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Exploratory analysis of stock-recruitment relationships for New Zealand red rock lobster (*Jasus edwardsii*)

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Pons, M.[1]; Rudd, M.B.[2]; Webber, D.N.[3] (2022). Exploratory analysis of stock-recruitment relationships for New Zealand red rock lobster (*Jasus edwardsii*).

***New Zealand Fisheries Assessment Report 2022/50*. 30 p.**

The relationship between parental (spawning) fish biomass and the resulting recruitment (typically at or just prior to the size at which individuals become vulnerable to fishing) is called the stock-recruitment relationship. Where established, this relationship can be used to predict the magnitude of recruitment that would be produced at different population sizes. It has been observed that biomass of the red rock lobsters (*Jasus edwardsii*) is higher inside marine protected areas compared with unprotected areas in New Zealand. Increasing the spawning stock biomass (*SSB*) within a stock may result in increased recruitment. Therefore, some sector groups claim that marine protected areas result in higher recruitment to red rock lobster fisheries by protecting spawning lobsters. However, the strength of stock-recruitment relationships has not been tested for New Zealand red rock lobster stocks and no stock-recruitment function is currently used in their assessments.

The present study explored simple linear Pearson correlations with different lag times (from 1 to 5 years) between times series of *SSB* and recruitment estimated by the most recently updated or current rock lobster assessments. All stocks combined, individual Quota Management Areas (QMAs) for CRA 1 to CRA 6, and some QMAs combined were examined. If a stock-recruitment relationship exists, a positive correlation between *SSB* and recruitment would have been expected.

There were no linear correlations between *SSB* and recruitment for any number of lagged years or stock grouping. This suggests that increases in *SSB* may not lead to subsequent increases in recruitment across the estimated range of stock levels. On the contrary, the outputs were generally consistent with weak negative correlations between estimated *SSB* and recruitment. This apparent negative relationship was slightly stronger for recruits per spawner (number of recruits/*SSB*), particularly for CRA 1 and CRA 5. A negative relationship between *SSB* and recruitment may be indicative of the operation of a biological process such as density-dependent competition by lobsters or cannibalism of young stages by adults. An alternative explanation for the general lack of correlation between model estimated *SSB* and recruitment is that their estimation is biased in some way by structural model assumptions (i.e., recruits and spawners are not adequately modelled) or non-representative inputs (e.g., uncertain historical catch).

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[2] Scaleability LLC, USA.
[3] Quantifish Limited, New Zealand.

1. INTRODUCTION

The relationship between the parental (spawning) fish biomass and the resulting recruitment (typically at or just prior to the size at which individuals become vulnerable to fishing) is called the stock-recruitment relationship. Where established, this relationship can be used to predict the magnitude of recruitment that would be produced at different population sizes. The most common stock-recruitment function used in fisheries, including many New Zealand stocks, is the Beverton-Holt function (Beverton & Holt 1957, Bull et al. 2012), where the predicted number of recruits reaches an asymptote as spawning biomass increases. The Ricker function (Ricker 1954), where the predicted number of recruits may asymptote or decrease with increasing spawning biomass due to various biological processes, is rarely used.

It has been observed that biomass of the red rock lobsters (*Jasus edwardsii*) is higher inside marine protected areas (MPAs) compared with unprotected areas in New Zealand (Kelly et al. 2000, Jack & Wing 2010). Jack & Wing (2010) also showed the importance of marine reserves to increase optimal reproductive potential of red rock lobster populations by protecting mature individuals. Based on this evidence, some sector groups claim that MPAs result in higher recruitment to red rock lobster (*Jasus edwardsii*) fisheries by protecting spawning lobsters. This claim has been used to push for more MPAs but has not been supported by evidence. Would an increase in red rock lobster spawning biomass above current levels lead to an increase in rock lobster recruitment to the fishery? Increasing the spawning stock biomass (*SSB*) and the reproductive potential of individuals within a stock may not result in increased recruitment if, for example, recruitment success is hampered by unfavourable environmental processes (e.g., unfavourable water temperature, prevailing wind directions, etc.).

Currently, there are no stock recruitment relationships included in any of the stock assessment models for New Zealand red rock lobsters. There has been some recent questioning among stakeholders of the assumption that a stock-recruit relationship is not required when modelling these stocks. This issue was discussed at a rock lobster fisheries research planning meeting convened by Fisheries New Zealand and the New Zealand Rock Lobster Industry Council in November 2020; it was agreed that possible relationships between *SSB* and recruitment should be explored.

This analysis uses the outputs of recent red rock lobster stock assessment models to evaluate the evidence for the strength and direction of stock-recruitment relationships for these stocks in New Zealand. For red rock lobsters, this relationship would be lagged in time between spawning and recruitment to the fishery (i.e., one year between spawning and settlement as pueruli plus two to three years until recruitment to the fishery in the assessment model) (Roberts & Webber 2022). Based on the assumption that a larger *SSB* leads to higher recruitment, a positive correlation between these quantities would be expected. The objective of this study is to explore simple linear cross-correlations between the time series of *SSB* and recruitment as estimated by the most recent rock lobster stock assessments. All stocks combined, individual Quota Management Areas (QMAs, Figure 1) for CRA 1 to CRA 6, and some QMAs combined were explored.

2. METHODS

The median annual values of SSB and recruitment of the posterior distribution were extracted from the most recent full base case stock assessment or rapid update assessment for QMAs CRA 1 to CRA 6 (i.e., all except CRA 7 and CRA 8[4]) (CRA 1, Rudd et al. 2021a; CRA 2, Webber et al. 2018; CRA 3, Webber et al. 2020; CRA 4, Rudd et al. 2021b; CRA 5, Webber et al. 2021; and CRA 6, Rudd et al. 2019).

A simple pairwise correlation analysis between time series of *SSB* and recruitment with different lags was applied. Rock lobsters are planktonic for 1 to 1.5 years before settlement to inshore benthic substrates and take another 2 to 3 years before they recruit to the fishery / stock assessment model at

[4] The most recent stock assessment of CRA 7/CRA 8 available at the time when this analysis was done (Haist et al. 2016) was considered problematic because of the confounding of recruitment with movement which the model assumed occurred between CRA 7 and CRA 8.

about 30 mm tail width (Bradford et al. 2014, Roberts & Webber 2022), so lags from 1 to 5 years were used. This was done for:

- each QMA, including CRA 1 to CRA 6;
- aggregated *SSB* and aggregated recruitment across all stocks;
- recruitment in CRA 3 compared with *SSB* in CRA 4 ('Rec3_SSB4');
- recruitment in CRA 3 compared with *SSB* in CRA 4 and CRA 5 ('Rec3_SSB4_5'); and
- aggregated recruitment in CRA 2, CRA 3, and CRA 4 compared with aggregated *SSB* in CRA 3, CRA 4, and CRA 5 ('Rec2_3_4_SSB3_4_5').

The time series for each stock started in 1945, except for CRA 2 and CRA 6, which started in 1979 and 1965, respectively (the full time series for these stock assessment models). When grouping CRA 2 in the last scenario, only the times series that overlapped from 1979 onwards was summed. For the two-region stock assessments (CRA 3 and CRA 5) correlations between *SSB* and recruits for each region separately and for both regions together were looked at. CRA 3 has two base models (one called CRA 3_r1_qdrift which excludes tags at liberty less than one year and the other CRA 3_r2_qdrift which includes all tags regardless of their time at liberty), each with two regions, so six correlations were explored for this stock. The complete time series of estimates of *SSB* and the number of recruits analysed in this study is shown in Figure 2. Figure 3 shows the same data, but each point is a yearly *SSB*-recruits pair, with *SSB* along the x-axis and recruits on the y-axis.

The following was explored: if y_t (i.e., the number of recruits) is correlated with x_t (i.e., *SSB*), lagged across a range of k years. The function *ccf* in R (R Core Team 2021) was used to compute the Pearson correlation or cross-correlation between these *SSB* and recruitment time series. This function calculates the correlation between x_{t+k} and y_t, where x_t is the median *SSB* at time t, k is the year lag ranging from $k = -1$ to $k = -5$, and y_t is the median recruits at time t.

The *ccf* function in R could help identify lags of the x-variable (i.e., *SSB*) that might be useful predictors of the y-variable (i.e., recruits). A negative value of k is a correlation between the x-variable at a time $t - k$ and the y-variable at time t. For example, $k = -3$ would give us the correlation between recruits at time t and *SSB* at time $t - 3$, or the relationship between recruits today and *SSB* three years ago. Correlation values range from -1 to 1, where values close to 0 imply no correlation. A strong correlation from a negative lag would indicate that current recruitment is related to past *SSB*.

The cross-correlations between recruits per spawner (number of recruits/*SSB*) and *SSB* were also explored to investigate if there is an increase in recruits per spawner when *SSB* increases.

3. RESULTS

Table 1 shows the correlation values between *SSB* and the number of recruits for each stock or combined stocks. Correlation values ranged from -0.41 to 0.30. Correlations were generally negative for all stocks. However, the correlations were very low or close to zero, indicating little to no correlation between model estimated *SSB* and recruitment. The highest negative correlation value observed (-0.41) was in CRA 5 for region 2 at $k - 5$. In general, the highest correlation occurred for $k - 3$ with a median of -0.21 for the time series considered. Exceptions included CRA 2 (see Figure 6) and the aggregated recruitment in CRA 2, CRA 3, and CRA 4 versus aggregated *SSB* in CRA 3, CRA 4, and CRA 5 ('Rec2_3_4_SSB3_4_5', see Figure 18) where correlations were positive, but also low, indicating little to no correlation between *SSB* and recruitment as well.

Figure 4 to Figure 20 show scatter plots of lagged correlation indices for every stock or stock combination with a smooth line to show tendencies for lags (k) -1 to -5. Some stocks (e.g., CRA 1) showed a slightly decreasing tendency (i.e., recruits decrease with higher *SSB*) and others (e.g., CRA 2) showed an opposite trend. In general, all analyses showed flat, smooth correlation lines, which indicates no linear stock-recruitment relationships. The Loess smooth curve for CRA 4 (Figure 13) showed a shape that resembles to a Ricker function, but the pattern was observed only for this stock.

The negative correlation between *SSB* and recruitment was slightly stronger when the relationship between recruits per spawner and *SSB* (Figure 21) was analysed. Recruits per spawner decrease with increasing *SSB*. In this case, all correlations were negative with a range of values between -0.06 and -0.70 (Table 2) with stronger negative correlations for CRA 1, CRA3_r2_qdrift, and CRA 5.

4. DISCUSSION

The results of this simple Pearson correlation analysis suggest that there are no linear relationships between *SSB* and recruits at any number of lagged years included in this analysis. Increases in estimated *SSB* were not positively correlated with increases in recruitment in subsequent years. Only CRA 2 showed a positive relationship between spawners and recruits, but the correlation values were very low (0.13 for lag -3 and -4, whereas values > 0.6 would suggest significant correlations). This stock was the most depleted, and this is probably why this relationship was seen.

The apparent negative relationship observed for all other stocks and stock combinations, particularly for the ratio of recruits per spawner as spawners increase (Figure 21, Table 2), could be indicative of the operation of a biological process such as density-dependent competition by lobsters on reefs or cannibalism of young stages by adults. Density dependence is typical of cryptic species such as lobster which require finite shelter on reefs to avoid predation (Butler et al. 1997).

The present study only considered linear relationships even though some stock-recruitment relationships are not strictly linear. Furthermore, a Bonferroni correction factor (normally used to counteract the problem of inflated type I errors when using multiple pairwise comparisons) was not considered in this analysis since no formal statistical or significance tests were performed.

Future work could assess the degree to which environmental (e.g., long-term changes in sea temperature and oceanography) or biological processes (e.g., population-level density dependence or cannibalism) might alter or obscure the effects of variable *SSB* on the number of recruits. Also, this analysis assumed that model-based estimates of *SSB* and recruits were accurate. An alternative explanation for the general lack of or negative correlation between model estimated *SSB* and recruits is that their estimation is biased in some way by model structural assumptions (i.e., recruits and spawners are not adequately modelled, or there may be a large cryptic biomass that contributes to recruitment but is not available to the fishery) or non-representative inputs (e.g., uncertain levels of historical catch).

Theoretically there must be a relationship between spawners and recruits at very low biomass levels, therefore it is still important to consider *SSB*-related risk constraints when considering reference levels and management thresholds.

