Application of CUSUM control charts to fourteen California fisheries

Christopher Free[1], John Wiedenmann[2]

[1] University of California, Santa Barbara, Santa Barbara, CA 93103; cfree14@gmail.com
[2] Rutgers University, New Brunswick, NJ 08901; john.wiedenmann@gmail.com

Summary

We tuned the cumulative sum (CUSUM) quality control method, a procedure used to detect when processes are "out-of-control", for application to fisheries through calibration on 121 stocks in the RAM Legacy Stock Assessment Database. The method was tuned to be precautionary and seeks to minimize the risk of misclassifying fish stocks in need of management attention as stable while also limiting the rate of false alarms. We applied the tuned CUSUM method to fourteen minor but developing California fisheries. Five developing California fisheries were identified as being in need of attention: (1) commercial fisheries for brown rock crab, redtail surfperch, shiner serfperch, and warty sea cucumber; and (2) recreational fisheries for ocean whitefish. However, due to the purposefully precautionary nature of the approach, we note that two of these classifications are likely to be false alarms.

1. Background

While many marine fish and invertebrate stocks have comprehensive stock assessments that take into account factors such as life history, age structure, and abundance trends, the majority of global fisheries remain unassessed and contribute to an increasing proportion of global catch. The dearth of data-rich assessments is due to a variety of factors including a lack of resources for data collection and evaluation. Although this problem is most prevalent in tropical, developing regions, it is also an issue for stocks with low economic importance, small population sizes, or challenging life histories. This is the case for several minor but developing commercial and recreational fisheries in California for species such as night smelt (*Spirinchus starksi*), ridgeback prawn (*Sicyonia ingentis*), warty sea cucumber (*Parastichopus parvimensis*), and white croaker (*Genyonemus lineatus*). Determining when these species require management attention is critical for sustainably developing these fisheries.

Cumulative sum (CUSUM) quality control methods present a promising approach for monitoring the catch of data-limited species and for determining when patterns in the catch might signal a need for closer management attention. CUSUM methods detect persistent changes in an observed process by measuring the cumulative sum of deviations of the process from its mean (Hawkins and Olwell 1997). By defining thresholds of expected variability, CUSUM can be used to identify when a process is "out-of-control". Scandol (2003) suggested that CUSUM methods could be used to monitor the catch time series of data-limited fisheries and determine when patterns in the catch should trigger management attention. Here, we tune

CUSUM to data-rich stocks in the RAM Legacy Database and use this tuned version of CUSUM to assess fourteen developing California fisheries and their need for management attention.

2. Methods

2.1 CUSUM control methods

The CUSUM approach is implemented in three steps. First, a standardized catch time series, $C_{sd,t}$, is calculated by centering the observed catch time series, $C_{obs,t}$, on zero and by scaling it to unit variance:

$$C_{sd,t} = [C_{obs,t} - mean(C_{obs,t})] \,/\, sd(C_{obs,t})$$

Second, cumulative deviations from the process mean are calculated as the upper and lower CUSUM time series where the upper CUSUM arm, ϕ_t^+, is calculated as:

$$\phi_t^+ = \begin{cases} 0, & t = 0 \\ \max(0, \phi_{t-1}^+ + C_{sd,t} - k), & t > 0 \end{cases}$$

and the lower CUSUM arm, ϕ_t^-, is calculated as:

$$\phi_t^- = \begin{cases} 0, & t = 0 \\ \min(0, \phi_{t-1}^- + C_{sd,t} + k), & t > 0 \end{cases}$$

and *k* is known as the allowance. Finally, the catch time series is identified as "out-of-control" in year *t* if either the lower or upper CUSUM arms fall outside the decision interval ($\pm h$):

$$\phi_t^+ > h \text{ or } \phi_t^- < -h$$

2.2 Tuning CUSUM to data-rich stocks

We identified optimal values for *h* and *k* by tuning CUSUM to data-rich stocks in the RAM Legacy Stock Assessment Database (RAM v4.41; Ricard et al. 2012). The tuning was performed using the 121 stocks with at least 20 years of catch data preceding 1980 and with an estimate of stock status (B/B_{MSY}) in 1980 (**Figure 1**). We tuned CUSUM to pre-1980 data to reduce the influence of management on patterns in the catch and to most fairly measure the ability for CUSUM to identify stocks in need of management attention.

