Chapter 4
Description of Marine Growth Checks Observed on the Scales of Salmon Returning to Scottish Home Waters in 1997

J.C. MacLEAN, G.W. SMITH and B.D.M. WHYTE

Introduction

Atlantic salmon (*Salmo salar* L.) catch information has been collected in a systematic manner from salmon fisheries throughout Scotland since 1952. These statistics show a steady decrease in total catch from the late 1960s until the present day (Anon. 1997). Although some of this decline can be explained by reductions in net fishing effort, in response to a reduced real value of salmon (Smart 1986), and a number of buy-out initiatives, these factors do not fully explain the reductions observed. Changes in marine survival may also be implicated in the decline. Records from the North Esk, a monitored river on the east coast of Scotland, indicate that while smolt production has been well maintained, estimates of marine survival have fallen by a factor of two (Shearer 1992). Furthermore, these observations are not confined to Scotland; similar trends in both home water catches and in marine survival have been observed throughout the North Atlantic (Anon. 1998).

The marine survival of salmonids is thought to be heavily influenced by events during the first few months of their lives at sea by factors such as ocean productivity and growth related predation pressures (e.g. Holtby *et al.* (1990) in Pacific salmon and Salminen *et al.* (1995) in Baltic salmon). As a result, recent research has focused on the early marine phase of the salmon's life cycle. In Atlantic salmon, observations by Friedland & Reddin (1993) revealed a correlation between the north-east Atlantic salmon catch and an index of spring habitat thought to be preferred by post-smolts. In addition, Friedland *et al.* (1998) demonstrated that the marine survival of smolts from two stocks, one in Scotland (North Esk) and the other in Norway (River Figgio) entering the eastern Atlantic Ocean were both positively correlated with a spring index of preferred habitat as defined by sea surface temperatures.

Recent surveys (e.g. Shelton *et al.* 1997, Holm *et al.* 1996 and Holst *et al.* 1993) have described the trophic conditions of the immediate post-smolt phase by intercepting these fish at sea. Results suggest that post-smolts have ample feeding opportunities in the early weeks at sea. An alternative line of enquiry to such direct observations, which covers the whole of the marine phase, seeks to follow past marine feeding opportunities from the scale patterns of returning adult salmon. Thus, Friedland *et al.* (in press) showed that the size of the growth increment in the first year at sea was correlated positively with the marine survival rate of the North Esk smolts.

The Freshwater Fisheries Laboratory, Pitlochry, routinely examines scale samples from maturing salmon returning to Scottish home waters. Analysis of samples from fish caught in 1997 indicated a higher than previously recorded incidence of summer checks. Such summer checks are recognised as a number of successive narrowly-spaced circuli occurring within a period of otherwise more widely-spaced circuli. Patterns of circuli spacing may be interpreted as reflecting changes in the immediate environment of the salmon. Thus variation in growth opportunity may be inferred from an analysis of scale patterns (Bagenal & Tesch 1978, Casselman 1987). Summer checks therefore, may indicate periods of reduced growth opportunity which may in turn be associated with low marine survival (Friedland *et al.* 1998).

A description is given of these unusual growth patterns in the scales of salmon returning to river catchments within a wide geographic area across Scotland and a comparison is made of their frequency of occurrence with historical data. The relevance of such observations to marine survival is considered in general and with particular reference to marine survival indices from the North Esk.

Material and methods

During 1997, samples of scales were collected from salmon caught in a number of fisheries throughout Scotland (Figure 4.1). In addition, scales from adult recaptures in Scottish home waters of North Esk salmon tagged as emigrating smolts were also analysed.

Scales were impressed and age was determined according to the methods given in Anon. (1985). Figure 4.2 illustrates the growth patterns observed on 1SW salmon in the presence and absence of summer checks. Figure 4.3 illustrates the comparable growth patterns in 2SW salmon.

The incidence of summer checks in scales obtained in 1997 samples was determined among both 1SW and 2SW salmon. In addition, scale samples from the North Esk net and coble fishery in a number of previous years were re-examined to test whether the frequency of summer checks was significantly different from those observed previously. In order to test whether summer checks were associated with differences in marine survival, scale sample data from smolt years showing both a relatively high return rate (1973 and 1983) and a relatively low return rate (1969, 1980 and 1990), as indicated by catch (Anon. 1997), were chosen and compared with indices of marine survival for smolts emigrating from the North Esk for the period 1965–96 derived using the methods described in Friedland *et al.* (1998).

