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ABSTRACT
Annual flights to survey southern right whales in winter/spring on the coast of southern Australia, between Cape Leeuwin (Western Australia) and Ceduna (South Australia) have been conducted over a 23-year period 1993-2015. These surveys have provided evidence of a population trend of around 6% per year, and a current (at 2014) population size of approximately 2300 of what has been regarded as the 'western' Australian right whale subpopulation. With estimated population size in the low thousands, it is presumed to be still well below carrying capacity. No trend information is available for the 'eastern' subpopulation of animals occurring around the remainder of the southern Australian Coast, to at least as far as Sydney, New South Wales and the populations size is relatively small, probably in the low hundreds. A lower than expected 'western' count in 2015 gives weak evidence that the growth rate may be starting to show signs of slowing, though an exponential increase remains the best description of the data. If the low 2015 count is anomalous, future counts may be expected to show an exponential increase, but if it is not, modelling growth as other than simple exponential may be useful to explore in future.

INTRODUCTION
Following increasing reports of southern right whales off the south coast of Western Australia in the early 1970s an annual programme of aerial surveys was undertaken there from 1976 (Bannister 1990). At first, flights covered an area east of Cape Leeuwin (34° 23'S, 115° 08'E) mainly to a point east of Israelite Bay, 25nm west of Pt Culver, at *ca* 124° 12'E, over a coastline length of *ca* 400 nmiles (*ca* 750 km). In some years they were extended as far as Twilight Cove (32° 17'S, 126° 05'E), covering some 500 nmiles (*ca* 900km) (Fig 1).

The results from those earlier areas for the period 1983-1992 (Bannister, 2001) showed substantial increases in the three classes of whale recorded ('all animals', 'unaccompanied' animals - i.e. juveniles or adults unaccompanied by calves of the year, and cow/calf pairs). The annual increase rates (range 7.1-13.5%) were comparable but slightly higher than estimates elsewhere, e.g. off South Africa and eastern South America at around seven per cent per year (IWC 2001). Given accruing information on movement of individuals between the Western Australian coast and South Australia, both within and between years, the surveys from 1993 were extended into South Australian waters to include the localities where, up to then, the majority of Australian sightings had been recorded, i.e. to Ceduna, SA (32°08'S, 133°41'), taking in the major calving area at Head of Bight, SA (31°30'S, 131°10E) and the historically significant right whaling area at Fowler Bay, SA (31°59'S, 132°34'E) (Fig. 1). The total area covered then extended over some 900 nmiles (*ca* 1700 km).

In each year 1993-2007 there were three flights – one 'long', between Cape Leeuwin WA and Ceduna, SA, undertaken when animal numbers were likely to be at a maximum on the coast (mid-August – mid-September) and two 'short', between Cape Leeuwin and Twilight Cove. The latter were timed for late July/early August and late September/early October, bracketing the long flight. The 'long' flight concentrated on obtaining a maximum count of animals present, while also obtaining identification photographs; each

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'short' flight concentrated on obtaining as many as possible of the latter. Since 2007, given funding constraints, only one ('long') flight has been undertaken, timed to coincide with peak abundance, i.e. between mid-August and mid-September.

Right whales are observed close to the coast each year mainly between July and October (Bannister 1990, 2001), with some localities more favoured than others. Cows accompanied by calves are found particularly in the Doubtful I Bay, WA, region, in and north east of Israelite Bay, WA and at Head of Bight, SA. 'Unaccompanied' animals are less predictable, but are often found west of Israelite Bay, WA, west of Twilight Cove, WA and along 'the cliffs' between Eucla, WA, and Head of Bight, SA.

