SERIES A (Freshwater) No. 32 1989

IRISH FISHERIES INVESTIGATIONS

R. D. Fluskey

An Analysis of the Gravels used by Spawning Salmonids in Ireland

IRISH FISHERIES INVESTIGATIONS

SERIES A (Freshwater) No. 32 1989

Roinn na Mara

(Department of the Marine)

An Anlaysis of the Gravels used by Spawning Salmonids in Ireland

by

R. D. Fluskey

DUBLIN:

PUBLISHED BY THE STATIONERY OFFICE

TO BE PURCHASED FROM THE
GOVERNMENT PUBLICATIONS SALE OFFICE, SUN ALLIANCE HOUSE
MOLESWORTH STREET, DUBLIN 2

Price: £1.30

An Analysis of the Gravels used by Spawning Salmonids in Ireland

by

R. D. FLUSKEY, Fisheries Research Centre, Department of the Marine, Abbotstown, Castleknock, Dublin 15

ABSTRACT

Samples of gravel from 79 sites selected for spawning by Atlantic salmon, 9 selected by sea trout and 13 within spawning areas but known to be unused by spawning salmonids were analysed.

For comparison reported data on 81 samples from sites used by Pacific salmon were similarly analysed. No significant difference was found between the range of gravel distributions used by salmon and that used by sea trout. It could not be proved that the sites unused by spawning fish were avoided because of excess coarseness or fineness. The range used by Pacific salmon was found to be wider than that used by Atlantic salmon. A separate analysis was made of the portion of gravel coarser than 4mm in diameter. From this a suitable mixture for use in rehabilitating disrupted spawning areas is proposed.

A proposal is made that for spawning gravel analysis the ∅scale where $\varnothing = -1.\log_2$ particle size be replaced by a θ scale where the multiplication by −1 is omitted.

Key words: Salmonids, spawning, gravel, site selection.

INTRODUCTION

A correlation between gravel composition and spawning success of salmonids has been accepted for more than 60 years; Harrison (1923) reported an inverse relationship between the quantity of sand and silt in redds and ova survival and Philips *et al* (1975) found an inverse relationship between a concentration of 1-3 mm sand in gravel mixtures and survival to emergence of Coho salmon *Oncorynchus kisutch* (Walbaum) and steelhead trout *Salmo gairdneri* (Richardson).

Most of the research into this aspect of ecology has taken place in North America (McNeill and Ahnell 1960, Peterson 1978, Wendling 1978 and Shirazi *et al* 1981). Little has been done in this field in Europe apart from a study of the spawning tributaries of the Rived Tweed (Mills 1973) and of potential spawning sites in the Thames catchment (Wilkinson 1983). Until 1982 no work of this kind had been done in Ireland.

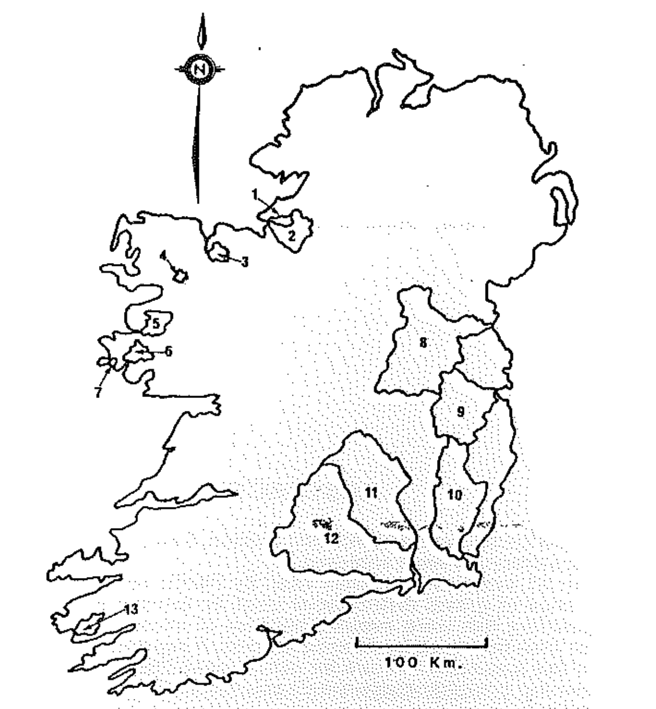
The objectives of the present study were (a) to identify the range of gravel particle sizes within which salmonids spawn in Ireland, (b) to find a more comprehensive and rigorous method of describing a gravel mixture than those in current use and (c) to identify the optimum gravel mixture for use in rehabilitating spawning stretches disrupted by such environmental impacts as arterial drainage.

