Predation and scavenging of salmon carcasses along spawning streams in the Scottish Highlands

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FINAL REPORT FOR THE ATLANTIC SALMON TRUST

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Abstract

Salmon carcasses were recorded during October - December along spawning streams in 3 study areas: 1 upper Shee Water, R. Tay system (2000 & 2001); 2. Upper Clunie Water, Aberdeenshire Dee system (2000 [part of area] and 2001) and 3. Kinlochewe River, R. Ewe system (2001 only). Estimates of numbers of salmon within each study area are based on fish observations, redd counts and counts at fish traps. Interpretations of "predated" vs. "scavenged dead" salmon carcasses were based on field observations of carcass condition, carcass location; amounts and parts of carcasses consumed; and from foot prints, trails, and other signs. Additional data for Kinlochewe relates to the movements and fate of 12 radio-tagged salmon within the study area.

Otters were found to be present in all study areas. Estimated mean densities of spawning salmon were 50 fish/km for Shee (both years), 20 fish/km for Clunie (both years) and 10 fish/km fr Kinlochewe (2001). The majority of carcasses were of males, and many were taken dead or near dead from the water towrds the end of the spawning period. Remains of females containing eggs were recorded from all three study areas. Contemporaneous otter spraints containing large salmonid eggs were recorded locations within 400m of over 75% of these carcasses in Clunie and Kinlochewe, and over 20% of these carcasses in Shee (where spraints were collected from only one bank, once per week). Crude minimum estimates for predated pre- or part- spawned female salmon are: 10% (2000) and 6% (2001) for Shee, 10% (2001) for Clunie and 10% (2001) for Kinlochewe of respective total adult female salmon populations.

Salmonid remains were the most frequently recorded item in otter spraints collected during the study period in all study areas. Both large and small (trout or salmon parr) salmonid remains were found. Otters were the principle scavengers of carcasses, although fox, mink and pine marten were also recorded. The vulnerability of salmon to otter predation is likely to vary according to stream channel morphology, predator and scavenger densities, and salmon and alternative prey densities. Levels of predation by otters may be elevated near natural or artificial obstructions to fish migration, and where there is little cover for adult fish. Salmon may become increasingly vulnerable to predation by otters as streams become shallower toward their upper reaches. These factors should be considered when estimating salmon spawning targets for stream systems and when developing recommendations for the management of freshwater habitat for salmon.

Contents

Introduction

Salmon are a rich source of marine derived nutrients and energy, and can represent an important seasonal food source for a diversity of wildlife including otters and juvenile salmonids (see Cederholm *et.al*., 2000, for review). Recent research in North America has highlighted the importance of Pacific salmon spawn and carcasses to the biological productivity and ecological development of spawning streams and riparian areas (Gresh *et al*., 2000; Cederholm *et al*., 1999; Wipfli *et al*., 1999). In Scotland, densities of spawning Atlantic salmon in most upland stream systems have been somewhat smaller than spawning densities associated with Pacific salmon river systems (cf. Mills, 1989; Gresh *et al.,* 2000). Unlike many of their Pacific counterparts, Atlantic salmon do not normally die *en masse* around redd sites following spawning (Watson, 1999). Previous studies have documented the predation of salmon by otters and the use of salmon carcasses by terrestrial and avian scavengers around relatively low altitude spawning areas along the River Dee and its tributaries in Aberdeenshire (Carss *et al*., 1990; Hewson, 1995a & 1995b).

This study aimed to investigate the patterns and causes of adult salmon mortality along upland spawning streams in Scotland.

Specific objectives were:

1. to obtain estimates of salmon spawning densities and carcass densities in different areas of the Scottish Highlands

2. to determine levels of mortality of adult salmon along spawning streams

3. to compare levels of predation of salmon between and within different spawning areas

4. to investigate the diet of otters during the salmon spawning season

5. to provide guidance for calculations of 'spawning targets' that includes consideration of anticipated salmon predation levels

Study sites

Field surveys were conducted within three study areas in the east and west Highlands of Scotland:

Shee Water

This area was selected as a relatively 'healthy' east coast system where relatively high densities of spawning salmon (>50 salmon / km stream) were anticipated. The Shee Water is within the River Tay catchment. The study area comprised of 20 km of streams above the bridge at Glenshee Lodge (NO 132 681).

This area was divided into 4 sections:

1. "Main river": Shee Water from Glen Shee Lodge to the confluence with the Allt a' Ghlinne Bhig (Glen Beag burn) near Spittal of Glen Shee (~3.3 km)

Relatively low gradient (1: 300) stream, 10 - 15m wide, flowing through alluvially reworked glacial moraines. Several pools of 2 -3+ m depth; with 'fords' of well-sorted gravel - pebbles. Some sections of bank lined with birch & willow trees or willow and rose scrub; other areas of less deeply rooted grasses. Extensive and rapid erosion of stream banks especially on corners of meanders, depositing >1000 tonnes of top soil per week into the river during the study period.

2. "Salmon reserve": Shee Water from confluence of Allt a' Ghlinne Bhig near Spittal to confluence of Glen Lochsie burn and Allt Ghlinn Thaitneach (Glen Taitneach burn) near Dalmunzie House (~2.5 km).

Low to medium gradient (1: 200 - 1: 100) stream, 8 - 12m wide. Lower part mainly flowing over alluvially reworked glacial deposits; upper part slightly steeper, eroding less well sorted post-glacial deposits. West bank thickly vegetated: willow and rose scrub, with birch and young spruce trees, revetted in places; east bank more 'open' and grassy, and eroding more rapidly.

3. "Glen Beag burn": Allt a' Ghlinne Bhig, from confluence near Spittal to highest redds, SE of Creag nan Eun (~8.0 km).

Mainly low to medium gradient (1:150 - 1:100) stream, 4 - 8m wide, flowing through open grassy sheep and deer grazed valley above a short (400m), steeper, (>1:20) cascade through wooded gully into lower, part-canalised, 600m section above confluence. Meandering in places, with well sorted alluvial gravels at tails of many pools (typically < 1.5m deep).

4. "Glen Taitneach burn": Allt Ghlinn Thaitneach, from confluence near Dalmunzie to highest redds, due west of Creag Dallaig (~6.0 km).

Medium gradient (1: 100 - 1: 50) stream, 2 - 8m wide, flowing mainly through open grassy sheep and deer grazed valley. One braided section midway up where fairly rapid erosion and reworking of glacial & post glacial deposits. Few pools > 1m depth. Fewer places with gravels suitable for salmon spawning (compared to Glen Beag burn).

The Glen Lochsie burn which joins the Shee water below Dalmunzie was not surveyed. Relatively small numbers of salmon may spawn within its lowermost reaches (< 3 km), but higher gradients, lack of suitable gravels and ultimately insurmountable falls prevent salmon from spawning further upstream (Summers, *pers. comm.*).

A fish counter situated near Blairgowrie (30 km downstream) indicated that relatively large numbers of salmon had entered the Ericht system earlier in 2000 (possibly more than 14, 000 fish); and that reasonable numbers of spawning salmon could be anticipated within the study area (*ibid*.). A preliminary survey along the riverbank (early October 2000) provided evidence of the occurrence of otters (spraint sites with fresh spraints, runs through vegetation, etc.).

Figure 1: Glen Beag Burn, Shee Water Study area, November 2001 [showing otter spraint site (↓) , and locations of some of the salmon carcasses found (↓)].

Clunie Water

This area was selected as it was located within the same land management area as the Shee and likely to have similar predator / scavenger populations, and because of interest in levels of predation around the FRS fish trap on th Baddoch Burn. The Clunie is within the River Dee catchment area and therefore has a distinct salmon population from that in the Shee. The fish trap recorded numbers of adult salmon entering the Baddoch Burn section of the study area (operated by Fisheries Research Services). From recent catch and trap records, relatively modest numbers of spawning fish were anticipated.

Following preliminary investigations along 3 km of the Baddoch Burn in 2000, the study site in 2001 consisted of 13 km of streams above the confluence with the Callater Water (NO155 883).

***Details**: medium - low gradient (1:50 - 1:250) streams, of width 5 - 12 m, flowing through heathery and grassy sheep, deer and rabbit grazed valley. Moderately well-sorted, alluvially reworked post-glacial gravels in some lower sections; fairly rapid erosion of stream banks in some sections. A plantation of ~15 year old Scots pine located around confluence of Clunie and Baddoch Burns.*

Kinlochewe

This area was selected as a west-coast site, and was adjacent to Beinn Eighe National Nature Reserve where a relatively high diversity of predators and scavengers was anticipated. The Wester Ross Fisheries Trust [WRFT]'s River Ewe Salmon radio-tracking project ran concurrently with the present project providing an opportunity to investigate the movements and fate of radio-tagged salmon.

***Details**: This study area comprised of 20km of low, medium and relatively high gradient streams above Loch Maree (NH 014 645). These included the Kinlochewe River, the lower Bruachaig river (below falls at NH 060 628); the A' Ghairbhe River, Lochs Coulin, Clair and Bharranch, and parts of other tributaries, defined by the movements of radio-tagged fish therein.*

Methods

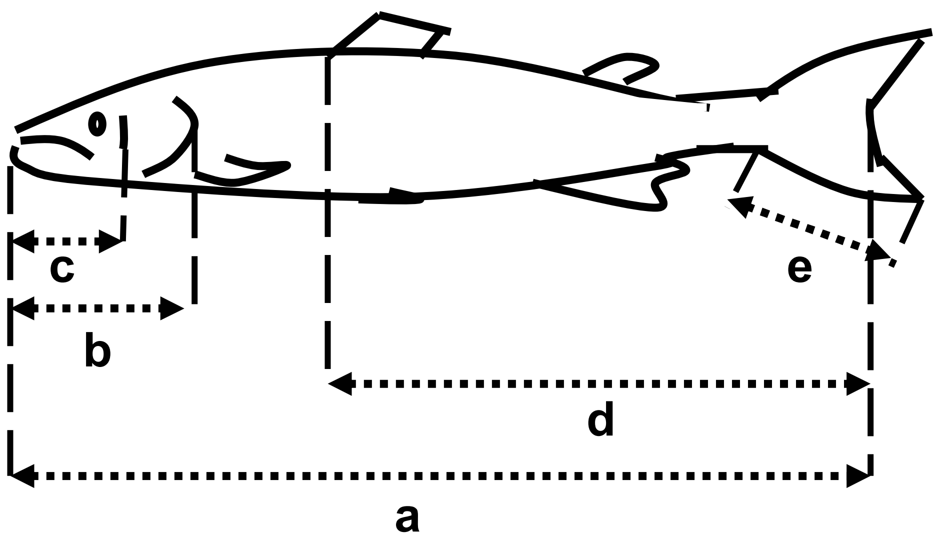
To assess the suitability of the River Shee for the present study a preliminary survey was conducted from the 4th to 18th of November 2000. On two occasions the Clunie was also visited to assess its suitability. As the preliminary survey did not cover the whole spawning season and was not as detailed as the 2001 study, comparisons between the two years have been made only where appropriate.

