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Trends in pelagic fish abundance from aerial sightings data

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1. Executive Summary

- New Zealand aerial sightings data are available since 1976 and give a time series for surface abundance of kahawai, jack mackerels, trevally, and blue mackerel. The data are collected mainly for the purseseine fishery. The aerial sightings data give a source of information on the relative abundance of these species that is partially independent of the fishery as some sightings not leading to purseseine sets are recorded.

- The data are for fish schools at or near the surface. Changes in surface abundance may not reflect changes in total abundance in the short term, but they should in the long term.

- Several ways of estimating relative abundance indices from the aerial sightings data are explored. One index uses the chance of sighting a species in an area, the others use estimated tonnages and school numbers. The emphasis is on long term trends, and methods are mainly non-parametric.

- Kahawai relative abundance indices in KAH 3 peaked in the early 1980s and then dropped. Kahawai may be visible in less of KAH 3 in the 1990s than previously. There are no obvious long term changes in other kahawai Fishstocks, though there may be an increase in KAH 1 in the 1990s.

- Jack mackerel relative abundance indices have increased in the 1990s in JMA 1, probably in JMA 3, and possibly in JMA 7. This rise may be due to the arrival of Peruvian jack mackerel in New Zealand waters.

- Trevally relative abundance indices give some conflicting trends for the more recent data. In TRE 1 the relative abundance decreased from the 1970s to the early 1980s: from the late 1980s, two indices suggest no change or slight decline and another suggests an increase. There may have been a change in the geographic distribution of trevally or a change in schooling behaviour. Data are sparse in other trevally Fishstocks.

- Blue mackerel relative abundance indices are also somewhat conflicting. One index suggests a peak in the late 1980s in the Bay of Plenty and the others suggest little change anywhere.

2. Introduction

Aerial sightings have been used in commercial fishing for pelagic fish in New Zealand waters since about 1976: the first published report on the use of aerial sightings in New Zealand was by Bell (1976). Research flights were run at regular intervals in the late 1970s and the fish schools spotted were described in a series of *Catch* articles which are listed separately after the References. Reports summarising the aerial sightings by year were produced in the mid 1980s (Wood & Fisher 1983, 1984, Swanson & Wood 1986a, 1986b). A substantial number of aerial sightings recording forms for the years covered were discovered after the publication of these reports. A New Zealand Fisheries Technical Report which describes the aerial sightings purseseine fishery operation, the database, and the data is in preparation by Paul Taylor. Material in this Technical Report is referred to but not described in detail here.

Indices of relative abundance are being produced elsewhere from aerial sightings data including that collected from commercial spotting pilots. Much of the work using designed experiments is aimed at finding abundance trends in marine mammals. Some examples are given below.

Lo *et al.* (1992) developed an index of relative abundance from fish spotter data based on extended delta–lognormal models and applied the method to northern anchovy. They found that environmental data, when available, improved the estimates of relative abundance. The spotter data are known to greater spatial accuracy (10 minute squares) in the anchovy fishery than in the New Zealand aerial sightings data (half degree squares).

A large, designed experiment has been underway for several years in the Great Australian Bight using aerial surveys to detect the abundance of southern bluefin tuna (*see*, for example, Chen & Polacheck 1994). Forney *et al.* (1991) use designed aerial surveys over a period of years to detect trends in harbour porpoise abundance from year to year using analysis of covariance. Buckland *et al.* (1992) summarised methods for estimating relative abundance of dolphin stocks in the eastern tropical Pacific Ocean using sightings data by trained observers and smoothing methods to remove large year to year apparent changes in relative abundance as part of their analysis.

Our approach is partly qualitative and based on techniques of exploratory data analysis, including smoothing. The data are inevitably messy, and for this reason we prefer to use non–parametric statistical methods rather than attempt to guess the exact distribution of the data (or subset of data) under consideration. The coarseness of the spatial position information is one reason why we have not attempted to fit something akin to a delta–lognormal model to the New Zealand data. We do, however, separately consider the probability of sighting fish and the amount seen (in number of schools and tonnage) when there is a sighting.

2.1 New Zealand aerial sightings data

Aerial fish spotting, by pilots in light aircraft, is an integral part of the purseseine fishing operation. Records of aerial sightings of pelagic fish are available in New Zealand from 1976 and form the longest, most reliable time series for pelagic schooling species. The data have been collected opportunistically and are mainly commercial (less than 2% are not) so do not have the nice (mathematical) properties of randomly sampled data. Nevertheless, the quantity of data means that it should be possible to produce indices of *relative* abundance using methods which do not place much emphasis on individual sightings. The research flights in the 1970s (*Catch* articles) are now mainly of historic interest and have been treated in the same way as the commercial flights.

Every 10–15 minutes, the pilot records the half degree square he is flying over. As appropriate, he writes down the number of schools, the species and tonnage estimates in the square. These data are transferred to a database, for which Paul Taylor is preparing a formal description. The variables in the four main tables in the database are listed in Appendix 1. Other tables define the codes used in the main tables. The table of most interest here is t_school_sight from which the species (species_code), number of schools (num_of_schools), and minimum and maximum school tonnages (ton_min and ton_max) in each sighting are obtained. The pilots record the total tonnage in a group of schools sometimes and this information is ignored. The date comes from t_flight_group (the tables are linked using flt_grp called flight group in this document). The grid variable in t_flightpath is used in Section 3 of this document. The information on sightings is by half degree latitude–longitude squares (location in t_school_sight and grid in t_flightpath).

Aerial sightings terms

Flight is a flight by one pilot between takeoff and landing.

Flight group is a collection of flights by one pilot. Usually, a flight group covers a half to one day's flying. For this report, there is no need to distinguish between flight and flight group, except for the formal table linking via flight group.

Square is one of the half degree squares used to record the aerial sightings. The boundaries of these squares lie along the lines of latitude and longitude in whole and half degrees. The squares are numbered and over 100 are involved.

Sighting is the recorded sighting of schools of a fish species in a square. A sighting frequently involves more than one school.

Region is a collection of squares. The regions used are mainly Fishstocks. The whole coverage of the aerial sightings database (all data) is also used as a region.

Visit is the pilot flying over a square and recording data for fish seen (or the absence of fish) in that area.

Appendix 2 contains the brief definitions of the Fishstock boundaries for kahawai, jack mackerel, and trevally and how they relate to the Quota Management Areas (Annala 1994). (Note: the Fishstock boundaries for the pelagic species do not follow the QMA boundaries strictly.) Appendix 2 also contains a map showing the area covered by the aerial sightings database. The 200 m depth contour can be used as a proxy for the outer limits of the coverage for the inshore pelagic species. No sightings are made south of about 42° S. The QMA boundaries and how they are defined in terms of the half-degree aerial sightings squares are also shown. The geographical distribution of the aerial sightings is determined by the purseseine fishery in the North Island and the north of the South Island.

In this document, Fishstocks are sometimes combined to give sufficient data for analysis. Hence, for kahawai, KAH 1 and KAH 9 are combined, and for trevally, TRE 2, TRE 3, and TRE 7 are combined. Blue mackerel are not yet in the Quota Management System and the blue mackerel data are divided into QMA 1 and QMAs 2, 3, 7, 8, and 9 combined. The area of the large jack mackerel trawl fishery is barely covered by the data so only parts of JMA 3 and JMA 7 are covered. Fishstock is used in this report to mean the combinations given above.

Table 1: Total number of sightings of species and species mixtures in Quota Management Areas. SKJ skipjack tuna; TRE trevally; EMA blue mackerel; JMA jack mackerel (all species); KAH kahawai. Occasional sightings are made of other species, such as kingfish, yellowfin tuna, whales, and porpoises.

Species	QMA 1	QMA 2	QMA 3	QMA 7	QMA 8	QMA 9	Total
SKJ	8 783	314	0	36	138	804	10 075
TRE	4 943	159	0	26	8	5	5 141
EMA	3 135	29	56	209	81	63	3 573
JMA	3 017	168	266	212	17	30	3 710
KAH	8 158	1289	816	2231	272	98	12 864
Baitfish	484	14	1	124	17	39	679
KAH,TRE	215	27	0	43	5	2	292
EMA,JMA	457	18	93	75	3	20	666
KAH,JMA	757	479	403	525	11	11	2 186
EMA,TRE	8	0	0	0	0	0	8
KAH,EMA,TRE	9	0	0	1	0	0	10
JMA,TRE	5	1	0	1	0	0	7
KAH,EMA	34	69	14	203	96	2	418
EMA,JMA,TRE	4	0	0	0	0	0	4
KAH,EMA,JMA	25	48	92	217	21	1	404
Pilchards	6	2	0	147	1	0	156

The main sightings in the database (Table 1) are of skipjack tuna (*Katsuwonus pelamis*), kahawai (*Arripis trutta*), jack mackerels (*Trachurus declivis, T. novaezelandiae, T. murphyi*), blue mackerel (*Scomber australasicus*), and trevally (*Pseudocaranx dentex*). Mixed schools

Table 2: Total number of sightings by year in Quota Management Areas.

Year	QMA 1	QMA 2	QMA 3	QMA 7	QMA 8	QMA 9	Total
1976	426	19	3	4	5	14	471
1977	1 578	36	2	57	52	51	1 776
1978	1 833	114	10	314	43	85	2 399
1979	2 069	127	6	361	70	14	2 647
1980	1 790	174	49	375	116	111	2 615
1981	1 768	179	30	290	61	34	2 362
1982	1 754	117	54	219	46	290	2 480
1983	1 422	200	35	210	73	135	2 075
1984	1 791	165	95	139	14	7	2 211
1985	1 463	237	72	211	25	20	2 028
1986	1 741	214	90	257	10	9	2 321
1987	1 859	191	101	220	6	1	2 378
1988	2 015	273	238	196	6	7	2 735
1989	1 796	103	166	317	60	141	2 583
1990	2 160	99	178	512	50	7	3 006
1991	1 807	190	349	218	18	1	2 583
1992	1 783	85	146	151	16	21	2 202
1993	1 672	105	130	117	11	142	2 177

Table 3: Total number of flight groups by year in Quota Management Areas.

Year	QMA 1	QMA 2	QMA 3	QMA 7	QMA 8	QMA 9	Total
1976	88	4	1	1	3	7	104
1977	310	12	1	20	24	22	389
1978	270	27	4	103	23	31	458
1979	336	59	4	127	21	8	555
1980	303	68	29	142	47	31	620
1981	341	67	20	115	31	15	589
1982	338	31	37	106	24	55	591
1983	300	73	23	104	30	29	559
1984	321	59	36	58	7	5	486
1985	287	82	40	111	19	7	546
1986	326	49	60	120	8	3	566
1987	326	65	72	108	4	1	576
1988	374	83	106	92	2	4	661
1989	364	30	91	159	17	22	683
1990	383	33	97	227	30	4	774
1991	363	54	119	103	11	1	651
1992	353	37	72	80	7	15	564
1993	330	37	74	70	4	43	558

of these species are also seen, but less frequently. We have not considered contributions from mixed schools because of the difficulty in defining the proportion of each species. West (1991) examined the skipjack tuna data and they are not considered in detail here. Sightings of baitfish and pilchards (near Nelson) occur at about 10% the number of times that sightings of the main species occur, and again these are not considered.

Most of the sightings are in QMA 1, and a large fraction of these sightings is in the Bay of Plenty (Table 2). Most of the sightings effort is in QMA 1 (Table 3). Sightings effort has tended to increase in QMA 3 over the time period and to be sporadic in QMAs 8 and 9 (*see* Table 3).

Some pelagic species are caught by other methods, both inside and outside the region of the purseseine fishery. For kahawai, the commercial fishery is mainly by purseseine. Trevally are caught predominantly in the same regions as the purseseine fishery, but by a variety of methods. Jack mackerels are caught throughout the purseseine fishery, and large quantities of jack mackerel are caught by trawling on the Challenger Plateau and around the South Island (Annala 1994). (Skipjack tuna rarely come south of the northern region of the North Island.)

The composition of the New Zealand inshore pelagic fish population has changed recently with the arrival of large numbers of Peruvian jack mackerel (*Trachurus murphyi*). Experienced pilots may be able to distinguish the jack mackerel schools by species from the air, but there may be identification problems, for example, when the Peruvian jack mackerel and kahawai form mixed schools. In this document, Peruvian jack mackerel are not separated from the endemic jack mackerels.

Because the aerial sightings data are collected largely for commercial purposes, apparent changes in abundance could reflect changes in fishing activity and consequently changes in sightings effort rather than changes in the number of fish present. Another problem with aerial sightings data, even when they are collected according to some experimental design, is that we have no estimate of the distribution of fish not visible from the air.

The schooling behaviour of fish probably varies throughout the year as a result of changing environmental conditions, so the appearance of larger quantities of fish on or near the surface in any year may not imply increased abundance.

2.2 Rationale for the analyses chosen

The approach used here to estimate relative abundance is like the line transect methods of aerial surveys (*see* Burnham *et al.* 1980). Taylor's approach uses tonnes per hour which is similar to catch per unit effort (Taylor, in prep.).

Throughout this document, the implicit assumption is that the fish have not moved out of a given half degree square in the time interval used for aggregation, though this might not be true, and in Section 3, we assume that all schools in an area are seen and recorded. We would like to be able to avoid both multiple and under counting of fish, but have done nothing explicit to eliminate miscounting. Ideally, less weight would be given to several sightings of a species in the same place over a short time (these are probably the same fish) than to a single sighting during a time of low spotting effort.

The distributions of the numbers of schools seen and tonnage estimates in a given time period are highly skewed (Figure 1). Notice how small the upper quartiles (upper sides of the box) are compared to the maxima of each year's data. The methods used to determine relative abundance indices should be simple and not influenced by outliers.

The distributions for the numbers of schools and the tonnage in a given area are composed of two parts: the probability of a fish species being sighted in a given area (typically 0.05–0.25 in the Bay of Plenty, *see* Section 3) and the distribution of the sightings. Only the second part is shown in Figure 1. In this report, these two parts are considered separately but should be considered together. So far, we have no method for combining these two pieces of information into a single index.

We chose to use the median, rather than the mean of the data, as the measure of central point of the distribution. Medians are generally more "robust", particularly with skewed data. Various other properties of the data could be used to define relative abundance indices, for example, a trimmed mean.

Some previous estimates of abundance of schooling fish have been based on maxima. However, large collections of schools are hard to count and tonnage estimates will have high variance. Therefore, methods based on maximum values are likely to be much less reliable than methods based on medians. The occurrence of large collections of schools does need investigation, primarily to see when and where they occur and what is causing large aggregations of fish to form.

Standardisation has not been attempted. Calculating an annual standardised CPUE index, for example, involves correcting the annual catch rate mean for changes in fishing power, environmental, spatial, and temporal factors. Changes in fishing power and environmental factors are adequately quantified for only a few fisheries and the standardisation primarily involves spatial and temporal factors. We believe that the use of medians rather than means also "corrects" for unwanted influences in the data by concentrating on the bulk of the data rather than the extremes. For the New Zealand aerial sightings data, differences in pilot ability to spot and estimate sizes of schools might be removed by standardisation. However, because the median is unaffected by the size of the extreme values (the mean is), any tendency for gross over or under estimation by a particular pilot is removed.

The abundance of pelagic fish can change in any combination of the following ways:

- a change in the geographical region where fish are seen;
- a change in the number of schools in an area;
- a change in the tonnage in the area.

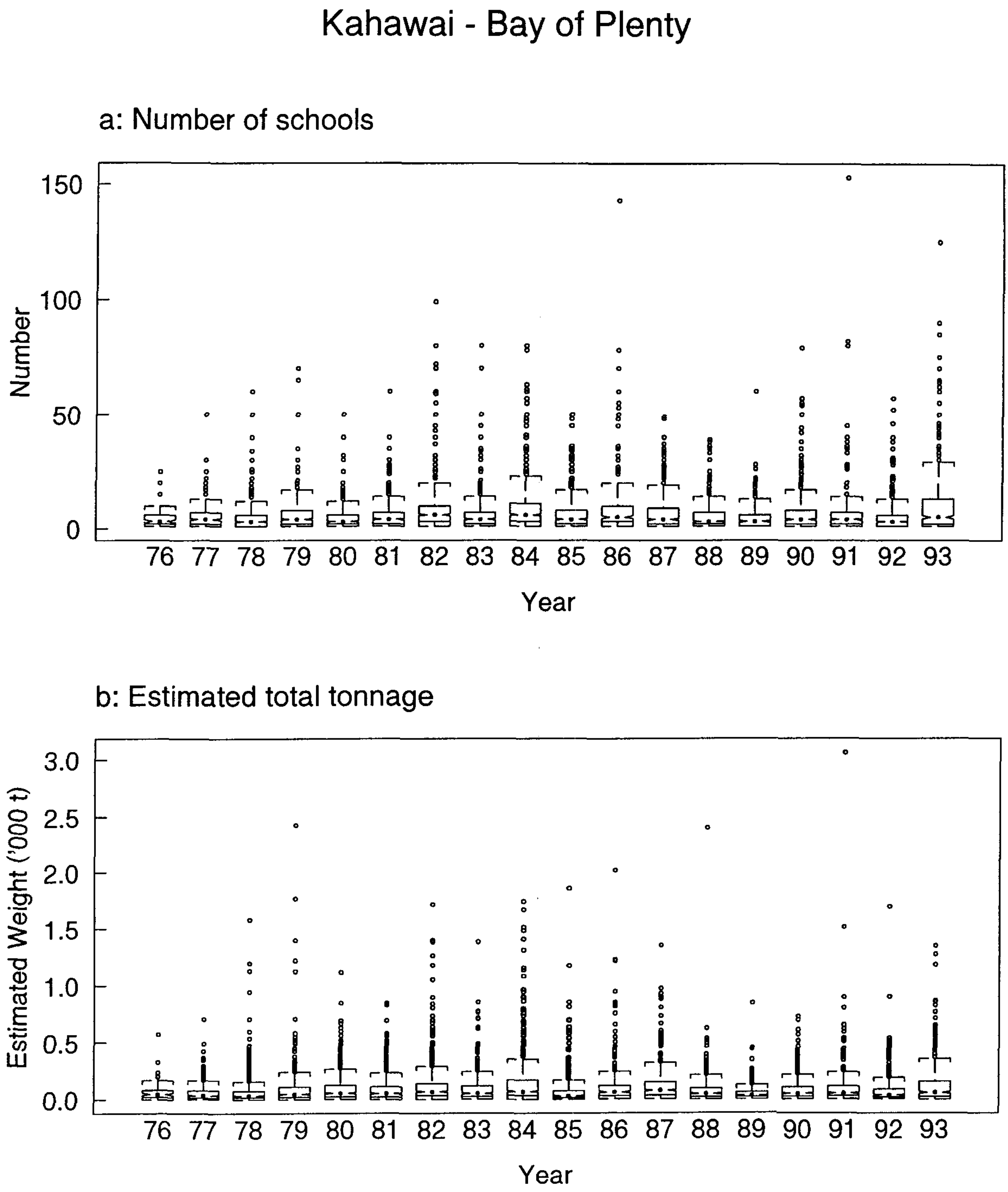

Figure 1: **Boxplots (defined in Appendix 3) showing the annual distributions of the number of schools and the estimated tonnage in them of kahawai in the Bay of Plenty (*see* Figure 2).**

The raw data we start with to investigate such changes are school numbers and tonnage estimates are extracted from the database for each sighting. The tonnage is estimated from the geometric mean of the minimum and maximum tonnages recorded by the pilot for each sighting of a group of schools as:

$$T_{stai} = N_{stai} * exp\left(\frac{log(T_{stai}^{Max}) + log(T_{stai}^{Min})}{2}\right)$$

where T is the tonnage, and N is the number of schools. The superscripts Max and Min are used for the maximum and minimum tonnage estimates. The subscripts s, t, a, and i stand for species, time, area, and sighting respectively. On extraction from the database, the time is in days and the area in half degree squares. For fish of a particular species, we aggregate the data to estimate relative abundance in larger areas (say, Fishstocks) and over longer periods of time (say, months).

To investigate whether any changes have occurred, we use three types of abundance indices which are calculated for kahawai, jack mackerels, trevally, and blue mackerel around the North Island of New Zealand and the north of the South Island.

Presence–absence or binomial index

The number of times a fish species was sighted, S_i, and the number of times an aerial sightings square was visited, O_i, are counted. The probability of sighting a particular species is estimated as $100 \times S_i/O_i$ and called the sightings percentage. This method depends heavily on knowing when a fish species was *not seen* and only the Bay of Plenty data are thought to have sufficient information on non–sightings (*see* Section 3).

School number and tonnage annual medians for a Fishstock

The annual medians of school number and tonnage are calculated for all data and for Fishstocks to give two relative abundance indices. An asymptotic confidence interval on the median is available (*see* Section 4).

Smoothed indices using summed (over squares) monthly medians

For the sightings in each aerial sightings square, the medians of school number and tonnage by month are found and then summed over the individual squares for a Fishstock and for all the data. Indices are the smoothed trends in the summed monthly medians (*see* Section 6).

Experiments with the Bay of Plenty data were used to decide how to amalgamate the data from individual aerial sightings squares to get the smoothed indices. Both daily and monthly data are used, and the median of all observations in the Bay of Plenty and the sum of medians from individual squares (*see* Section 5).

3. Presence–absence model for relative abundance indices

From previous experience of fish behaviour, catch positions, and so on, we have a reasonable idea of where a fish species may be found. An important concept in estimating abundance is the number of times a species was *not seen* in a given part of its known habitat. Therefore, we need to know when aerial sightings squares within the habitat were visited and no fish schools of that species seen. By assuming that fish schools of all species in a given square are recorded, we conclude that species not recorded are absent. The amount of data required for reasonable accuracy is ill defined; we require enough for asymptotic statistics results to apply and enough to minimise the influence of data inaccuracies. Only for the Bay of Plenty can we be reasonably sure there are sufficient data to generate the absence information.

The sighting percentage for a given species over a given time period in square i is defined as $100S_i/O_i$, where S_i is the number of times a species was sighted in square i, and O_i is the number of times square i was visited. The sighting percentage of a group of squares is defined as $\sum_i 100 \times S_i/\sum_i O_i$. No sightings of mixed schools are included in these calculations.

A $100(1-\alpha)\%$ confidence interval for the probability, p, of sighting a species is (Larsen & Marx 1986):

$$p \pm z_{\alpha/2}\sqrt{\frac{p(1-p)}{n}}$$

where n is the number of visits and $z_{\alpha/2}$ is the $\alpha/2$ point of the standard normal distribution. Since n is large, the approximations made in deriving this confidence interval are valid. It is assumed that p does not vary over time period and space region chosen, and the true confidence intervals may be wider than this (Chris Francis, MAF Fisheries Greta Point, pers. comm.).