MATERIALS AND METHODS

Between 1982 and 1983 spawning sites in 10 Atlantic salmon and 5 sea trout bearing rivers were sampled. Fig. 1 shows the catchments of these rivers and the salmonid species frequenting them.

Site Selection

The sampling sites chosen were those indicated precisely by members of the local fishery protection staff as having been used in the previous spawning season. On this basis 79 sites chosen by salmon and 9 chosen by sea trout were sampled. In 13 additional cases informants were asked to indicate sites within spawning stretches known not to have been used for spawning. These were, after analysis divided into two groups designated "fine" and "coarse" respectively.



No.	Catchment	Species	No.	Catchment	Species
1	Drumcliff	S	8	Boyne	S
2	Bonet	S	9	Liffey	S
3	Bunree	S	10	Slaney	S
4	Glenisland	S&T	11	Nore	S
5	Erriff	S&T	12	Suir	S
6	Ballynahinch	T	13	Cummeragh	T
7	Doohulla	T			

S : Salmon
T : Sea trout

Figure 1. Catchments surveyed and the salmonids frequenting them.

Sampling

A portable and collapsible coffer dam based on the design of Mundie (1971) was constructed to reduce the effects of flowing water and yet provide sufficient current to carry escaping fine material into a net incorporated in its downstream section. The apparatus, shown in Fig. 2, consisted of:

(i) a forepiece or breakwater which was a semicircular section of plastic sewerpipe of diameter 30.5cm and height 72cm brought to a point at its lower end to facilitate entry into the substrate.
(ii) two panels of 1.25mm marine plywood (length 40cm, height 50cm) which were fitted to the inner edges of forepiece (i) at about 45 degrees to act as deflecting wings.
(iii) two panels (70 × 50cm), of the same material fitted to the inner trailing edges of panels (ii) and each positioned roughly parallel to the river banks.
(iv) two further panels identical to panels (ii) which converged from the inner trailing edges of panels (iii) to form a tail to which was fitted a conical net (mouth 30.5cm diameter, length 125cm and mesh 125μm) ending in a screw-off container (length 18cm and diameter 10cm) with a window of 63μm netting.

All panels were serrated on the lower edge for ease of working into the gravel and weighted with lead to achieve negative buoyancy.

The coffer dam was erected around the selected site, each section being driven as deeply as possible into the river bed (the panels usually needed support which was provided by suitably sized stones found in the river). It was important that the junctions between any two components should not be closed completely as a moderate flow was necessary to carry escaping fine material into the net. Tests, with the net removed

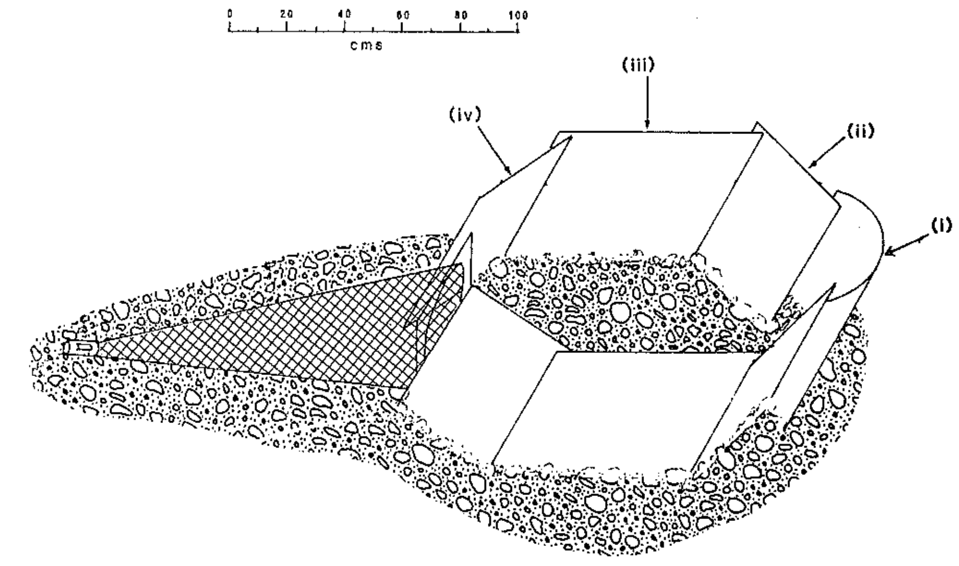


Figure 2. Isometric view of coffer dam and net used in sampling.

and using potassium permanganate as a dye, showed that the water flowing from the tail of the dam usually adopted the shape of the net indicating that hydraulic action due to the shape of the dam assisted in containment of fine material in the net.