5. ACKNOWLEDGEMENTS

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7. FIGURES

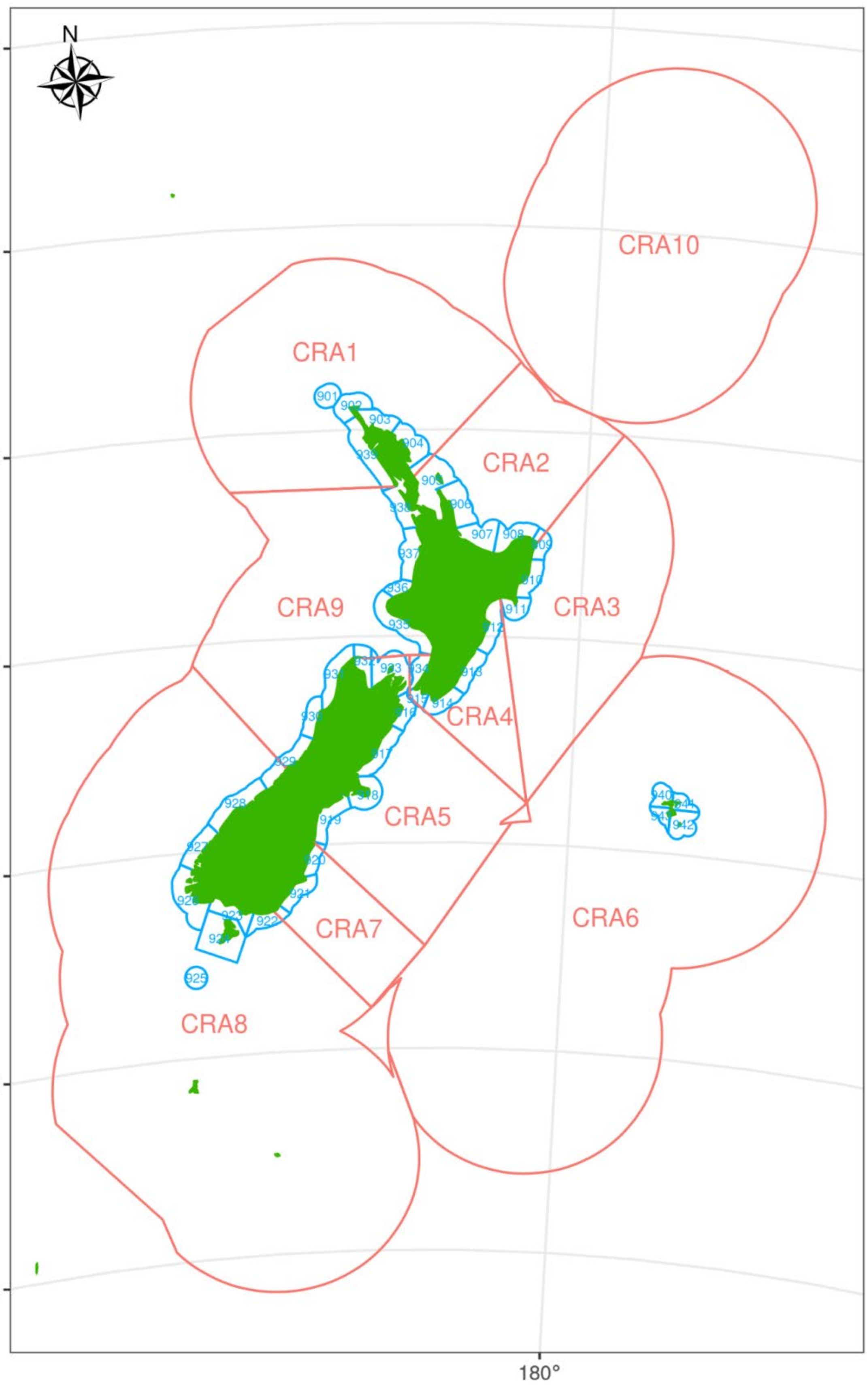

Figure 1: New Zealand red rock lobster (*Jasus edwardsii*) Quota Management Areas (QMAs) (polygons bounded by red lines) and statistical areas (polygons bounded with blue lines). Note that only the QMAs CRA 1 to CRA 6 are relevant to this assessment but not the statistical areas.

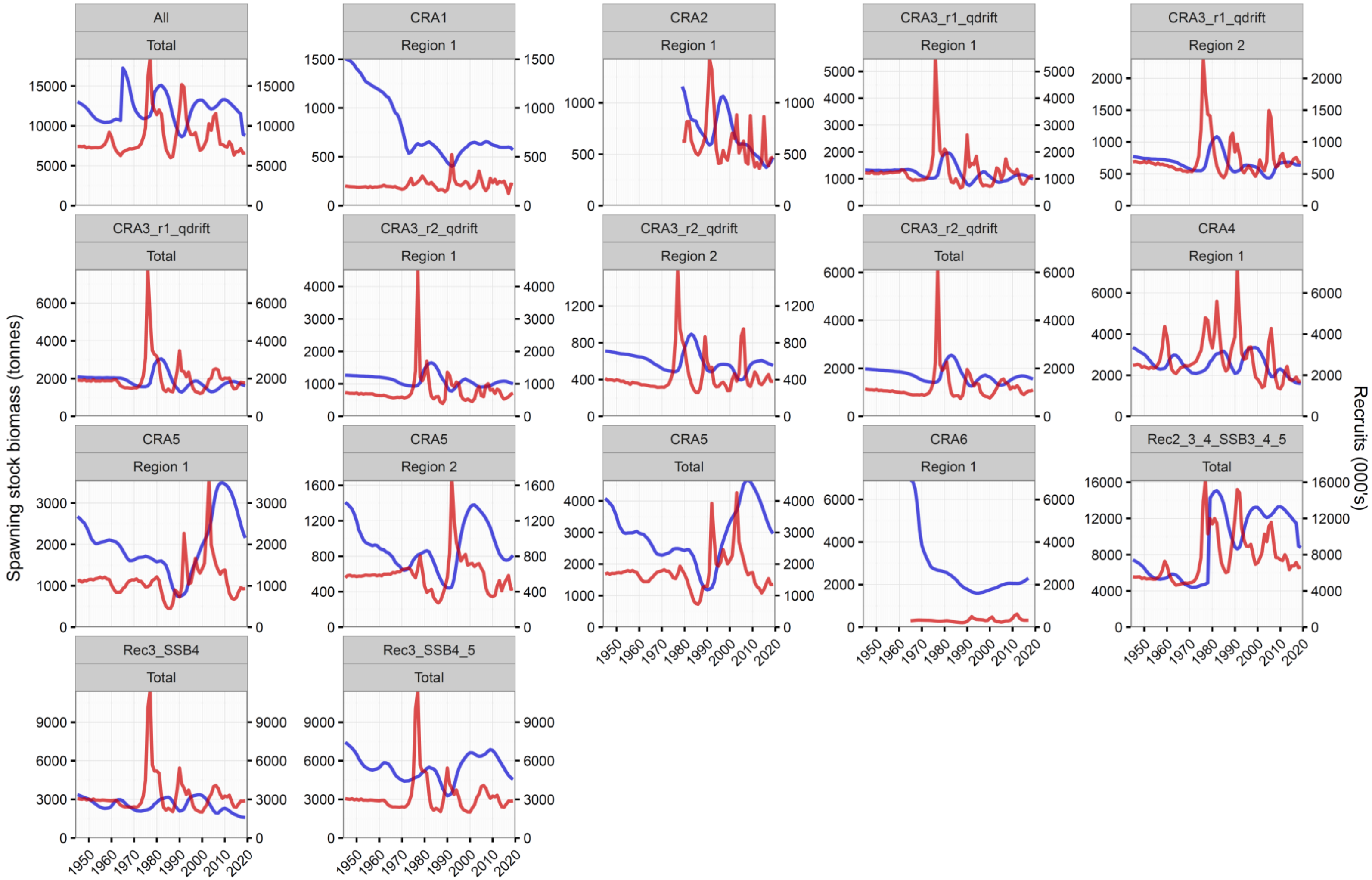

Figure 2: Spawning stock biomass (tonnes) on the primary y-axis (blue) and recruits (thousands of individuals) on the secondary y-axis (red) by year for each stock or combination of stocks. CRA 3_r1_qdrift: model which excludes tags at liberty less than one year; CRA 3_r2_qdrift: model which includes all tags regardless of their time at liberty; Rec3_SSB4: recruitment in CRA 3 compared with SSB in CRA 4; Rec3_SSB4_5: recruitment in CRA 3 compared with *SSB* in CRA 4 and CRA 5; and Rec2_3_4_SSB3_4_5: aggregated recruitment in CRA 2, CRA 3, and CRA 4 compared with aggregated *SSB* in CRA 3, CRA 4, and CRA 5.

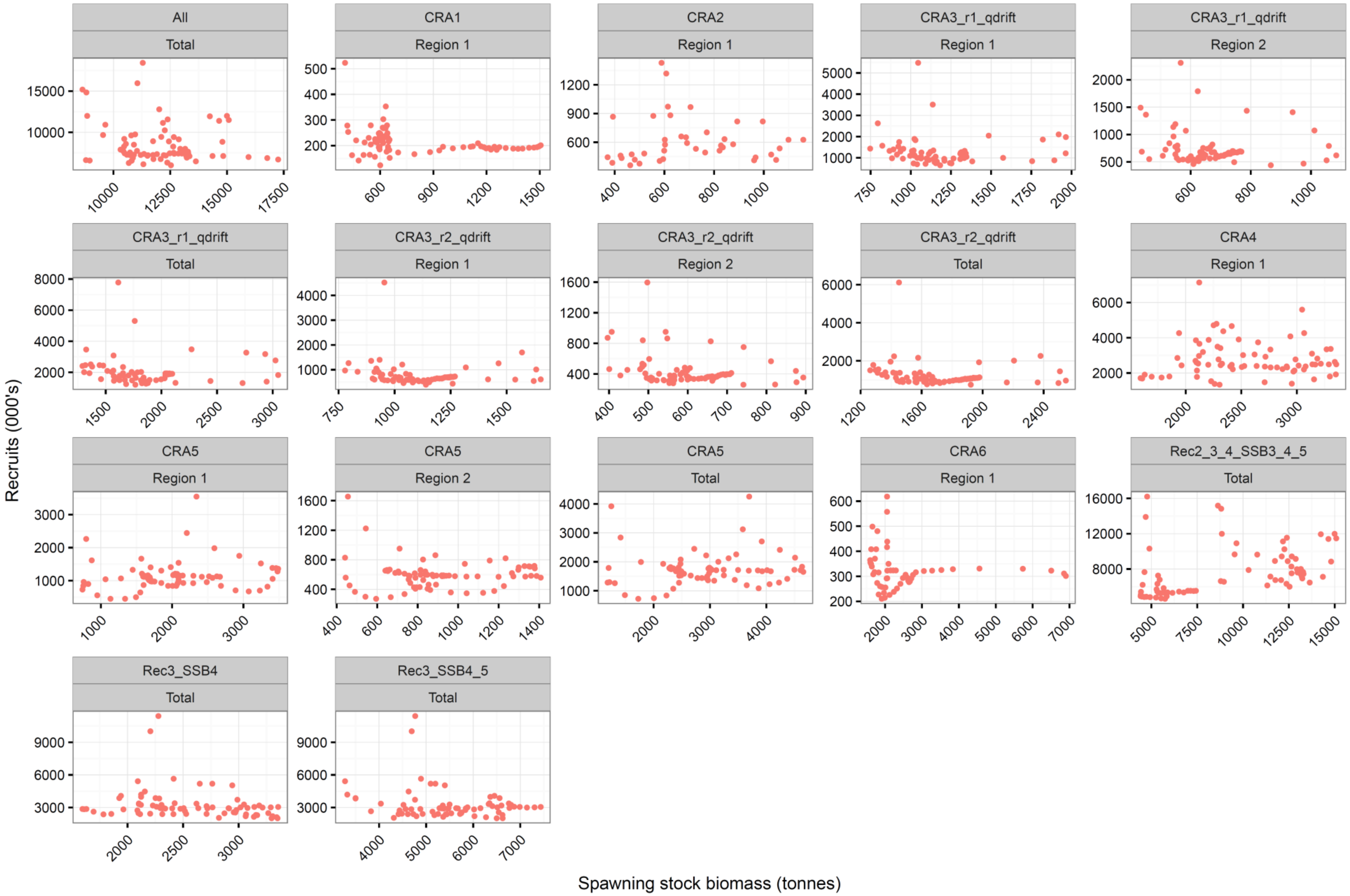

Figure 3: Relationship between recruits (thousands of individuals) and spawning stock biomass (tonnes) for each stock or combination of stocks in each panel. CRA 3_r1_qdrift: model which excludes tags at liberty less than one year; CRA 3_r2_qdrift: model which includes all tags regardless of their time at liberty; Rec3_SSB4: recruitment in CRA 3 compared with *SSB* in CRA 4; Rec3_SSB4_5: recruitment in CRA 3 compared with *SSB* in CRA 4 and CRA 5; and Rec2_3_4_SSB3_4_5: aggregated recruitment in CRA 2, CRA 3, and CRA 4 compared with aggregated *SSB* in CRA 3, CRA 4, and CRA 5.