3.1 Sighting percentages in the Bay of Plenty

The total number of visits to squares in the Bay of Plenty was roughly constant between 1977 and 1990 and dropped by about 40% in 1991 and 1992 and increased again somewhat in 1993 (Table 4). Data were not recorded for all of 1976, and the database is currently updated to December 1993. Squares 164, 165, and 147, closest to Tauranga, are the most often visited (*see* Table 4).

The sighting percentages for kahawai, jack mackerel, blue mackerel, and trevally are given in Table 5: the range of sighting percentages is different for the four species (*see* also Figure 3), so, for example, the results for trevally have more contrast, but do not have more accuracy in the individual sighting percentages. The most obvious feature of these plots is the marked decline in sightings of trevally from 1976 to 1992. Kahawai sightings show no long term trend but have significantly different values between some years. Jack mackerel sightings have risen since 1990. Blue mackerel sightings increased from about 1983 to 1987 and have declined since.

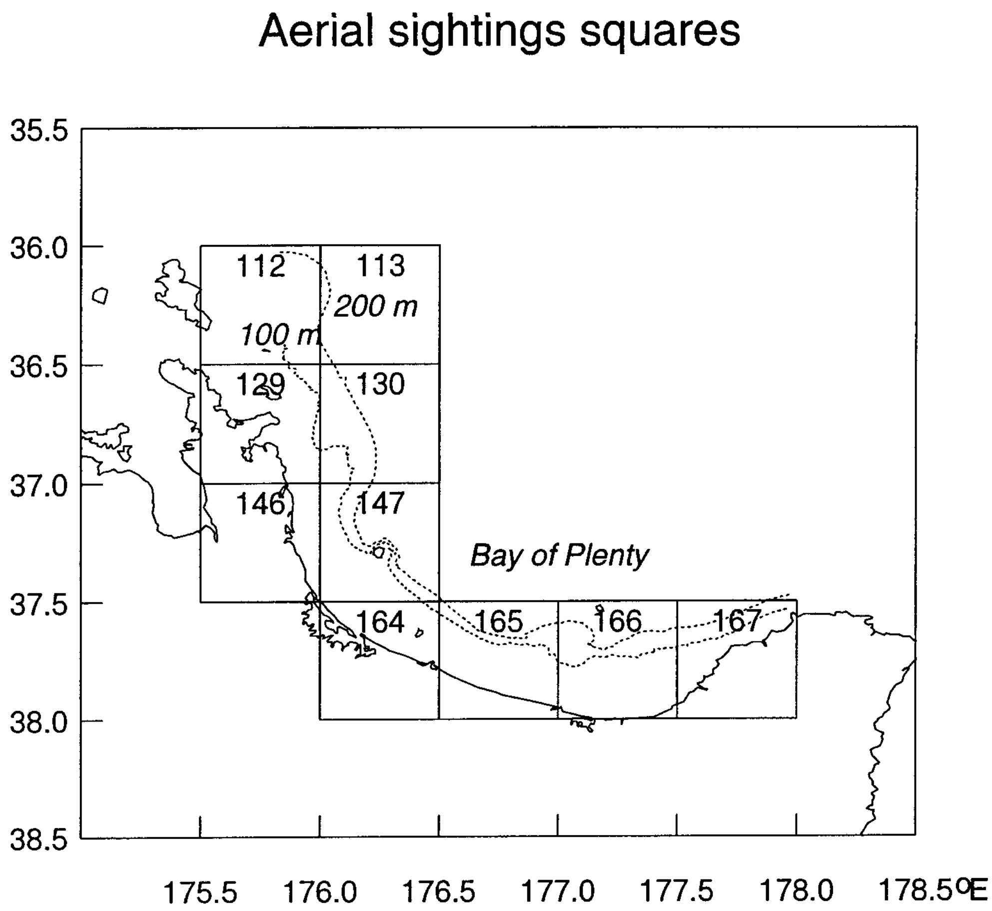

Figure 2: Map of the Bay of Plenty showing the aerial sightings half degree squares defining the Bay of Plenty region. The 100 m and 200 m depth contours are shown as dotted lines.

There may be a problem with the choice of squares to define the Bay of Plenty habitat for these species. Sightings in squares 112, 113, 129, and 130 are often of skipjack and perhaps should not be included when estimating the overall sighting percentages. Sightings effort in squares 166 and 167 seems to be sporadic and often the sightings are of large schools. Perhaps this part of the Bay of Plenty is visited only large fish schools are reported or because large schools are more visible over greater distances.

We can look at changes in the sighting percentages in individual half degree squares. Most of the sightings of kahawai and jack mackerel are in squares 164, 165, 146, and 147 (Table 5 and Figure 4). The sighting percentages for kahawai show a decrease in 146 and 164 and an increase in 165 over time and suggest a movement of kahawai away from the Coromandel east coast into other parts of the Bay of Plenty. The chance of seeing jack mackerel remained fairly constant until there were increases in 147 from about 1989, in 146 in 1993, and in 165 from 1991.

3.2 Discussion

The sighting percentages are based on the simple but powerful concept of presence–absence of a species. The sightings percentage depends on knowing when a species was not observed in a given aerial sightings square and the expected habitat of the species. We have not considered that the habitat of a particular species might change seasonally. This should not be a problem for a relative abundance index provided bias remains constant.

From the sighting percentages we can conclude the following.

- There is little trend in the overall kahawai abundance, though there is a change in the area where kahawai are most likely to be seen.
- There was a rise in jack mackerel abundance in the 1990s.
- There was a decline in the abundance of trevally, particularly in the 1970s.
- There was a peak in blue mackerel abundance in 1987.

Table 4: Number of times the individual half degree aerial sightings squares in the Bay of Plenty (*see* Figure 2) were visited each year.

	Aerial sightings square										
Year	112	113	129	130	146	147	164	165	166	167	Total
1976	12	1	19	37	46	68	67	83	18	9	360
1977	88	15	145	154	123	197	222	279	96	65	1 384
1978	86	35	115	130	120	197	224	284	87	59	1 337
1979	108	66	106	165	146	236	256	285	82	68	1 518
1980	98	73	73	127	102	223	220	209	78	50	1 253
1981	133	90	154	164	107	254	297	245	152	113	1 709
1982	65	48	120	149	143	240	283	239	98	73	1 458
1983	116	81	108	149	104	227	255	203	109	72	1 424
1984	54	30	89	119	102	223	283	234	125	85	1 344
1985	51	35	83	130	111	235	256	198	83	41	1 223
1986	123	87	100	220	31	278	223	222	108	29	1 421
1987	137	90	118	185	47	279	284	228	132	44	1 544
1988	117	56	111	159	65	289	326	230	123	38	1 514
1989	118	79	141	193	113	316	308	278	140	56	1 742
1990	100	84	99	195	85	272	235	200	111	36	1 417
1991	74	41	69	104	37	161	126	138	100	37	887
1992	68	34	68	87	20	167	138	134	81	28	825
1993	73	33	77	131	22	202	176	174	114	22	1 024

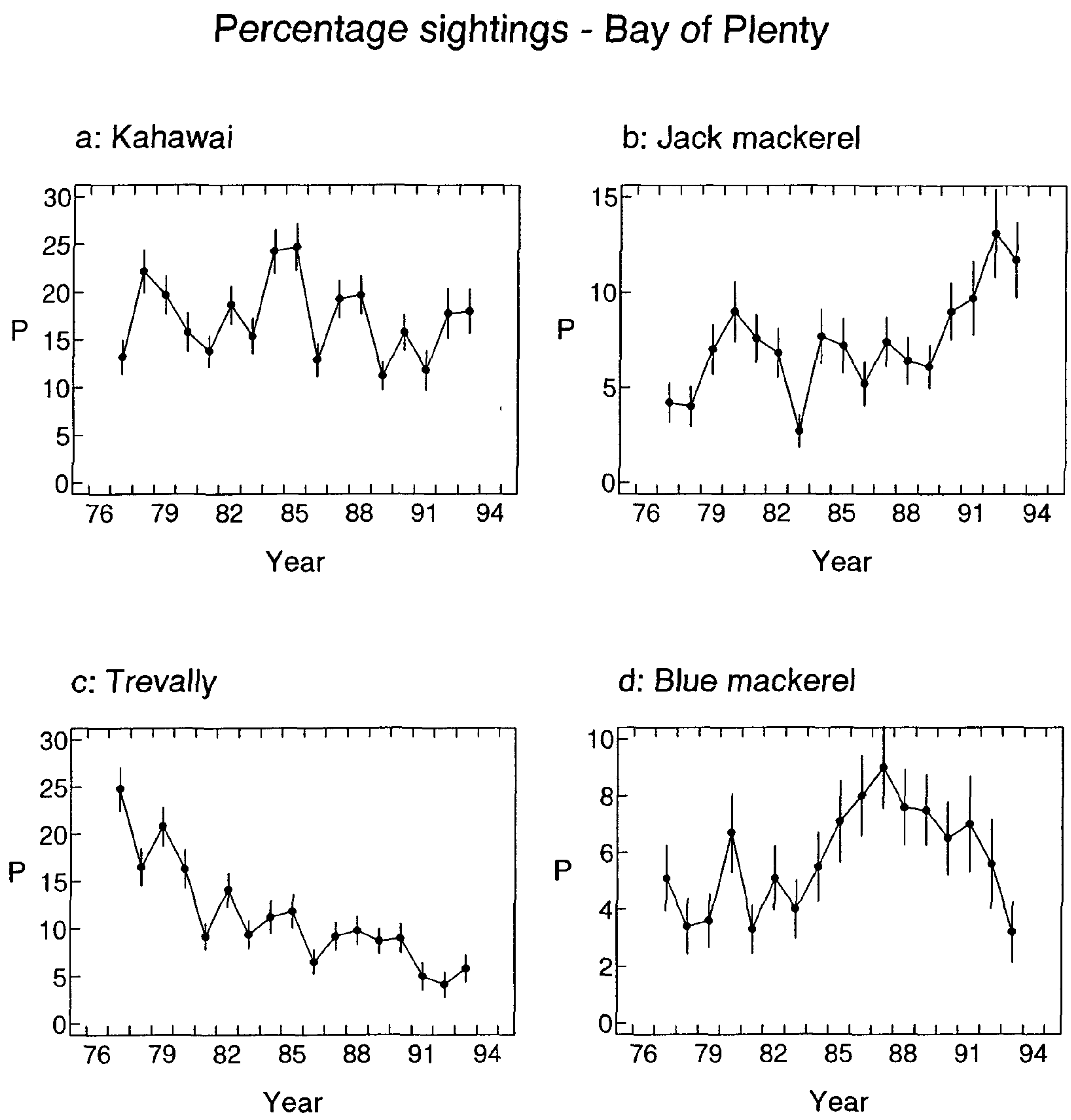

Figure 3: **Sighting percentages (*P*) in the Bay of Plenty (*see* Figure 2) for the four species. The data are from the last columns in Table 5. The vertical bars are 95% confidence intervals.**

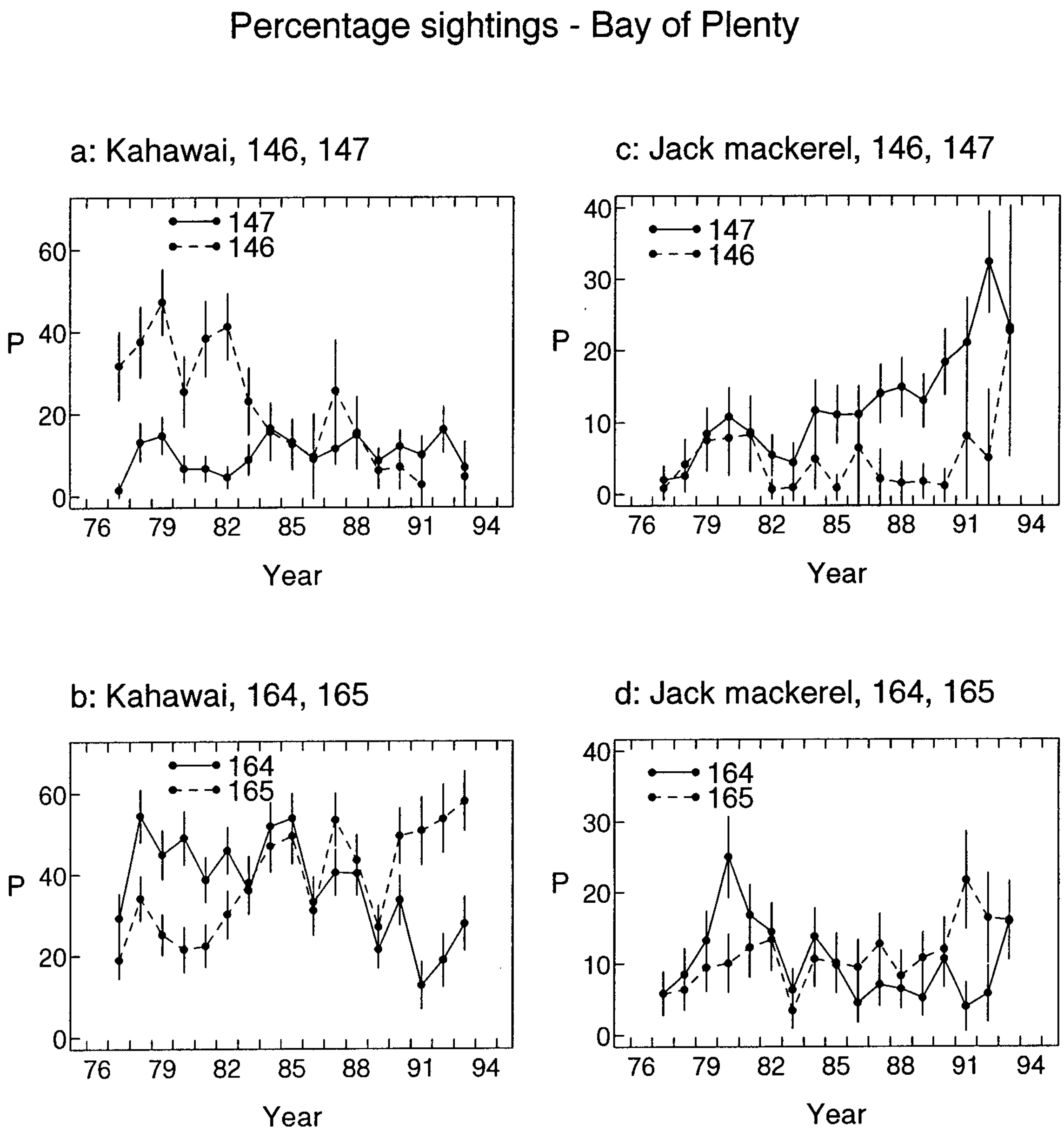

Figure 4: **Sighting percentages (P) for individual squares in the Bay of Plenty (*see* Figure 2) and kahawai and jack mackerel. The data are from the columns in Table 5 parts a and b. The vertical bars are 95% confidence intervals.**

Table 5: Sighting percentages in individual squares in the Bay of Plenty (*see* Figure 2) and the whole region (BP) for the four species.

a: Kahawai

Year	112	113	129	130	146	147	164	165	166	167	BP
1976	0	0	10.5	0	23.9	14.7	16.4	22.9	0	0	14.7
1977	0	0	6.2	2.6	31.7	1.5	29.3	19.0	7.3	3.1	13.2
1978	0	0	0	2.3	37.5	13.2	54.5	34.2	1.1	5.1	22.2
1979	0	0	2.8	0.6	47.3	14.8	44.9	25.3	0	5.9	19.7
1980	0	0	4.1	0.8	25.5	6.7	49.1	21.5	0	0	15.8
1981	0	0	1.9	0.6	38.3	6.7	38.7	22.4	2.0	0	13.8
1982	0	0	0	0.7	41.3	4.6	45.9	30.1	0	0	18.7
1983	0	0	1.9	0.7	23.1	8.8	36.1	37.9	2.8	0	15.4
1984	3.7	0	5.6	0.8	15.7	16.6	51.9	47.0	6.4	0	24.3
1985	3.9	0	16.9	2.3	12.6	13.2	53.9	49.5	2.4	0	24.7
1986	0.8	0	4.0	0.9	9.7	9.0	33.2	31.1	4.6	0	12.9
1987	0.7	0	4.2	2.7	25.5	11.5	40.5	53.5	3.8	2.3	19.3
1988	0	0	4.5	3.8	15.4	14.9	40.2	43.5	3.3	0	19.7
1989	0	0	2.1	7.3	6.2	8.5	21.4	27.0	2.1	0	11.2
1990	0	0	0	2.1	7.1	12.1	33.6	49.5	2.7	0	15.8
1991	0	0	0	0	2.7	9.9	12.7	50.7	2.0	0	11.8
1992	0	0	2.9	12.6	0	16.2	18.8	53.7	6.2	14.3	17.8
1993	0	0	0	2.3	4.5	6.9	27.8	58.0	7.0	36.4	18.0

b: Jack mackerel

Year	112	113	129	130	146	147	164	165	166	167	BP
1976	0	0	0	0	6.5	8.8	9.0	16.7	0	33.3	8.9
1977	2.3	0	0.7	4.5	0.8	2.0	5.9	5.7	7.3	10.8	4.2
1978	0	0	0	0.8	4.2	2.5	8.6	6.3	2.3	6.8	4.0
1979	3.7	1.5	0	4.8	7.5	8.5	13.3	9.5	0	2.9	7.0
1980	0	0	1.4	3.1	7.8	10.8	25.0	10.0	0	0	9.0
1981	2.3	0	0.6	2.4	8.4	8.7	16.8	12.2	3.9	4.4	7.6
1982	1.5	0	2.5	4.0	0.7	5.4	14.5	13.4	2.0	0	6.8
1983	0	0	0.9	2.0	1.0	4.4	6.3	3.4	0.9	0	2.7
1984	1.9	0	1.1	4.2	4.9	11.7	13.8	10.7	0	1.2	7.7
1985	2.0	0	6.1	7.7	0.9	11.1	9.7	10.0	0	0	7.2
1986	0.8	0	0	3.2	6.5	11.2	4.5	9.5	1.9	0	5.2
1987	2.9	0	1.7	7.6	2.1	14.0	7.0	12.7	3.8	0	7.4
1988	0.9	0	1.8	5.7	1.5	14.9	6.4	8.3	0.8	0	6.4
1989	0.8	0	0.7	7.3	1.8	13.0	5.2	10.8	0.7	0	6.1
1990	6.0	1.2	0	9.8	1.2	18.4	10.7	12.1	0.9	0	9.0
1991	0	0	1.4	5.8	8.1	21.1	4.0	21.7	7.0	0	9.7
1992	7.4	2.9	2.9	14.9	5.0	32.3	5.8	16.4	2.5	0	13.1
1993	1.4	0	3.9	4.6	22.7	23.3	15.9	16.2	1.8	0	11.7

Table 5: *continued*

c: Trevally											
Year	112	113	129	130	146	147	164	165	166	167	BP
1976	0	0	47.4	37.8	32.6	42.6	38.8	44.0	0	0	36.0
1977	0	0	21.4	23.4	28.5	12.7	45.9	40.1	1.0	1.5	24.8
1978	1.2	0	2.6	17.7	6.7	16.2	35.7	25.7	0	0	16.5
1979	1.9	0	9.4	30.3	28.1	26.7	27.7	27.7	0	0	20.8
1980	0	0	2.7	15.0	8.8	22.0	32.3	25.8	0	0	16.3
1981	0	0	1.3	7.3	19.6	12.2	20.2	12.7	0	0	9.2
1982	0	0	3.3	16.8	14.0	16.3	23.0	21.8	0	0	14.1
1983	0	0	6.5	8.7	1.0	23.3	11.0	15.8	0	0	9.4
1984	1.9	0	9.0	19.5	3.9	26.8	6.8	15.5	0	0	11.2
1985	2.0	0	28.0	24.0	0	17.1	8.6	13.1	1.2	0	11.8
1986	0.8	0	4.0	7.7	6.5	13.3	4.9	9.0	0	0	6.5
1987	1.5	0	12.7	15.7	2.1	11.1	12.0	13.2	0	0	9.2
1988	1.7	0	6.3	10.1	3.1	12.5	14.1	17.4	0	0	9.8
1989	2.5	0	2.8	8.8	0.9	14.6	13.6	14.0	0	0	8.7
1990	2.0	0	6.1	5.6	0	15.8	19.1	10.0	0	0	9.0
1991	0	0	1.4	4.8	0	11.3	4.8	10.1	0	0	5.0
1992	4.4	0	0	5.7	5.0	5.4	5.1	6.7	0	0	4.1
1993	0	0	0	6.1	4.5	5.9	13.6	8.0	0	0	5.8

d: Blue mackerel											
Year	112	113	129	130	146	147	164	165	166	167	BP
1976	8.3	0	0	2.7	2.2	11.8	13.4	2.4	5.6	11.1	6.6
1977	5.7	0	1.4	7.1	3.3	6.6	8.6	3.9	1.0	6.2	5.1
1978	1.2	0	1.7	2.3	1.7	7.6	4.0	1.8	2.3	11.9	3.4
1979	1.9	0	0	4.8	0.7	12.7	3.5	1.4	0	1.5	3.6
1980	6.1	0	2.7	2.4	5.9	14.3	15.5	0.5	0	0	6.7
1981	4.5	0	1.3	6.7	3.7	8.7	2.4	0.4	2.0	0	3.3
1982	4.6	0	0	4.0	10.5	11.3	7.1	1.3	1.0	0	5.1
1983	1.7	0	0.9	4.0	3.8	15.4	2.7	0	1.8	0	4.0
1984	9.3	0	0	8.4	1.0	19.4	3.2	0.9	1.6	2.4	5.5
1985	5.9	0	2.4	15.4	1.8	22.3	1.2	3.0	0	0	7.1
1986	5.7	1.1	3.0	8.2	25.8	24.8	3.1	0	0	0	8.0
1987	5.1	1.1	2.5	14.6	4.3	28.7	4.9	2.2	0	0	9.0
1988	2.6	0	0	10.7	4.6	25.6	3.1	3.0	0.8	0	7.6
1989	0.8	0	0.7	19.3	0	24.4	1.9	3.2	0	0	7.5
1990	4.0	0	0	15.9	2.4	18.8	1.3	0.5	0	0	6.5
1991	2.7	0	0	16.3	0	21.1	0	4.3	3.0	0	7.0
1992	4.4	5.9	0	9.2	0	19.2	0	0.7	0	0	5.6
1993	1.4	0	0	3.1	0	11.9	2.3	0	0	0	3.2

4. Annual medians

The annual median indices are the medians of the school numbers and tonnage estimates from all sightings in a Fishstock area over a year. That is, the median for a species s over the sightings i in N_{stai} and T_{stai} where time interval t is a year and the area a is a Fishstock (or the total coverage of the aerial sightings). Annual median indices are calculated for kahawai, jack mackerel, trevally, and blue mackerel (Figures 5–12). Despite the use of actual school numbers and tonnage estimates, these are relative, not absolute, abundance indices. The annual median is chosen for simplicity and robustness.