Results

Incidence of summer checks

The occurrence of a group of tightly-spaced circuli can have one of two interpretations. It may be interpreted as a summer growth check or, alternatively, it may be

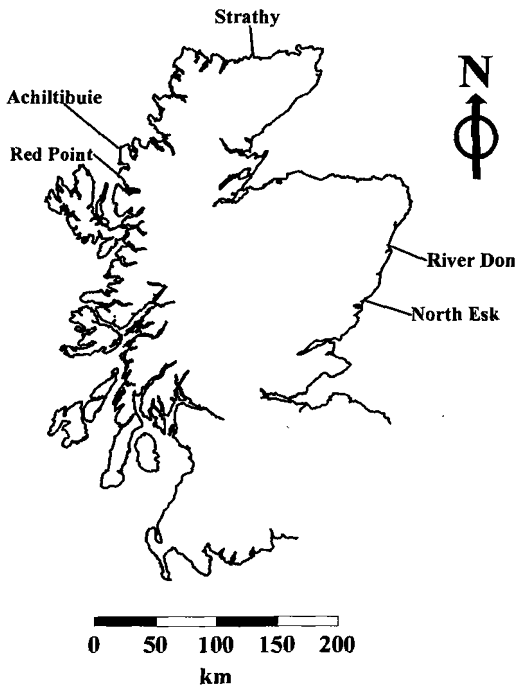

Fig. 4.1 Location of sites throughout Scotland from which samples of scales from returning adult salmon were collected.

considered to represent a winter annulus. The North Esk recapture data set provides scale samples from salmon tagged as emigrating smolts whose sea-age is therefore known and thus summer checks and annuli can be distinguished with confidence.

Substantial proportions of salmon returning in 1997 exhibited summer checks (Table 4.1). Evidence that checks were not misclassified winter annuli is provided by the observation that the incidence of validated summer checks from scale samples taken from the North Esk recapture data set (n = 50) was 26.0% in 1SW salmon, which was within the range observed in the fisheries examined throughout Scotland (20.0% (n = 1115) to 45.0% (n = 20)). Although the incidence of summer checks observed from 2SW North Esk recaptures (12.2% (n = 41)) was greater than that from the samples from the other sites (0% (n, range = 1–16) to 5.0% (n = 20)), this may be explained by the small sample sizes available.

All summer checks occurred during the first marine growing season in 1SW salmon or during the second marine growing season in 2SW salmon. Thus, the summer checks were laid down in the same calendar year (1996) in both sea-age groups examined. The incidence of summer checks in 2SW salmon was significantly less than in 1SW salmon (Wilcoxon test, $n = 7$, $z = -2.366$, $p = 0.018$) (Table 4.1).

Table 4.2 shows the incidence of summer checks in historical data sets from the North Esk net and coble fishery. For both 1SW and 2SW salmon, the incidence of