A power analysis undertaken by P Corkeron in 1992 (in Bannister, 1993) showed that a series of 'long' flights over five years, i.e. 1993-97, would be necessary to detect a trend in those data. But further power analysis by Corkeron in 1997 (in Bannister, 1997) showed that for animals appearing close to the coast on a three-year cycle, i.e. cow/calf pairs, a significant detectable trend would become apparent over a period encompassing five adult female reproductive, i.e. three-year, cycles, involving fifteen years from 1993, i.e. to 2007 inclusive. But given the very low figure recorded in 2007, the flights were extended annually from then. A study to develop a long-term monitoring strategy that would in future allow both efficient monitoring of population trend and abundance, and studies of linkages between population dynamics and environmental changes in the whales' feeding grounds, concluded that annual surveys are indeed appropriate (Bannister, Burnell, Hedley and Bravington, 2011).

Based on genetic evidence, involving mtDNA haplotype differentiation, as well their very much smaller numbers and lack of evidence of recovery, south-eastern right whales have been considered possibly a demographically separate sub-population from the more numerous and increasing south-western animals, although a recent genetic study (Carroll et al 2015) suggests the difference may result from differential historical extirpation rather than genetic distinction between two 'stocks'. For current purposes, however, a distinction continues to be made here between two subpopulations, 'western' and 'eastern'. The Southern Right Whale Conservation Plan 2011-2021 (Australian Government Dept of Sustainability, Environment, Water, Population and Communities, 2011), has given very high priority to measuring and monitoring population recovery in both Australian sub-populations, 'western' and 'eastern'.

This paper reports the results obtained from the 'long' flight series, 1993-2015, of animals regarded as belonging to the 'western' sub-population that winters along the southern Australian coast.

METHODS

All surveys have been undertaken with a high wing, single engine aircraft (Cessna 172) based in Albany WA, (35° 01'S, 117° 58'E) crewed by a pilot/observer and photographer/observer. Each flight occurs close to the coast, searching an area *ca* 1 nmile wide within which right whales, particularly cows about to give birth or with newborn calves, can be found.

The survey methodology involves direct counts of animals observed within the search area. The latter includes virtually all the area to which right whales resort in winter/spring, close to the coast, in particular for the females to give birth. Most animals, particularly cows accompanied by their calves of the year, are easily observed in the relatively clear waters on the south coast, and the probability of sighting is assumed to be 1. This makes for a relatively simple sighting protocol, repeatable over the years. The most important factor has been to ensure little or no change in pilot- or observer-efficiency, achieved in this case by employing, over as protracted a period as possible, the same charter company (since 1995), observer/photographer (1998-2015) and pilot/observer (1993-95, 1999-2004, 2006-2013, 2015). Flying is only undertaken on 'good' days, with wind speeds of <15 knots.

The area searched on the 'long' flight is broken up into flight 'legs' between salient points on the coast (Cape Leeuwin-Albany, Albany-Esperance, Esperance-Twilight Cove (all within Western Australia), Twilight Cove-Head of Bight (South Australia), Head of Bight-Ceduna (South Australia) (Fig 1). An additional leg is flown each year on the west coast between Perth and Cape Leeuwin. Apart from the Perth-Cape Leeuwin leg, each is generally covered twice, once 'outwards' and once 'inwards'. Although the observer has a general instruction to count on the outward leg and photograph on the return, counts and photographs tend to be obtained both ways. For comparison between years, the numbers used are for those legs where the cow/calf count is a maximum. Even though there may be up to two days between 'outward' and 'inward' counts (though usually not more than a day) the relatively sedentary cow/calf pairs are most unlikely to have moved between legs and thus confounded the results. The same cannot be said for 'unaccompanied' animals, which come and go much more rapidly and unpredictably.

RESULTS

Counts

The results for the years 1993-2015 are given in Table 1. As indicated above, the figures were obtained by combining, for each 'long' flight each year, the numbers of 'all animals', 'unaccompanied' animals and cow/calf pairs recorded for each leg where the cow/calf count was a maximum.