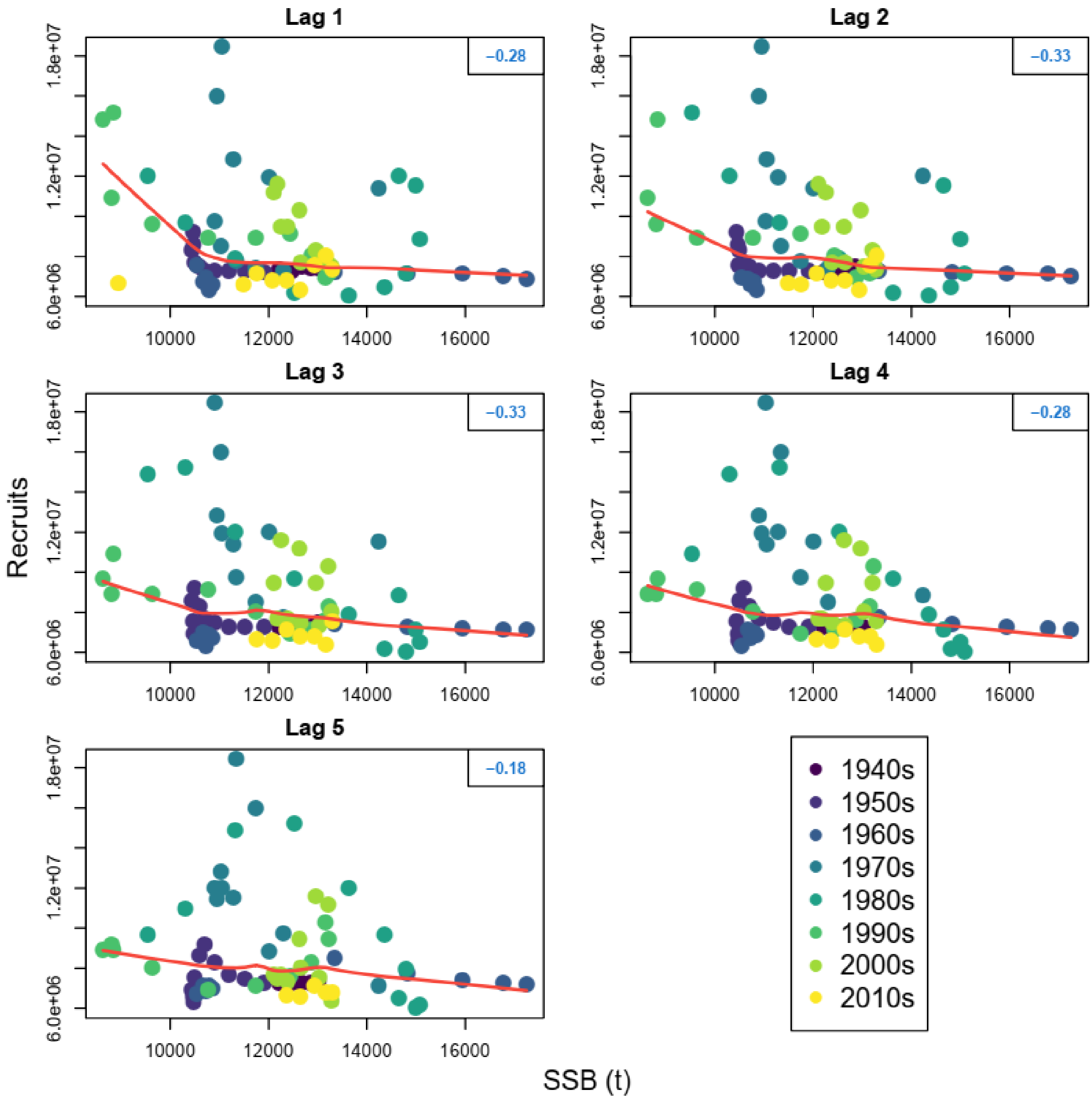

Figure 4: Recruits at time t versus SSB for $t + k$ for negative values of k from -1 to -5 for all QMAs combined. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

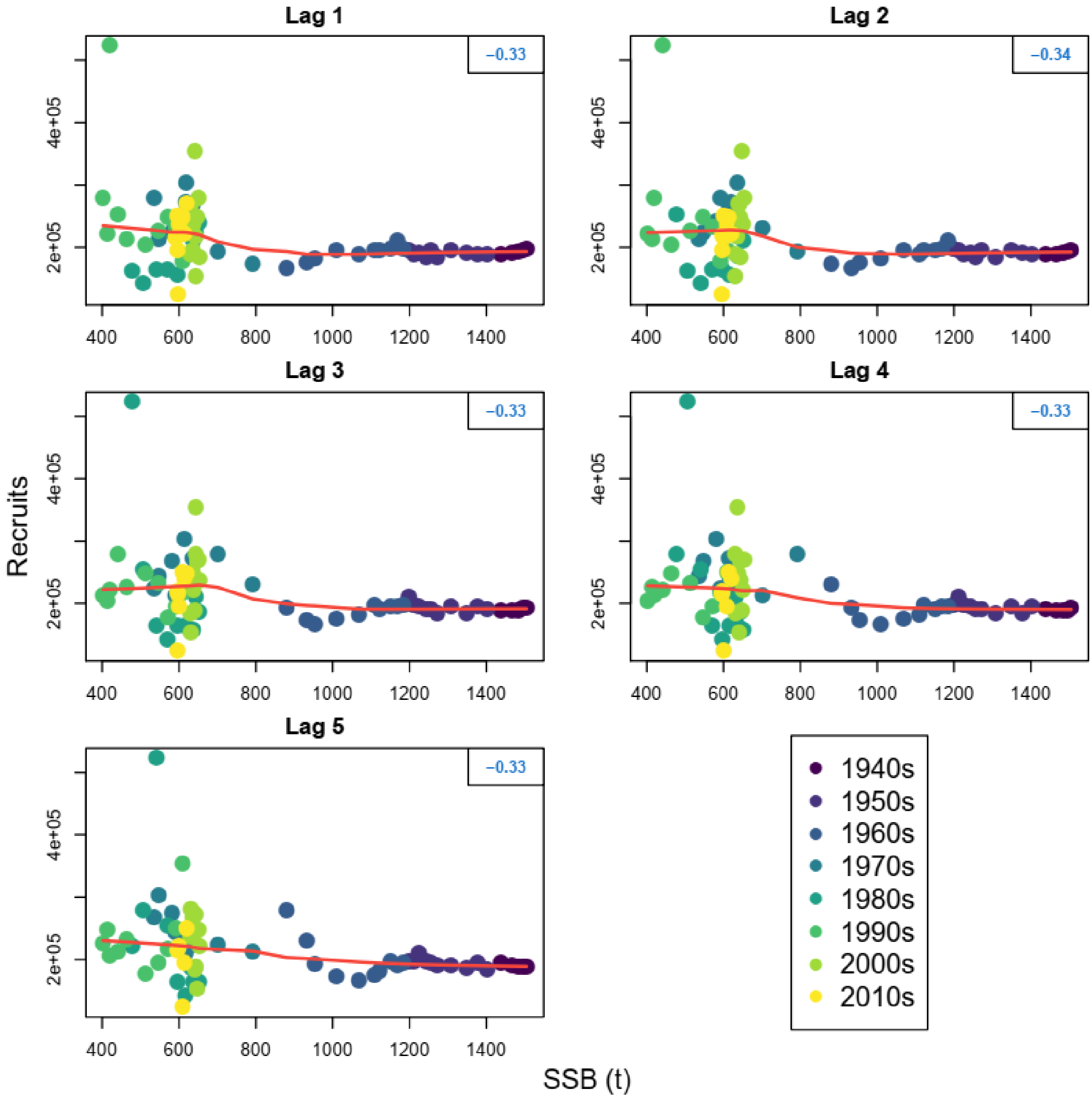

Figure 5: Recruits at time t versus SSB for $t + k$ for negative values of k from -1 to -5 for CRA 1. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

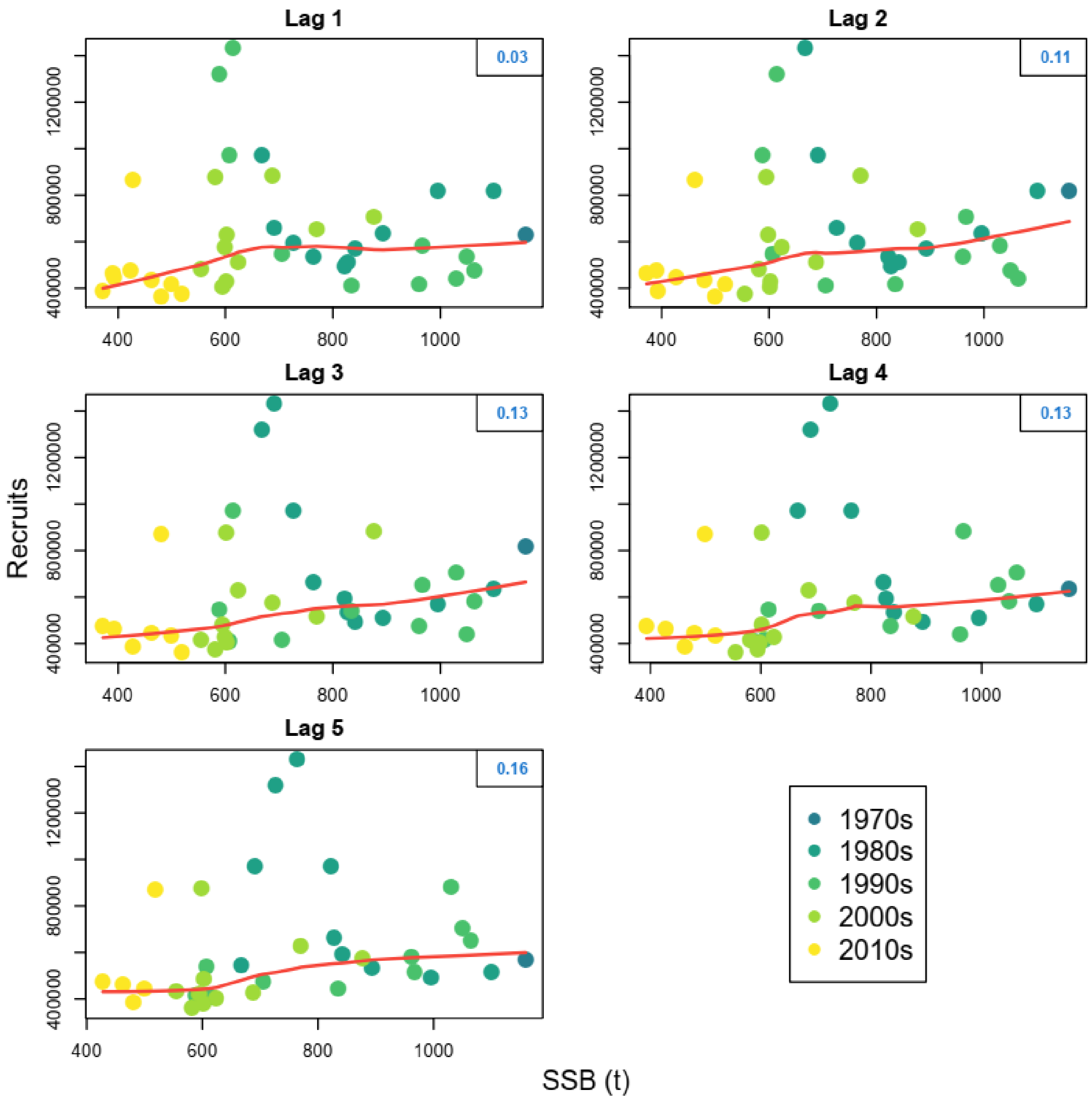

Figure 6: Recruits at time t versus SSB for $t + k$ for negative values of k from -1 to -5 for CRA 2. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

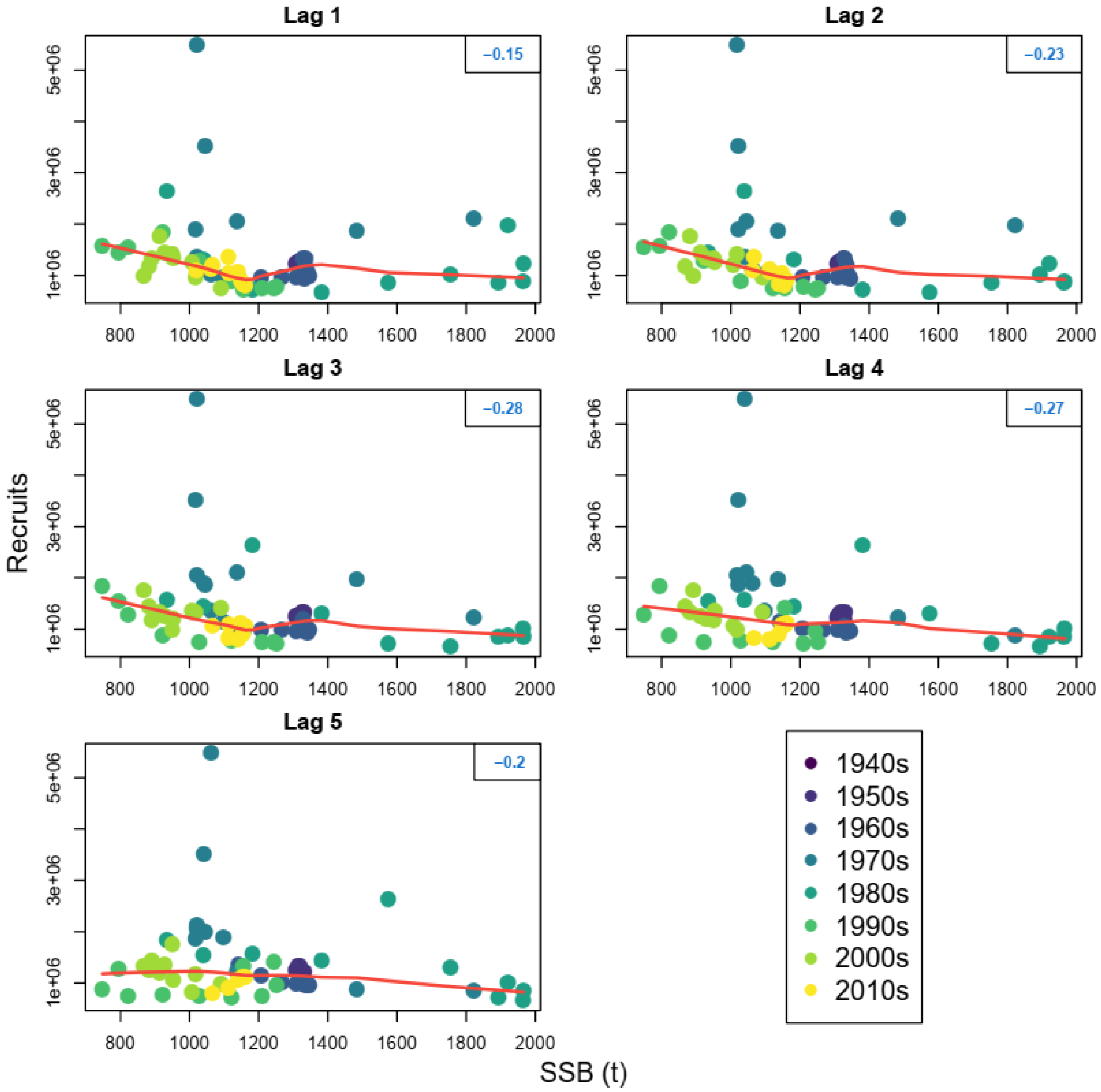

Figure 7: Recruits at time t versus SSB for $t+k$ for negative values of k from -1 to -5 for CRA 3_r1_qdrift (model which excludes tags at liberty less than one year) in region 1. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