Numbers of salmon within spawning streams

Estimates of numbers of spawning salmon were based on: observations of spawning fish and redd counts ('Shee'); trap counts and redd counts ('Clunie'); and rod catches, spawning observations and redd counts ('Kinlochewe'). Additional information was kindly provided by Dr Hamish Moir for the Glen Beag burn on the Shee. John Webb (Atlantic Salmon Trust) and Ian MacLaren (Fisheries Research Services) kindly provided details for the Baddoch trap on the Clunie.

Adult salmon carcasses

For each salmon carcass found the following details were recorded. The sex and presence of eggs in or around females, the following lengths (where possible): fork length (**a**), snout to back of operculum (**b**), snout to front of operculum (**c**), base of dorsal fin to fork of caudal fin (**d**), base to tip of caudal fin (**e**), weight, and location (recorded as the 8 figure OS grid reference and the distance from the stream).



Length measurements recorded on salmon carcasses

Signs of predation including tracks, teeth marks and faeces were examined. The parts of carcass consumed were drawn on a diagram. Fish that died non-violent deaths showing no signs of predation are referred to throughout the text as ‘kelts’, although it is accepted that not all of the carcasses referred to as ‘kelts’ will have spawned. To enable subsequent recognition all carcasses were tagged with a wire twist attached around the jaw bone. Carcasses were frequently checked for signs of scavenging after the initial observation. For the preliminary study in 2000, scales from salmon carcasses were aged.

Faecal analyses

During the 2001 study period, otter spraints (and mink scats at Shee Water) were regularly collected within the 3 study sites. At Kinlochewe, collection continued into early January 2002. Smell and shape were used to distinguish otter spraint from mink scats. Presence or absence of salmonid eggs was recorded for the fresh spraints in the field prior to freezing. Faeces were thawed prior to analysis, soaked in a saturated solution of biological washing powder for up to 48 hours at room temperature, rinsed through a sieve and dried (following Carss and Parkinson, 1996). Prey items were identified following Conroy *et. al.* (1993). Bones from large salmonids are often fragmented in faeces, so salmonids were categorised as small or large by eye only. Where atlas bones were available, salmonids were identified to species (Feltam and Marquis, 1989). Amphibians were also identified to species where possible (Brown, 1997). Presence or absence of the prey items was recorded for each spraint and expressed as percent frequency (the percent of spraints containing an item).

Analyses

All analyses were carried out using Minitab.
Examination of data for spawning observations (Moir, unpublished) allowed the 2001 study period for the Shee to be split into three time periods: early spawning (up to the 30th of October), peak spawning (31st October to 12th November) and late spawning (13th November to end).
To analyse the relationship between sex and carcass type on body length, a two way Analysis of Variance (ANOVA) was carried out using the GLM procedure for unbalanced sample sizes.

Results

Shee preliminary survey, 2000

A total of 94 carcasses were recorded within the Shee area (Figure 2) out of an estimated spawning population of 800-1200 salmon (Cunningham, 2001). Of these, 89 were considered as fresh predator kills, and 2 had died a non-violent death. Three could not be clearly defined into either category and were not analysed further.

Otter spraints were found next to 3 freshly predated carcasses and predated carcasses were eaten in a characteristic manner as described for otter predation by Carss *et. al.* (1990), and Hewson (1995a and b). In 70 predated salmon, the flesh immediately behind the head had been eaten. The lower section of the body was eaten in 57% of carcasses. The head had been removed in 16% of the carcasses, and the tail was removed in 24% of the carcasses. Two carcasses had no flesh removed other than the marks that showed they had recently been taken from the water.

Of the predated carcasses that could be sexed, 70% were male. Of the males that could be aged, 14% were 2 sea-winter fish, the remaining 86% were grilse. In comparison, 35% of females were 2 sea-winter fish, the remaining 65% were grilse. 72% of the females were taken before or during spawning. Carcasses were not randomly distributed throughout the study site, a higher number of males were observed in the Glen Beag burn (Table 1).

Section	*Females*	*Males*	*Unknown*	*Totals*
Main river	6	12	1	9
Salmon reserve	2	1	0	3
Glen Taitneach Burn	9	8	0	17
Glen Beag Burn	8	36	6	50
Totals	25	57	7	89

Table 1. Distribution of otter kills within the Shee study site, 2000.

Further signs of scavenging were observed at 20 carcasses on subsequent examination. It is most likely that the level of scavenging was under-estimated, as fish that had disappeared completely were not considered if there was any possibility that they had been washed downstream.

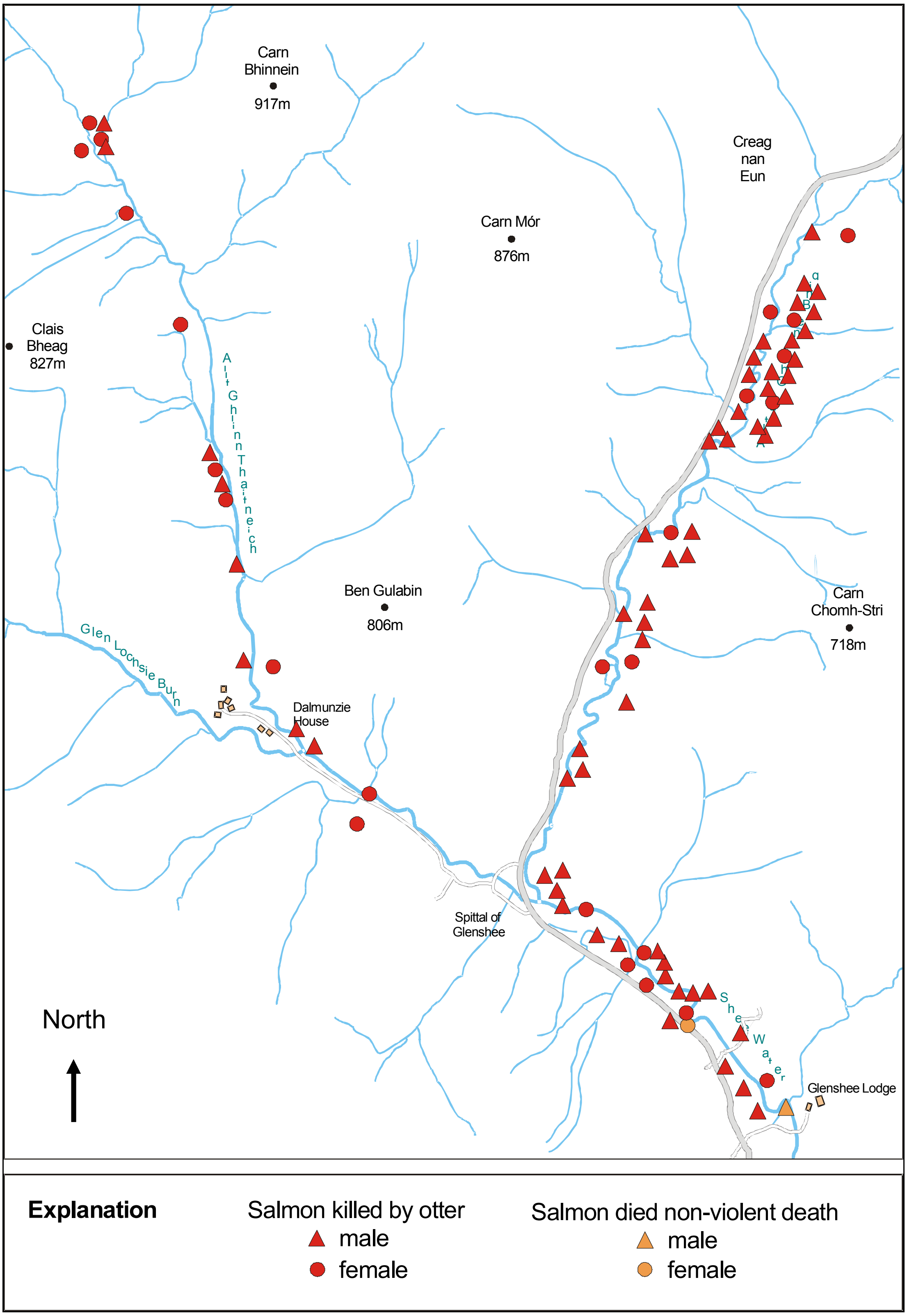


Figure 2: Distribution of salmon carcasses found in the Shee Water study area, November 2000. Note that surveys were limited to main stems of streams, and side burns were not surveyed.

Clunie preliminary survey (2000)

Parts of 21 predated salmon carcasses (16 males and 5 females) were found along the Baddoch Burn. 17 of these carcasses were found in woods near the fish trap (only 52 salmon entered the FRS trap). The other 4 carcasses were above the trap, including two females with eggs near spawning areas.

Shee, 2001

Spawning population size

The Shee was estimated to have a spawning population of 800-1000 salmon. Of these 300-400 were thought to be female and 500-600 male.

Carcasses

A total of 102 carcasses were recorded within the Shee area (Figure 3). Of these, 62 were considered as fresh predator kills, and 28 had died a non-violent death. Twelve could not be clearly defined into either category and were not analysed further. As in the preliminary survey, predated carcasses were eaten in a characteristic manner as described for otter predation by Carss *et. al.* (1990), and Hewson (1995a and b). Otter spraints were also found next to 9 recently predated carcasses. This, and the following otter and mink faecal analysis, suggests that otters were the primary predators.

Otter kills

In the freshly predated salmon, flesh behind the head was the most commonly eaten body part, eaten in a ventral to dorsal direction; all of the carcasses had part of this area missing. The rear section, behind the dorsal fin, was eaten in 44% of carcasses. The head had been removed in 30% of the carcasses, and the tail was removed in 12% of the carcasses. On 4 occasions only the jaw remained.

Of the 47 otter kills which could be sexed, 28 (60%) were male and 19 (40%) were female. There was a trend towards the females being taken at the beginning of the study period and males being taken towards the end (Figure 4). 15 (79%) of the females contained eggs, only 4 (21%) did not. Of the 4 that did not contain eggs, 3 were predated in the late spawning period.

