DO CATCH-BASED INDICES PROVIDE A RELIABLE INDEX OF ANNUAL RECRUITMENT FOR THE SOUTH AFRICAN ANCHOVY POPULATION?

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Summary

The ability of catch-based measures (both catch itself and measures of catch-rate/CPUE such as catch-per-set) to provide reliable indices of abundance of the annual anchovy recruitment on the South African west coast is investigated. Ground truthing is provided by the annual acoustic surveys of this abundance and corresponding estimates provided when this information is utilised in population assessments. The measures considered for the fishery as a whole reflect at most a 30% increase across the turn of the century, way below the some three-fold increase from before to after that time indicated by the surveys and assessment. The same is true for similar measures from catches made close to Robben or to Dassen Island, except when catches within 10 nm of these islands are considered, though surprisingly then this result of a similar increase to the survey results does not extend to catches within 20 nm. Nevertheless the CVs about the catch within 10 nm – recruitment relationships are some 70%, which is hopelessly too large for such measures to provide meaningful and reliable predictions of anchovy recruitment. Thus this study has failed to reveal any evidence to support the suggestion that anchovy catch- related measures might provide meaningful indices of anchovy recruitment abundance.

Introduction

In earlier local discussions (Island Closure Task Team Meeting of 10 March, 2014) information was provided on the basis for "expert opinion" choices of the parameter values of relationships linking penguin survival factors to food availability in the Weller *et al.* (2014) model of the Robben Island penguin population. This basis had been relationships between measurements of these survival rates and the "availability" of fish near Robben Island, as reported in Sherley *et al*. (2013). On subsequent investigation it became evident that the measure used for this "availability" was catch in the vicinity of the island - see Table 2 and Fig. 3 of Sherley *et al*. (2013). This was later confirmed in Weller and Sherley (2014).

There are a number of problems with this assumption of catch providing an index of abundance. At a broad level, it is equivalent to the application of a "catch-based method of assessment". The reliability of such methods has been seriously questioned for many reasons (e.g. Daan *et al.*, 2011; Carruthers *et al*., 2012), not the least of which is that such methods necessarily make some (usually implicit) assumption, which is not necessarily appropriate to the case under consideration, about the temporal trend of fishing effort in the fishery.

Those problems become the more severe when a fishery for a shoaling small pelagic species is involved. The major lesson learnt by fisheries scientists who lived through the collapses of a number of the world's largest fisheries for these species in the 1960's and 1970's was that CPUE measures (of which catch is a special case) for these species are NOT reliable as indices of their abundance. The reasons are that certainly the method of catching, and often also the approach to searching to find shoals, is not such as depends simply (if at all) on local fish density, leading to the dangerous situation of such indices hardly falling when overall abundance is in substantial decline.

Nevertheless, the fact that this argument has been seriously put forward for the South African anchovy resource, and specifically its annual recruitment which serves as the main source of food for penguins while breeding at west coast colonies, warrants that it be checked against available data for veracity or otherwise. (After all, if some measure of catch was indeed a reliable index of anchovy recruitment, then that measure should be

seriously considered for inclusion amongst the input data for the assessment of the anchovy population that forms the basis for its management.)

Fortunately fishery independent measures are available for anchovy recruitment, to provide a basis against which to check proposed catch-based indices of abundance. These are provided by the mid-year acoustic recruitment surveys of the west coast (and part of the south coast) which have been conducted regularly for nearly 30 years. The results from these surveys (Coetzee, 2014, Coetzee *et al.*, 2014) are shown in Figure 1. These surveys are however subject to relatively high survey sampling variance, plus further process error arising from annually differing proportions of the overall recruitment for the year being present in the survey area at the time of the survey. For this reason, a more precise estimate of annual recruitment is provided by the population-model-based assessment of the anchovy population which integrates the recruitment survey data with information from other sources. The results from that process (de Moor and Butterworth, 2012) are also shown in Figure 1, and are used as the primary basis against which to test candidate catch-based indices of abundance.

A considerable contrast in anchovy abundance over time is evident in Figure 1. Since the turn of the century this has averaged about three times its value before that time. The immediate test of any candidate catch-based index of abundance is whether it reflects this major change.

Data and Methods

The catch and effort data analysed in this paper has kindly been provided by DAFF (specifically Janet Coetzee and Jan van der Westhuizen). Figure 2 shows the time series of annual anchovy catches since 1987. In considering potential indices of anchovy abundance however, the focus needs to be on catch operations that were directed at anchovy, as distinct from anchovy by-caught in fishing effort directed at other major small pelagic species such as sardine and round herring. This focus has been effected by restricting to sets comprising more than a specified percentage of anchovy by mass; for later GLM-analysis purposes, catches from the grid blocks (10nm x 10 nm areas used to indicate catch positions) with less than five sets since 1987 were also omitted (their proportional contributions were negligible). .Figure 2 also shows the annual directed catch series calculated on this basis; it is evident that unless the percentage specified is set as 90%, such "directed" catches account for almost all of the total annual anchovy catch. Furthermore, given this small difference amongst different percentage specification choices, the criterion of >50% for a directed catch was used as a baseline for the analyses that follow (which also follows standard practice in the Pelagic Working Group).

Apart from catch itself, a number of catch-based "CPUE-like" indices were explored: catch-per-set, catch-per-day and sets-per-month. These were standardised using log-linear GLMs, with the baseline co-variate choice being year, month, vessel and grid (block) as fixed effects, together with month*grid as a random effect to allow for the changing spatial distribution pattern of anchovy over the course of a year. For catch-per-day, grid was taken to be the first block that day in which a set was made; for month-based measures, grid dependence was ignored.

Measures based on catches in the near vicinity of Robben and of Dassen Island were also considered. Areas nominally referenced as being within 10, 20 or 30 nm of each island were considered; specifically these were taken to be the grid block within which the island is found, the (inner) ring of blocks adjacent to that block, and an outer ring of blocks adjacent to that inner ring, respectively. Standardisation naturally excluded grid as a co-variate for measures within the 10 nm distance.

The basic statistic used to initially vet the potential of a catch-based measure to index anchovy recruitment biomass was the ratio (R) of average values during this compared to last century, which is compared to the same ratio for the anchovy population model recruitment estimates of de Moor and Butterworth (2012) which has a value of 2.71. The specific periods over which averages were taken to obtain this ratio were 1987-1999 and 2000-2011. However for the islands there are years in which the area within 10 nm was closed to pelagic fishing (2008 and 2009 for Dassen, and 2011 to 2013 for Robben Island); these years were omitted when calculating R for both catch-based indices and corresponding model-based values in such cases.

In some of the cases considered, particularly when *R* for the catch-based index approached that for the anchovy model estimates, further plots have been provided to throw more light on any potential relationship:

- a standard linear regression of the catch-based index against the recruitment model estimate, for which the squared correlation coefficient (r^2) is reported;
- a straight line through the origin fitted to the data, with the slope of the line given by the robust estimator of the ratio of the average values of each of the two data series;
- plots of "relative" residuals against year for each of these two relationships; for the standard linear regression, the residual is "relativised" by dividing by the average value of the catch-based indices, whereas for the line through the origin, this is achieved by dividing by the value which this line predicts for the catch-based index; in both cases a standard deviation (σ) is computed for these residuals, which effectively reflects the "percentage precision" with which the catch-based index reflects the "true" underlying anchovy recruitment; and
- repetition of the four plots above, but reversing the roles of the catch-based index and the recruitment model estimate, so that σ now relates (roughly speaking) to the precision with which the catch-based index could predict annual anchovy recruitment.

Results and Discussion

Catch-based indices for the fishery as a whole

Table 1 shows the *R* values for the various indices examined (catch, catch-per-set, catch-per-day and sets-per-vessel-per month). The reasons for also showing catch index results excluding 1987 and 1988 is that these were anomalous years, with record catches resulting primarily from adult anchovy on the Agulhas Bank aggregated close to shore and readily catchable during the first few months of the year as a result of unusual environmental conditions.

Immediately evident is that **none** of these indices reflect the some 170% increase shown by the anchovy assessment model (which is in turn based on the results from the fishery-independent acoustic surveys). At most increases of no more than 30% are evident. (The lack of much increase in the average annual catch given the anchovy abundance increase may surprise, since the TACs set for this fishery increase with increasing survey estimates of abundance; the reason is that although the TACs were indeed set higher, because of operational constraints, such as processing capacity limitations, the industry was unable to make full use of these higher allocations.)

Figure 3 shows detailed results for Scenario I (directed catches with >50% anchovy). Although catches do increase by about 50% over the range of recruitments that occurred, this recruitment range spans over a 10-fold increase, and very little of the variance is explained by the standard linear regression (r^2 = 0.043). For proportional relationships, standard deviations of relativised residuals (essentially CVs) range from about 0.8 to 1.0, even after omitting outliers.

Figure 4 shows standardised catch-per-set trends by year for such directed catches, with Figure 5 showing the detailed results. Again there is some indication of a slight increase in this index with the increase in anchovy abundance as the century turned, but also clear evidence of systematic error in any proportional relationship. Were the index to be used to predict recruitment, the associated CV would be 0.76 (though this drops to 0.53 if an outlier is omitted).

Catch-based indices restricted to catches near to Robben or Dassen Island

Figures 6 and 7 plot annual catches of anchovy within 10, 20 and 30 nm distances of Dassen and Robben Island respectively, while Table 2 provides values of *R* for catch and standardised catch-per-set indices. Again standardised catch-per-set indices provide very little indication of the large increase in anchovy abundance across the turn of the century. However there is rather better correspondence with the anchovy assessment model estimate increases for catches within 10 nm of the islands, particularly for Dassen Island for which *R* exceeds 3. This result is, however, somewhat strange, as it is not mimicked by catches within a 20 nm range which show a

much lesser increase – it seems that the increase in anchovy abundance may for some reason have led to the distribution (far more so than the quantity) of catches within 20 nm of both islands moving closer to the islands.

This result prompts a closer look at detailed results for anchovy catches within 10 and 20 nm distances of both islands, which are shown in Figures 8 and 9 for Robben and Figures 10 and 11 for Dassen Island. Focusing first on results for Robben Island within 10 nm (Figure 8), there is some indication of a linear relationship, but if the associated ability to forecast recruitment is considered, even after omitting outliers the associated CV is some 70% (this result is much worse for a 20 nm distance). Virtually identical results are evident for Dassen Island (see Figure 10 in particular).