Because of the nature of the aerial sightings data, a balance must be struck between *"double counting"*, that is, giving too much weight to the same schools recorded several times, and omitting too much data. We try to achieve this by the choice of time interval and area used in the amalgamation of the data. Putting too much emphasis on the extremely large values is likely to lead to problems, first because of the difficulties in estimating how many fish there are in a large aggregation of fish, and second because of mathematical difficulties in dealing with extreme values. (However, looking at the occurrence of large aggregations together with environmental factors may suggest some factors controlling fish behaviour.)

The gaussian-based asymptotic approximation (Stuart & Ord 1987) of the standard error s of the median (M) is given by

$$s = \frac{1.25R}{1.35\sqrt{n}}$$

where R is the interquartile range and n the number of observations. This approximation has reasonably broad application to other distributions (McGill *et al.* 1978). To get significant differences in medians at the 95% confidence level, McGill *et al.* (1978) include a compromise multiplying factor of 1.7 to give confidence intervals $M \pm 1.7s$.

This form is used for the confidence intervals in this report. Bootstrap estimates of the confidence intervals for the median tend to be unstable for these data, particularly when attempting to correct for bias using an accelerated bias correction function (Efron & Tibshirani 1993). The properties which make the median a robust estimator of the central part of a distribution also lead to difficulties with bootstrap–like calculations. There is an analytic expression for the bootstrap distribution of the median (Staudte & Sheather 1990, Efron 1982) but calculation of a confidence interval requires much computation when there are many data points.

4.1 Results for Fishstocks

The brief definitions of Fishstocks for kahawai, jack mackerel, and trevally are given in Appendix 2.

Kahawai — Figures 5 and 6

More than half the aerial sightings effort (*see* Table 3) was in KAH 1, and the least sightings effort was in KAH 2. Tonnage estimates tend to be larger in KAH 2 and 3 than in KAH 1. The variation in school size in KAH 3 decreased after 1984 and the median school size also dropped. The change in KAH 3 after 1984 coincides with a pilot change, but the use of a median should counter an inability to estimate large schools well.

The school numbers in KAH 1 and 9 may be lower since 1989 than they were in the early and mid 1980s, but the tonnage is not, despite year to year changes. There is no detectable change in either index in KAH 2 in the 1980s and 1990s. The lower values in the 1970s may be due to low sighting activity. A maximum in the school number and tonnage for all data occurred in 1982: there has been a general decrease since then with a slight increase in 1991 and 1993. Large schools and high tonnage in KAH 3 in the early 1980s and a subsequent decrease dominate the changes in the total data.

Jack mackerel — Figures 7 and 8

There has been a barely significant (confidence intervals not quite overlapping) increase in school number and tonnage in JMA 1 from 1977 to 1992. However, in 1993 the tonnage dropped to about the 1977 value, but the number of schools stayed higher than the 1977 value. Before 1988 or 1989, data were absent or scarce in JMA 3 and JMA 7, but school numbers and tonnage have risen in JMA 3 since 1990. Although there have been increases in both indices in JMA 7 from 1991 to 1993, the increases are not significant. The plots for all data suggest an increase in the number of schools sighted since 1977 with little change in estimated tonnage.

Trevally — Figures 9 and 10

Both school number and tonnage indices for TRE 1 suggest lower values in the mid 1980s than in 1977 or the 1990s, although the confidence intervals on the 1993 data points are wide. In TRE 2, 3, and 7 the school number and tonnage indices are higher in the mid 1980s than at either end of the time series, though most of the data is too ill–defined for a definite conclusion. For all data, both indices decrease from 1977 values and increase from about 1988. The recent rises in school number and estimated tonnage in TRE 1 are in contrast to the flat or falling sightings percentage for trevally in the Bay of Plenty.

Blue mackerel — Figures 11 and 12

Blue mackerel are not yet within the Quota Management System, and Fishstocks are not defined. Based on numbers of sightings, the data are split between QMA 1 and the rest of the country covered by aerial sightings, that is, QMA 2, 3, 7, 8, and 9. Outside QMA 1 most sightings are in QMA 7.

The blue mackerel school number in QMA 1 has remained essentially constant, but the estimated tonnage appears to have increased from 1989 to 1992. The school number and estimated tonnage of blue mackerel seem to have remained roughly constant in the rest of the purseseine fishery, but again there are few data. The plots for all data are much the same as for QMA 1.

Many of the purseseine sets targeting blue mackerel since 1989 were off the east Northland coast (E. Bradford, unpublished data) so the increased estimated tonnage in QMA 1 may not be in conflict with the decline in sightings percentage in the Bay of Plenty.

Comment

The discrete jumps and frequent changes in slope of these indices suggest that the median is not the best of the available robust estimators of location to use and any future work will investigate other robust estimators (for example, trimmed means).

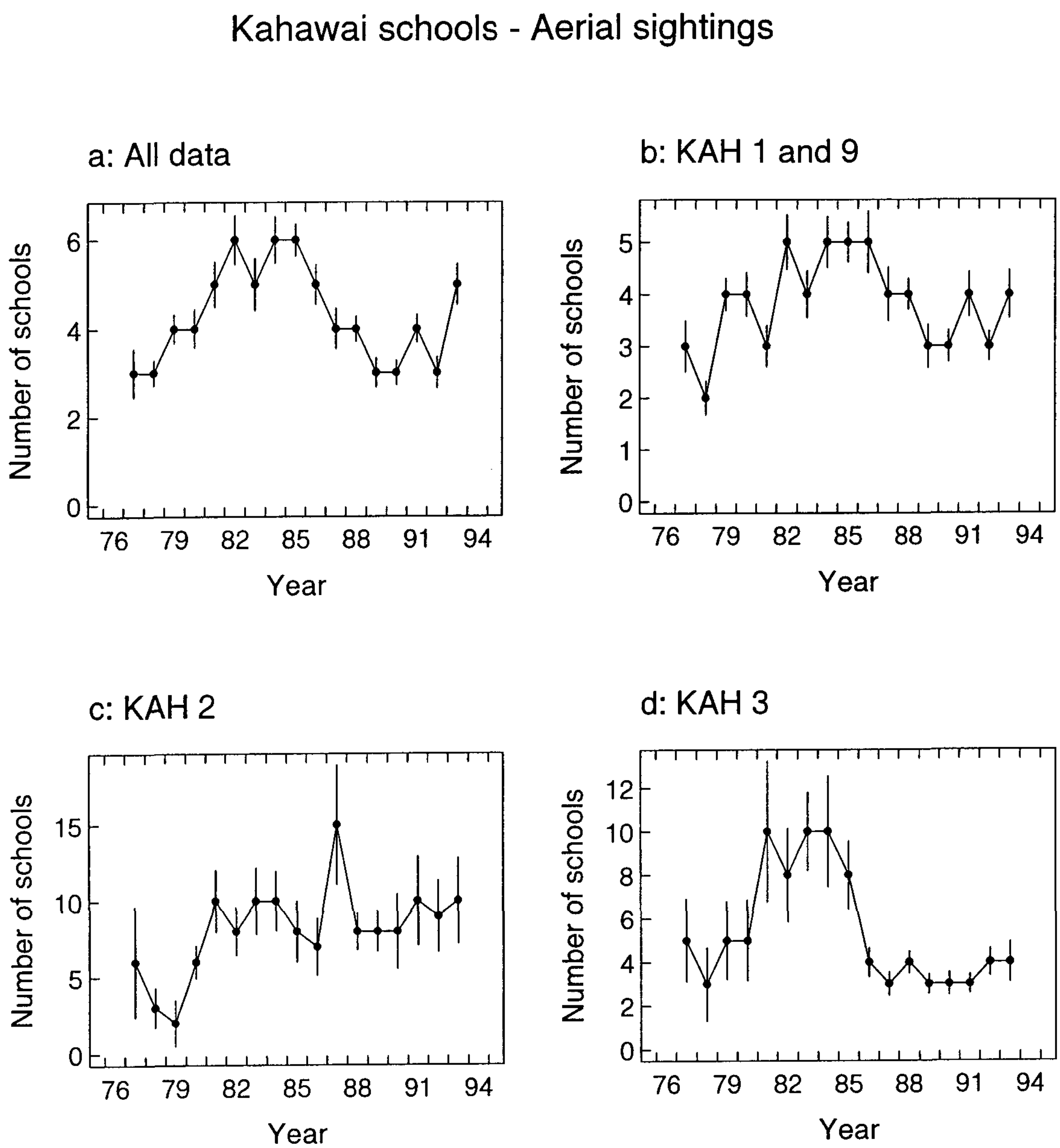

Figure 5: **Annual median values for the number of kahawai schools seen with approximate 95% confidence intervals.**

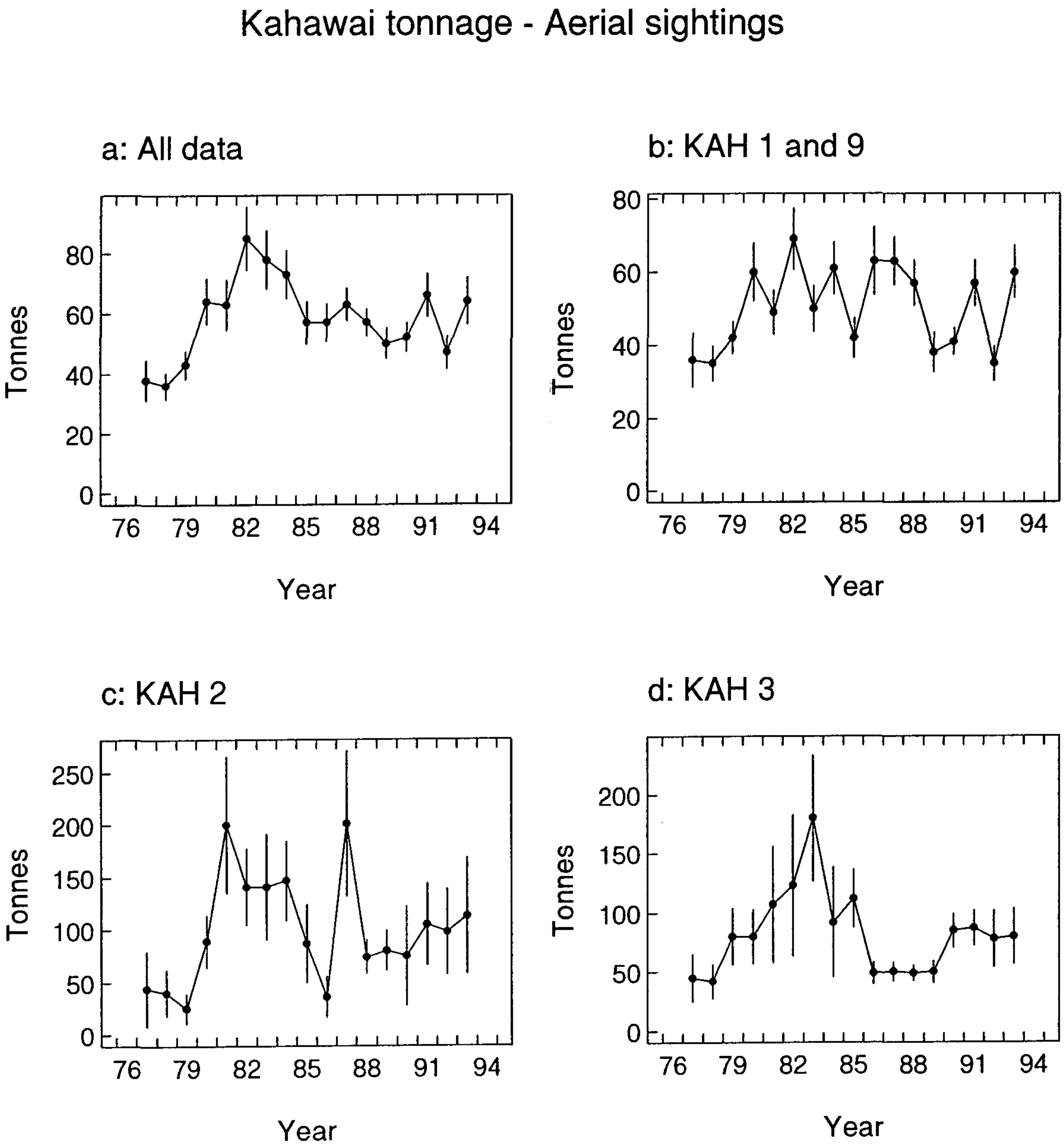

Figure 6: **Annual median values for the tonnage of kahawai seen with approximate 95% confidence intervals.**

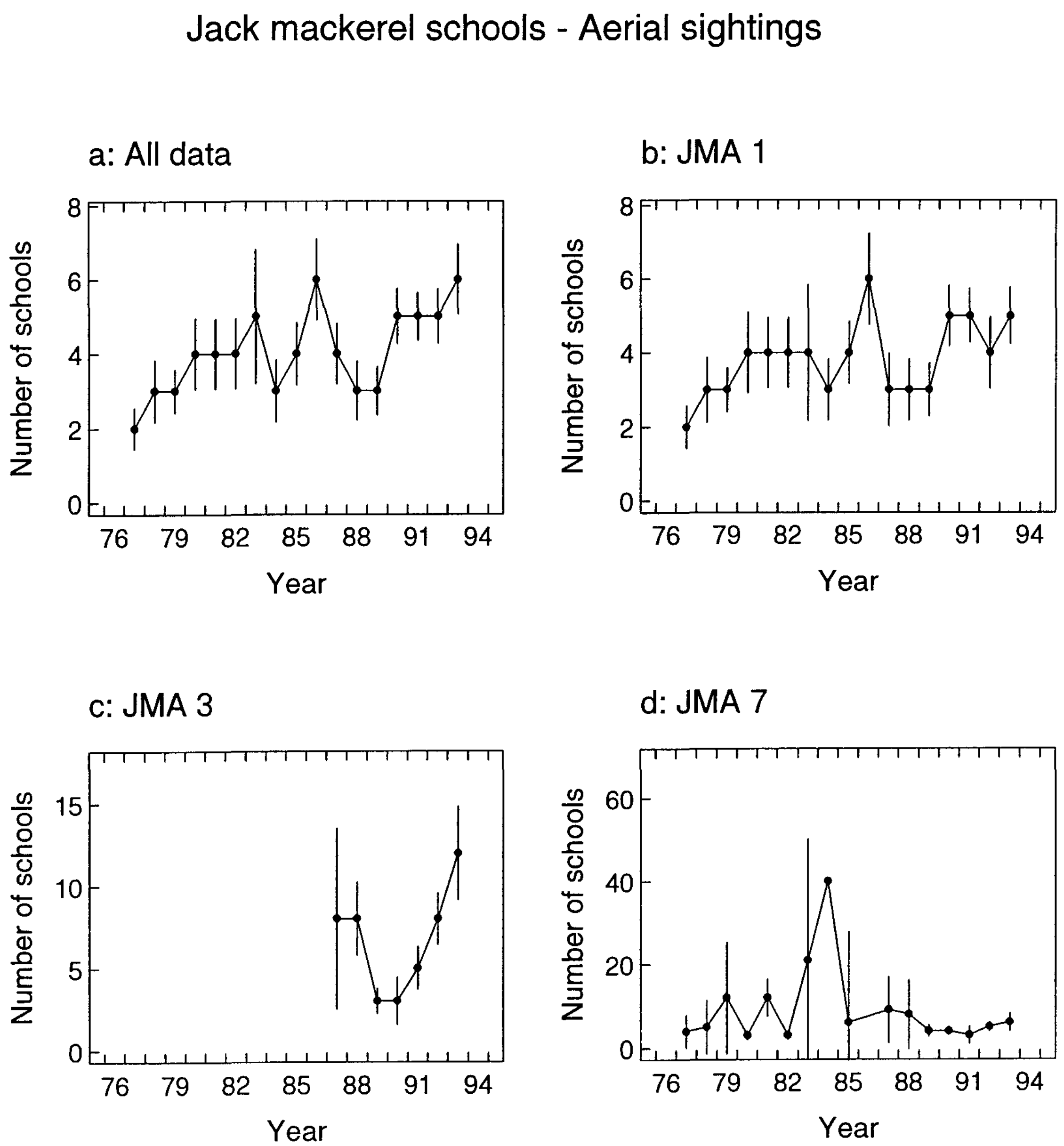

Figure 7: **Annual median values for the number of jack mackerel schools seen with approximate 95% confidence intervals.**

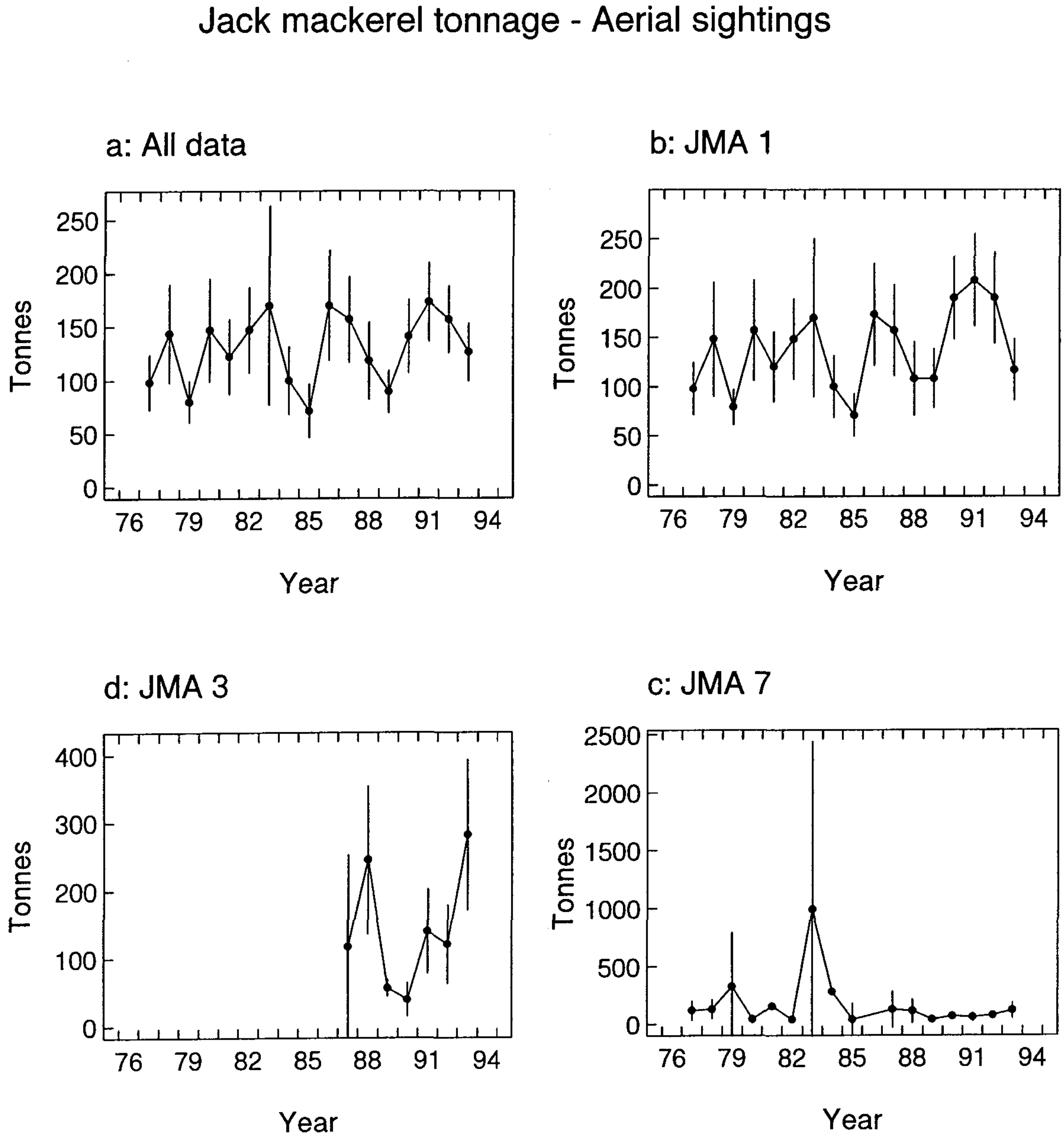

Figure 8: **Annual median values for the tonnage of jack mackerel seen with approximate 95% confidence intervals.**