As a check on counts from the aircraft, comparisons have in the past been made with those for comparable dates from shore-based operations at Head of Bight, South Australia. No major discrepancies have been found. For example, in 2006 the aerial survey counts there of 59 adults, 43 calves on 27 August and 57 adults, 45 calves on 28 August gave the same result, for calves, as the highest count, on 19 August in perfect conditions, of 55 adults and 43 calves from the land-based operation (R Pirzl, pers. comm.). In 2007 the aerial counts of 23 adults and 12 calves at Head of Bight on 1 September and 31 adults, 12 calves and 2 'yearlings' on 2 September compared favourably, though at the bottom end of the range, with daily counts of 12-20 calving pairs recorded at Head of Bight between 15 and 31 August (S Burnell, pers. comm.).

The 2007 total count ('all animals', Table 1) at 286 was lower than any since 2003 (273), largely as a result of the very low number of cow/calf pairs recorded. That contrasted with the very high count in 2005 (591) and the relatively high count in 2006 (427). The 2007 cow/calf pair count (57) was the second lowest in the series to then – only that for 1994 (48, excluding counts for 1996 and 1997 where there may have been some undercounting, see Bannister 1998, 2002) was lower. The cow/calf pair count was then the highest to date in 2008 and 2009, being exceeded only in 2013. But the most recent cow/calf count, in 2015, was also very low, at only 97 compared with 232 the previous year, 2014, and 220 in 2012, the previous calving year in a three-year calving cycle.

Trend

A simple exponential regression (i.e. a linear regression of the natural log of the count on year) of the data in Table 1 for 'all animals', for the period 1993-2015 gives an exponential rate of increase of 0.0563 (95% CI 0.0380-0.0747) corresponding to a percentage annual increase of 5.79 (95% CI 3.87-7.75); for cow/calf pairs the figures are 0.0588 (95% CI 0.0324-0.1031) and 6.06 (95% CI 3.29- 8.89) respectively (Table 2; Fig 2). As expected, the rates of increase of all animals and cow/calf pairs are both somewhat lower than for the time series extending up to the previous year, 1993-2014 (also shown in Table 2; Fig 3), given the lower new counts in 2015. They are slightly less precise than the equivalent rates of increase estimated previously but the fit of the regressions to the data is still very good.

Population size

Current population size is estimated using the simple model adopted at the International Right Whale Workshop held in Buenos Aires, Argentina, in September 2011 (IWC, 2013), based largely on evidence from increasing populations off Argentina and South Africa, whereby the cow/calf count over three years (to allow for the 3-year periodicity in calving) is multiplied by a factor of 3.94. Using the combined cow/calf count for 2013-2015 of 575 gives a current population size for the mid-point of that period (2014), for the 'western' Australian subpopulation, of 2266.

DISCUSSION

The surveys reported here have had the major aim of obtaining annual numbers of animals occurring close to the coast in the area where the majority of the 'western' Australian right whale subpopulation can be found in winter/early spring, i.e. between Cape Leeuwin, WA and Ceduna SA. From 1993-2015, the estimated annual rate of increase is around 6%.

Current population size in 2014 has been calculated at around 2300. It is assumed that the relatively low population size indicates that the population is currently well below carrying capacity, *K*.

Given the three-year periodicity in calving, different three-year cohort strengths can be expected, particularly for cow/calf pairs. A three-year cycle is apparent for cow/calf pairs, for 1998-2003 (Fig 2), but it breaks down thereafter. Southern right whale breeding success, as exemplified by cohort strength from year to year, has been correlated with changes in sea surface temperature attributed to climate change in the South Atlantic (Leaper et al, 2006) where conception can be affected by high sea surface temperatures (themselves the result of earlier El Niño events) in the autumn months preceding conception the following winter, with a resulting effect on pregnancy rates the following year. Similar effects have been reported for the Australian population by Pirzl et al (2008), where annual calf production has been linked to variability in the El Niño-Southern Oscillation (ENSO), with reduced reproductive output associated with El Niño conditions on a 2.5 to 3-year time lag. Extended intervals between successful calving events were associated with variability in the Southern Annular Mode (SAM)[4] on a 3-year time lag.

