a fishery-independent trap survey conducted 98  
 68 in the Calvert Cliffs region of western Chesapeake 99  
 69 Bay (Abbe, 1983; Abbe and Stagg, 1996; see Fig. 1).  
 70 Rugulo et al. (1998a) attributed the increase in land-  
 71 ings to the apparent increase in abundance and did  
 72 not adjust the landings series for reporting system  
 73 changes. In contrast, Miller and Houde (1999) con-  
 74 cluded that the change in reporting systems in 1981  
 75 was the dominant factor in the increase in reported  
 76 landings based on an intervention analysis of the tim-  
 77 ing 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 dif-  
 ferent 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 devel-  
 opment 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 rela-  
 tive abundance using multi-variable time series mod-  
 els (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 assess-  
 ing the effect of changes implemented near the end of  
 the landings series using time series models. Accord-  
 ingly, 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

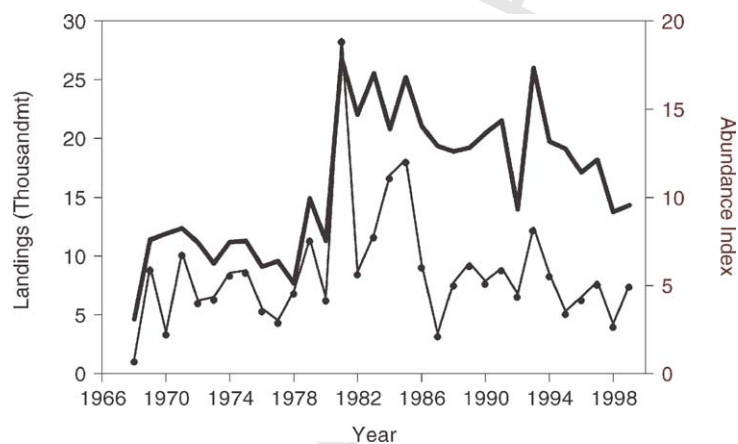


Fig. 1. Reported Maryland blue crab landings 1968–2001 (heavy solid line) and Calvert Cliffs trap-based abundance index (circles and thin solid line). Changes in reporting systems occurred in 1981 and 1994.

105 and in reporting systems, we sequentially fit time series models for the period 1968–1993 including (1) 106 a transfer function model relating reported Maryland 107 landings to the Calvert Cliff abundance index, (2) an 108 intervention model for landings as a function of the 109 change in reporting systems in 1981 and (3) a combined 110 model incorporating the abundance index and an 111 intervention term for the reporting changes. The distinction 112 between the transfer and intervention models (a special class 113 of transfer function models) is that the input term in the former 114 is a continuous random variable (relative abundance) while the 115 indicator variable in the latter essentially is a binary switch for 116 the reporting requirement change. We also developed an 117 intervention model for the period 1945–1993 to provide 118 a possible tool for adjusting the longer time series of 119 landings data (see also Miller and Houde, 1999).

120 Model parameters were estimated by the method of 121 maximum likelihood using the Box–Jenkins iterative 122 approach of model identification, estimation, and diagnostic 123 checking. Time series were checked for stationarity prior to 124 analysis. The abrupt change in landings in 1981, coincident 125 with the change in the reporting system, complicates 126 interpretation of stationarity of this series. In particular, 127 if the shift in level is due to the change in reporting systems, 128 adjusting the series by taking differences could obscure this 129 important effect. To overcome this problem, we analyzed the 130 landings series separately for the periods 1945–1980 and 131 1981–1993 and concluded that it was not necessary to 132 make adjustment for secular trends in the development of 133 intervention models because landings were stationary prior 134 to, and following, the change in reporting systems. We 135 transformed both the catch and relative abundance data to 136 natural logarithms to stabilize the variance prior to analysis. 137 The transformation results in a multiplicative model structure 138 and changes in landings can be represented as the product of 139 the (retransformed) coefficients and the input terms (relative 140 abundance and/or the intervention variable).