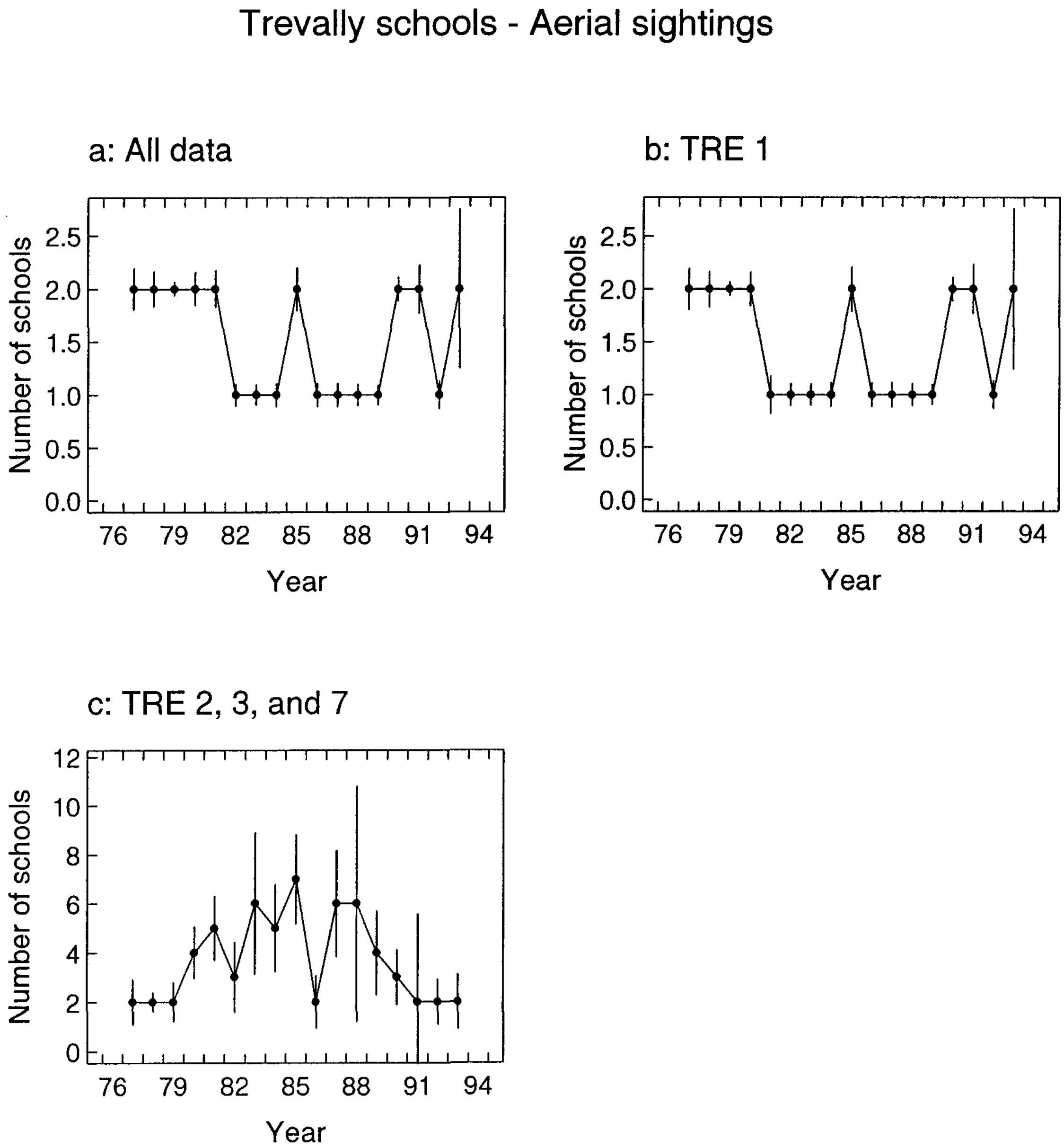

Figure 9: **Annual median values for the number of trevally schools seen with approximate 95% confidence intervals.**

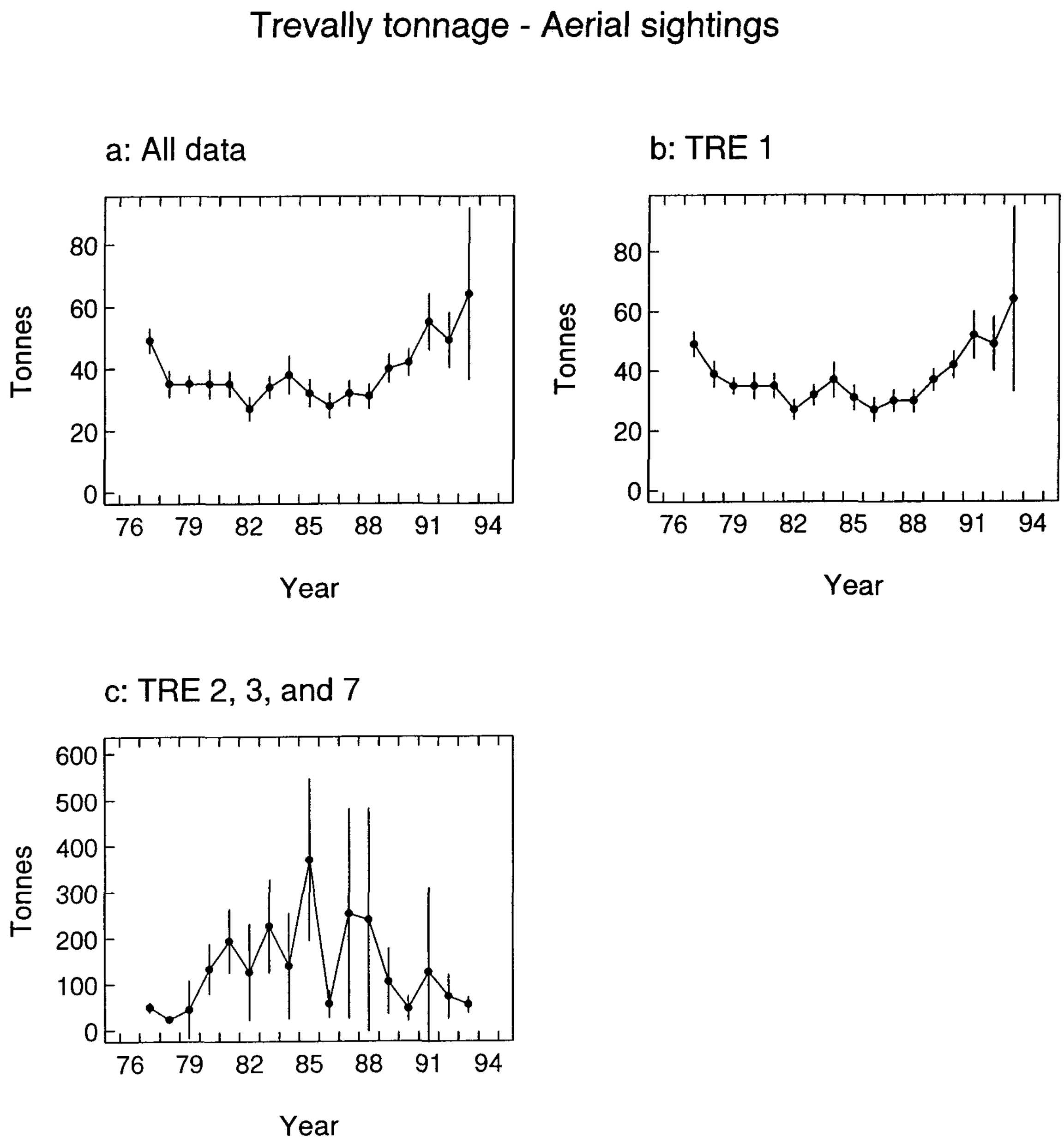

Figure 10: Annual median values for the tonnage of trevally seen with approximate 95% confidence intervals.

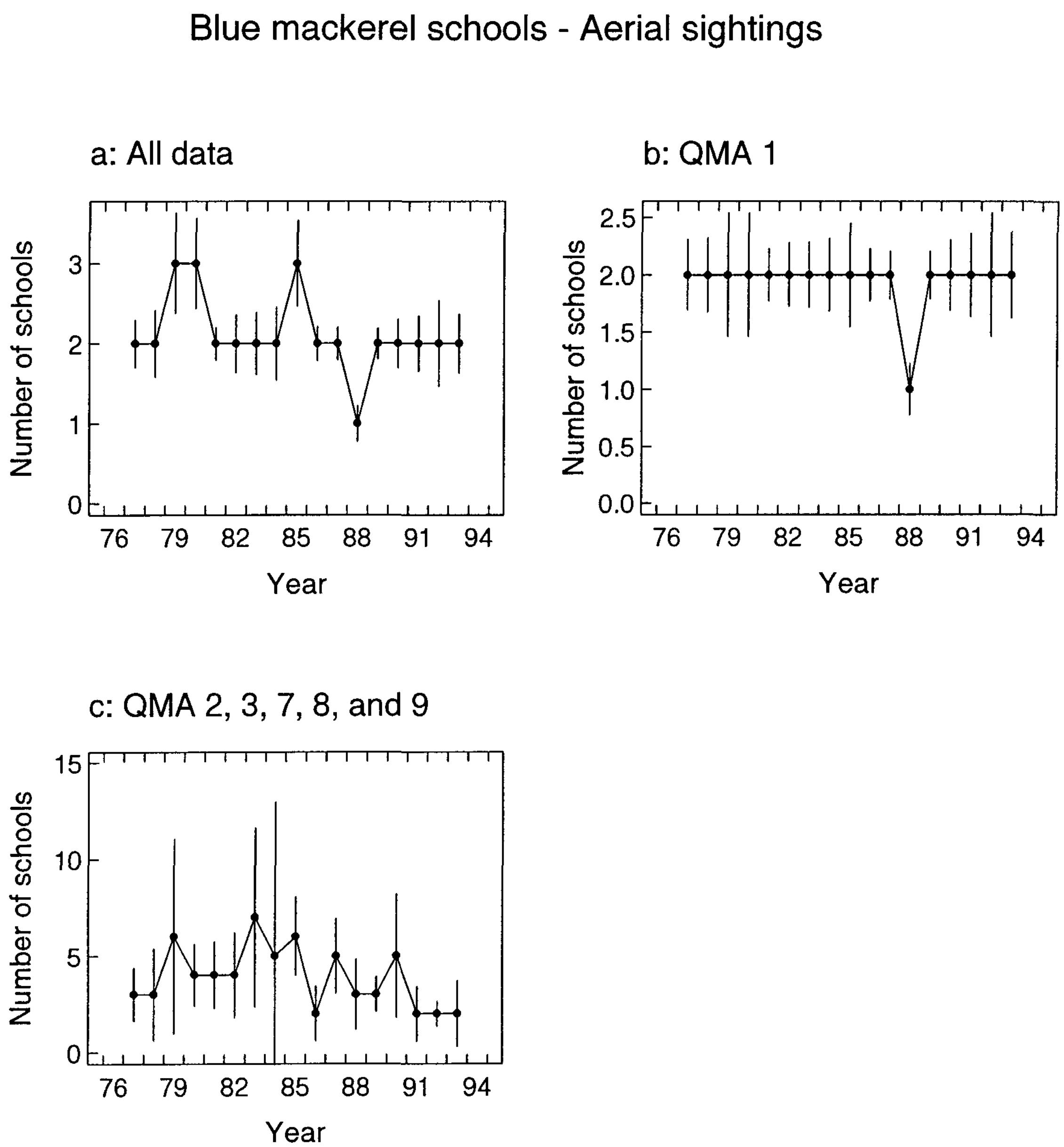

Figure 11: Annual median values for the number of blue mackerel schools seen with approximate 95% confidence intervals.

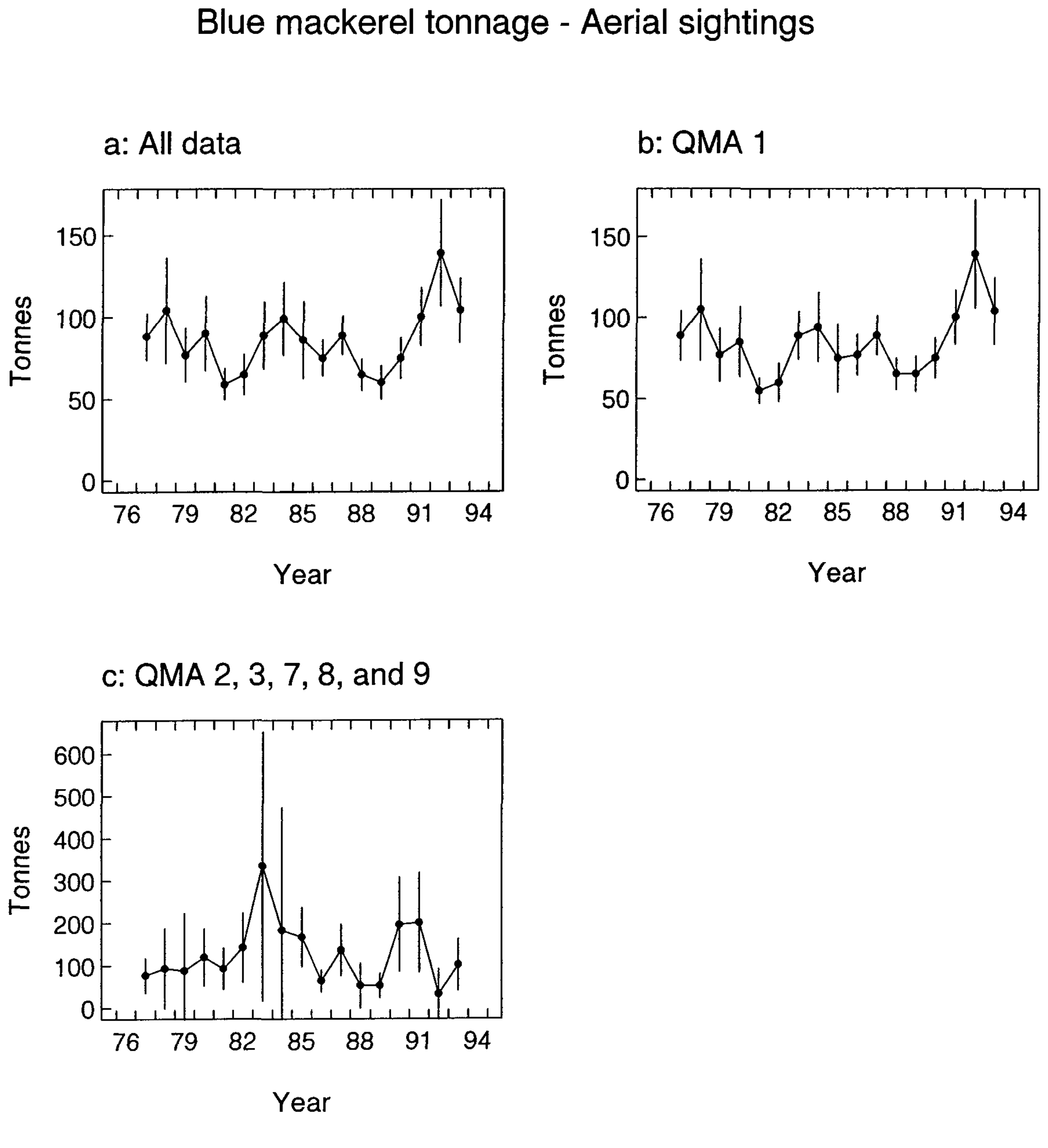

Figure 12: Annual median values for the tonnage of blue mackerel seen with approximate 95% confidence intervals.

5. A smoothing method

In this section, we examine the use of a local regression smoother called *loess* (Chambers & Hastie 1992) to obtain estimates of relative abundance. Smoothing all sightings records for a species in a Fishstock area is possible but computationally expensive and may not add anything. The aim, in this section, is to consider some ways to aggregate the data before smoothing. Hence, we look for differences between daily and monthly data aggregations, and at two ways of combining data from several aerial sightings squares. The median values of the number of schools and tonnage in a time interval and area are used as the raw points. The *loess* smooth of the raw points gives the trend (Bradford 1993) which is taken as the relative abundance index. Confidence intervals on the smoothed line can be calculated.

As used here, *loess* fits a local quadratic with tricubic weights in a band which contains 75% of the data: 95% confidence intervals are calculated. Local smoothers work within a window or band which is moved along the data. The larger the band width, the smoother the result and the smaller the confidence bounds. When the smoothing band width is large, features smaller than the bandwidth, such as seasonal cycles in the data, are removed. If the main interest is in the smaller features of the data, a smaller bandwidth or different methods would be used.

5.1 Examples using the Bay of Plenty kahawai data

Four aggregations of the data were made as described below and then smoothed. The kahawai data in the Bay of Plenty are extensive, have good coverage from year to year, and will therefore be used to illustrate the process. Kahawai sightings have a seasonal cycle in school number and estimated tonnage which is not of interest for our purposes.

- Monthly median school numbers or tonnage

    1. Calculate the median for each month and year over the whole region. That is, in N_{stai} and T_{stai}, (species s has one value only), the medians of school numbers and tonnage for sightings i are found where the time interval t is a month and the area a is the Bay of Plenty.

- Summed monthly median school numbers or tonnage

    1. Calculate the median for each month, year, and aerial sightings square. That is, in N_{stai} and T_{stai}, the medians are found where the time interval t is a month and the area a is an aerial sightings square.
    2. Sum over aerial sightings squares in the whole region. Now, the medians calculated in the first step are summed over all squares in the Bay of Plenty.

- Daily median school numbers or tonnage

    1. Calculate the median for each day over the whole region. That is, in N_{stai} and T_{stai}, the medians are found where the time interval t is a day and the area a is the Bay of Plenty.

- Summed daily median school numbers or tonnage

    1. Calculate the median for each day and aerial sightings square. That is, in N_{stai} and T_{stai}, the medians are found where the time interval t is a day and the area a is an aerial sightings square.
    2. Sum over aerial sightings squares in the whole region Now, the medians calculated in the first step are summed over all squares in the Bay of Plenty.

These data sets are plotted in Figures 13–16 together with the trend and the confidence bounds on the smoothed line. Daily data give too many data points (over 2 000) for the smoothed line to be clearly visible in Figures 15 and 16. Also, the large number of points causes computational difficulties in calculating confidence intervals on the smoothed line and these are not shown for the daily data.

The smoothed lines (divided by their means) of the school numbers and the tonnage are compared (Figure 17). The comparison is qualitative and the scaling gives one way of comparing not fully compatible curves (the monthly and daily time scales are not the same). The main features of the smoothed curves are the same for all four cases, that is, all the curves start from a low value in 1976, have a peak in the early 1980s, and a valley in the late 1980s and are rising in the most recent years. The relative magnitude of the main features varies somewhat.

At the ends of the data, fewer points are available to the smoothing process and smoothed curves are less accurately determined. The size of the end region depends upon the bandwidth and how well the smoothing function deals with reduction in available points . *Loess* deals reasonably well, although the apparent rising trend in recent years will not continue if future data are smaller and the current higher values of the smoothed estimate could reduce. (Continued increases in the data could lead to the current smoothed value being an underestimate but a move towards the mean value is more likely than a move away from it.)

The main conclusion from the similarity of the long term trends is that there is no obvious advantage in using daily rather than monthly medians. Using the summed (over individual aerial sightings squares) monthly median takes into account a possible variation of the spatial distribution of schooling kahawai. The smoothed summed monthly median indices (which we opt to use in Section 6) are perhaps flatter than the other indices for Bay of Plenty kahawai. A general conclusion is that although there is some variation in the surface abundance of kahawai in the Bay of Plenty, there is no evidence of a long term change.

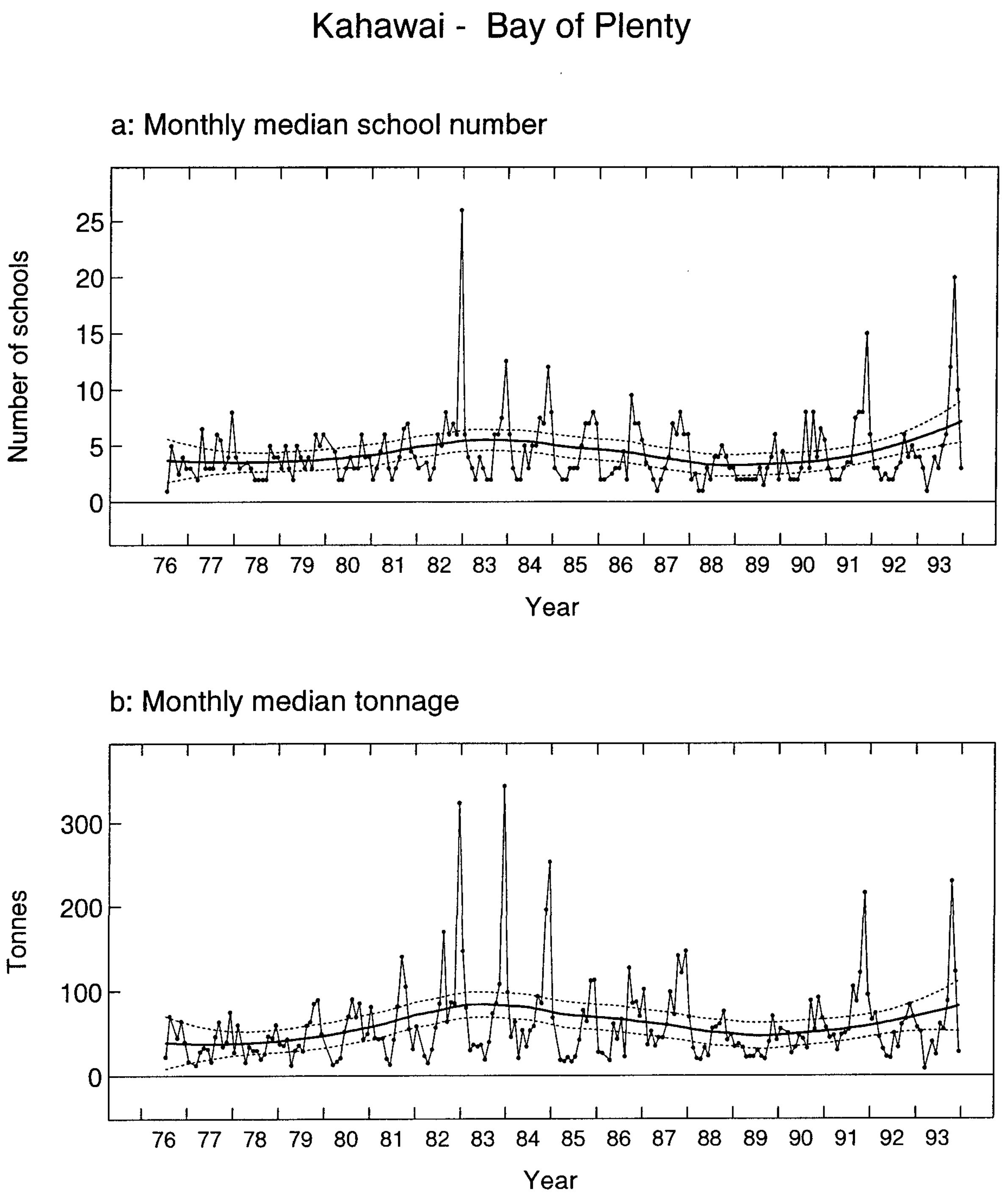

Figure 13: Monthly median values and loess smoothed estimates of kahawai school numbers and tonnage of kahawai seen in the Bay of Plenty (*see* Figure 2). 95% confidence intervals on the smoothed estimates are included.