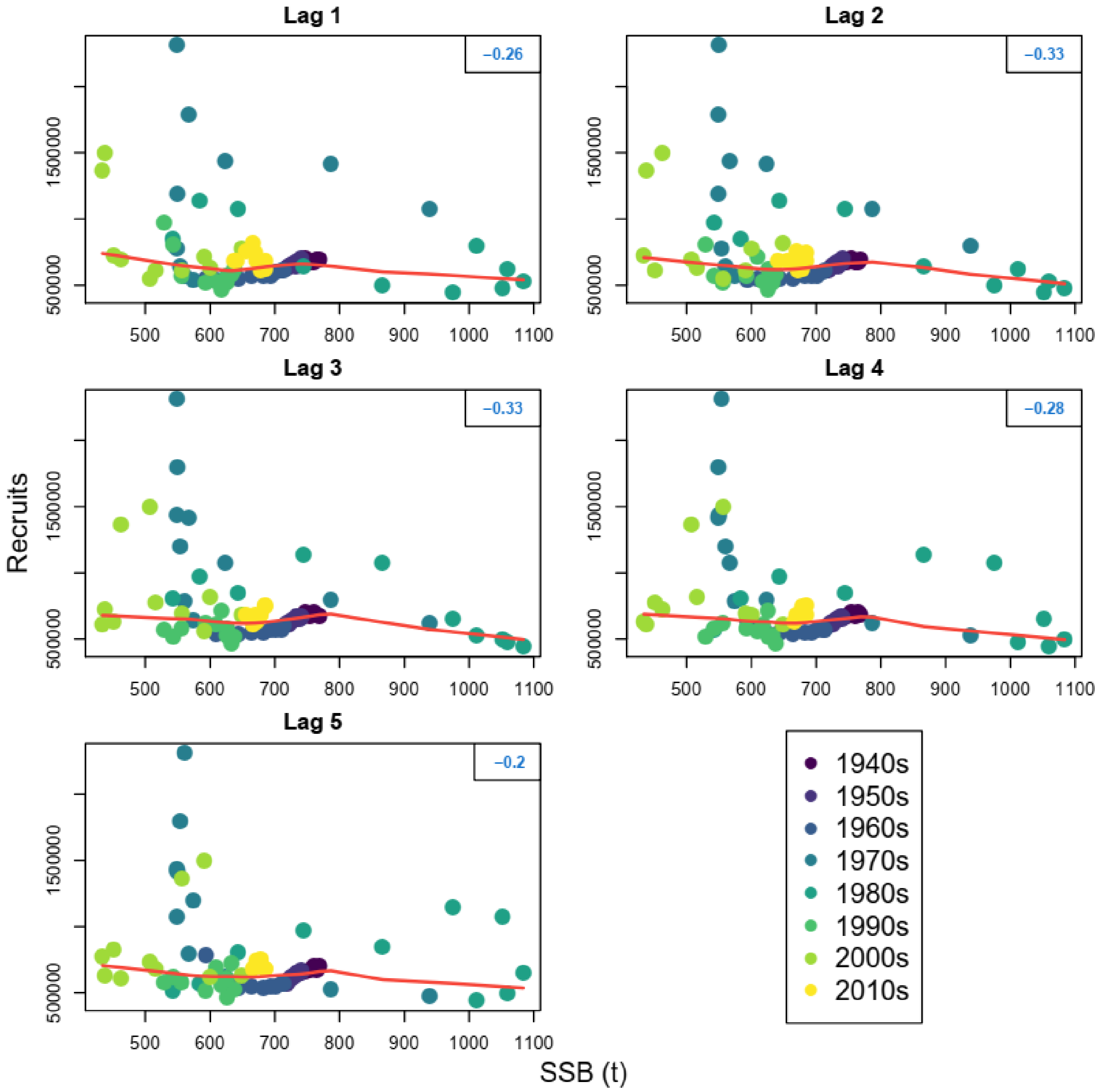

Figure 8: **Recruits at time t versus SSB for $t+k$ for negative values of k from -1 to -5 for CRA 3_r1_qdrift (model which excludes tags at liberty less than one year) in region 2. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.**

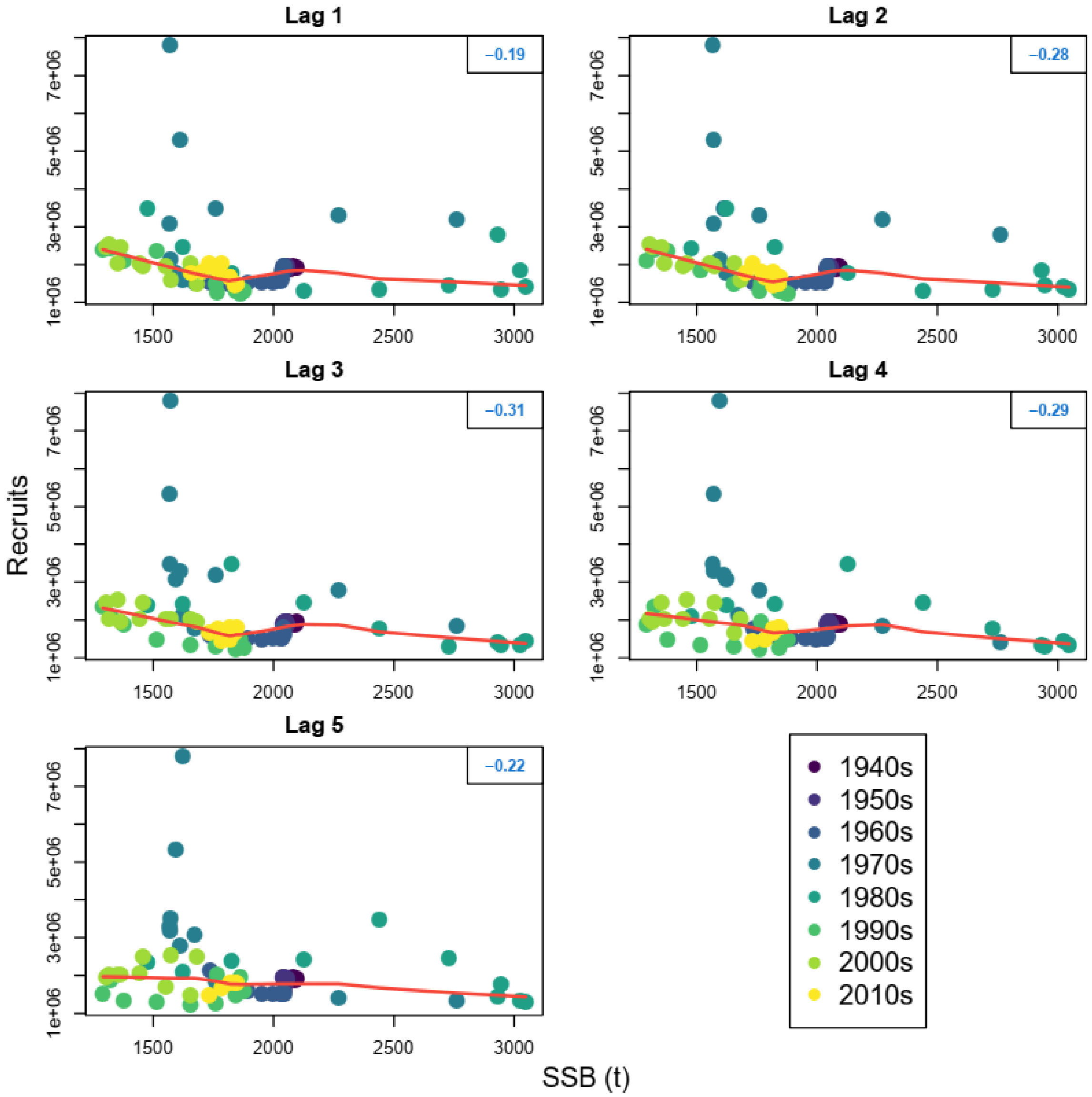

Figure 9: Recruits at time t versus *SSB* for $t+k$ for negative values of k from -1 to -5 for CRA 3_r1_qdrift (model which excludes tags at liberty less than one year) in both regions combined. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

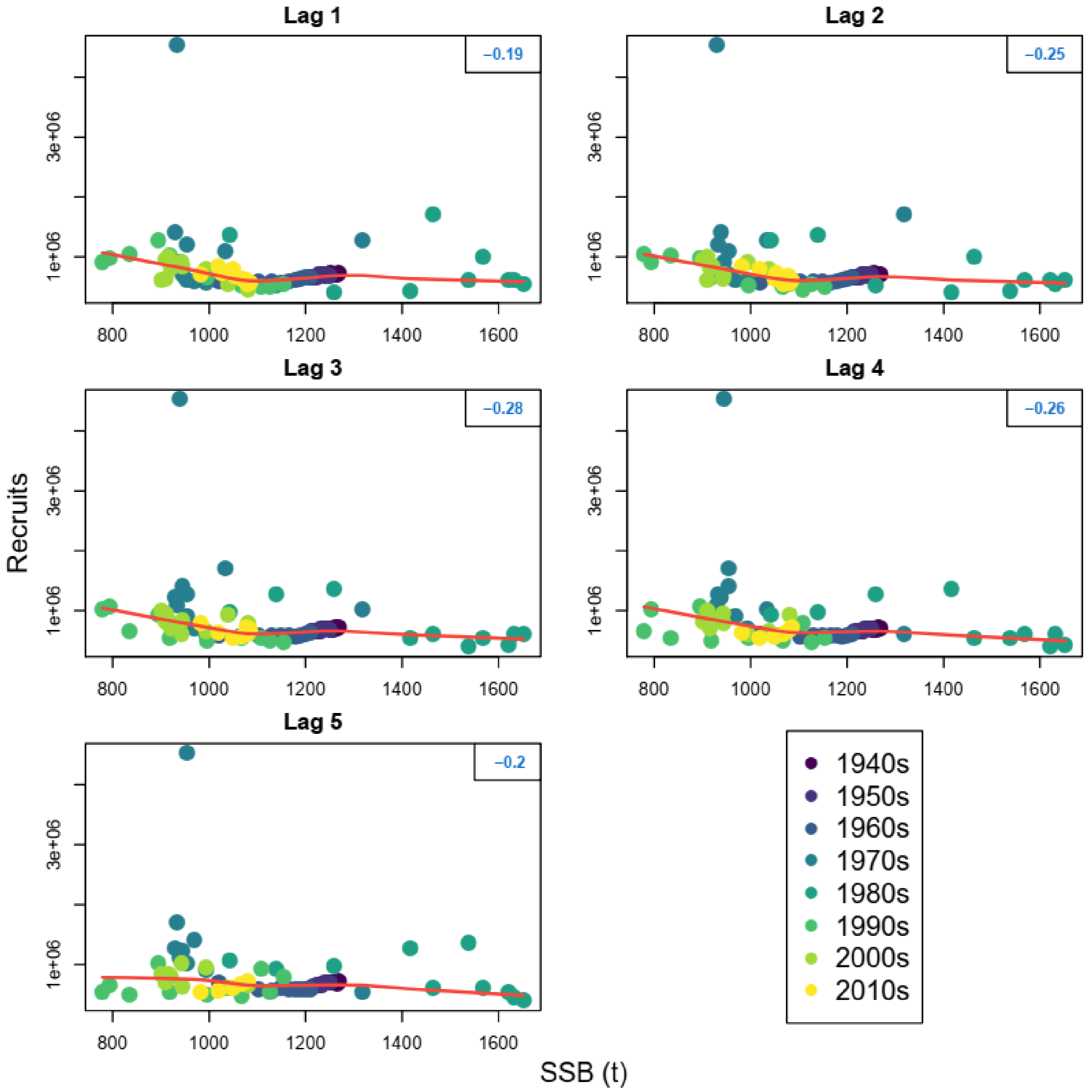

Figure 10: Recruits at time t versus SSB for $t+k$ for negative values of k from -1 to -5 for CRA 3_r2_qdrift (model which includes all tags regardless of their time at liberty) in region 1. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