Conclusions

When the fishery is considered as a whole, none of the catch-based indices considered provide any indication of an ability to reflect the magnitude of the substantial (about three-fold) increase in anchovy recruitment biomass across the turn of the century.

When the near vicinities (10 nm) of Robben and Dassen Islands are considered, there is some initial hint of the potential of catch as an index of abundance, as this does show a commensurate increase to the population model estimates as the century turned. However closer inspection reveals that the CV about such a relationship is some 70%. That is hopelessly too large for such an index to provide meaningful and reliable predictions of anchovy recruitment.

In summary, no evidence to support the suggestion that anchovy catch (or some catch-related measure) provides a meaningful estimate of anchovy recruitment abundance has been found in this study – a result which is consistent with the standard views in fisheries of the likely lack of utility of catch-based indices to reflect the abundance variations in small pelagic species.

Acknowledgements

Janet Coetzee and Jan van der Westhuizen (Department of Agriculture, Forestry and Fisheries) are thanked for providing the data upon which these analyses were based.

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Table 1: Ratio (*R*) of potential anchovy catch-based indices of abundance averaged over the pre-2000 (1987-1999) and post-2000 (2000-2011) periods. These are to be compared to the corresponding ratios for the recent surveys (4.03) (Coetzee, 2014) and the anchovy model estimates of 2.71 (de Moor and Butterworth, 2012). Results apply to the full fishing area except that grid cells with less than 5 sets have been omitted from other than calculations for all catches.

Index type	**Standardisation**	**Catch restriction**				
		All	>=30%	>=50%	>=70%	>=90%
Catch (I)	-	0.94	0.94	0.94	0.95	0.92
Catch with 87,88 omitted*	-	1.28	1.28	1.30	1.33	1.39
Catch per set (II)	Year			1.29		
	Year, month			1.31		
	Year, month, vessel			1.17		
	Year, month, vessel, grid		1.18	1.17	1.16	1.16
	Year, month, vessel, grid, month*grid		1.18	1.16	1.15	1.16
	Year, month, vessel, grid, month*grid, month*year, year*grid			1.15		
Catch per day	Year, month, vessel, grid, month*grid			1.02		
Sets per vessel per month	Year, month, vessel			0.86		
	Year, month, vessel, month*year			0.88		

*Survey ratio and anchovy model estimated ratio excluding 1987 and 1988 are 4.27 and 2.86 respectively.

Table 2: Ratios (*R*) as in Table 1, but here with different distances of Robben Island and Dassen Island. Results are restricted to set with >50% anchovy.

Index type	Standardisation	**Catch restriction**					
		Robben Island			**Dassen Island**		
		<10nm* (III)	<20nm (IV)	<30nm	<10nm*	<20nm (V)	<30nm (VI)
Catch	-	1.95	1.24	1.52	3.28	1.39	1.28
Catch with 87,88 omitted	-	2.34	1.58	1.89	3.41	1.66	1.61
Catch per set	Year, month, vessel, grid, month*grid	1.08	1.07	1.17	1.18	1.16	1.17

*Only one grid block, so standardisation excludes co-variants involving grid. The anchovy survey estimate and model estimate for *R* for the years concerned are 4.29 and 2.90 for Robben Island and 3.87 and 2.63 for Dassen Island.

Figure 1: Annual anchovy recruitment as indicated by surveys and by population model estimates.

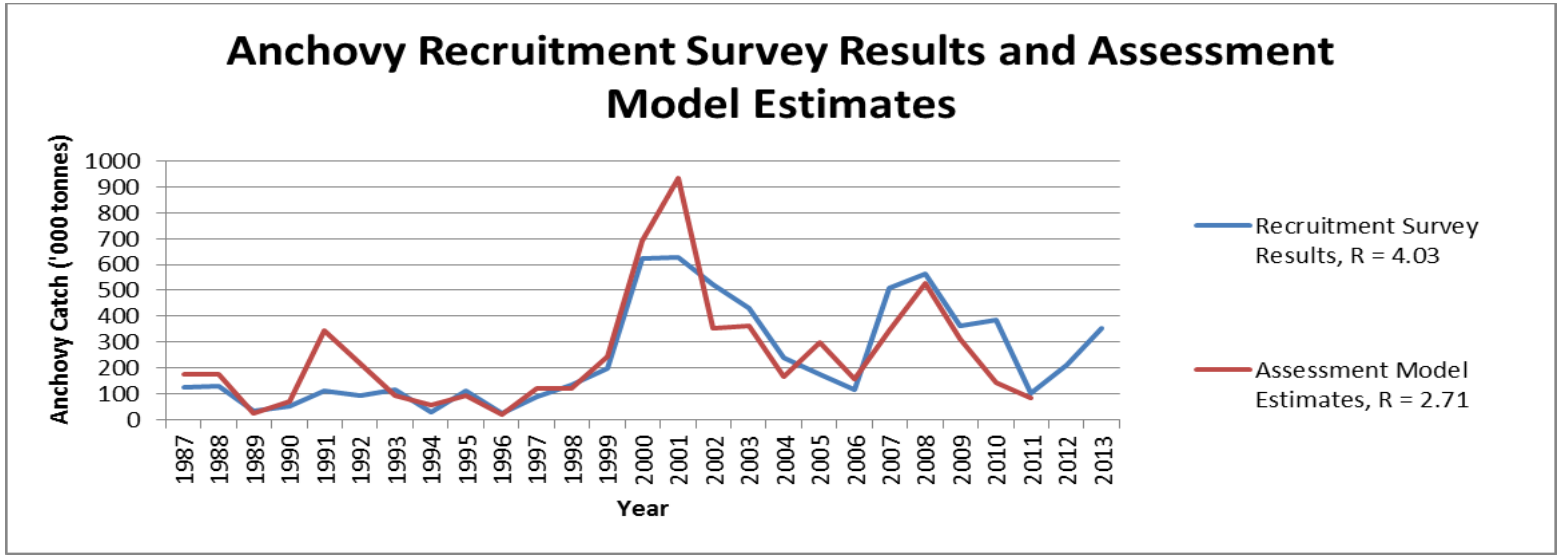


Figure 2: Annual anchovy catches for different definitions for directed catch, based on the mass of anchovy exceeding a specific proportion in a set.

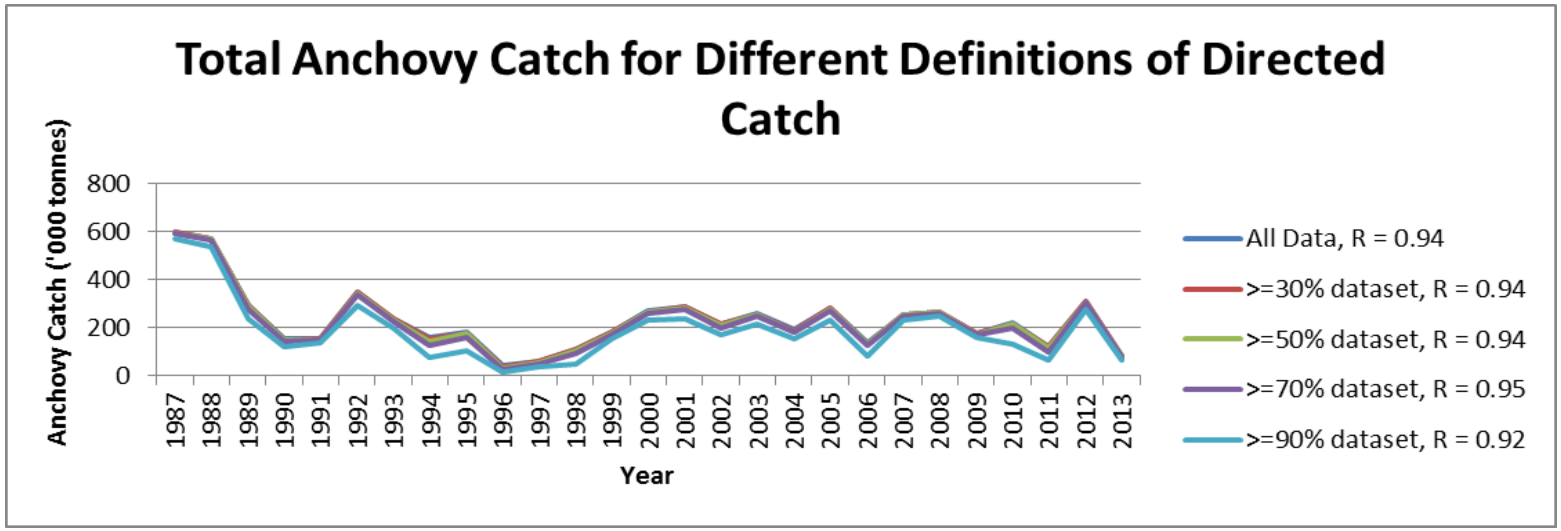


Figure 3a: Detailed regression results for directed anchovy catch (>50% proportion) for the whole fishery considered to be an index of recruitment: the catch based index is regressed against the recruitment model estimates.