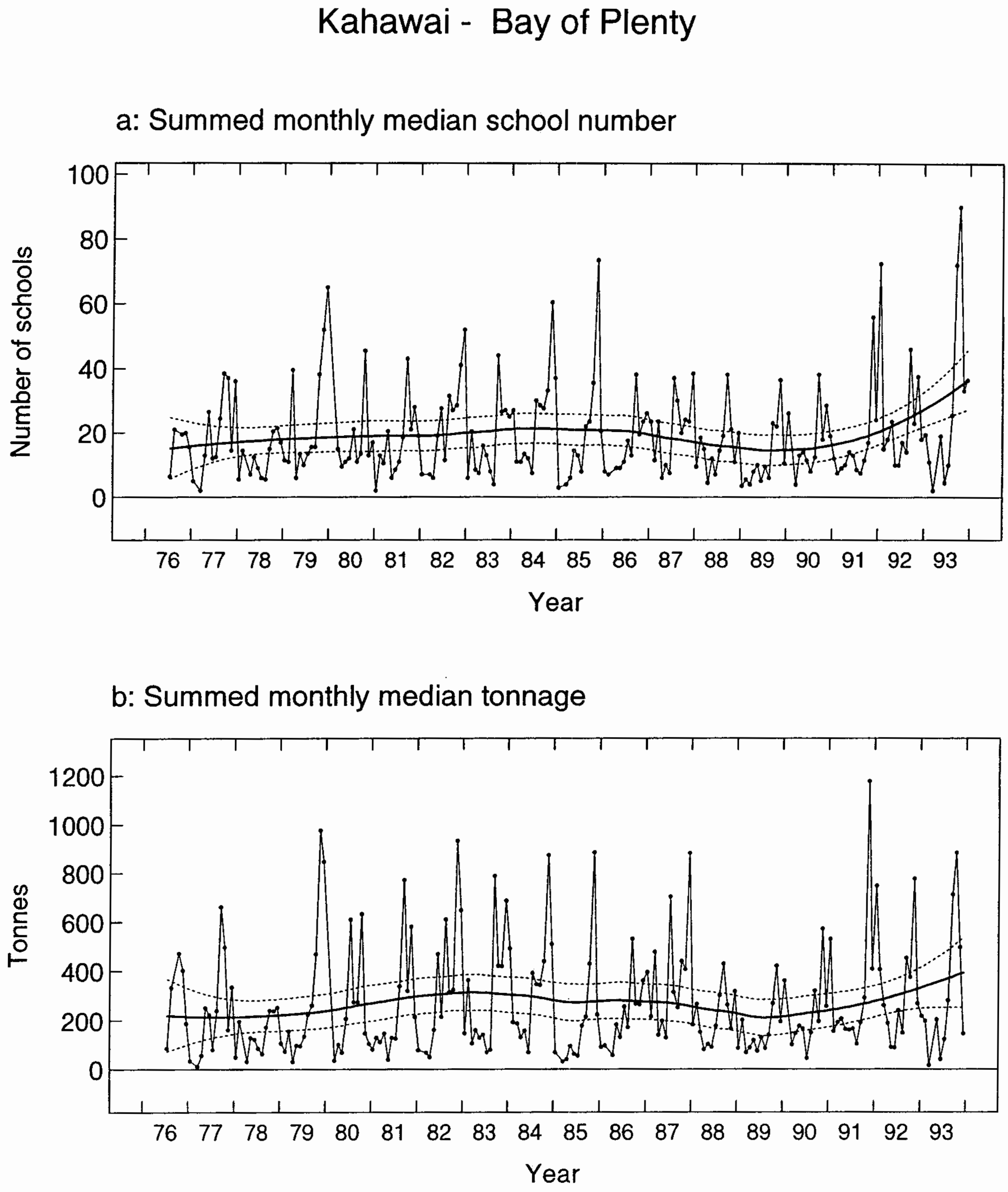

Figure 14: **Monthly summed median values and loess smoothed estimates of kahawai school numbers and tonnage of kahawai seen in the Bay of Plenty (*see* Figure 2). The summations are over medians in individual aerial sightings squares. 95% confidence intervals on the smoothed estimates are included.**

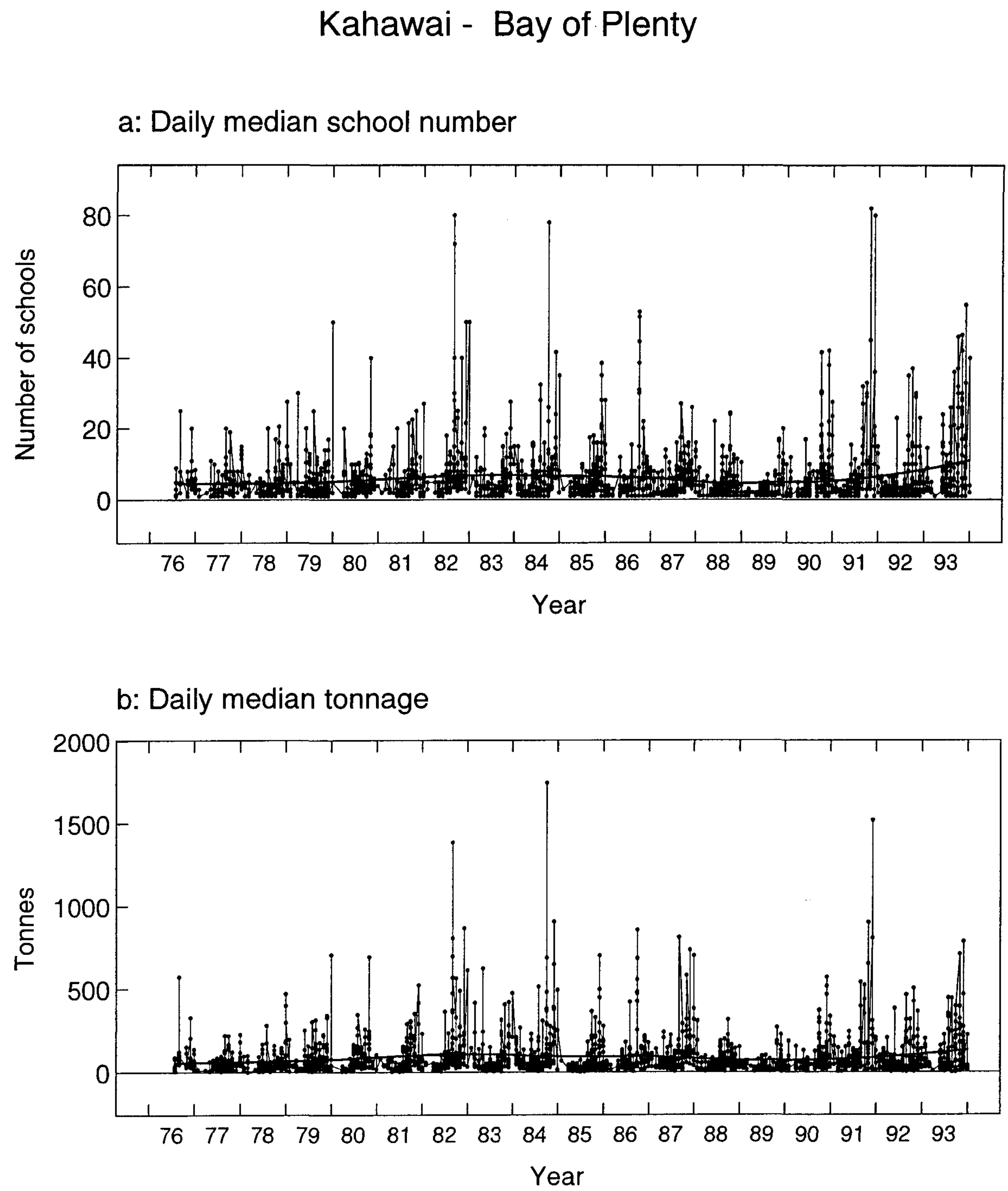

Figure 15: Daily median values and loess smoothed estimates of kahawai school numbers and tonnage seen in the Bay of Plenty (*see* Figure 2).

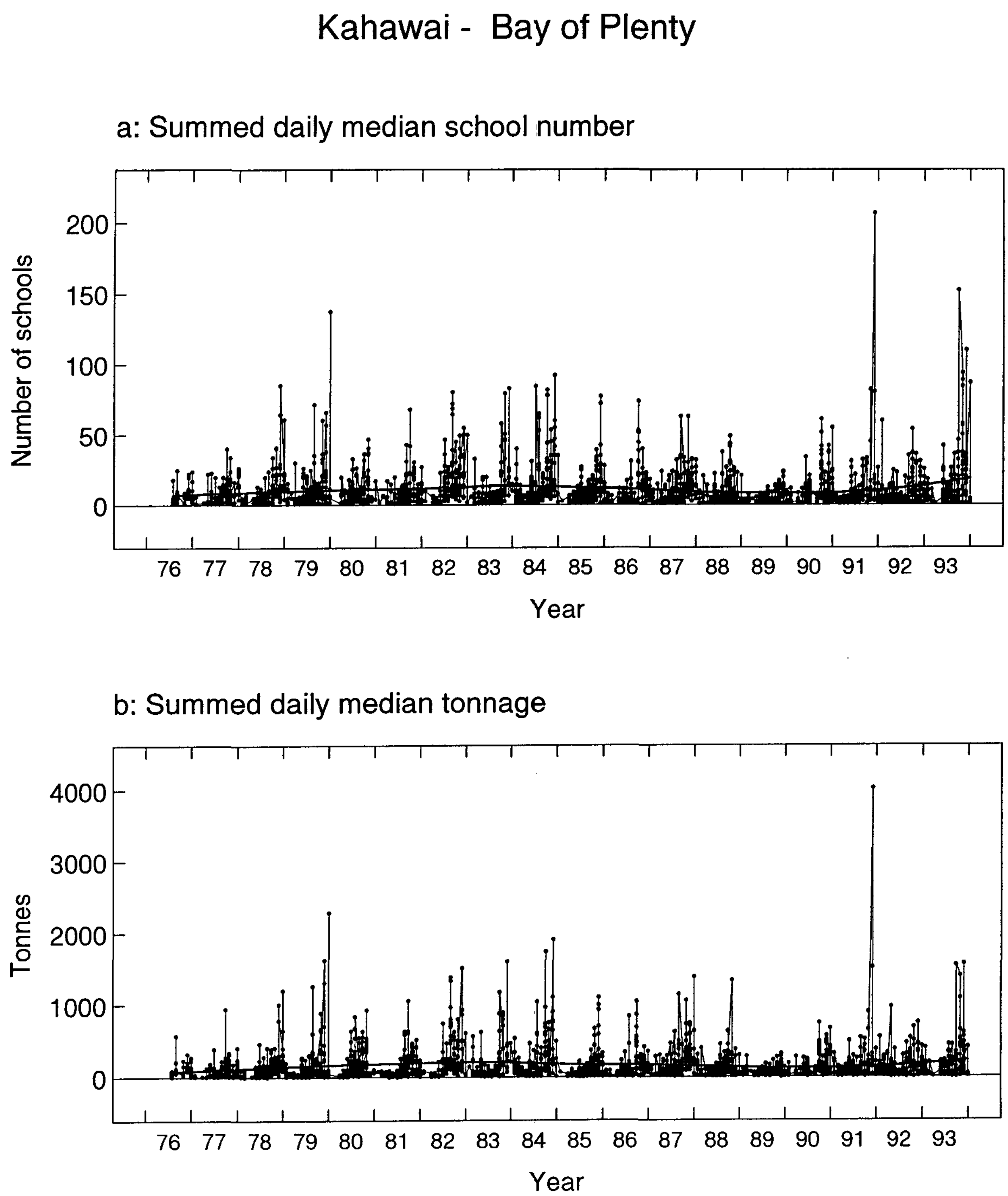

Figure 16: **Summed daily median values and loess smoothed estimates of kahawai school numbers and tonnage seen in the Bay of Plenty (*see* Figure 2). Summations are over medians in individual aerial sightings squares.**

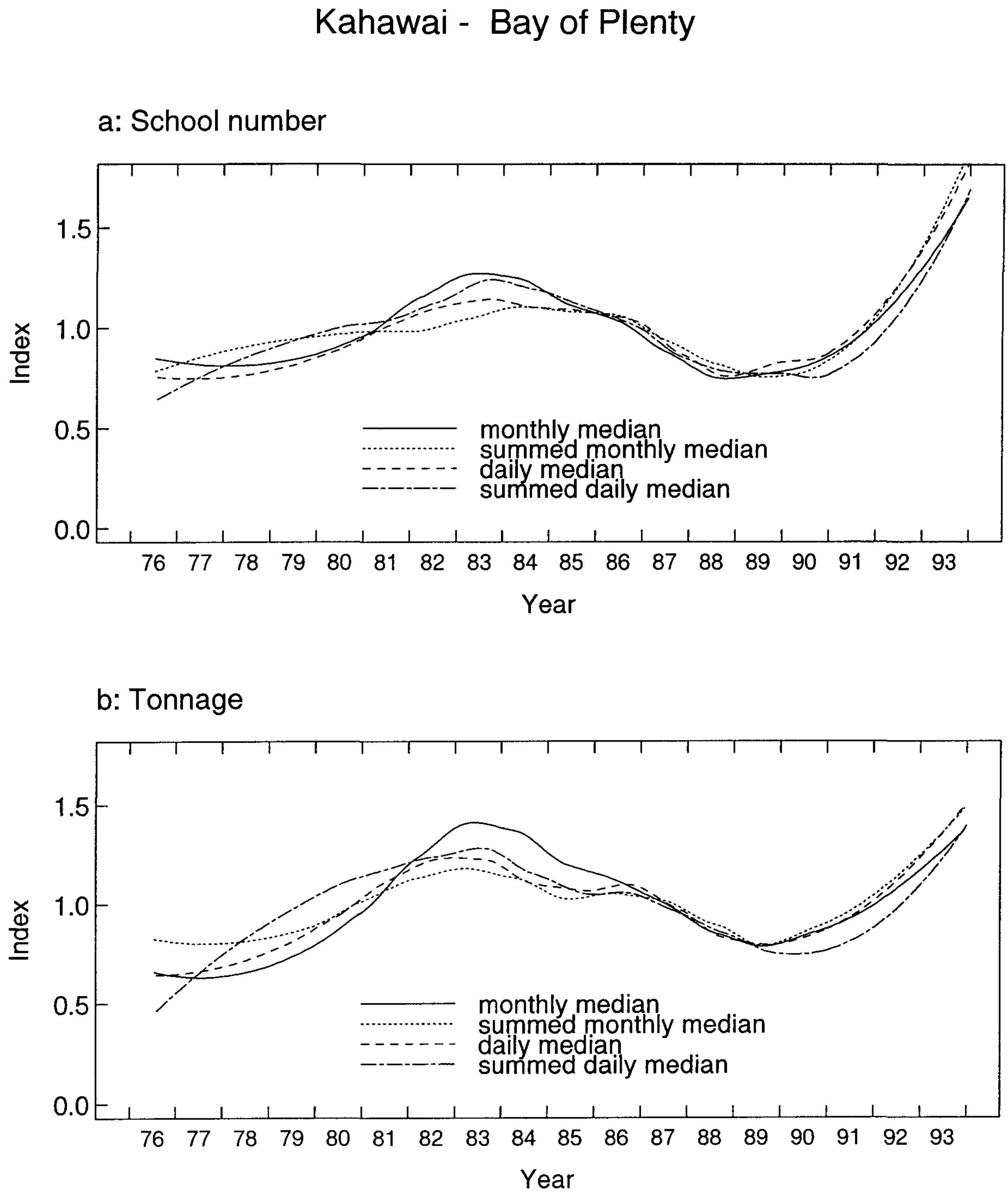

Figure 17: Schematic comparison of loess smoothed estimates of kahawai school numbers and tonnage seen in the Bay of Plenty (*see* Figure 2). Summations are over the median values in the individual aerial sightings squares. The curves are divided by their mean values.

6. Monthly relative abundance indices

Following the results in Section 5, we have chosen to use summed monthly median values of school number and estimated tonnage as an index for the four species. The region is a Fishstock, or the whole of the aerial sightings coverage. The inshore pelagics are divided into Fishstocks more for management convenience than for biological reasons and changes could occur in the whole fishery with increases in one part partially balanced by decreases in another.

The summed monthly median school numbers and tonnage and the number of contributing aerial sightings squares are plotted together with the *loess* smoothed line and its confidence limits (Figures 18–31). The number of squares contributing to each point gives a measure of the size of the region considered. The smoothed line has removed the seasonal cycle and the individual data points have less importance, that is, the smoothed line emphasises the long term trend and makes one easier to see, if it exists.

6.1 Kahawai, Figures 18–21

The number of schools of kahawai and the estimated tonnage in schools were high throughout New Zealand in 1982/83 (Figure 18). Both number of schools and tonnage are somewhat higher in the 1990s than they were in the late 1970s (*see* the smoothed line in Figure 18). The difference between the beginning and end of the data may not be significant because the confidence limits overlap. The tonnage has more contrast than the number of schools and peaked quite strongly in about 1983.

In KAH 1 and 9, neither the number of schools nor the tonnage show a trend over most of the data (Figure 19) although there are possible increases in the early 1990s (but remember that the end points of smoothing lines often show misleading trends). Also, the number of squares with sightings had no trend change until an increase in the 1990s suggesting that kahawai were more widespread in the 1990s than before.

In KAH 2, the number of schools, tonnage, and number of squares with sightings are almost flat (Figure 20).

In KAH 3, there are larger groups of schools containing larger tonnages of fish than in the more northern regions of New Zealand, and there is more contrast in the KAH 3 data. Both the number of schools and tonnage peaked in the early 1980s. A change of pilot could be causing some of the apparent change. The number of squares with sightings increased during the 1970s, remained constant during the 1980s, and declined in the 1990s suggesting a contraction of the region in which kahawai are found. Changes in KAH 3 are dominating the changes in the all New Zealand data.

6.2 Jack mackerel, Figures 22–25

Most of the sightings of jack mackerels were in JMA 1 (Figure 23), and so the same trends were seen in JMA 1 as throughout New Zealand (Figure 22).

In JMA 1, the number of schools, tonnage, and number of squares with sightings were almost flat until the 1990s when they all showed significant increases. The increase in jack mackerel abundance may be due to the entry of large numbers of Peruvian jack mackerel in New Zealand waters, an overall increase in abundance, a change in patterns of schooling behaviour, or any combination of these.

Jack mackerel aerial sightings in JMA 3 were rare until the late 1980s (Figure 24). This might mean a lack of interest in purseseining for jack mackerels in JMA 3 in the 1970s and early 1980s rather than an absence of jack mackerel schools. The scarcity of data in the first 10 years causes the the smoothed curves to appear rough, with little indication of trend changes.

Jack mackerel aerial sightings in JMA 7 are sparse until the late 1980s when they were more frequent. The trends in school number, tonnage, and number of squares with sightings are constant until the 1990s when they increased (Figure 25).

6.3 Trevally, Figures 26–28

Because most of the sightings were in TRE 1, the school numbers and tonnage in TRE 1 (Figure 27) show the same pattern as the throughout New Zealand data (Figure 26), though the trends are somewhat more pronounced. The school numbers, tonnage, and number of squares with sightings all declined during the 1970s and have been flat since. The decreases are not as dramatic as the decrease seen in the sightings percentage for the Bay of Plenty (*see* Figure 3).

Sightings of Trevally in TRE 2, 3, and 7 were rare and school numbers and tonnage show little trend (Figure 28).

6.4 Blue mackerel, Figures 29–31

For blue mackerel, the number of schools, tonnage, and number of squares with sightings are essentially constant (Figures 29, 30, and 31).

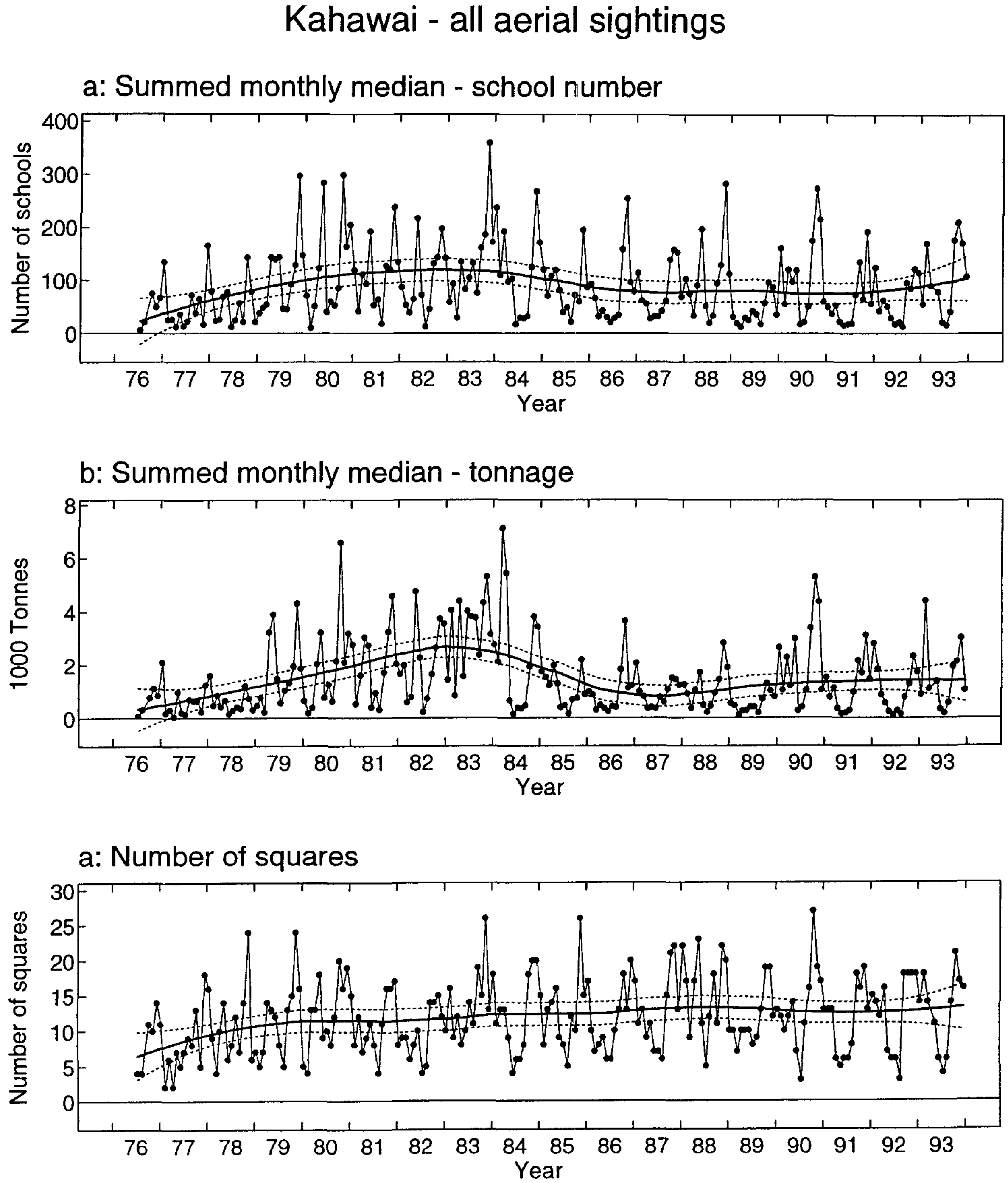

Figure 18: Summed monthly median values of school numbers and tonnage of kahawai seen throughout New Zealand together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where kahawai are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.