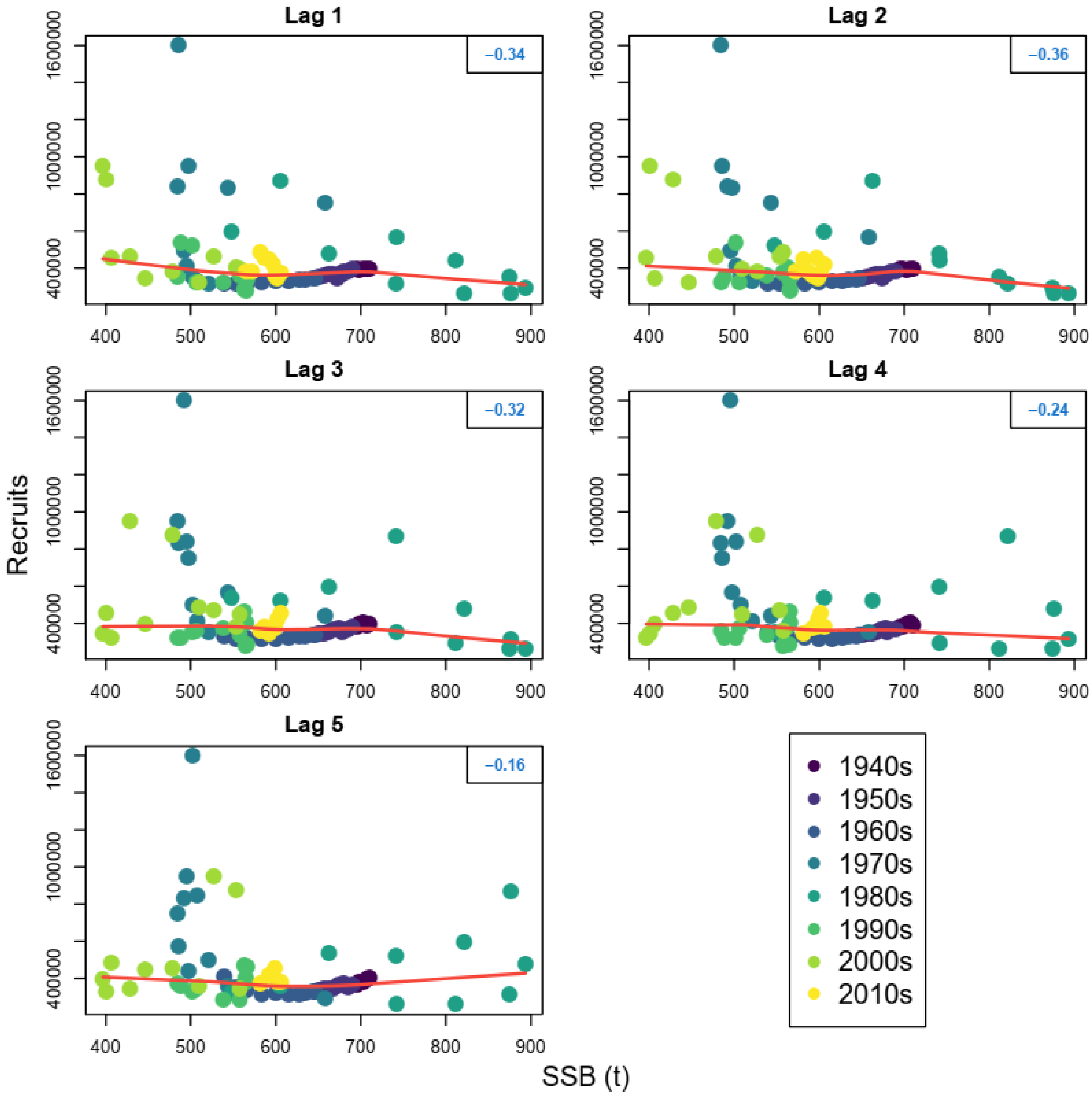

Figure 11: Recruits at time t versus SSB for $t+k$ for negative values of k from -1 to -5 for CRA 3_r2_qdrift (model which includes all tags regardless of their time at liberty) in region 2. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

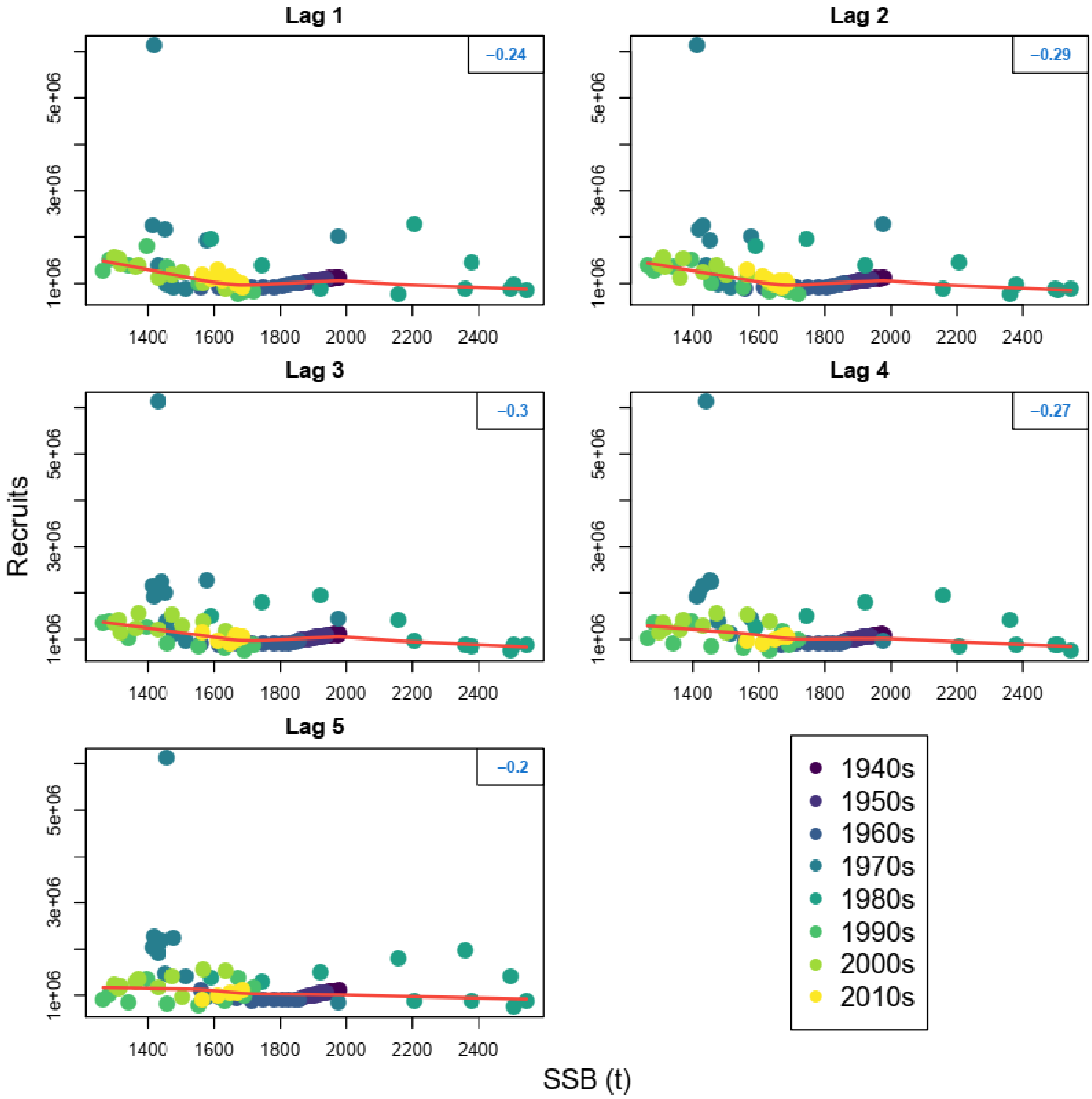

Figure 12: Recruits at time t versus *SSB* for $t+k$ for negative values of k from -1 to -5 for CRA 3_r2_qdrift (model which includes all tags regardless of their time at liberty) in both regions combined. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

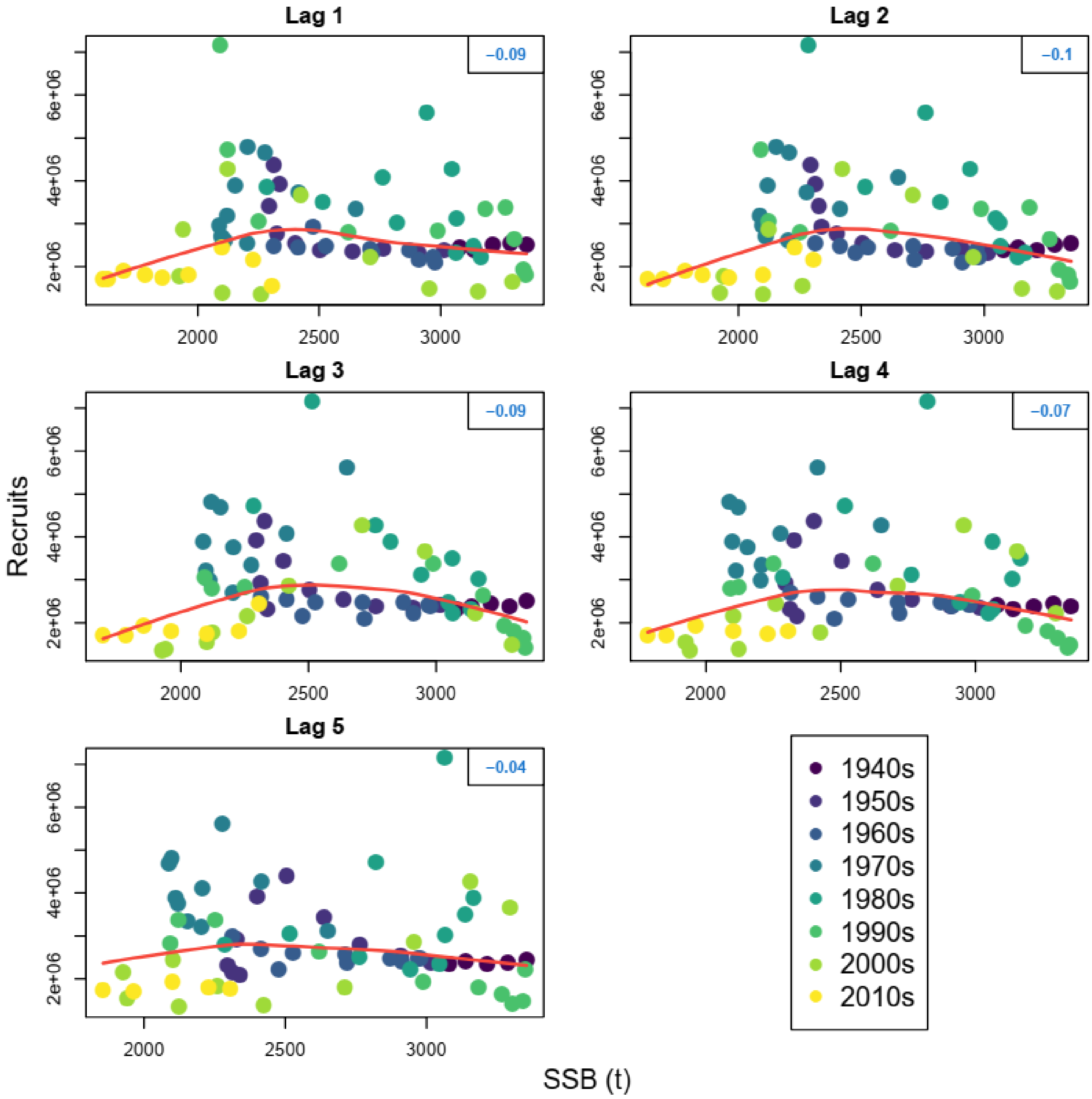

Figure 13: Recruits at time t versus SSB for $t + k$ for negative values of k from -1 to -5 for CRA 4. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

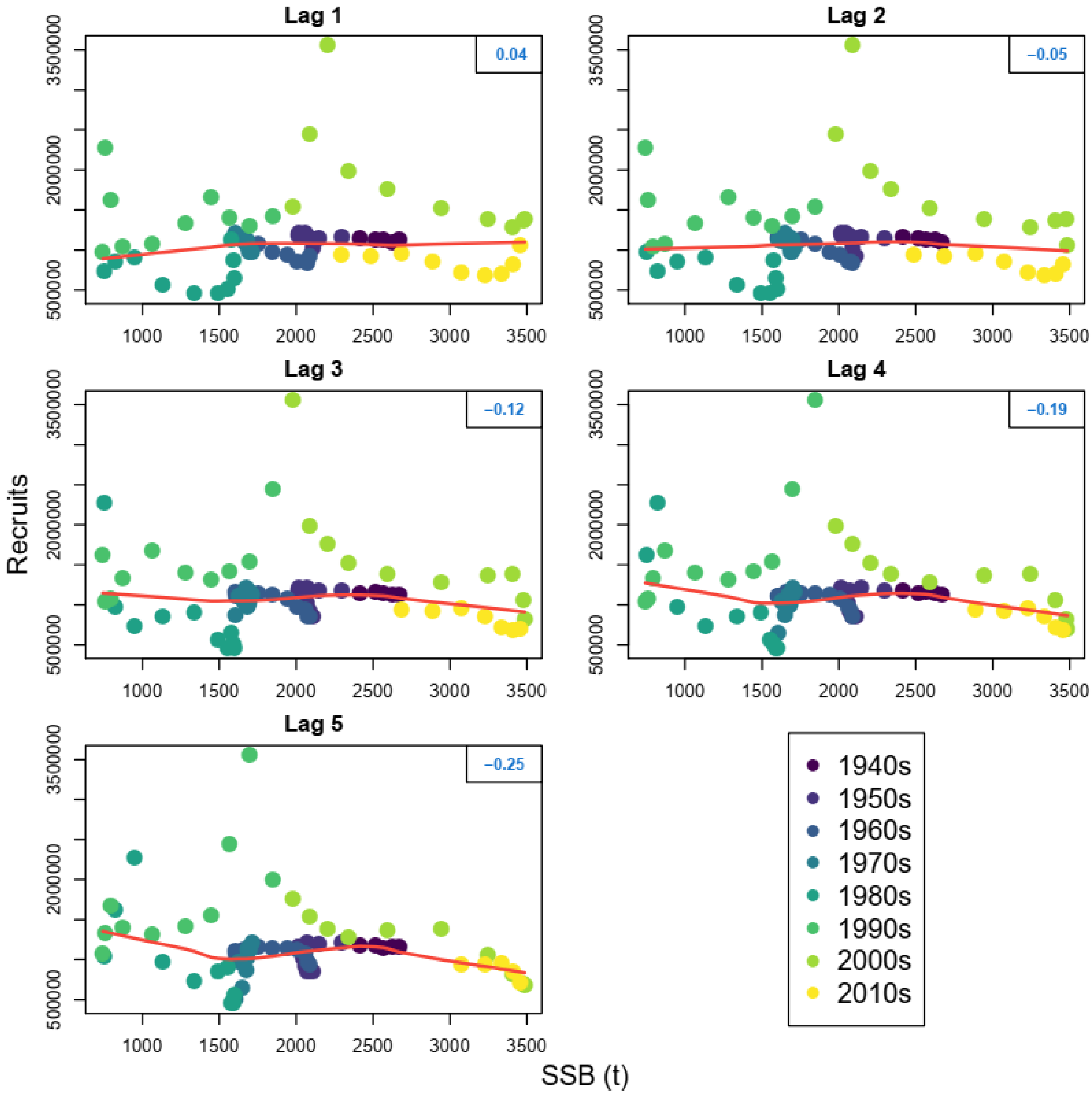

Figure 14: Recruits at time t versus SSB for $t + k$ for negative values of k from -1 to -5 for CRA 5 in region 1. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