A shovel with a small blade (24 × 20cm) was used to extract the sample by digging vertically to a depth of 25 to 30cm. This depth range was chosen because it encompasses the depths to which salmon redds are commonly excavated (Jones 1959). Usually 10 to 11 but never less than 8 litres of material were extracted and placed in a bucket. The contents of the net were carefully washed out and added to the sample.

Physical Analysis

On the river bank all material finer than 4mm was wet-sieved out of the sample, frequently washing both sieve and contents. About 50ml of a concentrated solution of alum was added to this material to hasten precipitation of colloidal matter and it was left aside in a bucket to settle. The particles coarser than 4mm were wet sieved through screens of 128, 64, 32, 16, 8 and 4mm aperture and the volumes of these fractions were determined by means of an overflow pipe and graduated cylinder in the manner described by McNeill and Ahnell (1960). By the time this had been done all suspended solids had precipitated from the water in the bucket containing the fine material and the supernatant water was decanted.

Occasionally it was necessary to sub-sample the fine material and an application of the steelyard principle was found to be the most effective apparatus for this purpose. The forepiece of the coffer dam ((i) in Fig. 1) when inverted doubled as the support for a steel beam 115cm long with notches cut at each end and incorporating a spirit level mounted centrally. The beam was loosely fastened to the support by a 6mm diameter bolt and an empty bucket was suspended from each of the notches. A tare weight was then moved along the beam until the spirit level indicated equilibrium, then, using a scoop of 150ml capacity the fine material was transferred alternatively to each of the buckets until all of the material was exhausted and equilibrium was again reached. The contents of one bucket were then discarded and the other retained. Usually the half sample thus obtained was sufficiently small for transport to the laboratory but occasionally it was necessary to repeat the procedure to obtain a quarter sample.

In the laboratory the fine material was dried for 8 hours at 105 degrees C and machine sieved for 20 minutes through a stack of sieves of 2, 1, 0.5, 0.25, 0.125 and 0.063 mm aperture. The fractions retained on each sieve were weighed to an accuracy of 1g and these weights were multiplied by the factor by which the sample had been split. A subsample of the fraction retained on the 2mm sieve was used to determine the density of the material and thence the volumetric measurements of the coarse particles taken on the river bank were converted to gravimetric measures. Corrections for the effects of wet sieving were applied according to table 5 of Shirazi *et al* (1981).

Statistical Analysis

The percentage of the total sample retained on each sieve was calculated and thence the percentage passing each sieve (i.e. the percentage finer than a given diameter) was determined.

In the case of each sample and each group of samples the following basic characteristics were determined:

Dg = geometric mean diameter, a measure of central tendency.

So = sorting coefficient, an indicator of dispersion of particles.

Fi = Fredle index, an indicator of permeability.

Dg and So were calculated by the method of moments (Shirazi *et al* 1981) and Fi is the quotient of Dg by So (Lotspeich and Everest 1981).

For purposes of comparison of the data obtained in the present study with the data given in Table A-1 of Shirazi *et al* (1981) on Pacific salmon, the latter were treated by the same methods as detailed above.

In the computations and presentation of results three interconnected scales (each having its particular function) were used; these were

(a) the particle diameter in mm

(b) a θ scale where $\theta = \log_2$ particle diameter.

(c) the descriptive scale of the American Geophysical Union (Bogardi, 1974 and Vanoni 1977).

Table 1 shows the relationship between these scales.

RESULTS

Table 2 gives a comparison between the means and standard deviations of the 79 Atlantic salmon samples taken during the present study and the 81 Pacific salmon samples reported by Shirazi *et al* (1981). This shows that the Dg of the mean distribution of Pacific salmon is 7.5mm greater than that for Atlantic salmon. So is smaller by 0.4mm and Fi is greater by a factor of 1.7 indicating in general a coarser, better sorted and more permeable distribution in the case of the samples taken by Shirazi *et al* (1981) than those taken in the present study.

