A new length-weight relationship for South African anchovy

C.L. de Moor* **and D.S. Butterworth***

Correspondence email: *carryn.demoor@uct.ac.za*

A time-invariant length-weight relationship, calculated from commercial data collected between 1990 and 1996, has been used during past anchovy assessments. These same data, together with length-weight data collected during the May recruit and November hydroacoustic surveys between 2006 and 2014, are re-analysed with alternative time-dependent length-weight relationships being considered.

Introduction

A time-invariant length-weight relationship $w = 0.0075 l^{3.11}$, where weight, *w*, is in grams and length, *l*, in centimetres, has been used during past anchovy assessments. This was calculated from 1990-1996 commercial data (Lynne Shannon pers. comm.; de Moor *et al*. 2012). This document investigates that same data together with length-weight data collected during the May recruit and November hydroacoustic surveys between 2006 and 2014 to see if the time-invariant length-weight relationship used previously should continue to be used. In addition, we investigate the possibility that the length-weight relationship changes within a year and between years.

Data

Given the possibility that the length-weight relationship may very within a year, the following three sets of data are treated separately given their different collection times during the year.

i) Observations of caudal length and wet body mass from anchovy sampled during the May surveys from 2006 to 2014[1].

ii) Observations of caudal length and wet body mass from anchovy sampled during the November surveys from 2006 to 2014.

iii) Observations of caudal length and wet body mass from anchovy sampled from commercial catches from 1990 to 1996.

Methods

The model predicted anchovy weight (in grams) is given by the following equation, with length, l, given in centimetres:

$$w_y^{pred,j} = a_y^j l^{b_y^j} \qquad (1)$$

The j superscript is used to denote May survey, November survey and/or commercial catch data.

The survey model parameters were estimated using a log-log regression, i.e. by minimising

* MARAM (Marine Resource Assessment and Management Group), Department of Mathematics and Applied Mathematics, University of Cape Town, Rondebosch, 7701, South Africa.

[1] In order to remove the influence of rounding errors, a number of observations were excluded from the 2012 May recruit survey data used in this analysis, as the electronic balance used during the survey initially only read to the nearest gram.

$$-\ln L^j = \sum_y \sum_i \frac{1}{2}\ln\left(2\pi\sigma^2\right) + \frac{\left(\ln\left(w_{y,i}^{obs,j}\right) - \ln\left(w_{y,i}^{pred,j}\right)\right)^2}{2\sigma^2} \tag{2}$$

with $w_{y,i}^{pred,j} = a_y^j \left(l_{y,i}^{obs,j}\right)^b$ (3)

and $$\sigma^2 = \frac{\sum_y \sum_i \left(\ln\left(w_{y,i}^{obs,j}\right) - \ln\left(w_{y,i}^{pred,j}\right)\right)^2}{\sum_y \sum_i 1} \tag{4}$$

where $w_{y,i}^{obs,j}$ denotes the observed weight (in grams) and $l_{y,i}^{obs,j}$ denotes the observed length (in cm) for each set (i) of length-weight observations in year y from data set j (May, November or Commercial). The commercial data and parameters allow for an additional dependency, viz month.

The survey and commercial data were analysed separately due to the possibility that targeting or distribution non-homogeneity may affect the length distributions for the latter.

Survey data

Initial results indicated that the curvature parameter, $b = b_y^j$, could be taken to be the same for both sets of data and for all years. Four alternative models, building in complexity in terms of the number of parameters estimated, were implemented:

i) The same *a* parameter for both surveys for all years, i.e. $a = a_y^{May} = a_y^{Nov}$.

ii) The same *a* parameter for all years, but different between surveys, i.e. $a^{May} = a_y^{May}$ and $a^{Nov} = a_y^{Nov}$.

iii) Different *a* parameters for all years, with a constant increase between May and November surveys, i.e. $a_y^{Nov} = a_y^{May} + c$.

iv) Different *a* parameters for all years and May/November surveys.

Commercial data

As for the survey data, a single curvature parameter $b = b_{y,m}^{Com}$ was estimated for all months and years.

v) The *a* parameter is independent of year, but increases by a constant amount from month to month,, i.e. $a_m^{Com} = a_{y,m}^{Com} = a_{y,m-1}^{Com} + c = a_{m-1}^{Com} + c$

vi) Different *a* parameters for all months, insisting on an increase throughout the year, i.e. $a_m^{Com} = a_{y,m}^{Com} \geq a_{y,m-1}^{Com} = a_{m-1}^{Com}$

vii) Different *a* parameters for all months, i.e. $a_m^{Com} = a_{y,m}^{Com}$

viii) Monthly *a* parameters varying according to an inverse normal distribution, i.e. $a_{y,m}^{Com} = a_m^{Com} = a_1 - a_2 N\left(\mu, \sigma^2\right)$

ix) Different *a* parameters for all months and years.

For very large data sets, there is a high probability that typical model selection methods result in preferring models which over-parameterise, in the sense that results do not differ biologically meaningfully. Thus the simple linear regression coefficient was also calculated as follows to indicate the extent to which an improvement in variance explanation was achieved:

$$r_y^{j\,2} = \frac{\left(\sum_i \left(\ln\left(w_{y,i}^{pred,j}\right) - \overline{\ln\left(w_y^{pred,j}\right)}\right)\left(\ln\left(w_{y,i}^{obs,j}\right) - \overline{\ln\left(w_y^{obs,j}\right)}\right)\right)^2}{\sum_i \left(\ln\left(w_{y,i}^{pred,j}\right) - \overline{\ln\left(w_y^{pred,j}\right)}\right)^2 \sum_i \left(\ln\left(w_{y,i}^{obs,j}\right) - \overline{\ln\left(w_y^{obs,j}\right)}\right)^2} . \tag{5}$$

Results and Discussion

Outliers

The survey and commercial data sets were trimmed of any outliers. This was done by excluding any data points which had a standardised residual greater than 4 or less than -4, from an initial fit of survey model iv) including all data, and commercial model vii). The residuals used are given by

Survey data: $$res_{y,i}^{j} = \frac{\ln\left(w_{y,i}^{obs,j}\right) - \ln\left(w_{y,i}^{pred,j}\right)}{SD^{Sur}}, \text{ with } SD^{Sur} = \sqrt{\frac{\sum_y \sum_j \sum_i \left(\ln\left(w_{y,i}^{obs,j}\right) - \ln\left(w_{y,i}^{pred,j}\right)\right)^2}{\left(\sum_y \sum_j \sum_i 1\right) - 1 - \sum_y \sum_j 1}} . \tag{6}$$

Commercial data: $$res_{y,i}^{j} = \frac{\ln\left(w_{y,m,i}^{obs,Com}\right) - \ln\left(w_{y,m,i}^{pred,Com}\right)}{SD^{Com}}, \text{ with } SD^{Com} = \sqrt{\frac{\sum_y \sum_m \sum_i \left(\ln\left(w_{y,m,i}^{obs,Com}\right) - \ln\left(w_{y,m,i}^{pred,Com}\right)\right)^2}{\left(\sum_y \sum_m \sum_i 1\right) - 1 - \sum_y \sum_m 1}} . \tag{7}$$

After excluding the first set of 283 outliers from the survey data (Figure 1), model iv) was re-fit. The SD would be smaller and some residuals that were previously between -4 and 4 were then outside this range. These further 226 outliers were then excluded. Recalculating the SD and re-fitting the model once again resulted in a few outliers (Figure 2), but no further rounds of removing outliers were undertaken.

The commercial data were first trimmed of 132 outliers (Figure 3). Model vii) was refit, and given the smaller SD, 33 further outliers were then excluded. Recalculating the SD and re-fitting the model once again resulted in only a few remaining outliers (Figure 4), and no further rounds of removing outliers were undertaken.

Survey data

Table 1 lists the estimated parameter values from survey models i) to iv) and Figure 5 compares the estimated *a* parameters. There is an 8.5% and 5.1% difference (calculated as (max – min)/average) between the annual *a* parameters estimated from the May and November survey data when using model iv), respectively. The AIC model selection criterion shows model i), which estimates a single weight-length relationship for both surveys and all years, is clearly not supported by the data. The AIC values indicate that the data prefer model iv). Given the non-negligible 5.1-8.5% difference in annual *a* parameters, it would seem best to use this model. However, there is no increase in the regression coefficient within three decimal places between the models, implying that although AIC suggests selecting model iv), the associated results do not differ biologically meaningfully from those of models ii) and iii).

Figure 6 shows the model fits to the data for the AIC-preferred model iv).

Table 2 and Figure 7 gives the November biomass for 2006-2014 estimated using current model predicted November numbers-at-length[2] and the length-weight relationships from model ii) and model iv). This shows that the impact of the alternative models for the length-weight relationship is less than at most 3% difference in biomass.

Commercial data

Table 3 lists the estimated parameter values from commercial models v) to ix) and Figure 8 compares the estimated *a* parameters. There is a 9-11% difference between the monthly *a* parameters for models viii) and vii), and a 31% difference between the annual and monthly *a* parameters for model ix). The AIC model selection criterion favours model ix), in which different *a* parameters are estimated for every year and month and given the relatively large (31%) difference in monthly and annual *a* parameters, it would seem best to use this model. However, there is no increase in the regression coefficient within three decimal places between the models, implying that although AIC suggests selecting model ix), the associated results do not differ biologically meaningfully from those of models v) to viii).

Figure 9 shows the model fits to the data for the AIC-preferred model ix).

Implications of Results

Considering the new anchovy length-weight relationships estimated from survey data between 2006 and 2014, model iv) is best supported by model selection criteria. Implementing this relationship would result in more accurate annual relationships being used annually from 2006 onwards. An average (2006-2014) *a* parameter would be used for all years prior to 2006. The disadvantage of this model is that prior to all future assessments, the annual length-weight relationships should be recalculated given the new data. Furthermore, and additionally demanding, a new anchovy length-weight relationship should be calculated with samples from each survey, before the survey data can be finalised.

Model ii), which provided results not meaningfully different biologically to those from model iv), with an impact on model estimated biomass of at most 3%[3], would not require annual updates to the length-weight relationship for surveys, and could be considered reliable for a number of years prior to being re-estimated once a substantial amount of new data

[2] The anchovy assessment is not yet finalised.
[3] Based on the current anchovy assessment results, which are not yet finalised.

become available. However, adopting the new length-weight relationships from model ii) still requires an update to past survey data.

Model selection criteria prefer a model which estimates individual *a* parameters for every year and month (model ix), when considering length-weight relationships estimated from monthly commercial data between 1984 and 1996. Implementing this relationship would result in more accurate annual relationships being used prior to 1997, compared to the other models which only consider a difference in the *a* parameters by month. An average monthly *a* parameter would be used for 1997 to 2014. The disadvantage of this model is that prior to all future assessments, the annual and monthly length-weight relationships should be recalculated given new data.

Models vii) and viii), which provided results not meaningfully different biologically to those from model ix), would not require annual updates to the commercial length-weight relationships and could be considered reliable for a number of years prior to being re-estimated once a substantial amount of new data become available.

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References

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Table 1. Model estimated parameters for the length-weight relationship when fitting to May and November survey data. AIC ($2n-2\ln L$), where $-\ln L$ is given by equation (2), *n* denotes the number of parameters estimated, and $D=39331$ denotes the number of data points. ΔAIC denotes the difference in AIC in the models, compared to the model with the lowest AIC, model iv). The simple linear regression coefficients are also given by year and data set.

	Survey Model					Survey Model			
	i)	ii)	iii)	iv)		i)	ii)	iii)	iv)
Number of parameters	2	3	11	19		2	3	11	19
a_{2006}^{May}	0.0064	0.0072	0.0073	0.0074	${r_{2006}^{May}}^2$	0.988	0.988	0.988	0.988
a_{2006}^{Nov}	0.0064	0.0077	0.0078	0.0077	${r_{2006}^{Nov}}^2$	0.956	0.956	0.956	0.956
a_{2007}^{May}	0.0064	0.0072	0.0072	0.0074	${r_{2007}^{May}}^2$	0.978	0.978	0.978	0.978
a_{2007}^{Nov}	0.0064	0.0077	0.0077	0.0076	${r_{2007}^{Nov}}^2$	0.979	0.979	0.979	0.979
a_{2008}^{May}	0.0064	0.0072	0.0072	0.0071	${r_{2008}^{May}}^2$	0.988	0.988	0.988	0.988
a_{2008}^{Nov}	0.0064	0.0077	0.0077	0.0078	${r_{2008}^{Nov}}^2$	0.939	0.939	0.939	0.939
a_{2009}^{May}	0.0064	0.0072	0.0074	0.0075	${r_{2009}^{May}}^2$	0.957	0.957	0.957	0.957
a_{2009}^{Nov}	0.0064	0.0077	0.0080	0.0080	${r_{2009}^{Nov}}^2$	0.914	0.914	0.914	0.914
a_{2010}^{May}	0.0064	0.0072	0.0071	0.0072	${r_{2010}^{May}}^2$	0.959	0.959	0.959	0.959
a_{2010}^{Nov}	0.0064	0.0077	0.0076	0.0077	${r_{2010}^{Nov}}^2$	0.927	0.927	0.927	0.927
a_{2011}^{May}	0.0064	0.0072	0.0069	0.0069	${r_{2011}^{May}}^2$	0.967	0.967	0.967	0.967
a_{2011}^{Nov}	0.0064	0.0077	0.0075	0.0076	${r_{2011}^{Nov}}^2$	0.909	0.909	0.909	0.909
a_{2012}^{May}	0.0064	0.0072	0.0071	0.0070	${r_{2012}^{May}}^2$	0.932	0.932	0.932	0.932
a_{2012}^{Nov}	0.0064	0.0077	0.0076	0.0078	${r_{2012}^{Nov}}^2$	0.894	0.894	0.894	0.894
a_{2013}^{May}	0.0064	0.0072	0.0071	0.0070	${r_{2013}^{May}}^2$	0.979	0.979	0.979	0.979
a_{2013}^{Nov}	0.0064	0.0077	0.0076	0.0078	${r_{2013}^{Nov}}^2$	0.897	0.897	0.897	0.897
a_{2014}^{May}	0.0064	0.0072	0.0073	0.0072	${r_{2014}^{May}}^2$	0.963	0.963	0.963	0.963
a_{2014}^{Nov}	0.0064	0.0077	0.0078	0.0080	${r_{2014}^{Nov}}^2$	0.933	0.933	0.933	0.933
$b=b_y^j$	3.1584	3.0934	3.0918	3.0892					
AIC	-53109.6	-55758.3	-56478.0	-57097.8					
ΔAIC	3988.3	1339.5	619.8	-					

Table 2. The model estimated total November biomass (in thousands of tons) resulting from the application of the length-weight relationship using survey models ii) and iv), and the length-weight relationship used previously.

Year	Previously used	Model ii)	Model iv)	Model ii) : Previously used	Model ii) : Model iv)
2006	2637.268	2597.380	2567.951	0.98	1.01
2007	3533.420	3480.976	3398.252	0.99	1.02
2008	4542.414	4472.586	4525.051	0.98	0.99
2009	4375.568	4305.668	4412.303	0.98	0.98
2010	2759.385	2714.180	2679.768	0.98	1.01
2011	1678.521	1655.202	1615.319	0.99	1.02
2012	3758.199	3702.770	3703.474	0.99	1.00
2013	4866.336	4790.232	4790.316	0.98	1.00
2014	3739.569	3677.750	3772.835	0.98	0.97

Table 3. Model estimated parameters for the length-weight relationship when fitting to monthly commercial data. AIC ($2n-2\ln L$), where $-\ln L$ is given by equation (2), n denotes the number of estimated parameters, and $D=53153$ denotes the number of data points. ΔAIC denotes the difference in AIC in the models, compared to the model with the lowest AIC, model ix). The simple linear regression coefficients are also given by month and year.

		$a_{y,m}^{Com}$												$b=b_{y,m}^{Com}$			
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		Number of parameters	AIC	ΔAIC
Model v)		0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	3.1431	3	-78348.5	10577.6
Model vi)		0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	3.1428	13	-78328.5	10577.7
Model vii)		0.0082	0.0081	0.0081	0.0081	0.0079	0.0078	0.0075	0.0073	0.0076	0.0076	0.0081	0.0079	3.1431	13	-82512.6	6393.5
Model viii)		0.0082	0.0082	0.0081	0.0081	0.0080	0.0077	0.0075	0.0074	0.0075	0.0077	0.0079	0.0081	3.0979	4	-82373.6	6532.6
Model ix)	1984	0.0087	0.0084	0.0084	0.0085	0.0082	0.0080	0.0083	0.0073	0.0076	0.0081	0.0084	0.0080	3.0917	157	-88906.2	-
	1985	0.0080	0.0085	0.0080	0.0086	0.0083	0.0084	0.0083	0.0081	0.0087	0.0076	0.0081	0.0079				
	1986	0.0079	0.0081	0.0088	0.0086	0.0082	0.0076	0.0074	0.0075	0.0080	0.0076	0.0081	0.0079				
	1987	0.0087	0.0083	0.0084	0.0081	0.0079	0.0081	0.0076	0.0076	0.0078	0.0076	0.0081	0.0079				
	1988	0.0085	0.0085	0.0081	0.0077	0.0080	0.0074	0.0073	0.0073	0.0076	0.0076	0.0080	0.0079				
	1989	0.0079	0.0081	0.0079	0.0080	0.0078	0.0076	0.0078	0.0073	0.0076	0.0076	0.0081	0.0079				
	1990	0.0065	0.0072	0.0085	0.0079	0.0079	0.0083	0.0075	0.0073	0.0076	0.0076	0.0081	0.0079				
	1991	0.0077	0.0080	0.0079	0.0078	0.0079	0.0075	0.0069	0.0073	0.0087	0.0068	0.0081	0.0079				
	1992	0.0082	0.0083	0.0083	0.0079	0.0080	0.0072	0.0071	0.0077	0.0076	0.0076	0.0081	0.0079				
	1993	0.0085	0.0080	0.0076	0.0075	0.0076	0.0078	0.0072	0.0073	0.0063	0.0076	0.0081	0.0079				
	1994	0.0082	0.0081	0.0081	0.0077	0.0079	0.0078	0.0075	0.0073	0.0076	0.0076	0.0081	0.0079				
	1995	0.0071	0.0064	0.0070	0.0076	0.0077	0.0078	0.0077	0.0066	0.0076	0.0076	0.0081	0.0079				
	1996	0.0075	0.0081	0.0081	0.0081	0.0079	0.0078	0.0075	0.0073	0.0076	0.0076	0.0081	0.0079				

Table 3 (cont).

		r_m^2															
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		Number of parameters	AIC	ΔAIC
Model v)	1984	0.977	0.888	0.953	0.958	0.966	0.961	0.971			0.950	0.906	0.909				
	1985	0.980	0.979	0.989	0.983	0.977	0.954	0.963	0.878	0.947							
	1986	0.982	0.898	0.967	0.968	0.964	0.970	0.947	0.925	0.960							
	1987	0.883	0.803	0.873	0.868	0.934	0.964	0.966	0.973	0.965							
	1988	0.898	0.915	0.912	0.966	0.974	0.961	0.978	0.975	0.972	0.965	0.964					
	1989	0.901	0.938	0.942	0.952	0.961	0.967	0.974									
	1990	0.726	0.987	0.978	0.982	0.966	0.937										
	1991	0.838	0.978	0.965	0.964	0.954	0.946	0.961		0.844	0.787						
	1992	0.917	0.955	0.957	0.966	0.963	0.959	0.949	0.938	0.945							
	1993	0.922	0.902	0.864	0.959	0.981		0.992		0.917							
	1994				0.954												
	1995	0.906	0.817	0.954	0.966	0.986	0.983	0.971	0.988	0.977							
	1996	0.963															
Model vi)	1984	0.977	0.888	0.953	0.958	0.966	0.961	0.971			0.950	0.906	0.909				
	1985	0.980	0.979	0.989	0.983	0.977	0.954	0.963	0.878	0.947							
	1986	0.982	0.898	0.967	0.968	0.964	0.970	0.947	0.925	0.960							
	1987	0.883	0.803	0.873	0.868	0.934	0.964	0.966	0.973	0.965							
	1988	0.898	0.915	0.912	0.966	0.974	0.961	0.978	0.975	0.972	0.965	0.964					
	1989	0.901	0.938	0.942	0.952	0.961	0.967	0.974									
	1990	0.726	0.987	0.978	0.982	0.966	0.937										
	1991	0.838	0.978	0.965	0.964	0.954	0.946	0.961		0.844	0.787						
	1992	0.917	0.955	0.957	0.966	0.963	0.959	0.949	0.938	0.945							
	1993	0.922	0.902	0.864	0.959	0.981		0.992		0.917							
	1994				0.954												
	1995	0.906	0.817	0.954	0.966	0.986	0.983	0.971	0.988	0.977							
	1996	0.963															