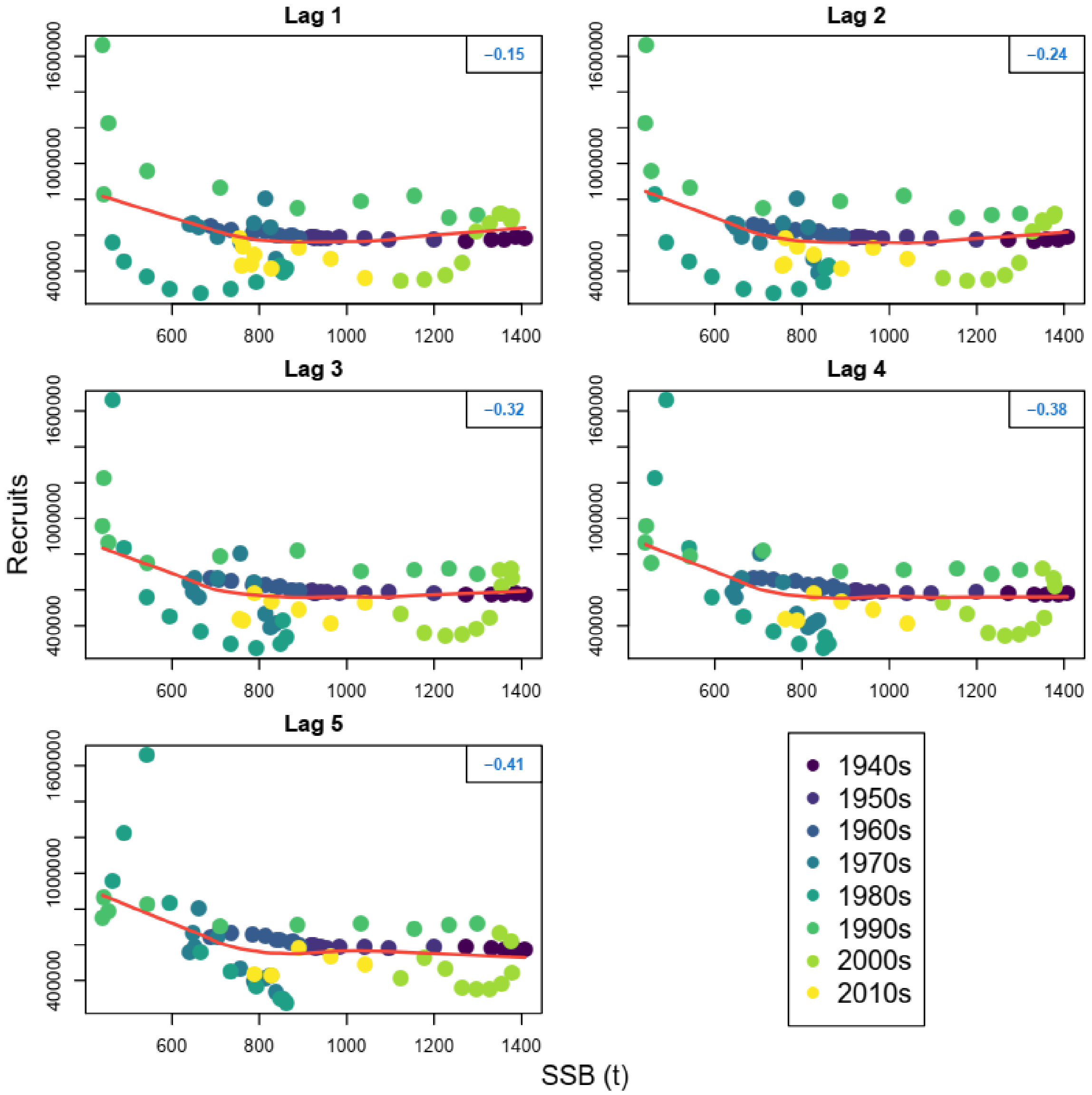

Figure 15: Recruits at time t versus SSB for $t + k$ for negative values of k from -1 to -4 for CRA 5 in region 2. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

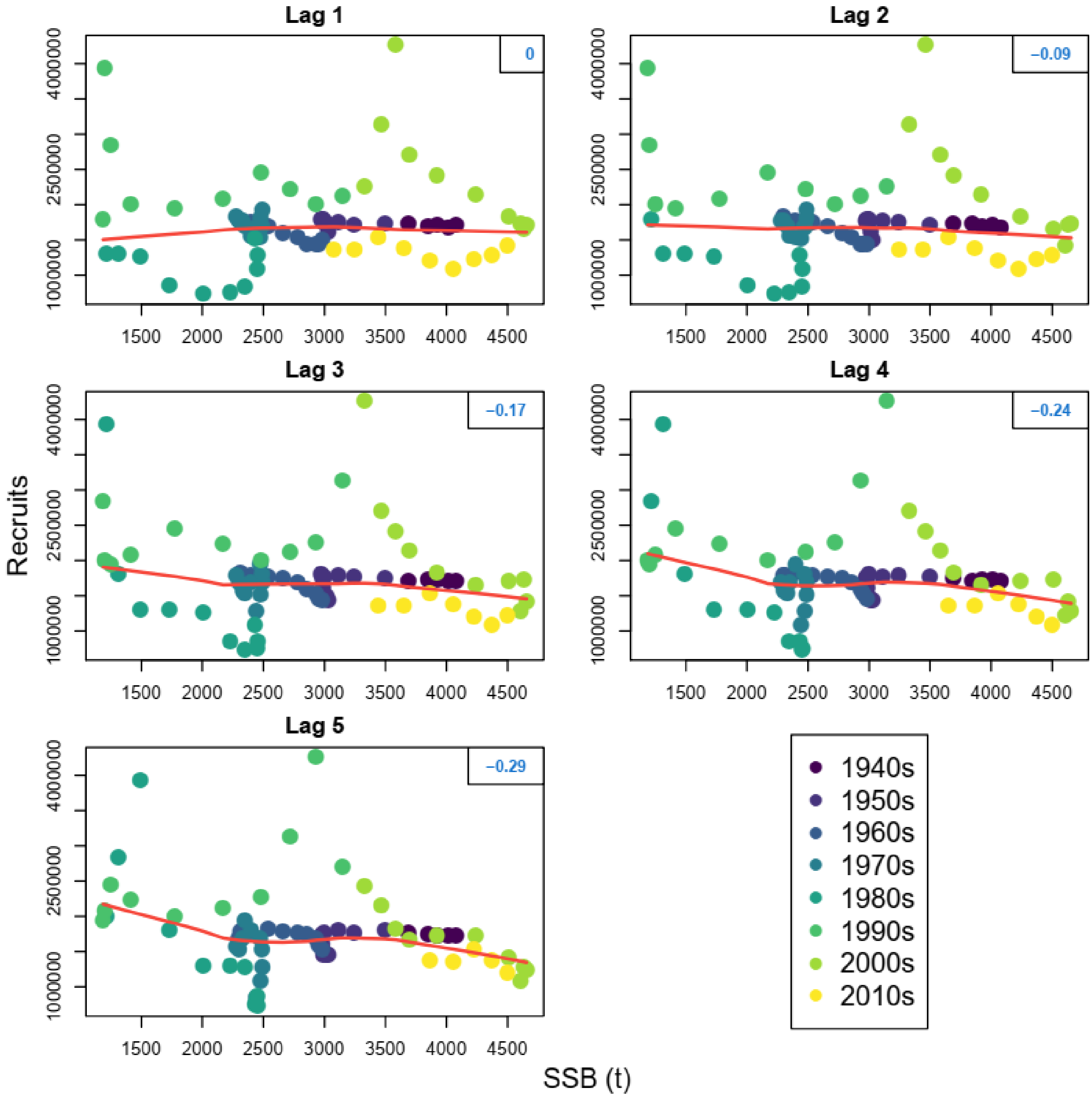

Figure 16: Recruits at time t versus SSB for $t + k$ for negative values of k from -1 to -5 for CRA 5 for both regions. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

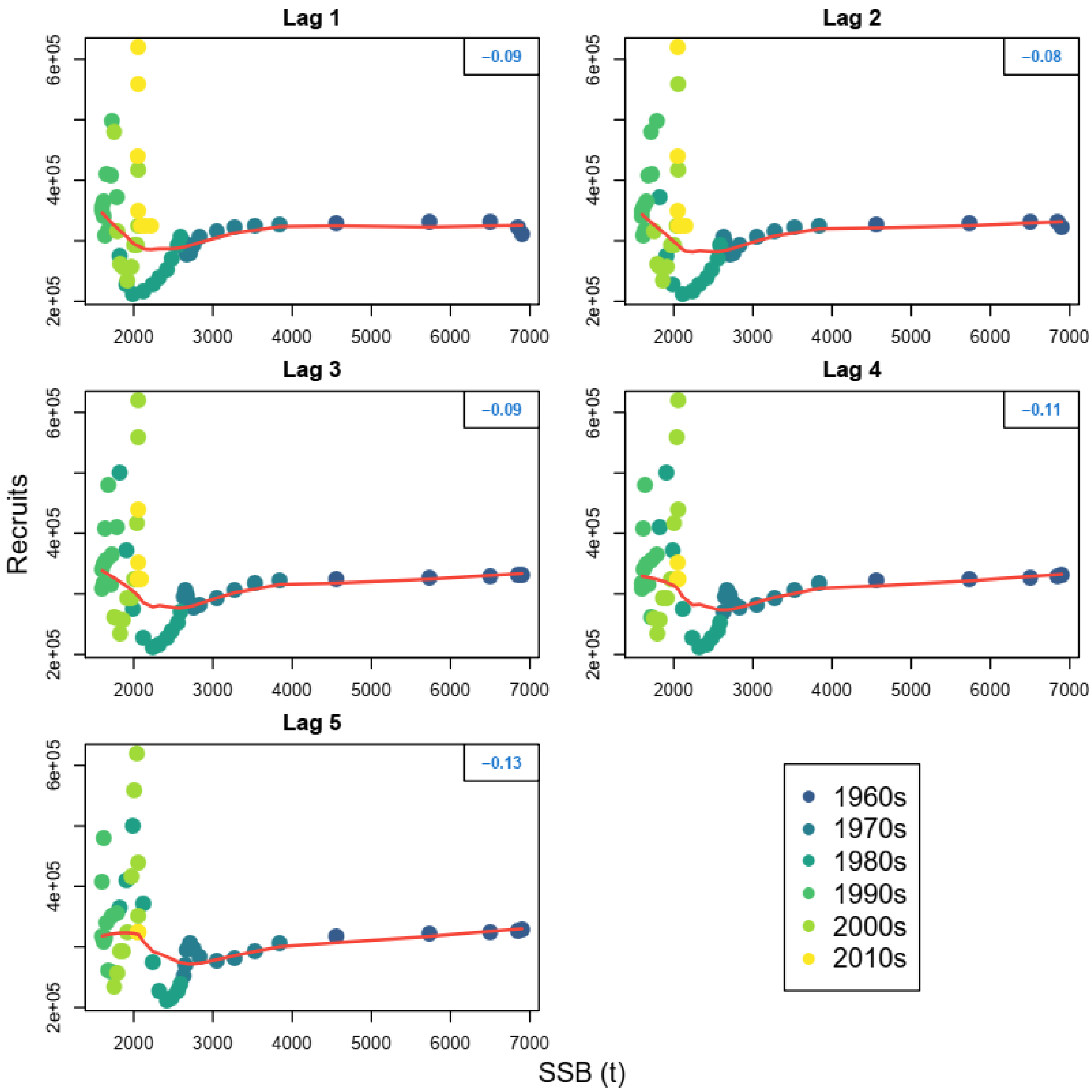

Figure 17: Recruits at time t versus SSB for $t + k$ for negative values of k from -1 to -5 for CRA 6. The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