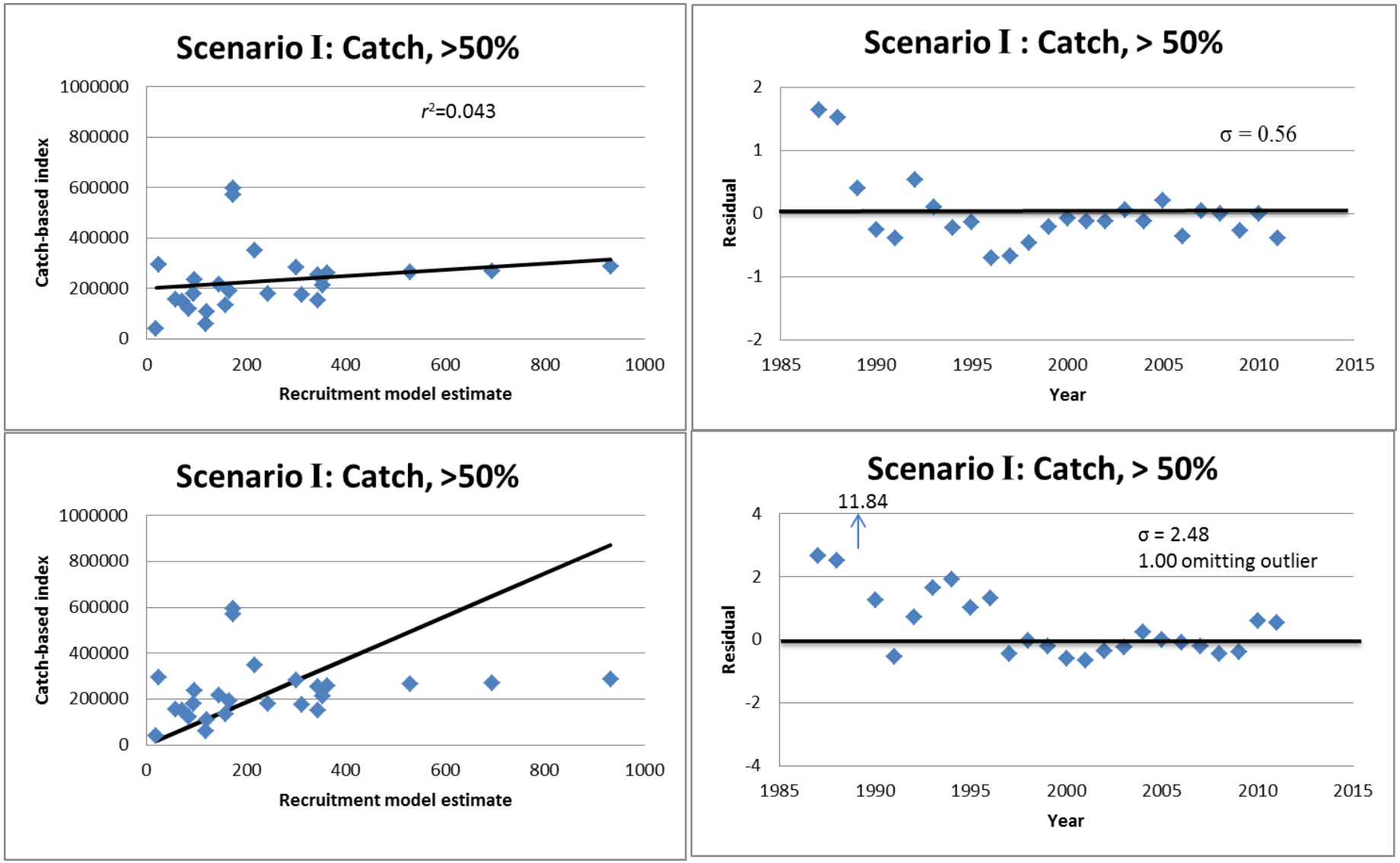


Figure 3b: Detailed regression results for directed anchovy catch (>50% proportion) for the whole fishery considered to be an index of recruitment: the recruitment model estimates are regressed against the catch based index.

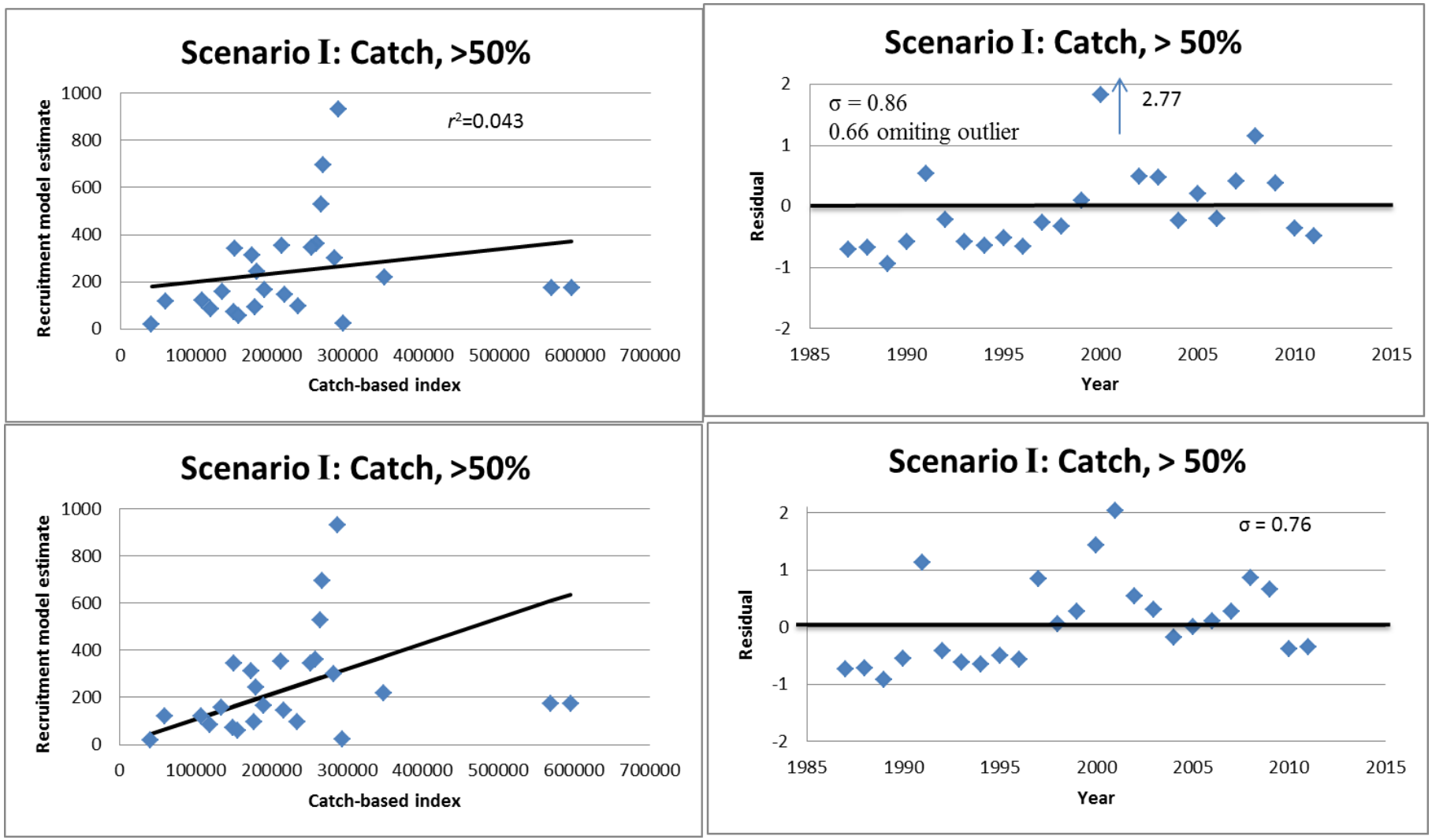


Figure 4: Standardised catch-per-set annual indices for different definitions of directed anchovy catch.