Table 3 (cont).

		r_m^2															
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		Number of parameters	AIC	ΔAIC
Model vii)	1984	0.977	0.888	0.953	0.958	0.966	0.961	0.971			0.950	0.906	0.909				
	1985	0.980	0.979	0.989	0.983	0.977	0.954	0.963	0.878	0.947							
	1986	0.982	0.898	0.967	0.968	0.964	0.970	0.947	0.925	0.960							
	1987	0.883	0.803	0.873	0.868	0.934	0.964	0.966	0.973	0.965							
	1988	0.898	0.915	0.912	0.966	0.974	0.961	0.978	0.975	0.972	0.965	0.964					
	1989	0.901	0.938	0.942	0.952	0.961	0.967	0.974									
	1990	0.726	0.987	0.978	0.982	0.966	0.937										
	1991	0.838	0.978	0.965	0.964	0.954	0.946	0.961		0.844	0.787						
	1992	0.917	0.955	0.957	0.966	0.963	0.959	0.949	0.938	0.945							
	1993	0.922	0.902	0.864	0.959	0.981		0.992		0.917							
	1994				0.954												
	1995	0.906	0.817	0.954	0.966	0.986	0.983	0.971	0.988	0.977							
	1996	0.963															
Model viii)	1984	0.977	0.888	0.953	0.958	0.966	0.961	0.971			0.950	0.906	0.909				
	1985	0.980	0.979	0.989	0.983	0.977	0.954	0.963	0.878	0.947							
	1986	0.982	0.898	0.967	0.968	0.964	0.970	0.947	0.925	0.960							
	1987	0.883	0.803	0.873	0.868	0.934	0.964	0.966	0.973	0.965							
	1988	0.898	0.915	0.912	0.966	0.974	0.961	0.978	0.975	0.972	0.965	0.964					
	1989	0.901	0.938	0.942	0.952	0.961	0.967	0.974									
	1990	0.726	0.987	0.978	0.982	0.966	0.937										
	1991	0.838	0.978	0.965	0.964	0.954	0.946	0.961		0.844	0.787						
	1992	0.917	0.955	0.957	0.966	0.963	0.959	0.949	0.938	0.945							
	1993	0.922	0.902	0.864	0.959	0.981		0.992		0.917							
	1994				0.954												
	1995	0.906	0.817	0.954	0.966	0.986	0.983	0.971	0.988	0.977							
	1996	0.963															

Table 3 (cont).

		r_m^2															
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		Number of parameters	AIC	ΔAIC
Model ix)	1984	0.977	0.888	0.953	0.958	0.966	0.961	0.971			0.950	0.906	0.909				
	1985	0.980	0.979	0.989	0.983	0.977	0.954	0.963	0.878	0.947							
	1986	0.982	0.898	0.967	0.968	0.964	0.970	0.947	0.925	0.960							
	1987	0.883	0.803	0.873	0.868	0.934	0.964	0.966	0.973	0.965							
	1988	0.898	0.915	0.912	0.966	0.974	0.961	0.978	0.975	0.972	0.965	0.964					
	1989	0.901	0.938	0.942	0.952	0.961	0.967	0.974									
	1990	0.726	0.987	0.978	0.982	0.966	0.937										
	1991	0.838	0.978	0.965	0.964	0.954	0.946	0.961		0.844	0.787						
	1992	0.917	0.955	0.957	0.966	0.963	0.959	0.949	0.938	0.945							
	1993	0.922	0.902	0.864	0.959	0.981		0.992		0.917							
	1994				0.954												
	1995	0.906	0.817	0.954	0.966	0.986	0.983	0.971	0.988	0.977							
	1996	0.963															

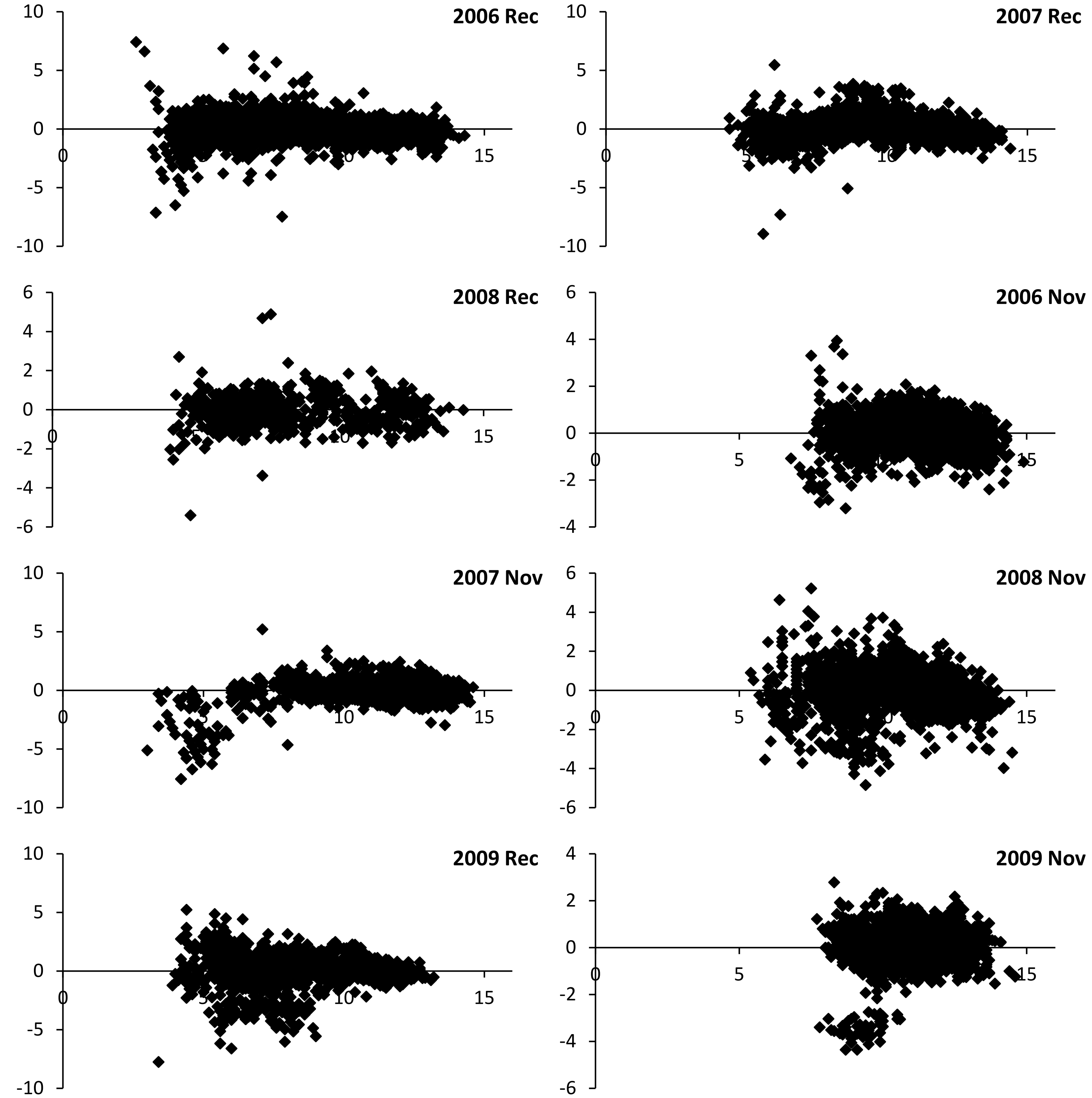


Figure 1. The residuals (as given by equation (6)) from the original survey model iv) fit including all the data. Note that the vertical axis range differs by plots, depending on the range of residuals.

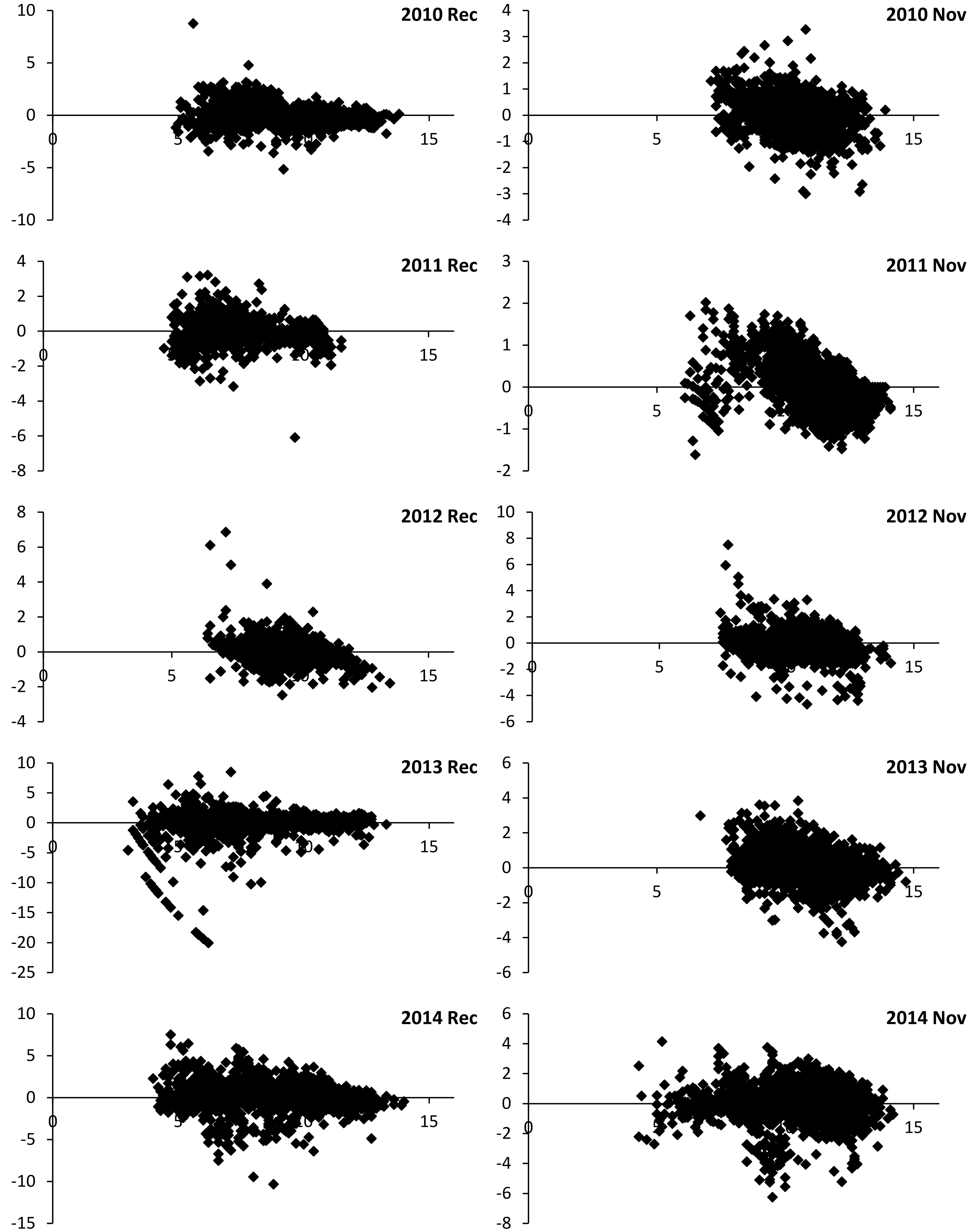


Figure 1 (cont).

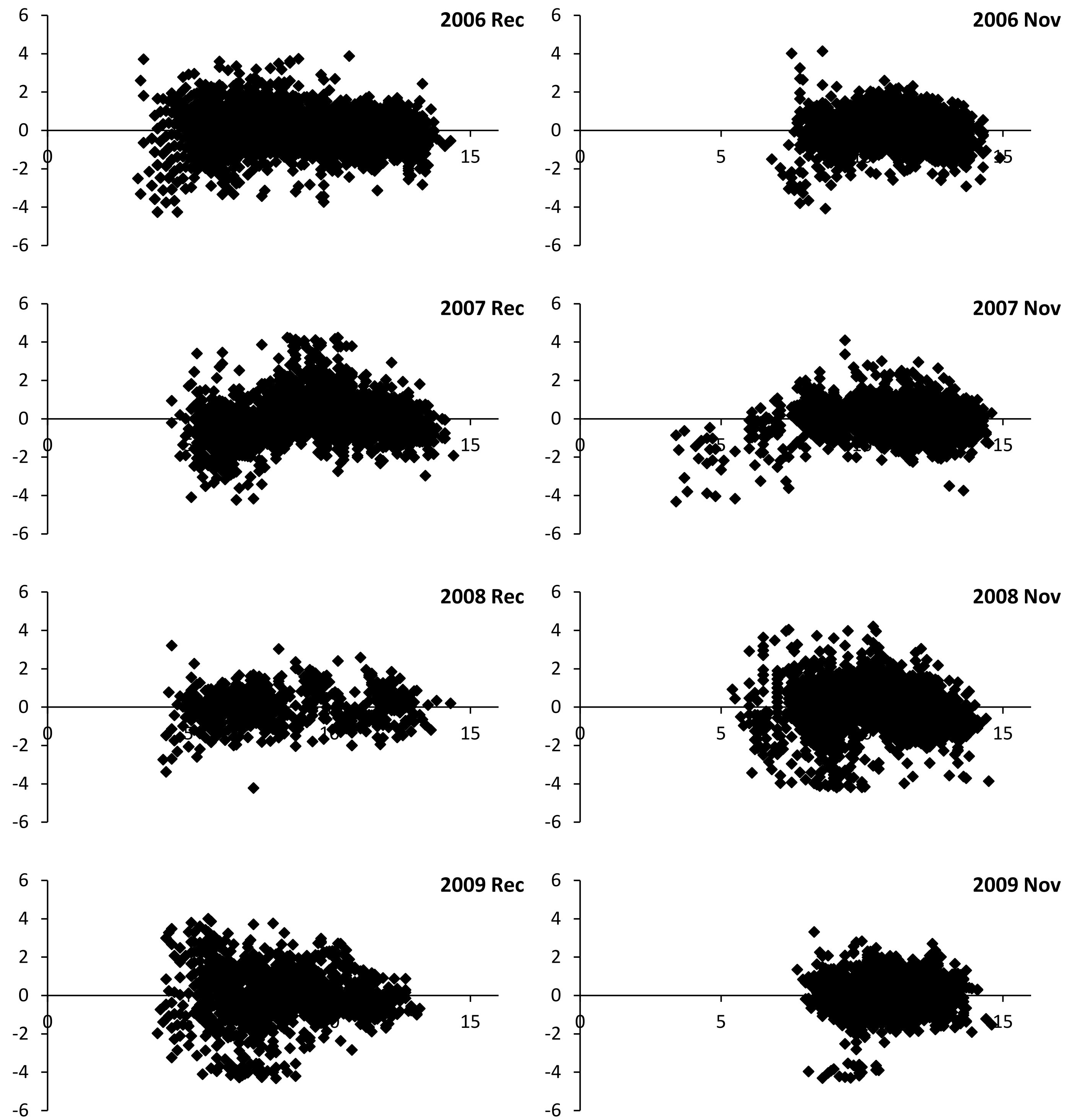


Figure 2. The residuals (as given by equation (6)) from the survey model iv) fit shown in Figure 5, after excluding outliers.

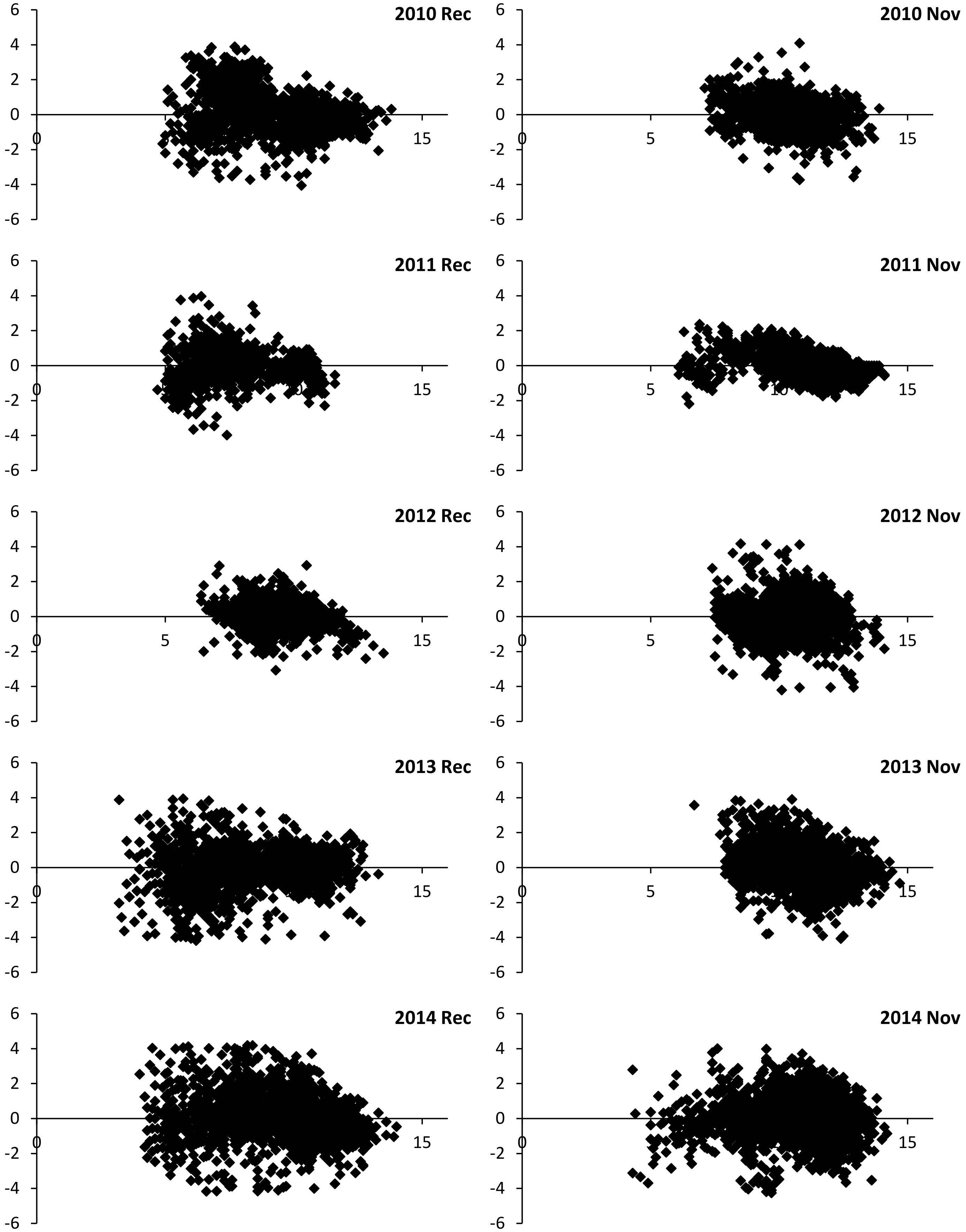


Figure 2 (cont).