141 The model for landings as a function of the transformed 142 relative abundance series ( $x_t$ ) and the intervention ( $I_t$ ) can 143 be written as:

$$144 \quad y_t = \Theta_0 + \beta(B)x_t + \omega(B)I_t + \eta_t$$

145 where  $y_t$  is the transformed landings series at time  $t$ , 146  $\Theta_0$  a constant,  $\beta$  and  $\omega$  are the coefficients, and  $B$  the

147 so-called backward shift operator where:

$$148 \quad z_{t-m} = B^m z_t$$

149 The backshift operator provides a convenient way of 150 representing lagged values (of order  $m$ ) of the random 151 variable  $z$ . The error component  $\eta_t$  can be represented as an 152 autoregressive moving average process (Box and Jenkins, 1976): 153

$$154 \quad \eta_t = \frac{\theta_i(B)}{\phi_i(B)} a_t$$

155 where  $a_t$  is the random shock (Box and Jenkins, 1976), 156  $\phi_i$  the autoregressive parameters, and the  $\theta_i$  the moving 157 average parameters. A model with more complicated 158 intervention terms is possible to reflect a graduated 159 change in the system but was not necessary in this 160 analysis. The model can be generalized to account for 161 additional input terms as:

$$162 \quad y_t = \Theta_0 + \sum_{j=1}^r \beta_j(B)x_{j,t} + \sum_{k=1}^s \omega_k(B)I_{k,t} + \frac{\theta_i(B)}{\phi_i(B)} a_t$$

163 where the subscripts  $j$  and  $k$  represent different abundance 164 and intervention series, respectively (Kendall and Ord, 1990). 165 As more data accrue, the impact of the 1994 reporting 166 requirement change can be assessed using the generalized 167 model with the inclusion of an additional intervention term. 168

169 We first developed separate models for the transfer and 170 intervention elements to provide insights into the relative 171 importance of these individual components and then constructed 172 the combined model. To develop the transfer function model, 173 we first tested for stationarity and autocorrelation in the 174 log-transformed Calvert Cliffs series. This analysis indicated 175 that the abundance index was stationary and could best be 176 described as a white noise stochastic process. Further 177 filtering (or pre-whitening, Box and Jenkins, 1976) of this 178 series was therefore unnecessary prior to estimation of the 179 cross-correlation function and subsequent model fitting. 180

181 We used the akaike information criterion (AIC) for model 182 selection. The AIC is a robust information-theoretic measure 183 (Burnham and Anderson, 1998) that explicitly addresses the 184 issue of model parsimony. Models with a greater number of 185 parameters are assessed a penalty. The model with the lowest 186 AIC score is deemed the most appropriate model among those 187 188 189 190 191 192

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)	0.309	15.320
	$\beta_0 = 0.624$ (0.118)		
Transfer with ARMA errors	$\theta_0 = 1.957$ (0.269)	0.232	4.717
	$\beta_0 = 0.442$ (0.085)		
	$\phi_1 = 0.924$ (0.105)		
	$\theta_1 = 0.499$ (0.249)		
Transfer with differencing	$\theta_0 = -0.698$ (0.198)	0.316	16.451
	$\beta_\eta = 0.466$ (0.121)		
Intervention	$\theta_0 = 2.314$ (0.066)	0.237	1.495
	$\omega_0 = 0.746$ (0.093)		
Combined	$\theta_0 = 1.840$ (0.108)	0.17	-14.318
	$\beta_\eta = 0.359$ (0.074)		
	$\omega_0 = 0.570$ (0.076)		

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

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

$$196 \text{ AIC} = -2 \log_e[\mathcal{L}(\hat{\Phi} | x)] + 2K + \frac{2K(K + 1)}{n - k - 1}$$

197 where the first term in brackets is the likelihood func-  
198 tion,  $\hat{\Phi}$  the vector of estimated parameter values,  $K$   
199 the number of parameters, and  $n$  the number of obser-  
200 vations (Burnham and Anderson, 1998).