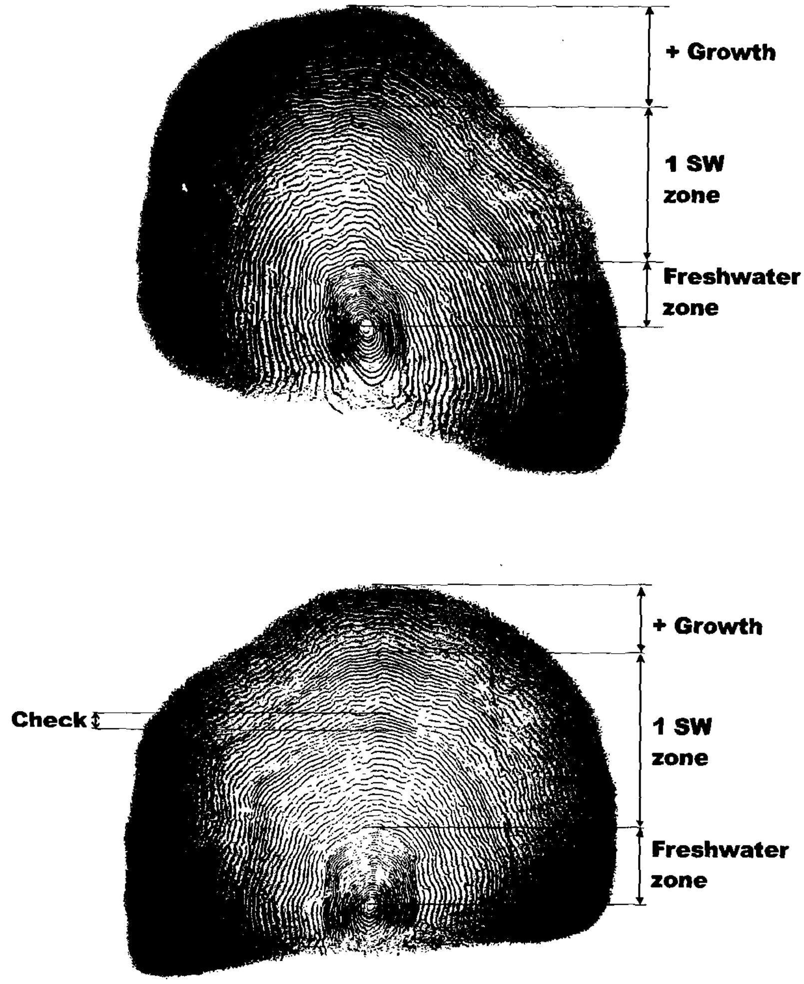

Fig. 4.2 Illustration of scale growth patterns observed in 1SW adult returns in the absence of (above) and in the presence of (below) a summer check.

summer checks in 1997 was outwith the 95% confidence limits for the historical data sets examined.

Incidence of summer checks in relation to month of capture

Table 4.3 shows the incidence of summer checks, by month, in 1SW and 2SW fish sampled from the largest data set, the North Esk net and coble fishery. In 1SW salmon, the incidence of summer checks varied significantly among months (G-test, $G = 25.76$, $df = 3$, $p < 0.001$), the incidence of summer checks rose through May and June, peaking in July (26.5%) before dropping again in August. For 2SW salmon

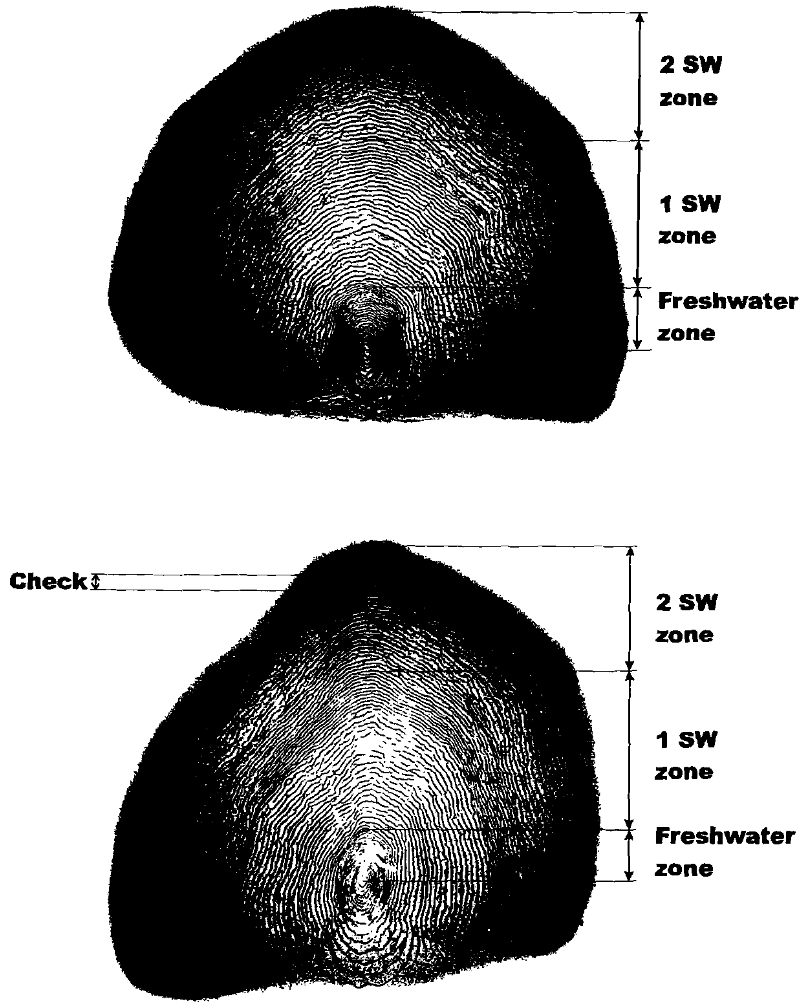

Fig. 4.3 Illustration of scale growth patterns observed in 2SW adult returns in the absence of (above) and in the presence of (below) a summer check.

there was no discernible temporal pattern in the incidence of summer checks (G-test, $G = 0.25$, $df = 2$, $p > 0.75$).