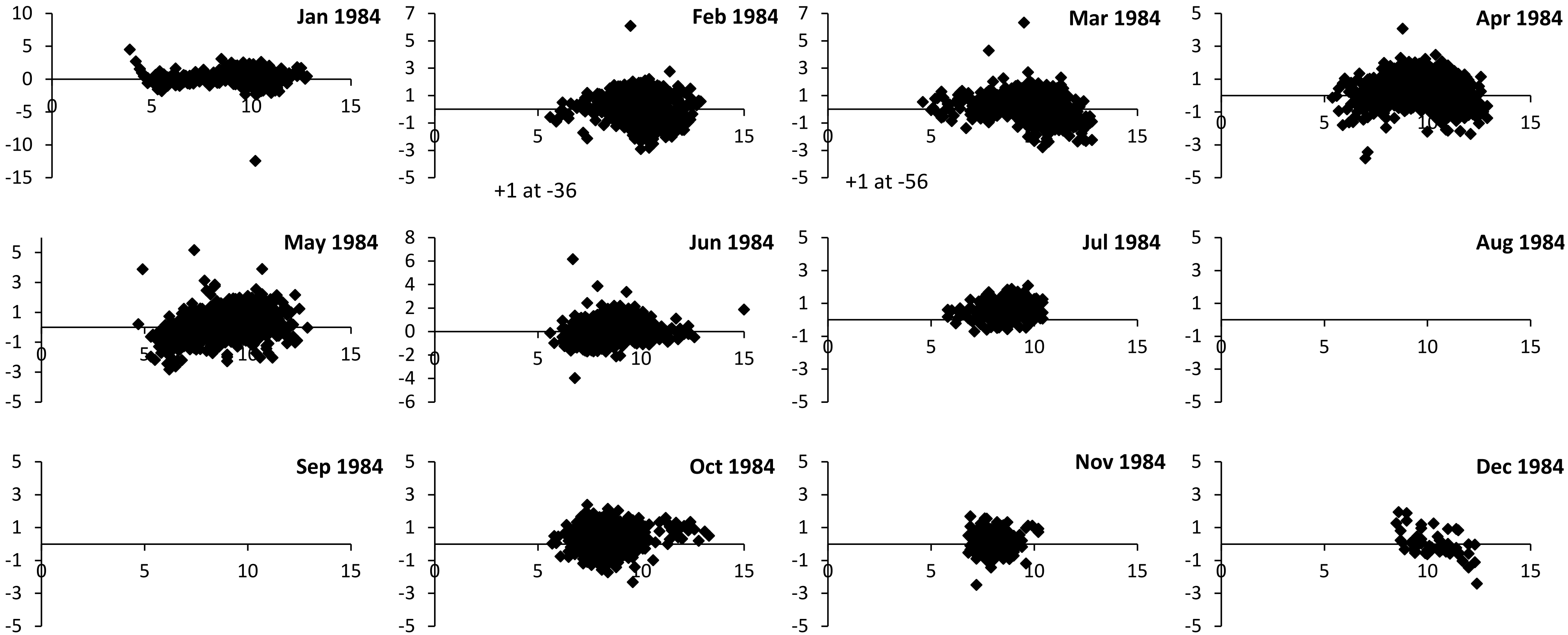


Figure 3. The residuals (as given by equation (7)) from the original commercial model vii) fit including all the data. Note that the vertical axis range differs by plots, depending on the range of residuals.

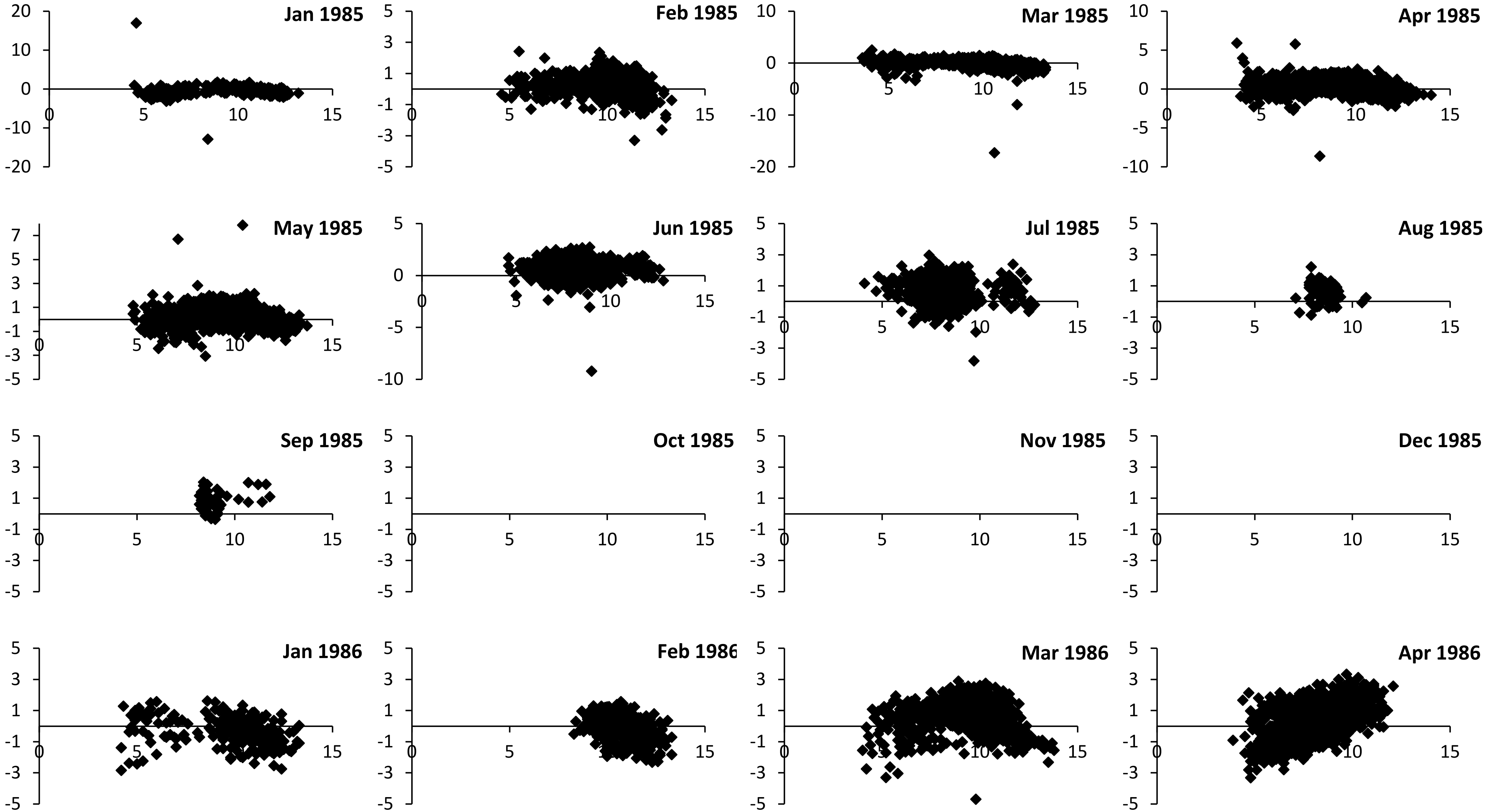
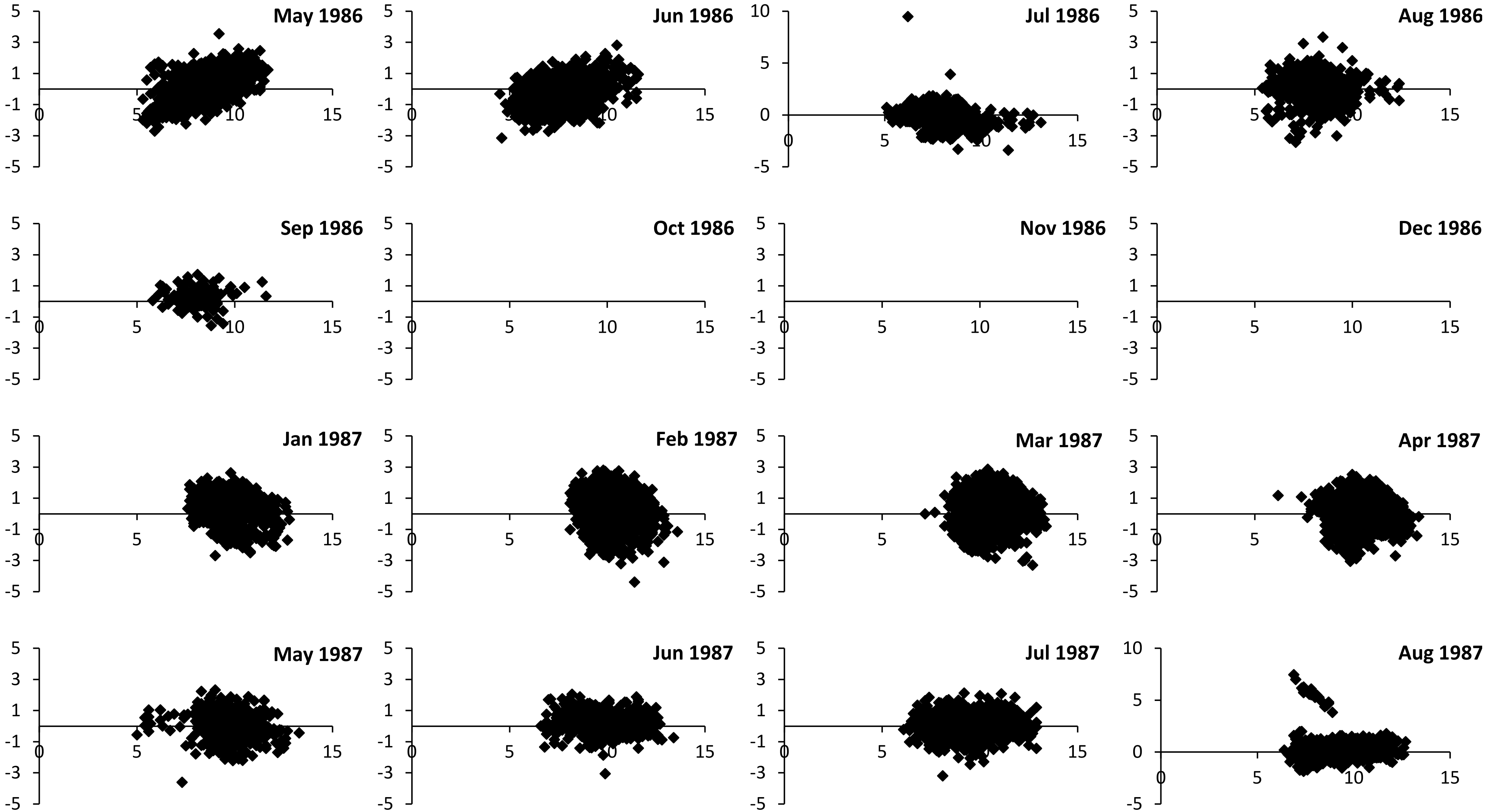


Figure 3 (cont).



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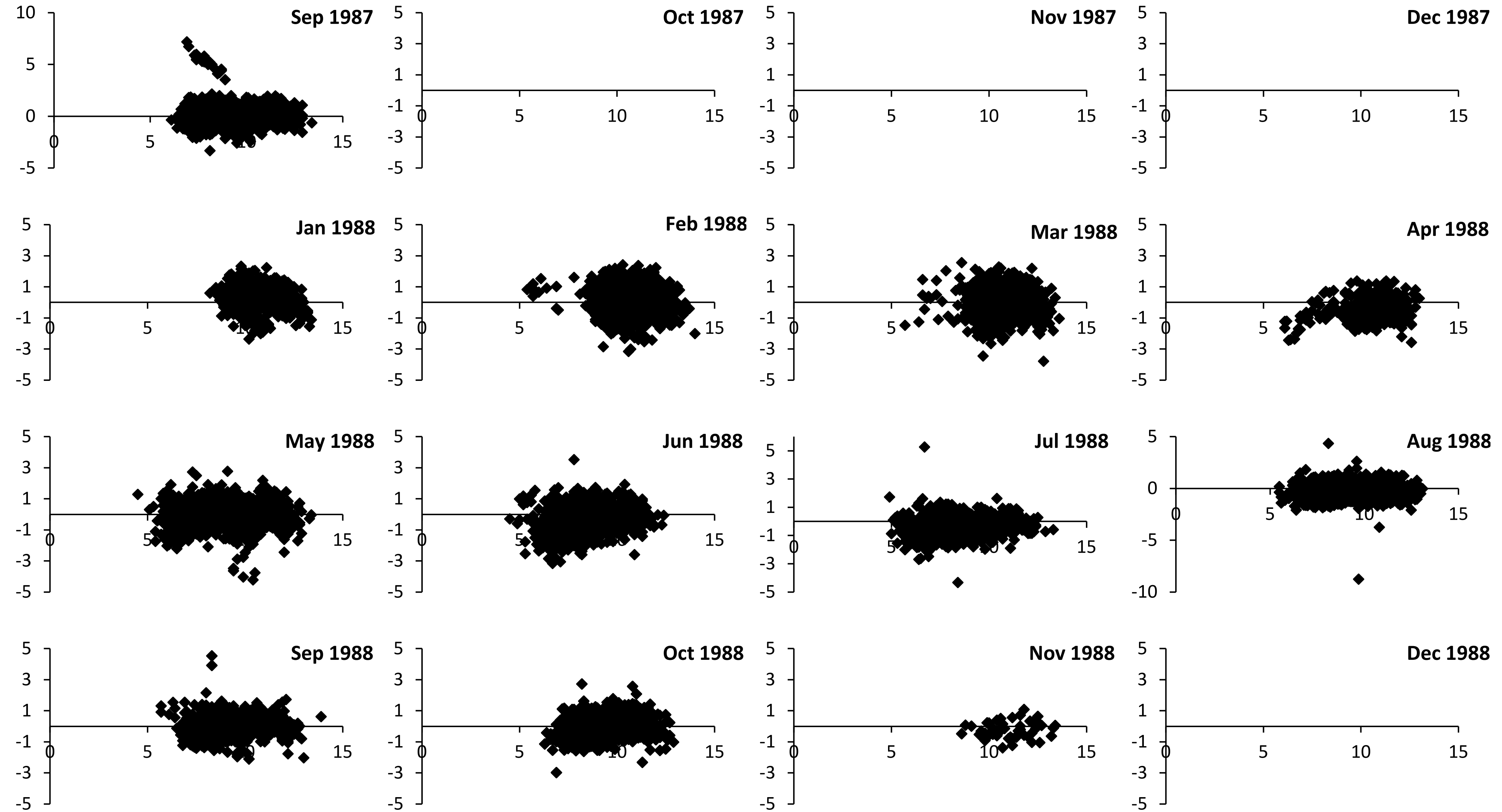

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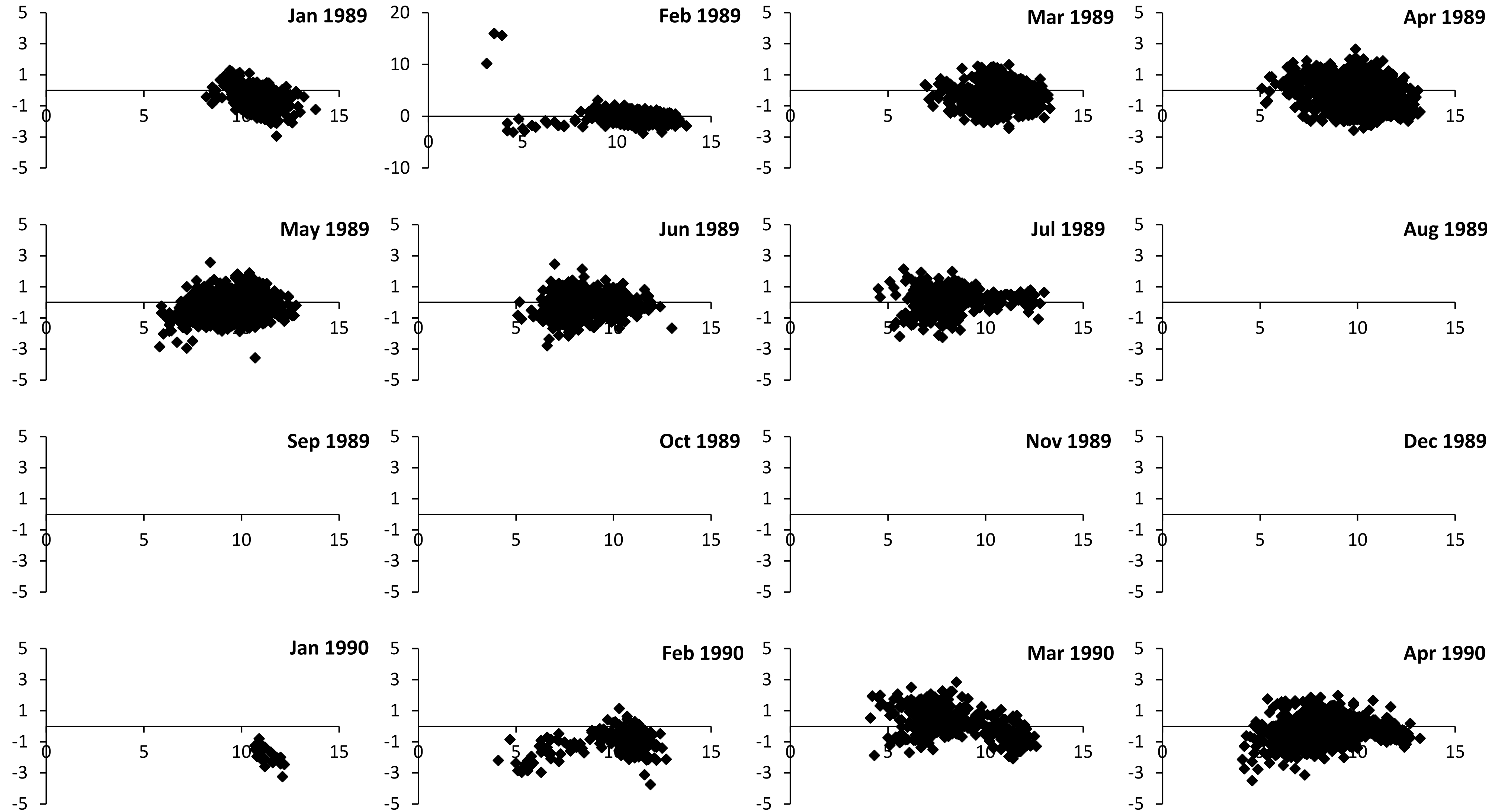

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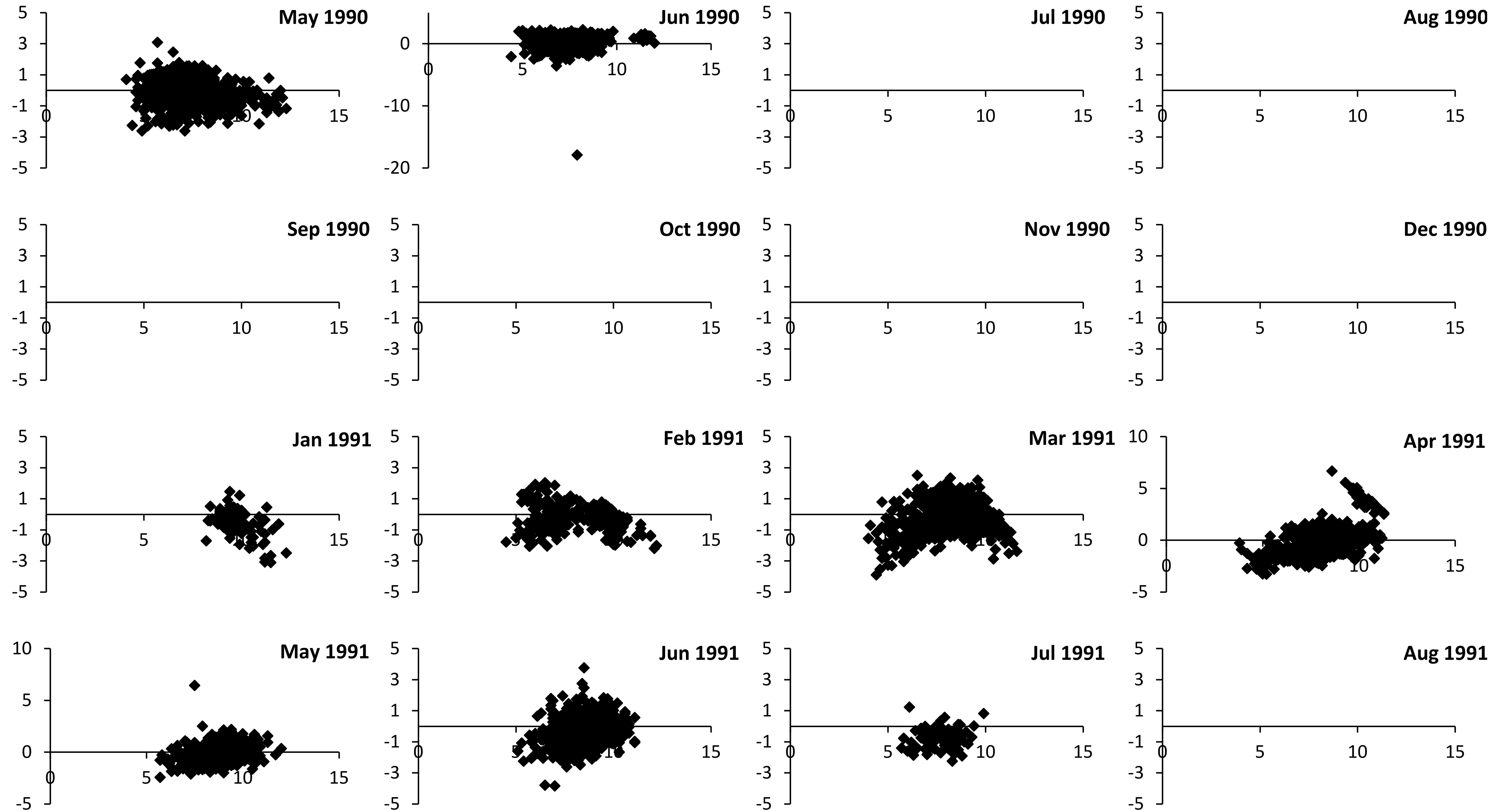