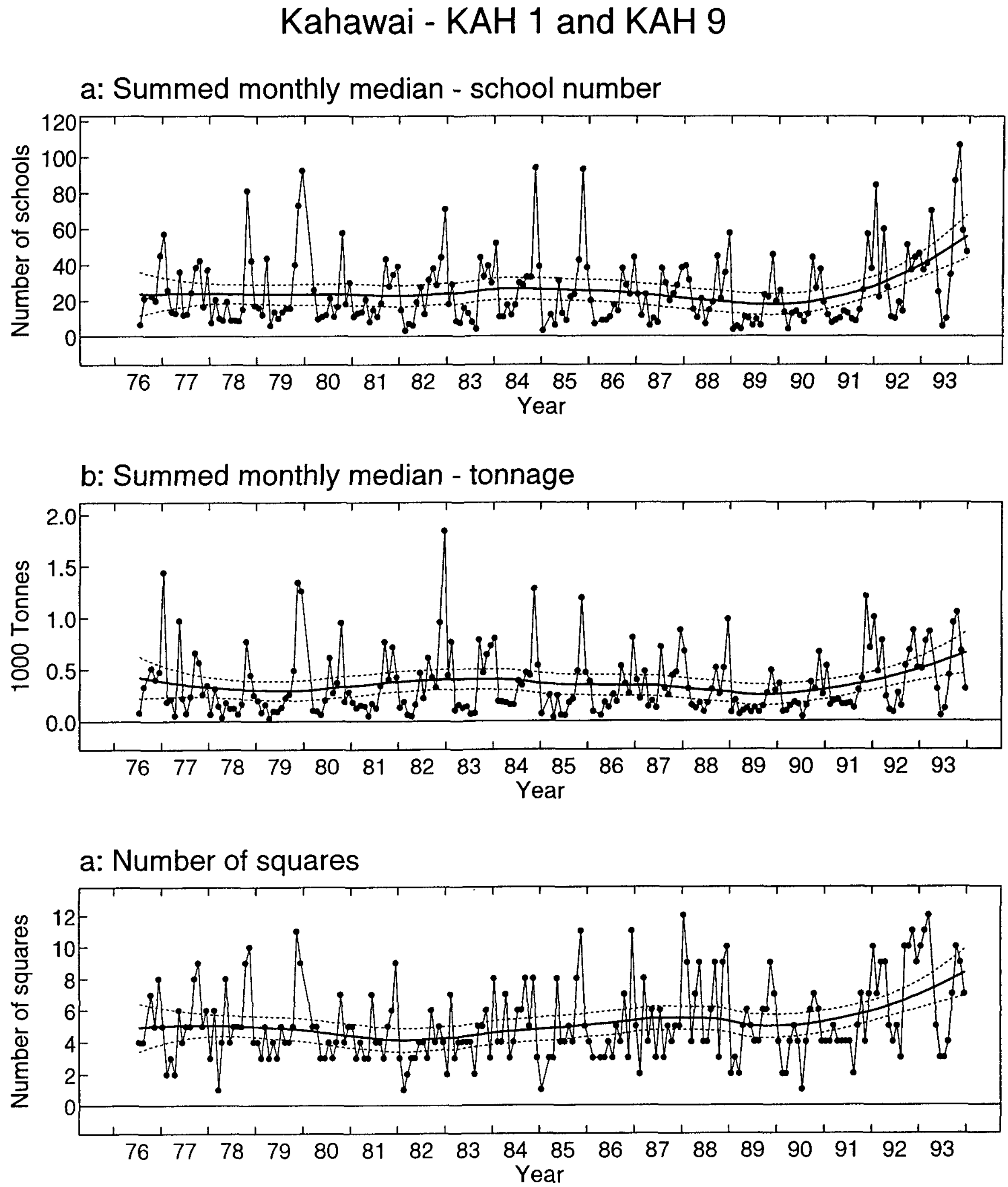

Figure 19: **Summed monthly median values of school numbers and tonnage of kahawai seen in KAH 1 and KAH 9 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where kahawai are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.**

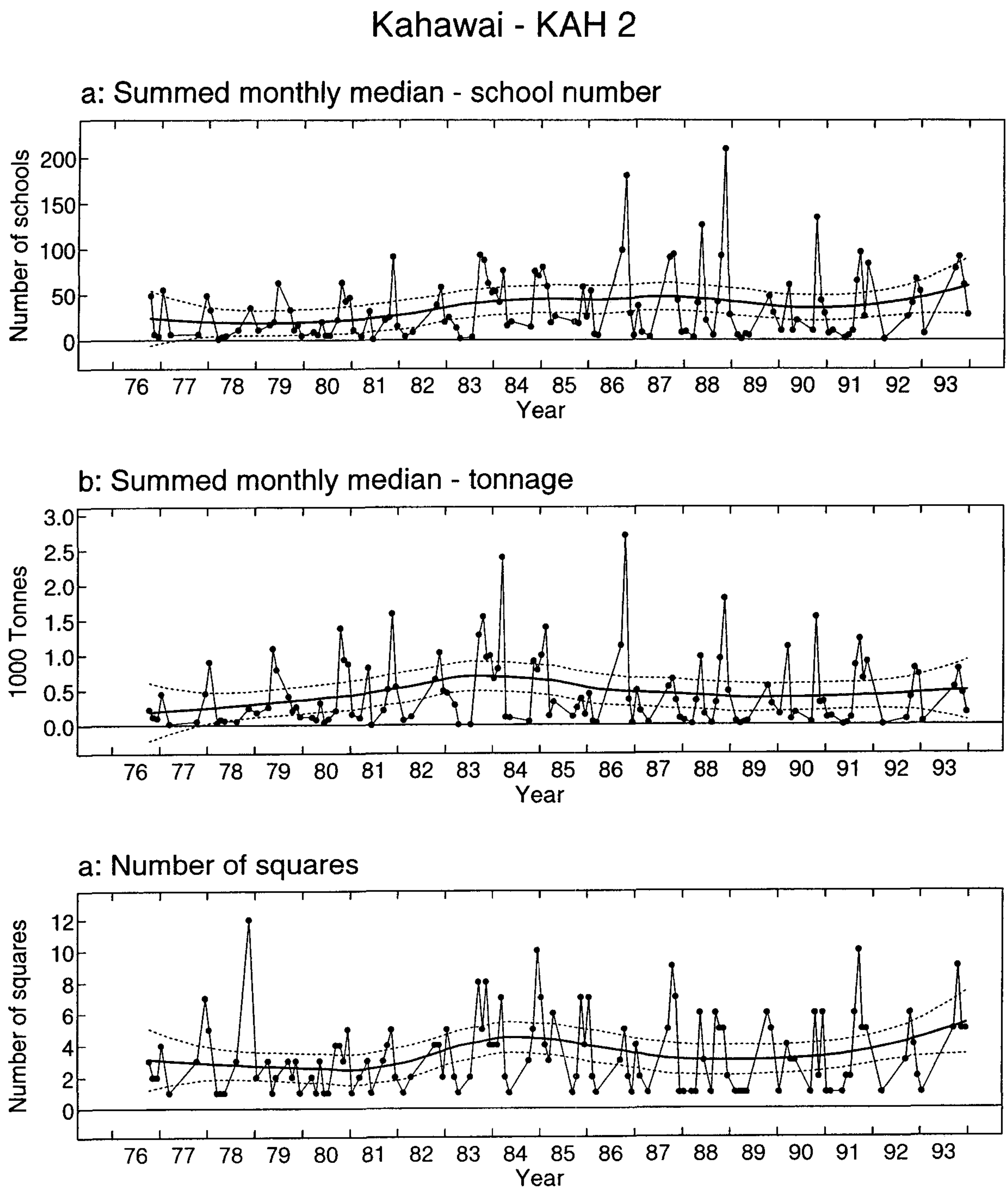

Figure 20: Summed monthly median values of school numbers and tonnage of kahawai seen in KAH 2 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where kahawai are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.

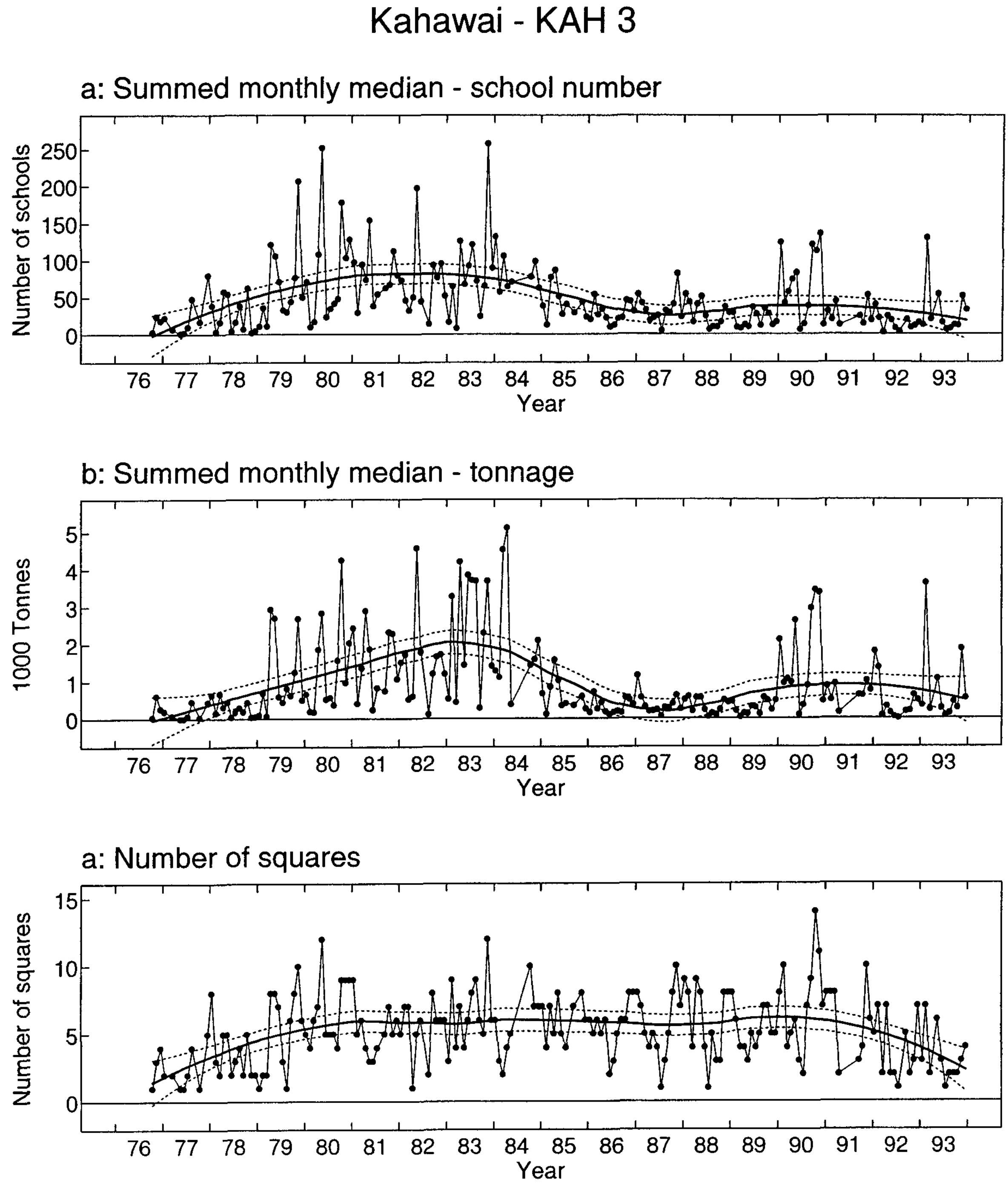

Figure 21: Summed monthly median values of school numbers and tonnage of kahawai seen in KAH 3 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where kahawai are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.

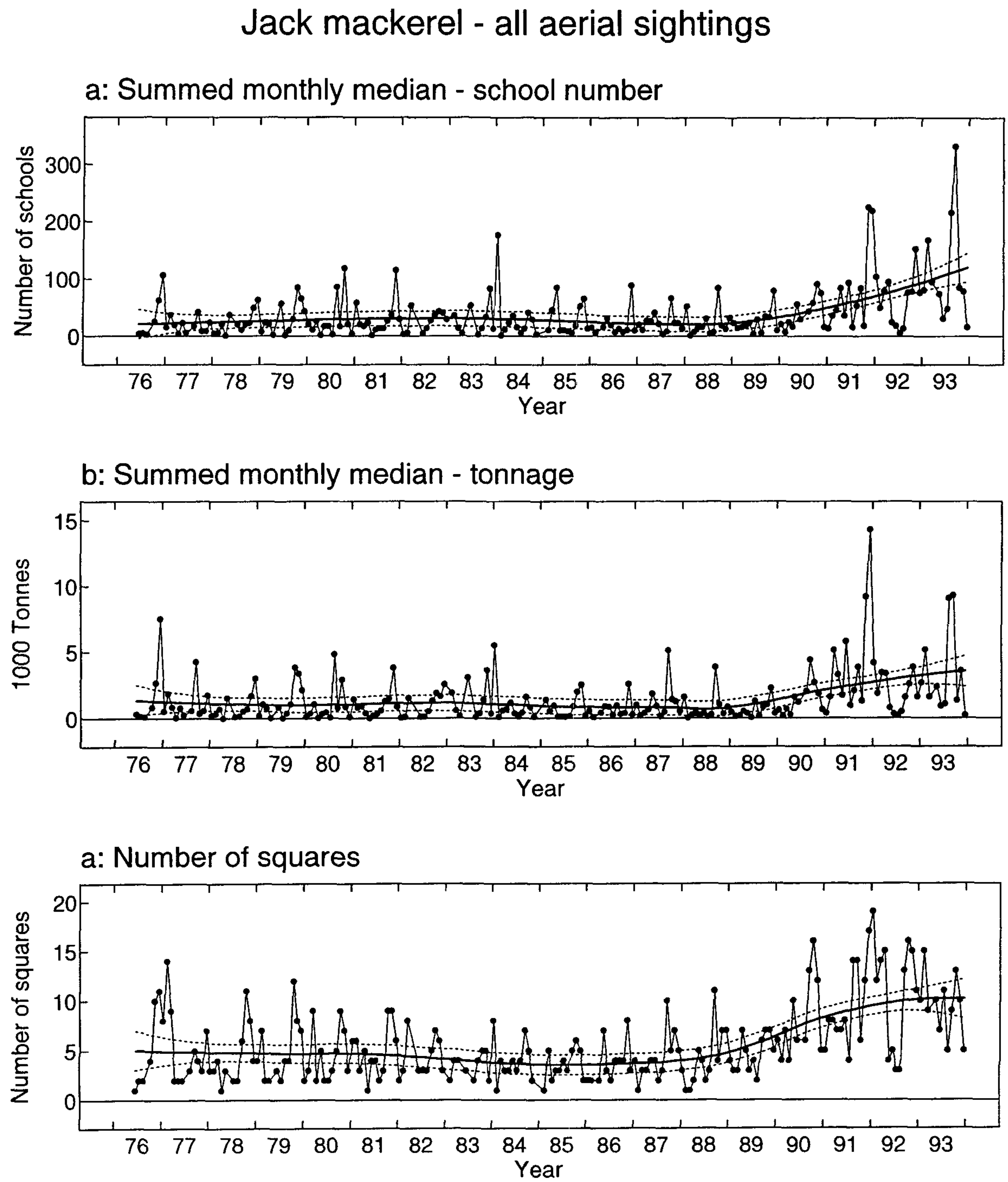

Figure 22: Summed monthly median values of school numbers and tonnage of jack mackerel seen throughout New Zealand together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where jack mackerel are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.

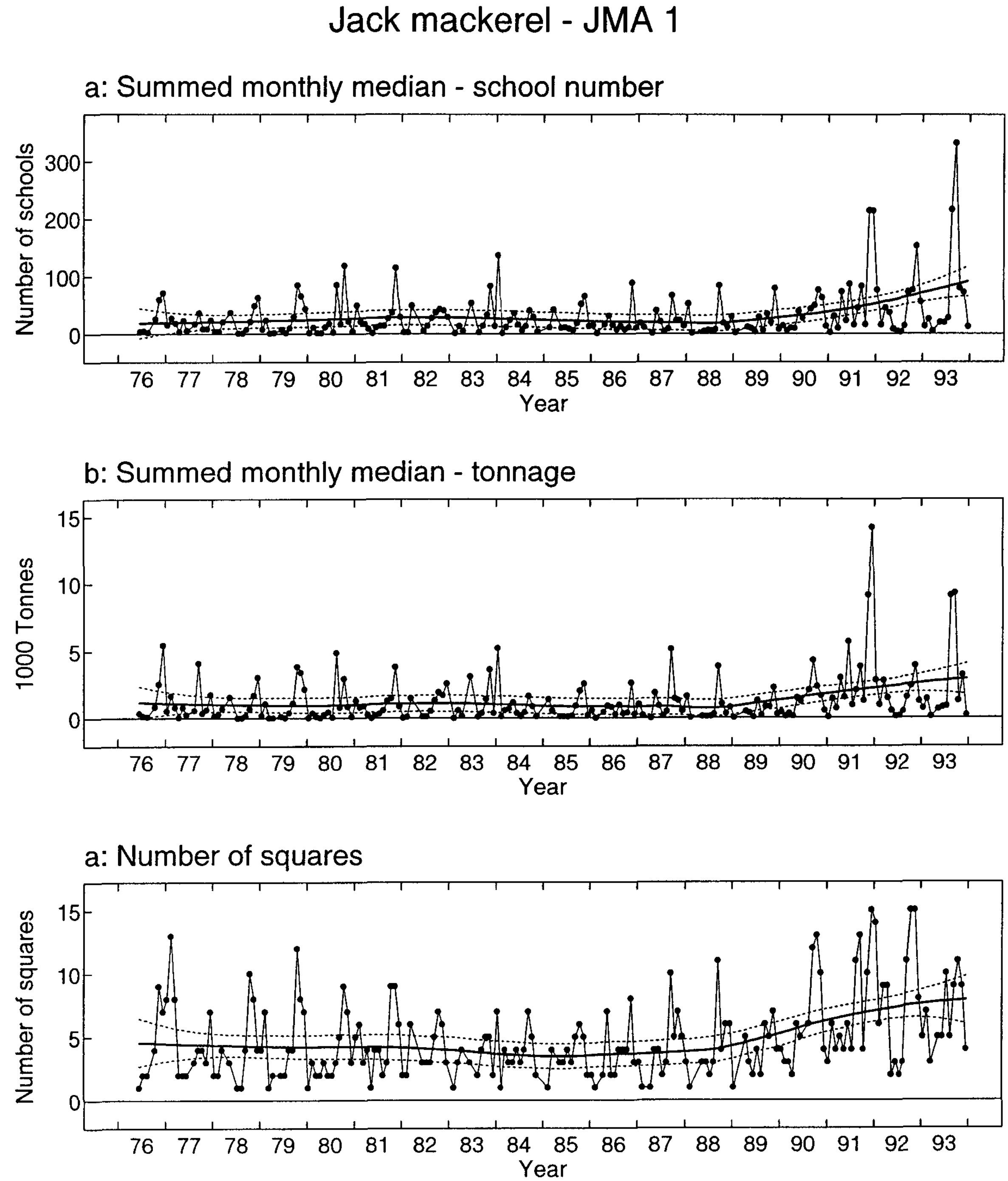

Figure 23: **Summed monthly median values of school numbers and tonnage of jack mackerel seen in JMA 1 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where jack mackerel are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.**

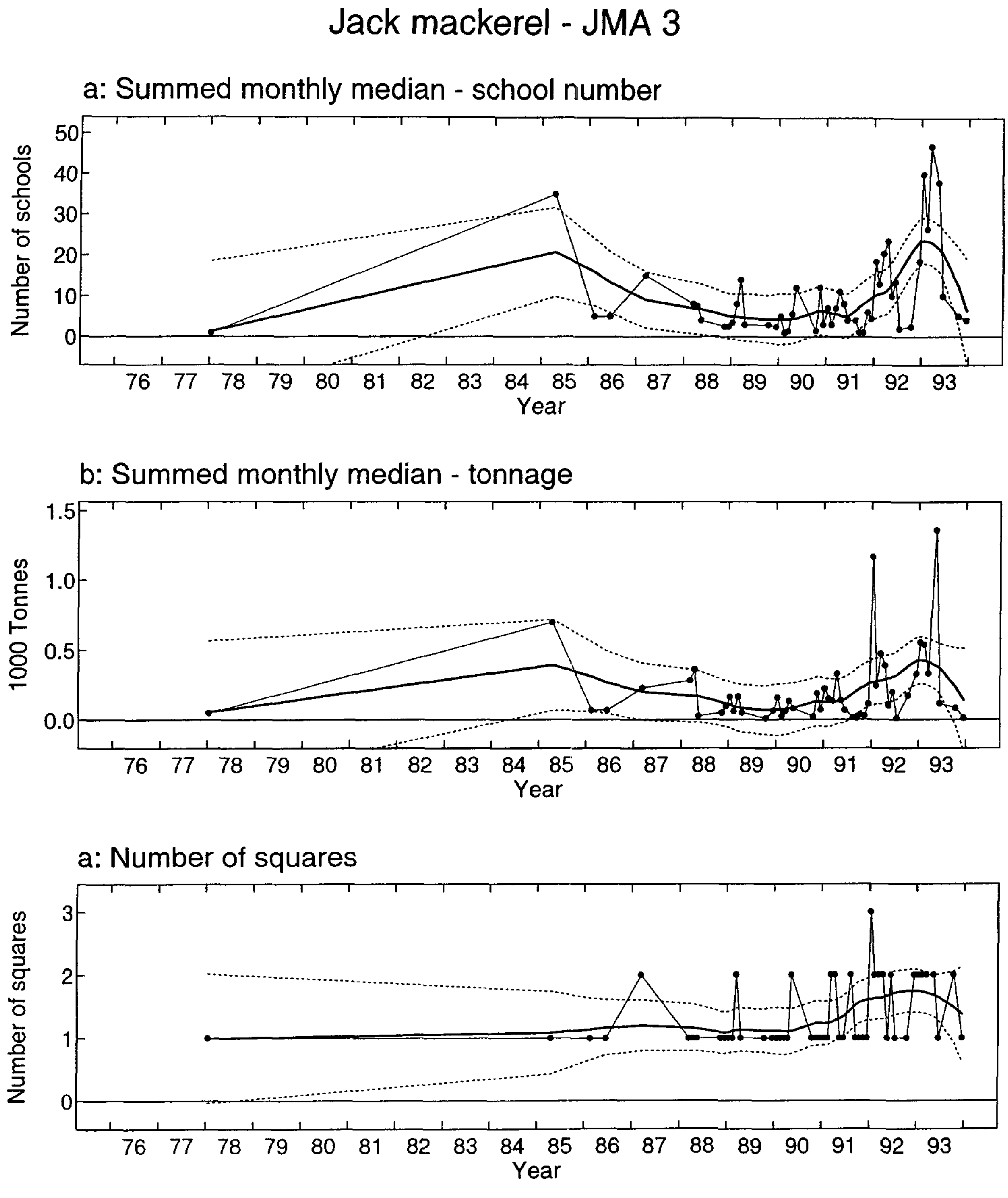

Figure 24: **Summed monthly median values of school numbers and tonnage of jack mackerel seen in JMA 3 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where jack mackerel are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.**