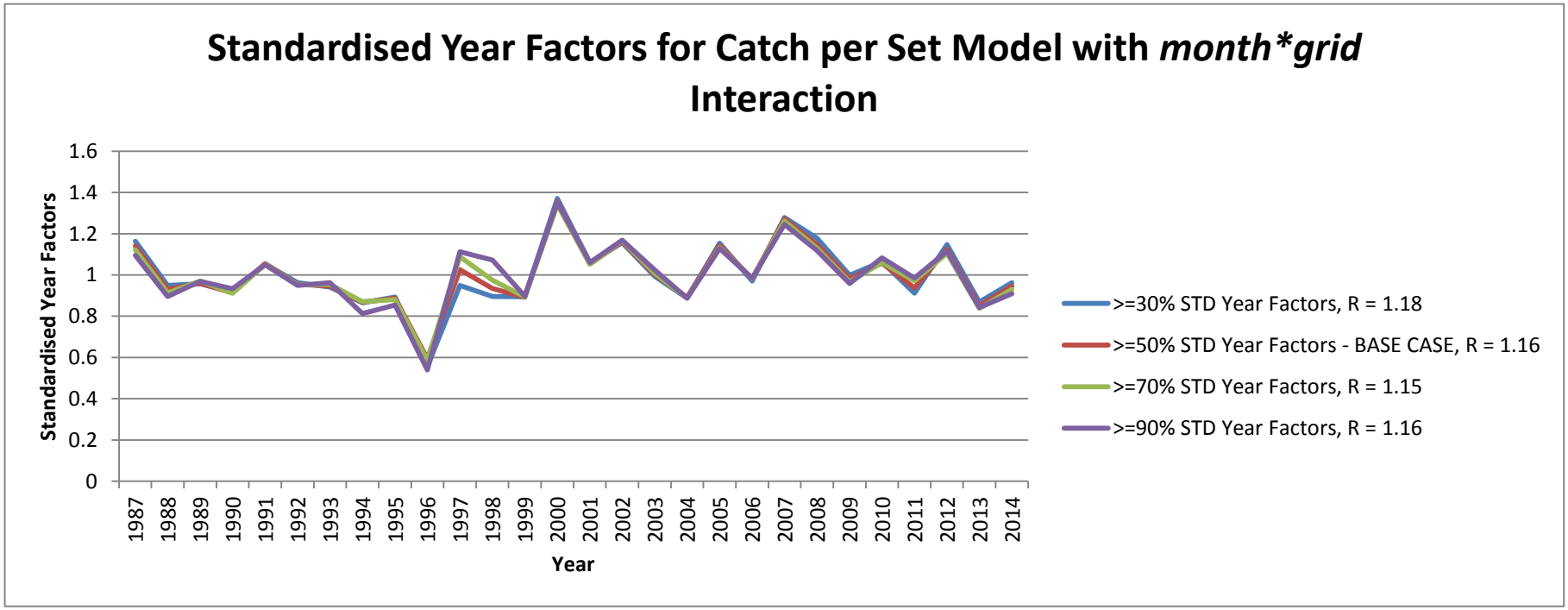
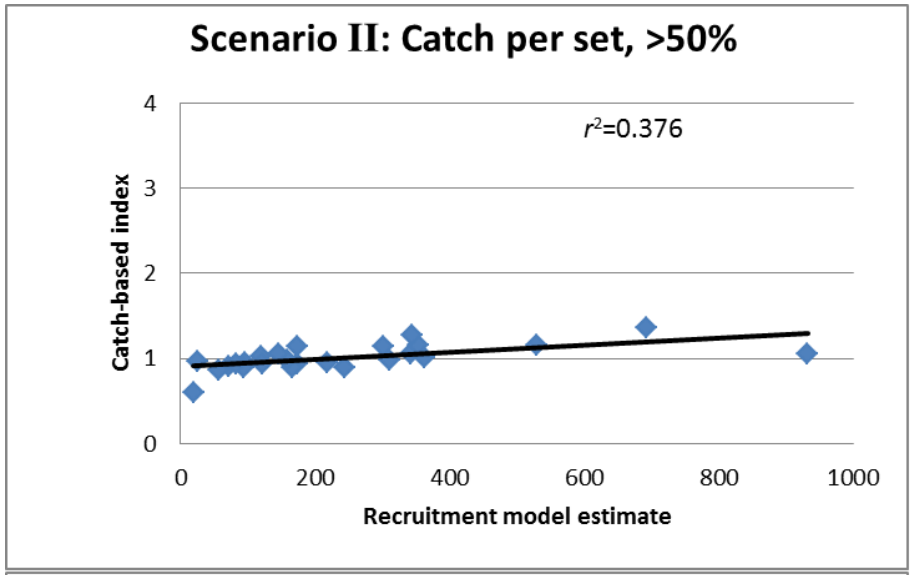
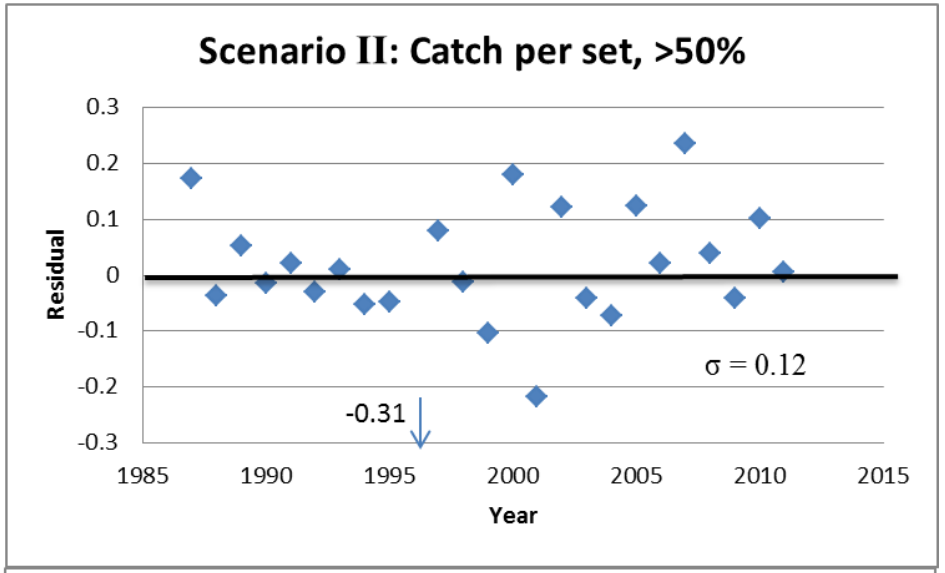
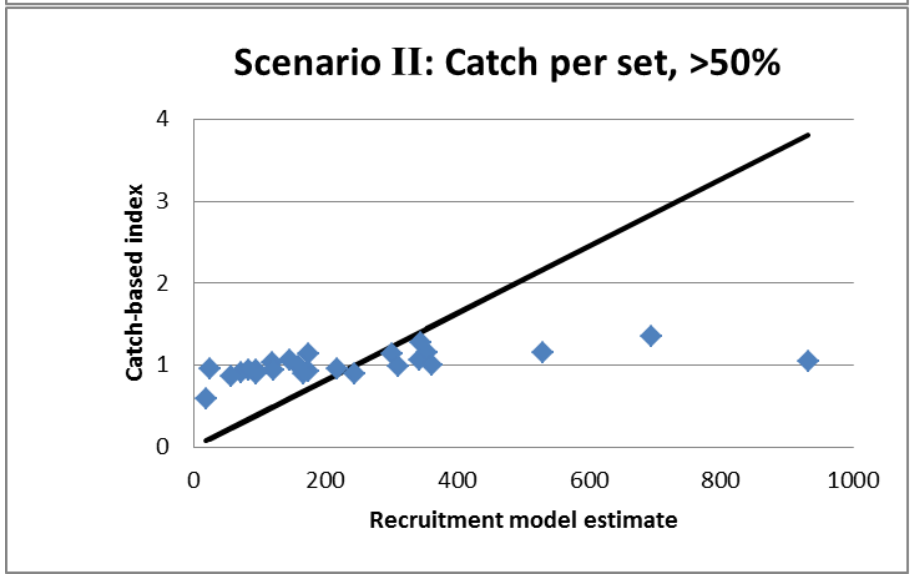


Figure 5a: Detailed regression results for directed anchovy catch-per-set (>50% proportion) for the whole fishery considered to be an index of recruitment: the catch based index is regressed against the recruitment model estimates.







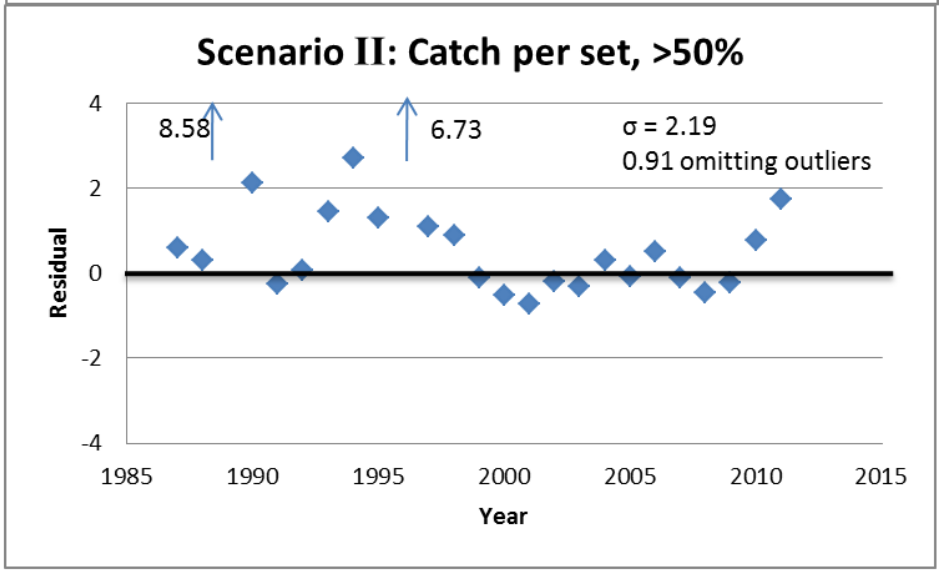


Figure 5b: Detailed regression results for directed anchovy catch-per-set (>50% proportion) for the whole fishery considered to be an index of recruitment: the recruitment model estimates are regressed against the catch based index.

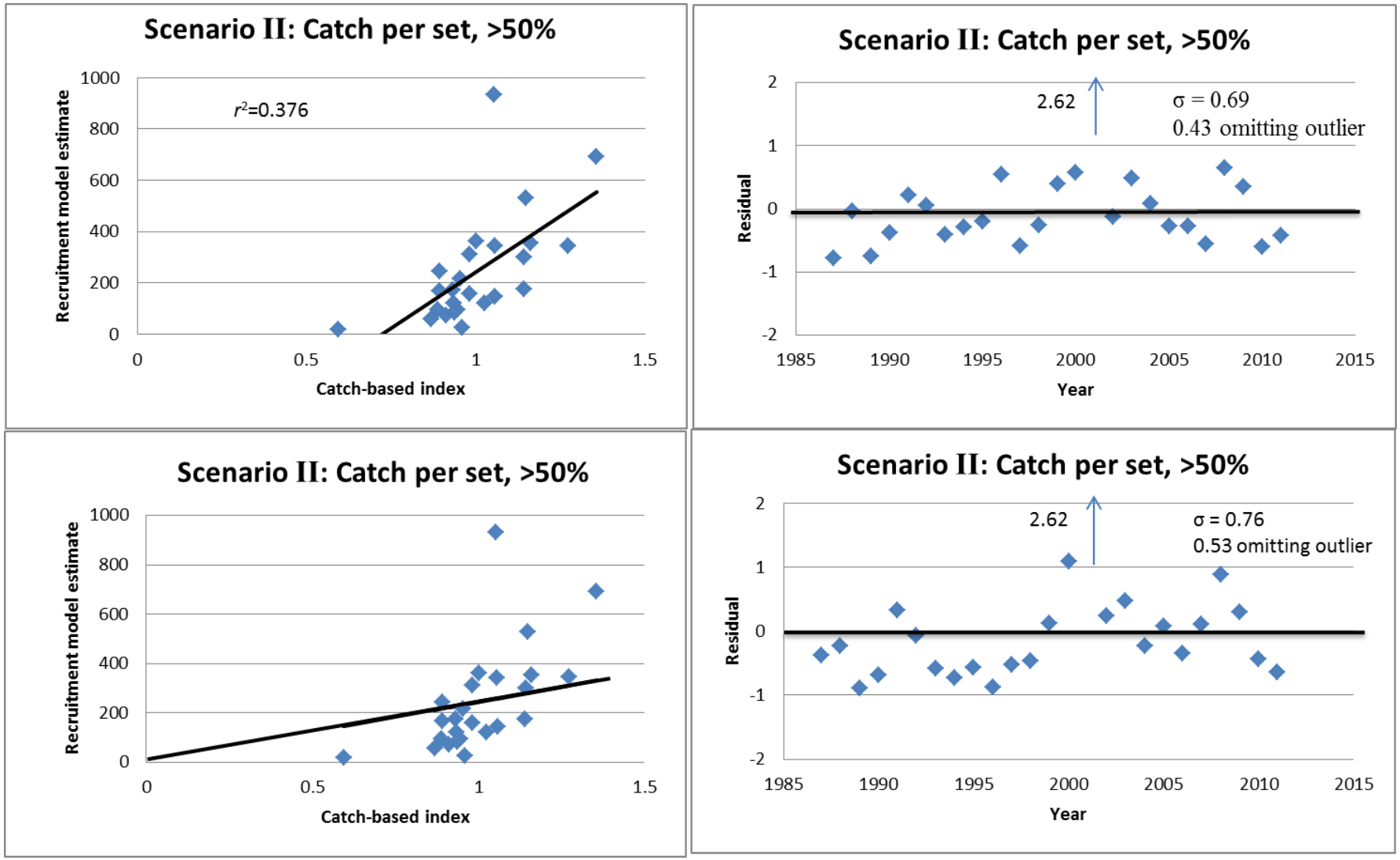


Figure 6: Annual anchovy catches within 10, 20 and 30 nm of Dassen Island (note that the 10nm area was closed to pelagic fishing in 2008 and 2009).