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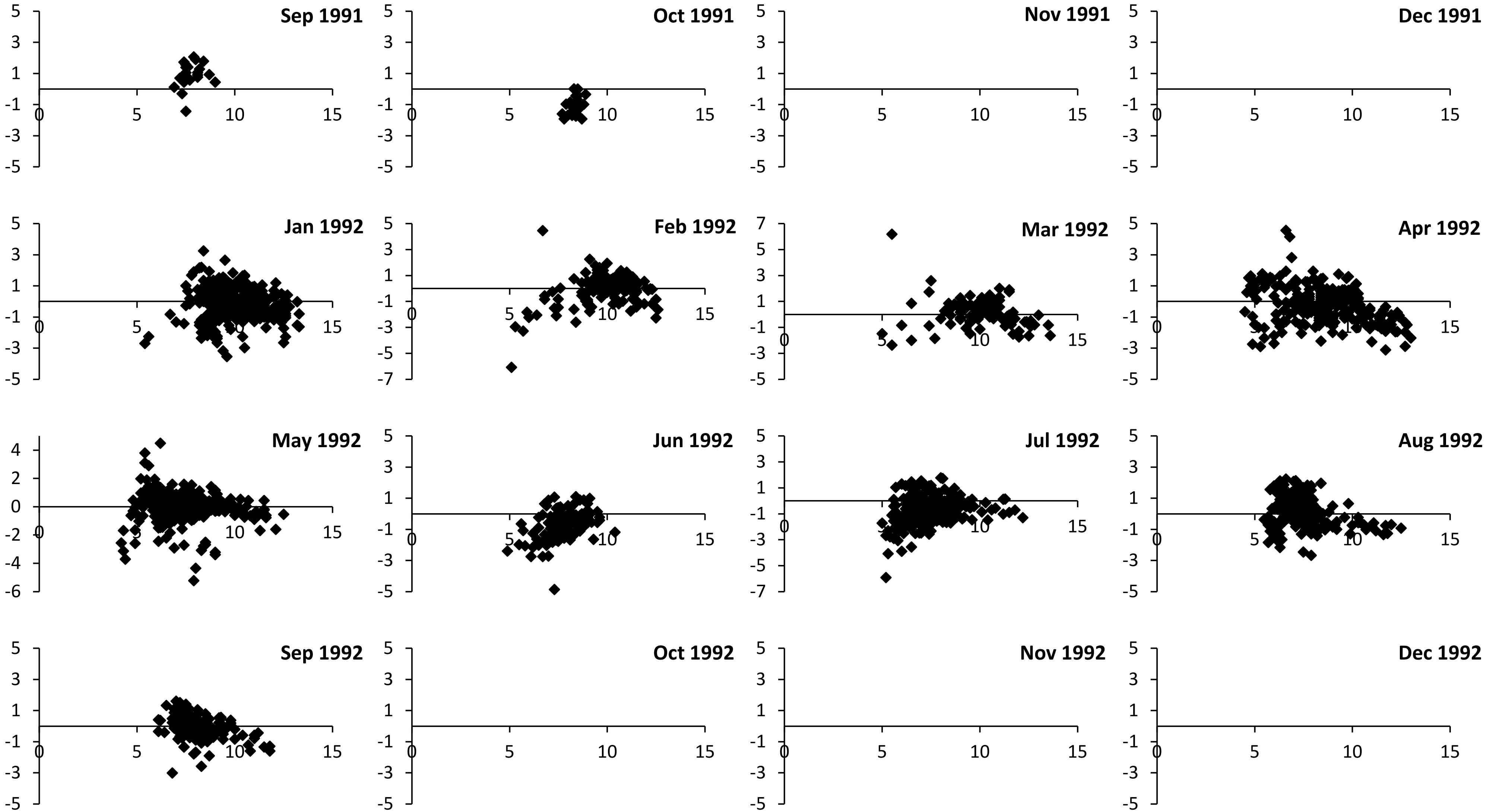

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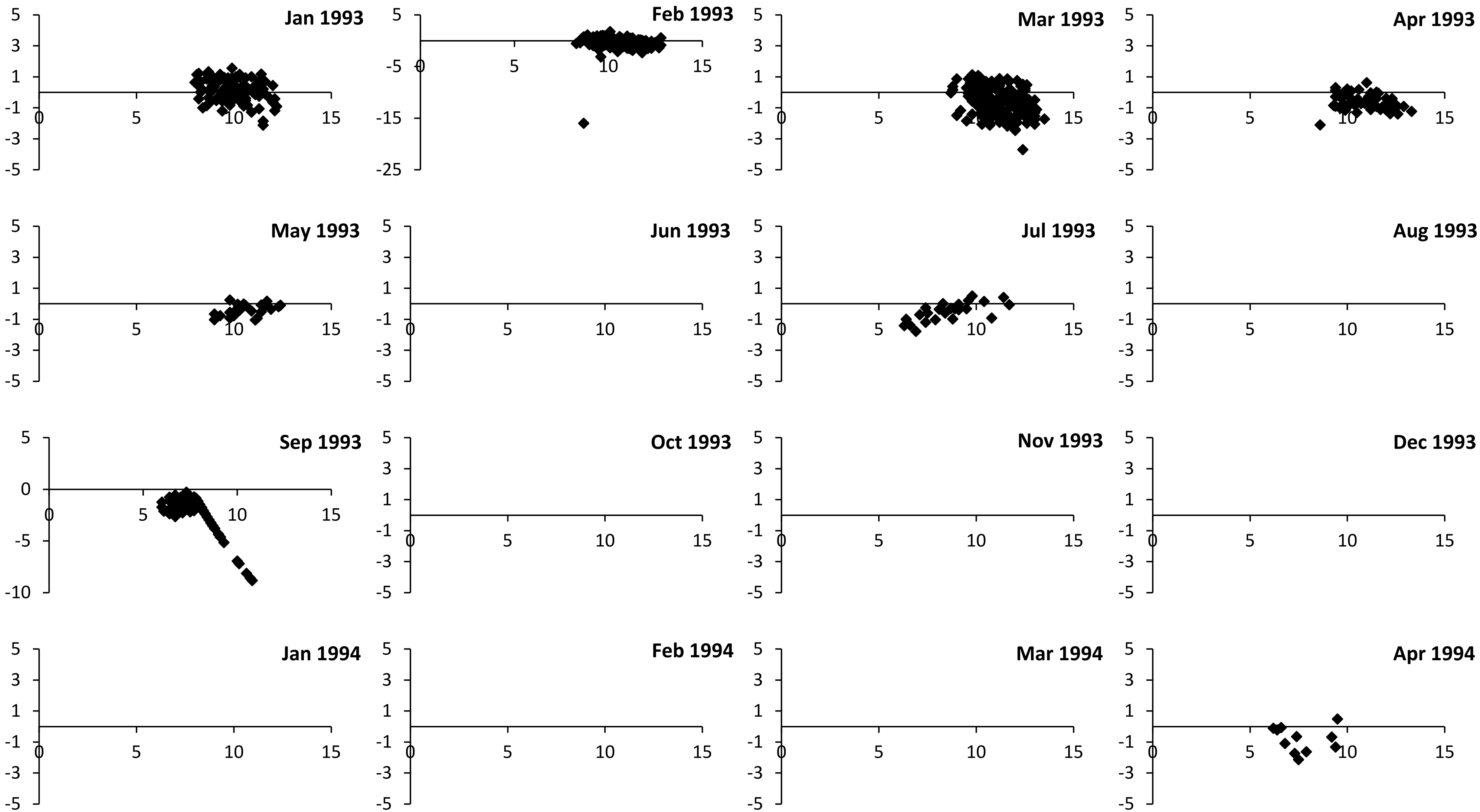

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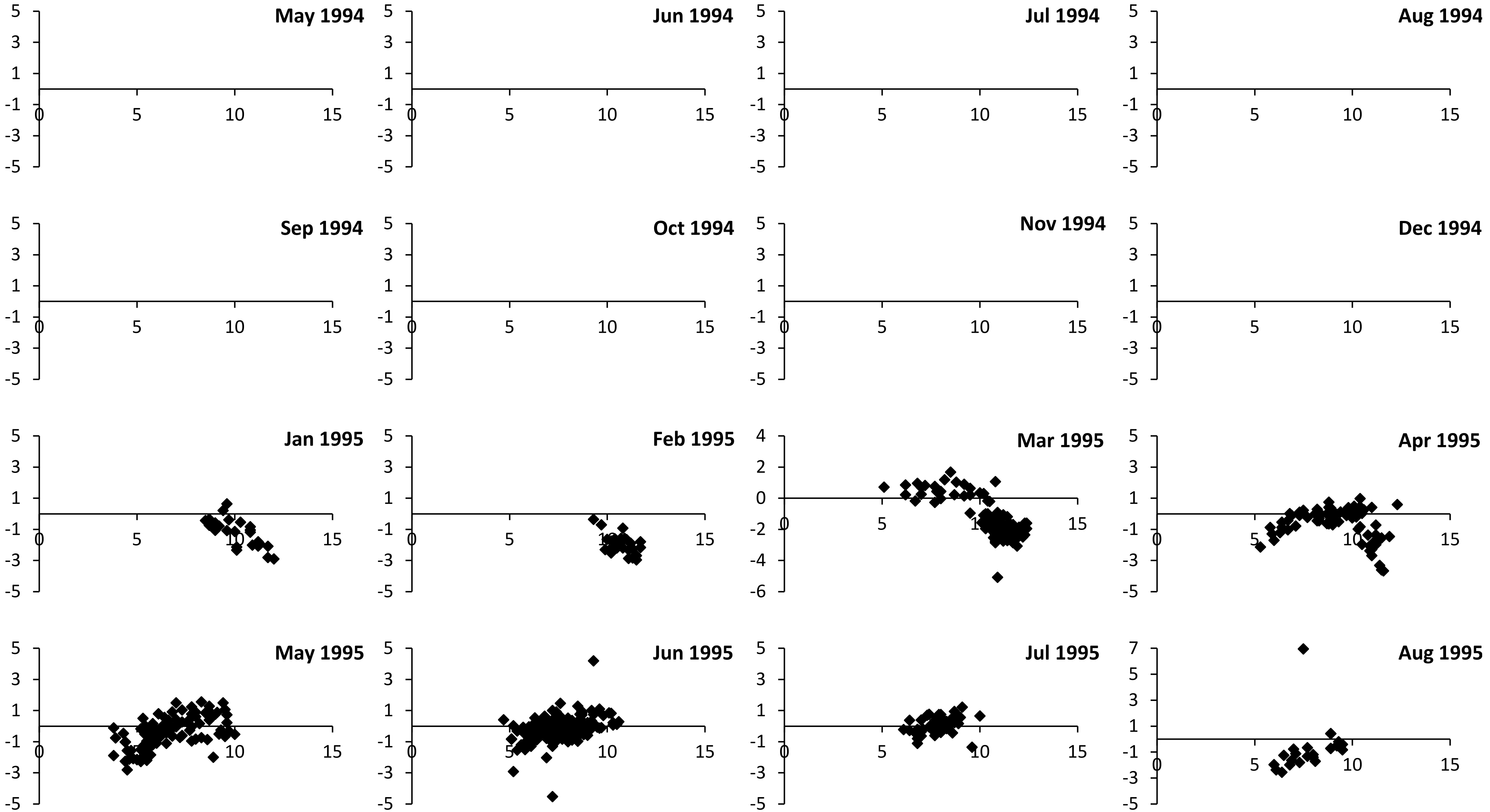

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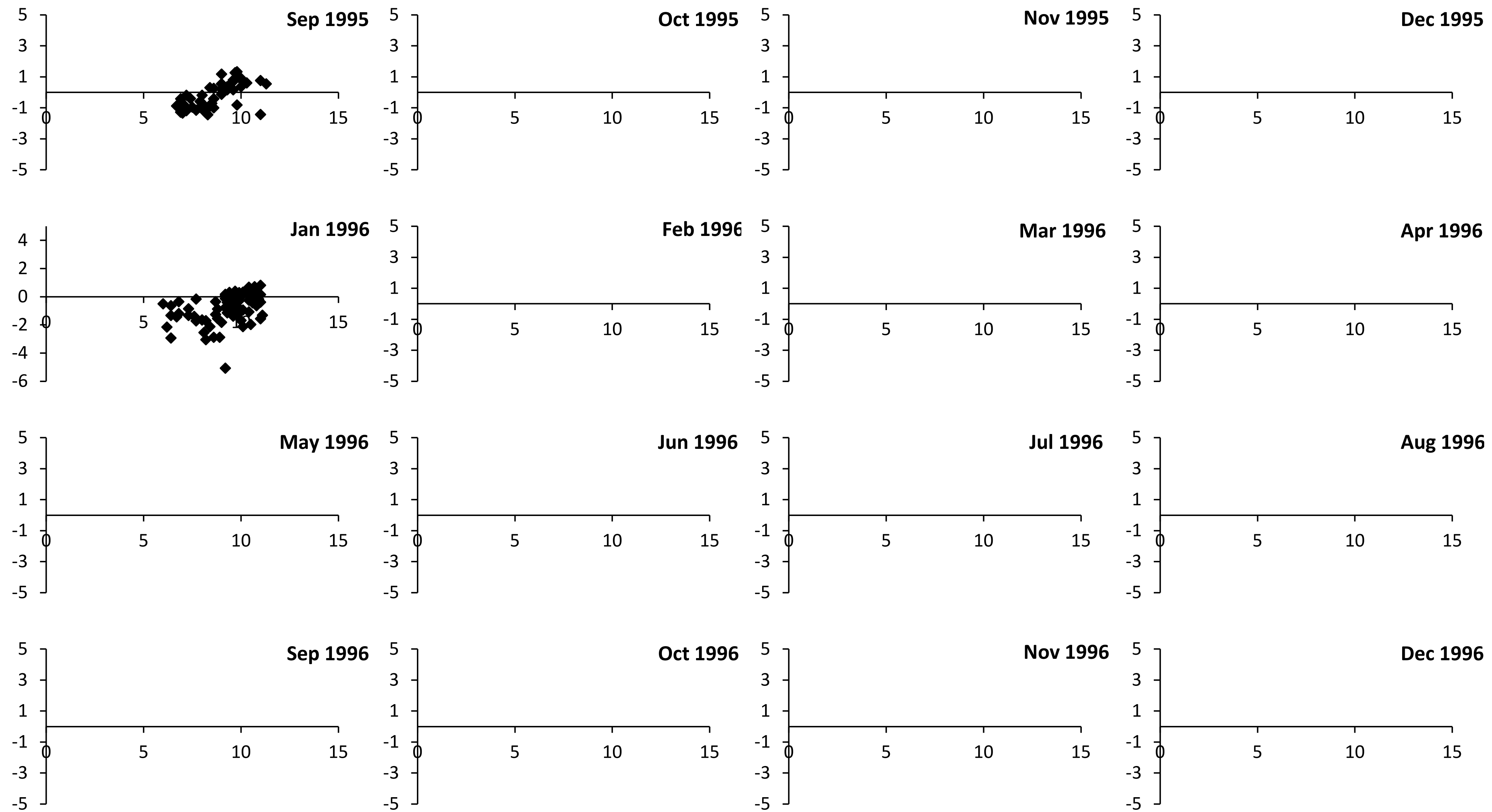


Figure 3 (cont).

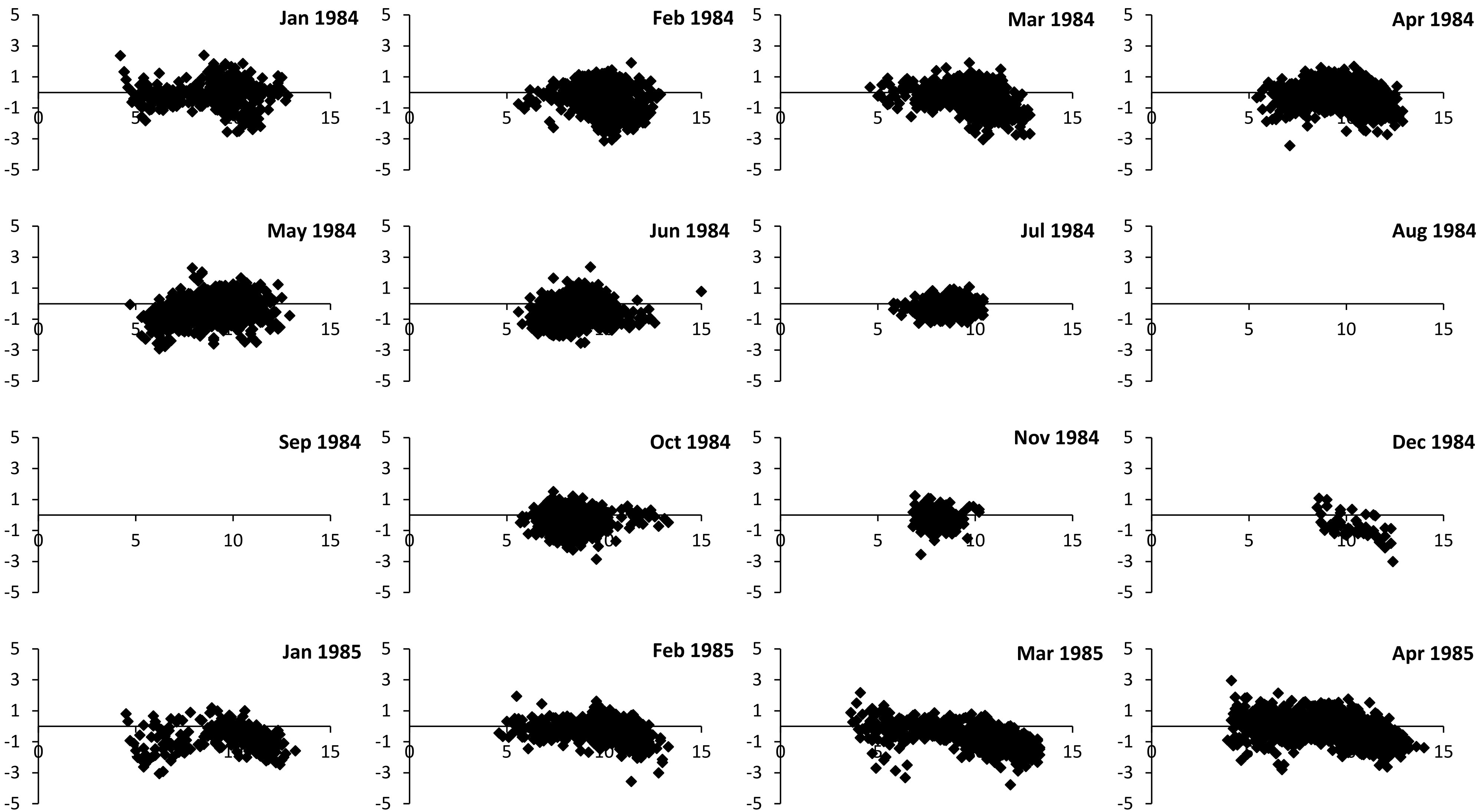
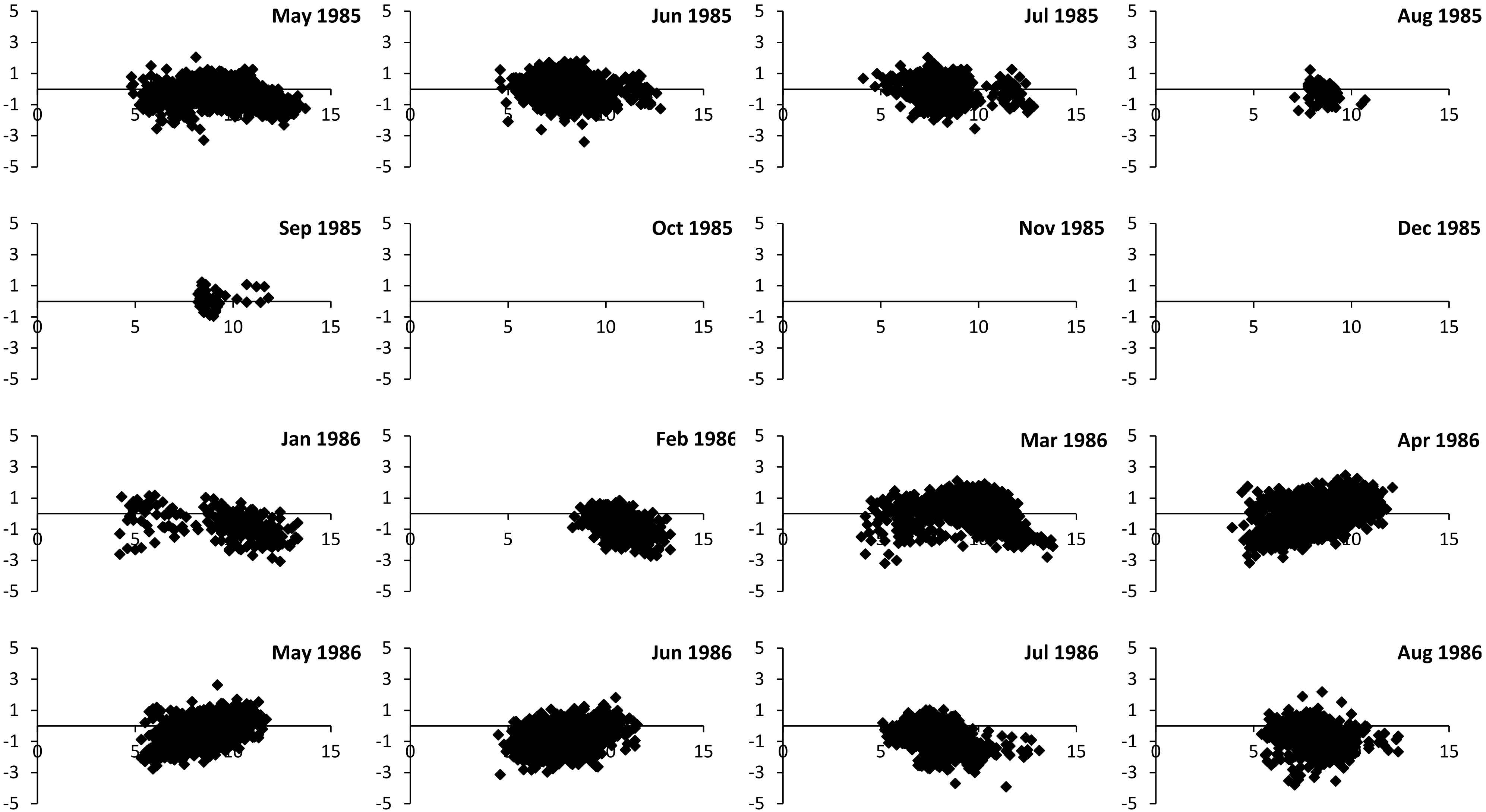


Figure 4. The residuals (as given by equation (7)) from the commercial model vii) fit, after excluding outliers.