201 **3. Results**

202 A simple transfer function model under the as-  
203 sumption of a white noise error structure is equivalent  
204 to the ordinary least-squares regression model. If  
205 the model accurately reflects the underlying process,  
206 model residuals should be randomly distributed about  
207 the predicted response. We first fit a simple trans-  
208 fer function with uncorrelated errors and found that  
209 all residuals but one were negative prior up to and  
210 including 1981 and all but one were positive after  
211 1981. This pattern indicates that temporal changes in  
212 the landings series are not a simple linear function

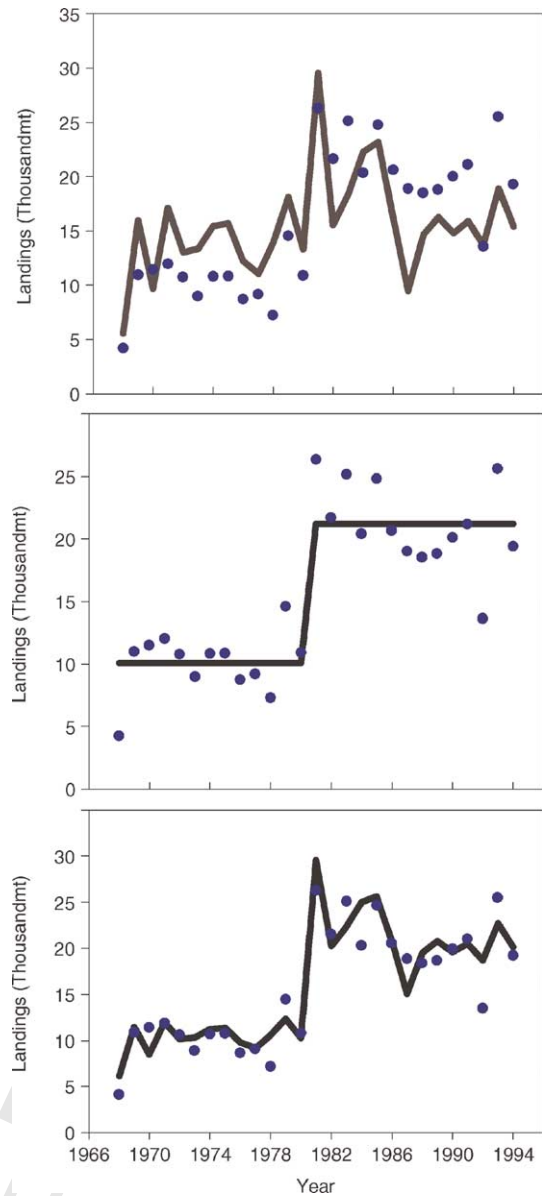


Fig. 2. Comparison of observed (circles) and predicted (lines) for simple transfer function model with no ARMA component (upper), an intervention model (middle) and combined model (lower).

of changes in abundance as measured by the Calvert  
Cliff series. Further diagnostic checking indicated  
that first-order autoregressive (AR) and moving aver-  
age (MA) terms were necessary to account for the  
residual pattern (Table 1). Inclusion of these terms  
resulted in a large decrease in the AIC<sub>c</sub>, indicating