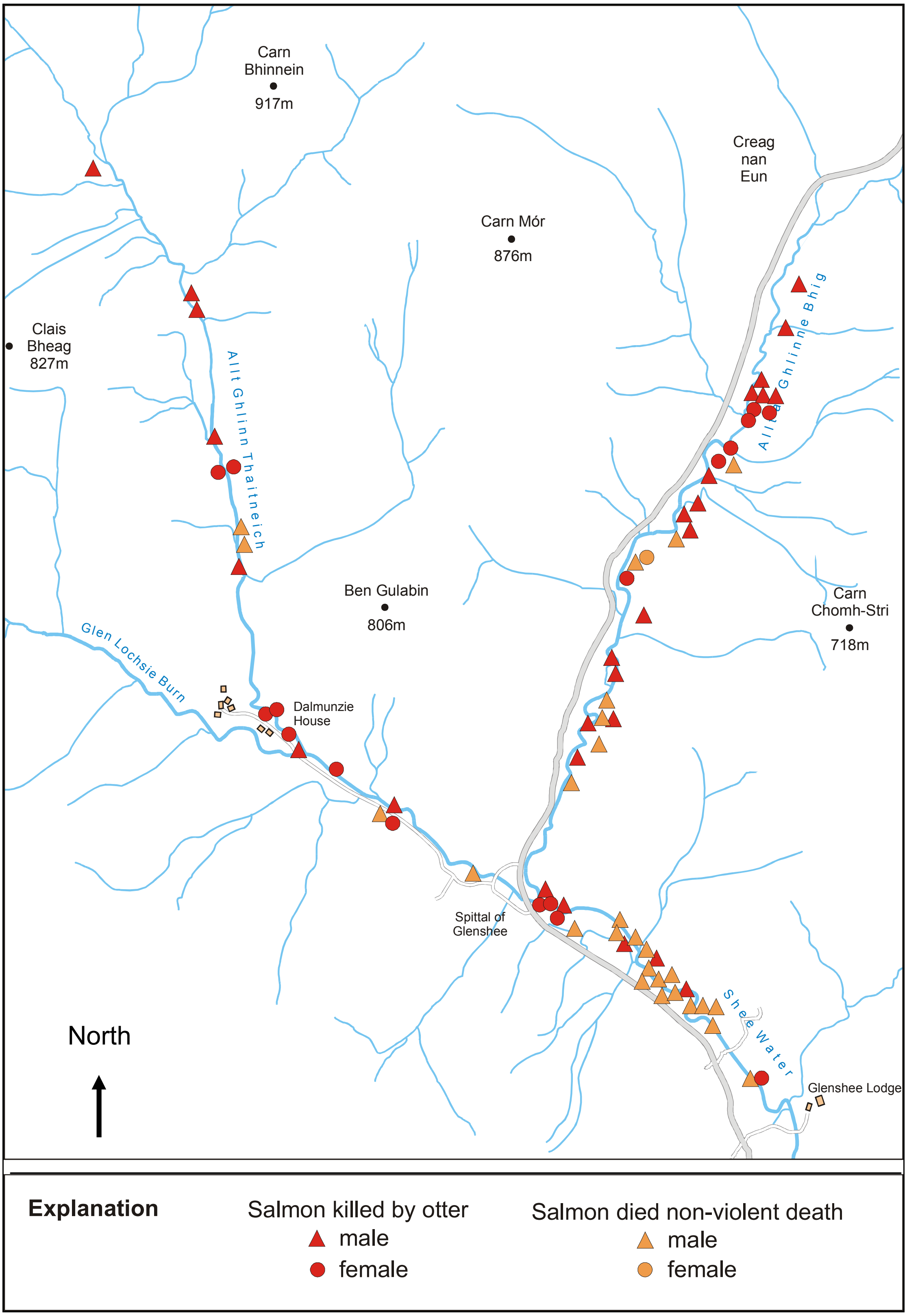
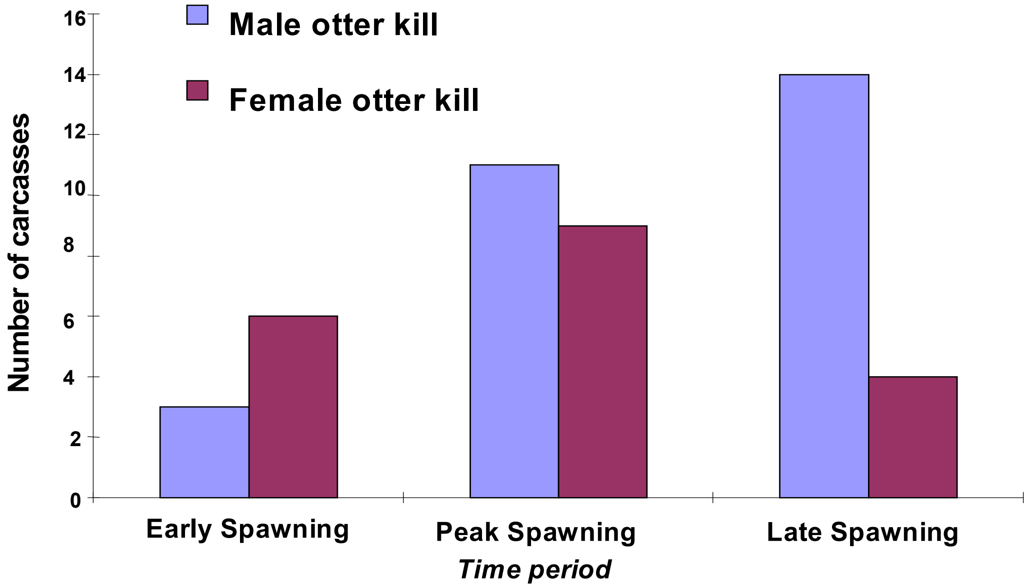


Figure 3. Distribution of salmon carcasses found in the Shee Water study area, October - November, 2001. Note that surveys were limited to main stems of streams, and side burns were not surveyed.

Figure 4. The relationship between spawning time period and sex of otter kill.



To estimate the original lengths of the predated salmon, regression equations were calculated for 4 body measurements from the intact salmon. As salmon show sexual dimorphism, regression relationships were examined separately for males and females (Figure 5-8). The strongest relationship for each sex (Fig. 5 for males, Fig. 6 for females) was used to calculate the original fork length where possible, otherwise the next best relationship was calculated. The mean length for male carcasses was 63.3cm, the mean for females was 64.4cm.

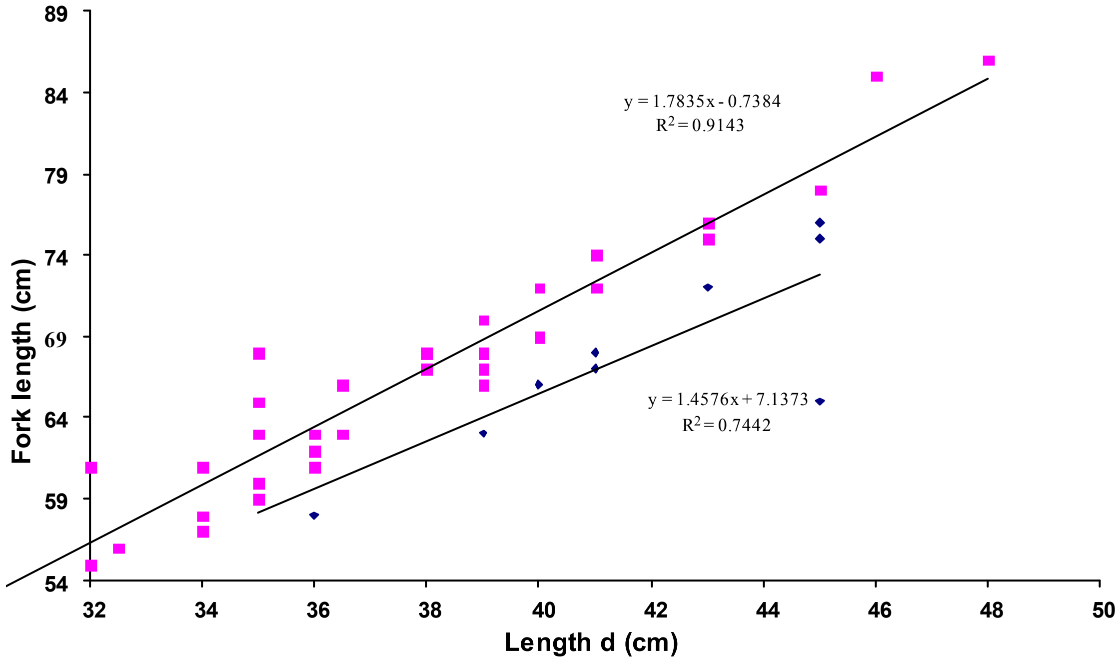


Figure. 5. Relationship between length d and fork length, Shee salmon 2001 (Male pink, female blue).

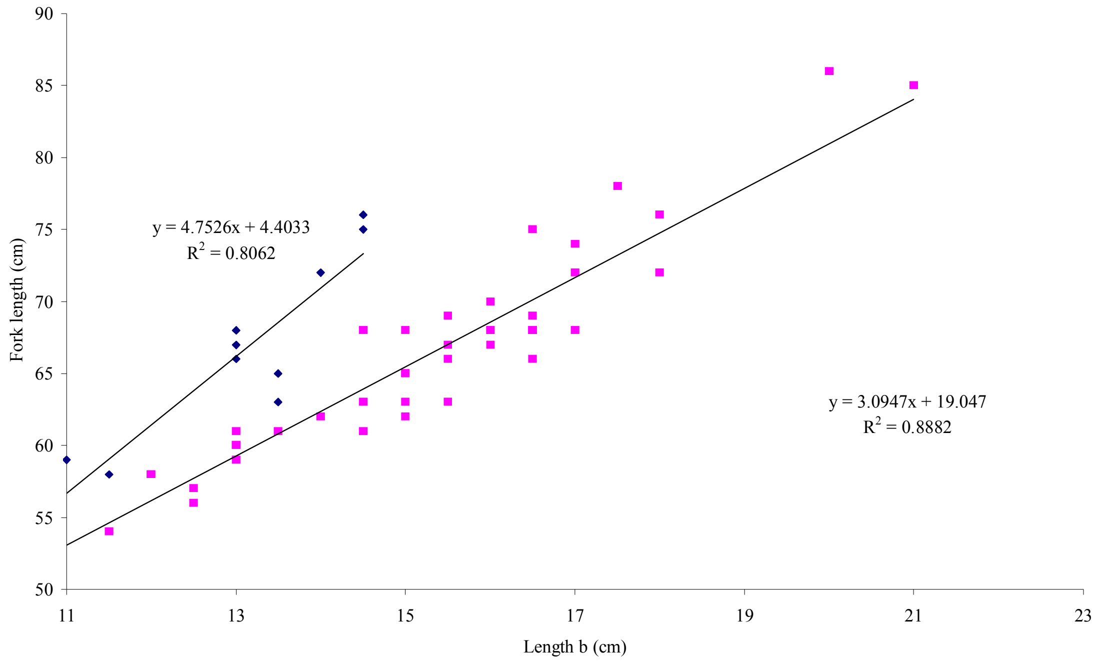


Figure. 6. Relationship between length b and fork length (a), Shee salmon 2001.