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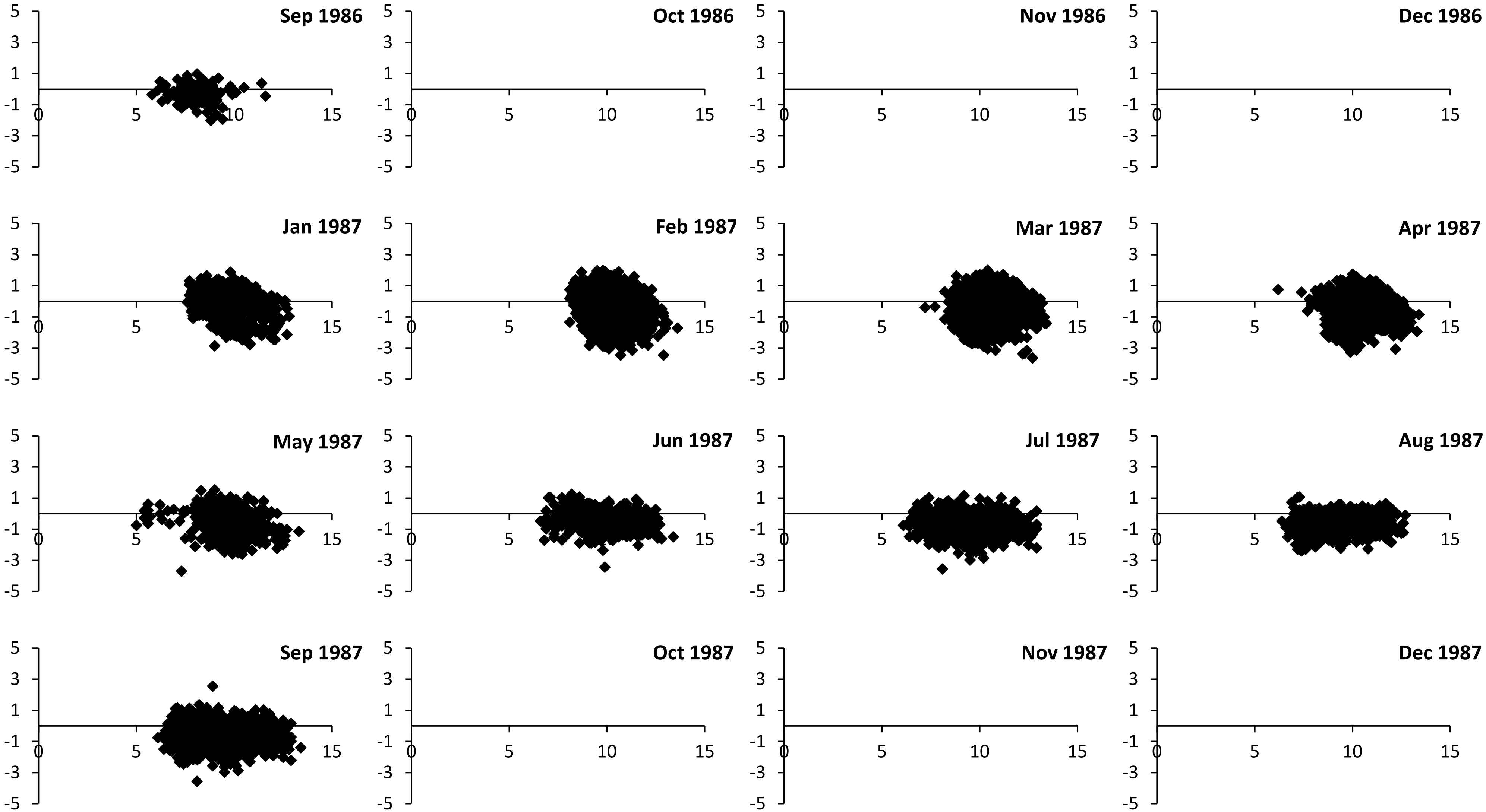

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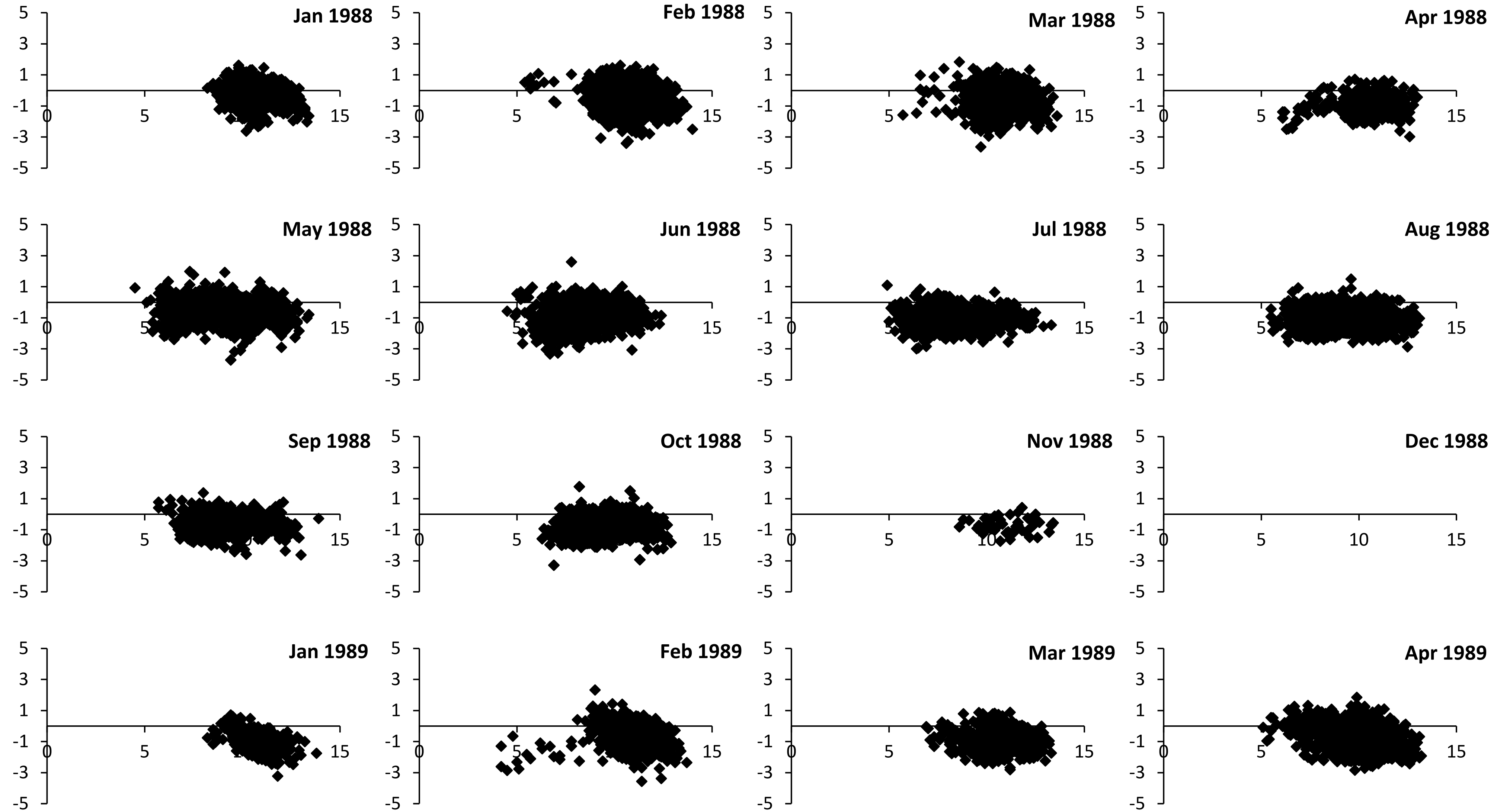

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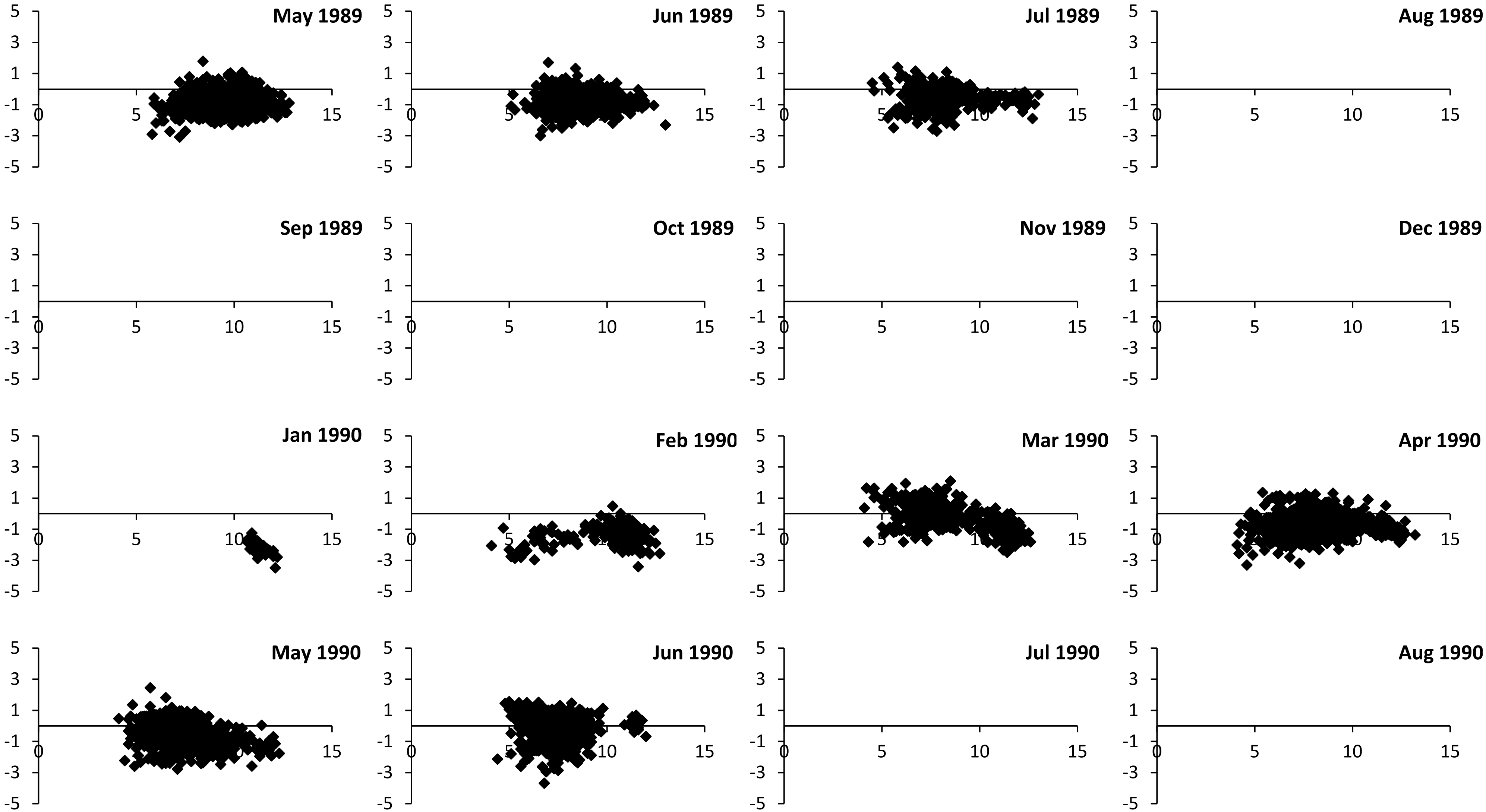

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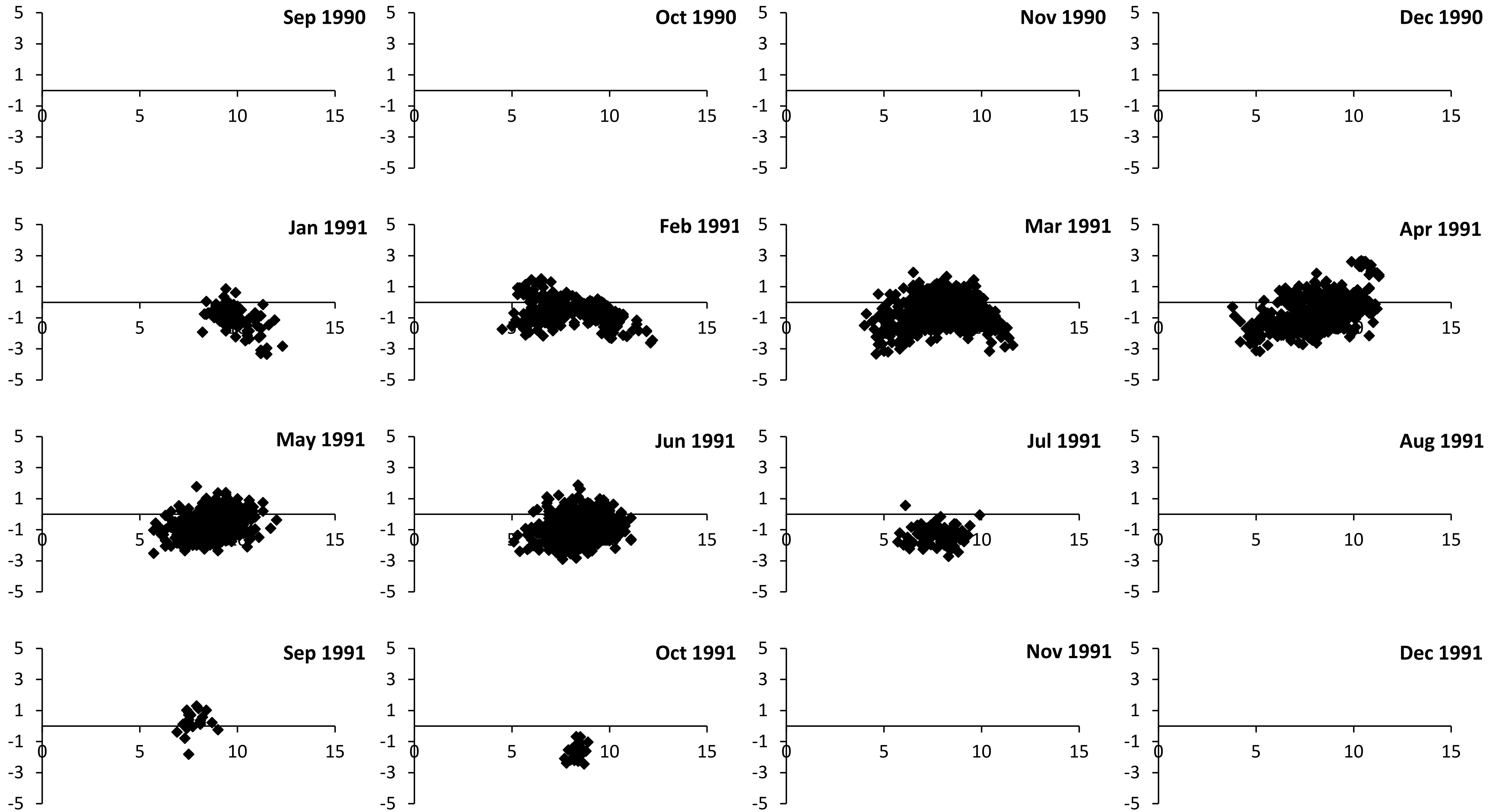

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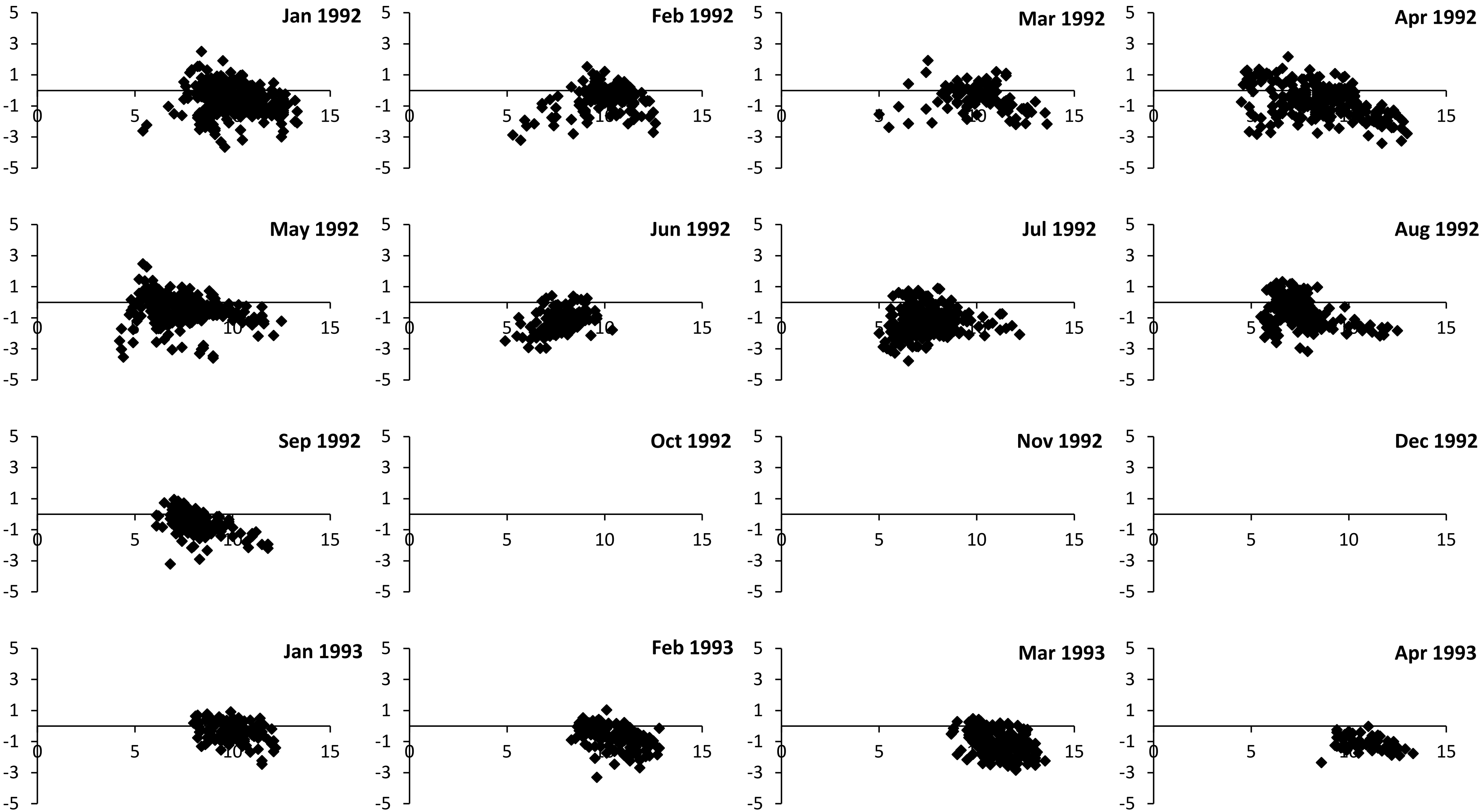