We evaluated 6 values of *k* (0.25 to 1.50 by 0.25) and 50 values of *h* (0.1 to 5.0 by 0.1). We applied CUSUM to each stock using each combination of these parameters and recorded whether CUSUM identified the stock as "in-control" (i.e., $\phi_{1980}^+ < h \; and \; \phi_{1980}^- > -h$) or "out-of-control" (i.e., $\phi_{1980}^+ > h \; or \; \phi_{1980}^- < -h$). An in-control designation suggests that the stock is stable and not a priority for management. An out-of-control designation suggests that a stock is in need of management attention. We then ask: "how well do the CUSUM designations predict the need for management attention now or in the near future (i.e., next five years)?" To answer this question, we compared the CUSUM designations to B/B_{MSY} estimates from 1980-1985 using four B/B_{MSY} thresholds that could indicate a need for management attention: 1.4, 1.3, 1.2, and 1.1. We selected these thresholds because management is generally necessary before stocks are fished below a B/B_{MSY} of 1.0 (i.e., a common fisheries management target). We categorized the accuracy of each CUSUM prediction into the following error types:

1. **True positive -** the fishery is below the reference point (i.e., in need of attention) and CUSUM correctly identifies it as in need of attention;
2. **True negative -** the fishery is above the reference point (i.e., stable) and CUSUM correctly identifies it as stable;
3. **False positive -** the fishery is above the reference point (i.e., stable) and CUSUM incorrectly identifies it as in need of attention;
4. **False negative -** the fishery is below the reference point (i.e., in need of attention) and CUSUM incorrectly identified it as stable.

We calculated the probability of each error type for each combination of tuning parameters and B/B_{MSY} trigger points and identified the optimal tuning parameters as those that (1) minimize false negatives (i.e., where CUSUM incorrectly identifies stocks as stable); (2) maximize true positives (i.e., where CUSUM correctly identifies stocks as requiring attention); and (3) limits the rate of false positives (i.e., false alarms where CUSUM incorrectly identifies stable stocks as requiring attention) to less than 40%. This precautionary approach seeks to minimize the risk of missing stocks that require attention while also curtailing the rate of false alarms.

2.3 Applying CUSUM to data-poor stocks

We applied the tuned CUSUM to fourteen developing California fisheries. These fisheries include ten commercial fisheries with total landings in pounds of fish and four recreational fisheries with total landings in numbers of fish (**Table 1**). Ocean whitefish are targeted in both commercial and recreational fisheries and each sector is analyzed separately. The landings time series for brown rock crab and shiner surfperch were missing values and these gaps were imputed using linear interpolation (**Figure 3**).

3. Results

3.1 Tuning CUSUM to the RAM Legacy Database

Figure 2 illustrates the performance tradeoffs inherent to each combination of *h*, *k*, and B/B_{MSY} trigger point threshold when testing CUSUM on the 121 data-rich stocks. We judged k=0.5 and h=1.0 to present the optimal balance between minimizing false negatives, maximizing true positives, and curtailing false alarms. Although a *k* of 0.25 maximizes the probability of true positives and minimizes the probability of false negatives, it exhibits a high rate of false positives (false alarms), which dilutes the usefulness of a trigger warning in prioritizing stocks in need of attention. These tuning parameters correctly identified the status of 50% of stocks and misclassified 9% of stocks in need of attention as stable. The probability that a stock classified as in need of attention is actually stable is about 46%.

3.2 Application to CA fisheries

Five developing California fisheries were identified as being in need of attention: (1) commercial fisheries for brown rock crab, redtail surfperch, shiner serfperch, and warty sea cucumber; and (2) recreational fisheries for ocean whitefish (**Table 1; Figure 4**).

References

Hawkins, D.M., Olwell, D.H. (1997) Cumulative Sum Charts and Charting for Quality Improvement. Springer, New York.

Scandol, J.P. (2003) Use of cumulative sum control charts of landed catch in the management of fisheries. *Fisheries Research* 64: 19-36.

Ricard, D., Minto, C., Jensen, O.P., Baum, J.K. (2012) Examining the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. *Fish and Fisheries* 13(4): 380-398.