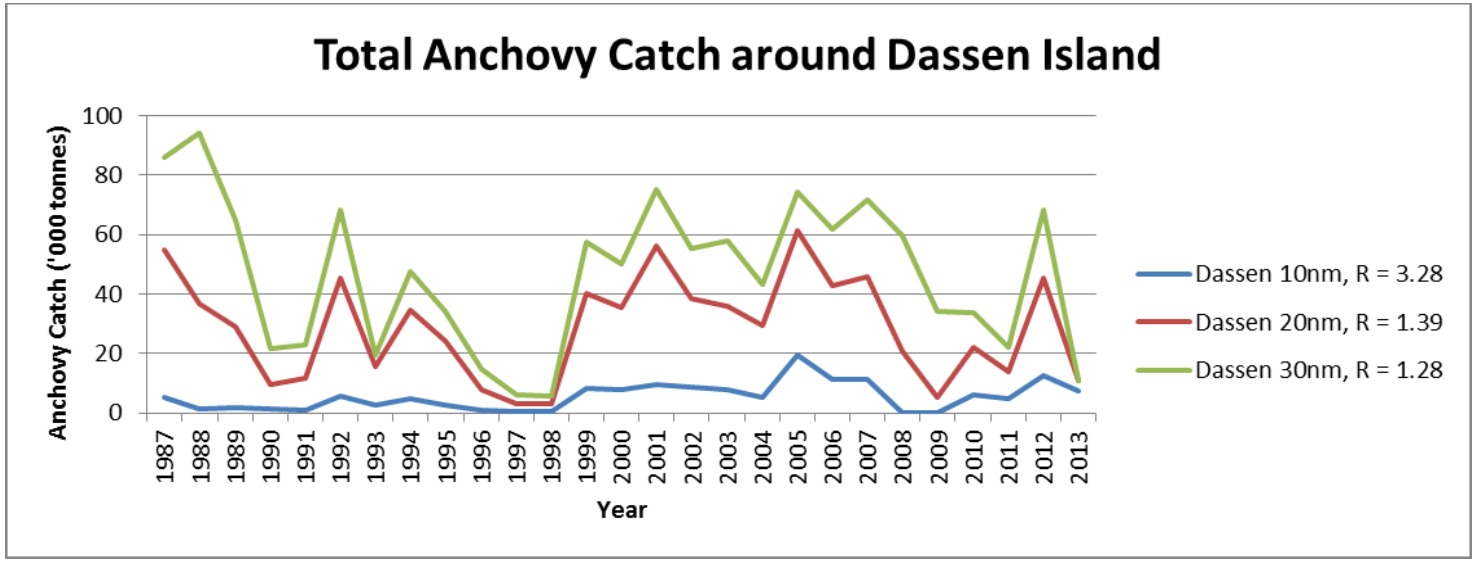


Figure 7: Annual anchovy catches within 10, 20 and 30 nm of Robben Island (note that the 10nm area was closed to pelagic fishing for 2011-2013).

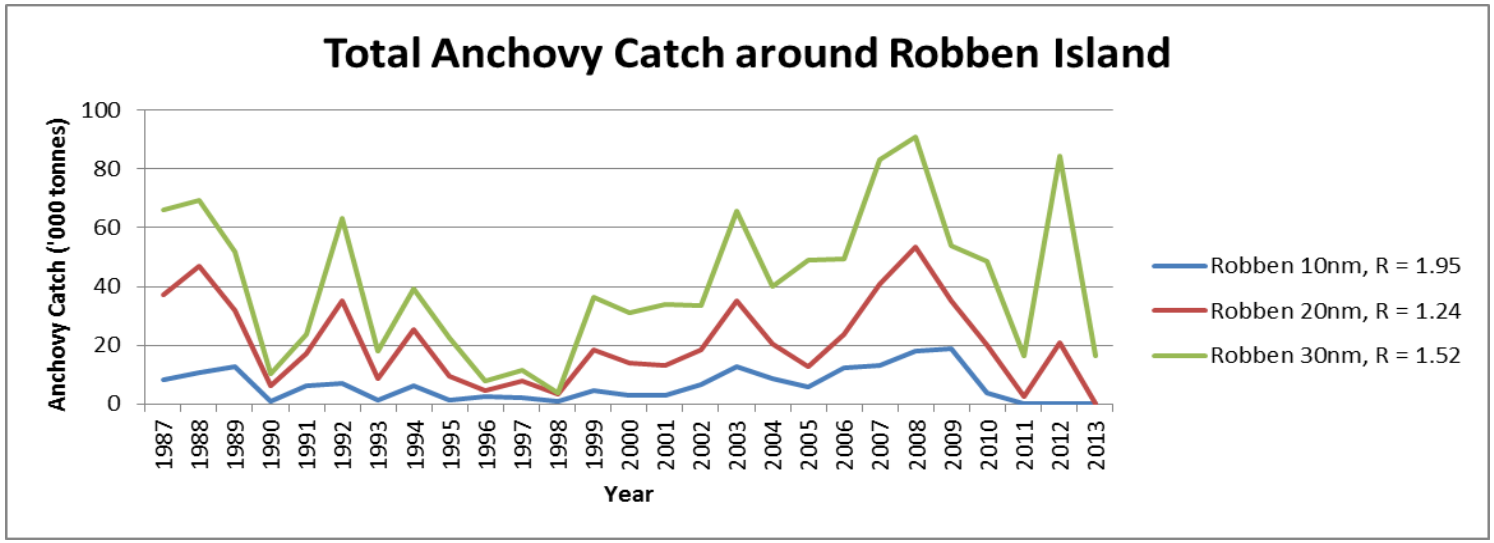


Figure 8a: Detailed regression results for directed anchovy catch (>50% proportion) for the fishery within **10nm** of Robben Island considered to be an index of recruitment: the catch based index is regressed against the recruitment model estimates.

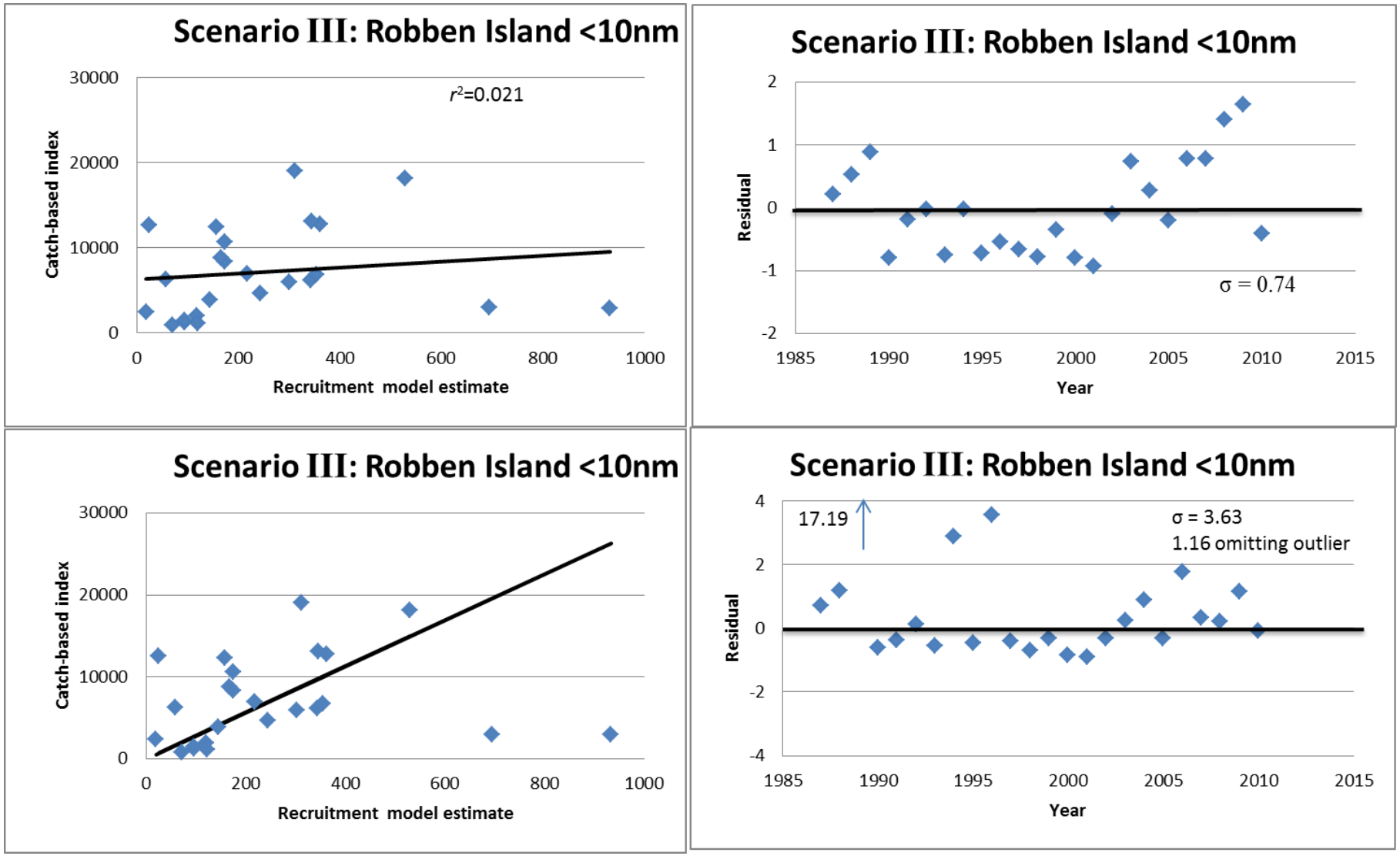


Figure 8b: Detailed regression results for directed anchovy catch (>50% proportion) for Robben island within **10nm** considered to be an index of recruitment: the recruitment model estimates are regressed against the catch based index.