The high values of the standard deviations in each case indicate a broad range of observed values particularly at the θ = 5 (32mm) point of the scale. Fig. 3 where 95% confidence limits are drawn about the mean of each distribution illustrates the broadness of these ranges. The upper limits are almost coincidental except between θ values 1 and 3 (2 to 8mm), where a greater degree of fineness for the Atlantic salmon distribution is indicated, while the lower limit of the distribution for Pacific salmon extends far beyond that for Atlantic salmon (another indication of the relative coarseness of the Pacific salmon samples). A "t" test on the two distributions proved that the difference between the gravels used by Atlantic salmon and those used by Pacific salmon is highly significant ($P < .001$).

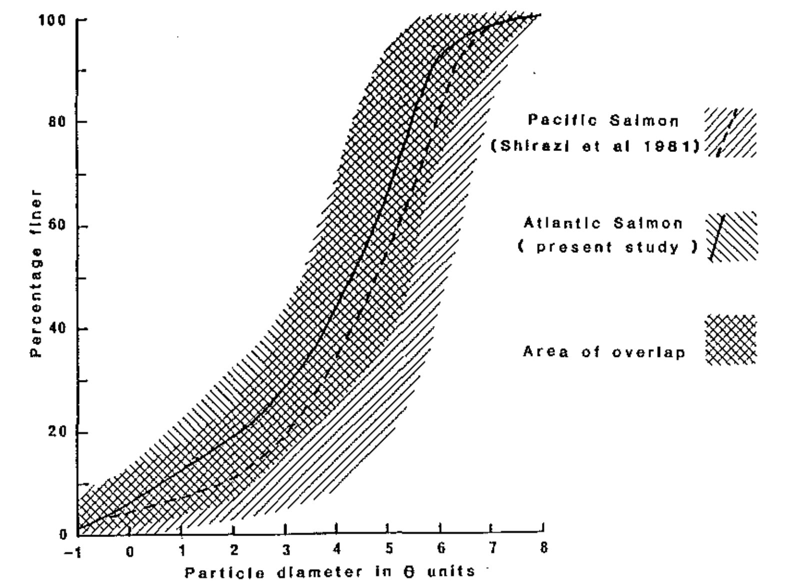


Figure 3. Mean cumulative frequency distributions of spawning gravels used by Pacific and Atlantic salmon with 95% confidence limits.

Characteristics of Salmon Spawning Gravels

The observed percentages finer than each particle size in each of the 79 samples taken from sites identified as having been used by spawning salmon were ranked in ascending order and the following values extracted from the rankings; the highest and lowest values, the median values and the upper and lower quartiles. These values are given in Table 3.

Fig 4 shows the data of Table 3 plotted to a logarithmic scale; inspection of the figure shows that the points between θ values 0 and 5 are almost co-linear at an acute angle with x axis while points between θ values −4 and −1 are also almost co-linear but at a much steeper gradient. The relationship between the values was found (by the least squares method) to be of the form