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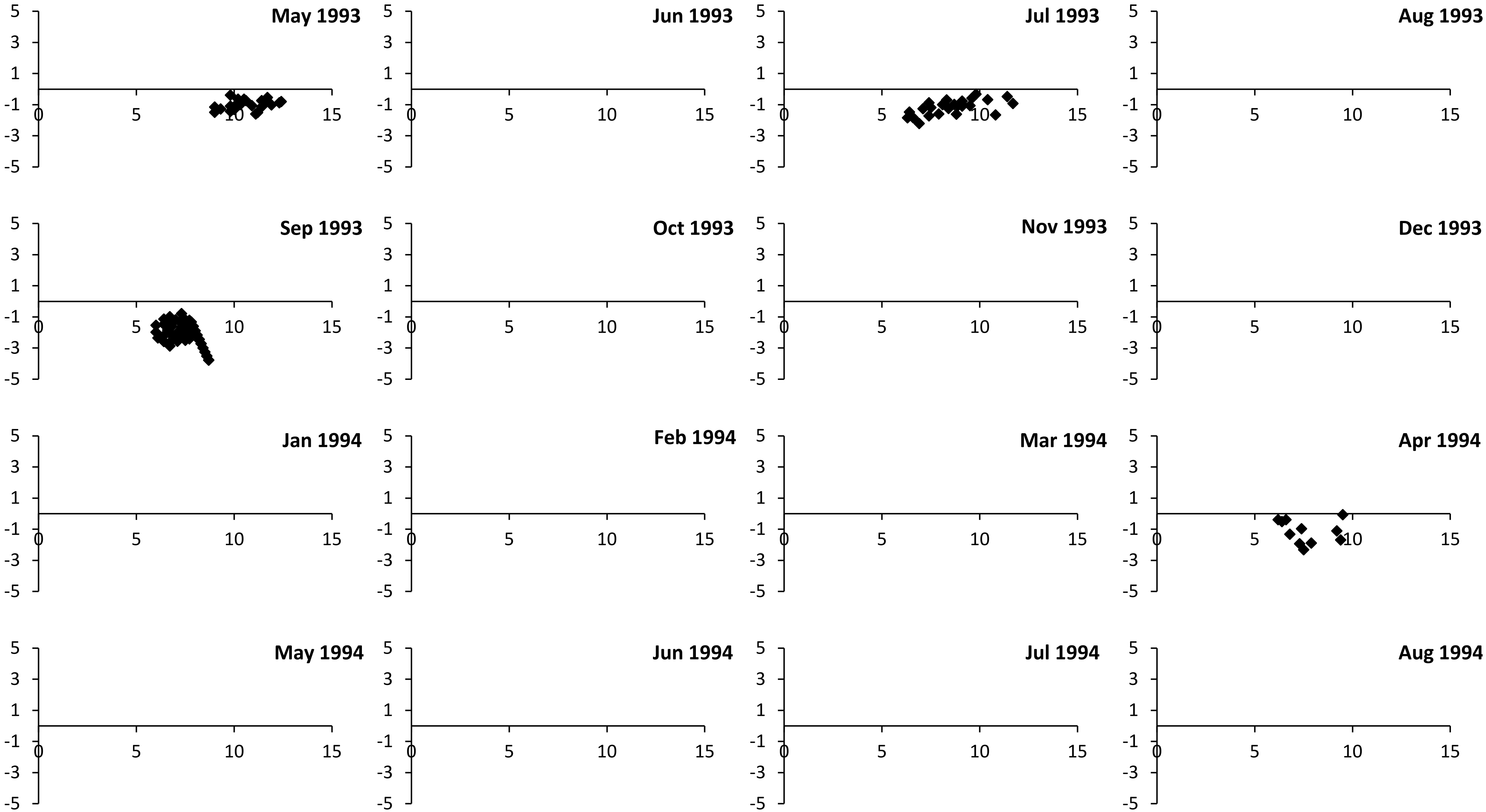

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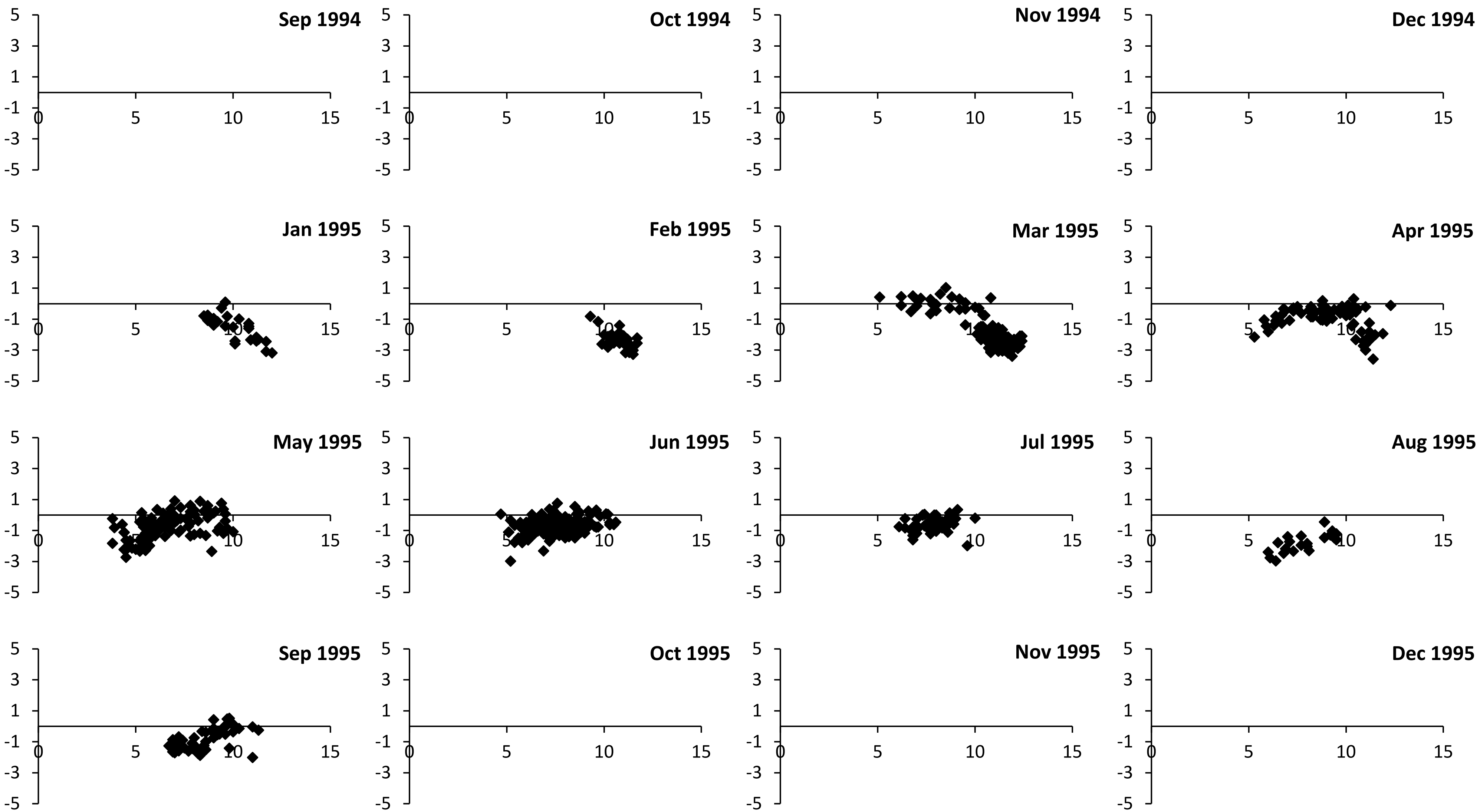

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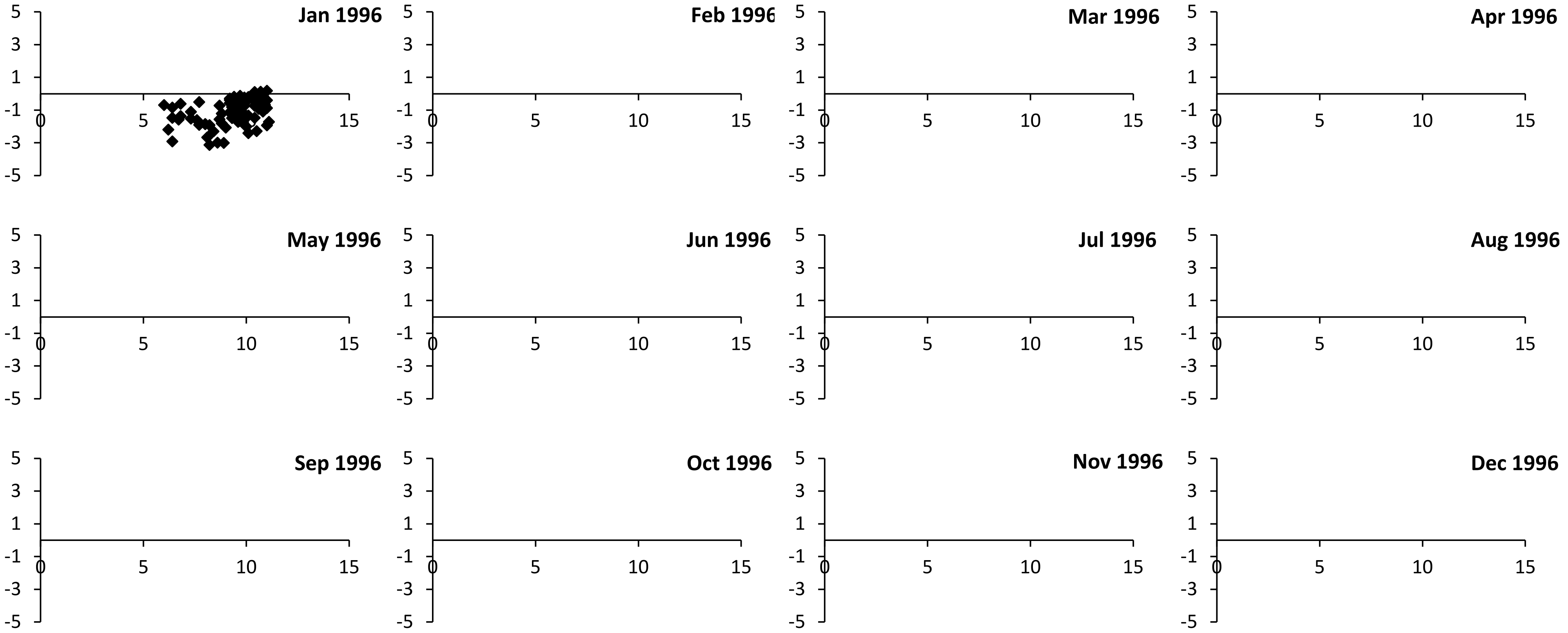

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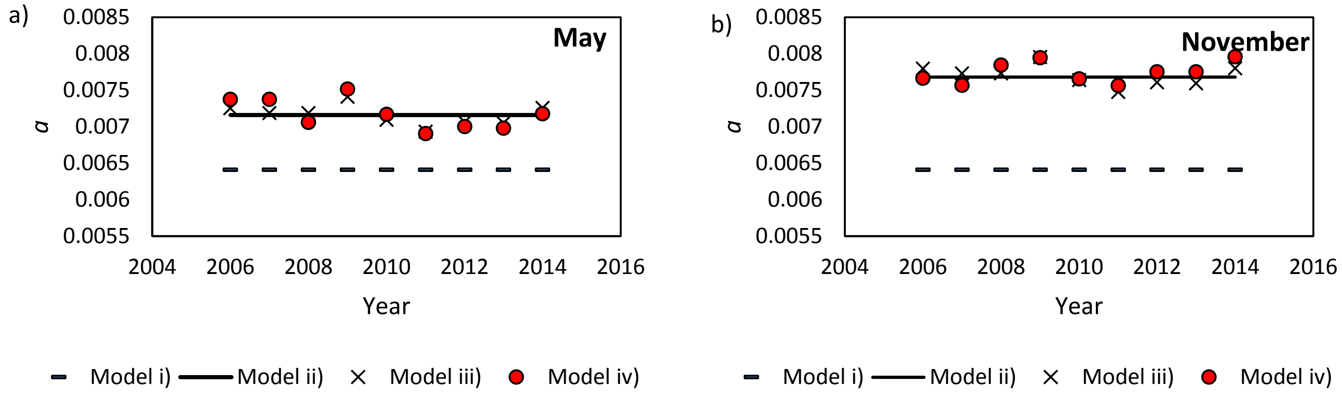


Figure 5. The estimated *a* parameters by survey model for a) May surveys and b) November surveys, as given in Table 1.

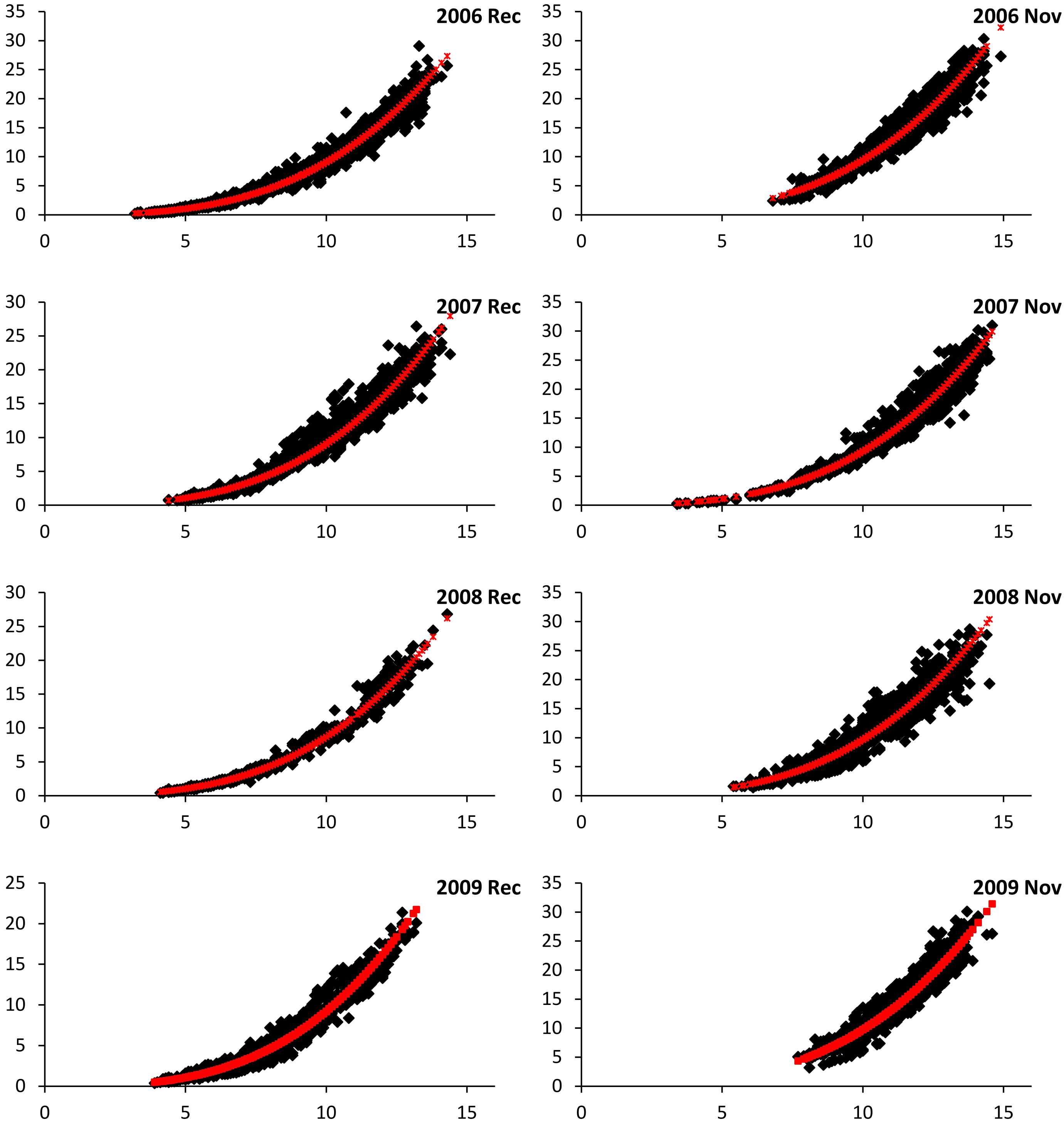


Figure 6. The observed (filled diamonds) and survey model iv) predicted (red crosses) length-weight relationships.

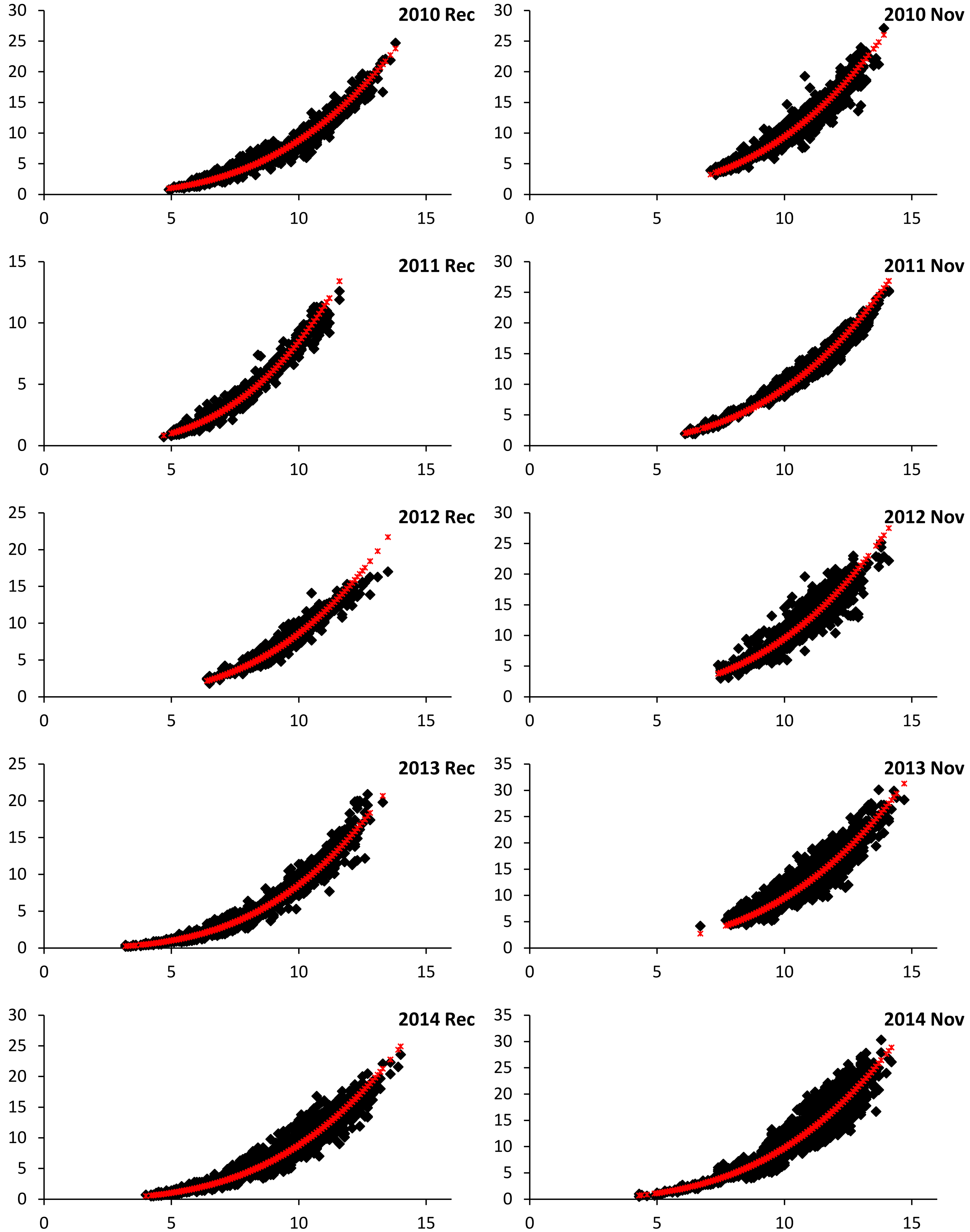


Figure 6 (cont).