Tables and Figures

Table 1. Fourteen developing California fisheries evaluated in the analysis.

Stock	Years of data	Mean landings (1000s)	Units	Status
Commercial fisheries				
Brown rock crab (*Romaleon antennarium*)	1997-2017	60.1	pounds	in need of attention
Dungeness crab (*Metacarcinus magister*)	1997-2017	15534.9	pounds	stable
Jacksmelt (*Atherinopsis californiensis*)	1997-2017	22.4	pounds	stable
Kellet's whelk (*Kelletia kelletii*)	1997-2017	94.0	pounds	stable
Night smelt (*Spirinchus starksi*)	1997-2017	323.9	pounds	stable
Ocean whitefish (*Caulolatilus princeps*)	1997-2017	7.4	pounds	stable
Redtail surfperch (*Amphistichus rhodoterus*)	1997-2017	17.1	pounds	in need of attention
Ridgeback prawn (*Sicyonia ingentis*)	1997-2017	459.1	pounds	stable
Shiner surfperch (*Cymatogaster aggregata*)	1997-2017	0.2	pounds	in need of attention
Warty sea cucumber (*Parastichopus parvimensis*)	2003-2017	296.8	pounds	in need of attention
Recreational fisheries				
Bonito (*Sarda chiliensis*)	2005-2017	109.0	individuals	stable
Corbina (*Menticirrhus undulatus*)	2005-2017	14.2	individuals	stable
Ocean whitefish (*Caulolatilus princeps*)	2005-2017	59.5	individuals	in need of attention
White croaker (*Genyonemus lineatus*)	2005-2017	110.2	individuals	stable