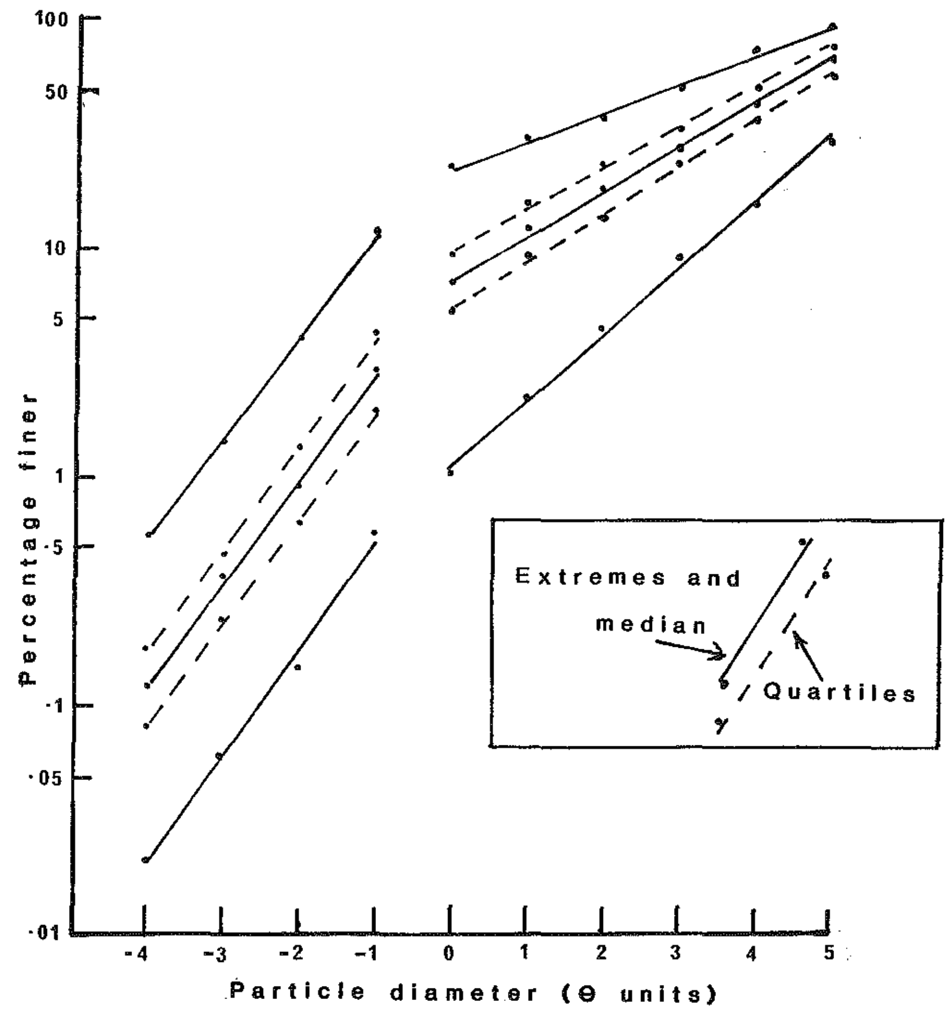


Figure 4. Data points and regression lines of Table 3.

$y = A.e^{Bx}$ ....Equation 1a

and $y = a.e^{bx}$ ....Equation 1b.

where x = particle diameter in θ units

y = percentage finer than a given diameter

A and a = intercept of regression line

and B and b = slope of regression line

The constants A and B refer to that part of the distribution between θ values 0 and 5 (1mm to 32mm) and a and b to the part of the distribution between θ values −4 and −1 (0.063mm to 0.5mm). The quantity of particles outside these ranges in a typical spawning gravel mix is considered to be insignificant.

The values of the constants and coefficients of determination (r^2) for each regression line are given in Table 4. The high values of r^2 (mean 0.9954 with a range of 0.9903 to 0.994) indicate that a spawning gravel mixture can be described by quoting the constants A, B, a and b.

The narrowness of the interquartile range (A = 5.42 to 9.71 and B = 0.41 to 0.47) inspired a method of qualitatively categorising spawning gravel based on bands bounded by the regression lines of Fig. 4 but using only that part of the distribution lying between θ values 0 and 5 (typically 85% to 95% of a spawning gravel mix falls within this range and it is also the part of the distribution least liable to change under the influence of hydraulic action).

Table 5 shows the proposed criteria; in the case of the "A" values the interquartile range is designated Class A, the ranges between the extremes and the quartiles, Class B and outside the extremes Class C. The subscript f (indicating a tendency towards fineness) is added to the B and C classes above the upper quartile and the subscript c (indicating a tendency towards coarseness) below the lower quartile. The values of "B" determine the proportions of the various particle sizes in a given gravel mixture and are therefore designated as Grades, moreover they increase as coarseness increases and so have been assigned ascending numbers from −2 to +2 where the negative sign indicates fineness and the positive coarseness. The values in the interquartile range are assumed to be neither coarse nor fine and are therefore assigned the number 0.

Analysis of Atlantic salmon spawning gravel

The basic characteristics of the spawning gravels sampled in the ten river catchments surveyed are detailed in Table 6. The broad range of values encountered in the survey is again apparent.

Of the 37 sites, 19 qualified for Class A and 9 each for Bf and Bc, 14 qualified for Grade 0, 13 for −1 and 10 for +1. Application of 95% confidence limits gave ranges of 7.27 to 8.49 for A, 0.40 to 0.44 for B, with categories ranging between A-1 and A0.

Analysis of sea trout spawning gravel

Table 7 presents the results of analysing the data obtained from the five sea trout bearing rivers surveyed.