Effect of summer check on size at capture

Figure 4.4 compares the average fork length at capture of salmon with and without summer checks, by month, for both 1SW and 2SW salmon for the North Esk net and coble fishery data set. There were no significant differences in fork length between salmon with and without summer checks (Table 4.4).

Table 4.1 Incidence of summer checks in 1SW and 2SW salmon sampled from sites around Scotland in 1997.

	1SW salmon		2SW salmon	
Sample site	Number sampled	Number with summer checks (%)	Number sampled	Number with summer checks (%)
Recaptures of North Esk smolts, various sites	50	13 (26.0)	41	5 (12.2)
North Esk, net & coble	1115	223 (20.0)	528	14 (2.7)
North Esk, rod & line	52	15 (28.8)	185	3 (1.6)
Redpoint, fixed engine	32	13 (40.6)	1	0 (0)
Achiltibuie, fixed engine	20	9 (45.0)	1	0 (0)
Strathy, fixed engine	285	66 (23.2)	16	0 (0)
River Don, netting for broodstock	73	28 (38.4)	20	1 (5.0)

Table 4.2 Incidence of summer checks in annual samples of 1SW and 2SW salmon from the North Esk net and coble fishery.

	1SW salmon		2SW salmon	
Year	Number sampled	Number with summer checks (%)	Number sampled	Number with summer checks (%)
1969	1335	4 (0.3)	860	4 (0.5)
1973	1419	14 (1.0)	1045	14 (1.3)
1980	456	0 (0)	928	7 (0.8)
1983	226	0 (0)	403	3 (0.7)
1990	619	0 (0)	431	2 (0.5)
1997	1115	223 (20.0)	528	14 (2.7)

Table 4.3 Incidence of summer checks, by month, in 1SW and 2SW salmon sampled from the North Esk net and coble fishery in 1997.

	1SW salmon		2SW salmon	
Month	Number sampled	Number with summer checks (%)	Number sampled	Number with summer checks (%)
February			38	2 (5.3)
March			56	1 (1.8)
April	1	0 (0)	40	0 (0)
May	20	2 (10)	203	7 (3.4)
June	379	69 (18.2)	102	2 (2.0)
July	461	122 (26.5)	50	2 (4.0)
August	254	30 (11.8)	39	0 (0)

Location of summer checks with respect to growth attained in year of incidence

The position of the summer check was expressed as a proportion of the total scale growth attained in the year the summer check occurred for both 1SW and 2SW salmon. Figure 4.5 shows the distributions of these proportions where 0 represents the beginning of the relevant growth season on the scale and 1 indicates the end of that period. For 1SW salmon, the proportions are spread around a mean of 0.70 ± 0.004 and for 2SW salmon around a mean of 0.71 ± 0.015. These distributions were not significantly different (Mann-Whitney U test, $n = 237$, $U = 1269.5$, $p = 0.238$).

The relationship between summer checks and marine survival indices

Figure 4.6 presents the marine survival indices of North Esk smolts, 1965–96 both for 1SW and 2SW returns. In general, survival indices have been lower in the latter part of the time series for both 1SW and 2SW salmon. Although the marine survival indices for the 1SW returns from the 1996 smolt cohort and for the 2SW returns from the 1995 smolt cohort (both of which returned to home waters in 1997) are the lowest on record, there is no correlation between marine survival and the incidence of growth checks for the years examined (Spearman rank correlation, $r_s = 0.152$, $n = 6$, $p > 0.5$, for 1SW salmon and $r_s = 0.029$, $n = 6$, $p > 0.5$, for 2SW salmon).