The low 2007 cow/calf count has been considered an anomaly, particularly given inspection of the residuals of the fitted exponential regressions for data through 2014 (Fig 3). But, with the addition of the 2015 data, for the first time, the residuals reveal weak evidence that the growth rate may be starting to show signs of slowing (Fig 2). However, this pattern is strongly influenced by the lower than expected counts in 2015 and an exponential increase is still the best description of the data. If the low 2015 counts are anomalous, future counts may be expected to continue to show an exponential increase. However, if this is not the case, it may be useful in future to explore models of population growth other than simple exponential growth to investigate more robustly whether the growth rate is starting to slow down.

The results of 'matching' identification photographs of animals calving in 2004, and which would have been expected to calve next in 2007 (Table 3), show that only a low proportion (31%) of adult females calving in 2004 and identified later (ca 66% of those identified in 2004) did so after three years, i.e. in 2007, while more did after four years, in 2008 (46%), and some (18%) calved next after five years, in 2009 (Table 3). The numbers calving after four and five years suggest that there may have been little or no actual reduction in population numbers, rather a change in breeding pattern. Whether the same is true of the low numbers calving in 2015 may become evident from modelling population growth, as well as from the results of 'matching' those animals in the future.

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[4] SAM is the dominant climate signal in the Southern Ocean; it is a measure of oscillations in atmospheric pressure between the polar region and ~40°S and affects oceanic conditions through changes in the strength and latitude of westerly winds (see Pirzl et al 2008 for further explanations and references).

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Table 1: Right whale aerial survey, C. Leeuwin WA-Ceduna SA, 1993-2015. Comparable numbers seen.

Year	a. **All animals**	b. **'Unaccompanie d' animals**	c. **Cow/calf pairs**
1993	167	47	60
1994	191	95	48
1995	267	139	64
1996[5]	233	123	55
1997[1]	254	148	53
1998	342	120	111
1999	325	157	84
2000	259	113	73
2001	447	163	142
2002	377	163	107
2003	273	85	94
2004	356	142	107
2005	591	237	177
2006	427	127	150
2007	286	172	57
2008	702	230	236
2009	782	294	244
2010	519	251	134
2011	657	185	236
2012	715	275	220
2013	706	214	246
2014	623	159	232
2015	462	268	97

[5] Probable undercounts (see Bannister 1998, 2002)

Table 2: Best fit regressions to the data of

Table , C. Leeuwin WA-Ceduna SA,
excluding 1996, 1997.

Period	**1993-2015**		**1993-2014**	
Class	**All animals**	**Cow/calf pairs**	**All animals**	**Cow/calf pairs**
Exponential increase	0.0563	0.0588	0.0628	0.0704
SE	0.0088	0.0126	0.0086	0.0115
95% CI	0.0380-0.0747	0.0324-0.0852	0.0446-0.0809	0.0462-0.0945
p	0.000004	0.00017	0.000001	0.00001
R^2	0.685	0.534	0.747	0.676
Percentage annual increase	5.79	6.06	6.48	7.29
SE	0.880	1.27	0.866	1.16
95% CI	3.87-7.75	3.29-8.89	4.57-8.42	4.73-9.91

Table 3: Breeding success in the 2004 adult female cohort, 2004-2009. Figures for 2005 and later represent the number of cows that had a calf in 2004 that subsequently calved in that year out of the total number of cows that had a calf in 2004 seen that year.