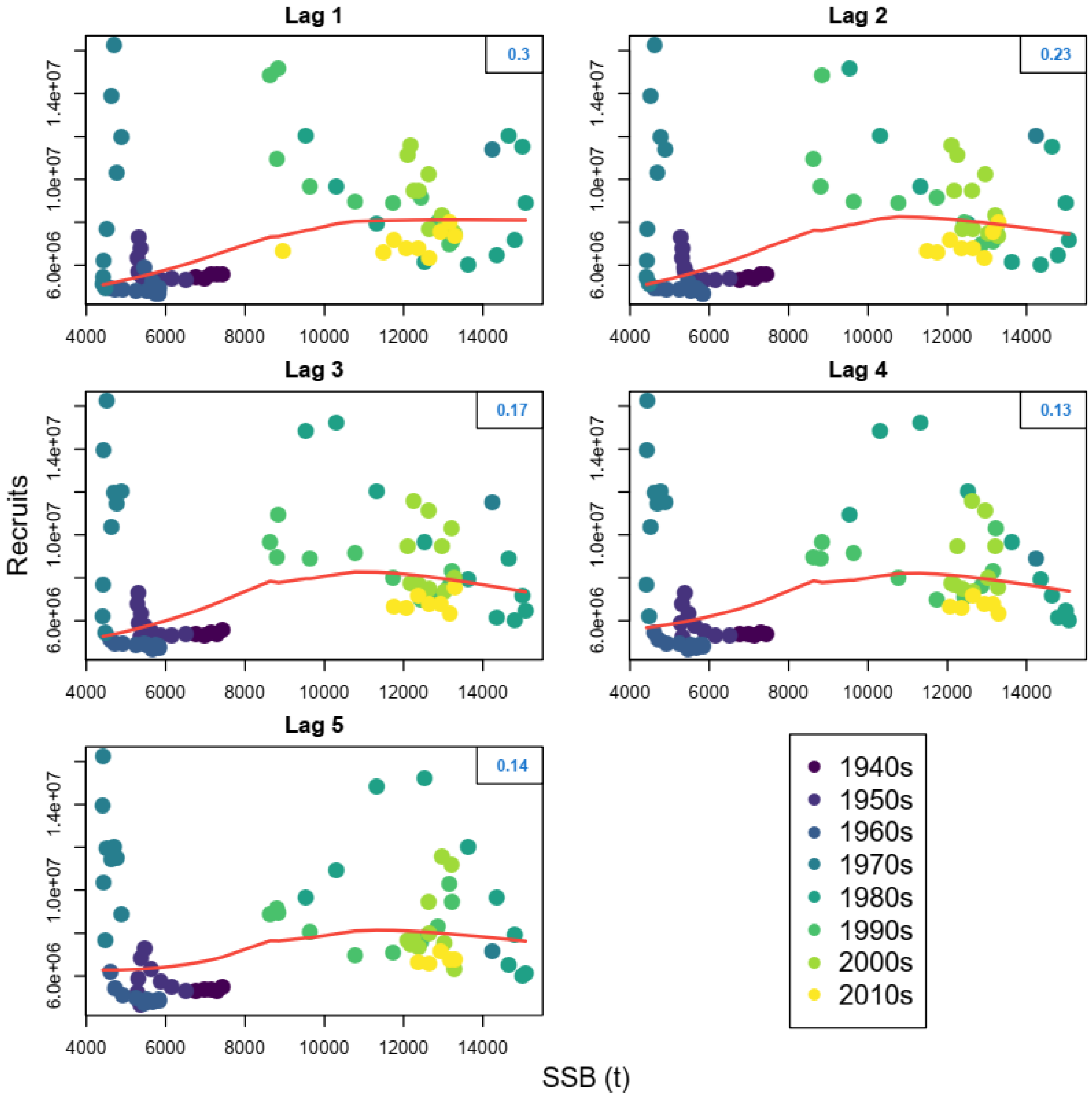

Figure 18: Recruits at time *t* versus *SSB* for *t* + *k* for negative values of *k* from -1 to -5 for recruitment in CRA 2, 3, and 4 vs. *SSB* in CRA 3, 4, and 5 (Rec2_3_4_SSB3_4_5). The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

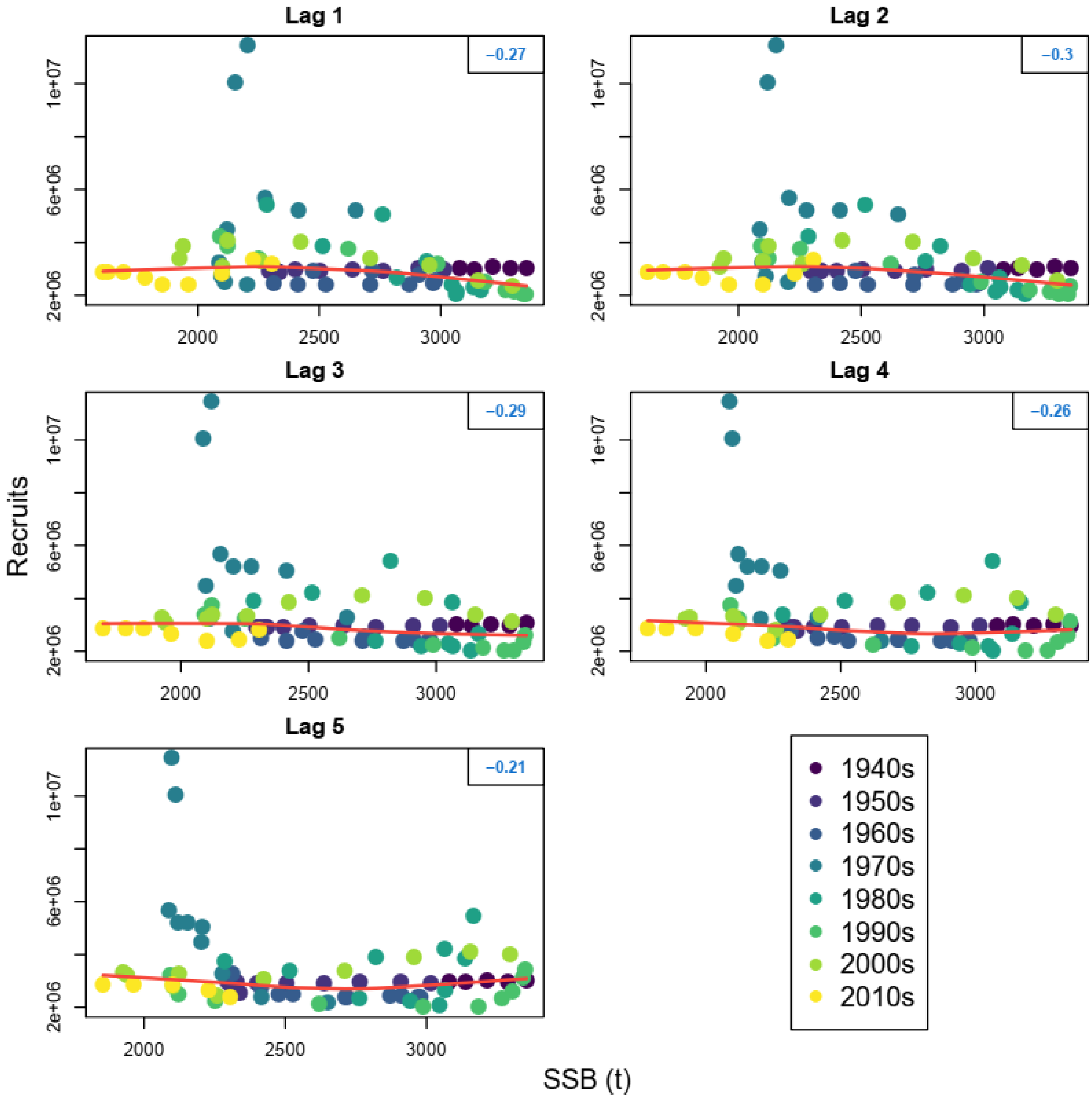

Figure 19: Recruits at time *t* versus *SSB* for *t* + *k* for negative values of *k* from -1 to -5 for recruitment in CRA 3 vs. *SSB* in CRA 4 (Rec3_SSB4). The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

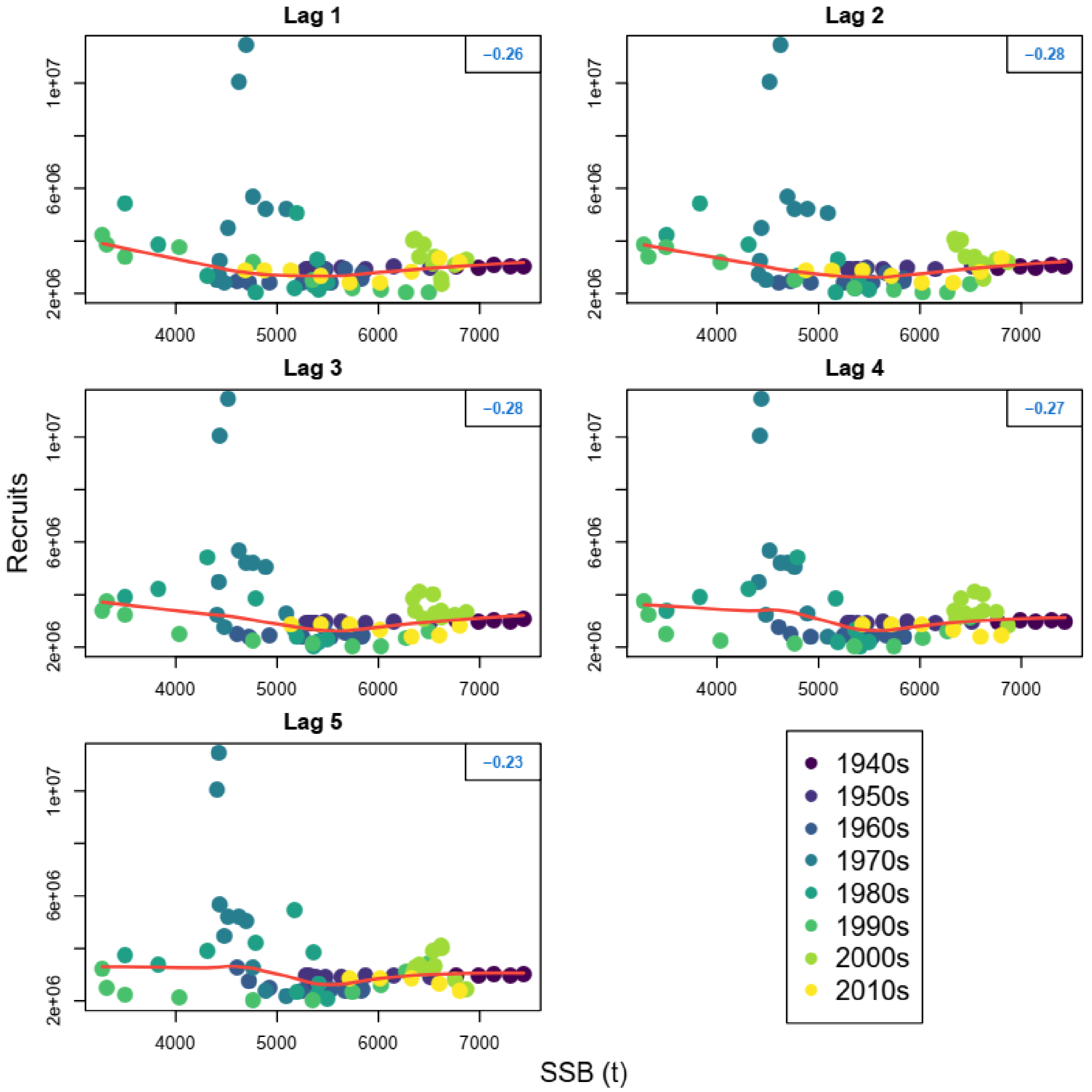

Figure 20: Recruits at time *t* versus *SSB* for $t + k$ for negative values of *k* from -1 to -5 for recruitment in CRA 3 vs. *SSB* in CRA 4 and 5 (Rec3_SSB4_5). The points have been coloured differently for each decade. The number on the top right of each plot is the estimated correlation value and the red line is a loess smoother.