Two sites qualified for Class A, one for Bf and two for Bc. Four sites were of Grade +1 and one of Grade −1. Application of 95% confidence limits gave ranges of 2.62 to 14.58 for A, 0.35 to 0.63 for B with categories ranging between Bf−1 and Bc+1.

In general a similar range of values was encountered in the survey of sea trout spawning sites as was encountered for Atlantic salmon, but because of the small data base the results cannot be taken as conclusive.

Analysis of sites indicated as unused by spawning salmonids

Table 8 gives the basic characteristics of the 13 samples which were collected under this heading. They were separated into coarse and fine categories depending on whether the values of A were less than or greater than the median found for the 79 Atlantic salmon samples. On this basis samples 1 to 4 were defined as coarse and samples 5 to 13 as fine.

In the case of the coarse samples one site qualified for Class A and the other three for Class Bc. Three sites were of Grade +1 and one of Grade −1 while the mean of all four sites was of category Bc+1.

In the case of the samples defined as fine the data show that one site qualified for Class A and the remaining eight for Class Bf, one was of Grade 0, seven of Grade −1 and one of Grade −2. Application of 95% confidence limits gave ranges of 10.28 to 14.94 for A and 0.289 to 0.39 for B, both limits being in category Bf−1.

Since none of the samples fell into Class C and only one was of Grade −2 and none of Grade +2 it cannot be concluded that they were avoided by spawning fish due to excess coarseness of fineness but perhaps due to hydraulic conditions at the sites.

Frequency of coarse particles and its application in rehabilitation of spawning stretches.

To identify the optimum mixture for introduction into a disrupted spawning area a special study was made of the distribution of particles coarser than θ2 (fine gravel).

Of the 88 sites used by salmon and sea trout, large cobble (>θ7) was present in only 14% of the sites and small cobble (θ6 to θ7) was present in 70% of the sites.

Of the 81 sites surveyed by Shirazi *et al* (1981), large cobble was present in 10% of the sites and small cobble in 84%.

Because of the rarity of the large cobble grade it was grouped with small cobble under the common name of cobble.

Where large cobble was present it was usually represented in the sample by one stone of mean weight 2kg, the average number of small cobbles (where present) was five of mean weight 0.5kg, the average number of very coarse particles was 180 of mean weight 100g and of coarse gravel 660 of mean weight 16g. No counts were made of particles finer than coarse gravel.

The relative proportions (by weight) of material present in each of the five grades are shown in Fig. 5 for each of the three species studied and for each of the six salmon bearing rivers most intensively surveyed. The common trend was of a low content of cobble, a maximum pecentage of very coarse gravel followed by a steady decline to a low content of fine gravel.