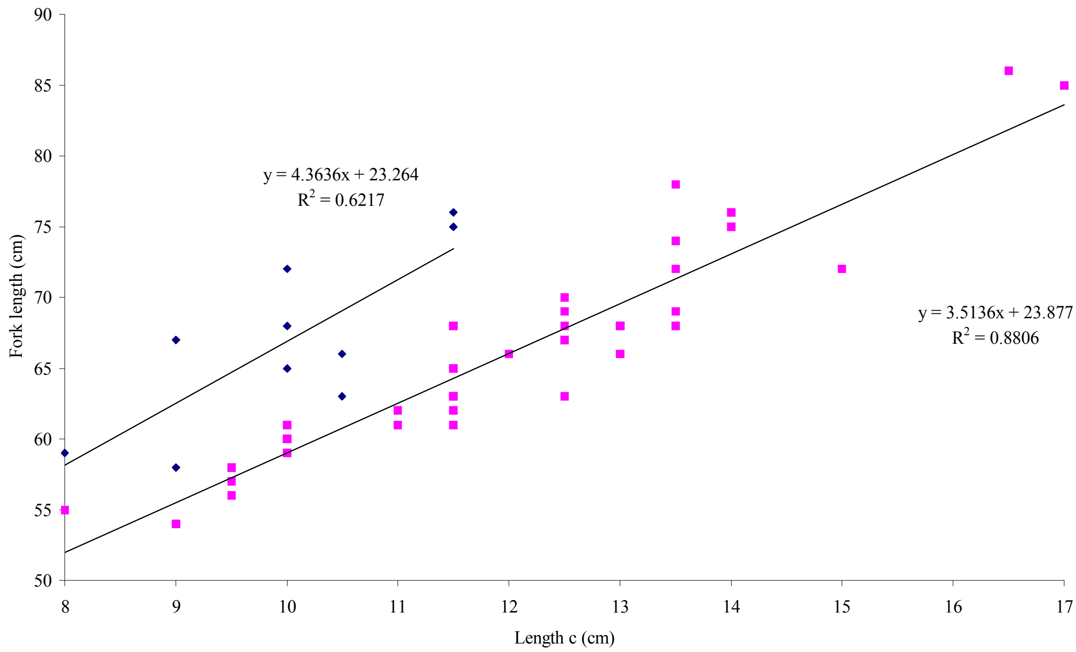


Figure. 7. Relationship between length c and fork length (a), Shee salmon 2001.

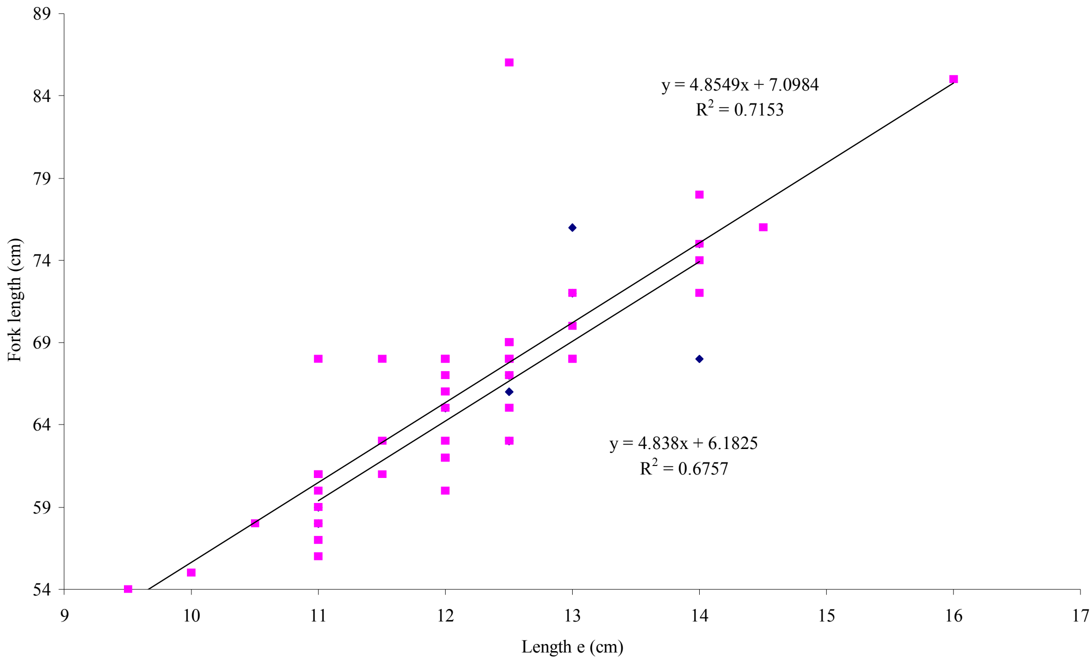


Figure 8. Relationship between length e and fork length (a), Shee salmon 2001.

The original body weight of male otter kills was calculated using the relationship between the weight and fork length from complete males ($W=2E\text{-}06L^{3.347}$, where W = weight in kg and L = length in cm). The weight of the carcass remaining was subtracted from the calculated weight of the original fish to give an estimate of the 'meal' weight (following Carss *et. al.* 1990). The mean meal weight was 0.67 kg (range from 0.38-1.51kg).

Of the 62 otter kills that were observed, 45.2% were subsequently scavenged. Three of these carcasses were further scavenged. A total of 10 carcasses were completely removed from the site where they were originally discovered, one of which could probably be attributed to otters as a fresh spraint was deposited at the carcass site within the 3 days between the carcass being originally found and disappearing. The mean meal size of a second visit to a carcass was 0.66 kg.

Kelts

Of the 28 fish that had died non-violent deaths and showed no signs of predation when first observed, 7 were later scavenged. Three had the characteristic otter predation signs of flesh taken from behind the head, 2 had only the head remaining and 2 were removed completely.

Comparison of kelts and otter kills

96% of kelts were male. This was significantly higher than the proportion of otter kills (χ^2=12.2, d.f.=1, $p<0.05$). Most of these kelts were observed within the late spawning period. This was significantly different to the otter kills which were found throughout the study period (χ^2=20.7, d.f.=2, $p<0.05$; Figure 9.).

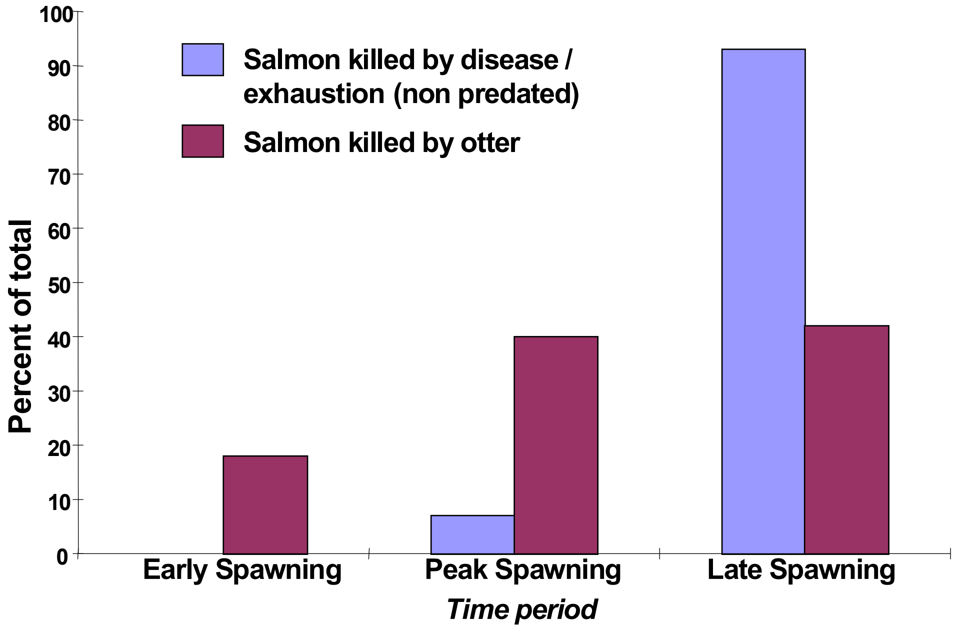


Figure 9. Comparison of the time periods within which otter kill and kelt carcasses were found.

Otter kills and kelts were of similar lengths (Figure 10). An ANOVA found no influence of carcass type, sex or the interaction of these variables on fork length (p>0.05).

Figure 10. Mean fork length of kelts and otter kills.

All dead kelts found had medium or high levels of fungal infection (Figure 11). This was significantly higher than the levels observed on otter kills (χ^2=47.9, d.f.=2, $p<0.05$). When the fungus levels were examined in relation to the 3 spawning time periods, 11 predated fish with no or low levels of fungal infection were observed in the late spawning period. The difference between the kills and kelts can not therefore be explained by the time of spawning season in which the carcasses were found.

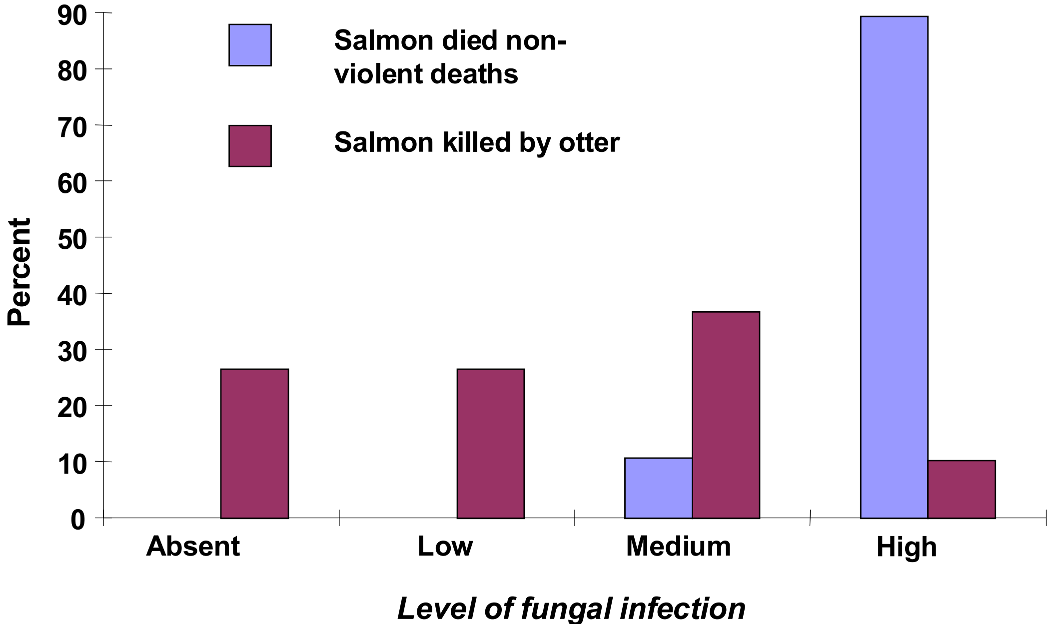


Figure 11. Levels of fungal infection observed on kelts and otter kills.

Location of carcasses

78.6% of kelts were first observed in the water while only 1.8% of otter kills were observed in the water (χ^2=54.6, d.f.=1, $p<0.05$). The median distance of kills from the river edge was 1.25m. Only 8.9% of otter kills were found adjacent to a pool, the rest being found next to runs. The proportion of kelts found in or near pool habitat was slightly higher at 16.7%.