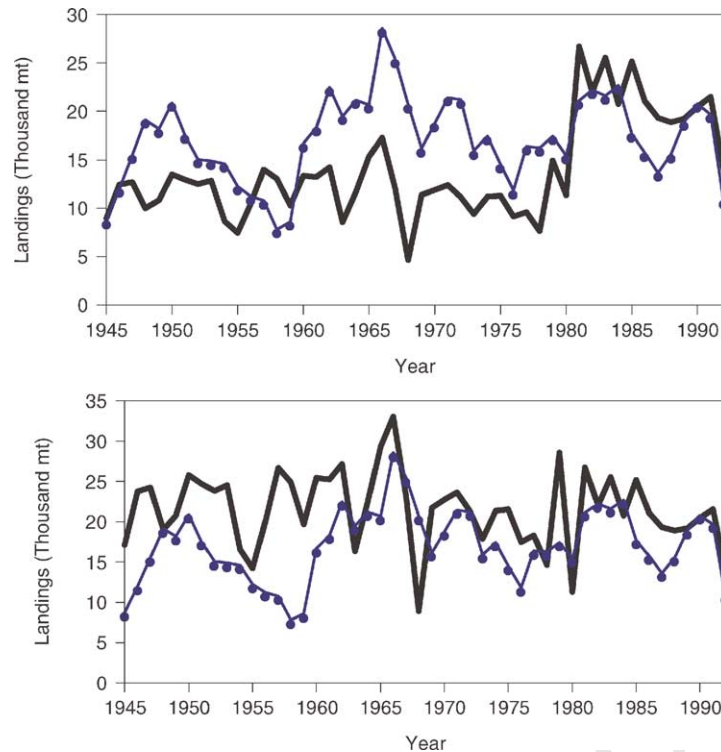


Fig. 3. Comparison of Maryland (heavy solid line) and Virginia (circles and thin solid line) blue crab landings for unadjusted (upper panel) and adjusted (lower panel) Maryland data.

219 a substantially improved fit (Table 1; Fig. 2). The  
 220 autoregressive parameter was, however, close to the  
 221 bounds of stationarity for this system indicating possi-  
 222 ble further model deficiencies. We therefore examined  
 223 an alternative model based on the first-differenced  
 224 landings series. The residuals of this model did  
 225 not differ significantly from white noise following  
 226 specification of a simple model including only the  
 227 Calvert Cliffs abundance index. The AIC was slightly  
 228 higher for this model than for the transfer function  
 229 model with a white noise error structure (Table 1)  
 230 and substantially higher than that for the trans-  
 231 fer model with autoregressive and moving average  
 232 terms.

233 It is instructive to note that had ordinary least-squares  
 234 regression analyses has been used to evaluate the  
 235 relationship between abundance and landings with-  
 236 out careful analysis of residual patterns, it would  
 237 have been concluded that the change in landings  
 238 was strongly influenced by changes in abundance

( $F_{1,30} = 20.46$ ;  $P < 0.0001$ ;  $R^2 = 0.41$ ). The nomi-  
 239 nal significance levels noted above would have been  
 240 very misleading, however, because of the strong auto-  
 241 correlation and distinct pattern in the residuals which  
 242 indicate deficiencies in the model specification.  
 243

244 Development of a model including only an interven-  
 245 tion term for the change in reporting systems in  
 246 1981 indicated a significant effect due to the change  
 247 in reporting methods. Examination of model residuals  
 248 indicated that no further terms were required (i.e. the  
 249 residuals followed a white noise stochastic process).  
 250 Based on the AIC scores, the intervention model re-  
 251 sulted in a substantially better fit than the simple  
 252 transfer function model with uncorrelated errors and in-  
 253 dicated an improved fit when compared with the more  
 254 complex transfer function models (Table 1; Fig. 2).

255 The full model including both abundance and inter-  
 256 vention terms resulted in a dramatic improvement in  
 257 the model fit over the alternatives as measured by the  
 258 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

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

261 Development of the models including both inter-  
262 vention and abundance terms can only be applied for  
263 the period, since 1968. The clear indication of the im-  
264 portance of the changes in the reporting system in  
265 1981 suggests the utility in developing an intervention  
266 model for the full catch time series to provide a broader  
267 historical perspective on stock status. We therefore  
268 constructed an intervention model for the landings se-  
269 ries for the period 1945–1993. The intervention term  
270 for the change in reporting systems in 1981 was sig-  
271 nificant and examination of the residuals indicated that  
272 no further terms were required for the noise compo-  
273 nent (see Table 2). The intervention model can be  
274 used to develop an estimate of the earlier landings if  
275 it can be assumed that the degree of under-reporting  
276 was roughly constant during 1945–1980. Compari-  
277 son of Maryland and Virginia blue crab landings both  
278 adjusted and unadjusted for the change in Maryland  
279 reporting requirements using the coefficients derived  
280 from the intervention analysis on the 1945–1993 lan-  
281 dings data show a much stronger coherence for the ad-  
282 justed data (Fig. 3), again suggesting that calibration  
283 for the reporting change is justified.