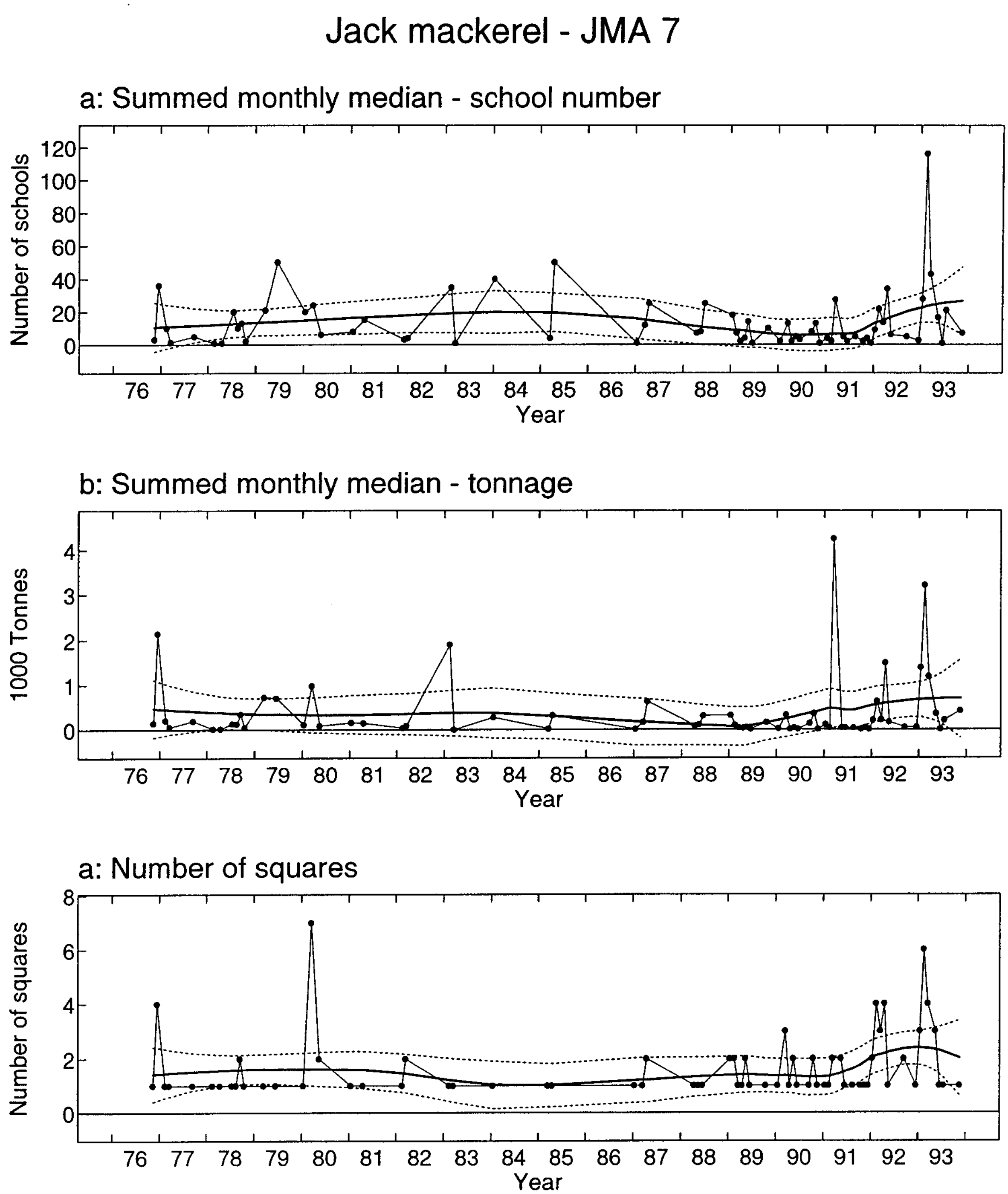

Figure 25: Summed monthly median values of school numbers and tonnage of jack mackerel seen in JMA 7 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where jack mackerel are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.

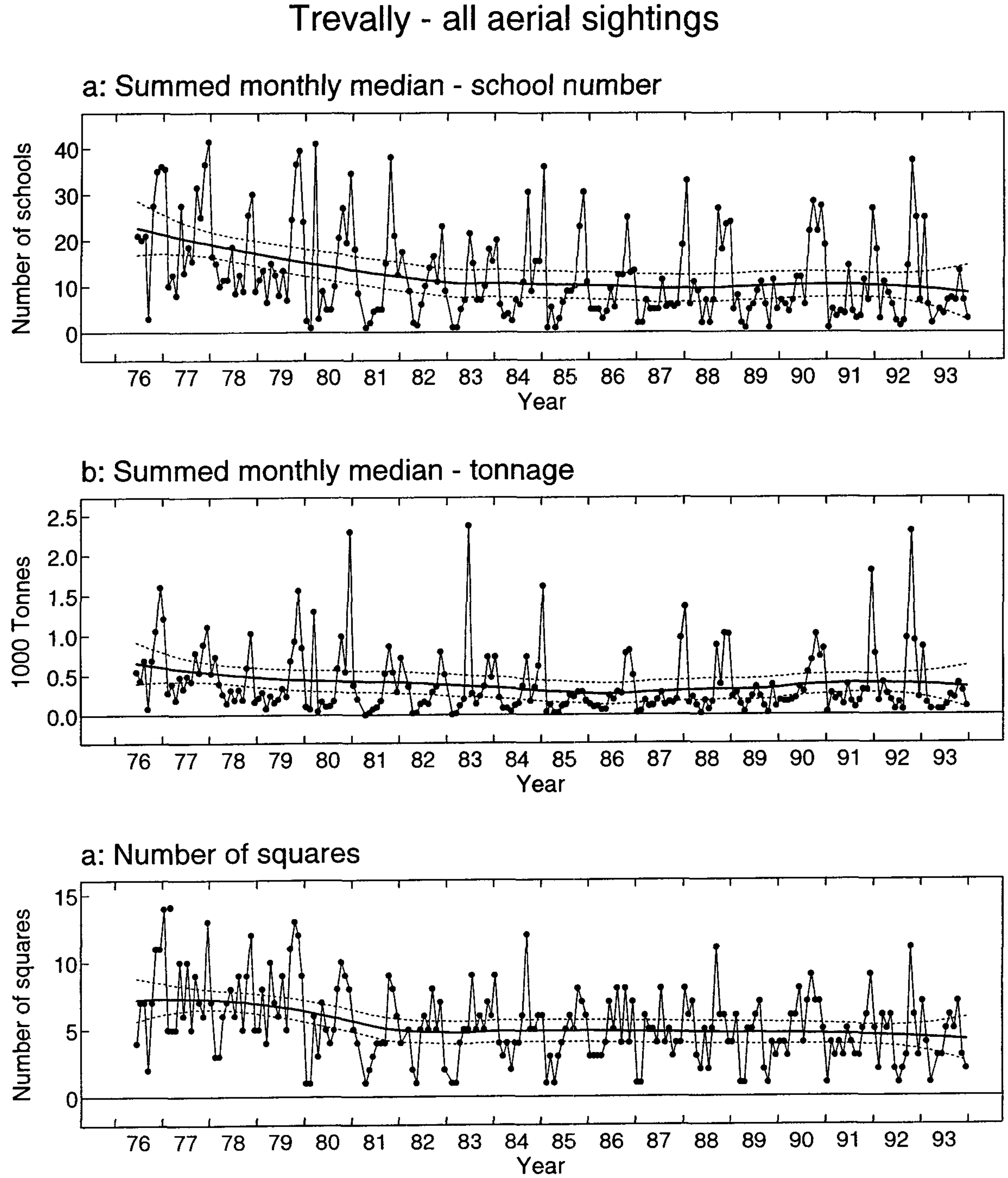

Figure 26: Summed monthly median values of school numbers and tonnage of trevally seen throughout New Zealand together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where trevally are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.

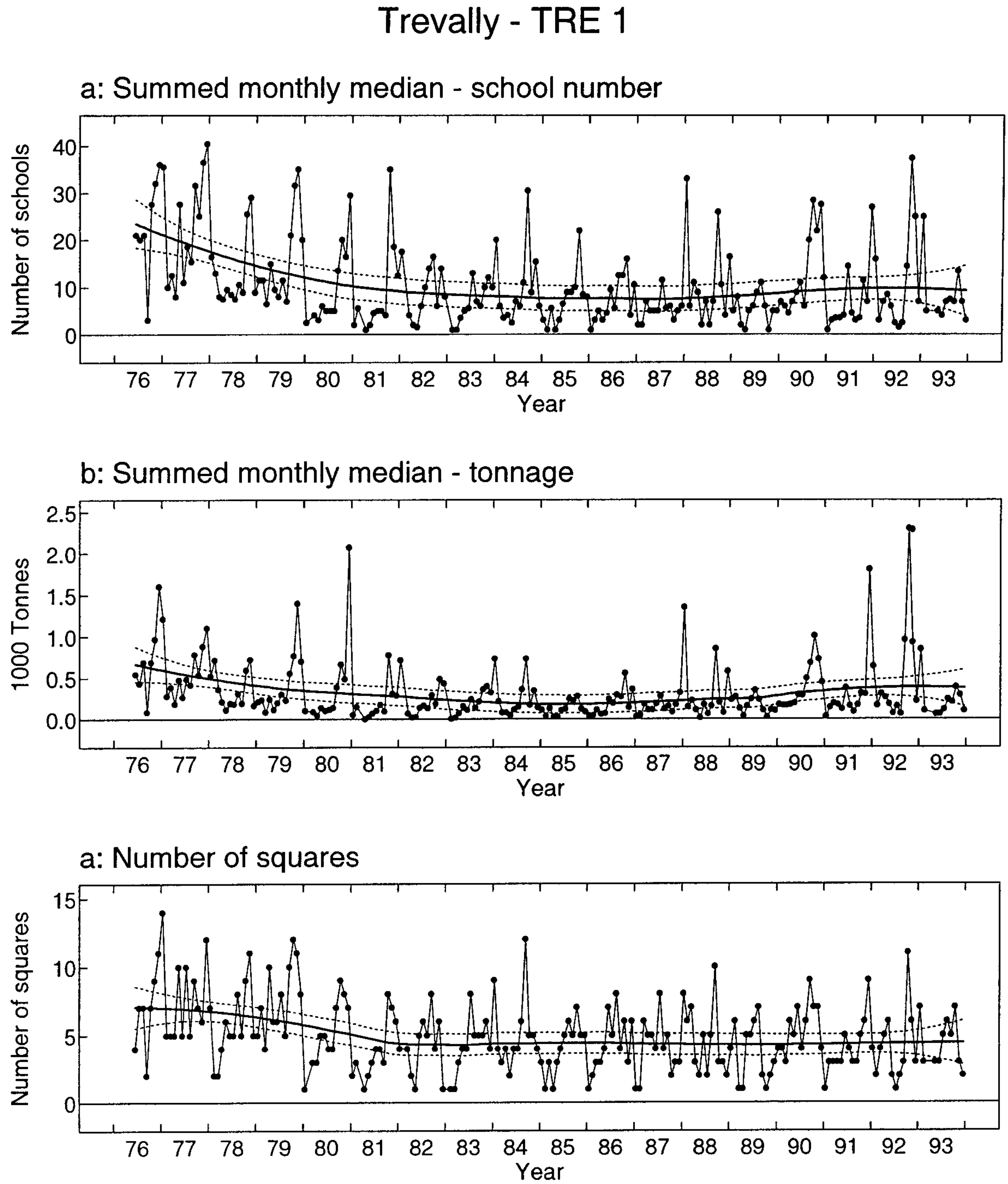

Figure 27: **Summed monthly median values of school numbers and tonnage of trevally seen in TRE 1 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where trevally are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.**

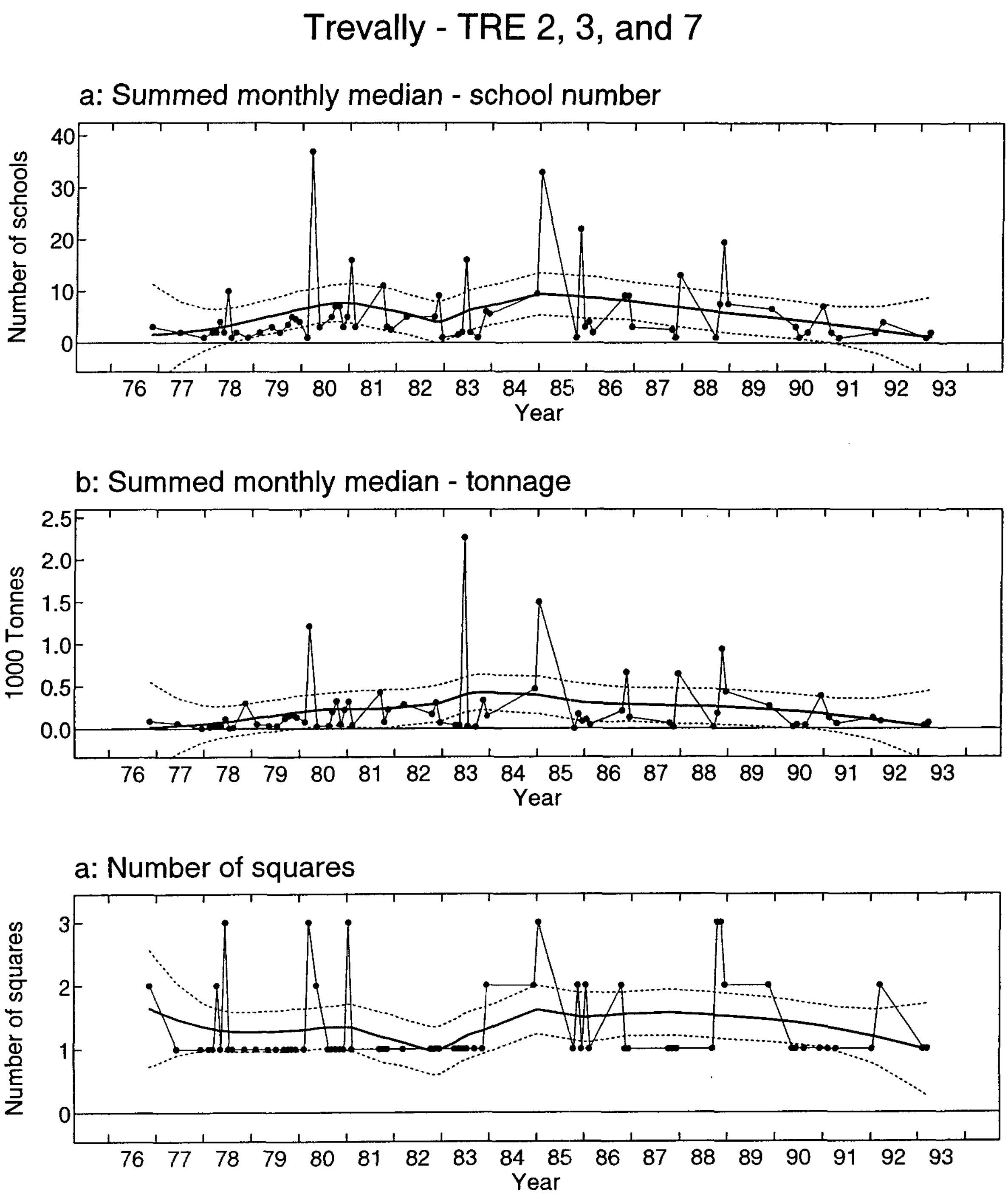

Figure 28: **Summed monthly median values of school numbers and tonnage of trevally seen in TRE 2, 3, and 7 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where trevally are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.**

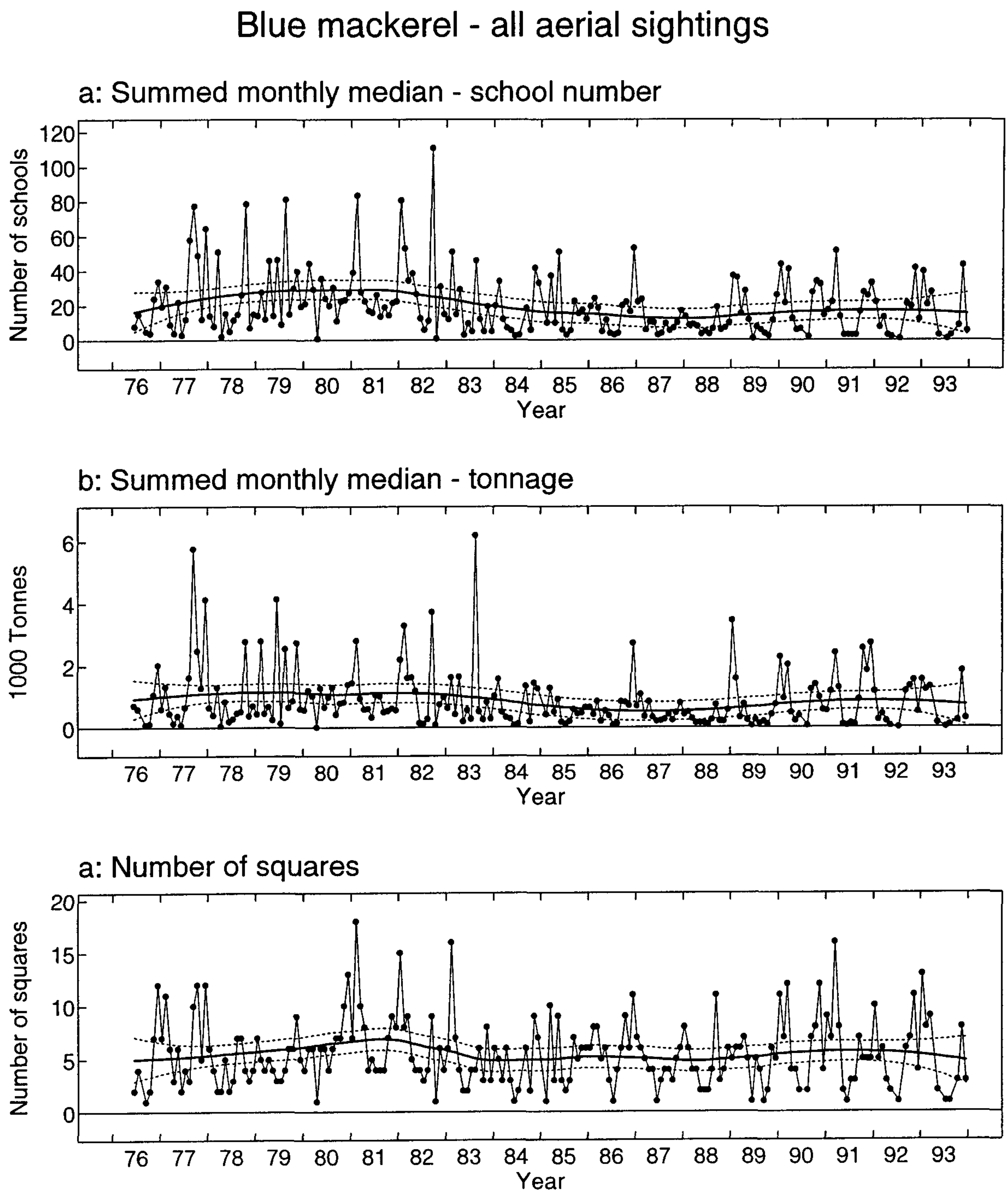

Figure 29: **Summed monthly median values of school numbers and tonnage of blue mackerel seen throughout New Zealand together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where blue mackerel are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.**