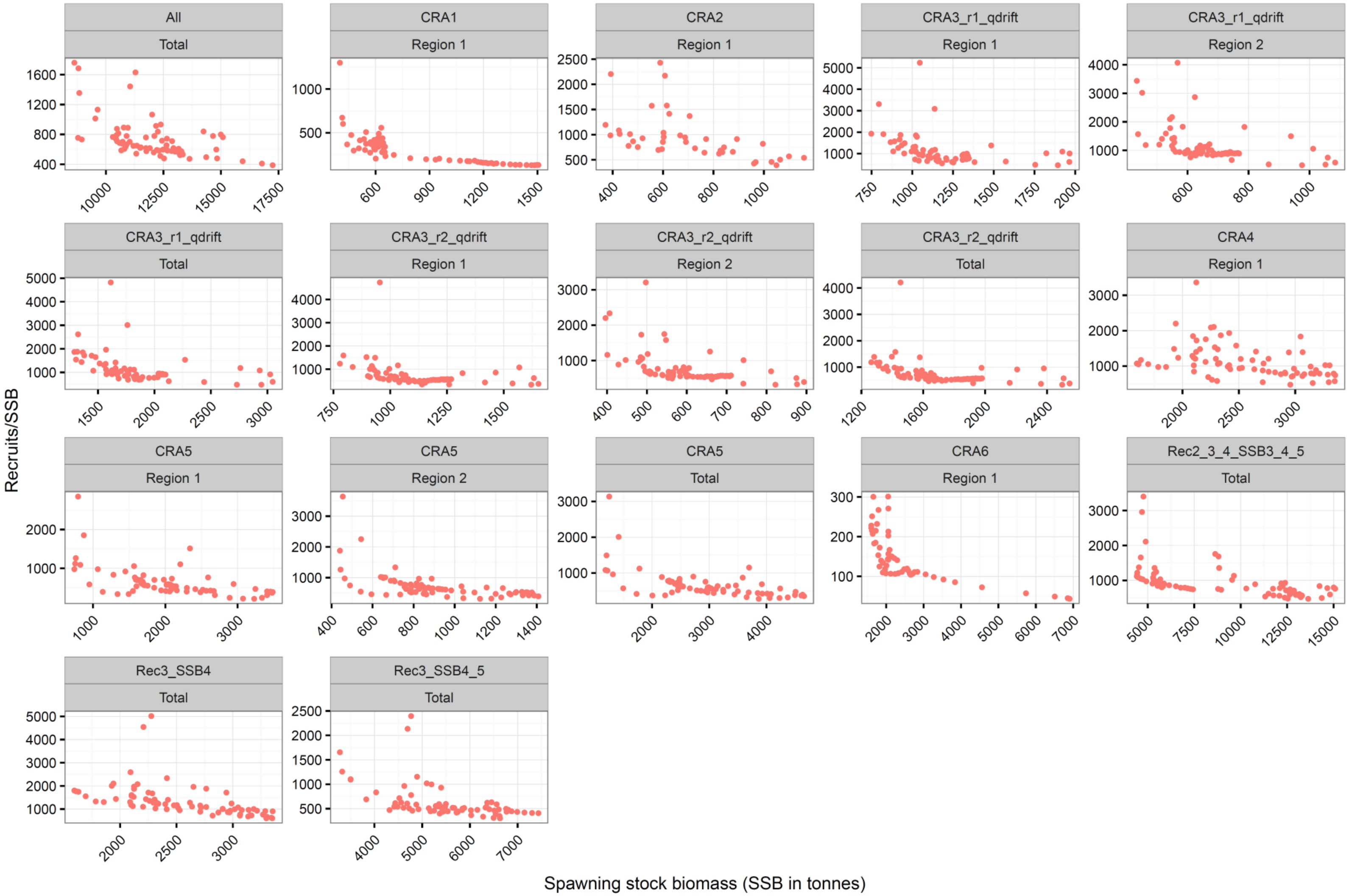

Figure 21: Recruits per spawner (recruits/SSB) against spawning stock biomass (SSB; tonnes) for each stock or combination of stocks in each panel. CRA 3_r1_qdrift: model which excludes tags at liberty less than one year; CRA 3_r2_qdrift: model which includes all tags regardless of their time at liberty; Rec3_SSB4: recruitment in CRA 3 compared with *SSB* in CRA 4; Rec3_SSB4_5: recruitment in CRA 3 compared with *SSB* in CRA 4 and CRA 5; and Rec2_3_4_SSB3_4_5: aggregated recruitment in CRA 2, CRA 3, and CRA 4 compared with aggregated *SSB* in CRA 3, CRA 4, and CRA 5.

8. TABLES

Table 1: Pearson cross-correlation (CCF) values between recruits and spawning stock biomass for negative lags (from -1 to -5) for each stock or stocks combinations. CRA 3_r1_qdrift: model which excludes tags at liberty less than one year; CRA 3_r2_qdrift: model which includes all tags regardless of their time at liberty; Rec3_SSB4: recruitment in CRA 3 compared with *SSB* in CRA 4; Rec3_SSB4_5: recruitment in CRA 3 compared with *SSB* in CRA 4 and CRA 5; and Rec2_3_4_SSB3_4_5: aggregated recruitment in CRA 2, CRA 3, and CRA 4 compared with aggregated SSB in CRA 3, CRA 4 and CRA 5. (Continued on next page)

Lag (k)	Stock	Region	CCF
-1	All	Total	-0.28
-2	All	Total	-0.33
-3	All	Total	-0.33
-4	All	Total	-0.28
-5	All	Total	-0.18
-1	CRA 1	region 1	-0.33
-2	CRA 1	region 1	-0.34
-3	CRA 1	region 1	-0.33
-4	CRA 1	region 1	-0.33
-5	CRA 1	region 1	-0.33
-1	CRA 2	region 1	0.03
-2	CRA 2	region 1	0.11
-3	CRA 2	region 1	0.13
-4	CRA 2	region 1	0.13
-5	CRA 2	region 1	0.16
-1	CRA 3_r1_qdrift	region 1	-0.15
-2	CRA 3_r1_qdrift	region 1	-0.23
-3	CRA 3_r1_qdrift	region 1	-0.28
-4	CRA 3_r1_qdrift	region 1	-0.27
-5	CRA 3_r1_qdrift	region 1	-0.20
-1	CRA 3_r1_qdrift	region 2	-0.26
-2	CRA 3_r1_qdrift	region 2	-0.33
-3	CRA 3_r1_qdrift	region 2	-0.33
-4	CRA 3_r1_qdrift	region 2	-0.28
-5	CRA 3_r1_qdrift	region 2	-0.20
-1	CRA 3_r1_qdrift	Total	-0.19
-2	CRA 3_r1_qdrift	Total	-0.28
-3	CRA 3_r1_qdrift	Total	-0.31
-4	CRA 3_r1_qdrift	Total	-0.29
-5	CRA 3_r1_qdrift	Total	-0.22
-1	CRA 3_r2_qdrift	region 1	-0.19
-2	CRA 3_r2_qdrift	region 1	-0.25
-3	CRA 3_r2_qdrift	region 1	-0.28
-4	CRA 3_r2_qdrift	region 1	-0.26
-5	CRA 3_r2_qdrift	region 1	-0.20
-1	CRA 3_r2_qdrift	region 2	-0.34
-2	CRA 3_r2_qdrift	region 2	-0.36
-3	CRA 3_r2_qdrift	region 2	-0.32

-4	CRA 3_r2_qdrift	region 2	-0.24
-5	CRA 3_r2_qdrift	region 2	-0.16
-1	CRA 3_r2_qdrift	Total	-0.24
-2	CRA 3_r2_qdrift	Total	-0.29
-3	CRA 3_r2_qdrift	Total	-0.30
-4	CRA 3_r2_qdrift	Total	-0.27
-5	CRA 3_r2_qdrift	Total	-0.20
-1	CRA 4	region 1	-0.09
-2	CRA 4	region 1	-0.10
-3	CRA 4	region 1	-0.09
-4	CRA 4	region 1	-0.07
-5	CRA 4	region 1	-0.04
-1	CRA 5	region 1	0.04
-2	CRA 5	region 1	-0.05
-3	CRA 5	region 1	-0.12
-4	CRA 5	region 1	-0.19
-5	CRA 5	region 1	-0.25
-1	CRA 5	region 2	-0.15
-2	CRA 5	region 2	-0.24
-3	CRA 5	region 2	-0.32
-4	CRA 5	region 2	-0.38
-5	CRA 5	region 2	-0.41
-1	CRA 5	Total	0.00
-2	CRA 5	Total	-0.09
-3	CRA 5	Total	-0.17
-4	CRA 5	Total	-0.24
-5	CRA 5	Total	-0.29
-1	CRA 6	region 1	-0.09
-2	CRA 6	region 1	-0.08
-3	CRA 6	region 1	-0.09
-4	CRA 6	region 1	-0.11
-5	CRA 6	region 1	-0.13
-1	Rec2_3_4_SSB3_4_5	Total	0.30
-2	Rec2_3_4_SSB3_4_5	Total	0.23
-3	Rec2_3_4_SSB3_4_5	Total	0.17
-4	Rec2_3_4_SSB3_4_5	Total	0.13
-5	Rec2_3_4_SSB3_4_5	Total	0.14
-1	Rec3_SSB4	Total	-0.27
-2	Rec3_SSB4	Total	-0.30
-3	Rec3_SSB4	Total	-0.29
-4	Rec3_SSB4	Total	-0.26
-5	Rec3_SSB4	Total	-0.21
-1	Rec3_SSB4_5	Total	-0.26
-2	Rec3_SSB4_5	Total	-0.28
-3	Rec3_SSB4_5	Total	-0.28
-4	Rec3_SSB4_5	Total	-0.27
-5	Rec3_SSB4_5	Total	-0.23

Table 2: Cross-correlation (CCF) values between recruits per spawner and spawning stock biomass for negative lags (from -1 to -5) for each stock or stocks combinations. CRA 3_r1_qdrift: model which excludes tags at liberty less than one year; CRA 3_r2_qdrift: model which includes all tags regardless of their time at liberty; Rec3_SSB4: recruitment in CRA 3 compared with SSB in CRA 4; Rec3_SSB4_5: recruitment in CRA 3 compared with SSB in CRA 4 and CRA 5; and Rec2_3_4_SSB3_4_5: aggregated recruitment in CRA 2, CRA 3, and CRA 4 compared with aggregated SSB in CRA 3, CRA 4 and CRA 5. (Continued on next page)

Lag	Stock	Region	CCF
-1	All	Total	-0.57
-2	All	Total	-0.52
-3	All	Total	-0.42
-4	All	Total	-0.27
-5	All	Total	-0.09
-1	CRA1	region 1	-0.70
-2	CRA1	region 1	-0.68
-3	CRA1	region 1	-0.66
-4	CRA1	region 1	-0.63
-5	CRA1	region 1	-0.60
-1	CRA2	region 1	-0.48
-2	CRA2	region 1	-0.37
-3	CRA2	region 1	-0.27
-4	CRA2	region 1	-0.19
-5	CRA2	region 1	-0.10
-1	CRA3_r1_qdrift	region 1	-0.45
-2	CRA3_r1_qdrift	region 1	-0.45
-3	CRA3_r1_qdrift	region 1	-0.41
-4	CRA3_r1_qdrift	region 1	-0.32
-5	CRA3_r1_qdrift	region 1	-0.18
-1	CRA3_r1_qdrift	region 2	-0.54
-2	CRA3_r1_qdrift	region 2	-0.53
-3	CRA3_r1_qdrift	region 2	-0.45
-4	CRA3_r1_qdrift	region 2	-0.33
-5	CRA3_r1_qdrift	region 2	-0.19
-1	CRA3_r1_qdrift	Total	-0.50
-2	CRA3_r1_qdrift	Total	-0.50
-3	CRA3_r1_qdrift	Total	-0.45
-4	CRA3_r1_qdrift	Total	-0.35
-5	CRA3_r1_qdrift	Total	-0.20
-1	CRA3_r2_qdrift	region 1	-0.39
-2	CRA3_r2_qdrift	region 1	-0.39
-3	CRA3_r2_qdrift	region 1	-0.36
-4	CRA3_r2_qdrift	region 1	-0.28
-5	CRA3_r2_qdrift	region 1	-0.18
-1	CRA3_r2_qdrift	region 2	-0.55
-2	CRA3_r2_qdrift	region 2	-0.51
-3	CRA3_r2_qdrift	region 2	-0.42
-4	CRA3_r2_qdrift	region 2	-0.30
-5	CRA3_r2_qdrift	region 2	-0.18

-1	CRA3_r2_qdrift	Total	-0.44
-2	CRA3_r2_qdrift	Total	-0.44
-3	CRA3_r2_qdrift	Total	-0.39
-4	CRA3_r2_qdrift	Total	-0.30
-5	CRA3_r2_qdrift	Total	-0.19
-1	CRA4	region 1	-0.45
-2	CRA4	region 1	-0.38
-3	CRA4	region 1	-0.28
-4	CRA4	region 1	-0.16
-5	CRA4	region 1	-0.06
-1	CRA5	region 1	-0.61
-2	CRA5	region 1	-0.64
-3	CRA5	region 1	-0.64
-4	CRA5	region 1	-0.63
-5	CRA5	region 1	-0.59
-1	CRA5	region 2	-0.59
-2	CRA5	region 2	-0.60
-3	CRA5	region 2	-0.59
-4	CRA5	region 2	-0.56
-5	CRA5	region 2	-0.50
-1	CRA5	Total	-0.62
-2	CRA5	Total	-0.64
-3	CRA5	Total	-0.64
-4	CRA5	Total	-0.62
-5	CRA5	Total	-0.58
-1	CRA6	region 1	-0.63
-2	CRA6	region 1	-0.59
-3	CRA6	region 1	-0.54
-4	CRA6	region 1	-0.49
-5	CRA6	region 1	-0.45
-1	Rec2_3_4_SSB3_4_5	Total	-0.57
-2	Rec2_3_4_SSB3_4_5	Total	-0.56
-3	Rec2_3_4_SSB3_4_5	Total	-0.54
-4	Rec2_3_4_SSB3_4_5	Total	-0.50
-5	Rec2_3_4_SSB3_4_5	Total	-0.45
-1	Rec3_SSB4	Total	-0.53
-2	Rec3_SSB4	Total	-0.50
-3	Rec3_SSB4	Total	-0.42
-4	Rec3_SSB4	Total	-0.33
-5	Rec3_SSB4	Total	-0.23
-1	Rec3_SSB4_5	Total	-0.54
-2	Rec3_SSB4_5	Total	-0.53
-3	Rec3_SSB4_5	Total	-0.48
-4	Rec3_SSB4_5	Total	-0.41
-5	Rec3_SSB4_5	Total	-0.33