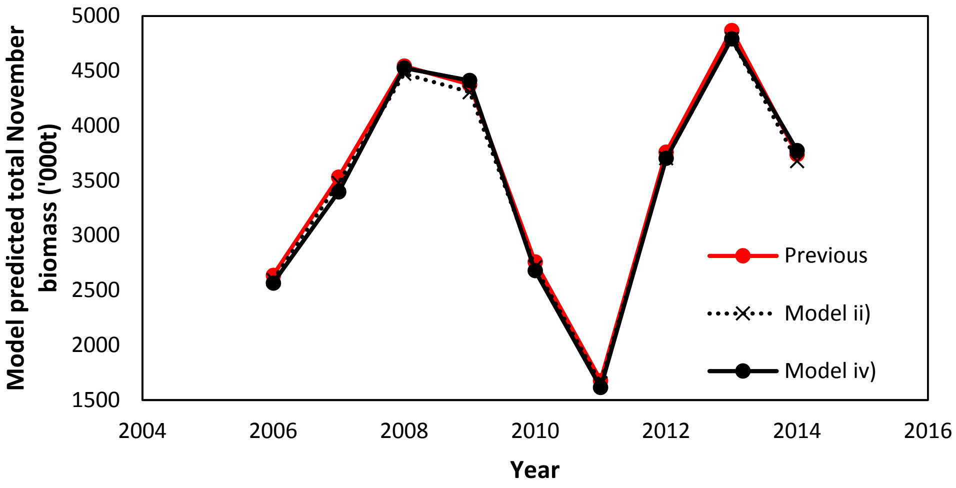


Figure 7. The model estimated total November biomass (in thousands of tons) as given in Table 2, resulting from the application of the length-weight relationship using survey models ii) and iv) and using the previous length-weight relationship.

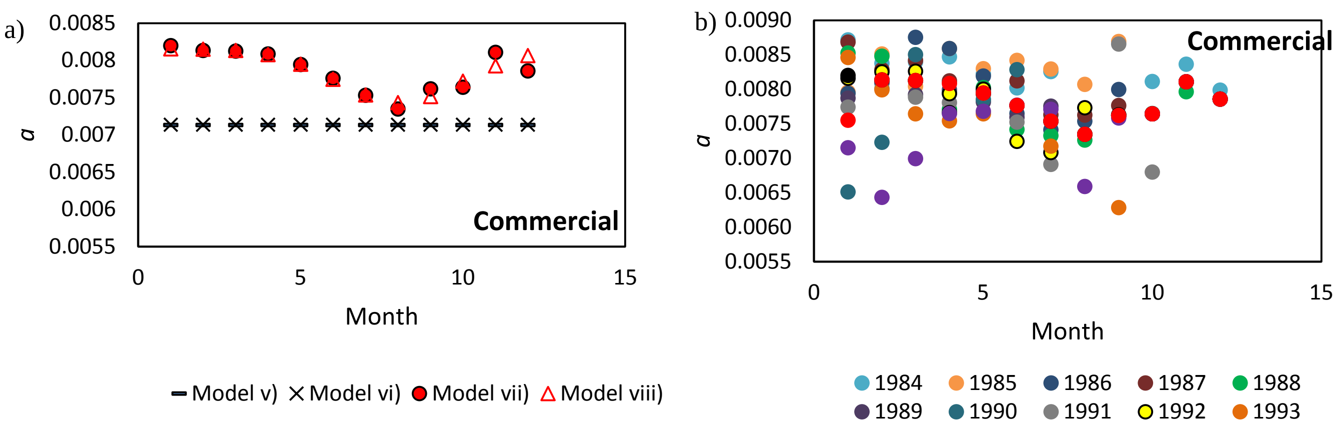


Figure 8. The estimated *a* parameters by a) commercial models v) to viii) and b) commercial model ix), as given in Table 3.

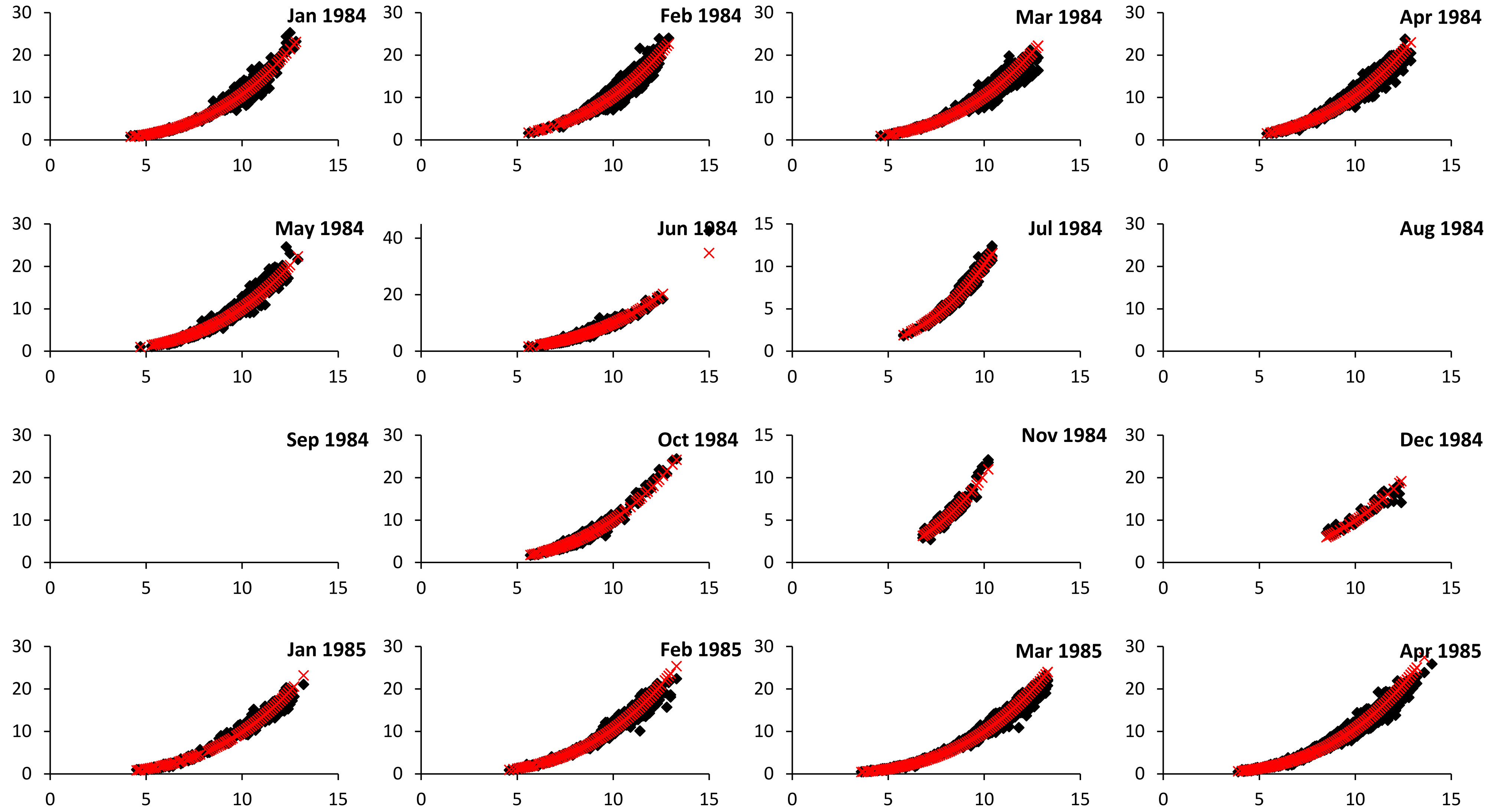
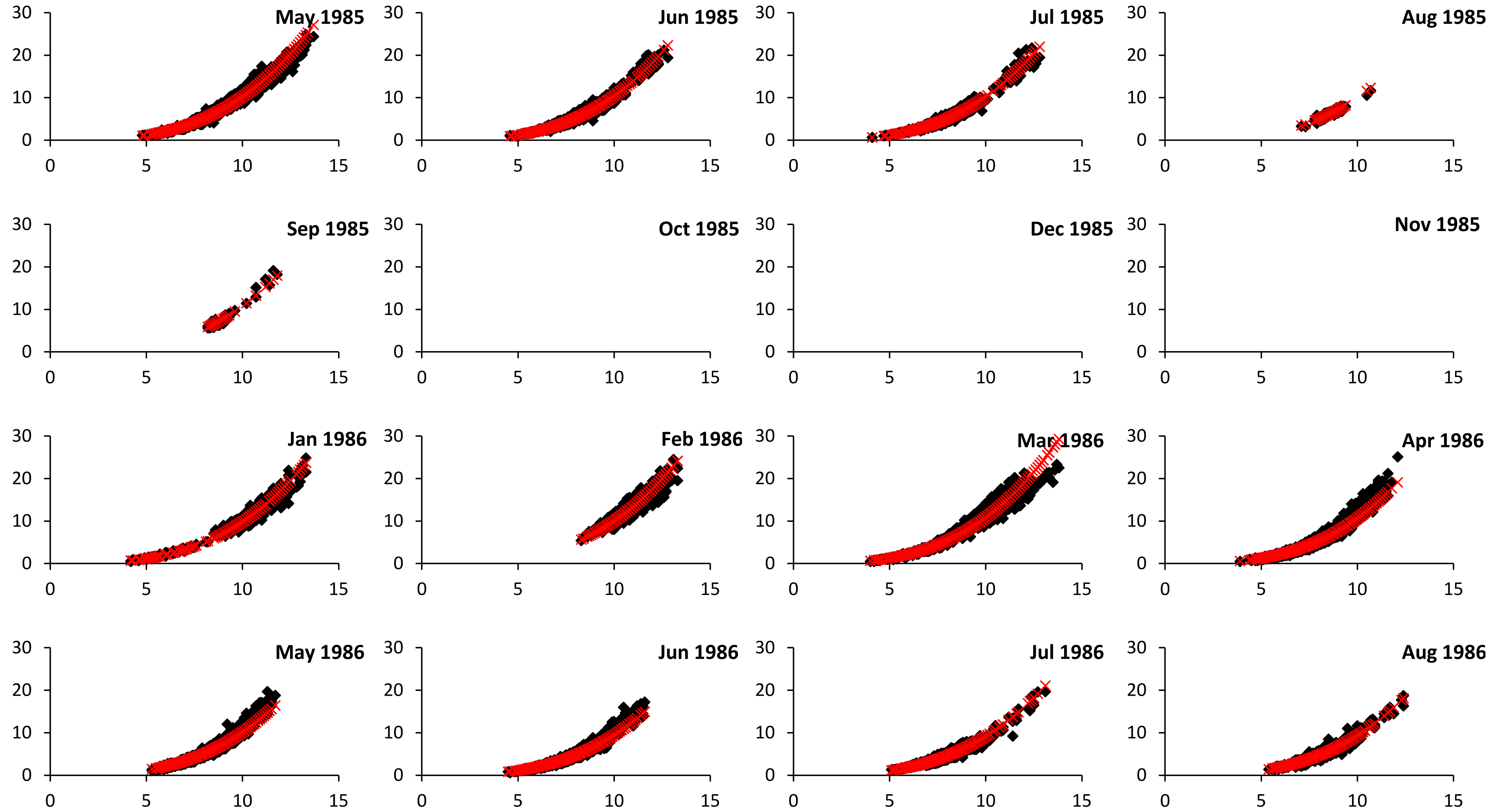


Figure 9. The observed (filled diamonds) and commercial model ix) predicted (red crosses) length-weight relationships.



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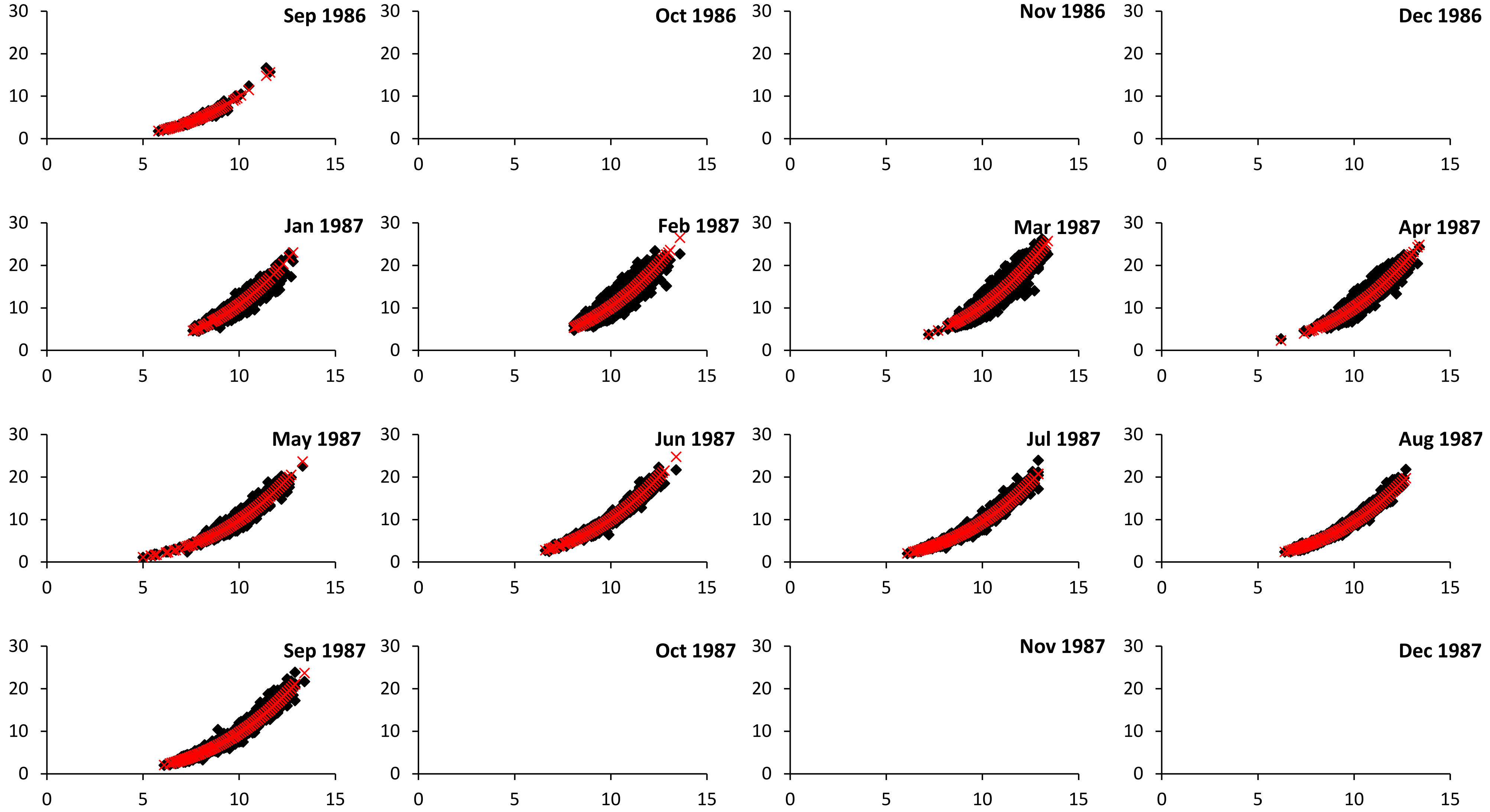

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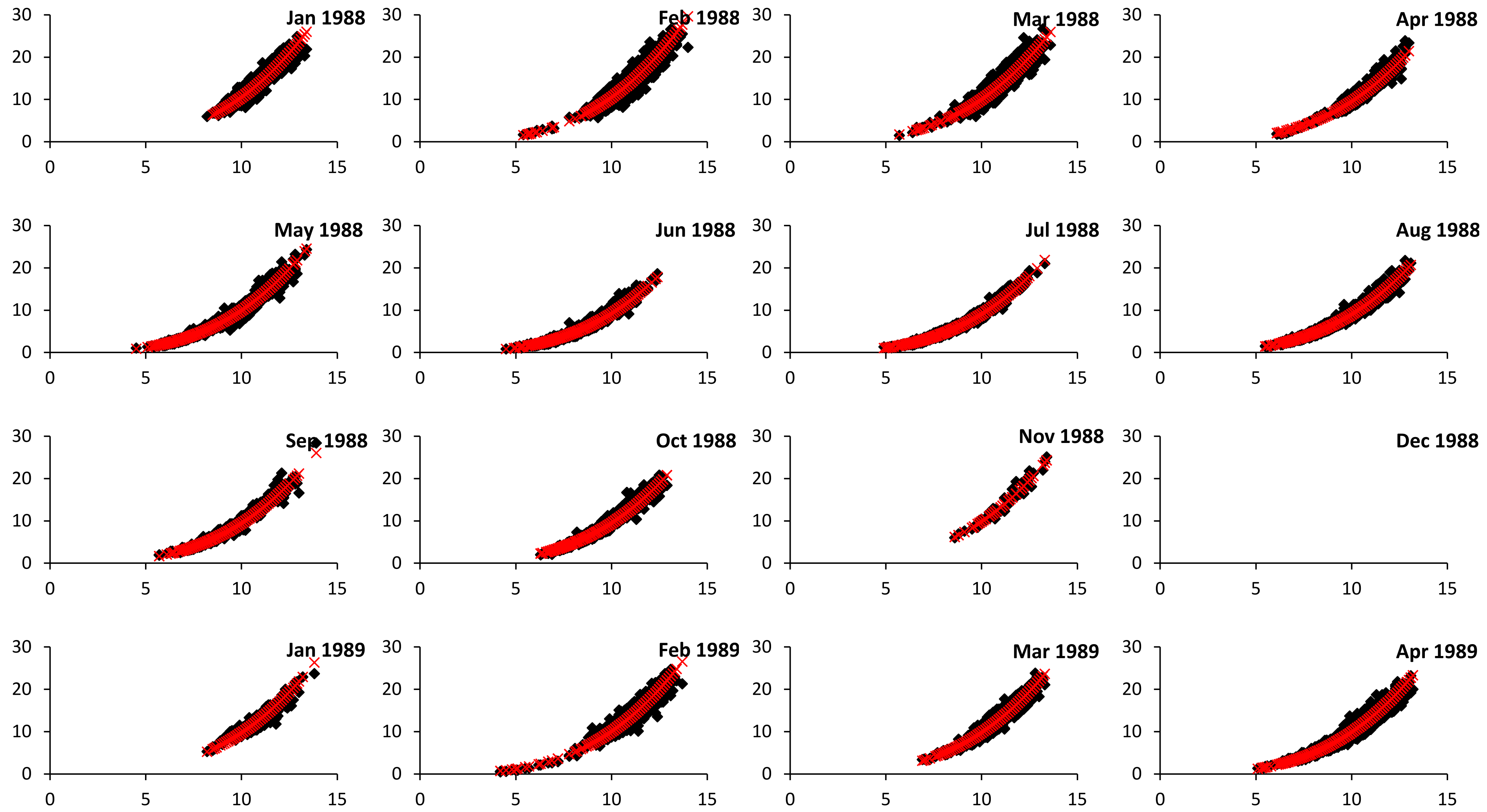