Within site variation

The kills and kelts were not evenly distributed throughout the Shee study site (χ^2=23.3, d.f.=3,$p<0.05$, see Figure 2). In particular, far more kills were observed on the Glen Beag burn (Table 2) than expected by chance and far more kelts on the main river (Table 3). On all river sections the majority of kelts were male, however only on the Glen Beag burn were the majority of otter kills male. On the other sections the ratios of males to females were more equal (Table 2).

Table 2. Distribution of otter kills within the Shee study site.

Section	*Females*	*Males*	*Unknown*	*Totals*
Main river	3	4	1	8
Salmon reserve	2	1	0	3
Glen Taitneach Burn	7	6	2	15
Glen Beag Burn	7	17	12	36
Totals	19	28	15	62

Table 3. Distribution of kelts within the Shee study site.

Section	*Females*	*Males*	*Unknown*	*Totals*
Main river	0	17	0	17
Salmon reserve	0	1	0	1
Glen Taitneach Burn	0	2	0	2
Glen Beag Burn	1	7	0	8
Totals	1	27	0	28

No significant difference was found for male kelt fork length between the different areas of the Shee system ($F=0.2$, $p>0.05$). The same was true for fork length of male otter kills ($F=0.1$, $p>0.05$).

Clunie, 2001

Spawning population size

The Clunie was estimated to have 230-280 salmon, of which 80-100 were female and 150-190 male.

Carcasses

Parts of 14 salmon carcasses (6 females and 8 males) were recorded during surveys at 6 to 14 day intervals in October and November. All female carcasses were of pre- or part-spawned fish.

Following the discovery on 7th October 2001 of predated salmon (one female and 2 males) in or by the FRS Baddoch fish trap, an electric fence was erected by FRS staff along about 50m of stream bank (Figure 19). This fence apparently deterred further predation by otters from around the trap area. Of 81 adult salmon (62 males and 19 females) that subsequently entered the trap and were released upstream to spawn, all females were recaptured back at the trap following spawning on their return downstream (I. MacLaren *pers. comm.*). However, 15 males failed to return. Parts of predated or scavenged males were discovered around spawning areas (J. Webb *pers. comm.*).

Kinlochewe, 2001

Population size

The Kinlochewe study area was estimated to have 150-300 salmon.

Carcasses

Twelve radio-tagged salmon (6 males and 6 females) were present within the Kinlochewe study area at the beginning of November 2001. In early December, the radio-tags of 5 males and 1 female were recovered from stream banks or stream-side locations, all within 2km of Kinlochewe village (Figure 16,17). Scales and other fragments of carcasses were present at two of the locations where tags were recovered; another tag was recovered from a position where it could not have been washed into. The remaining 3 tags were recovered from the river, in pools immediately downstream of shallow fords. One of these tags had distinct bite marks. From surveys of spraint sites, otters were present within this part of the study area throughout November. Interpretation of radio-tracking data suggests that all 6 fish were predated by otter, between mid-November and early December.

The one surviving male and 5 females were tracked to areas where spawning activity was observed or inferred. All of these fish were subsequently located in lochs downstream of inferred spawning areas.

The remains of 2 untagged pre- or part spawned female salmon were found from the upper part of the Kinlochewe study area where two of the tagged salmon were present. One of the predated salmon was taken in the Loch Clair area, one on the bank by the Cruive Pool (NH 005 580), the other on the bank by the Bharranch burn (NG982 575). Otter spraints containing large salmonid eggs were collected from within 20m of the Cruive carcass; and within 500m of the Bharranch carcass.

Remains of 3 other carcasses (scales, pyloric caecae), were found along the Kinlochewe River. Three other dead or dying salmon in 'Kinlochewe' (all males) were subsequently removed from pools by scavengers.

One of 13 other salmon tagged within the Ewe system returned to sea from the R. Ewe. She was subsequently relocated in the Aultbea river. In early December, her radio-tag, fragments of fin and two eggs were found on the banks of the Aultbea river at (NG 881 888).

Estimation of predation levels in 2001

Crude estimates of actual levels of salmon predation along streams have been obtained as follows:

Shee

The 15 predated pre- or part spawned female salmon recorded within Shee, represent about 5% of the estimated number of female salmon. Stream banks were routinely surveyed at intervals of no more than 4 days. The majority of recorded carcasses were observed on at least two occasions, and fragments of carcasses typically remained visible for periods in excess of 1 week. Few 'old' carcasses that may have been over-looked during earlier surveys were recorded. Therefore, the numbers of carcasses recorded were likely to be fairly close to the actual numbers of fish taken from the water, with no more than 20 pre- spawned female salmon taken, giving a predation level of about 6%.

Clunie

The 6 predated pre- or part spawned female salmon recorded within the Clunie study area represented about 5 -10% of the estimated number of adult female salmon within this study area.

In contrast to Shee, two freshly killed male salmon had completely disappeared within 3 days of the initial observation. No large parts of carcasses (including whole fins and heads) were observed on more than one occasion except by the Baddoch trap, where human activities and the electric fence may have deterred scavenging. The total number of salmon taken from this study area during the period early October - early November can be estimated as about 55 (40 + 15 Baddoch males), including 9 pre- or part spawned females. This gives a predation level for pre-spawned females of about 10%.

Kinlochewe

One of six radio-tagged female salmon was predated giving a predation level of 16.5%. However, only three predated female salmon were recorded in total, representing less than 5% of the estimated number of female salmon present within this area. In comparison with the Shee, less regular surveys and anecdotal evidence of higher rates of scavenging suggest that not all carcasses were found. Predation levels are therefore likely to have been higher than the estimated 5%.

Otter population size

A comparison of cumulative totals of all fresh otter kills at the Shee (Figure 12) shows that although the 2000 survey took place in only a short period many more salmon were being preyed upon than at any point in 2001. Previous research has found that one salmon is taken per otter per night with no excess killing (Carss *et. al*., 1990). This suggests at least 5 otters in one night within the study site in 2000, and at the most 3 in one night in 2001.

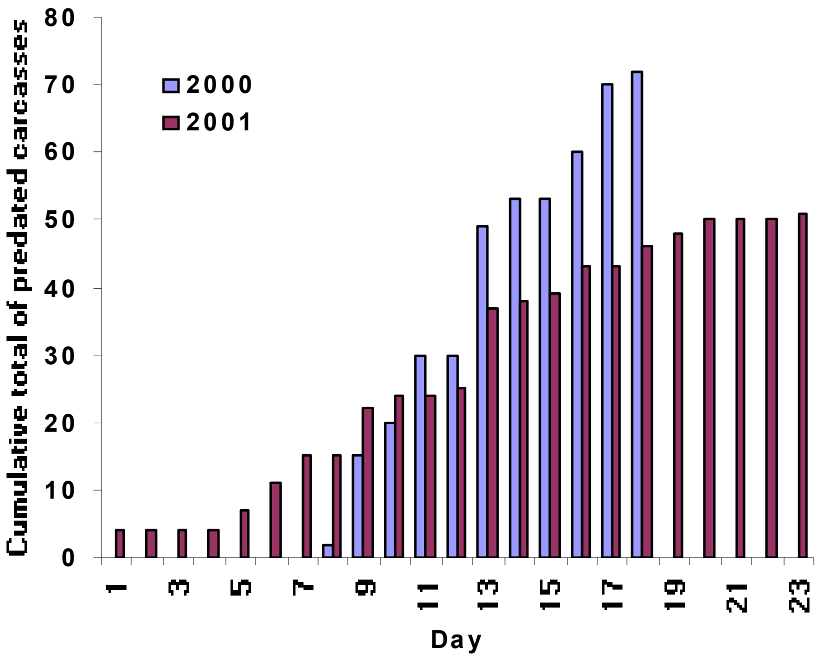


Figure 12: Comparison of cumulative totals of predated salmon carcasses found in Shee study area, 2000 vs. 2001. Note that in 2000 survey work finished after day 18.

Faecal analyses

A total of 163 otter spraints were collected during the study period. Salmonid eggs were observed in some otter spraints in all three study areas. The percent of salmonids was very similar between all three study sites and they were predominant in the diet (Figure 13).

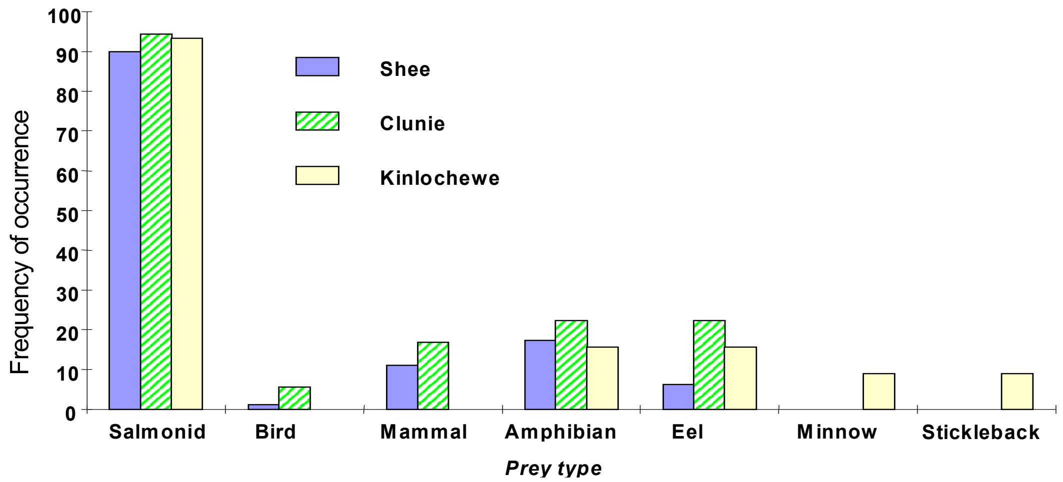


Figure 13. Frequency of occurrence of prey remains in otter spraints during 2001 salmon spawning.

Although spraints were collected during salmon spawning, remains of small salmonids were common at all 3 sites (Figure 14). Only at the Clunie did the number of spraints containing large salmonid remains outnumber spraints containing small salmonids. Remains of large salmonids were highest at the Clunie and lowest at Kinlochewe. The reverse was true of small salmonids, being most common at Kinlochewe and lowest at the Clunie.