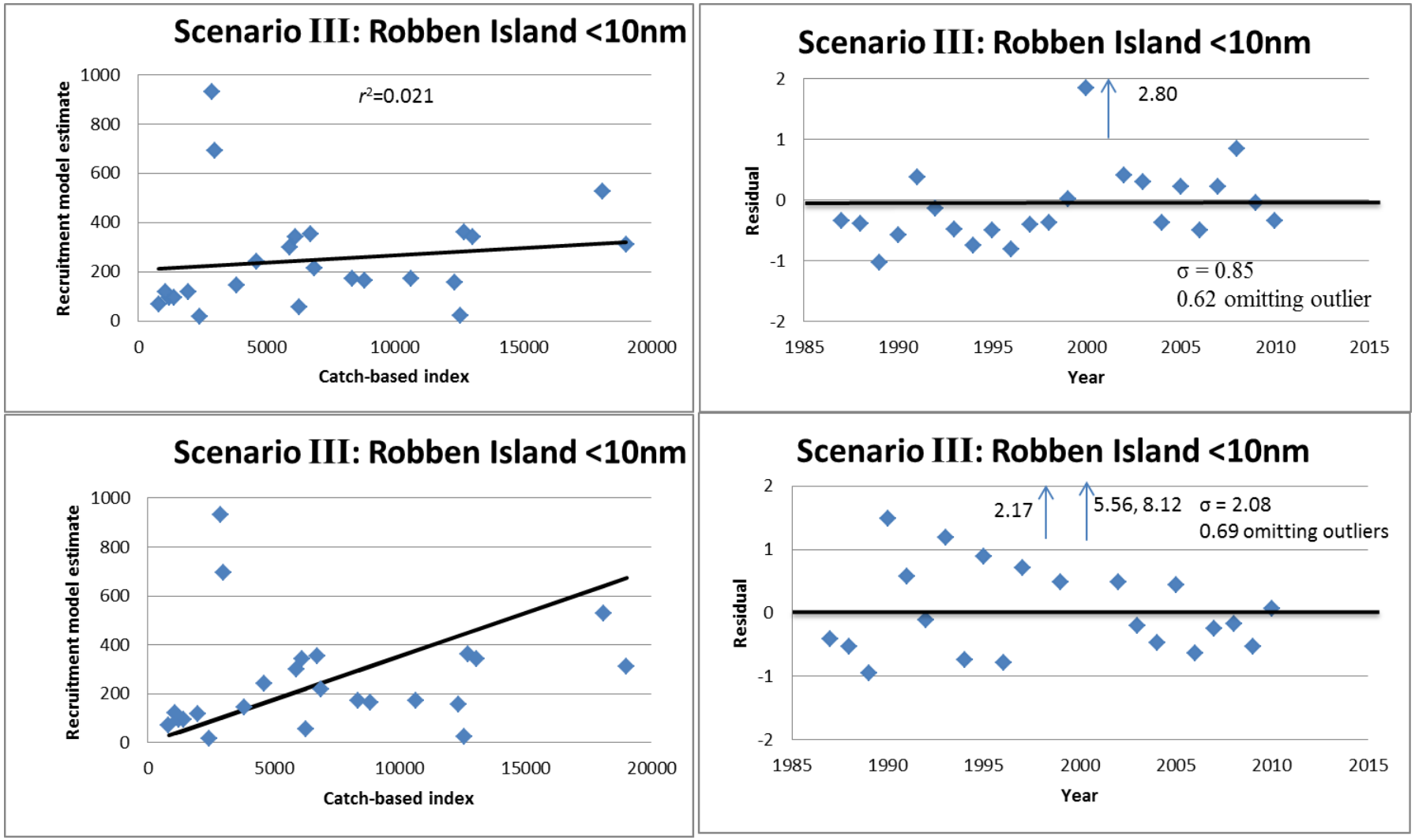
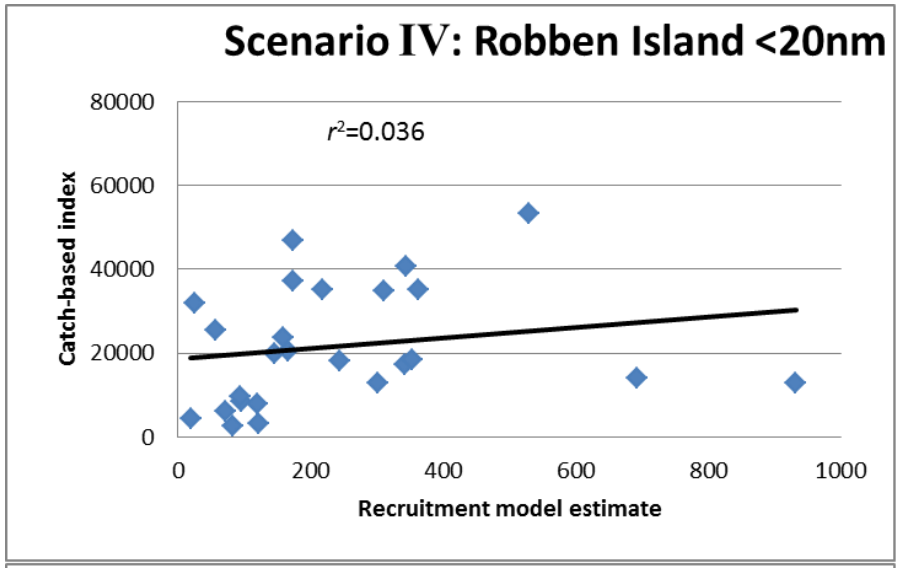
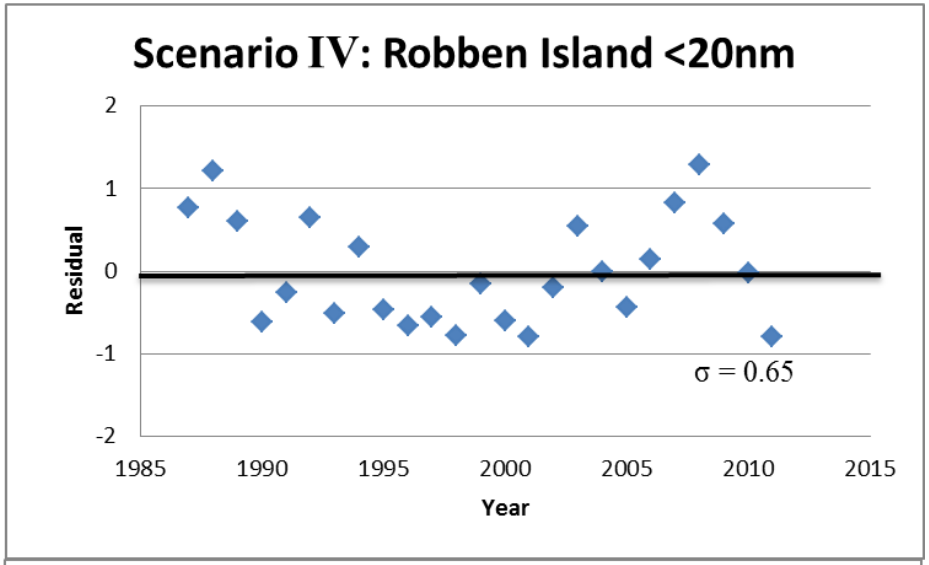
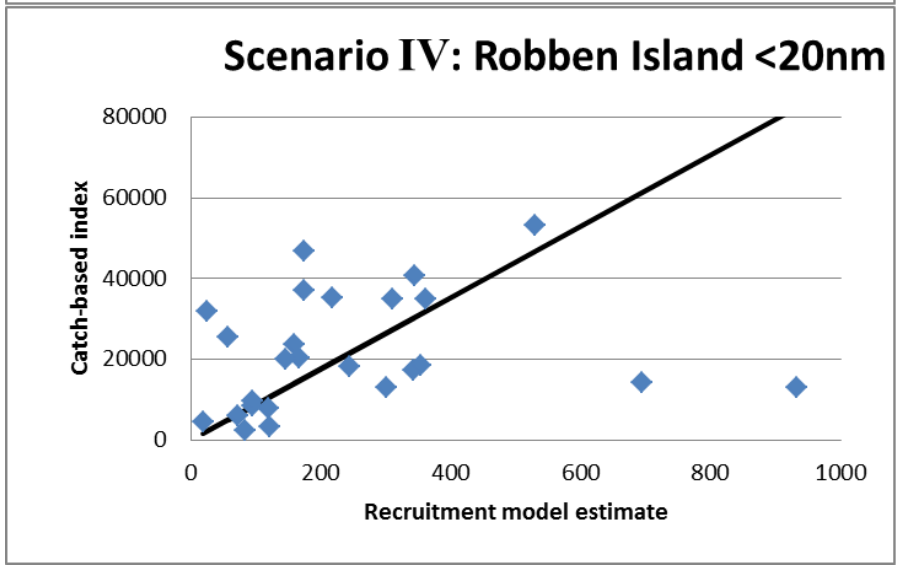


Figure 9a: Detailed regression results for directed anchovy catch (>50% proportion) for the fishery within **20nm** of Robben Island considered to be an index of recruitment: the catch based index is regressed against the recruitment model estimates.