Class	**2004**	**2005**	**2006**	**2006**	**2008**	**2009**
Cow/calf pairs	**61(100%)**	**0(0)**	**3(5)**	**19(31)**	**28(46)**	**11(18)**

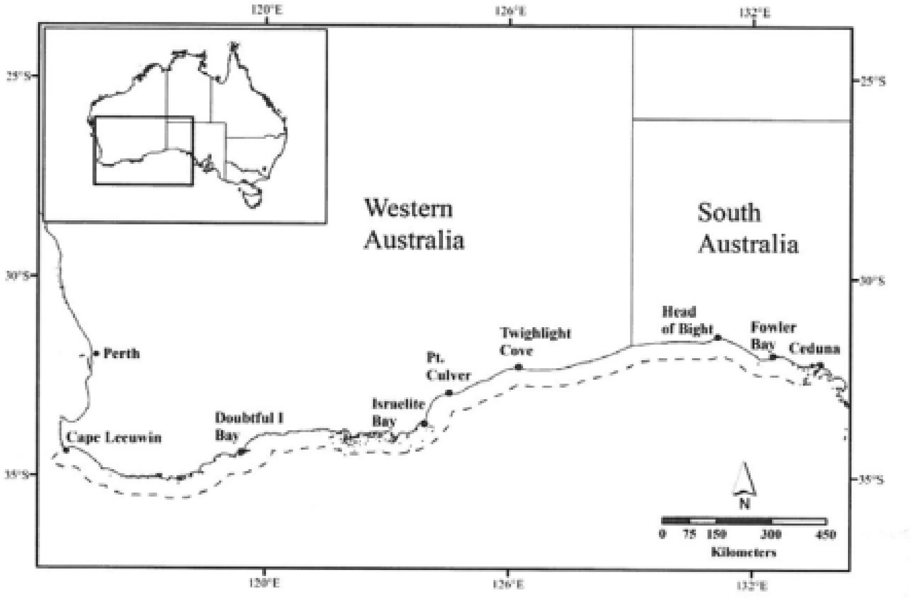
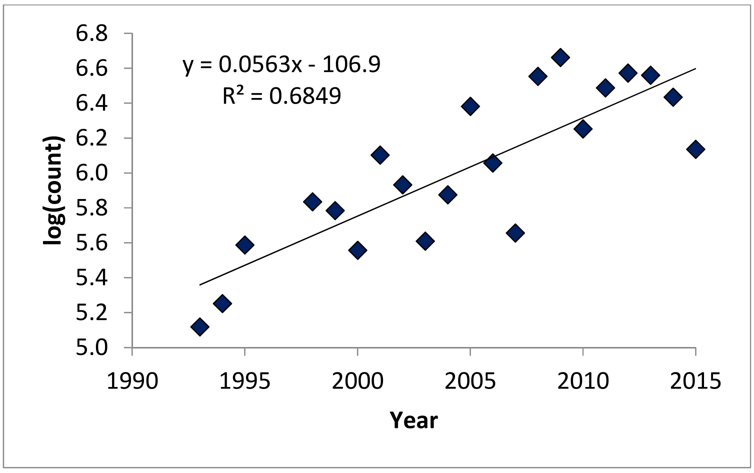
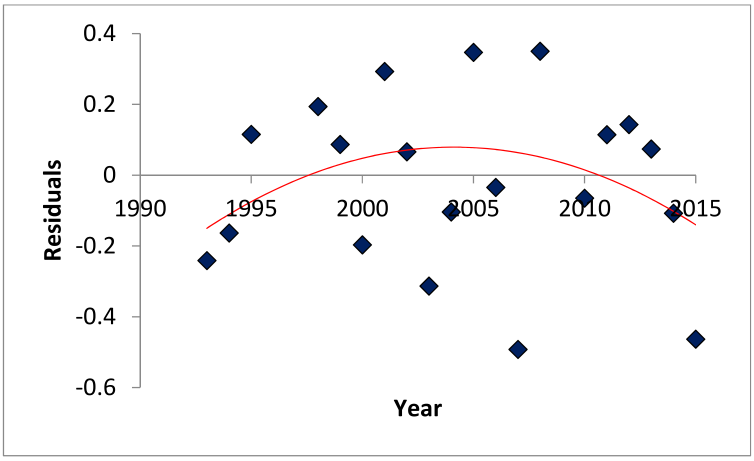