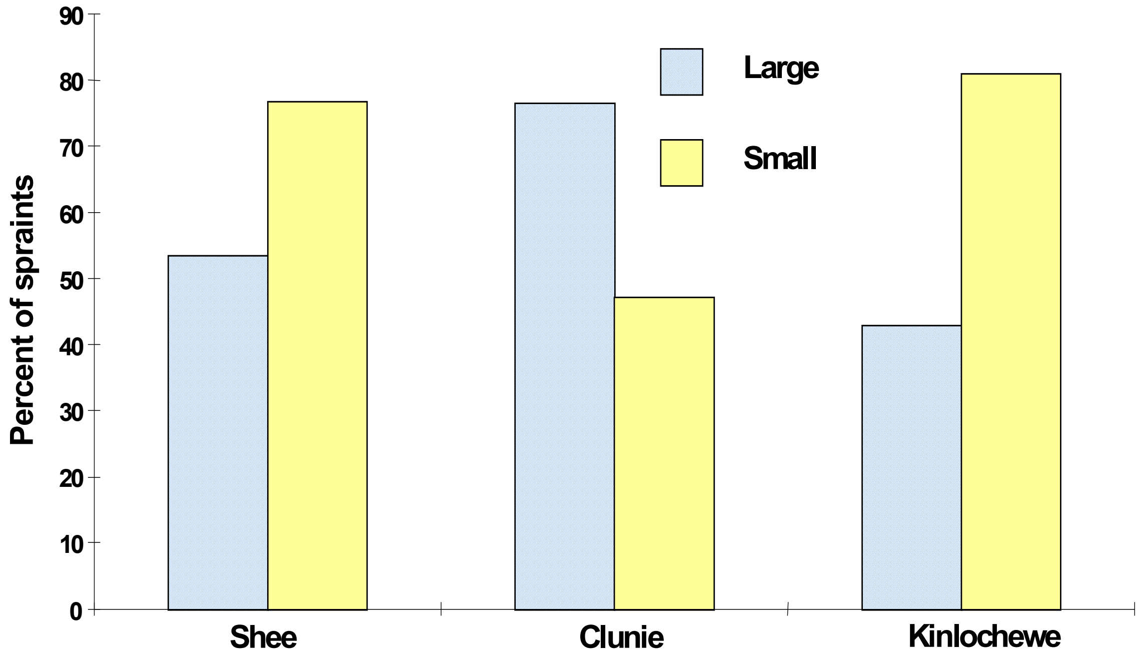


Figure 14. Percent of spraints containing salmonids identified as small or large.

In both Shee and Kinlochewe spraints, trout and salmon atlas bones were identified, however numbers were too small for comparisons. Amphibians and eels occurred in the otter diet at all three sites. The only amphibian species identified was the common frog (*Rana temporaria*) which was found in spraints from all 3 sites. Bird and mammal remains occurred in the Shee and Clunie spraints, but not Kinlochewe. Minnow and stickleback remains occurred only at Kinlochewe.

In the spraint samples taken during December and January at Kinlochewe the occurrence of minnow, stickleback and amphibian increased markedly (Figure 15). The occurrence of salmonids dropped from 93% to 79%. Of these spraints only 20% were observed to contain large salmonid remains, all contained small salmonid bones.

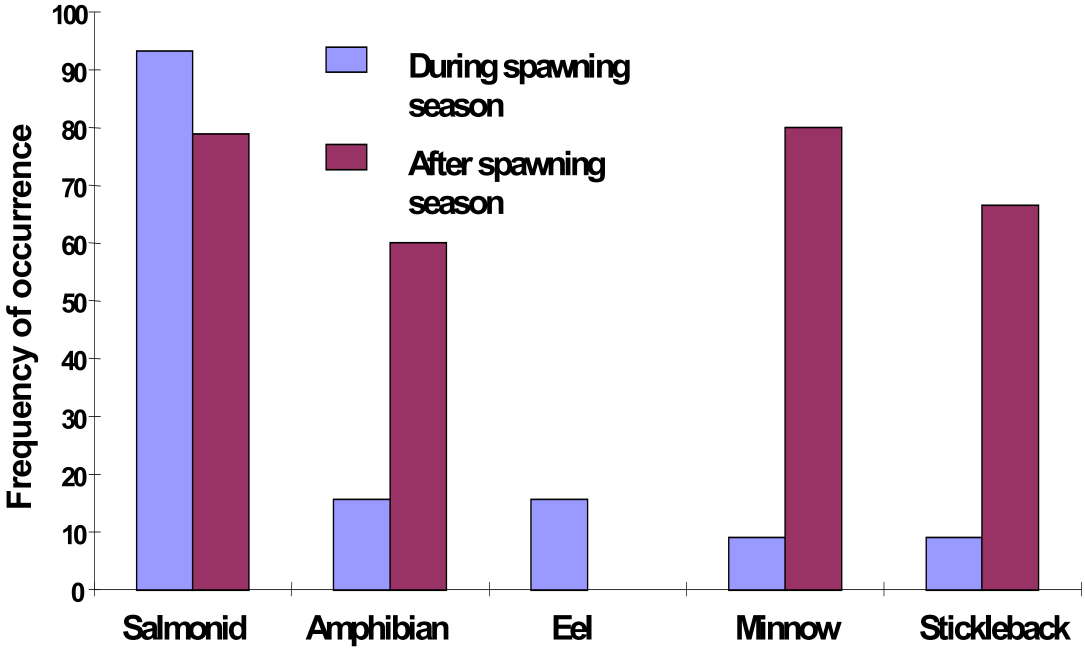


Figure 15. A comparison of frequency of occurrence of prey remains in otter spraints during and shortly after salmon spawning, Kinlochewe system, 2001.

A total of 15 mink scats were collected from the Shee study site. The percent frequency of prey remains was very different from that of otter spraints at the Shee (Figure 16). The highest frequency occurred for mammal remains, followed by bird remains. Of the 2 scats containing salmonids one contained large remains and one contained small remains.

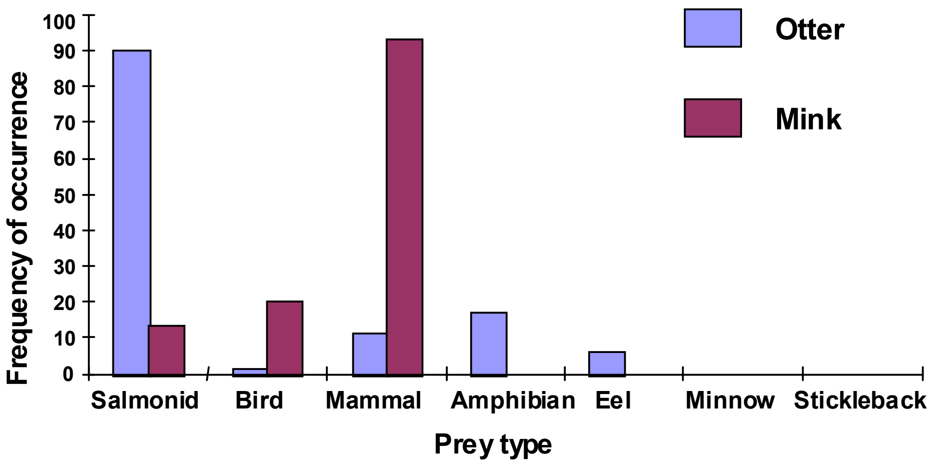


Figure 16. A comparison of frequency of occurrence of prey remains in otter and mink faeces during 2001 salmon spawning, River Shee.

Figure 17. For many carcasses, evidence of otter predation was largely circumstantial. Here in Glen Beag, observations were as follows:

a) otter tracks *(note exit hole from water)*/ trail from water to carcasses (top and bottom left); b) salmon carcasses eaten from the back of head towards the dorsal fin, on top of fresh snow (right); fresh blood around the carcass, indicating that the fish was alive or only recently dead prior to being eaten; nearby otter spraints containing large salmonid remains (see Figure 18)

(*Photos by Andrew Harwood, Glen Beag, Shee study area, November 2001)*

Figure 18: Some field notes:

a. The designated spawning status of female salmon was based on the presence / absence of salmon eggs around the carcass (right).

b. Fresh spraints by the carcasses shown in figure 14 Glen Beag Burn, November 2001 (right middle)

c. Otter spraint with salmonid eggs. Loch Bharranch, November 2001 (bottom right)

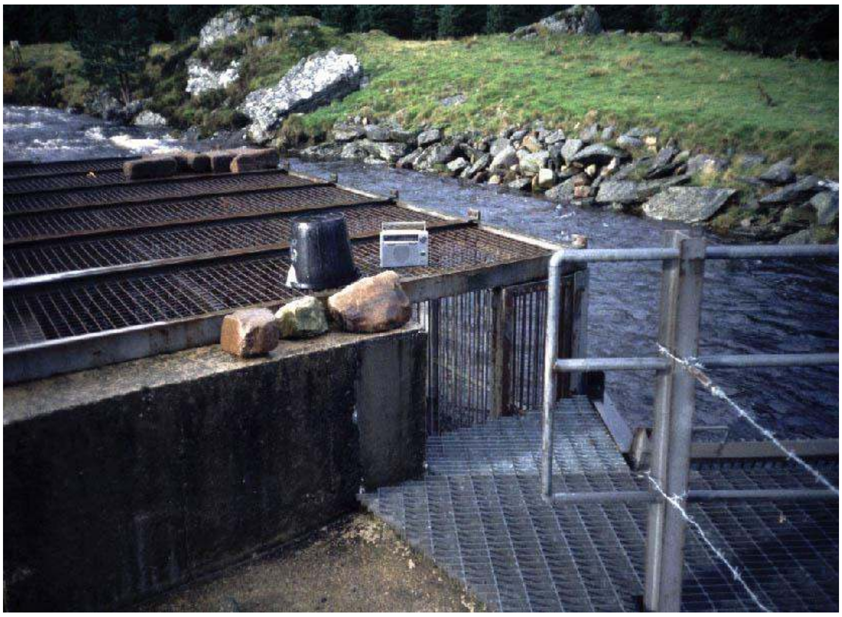
d. A few grilse scales and a few eggs were found on the river bank, near this freshly excavated salmon redd at 435m altitude. Upper Glen Beag burn, November 2000 (below)

Figure 19. Predation at FRS Baddoch fish trap

- ***In autumn 2000, 23 predated salmon carcasses were found by the FRS Baddoch fish trap, including an estimated 30% of females that had entered the burn to spawn. Only 52 salmon entered the trap.***

- ***In autumn 2001, otter predation by the trap was successfully discouraged by FRS via use of radio under a bucket (tuned to BBC Radio 4), and temporary installment of an electric fence around the trap. 81 salmon entered the trap.***

The upstream (adult) chamber within which at least one adult salmon was captured in 2001

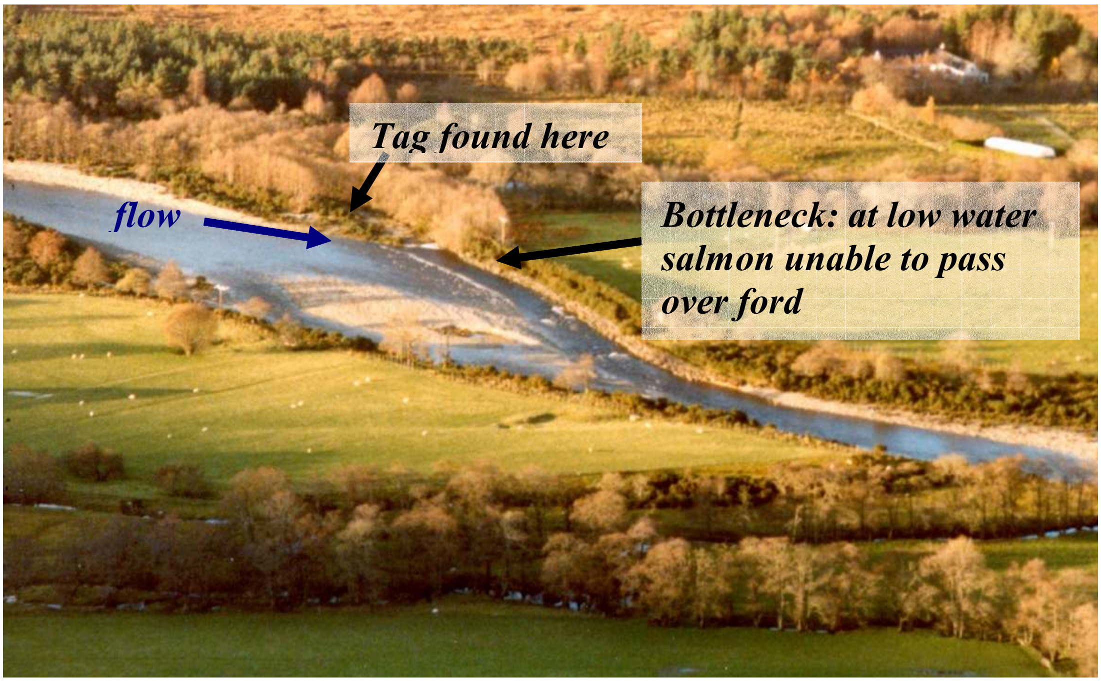


After this electric fence was set up by FRS Freshwater Fisheries Laboratory, predation of salmon by the trap ceased.