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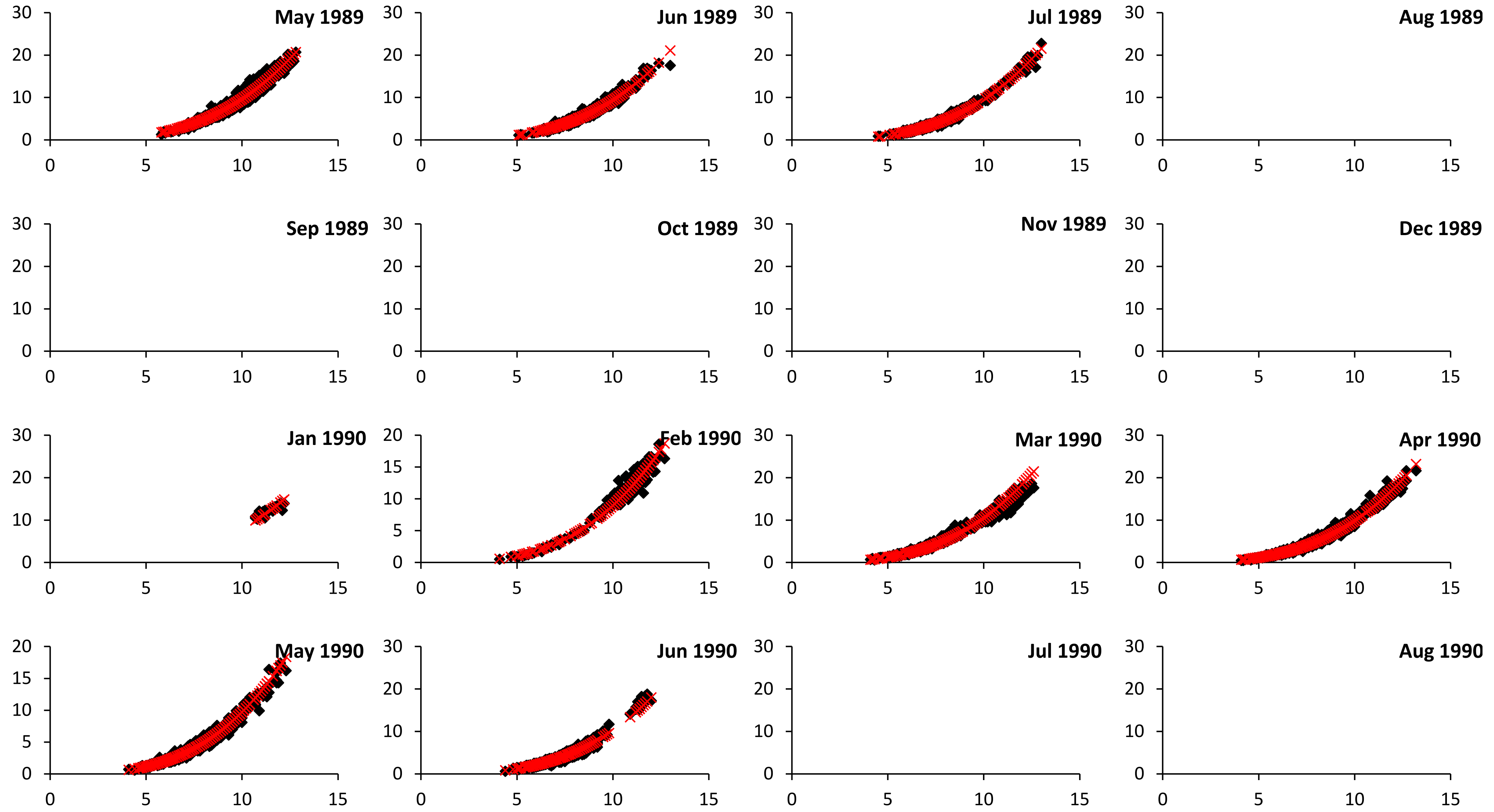

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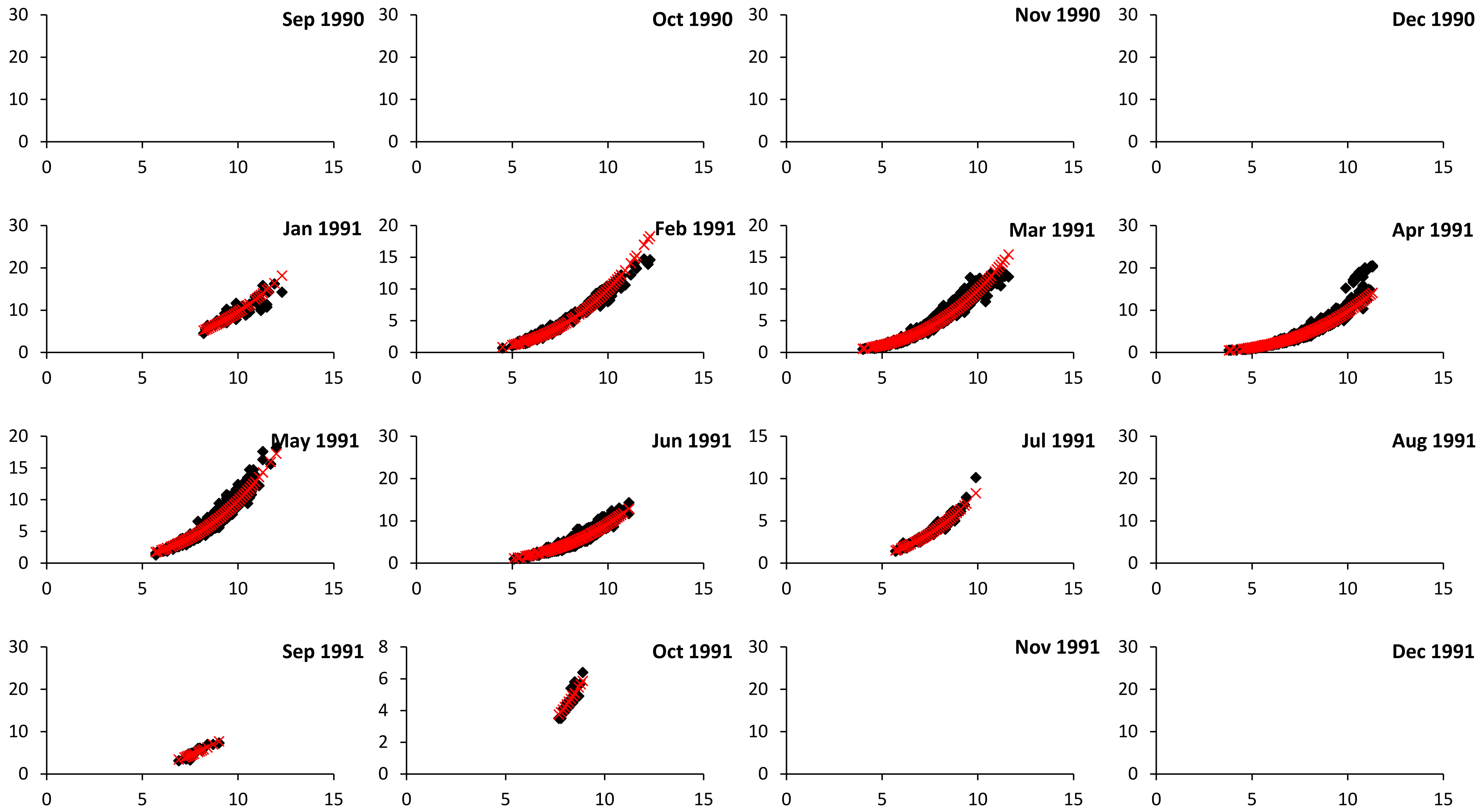

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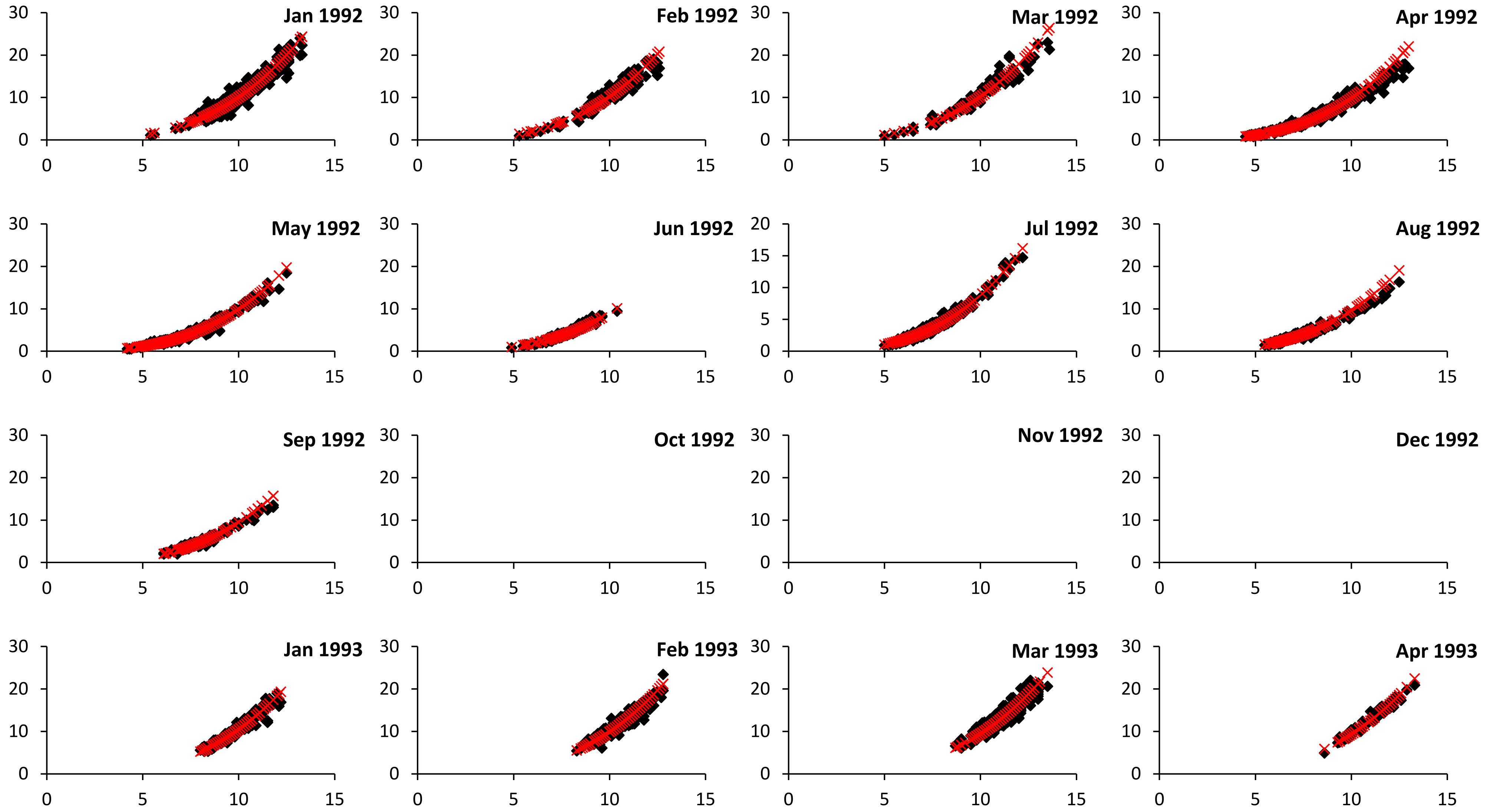

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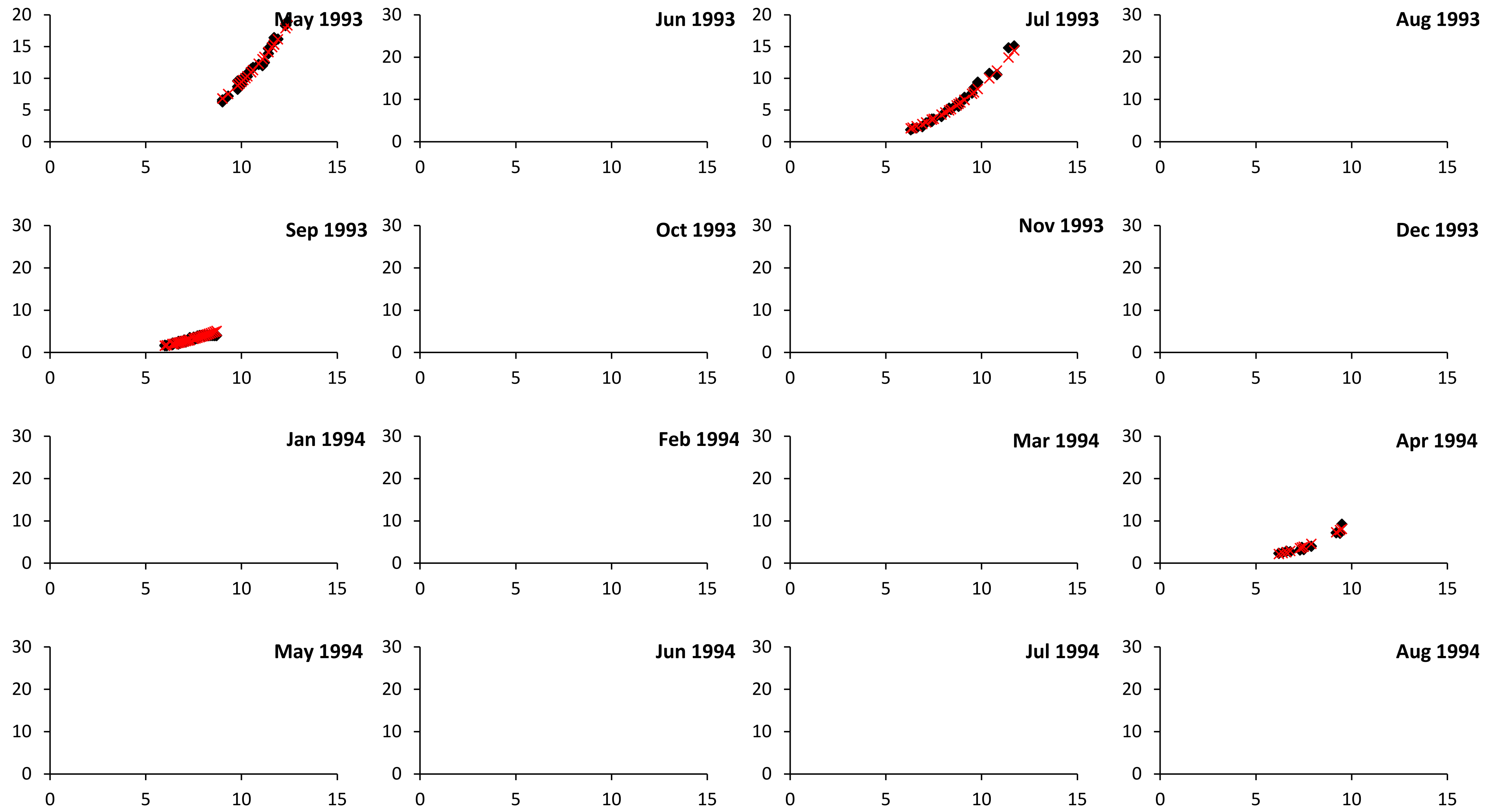

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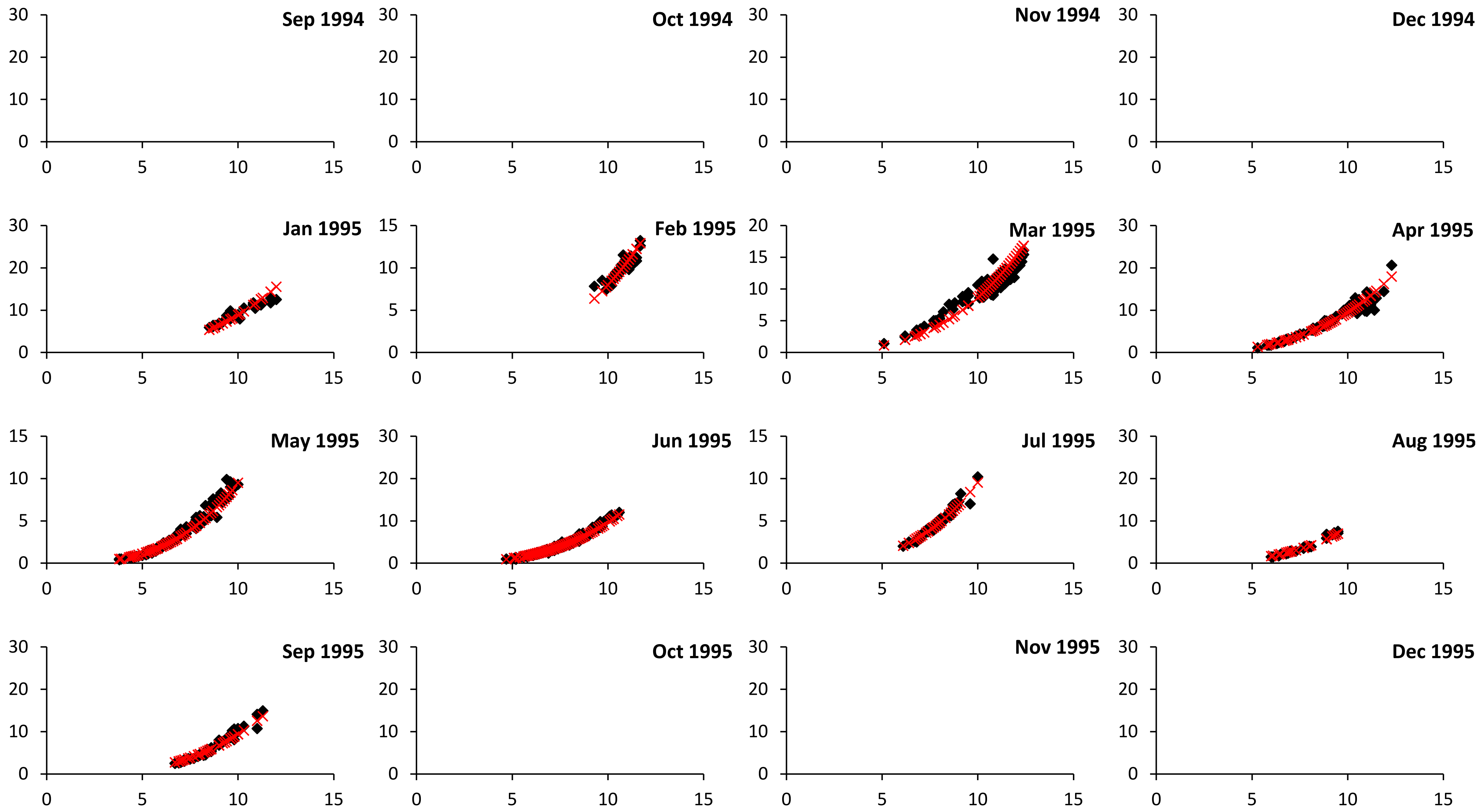

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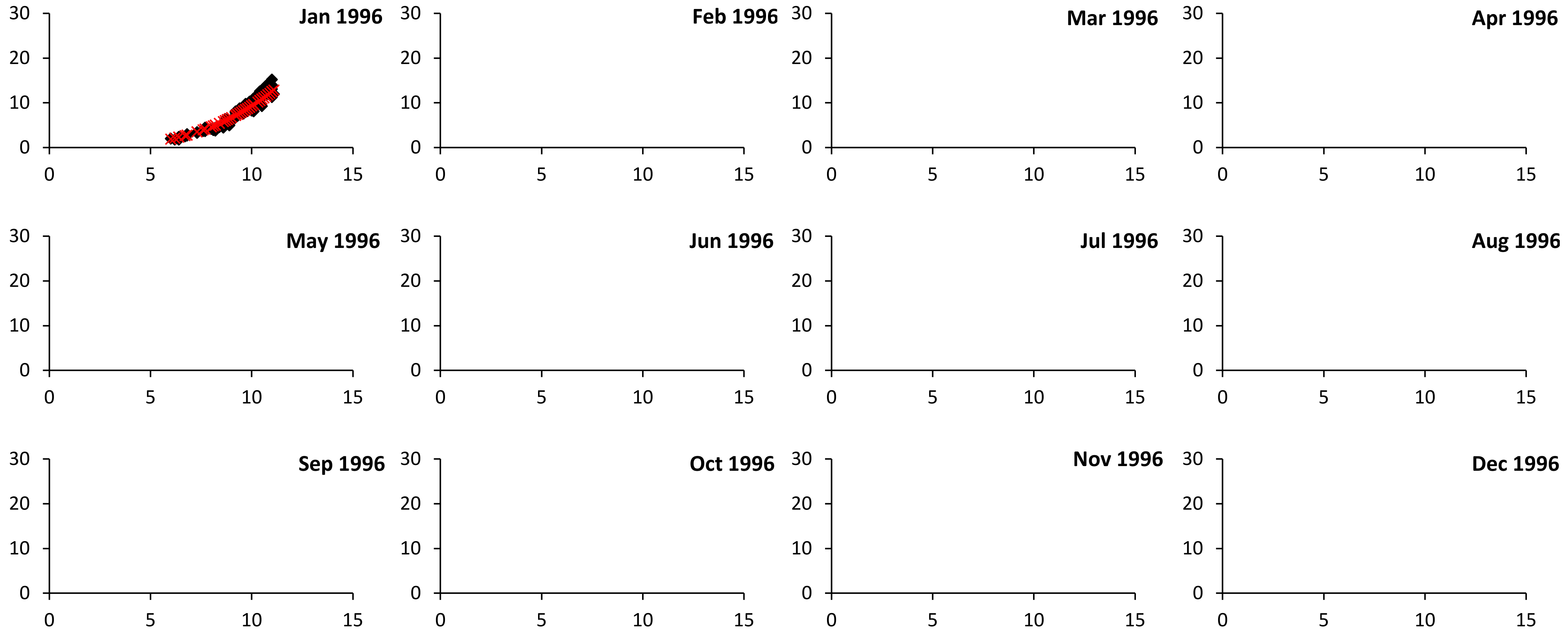

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