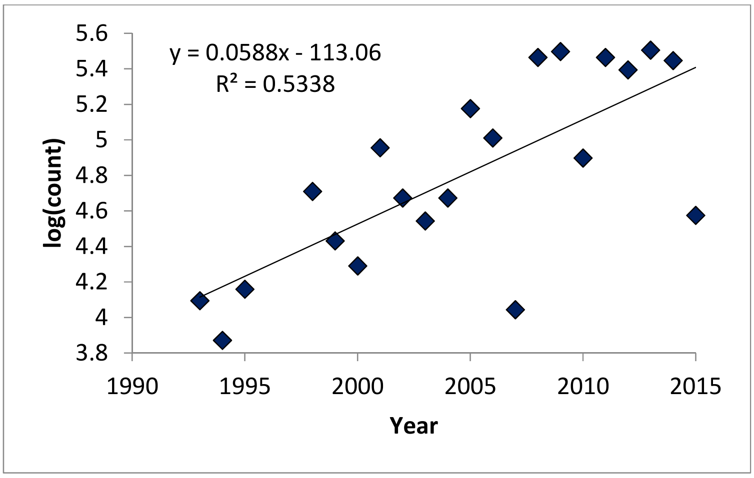
Fig. 1. Right whale aerial survey off southern Australia from 1993 to 2015. Dashed line represents approximate survey route

(a) All animals





(b) Cow/calf pairs



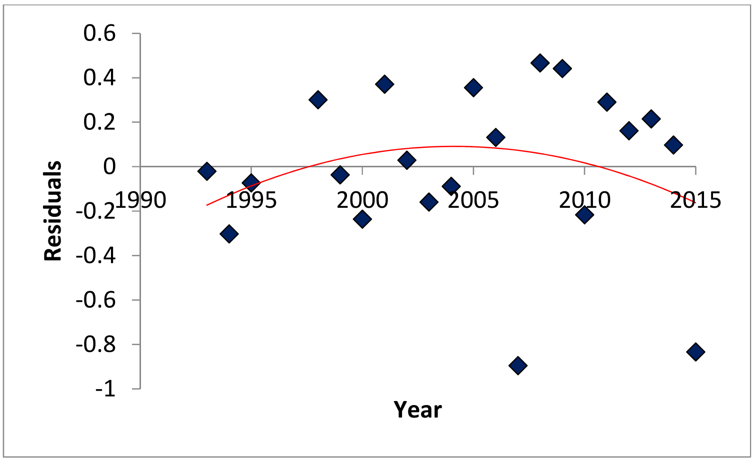


Fig. 2. Plots of the fitted linear regression and residuals for the data in Table 2 for 1993-2015, excluding 1996 and 1997. The smooth red lines fitted through the residuals show weak evidence that the exponential growth rate may be slowing. (a) All animals. (b) Cow/calf pairs.