(Pictures by Ian McLaren, FRS)

Figure 21: Interpretation of fate of radio-tagged carcasses

a) Kinlochewe River, Wester Ross - shallow ford near Anancaun (*gael.: 'ford of heads'*). The tag and parts of a radio-tagged salmon were found nearby, and appeared to have been taken during a period of low water in mid November 2001.



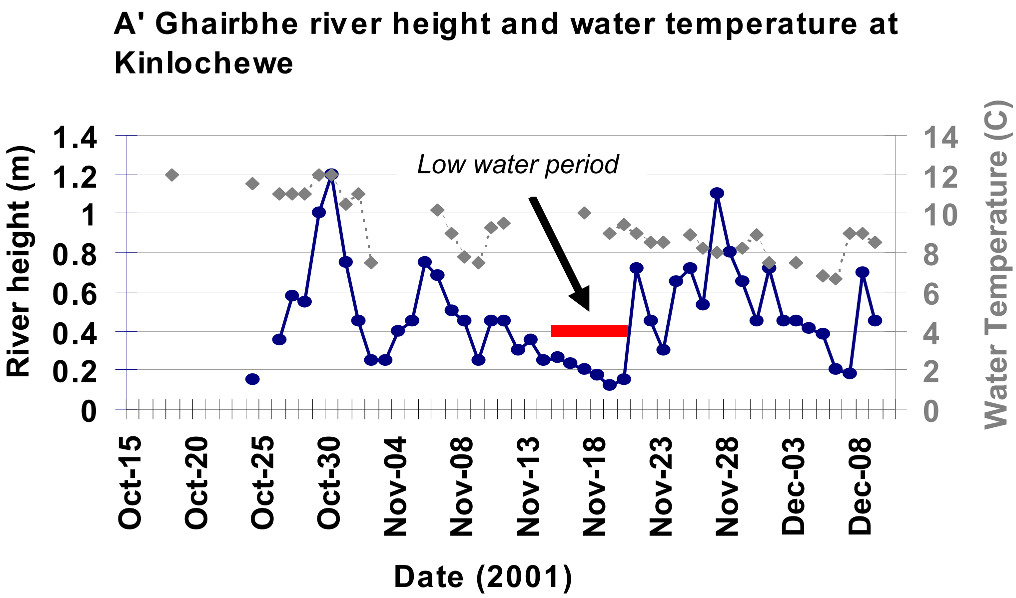
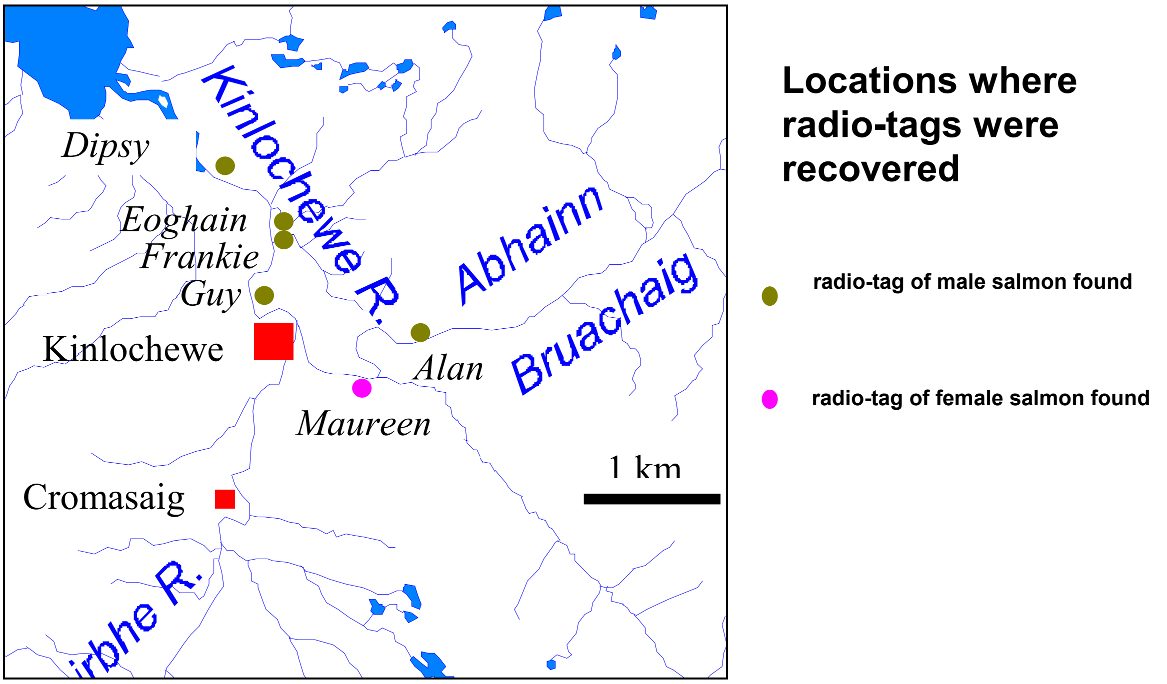


Figure 22. Radio-tags were recovered from river banks or from shallow water between 30th November and 6th December (inclusive) Fresh otter spraints were found near where radio-tags were recovered during October and November, 2001



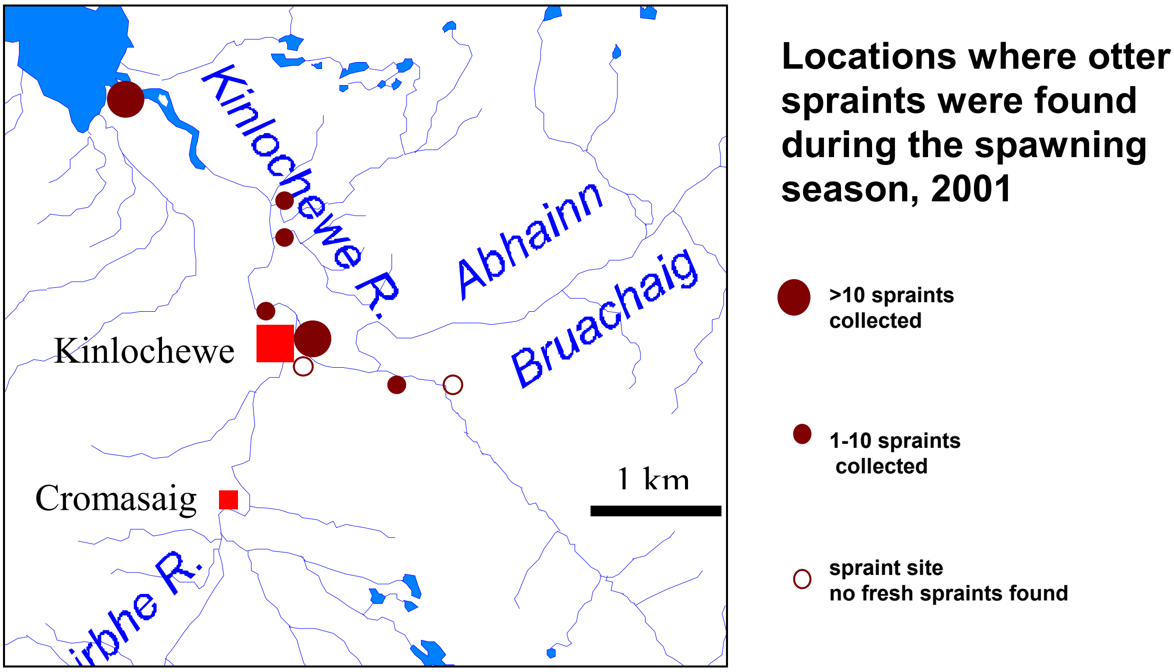


Figure 22. The radio-tag of a female grilse ('Bewsher') was found on the bank of the Aultbea River, Wester Ross on 1st December 2001, beside 2 eggs and fin parts. Prior to entering the Aultbea River, the fish had returned to sea having been radio- tagged and released into the River Ewe in July 2001.

Figure 23. Camera trap set over a salmon carcass by Kinlochewe River, December, 2001

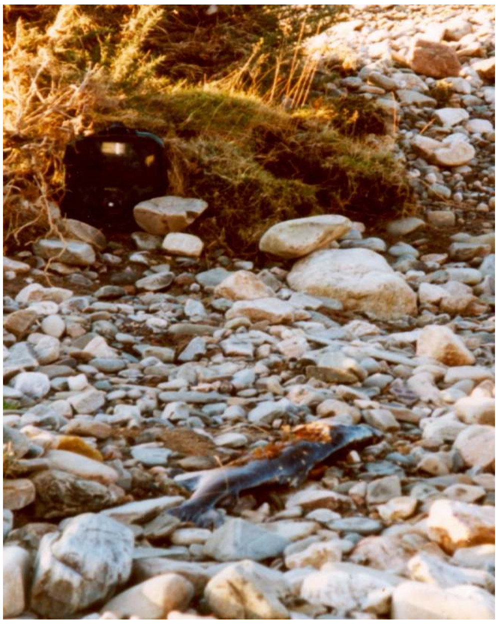


Figure 24. Otter scavenging salmon carcass by Kinlochewe River, early December 2001. Taken by trap camera.

Figure 25. Pine marten, self-portrait, by Kinlochewe River, December 2001

Discussion

Numbers of spawning salmon

The Shee Water contained the highest estimated numbers of spawning salmon, with up to 5 times the number of adult salmon estimated for Kinlochewe. At a basic level the numbers of predated carcasses found mirrored this difference, with by far the highest numbers occurring on the Shee.