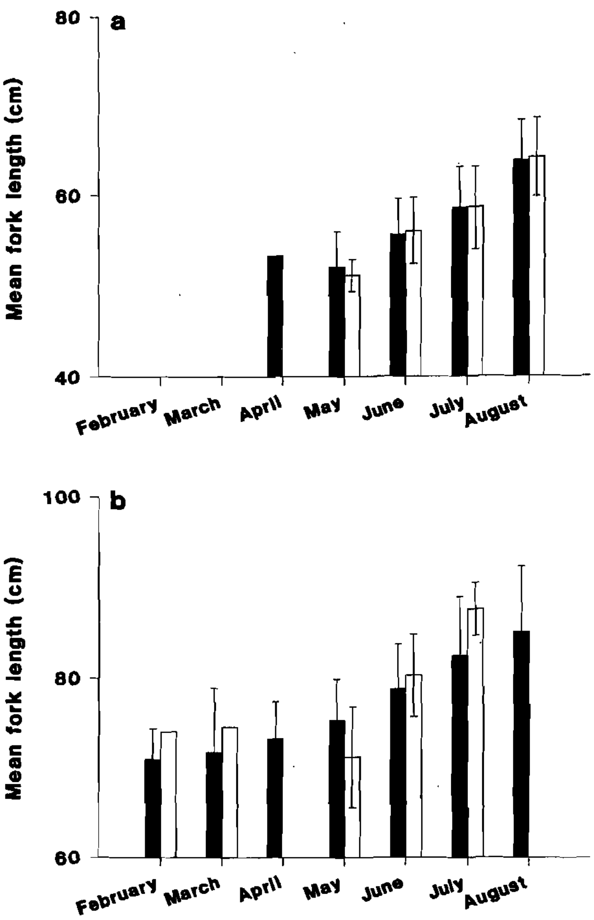

Fig. 4.4 Comparison of fork lengths at capture by month between adult returns with (white bars) and without (black bars) summer checks for (a) 1SW and (b) 2SW salmon. Error bars indicate 1 standard deviation of each mean value.

Discussion

Summer checks have been observed on scales taken during routine sampling from various locations throughout Scotland since 1963. Their incidence has, however, always been rare; in the data sets re-examined, less than 1.5% of 1SW and 2SW salmon showed the checks. The occurrence of summer checks on the scales of salmon returning to Scottish home waters in 1997 was significantly greater than these historical levels. Scale samples were taken from fisheries located in the east, north and west of Scotland, suggesting that the phenomenon affected salmon both originating from, and returning to, areas at least as large as Scotland.

The spacing between the circuli reflects the rate of growth (Bagenal & Tesch 1978, Casselman 1987). In general, widely-spaced circuli represent periods of rapid growth

Table 4.4 Results of a comparison (Mann Whitney U test) of the lengths of returning adult salmon between those with summer growth checks on their scales and those without.
§ indicates not enough data to carry out the analysis.

	1SW salmon			2SW salmon		
	N	U	P	N	U	P
February	§			38	12.0	0.116
March	§			58	11.5	0.309
April	§			§		
May	20	19	0.899	203	961.5	0.071
June	379	10020.5	0.412	102	79.5	0.620
July	461	20352.5	0.067	50	19.0	0.151
August	254	3128.5	0.540	§		

(e.g. in the summer) while narrowly spaced circuli represent slower winter growth. Thus, summer checks reflect periods of limited growth. However, the cause of the summer checks is unknown. One possibility is that there have been changes in the marine environment that limit the growth of salmon through lack of food. For example, Perry *et al.* (1996) demonstrated a link between dietary composition and growth in Pacific salmon. Furthermore, Brett (1979) has shown that, in salmonids in general, there is an association between water temperatures and growth. Alternatively, oceanographic and/or climatological changes may alter the environmental cues perceived by salmon resulting in atypical migration routes being pursued through less-suitable habitat.

Although the cause of the summer checks is unclear, their relative position in the scale may allow some inference to be made as to the timing and geographical scope of the phenomenon. The location of the summer checks in relation to the overall growth increment on the scale is fairly restricted (Fig. 4.5), indicating that the causal event is synchronised in time over all returns. While summer checks are present in scale samples taken from salmon returning to home waters throughout the sampling season (February to August) the extent to which they occur varies both with month and sea age at return (Table 4.3). A possible mechanism to explain this observation is that the causal effect is not uniform throughout the marine habitat and that run timing differences both between and within sea-age classes is related to different marine migration patterns. Thus, different groups of returning salmon may have been exposed to the causal event to differing degrees. This may also suggest that the temporal structuring of returning salmon populations is on a scale of a month, or possibly less.