#### 284 4. Discussion

285 Our analysis indicates that changes in the reporting  
286 system for blue crab in Maryland in 1981 substan-  
287 tially affected the catch statistics for this species.  
288 It can be inferred that the change to a probability  
289 interview system resulted in an approximate dou-  
290 bling in landings relative to those under the previous  
291 self-reporting system. There is no reason to believe  
292 that the probability interview scheme could have re-  
293 sulted in an upward bias by a factor of 2. However,  
294 it would not be uncommon to have a downward bias  
295 in the self-reporting systems of the type employed

296 prior to 1981, because of harvester's concerns related  
297 to income reporting and taxation. The change in re-  
298 porting systems was in fact motivated by concerns  
299 that the mail census method employed prior to 1981  
300 was providing a substantial underestimate of land-  
301 ings because of inaccurate reporting and because all  
302 gear sectors were not represented (Summers et al.,  
303 1983a,b). We therefore conclude that an upward  
304 adjustment is necessary for the pre-1981 landings  
305 series. The methods employed here provide a means  
306 of quantifying the magnitude of the change while  
307 accounting explicitly for the time series nature of the  
308 data.

309 The combined intervention-transfer model does in-  
310 dicate that changes in abundance account for a sig-  
311 nificant component of the variation in landings. We  
312 suggest that changes in abundance and/or availability  
313 are most appropriately viewed as contributing to fluc-  
314 tuations in landings superimposed on the larger-scale  
315 changes attributable to the switch in reporting systems  
316 (see Fig. 2).

317 If adjustments for the reporting system change are  
318 accepted, profound implications for the presumed  
319 stock status follow. In particular, the inference that  
320 population levels increased markedly during the early  
321 1980s and remained at high levels until recently  
322 is not tenable. The adjusted long term catch series  
323 rather shows relatively stable landings levels until the  
324 mid-late 1990s. Any evaluation of stock status relying  
325 on trends in landings-per-unit-effort or on statistical  
326 catch-at-age methods would be strongly influenced by  
327 use of the unadjusted catch series. The consequences  
328 of not adjusting for the change in reporting systems  
329 in terms of risk to the resource are substantial in this  
330 instance.

331 Transfer function and/or intervention models have  
332 proven useful in evaluating factors affecting landings  
333 in other crustacean stocks (e.g. Noakes, 1986; Foga-  
334 rty, 1988, 1989). In the present case, the availability  
335 of fishery-independent information is especially valu-  
336 able in separating the effects of statistical reporting  
337 requirements from changes in underlying population  
338 levels. The Calvert Cliffs abundance index has pre-  
339 viously been shown to provide critical insights into  
340 changes in abundance and demographic characteristics  
341 of blue crab in the Maryland portion of Chesapeake  
342 Bay (Abbe, 1983; Abbe and Stagg, 1996; Rugulo et al.,  
343 1998b; Miller and Houde, 1999).

344 The time series methods employed here provide a  
 345 useful approach to assessing the impacts of reporting  
 346 system changes in the absence of other information  
 347 for inter-calibration of reporting methods. It should  
 348 be noted that the time series available for analysis are  
 349 relatively short and some caution must be exercised  
 350 in interpretation. The large contrast in the landings  
 351 data following the switch to the probability sampling  
 352 scheme, however, does appear to permit valid statisti-  
 353 cal inference concerning the effects of the change.  
 354 It would have been instructive to have a period of  
 355 overlap between the old and new reporting systems to  
 356 fully evaluate the implications of the switch in report-  
 357 ing requirements and we recommend that where possi-  
 358 ble, changes in reporting methodologies be accompa-  
 359 nished by calibration studies to assess impacts. The  
 360 combined information derived from landings trends  
 361 and fishery-independent monitoring programs, how-  
 362 ever, provides sufficient evidence of an impact of the  
 363 change in reporting system. Accordingly, we recom-  
 364 mend that adjustment for the change in the Maryland  
 365 reporting system be used in stock assessment and the  
 366 development of management advice for the blue crab  
 367 in Chesapeake Bay.

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