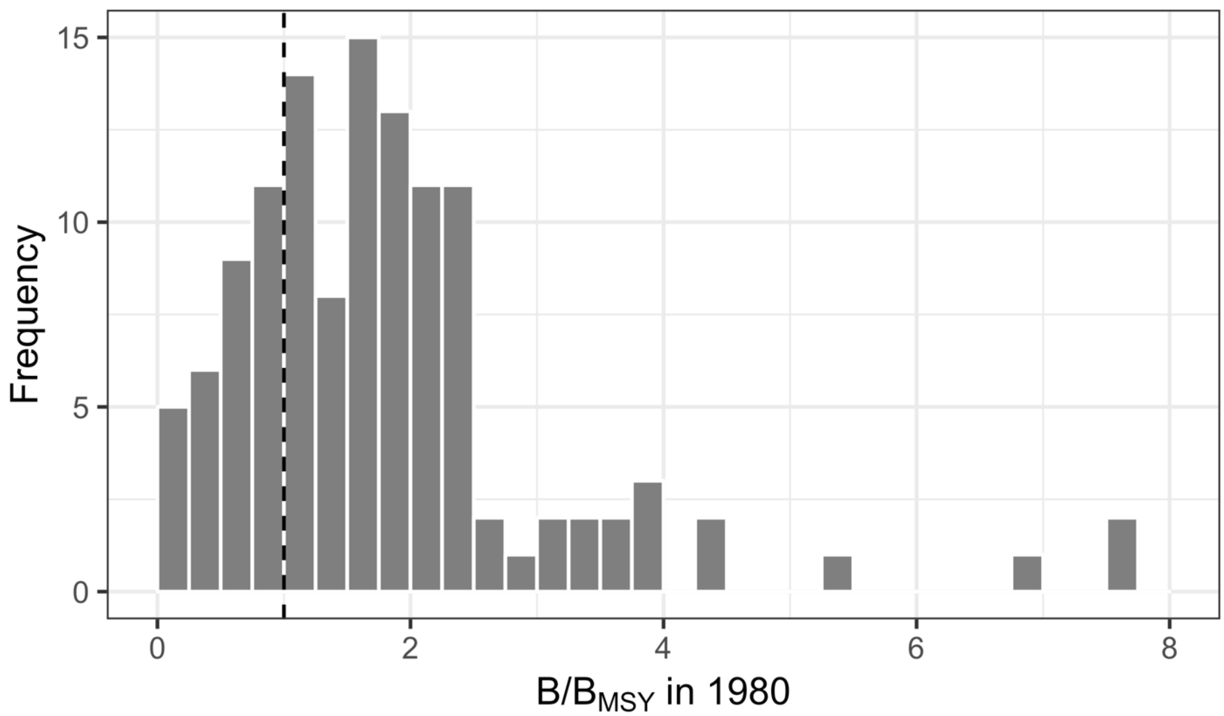

Figure 1. B/B_{MSY} in 1980 of the 121 data-rich stocks from the RAM Legacy Database used to tune CUSUM for application to fisheries catch data. The vertical line indicates a B/B_{MSY} of 1.0 which is a common fisheries management target. Management should begin before a stock is fished below a B/B_{MSY} of 1.0 in order to achieve this target.

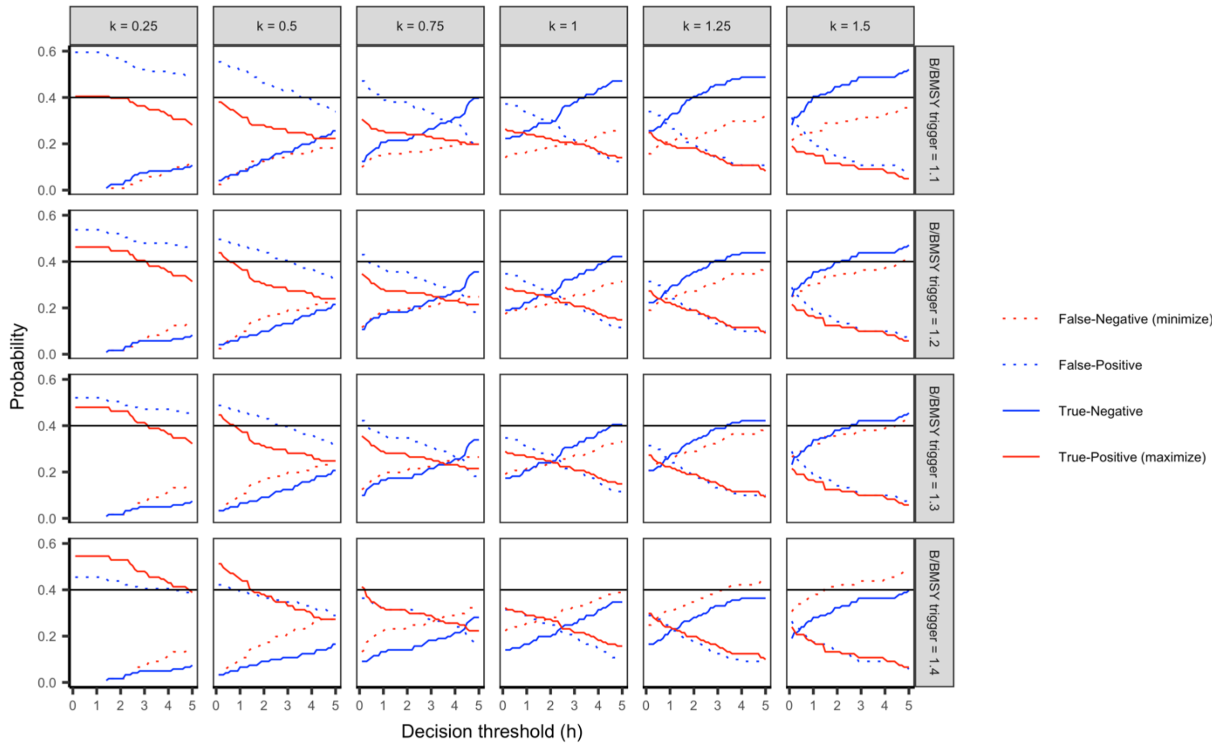

Figure 2. Visualization of the CUSUM parameter tuning process. Colored lines show the probability of each error type for each combination of allowance (*k*), decision interval (*h*), and B/B_{MSY} trigger value. We selected k=0.5 and h=1.0 as the optimal CUSUM parameters because they (1) minimize the classification of stocks in need of attention as stable (false-negatives) and (2) maximize the correct classification of stocks in need of attention (true-positives); while (3) curtailing false alarms (false-positives) to a probability of 40%.