Predation rates and prey selection

In freshwater, predation by otters takes place primarily at night (Carss *et al.*, 1990, Green *et al.,* 1984) and it is rarely possibly to catch them 'red handed'. The interpretation of the identity of predators and scavengers of salmon carcasses tends therefore to be based largely on circumstantial evidence. In the present study, teeth marks were recorded on some carcasses, but they are not easily used to distinguish predators from subsequent scavengers. However, for the majority of carcasses, evidence was generally robust enough to conclude that they were otter kills (e.g. Figure 17 and 18).

Both adult male and female salmon were predated at all three study sites. The overall high incidence of male otter kill carcasses found in the present study has been observed previously (Carss *et. al.* 1990) and suggests that the males are, in general, more vulnerable to otter predation than females. However, examining the predation rates in more detail showed that levels of predation of male salmon before the spawning period were no higher than of female salmon. During the spawning period, both male and female salmon were taken from spawning streams but as the spawning period progressed more males were taken. The behaviour and deteriorating condition of male salmon may have made them increasingly vulnerable to predation as the spawning period progressed. Radio-tagging studies have shown that male salmon tend to wander more extensively than female salmon during the spawning period (Webb and Hawkins, 1986; Cunningham, Starr and Butler, 2002) which is likely to increase their risk of predation (cf. Carss, et al 1990).

Mortality of adult female salmon along spawning streams was almost entirely associated with predation by otters. Although the number of female salmon taken by otters was lower than the number of males, it is interesting that the 2001 Shee sample of carcasses contained a significant number of female fish, more than in previous studies (cf. Carss *et. al.* 1990). The majority of female salmon taken by otters were fish that were pre- or part spawned. Levels of mortality of pre- or part-spawned female salmon along spawning streams were typically about 5 - 10% of females present.

There are a number of possible causes for the relatively high proportion of female salmon taken during the early period of the spawning season. Female salmon may 'lead the way' towards spawning reaches and are initially present in equal or greater numbers than male salmon or it may be that pre-spawned (ovulated) female salmon may be more easily caught than male salmon. Finally, otters may target female salmon because they prefer the salmonid eggs contained therein.

Although the number of female salmon predated was relatively lower than the number of males there is more potential for the salmon population dynamics to be affected. It is well documented that each male salmon is capable of spawning with several females (Webb and Hawkins, 1989,) and predation may do little more than to reduce male competition. The numbers of salmon which succeed in returning to spawn a second time are extremely low (Mills, 1989) so it is not likely that otter predation would affect angling. In healthy rivers, predation of pre-spawning gravid females may only serve to reduce competition between fry or reduce the number of eggs eaten by the small salmonids present in the river. However, in rivers where the fish population is already at a suboptimal level, predation of gravid females could reduce the number of eggs, and consequentially parr in the river.

A difference in levels of fungal attack on the dead kelts and otter kills suggested there may have been selection of healthier fish by otters, however this should be treated with some caution. Often all that remained of a predated fish was the head and tail and so there was a smaller proportion of the body to find fungus on. Secondly, the otter kills were usually on shore while the dead kelts were often observed in the water. It may be that the fungus was either more obvious in the water, or continued to bloom in the water.

Salmonids were the major food source for otters during the study period. Although the large salmonids were clearly an important prey item for otters, the importance of small salmonids can not be overlooked. It is well documented that precocious parr actively spawn with adult fish and this may make them more vulnerable to predation (Mills, 1989). Salmon parr and trout may also be present on the spawning grounds consuming eggs (Egglishaw, 1967; Youngson & Hay, 1996), again making them vulnerable.

The slightly extended period of spraint collection at Kinlochewe revealed that the otter diet started changing quite rapidly after the end of salmon spawning, with an increase in alternative prey items such as stickleback and minnow. The occurrence of amphibians was similar to occurrences during the winter in previous studies and it is likely that frogs were taken while hibernating within the river (Brown, 1997).

Subsequent scavenging

Almost half of the carcasses on the Shee Water in 2001 were further scavenged on one occasion and some a second time. Although complete removal of adult salmon carcasses from river-banks is usually attributed to foxes (Hewson 1990a and b), in at least one instance the presence of fresh otter spraints at the carcass site suggested that it had been further scavenged by otters. Hewson (1995b) suggested that scavenged salmonid carcasses were the major food item of otters on the Dee towards the end of the spawning season and thereafter. A trap camera set over a salmon carcass at Kinlochewe during the study period photographed both pine marten and otter.

The diet of mink and otters within the Shee catchment appeared to overlap very little during salmon spawning, with high frequency of occurrence of mammals in mink scats and high frequency of occurrence of salmonids in otter spraints. This suggests that mink neither predated nor scavenged on salmon to any great degree. However, some caution should be taken when extrapolating this as the sample size for mink was very small.

As the present study suggests that otters return to scavenge on carcasses, it is likely that klepto-scavenging, particularly by foxes, may cause otters to take more salmon than they might otherwise need to satisfy their own appetite. Human activities that affect densities of scavengers (e.g. fox control) may therefore influence rates of predation of adult salmon along spawning streams. Following spawning, accumulations of large numbers of dead male salmon in the water may be more likely where predator and scavenger densities are subject to 'control' or where there is other disturbance by humans. It is likely that game-keeping activities were more rigorous within the Shee water study area that at Kinlochewe, which together with higher densities of spawning fish may explain why high numbers of dead kelts were observed only at the Shee.

Management practices and salmon spawning targets

Levels of predation by otters may also be influenced by land use and river management practices. Catchment management practices that alter flow regimes (e.g. 'spatiness') of spawning streams and thus stream morphology are likely to contribute to levels of predation. The recovery of radio tags from predated salmon at Kinlochewe has shown that adult salmon are likely to be particularly vulnerable to capture where stream banks have been eroded and riffle areas have become widened and excessively shallow. Rapid reductions in water levels (following spates) may expose fish to predation. To escape from otters, salmon need water of sufficient depth to move easily from pool to pool. Deep, undercut banks may also provide partial refuge from otters.

Other human activities are likely to affect otter behaviour. Levels of predation by otters were higher around the Baddoch fish trap than in other areas in 2000 and again initially in 2001 until the electric fence was erected (Figure 19). In Wester Ross, otters are known to live adjacent to at least one fish trap and further research is required to investigate whether other fish traps are subjected to high levels of predation by otters. The implications for research studies based on fish trap returns (especially investigations relating to 'natural' smolt - adult salmon survival rates) are rather profound. From the present study we suggest that when otters are present around fish traps, it is probably fair to assume that catches of upstream migrating adults will be at least 10% lower than they would otherwise be, unless the trap has been specifically designed to minimise opportunities for otter predation.

For the purposes of setting spawning targets for vulnerable populations of wild salmon that spawn in semi-natural environments, all of these factors need to be considered. Population densities of predators and scavengers (especially otters and foxes) need to be assessed, along with the condition of spawning streams. Adult salmon may be particularly vulnerable to capture in areas where the banks of spawning streams have been eroded, often as a consequence of heavy grazing; and where densities of predators and scavengers are high.

In conclusion, where otters are present along spawning streams, mortality of adult female salmon should be anticipated in calculations of salmon spawning targets. Although Shee data suggest mortality levels of 6% of female salmon, higher mortality levels are probable in areas with less healthy salmon stocks, higher otter densities and where stream morphology or rapid changes in water level expose fish more than usual to predation.

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References

Brown, L. J. (1997) The Ecology of anurans in a wetland system in north-east Scotland and implications for predation by otters (*Lutra lutra*). PhD Thesis, University of Aberdeen

Carss, D. N., Kruuk, K. and Conroy, J. W. H. (1990) Predation on adult Atlantic salmon, *Salmo salar* L., by otters *Lutra lutra* (L.) within the River Dee system, Aberdeenshire, Scotland. J. Fish Biol., 37, 935-944.

Carss, D. N. and Parkinson, S.G. (1996) Errors associated with otter Lutra lutra faecal analysis 1: Assessing general diet from spraints. J. Zool. Lond. **238**: 301 -317

Cederholm, C. J., D. H. Johnson, R. E. Bilby, L. G. Dominguez, A. M. Garrett, W. H. Graeber, E. L. Greda, M. D. Kunze, B. G. Marcot, J. F. Palmisano, R. W. Plotnikoff, W. G. Pearcy, C. A. Simenstad, and P. C. Trotter (2000) Pacific Salmon and Wildlife-Ecological Contexts, Relationships and Implications for Management.Special Edition Technical Report, Prepared for D. H. Johnson and T. A. o'Neil (Manag. Dirs.) Wildlife-Habitat Relationships in Oregon and Washington. Washington Dept. of Fish and Wildlife, Olympia.

Conroy, J.W.H., Watt, J., Webb, J.B. & Jones, A. (1993) A guide to the identification of prey remains in otter spaint. Occ Publ. Mamm. Soc. No. 16. London: The Mammal Society

Cunningham, P. 2001: The occurrence of Atlantic salmon (*Salmo salar*) carcasses along spawning streams in Scotland, with notes on stream fertility. 1: upper Shee water (Tay system) & tributaries, November 2000.

Cunningham, P. D., Starr, K., and Butler, J. (2001) River Ewe Salmon Radio-tracking Study. Wester Ross Fisheries Trust, March 2001

Feltham, M. J. and Marquiss, M. (1989) The use of first vertebrae in separating, and estimating the size of, trout (*Salmo trutta*) and salmon (*Salmo salar*) in bone remains. J. Zool., London. 219:113-122

Hewson, R. 1995a. Use of salmonid carcasses by vertebrate scavengers. J. Zool., Lond., 235, 53-65.

Hewson, R. 1995b. Otters (Lutra lutra) as scavengers: an experiment. Naturalist, 120, 15-20.

Green, J., Green, R. & Jeffries, D. J. 1984. A radio-tracking survey of otters (*Lutra lutra*) in a Perthshire river system. Lutra, 27, 85-145.

Gresh, T., Lichatowich, J. and Schoonmaker, P. (2000) An Estimation of Hisoric and Current Levels of Salmon Production in the Northeast Pacific Ecosystem. Fisheries, 25, No. 1, Jan 2000

Mills, D. H. (1989) Ecology and Management of Atlantic Salmon. London: Chapman and Hall.

Moir, H. (2002) unpublished records of salmon spawning in the Glen Beag burn. River Dynamics, Ltd, email: hmoir@hotmail.com

Watson, R. (1999) Salmon, Trout and Charr of the World A Fisherman's Natural History. Swan Hill, London.

Webb, J. and A. D. Hawkins. (1986) The movements and spawning behaviour of adult salmon in the Girnock Burn, a tributary of the Aberdeenshire Dee, 1986. Scottish Fisheries Research Report. 40, 42pp.

Wipfli, M. S., Hudson, J. P., Chalmer, D. T., and Caouette, J. P. (1999) Influence of salmon spawner densities on stream productivity in S. E. Alaska. Can. J. Fish. Aquat. Sci., 56: 1600 - 1611