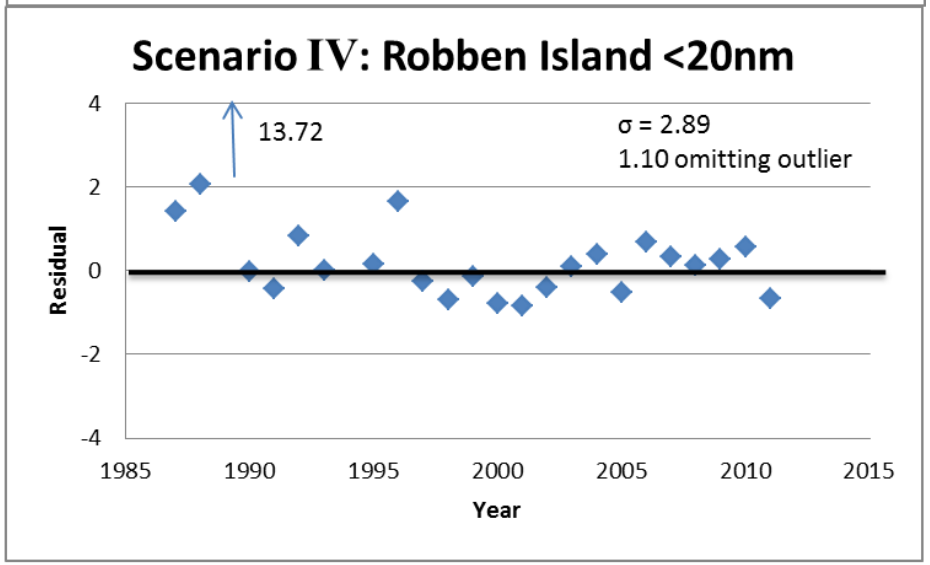


Figure 9b: : Detailed regression results for directed anchovy catch (>50% proportion) for Robben island within **20nm** considered to be an index of recruitment: the recruitment model estimates are regressed against the catch based index.

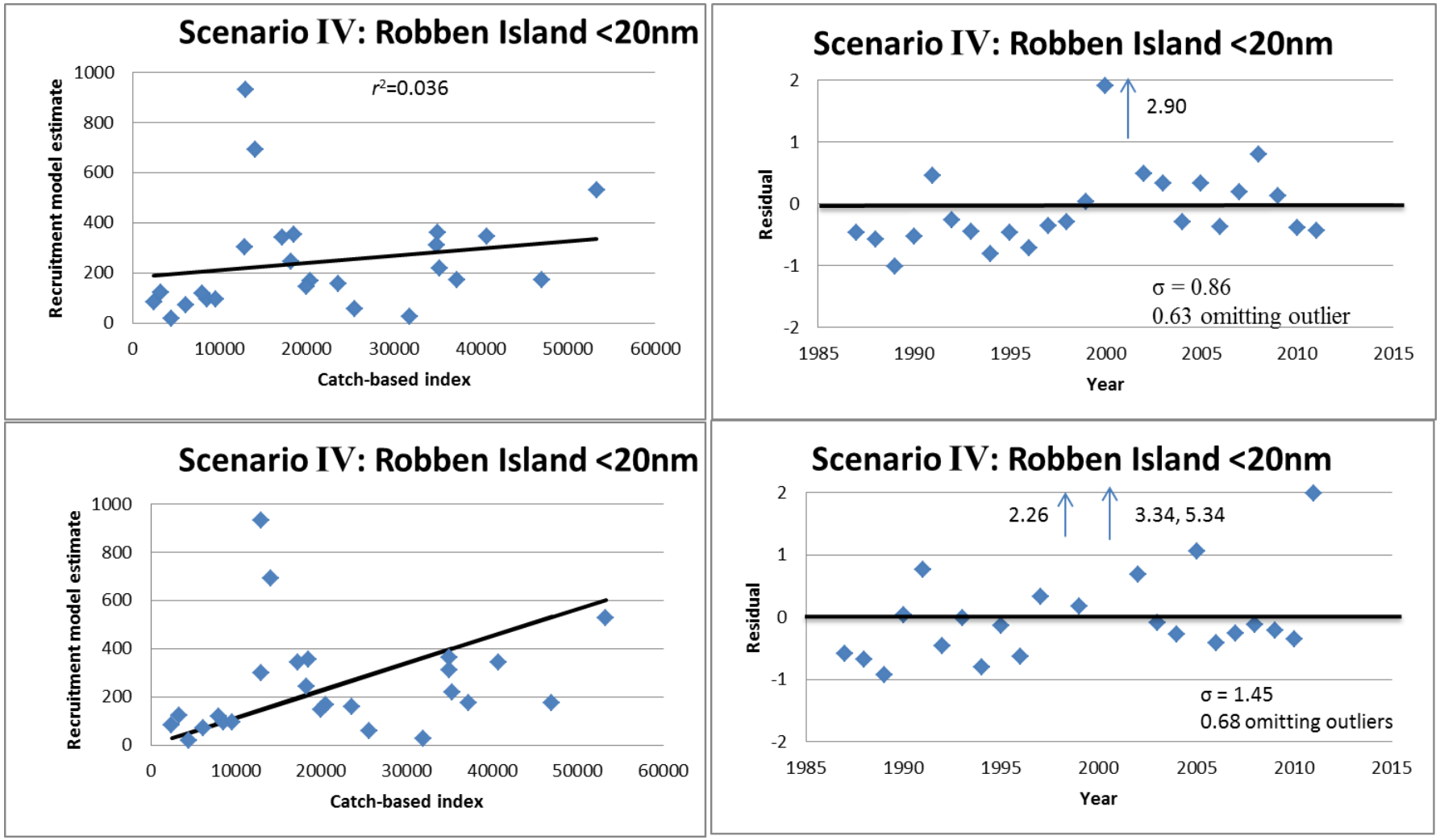


Figure 10a: Detailed regression results for directed anchovy catch (>50% proportion) for the fishery within **10nm** of Dassen Island considered to be an index of recruitment: the catch based index is regressed against the recruitment model estimates. Points for 2008 and 2009 when the island was closed to pelagic fishing within 10nm are not shown or taken into account in the regressions.

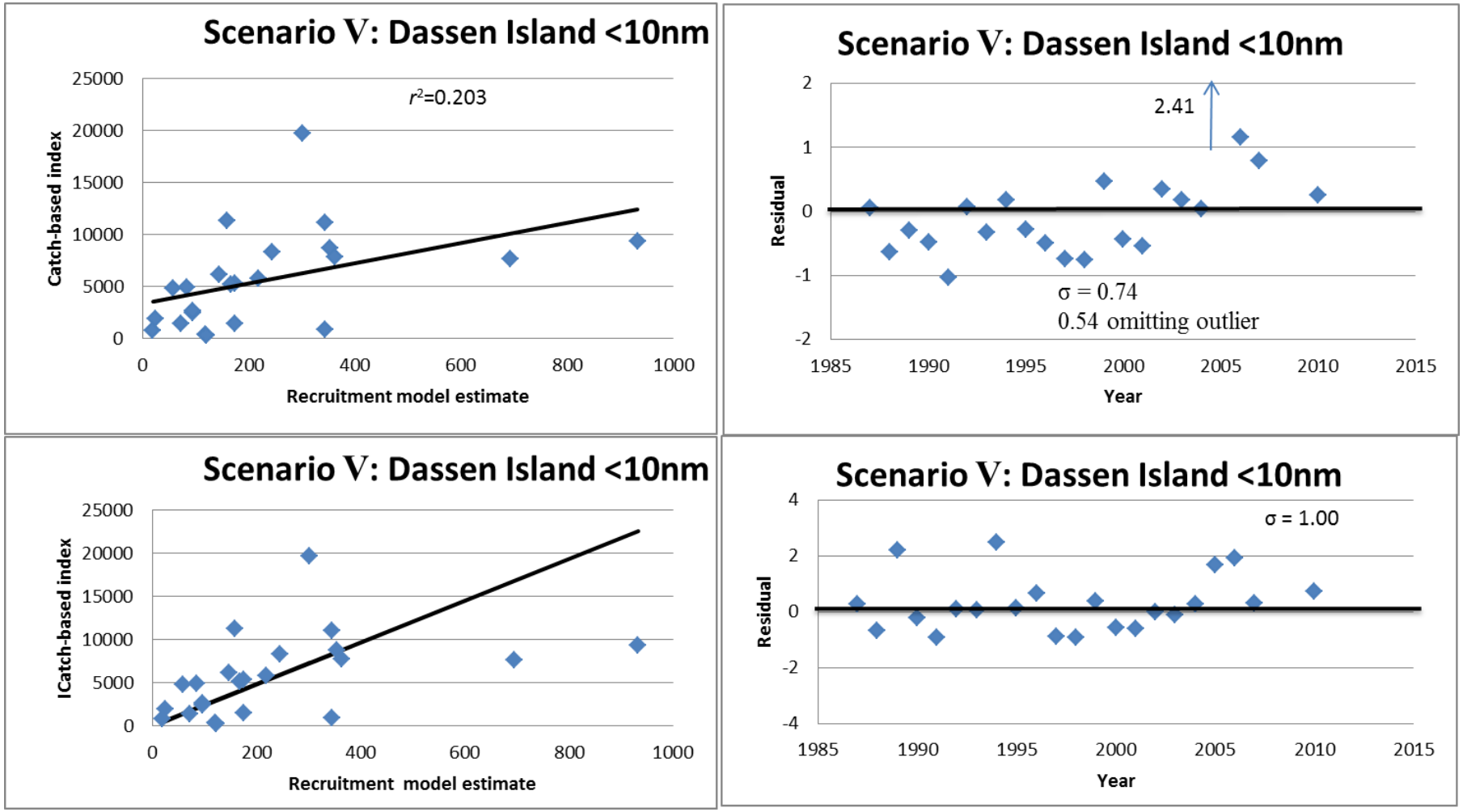


Figure 10b: Detailed regression results for directed anchovy catch (>50% proportion) for the fishery within **10nm** of Dassen Island considered to be an index of recruitment: the recruitment model estimates are regressed against the catch based index. Points for 2008 and 2009 when the island was closed to pelagic fishing within 10nm are not shown or taken into account in the regressions.