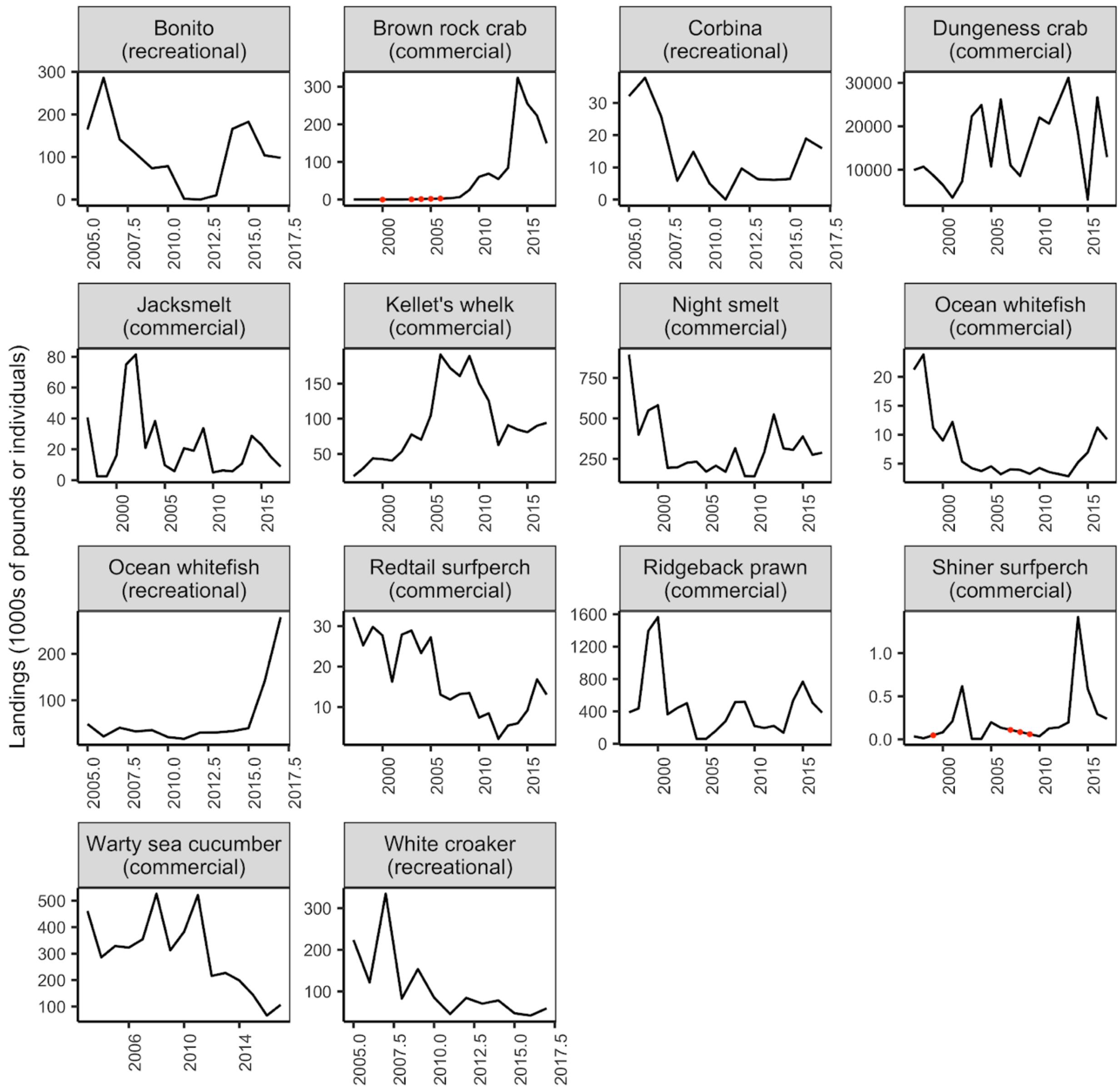

Figure 3. Landings time series for the fourteen California fisheries. Red points indicate imputed landings values. Landings for commercial and recreational fisheries are reported in pounds and number of individuals, respectively.