The high incidence of summer checks reported in maturing salmon returning to the Scottish coast in 1997 is a new phenomenon. The position of the checks in the 1SW and 2SW salmon examined shows that the causal event occurred in 1996. Friedland *et al.* (in press) have demonstrated associations between changes in ocean climate with changes in growth and survival in Atlantic salmon. While the checks reported here

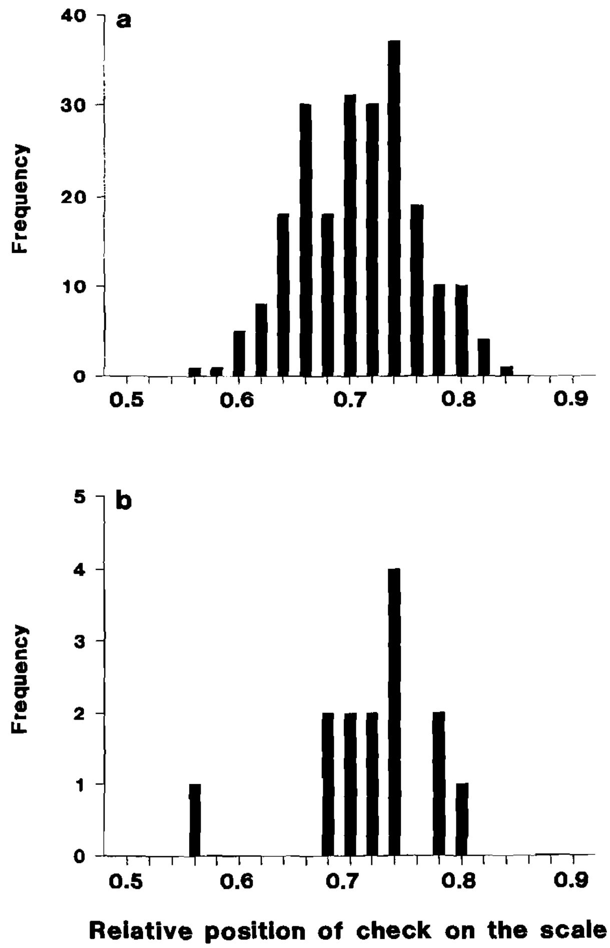

Fig. 4.5 Position of the summer check, expressed as a proportion of the total growth attained in the year in which the check occurred, for (a) 1SW and (b) 2SW salmon.

suggest that further, perhaps related, changes occurred in the ocean in the latter part of 1996, no link was shown with either growth or survival. In spite of this lack of apparent correlation, the observations described here further focus our attention on the marine phase of the salmon's life cycle and on changes in the marine environment that may have an impact upon growth and survival.

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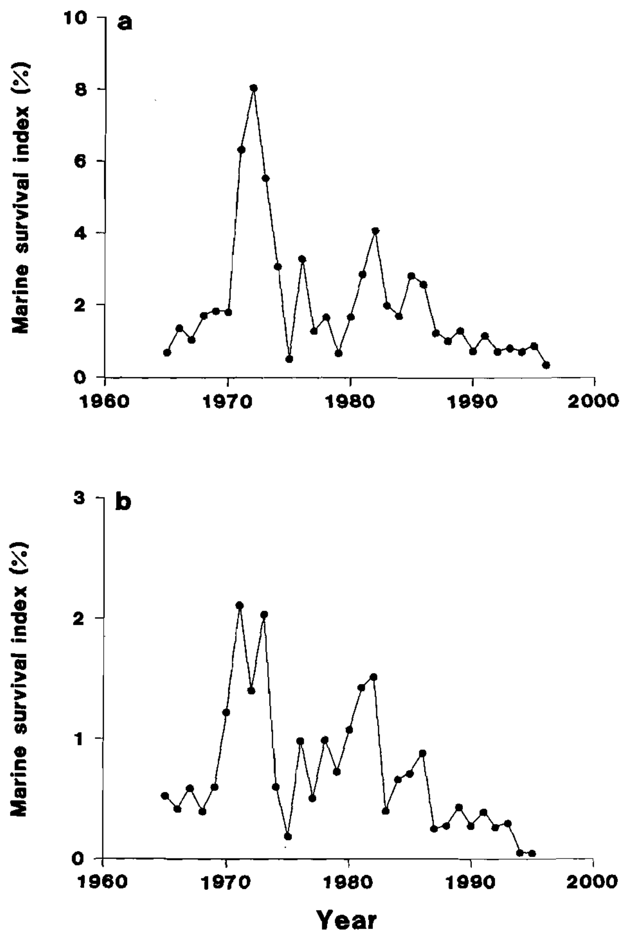

Fig. 4.6 Marine survival indices for North Esk smolts for (a) 1SW and (b) 2SW returns, 1965–96.