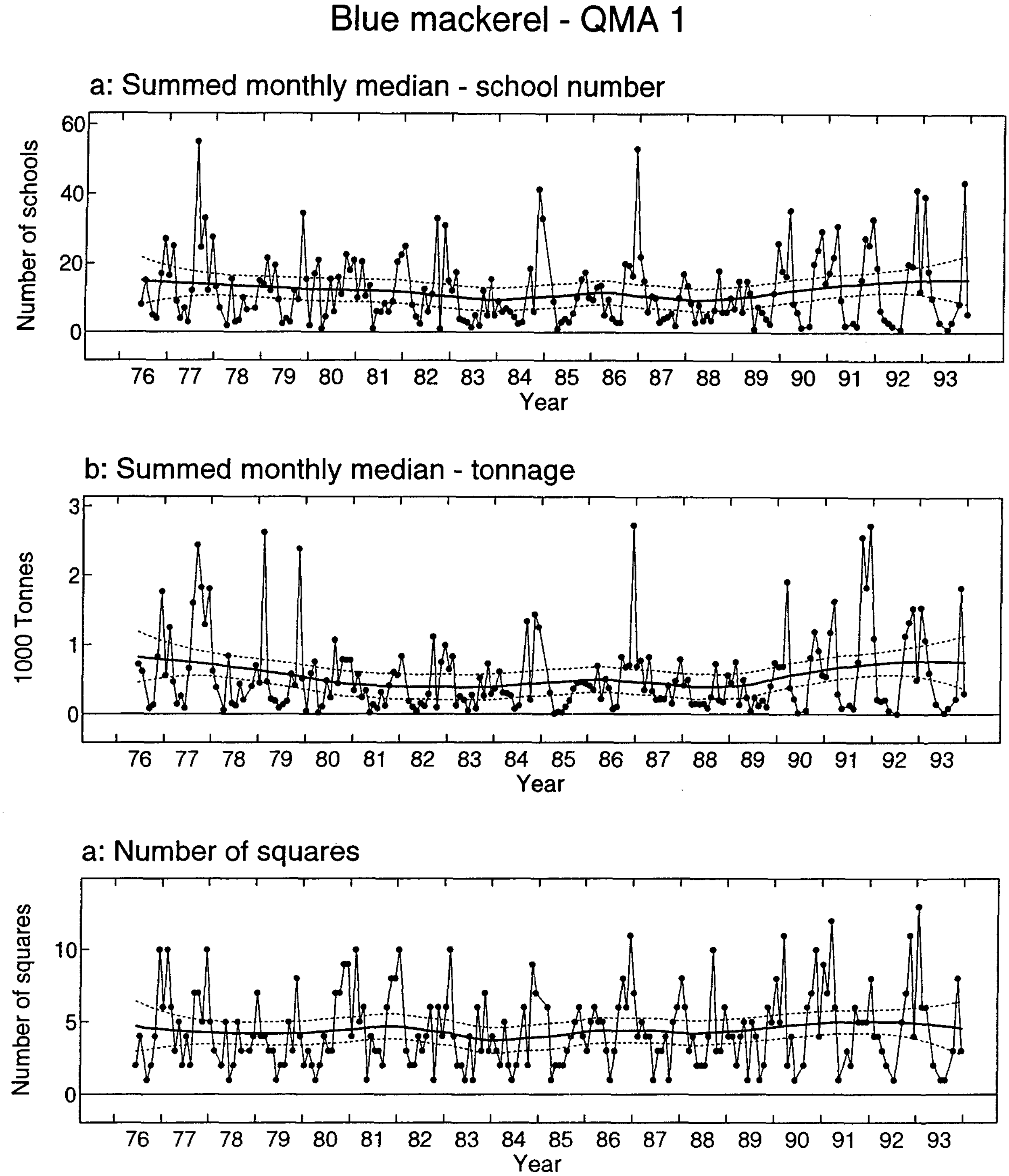

Figure 30: **Summed monthly median values of school numbers and tonnage of blue mackerel seen in QMA 1 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where blue mackerel are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.**

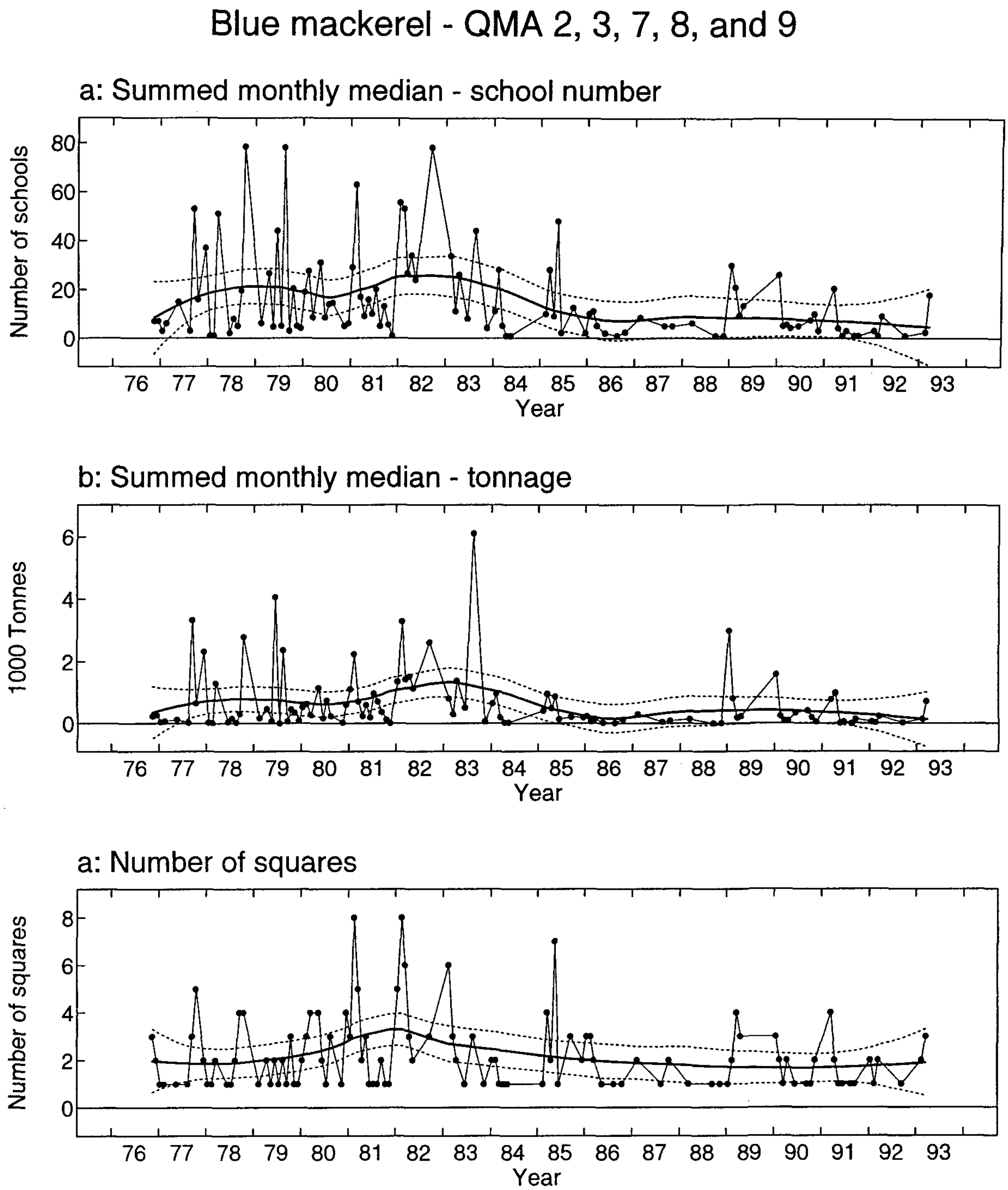

Figure 31: **Summed monthly median values of school numbers and tonnage of blue mackerel seen in QMA 2, 3, 7, 8, and 9 together with the loess smoothed curves and confidence intervals on the smooth. The summations are over the individual values for all aerial sightings squares where blue mackerel are seen in each month. The bottom graph shows the number of aerial sightings squares contributing and the loess smoothed line.**

7. Discussion

Changes in relative abundance of pelagic fish could occur as a change in the geographic region where fish are seen, a change in the number of schools in an area, a change in the tonnage in the area, or any combination of these.

We have considered three methods of calculating relative abundance indices for pelagic fish (kahawai, jack mackerel, trevally, and blue mackerel) from commercial aerial sightings data. One method calculates the sightings percentage or percentage of times a fish species was sighted in a given region to express changes in geographical region. The other two methods look for changes in the number of schools of a species sighted and the estimated tonnage in these schools, that is, changes of quantity given that some fish are present. The simplest method calculates annual medians of school numbers and tonnage for a Fishstock. The year to year changes in these medians seem too great, even when there is no overall long term trend, which suggests using another estimate for the "centre" of the data, or smoothing. The last method smooths summed monthly medians of school numbers and tonnage over Fishstock areas. This smoothed trend gives the easiest way of detecting any long term changes.

Large quantities of data are required if these simple methods are to give reliable indices of abundance — the sightings percentage was calculated only for the Bay of Plenty which has the most sightings effort. "Large" is not precisely defined; it does mean enough data for some asymptotic statistical results to hold and as we are seeking gross structure in the data we want enough data to minimise the influence of errors. The data for school numbers and tonnage were most prolific in QMA 1 (all species) and data in KAH 3 and JMA 3 and 7 increased from the late 1980s. The indices for kahawai and jack mackerel are best defined. Sightings of trevally and blue mackerel may not have been always recorded when the purseseine fishery had no interest in these species.

The indices may provide indications of changes which have occurred or are occurring in the inshore pelagic fish stocks. Thus, they could provide a way of monitoring changes in these fish stocks at little additional cost to that already committed to collecting and storing the data. Aerial sightings of fish schools will continue for commercial reasons.

7.1 Kahawai

For kahawai, the sightings percentages in the Bay of Plenty (*see* Figure 3) and the annual medians of school numbers and tonnage in KAH 1 (*see* Figures 5 and 6) show no consistent long term trends. The smoothed trends (*see* Figure 19) suggest increases in the 1990s. Both the annual median and the smoothed trends (*see* Figures 5, 6, and 21) show maxima in KAH 3 in the early 1980s and are essentially constant since the late 1980s. However, the number of squares with sightings in KAH 3 seems to have decreased in the 1990s. There is little detectable change in KAH 2 (*see* Figures 5, 6, and 20).

The sightings percentages in individual aerial sightings squares (*see* Figure 4) suggest that there has been a movement of kahawai eastwards away from the Coromandel east coast. The sightings percentage is the fraction of sightings on which a species was seen and does not depend on variations in sighting activity.

Thus we have found no indication of a decrease in kahawai abundance in KAH 1 and have found suggestions of an increase in relative abundance. These data do not sample the close inshore kahawai where local depletion may have occurred.

7.2 Jack mackerel

For jack mackerel, the sightings percentage in the Bay of Plenty shows an increase since the late 1980s (*see* Figure 3) and, in JMA 1, the annual medians indicate little change with possible increases in school numbers (*see* Figures 7 and 8). The smoothed trends also suggest increases from 1990 (*see* Figure 23) which are just significant, especially for the number of schools. Data are only adequate in JMA 3 and 7 from the late 1980s and there may have been increases in JMA 3 since 1990 (*see* Figures 7, 8, 24, and 25).

The recent possible increase in jack mackerel sightings may be a consequence of the invasion of New Zealand waters by the Peruvian jack mackerel. We do not yet know whether there has been a change in abundance of the endemic jack mackerel species.

7.3 Trevally

For trevally, the sightings percentage in the Bay of Plenty declined from 1977 to 1993 (*see* Figure 3). The median tonnage in TRE 1 appears to have decreased in the late 1970s and increased since the late 1980s (*see* Figure 10). The median number of schools may show the same trend but is more difficult to interpret (*see* Figure 9). The smoothed trends in the school numbers, tonnage, and number of squares with sightings decreased during the 1970s and early 1980s with no subsequent change (*see* Figure 27). Thus, the signals in TRE 1 are confused; there may have been a change in spatial distribution (the sightings percentage covers only part of TRE 1) or a change in the number and size of schools forming a group. Lack of data means that we can say little about the change in relative abundance of trevally in other parts of New Zealand (*see* Figures 9, 10, and 28).

7.4 Blue mackerel

For blue mackerel, the sightings percentage in the Bay of Plenty suggests a rise in abundance during the mid 1980s with a subsequent decrease (*see* Figure 3). The annual median school numbers suggest no change in QMA 1 (*see* Figure 11) and the median tonnages suggest an increase from the late 1980s through the 1990s (*see* Figure 12). The smoothed trends (*see* Figure 30) suggest little change, with the recent rise being not significant. Again, the differences in trend may be partly due to the sightings percentages being only for the Bay of Plenty. Elsewhere, there are not enough data (*see* Figures 11, 12, and 31) to define trends.

8. Acknowledgments

We thank John Annala, Chris Francis, and Malcolm Francis for extensive comments on earlier versions of this report and Brian Jones for his encouragement and input during the development of the methods used.

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9.1 Catch articles

These are given in time sequence. Some of the early articles had no specific authorship.

Anon. 1975: Aerial fish spotting. *Catch'75, 2,1*:3–7.

Anon. 1975: Aerial survey of pelagic fish. *Catch'75, 2,6*:3–4.

Anon. 1975: Pelagic species summer survey. *Catch'75, 2,11*:6–7.

James, G.D. 1976: December '75 pelagic fish survey. *Catch'76, 3,1*:13–14.

Eggleston, D. 1976: Aerial survey of school fish. *Catch'76, 3,3*:12–13.

Habib, G. 1976: North-east coast aerial survey. *Catch'76, 3,5*:12–13.

James, G.D. 1976: July aerial survey. *Catch'76, 3,7*:12–13.

Robertson, D. & Clement, G. 1976: September aerial survey. *Catch'76, 3,10*:12–13.

Anon. 1976: October aerial survey. *Catch'76, 3,11*:12–13.

Francis, R. 1977: January aerial survey. *Catch'77, 4,1*:12–13.

Anon. 1977: March aerial survey. *Catch'77, 4,3*:12–13.

Anon. 1977: Reports on several pelagic species. *Catch'77, 4,4*:5–15.

Clement, G. & Paulin, C. 1977: May aerial survey. *Catch'77, 4,5*:12–13.

Clement, G. 1977: Fish schools abundant in August aerial survey. *Catch'77, 4,8*:16–17.

Clement, G. & Neale, P. 1977: September aerial survey — blue mackerel on the move. *Catch'77, 4,9*:20–21.

Canning, S. 1977: October aerial survey — school fish absent. *Catch'77, 4,10*:16.

Anon 1977: Schoolfish survey around New Zealand — fewer skipjack. *Catch'77, 4,11*:12–15.

Clement, G. & Habib, G. 1978: Aerial surveys move south to take in new grounds. *Catch'78, 5,1*:8–9.

Clement, G. 1978: Summer survey revealed large kahawai schools. *Catch'78, 5,4*:14.

Clement, G. 1978: Few trevally spotted in reef haunts. *Catch, 5,4*:14–15.

Clement, G. 1978: Warm sea explains unusually late showing of tuna inshore. *Catch'78, 5,7*:14.

Clement, G. 1978: Aerial survey: Few schoolfish spotted over winter months. *Catch'78, 5,9*:18–19.

Clement, G. & McShane, S. 1978: Aerial pelagic survey: Better schools about in September. *Catch'78, 5,11*:20–21.

McShane, S. & Clement, G. 1978: October aerial survey. *Catch'78 5,12*:9.

McShane, D.J. 1979: Little schoolfish activity on November survey. *Catch'79, 2*:24–25.

McShane, D.J. 1979: April aerial survey. *Catch'79, 6,5*:23.

McShane, D.J. 1979: May/June aerial survey. *Catch'79, 6,6*:8.

Appendix 1: Main tables in the aerial sightings database

Paul Taylor is the database administrator of the aerial sightings database and is preparing a formal description of it.

The variables in the four main tables in the database are listed below. Tables defining the various codes exist. The flight table has not been used in this document. Not all the attributes in the sightings table have values. The attribute "location" in the sightings table and the attribute "grid" in the flight path table are the aerial sightings square number. The attribute flt_grp (or flight group) is used as the main table linking attribute.

Table: t_flight_group First of the four main tables — contains reference data for a group of flights.

Attributes: flt_grp; date; pilot_code; customer_code; aircraft_code; vessel_code.

Table: t_flight Second of the four main tables — contains flight duration and airfield data for individual flights — "flt_grp" identifies a group of flights by a pilot on a single day — 10 flights is maximum and usually there are less than five (not used in this report).

Attributes: flt_grp; flt_num; up_field; up_time; dn_field; dn_time; hr_min; hr_dec.

Table: t_school_sight Third of the four main tables — contains data on the species sighted, estimates of tonnage, location and time of the sighting, and some environmental data

Attributes: flt_grp; flt_num; sight_num; species_code; num_of_schools; ton_min; ton_max; ton_tot_pil (pilot estimate, infrequently given and not used); ton_tot_calc (number of schools times arithmetic mean of minimum and maximum tonnage); sighting_time; sea_cond_code; water_temp (not usually present); location; lat_d; lat_m; long_d; long_m; long_ew (latitude and longitude, not present).

Table: t_flightpath Fourth of the four main tables — contains records of the half degree squares flown during a group of flights (see t_flight) and the 10–15 minute periods spent therein

Attributes: flt_grp; grid; ticks; tic_factor.

Appendix 2: Definitions of Fishstocks

The QMA boundaries are shown in figure on the next page. The 200 m depth contour gives a rough guide to the outer limit of the range of the schooling inshore pelagic species. The aerial sightings squares of interest are those half degree squares within the 200 m contour. Plots indicating the number of sightings of the main species are in preparation.

Approximate definitions of the Fishstock boundaries for kahawai, jack mackerel, and trevally are tabulated below (from Annala 1994). The pelagic Fishstock boundaries do not follow the QMA boundaries precisely, but the differences are of no practical consequence for this document.

Kahawai

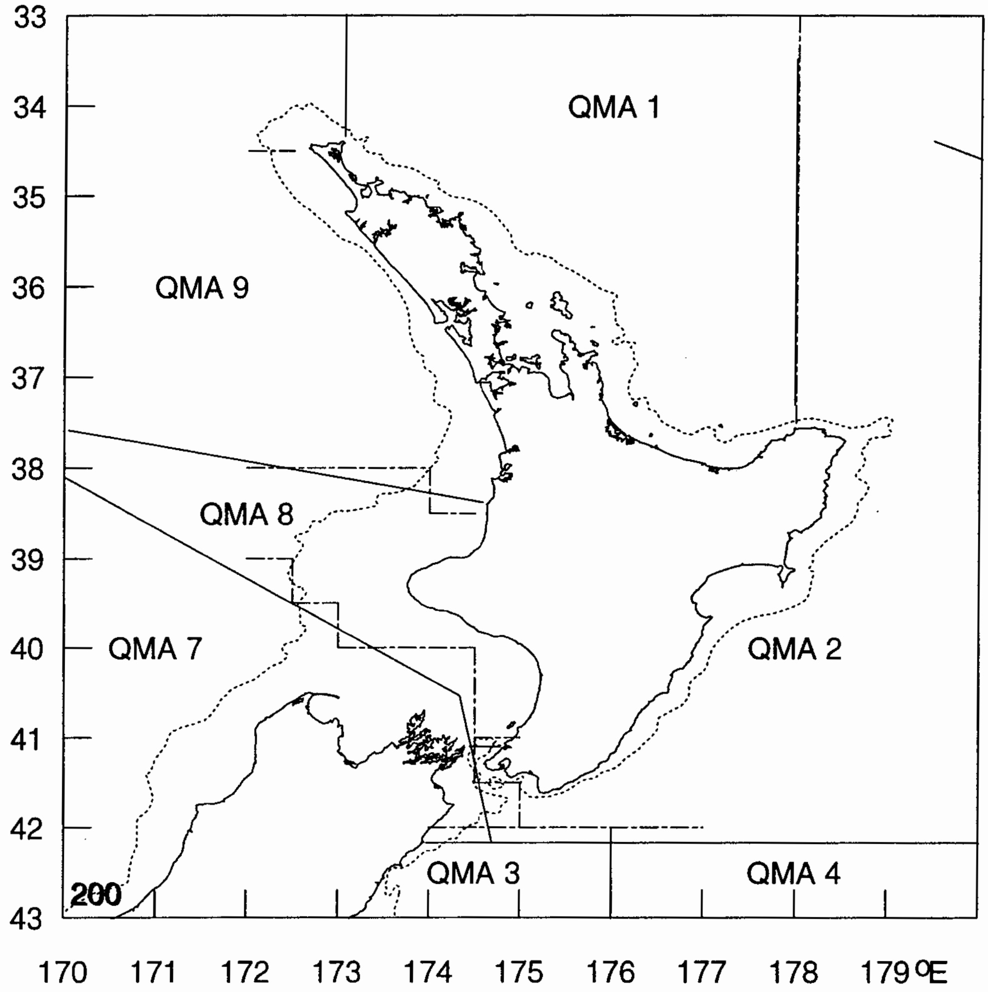
Fishstock		QMA
KAH 1	Auckland (East)	1
KAH 2	Central (East)	2
KAH 3	South–East, Southland,Sub–Antarctic, Challenger, Central (West)	3,4,5,6,7, & 8
KAH 9	Auckland (West)	9
KAH 10	Kermadec	10

Jack mackerel

Fishstock		QMA
JMA 1	Auckland (East), Central (East)	1,2
JMA 3	South–East, Southland, Sub–Antarctic	3,4,5, & 6
JMA 7	Challenger, Central (West), Auckland (West)	7,8, & 9
JMA 10	Kermadec	10

Trevally

Fishstock		QMA
TRE 1	Auckland (East)	1
TRE 2	Central (East)	2
TRE 3	South–East, Southland, Sub–Antarctic	3,4,5, & 6
TRE 7	Challenger, Central (West), Auckland (West)	7,8 & 9
TRE 10	Kermadec	10



QMA boundaries. The full lines are the actual QMA boundaries; the dash–dot line shows the aerial sightings QMA boundaries. The dotted line is the 200 m depth contour.

Appendix 3: Mathematical terms

Boxplot consists of a rectangle which extends from the lower to the upper quartile. Lines (whiskers) are drawn to the nearest value not beyond 1.5*(inter-quartile range) from the quartiles. Points indicate possible outliers. The dot within the rectangle shows the median. The notches in the sides of the boxes indicate the 95% confidence intervals that the medians are different.

Median is the value of the middle item when the number of items (n) is odd, and the mean of the two middle items when n is even. The data items have first been ordered according to size.

Quartiles divide the data, ordered by size, into 4 equal groups and may be labelled lower, middle, and upper in increasing size. The middle quartile is the median.

Interquartile range is the difference between the upper and lower quartiles and includes half the data (by definition of quartiles).

Loess is a local weighted regression smoothing function. Local regression models provide methods for fitting *regression functions*, or *regression surfaces*, to data. In the first case, there is only one predictor and in the second there is more than one predictor. Consider any point x in the space of the predictors. One basic specification in a local regression model is that there is a neighbourhood (the smoothing band) containing x in which the regression surface is well approximated by a function from a specific parameter class; for the S implementation (Chambers & Hastie 1992) there are two classes — polynomials of degree 1 or 2. The specifications of local regression models lead to methods of fitting that consist of smoothing the response as a function of the predictors; thus the fitting methods are non-parametric regression procedures. Figure 7.8 in Efron & Tibshirani (1993) gives a pictorial representation of how *loess* works.

The *loess* smoothed line is taken to give the long term trend in the data and is added to the data plots together with 95% confidence limits on the smoothed line (*see*, for example, Bradford 1993).

Trend is the direction of changes over several years. Smoothing the data, either by eye (with a small number of points) or by computation with a large number of points gives the trend in the sense used here.