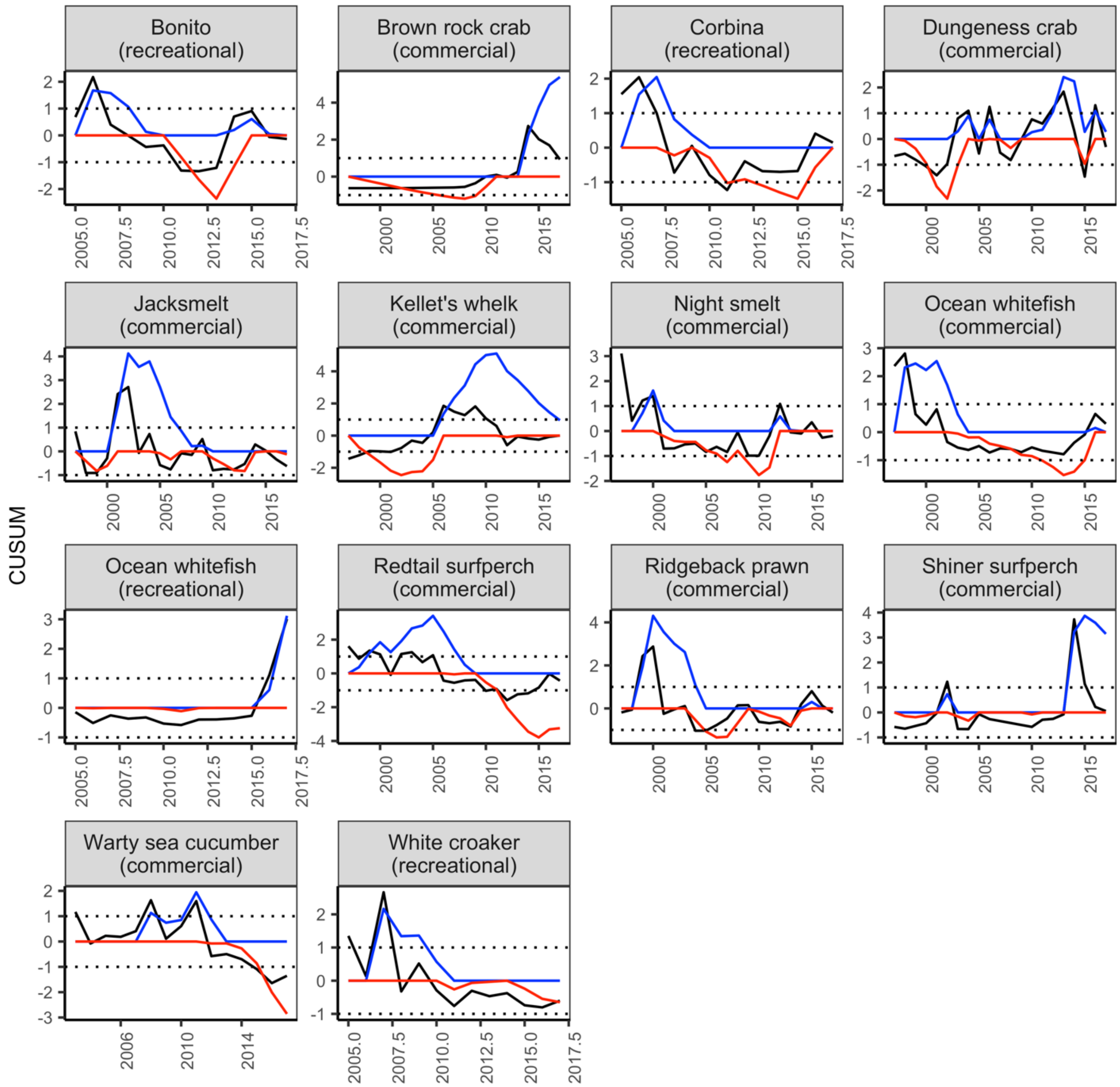

Figure 4. Application of the tuned CUSUM approach (h=1 and k=0.5) to the landings time series of the fourteen California fisheries. Black lines indicated the standardized (i.e., centered and scaled) landings time series. Blue and red lines indicate the upper and lower CUSUM arms, respectively. Dotted lines indicate the decision intervals. If either the upper or lower CUSUM arms cross these thresholds in 2017, the fishery is classified as “out-of-control” or in need of attention.