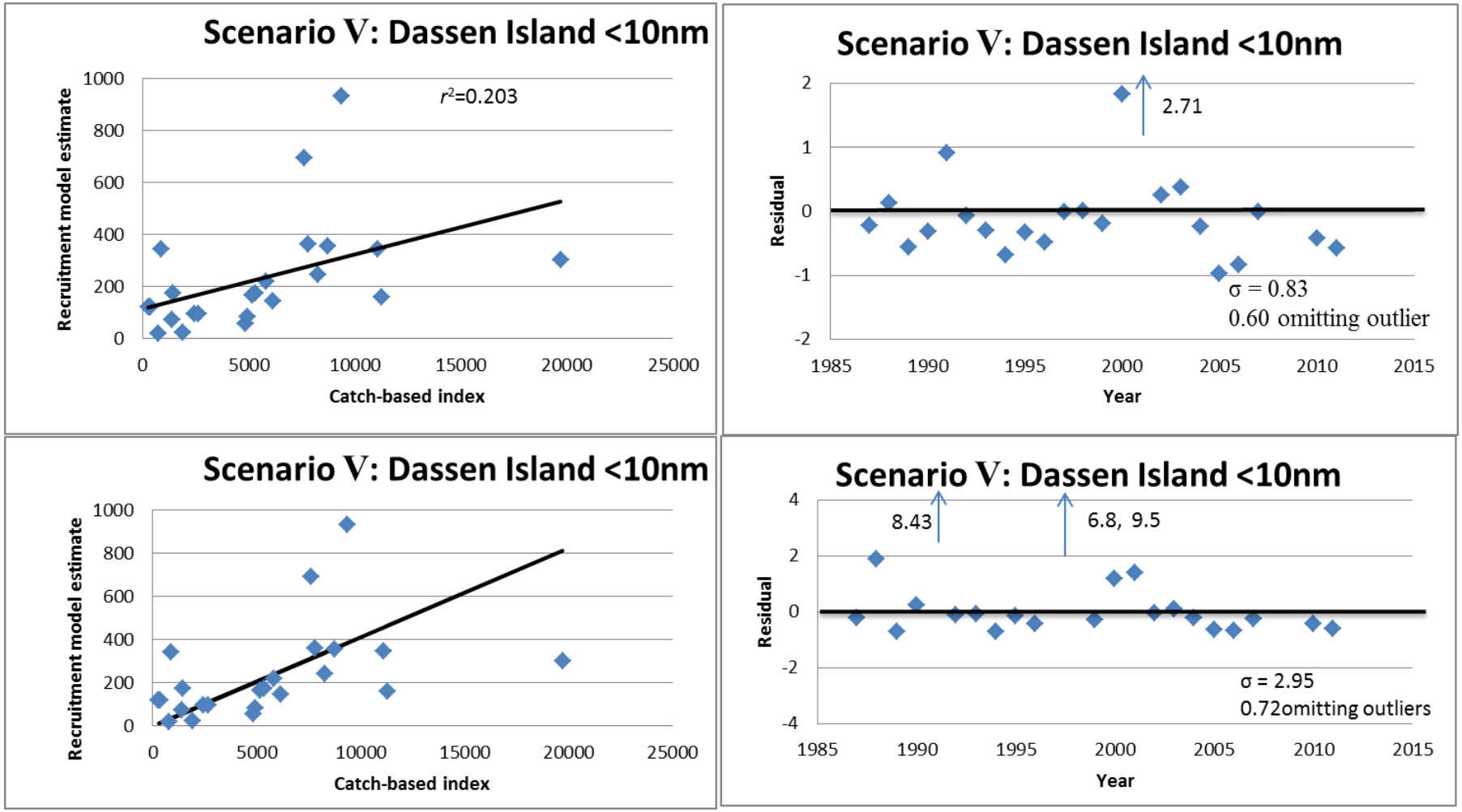
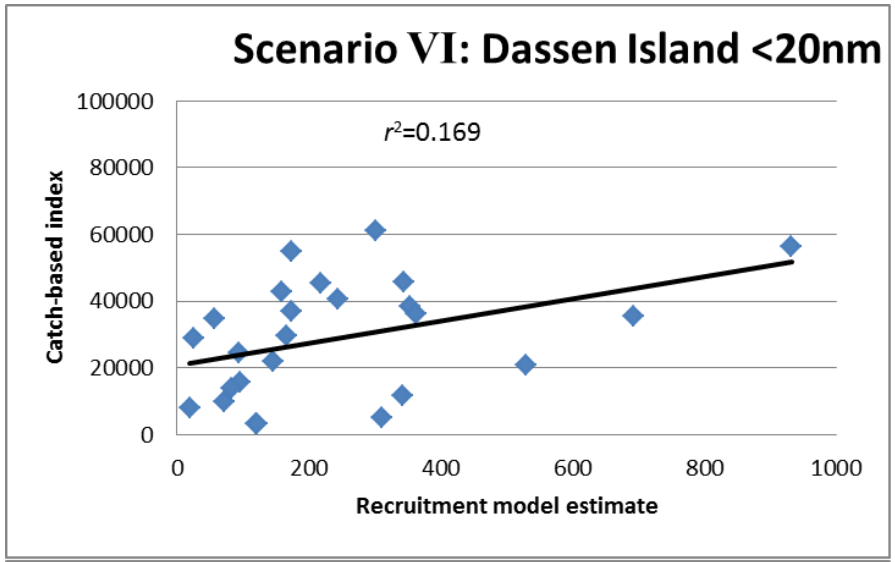
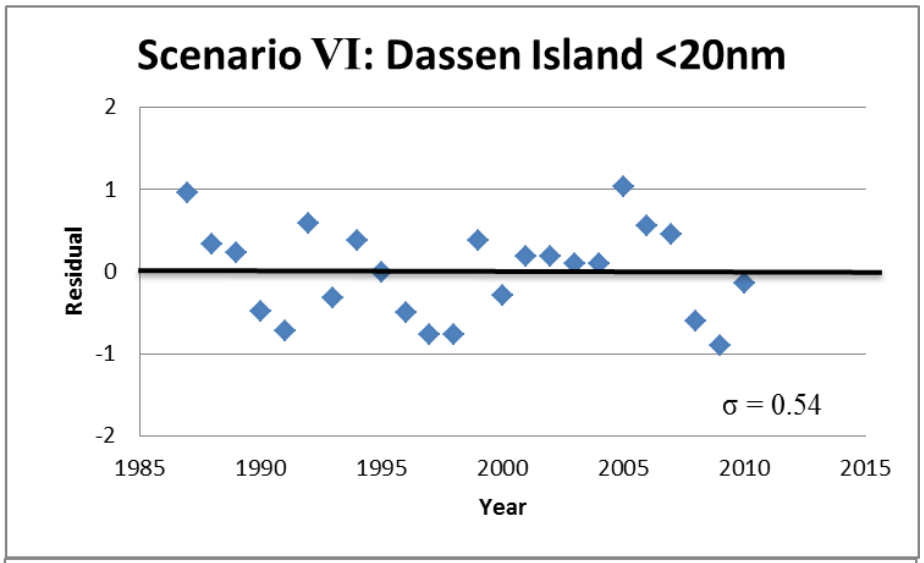
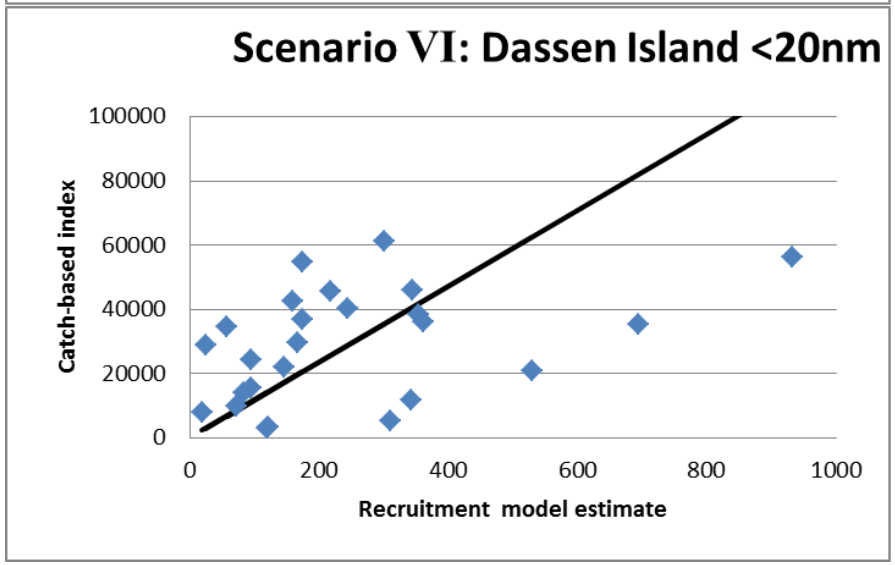


Figure 11a: Detailed regression results for directed anchovy catch (>50% proportion) for the fishery within **20nm** of Dassen Island considered to be an index of recruitment: the catch based index is regressed against the recruitment model estimates.







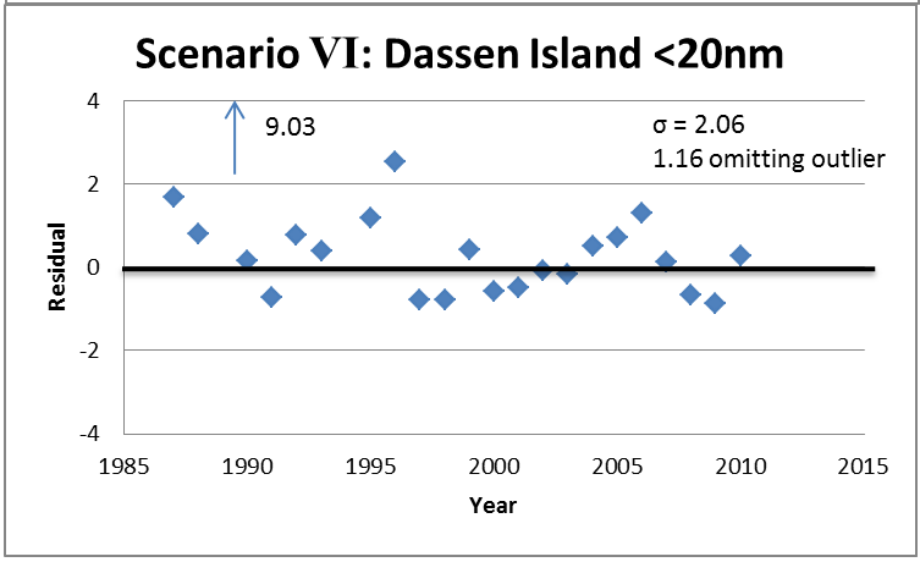


Figure 11b: Detailed regression results for directed anchovy catch (>50% proportion) for the fishery within **20nm** of Dassen Island considered to be an index of recruitment: the recruitment model estimates are regressed against the catch based index.