References

Anon. (1985) *Atlantic Salmon Scale Reading. Report of the Atlantic Salmon Scale Reading Workshop.* ICES, Copenhagen.

Anon. (1997) Scottish Salmon and Sea Trout Catches:1996. Statistical Bulletin No Fis/1997/1. Edinburgh, Scottish Office, October 1997.

Anon. (1998) Report of the ICES North Atlantic Salmon Working Group, CM 1998/ACFM 15. International Council for the Exploration of the Sea, Copenhagen, 293 pp.

Bagenal, T.B. & Tesch, F.W. (1978) Age and Growth. In: *Methods for Assessment of Fish Production in Fresh Waters*, 3rd edn (ed. T.B. Bagenal), pp. 101–36. Blackwell Scientific Publications, Oxford.

Brett, J.R. (1979) Environmental factors and growth. In: *Fish Physiology* (eds J.S. Hoar, D.J. Randall & J.R. Brett), vol. 8, pp. 599–675. Academic Press, London.

Casselman, J.M. (1987) Determination of Age and Growth. In: *The Biology of Fish Growth* (eds A.H. Weatherly & H.S. Gill), pp. 209–42. London, Academic Press.

Friedland, K.D. & Reddin, D.G. (1993) Marine survival of Atlantic salmon from indices of post-smolt growth and sea temperature. Fourth International Atlantic Salmon Symposium, St Andrews, Canada. In: *Salmon in the Sea and New Enhancement Strategies* (ed. D. Mills), pp 119–38. Fishing News Books, Oxford.

Friedland, K.D., Hansen, L.P. & Dunkley, D.A. (1998) Marine temperatures experienced by postsmolts and the survival of Atlantic Salmon, *Salmo salar* L. in the North Sea area. *Fisheries Oceanography*, 7(1), 22–34.

Friedland, K.D., Hansen, L.P., Dunkley, D.A. & MacLean, J.C. (in press) Linkage between ocean climate, post-smolt growth, and survival of Atlantic Salmon (*Salmo salar* L.) in the North Sea area. *ICES Journal of Marine Science.*

Holm, M., Holst, J.C. & Hansen, L.P. (1996) Salmon in the Norwegian Sea. Fishing experiments and recorded captures of salmon in the Norwegian Sea and adjacent areas, July 1991–August 1995. *Fisken og Havet*, **1**, 13.

Holst, J.C., Nilsen, F., Hodneland, K. & Nylund, A. (1993) Observations of the biology and parasites of postsmolt Atlantic salmon, *Salmo salar*, from the Norwegian Sea. *Journal of Fish Biology*, **42**, 962–6.

Holtby, L.B., Andersen, B.C. & Kadowaki, R.K. (1990) Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Onchorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences*, **47**, 2181–94.

Perry, R.I., Hargroves, N.B., Waddell, B.J. & Mackas, D.L. (1996) Spatial variations in feeding and condition of juvenile pink and chum salmon off Vancouver Island, British Columbia. *Fisheries Oceanography*, **51**, 73–88.

Salminen, M., Kuikka, S. & Erkamo, E. (1995) Annual variability in survival of sea ranched Baltic salmon, *Salmo salar* L.: significance of smolt size and marine conditions. *Fisheries Management and Ecology*, 2,171–84.

Shearer, W.M. (1992) *The Atlantic Salmon, Natural History, Exploitation and Future Management*. Halsted Press, New York.

Shelton, R.G.J., Turrell, W.R, MacDonald, A., McLaren, I.S. & Nicoll, N.T. (1997) Records of post-smolt Atlantic salmon, *Salmo salar* L., in the Faroe-Shetland Channel in June 1996. *Fisheries Research*, **31**, 159–62.

Smart, G.N.J. (1986) Recent changes in fishing methods. In: *The Status of Atlantic Salmon in Scotland.* (eds D. Jenkins & W.M. Shearer) 50–54. Institute of Terrestrial Ecology, Huntingdon.