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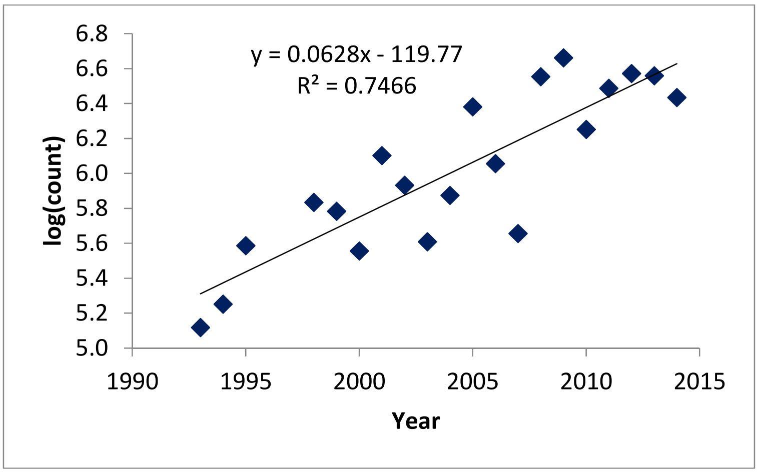
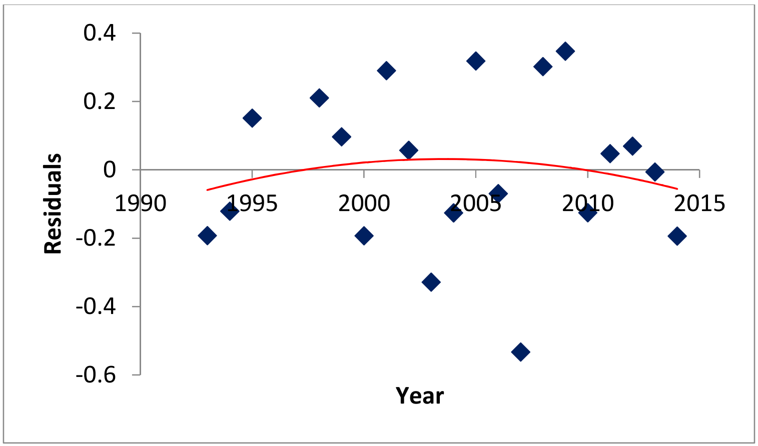
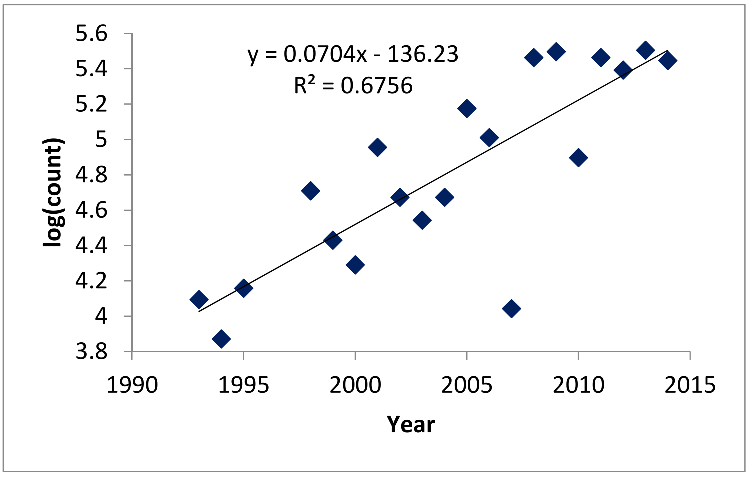




(b) Cow/calf pairs



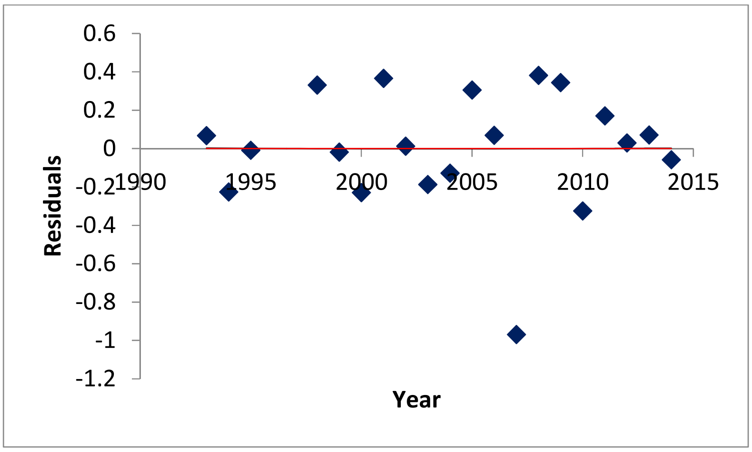


Fig. 3. Plots of the fitted linear regression and residuals for the data in Table 2 for 1993-2014, excluding 1996 and 1997. The smooth red lines fitted through the residuals show little or no evidence that the exponential growth rate may be slowing. (a) All animals. (b) Cow/calf pairs.