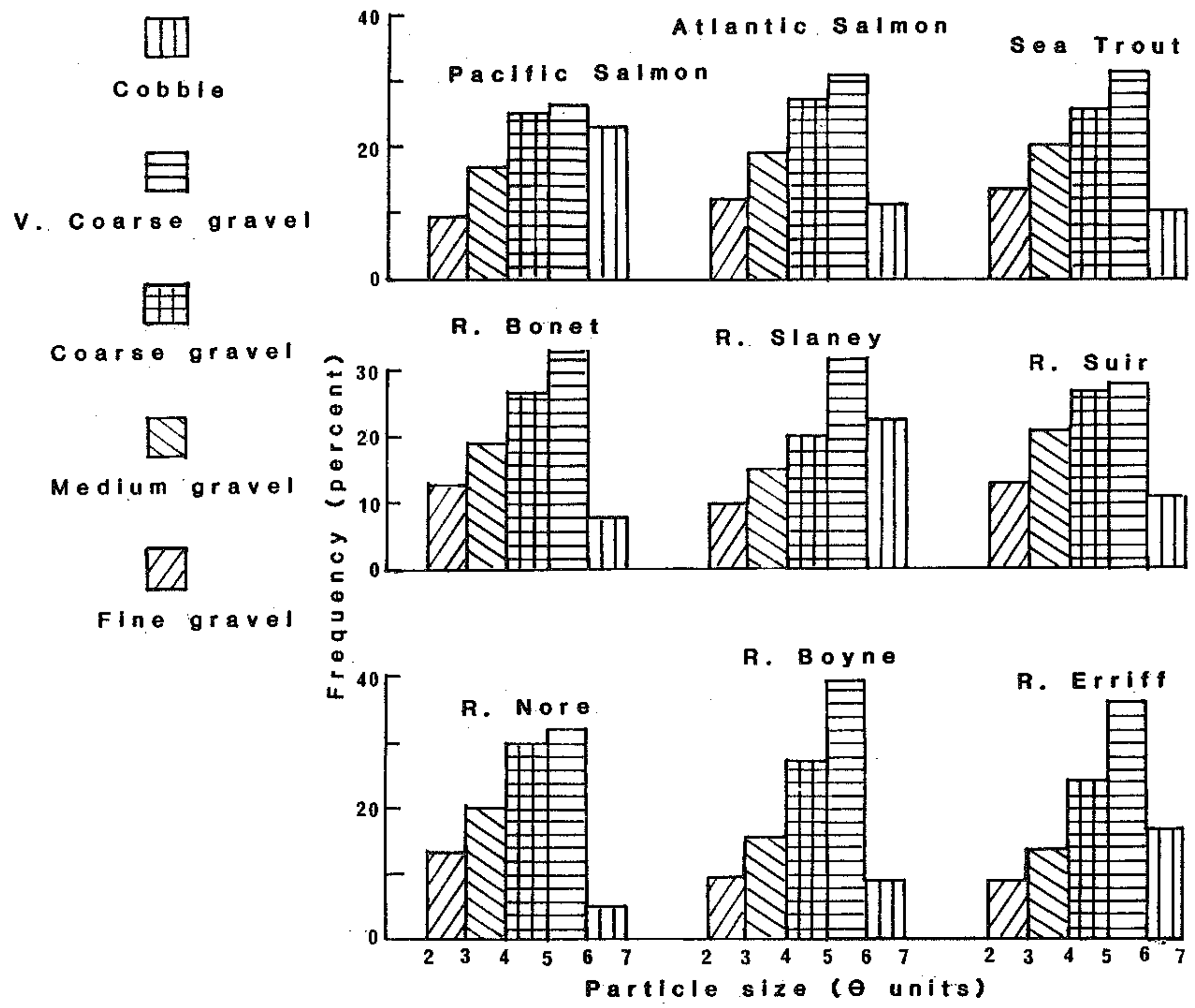


Figure 5. Frequency distributions of particles coarser than 4 mm diameter.

Variations in the distributions among the six rivers were:—

Cobble ranged from 5% (R. Nore) to 23% (R. Slaney)

Very coarse gravel ranged from 32% (R. Slaney) to 39% (R. Boyne and R. Nore)

Coarse gravel ranged from 20% (R. Slaney) to 27% (Rs. Bonet, Boyne and Suir)

Medium gravel ranged from 14% (R. Erriff) to 21% (R. Suir)

Fine gravel ranged from 9% (R. Erriff) to 13% (Rs. Bonet, Suir and Nore).

The analysis of the data for Atlantic salmon, Pacific salmon and sea trout is shown in Table 9.

There is no significant difference between the mixtures selected by Atlantic salmon and those selected by sea trout. The main difference between the Pacific salmon distribution and that for Atlantic salmon is in the cobble range (double that for Atlantic salmon). There was 7% less very coarse gravel in the mixture chosen by Pacific salmon while the proportions of the other three grades were slightly lower than those chosen by Atlantic salmon.

On the basis of the data in Table 9 a gravel mixture suitable for rehabilitating disrupted spawning stretches or for use in artificial spawning beds is

Cobble (64 to 190mm)	10%
Very coarse gravel (32 to 64mm)	35%
Coarse gravel (16 to 32mm)	25%
Medium gravel (8 to 16mm)	20%
Fine gravel (4 to 8mm)	10%

DISCUSSION

The present study relied on the indication by experienced fishery workers of precise sites within spawning areas known to have been used by spawning salmonids during the previous spawning season. The method used by Shirazi *et al* was to select within each of 27 spawning areas three samples, one each from sites which they judged visually before extraction to be of coarse, medium and fine composition. Shirazi was asked whether the relative coarseness as deduced from his data indicated a preference of Pacific salmon for a coarser subtrate than that chosen by Atlantic salmon; he opined (pers. comm.) that the relative coarseness was due to the wideness of his data base. An alternative explanation lies in the difference of method of selection of sampling sites.

In spite of this difference the virtual coincidence of the upper 95% confidence limits for each of the studies (Fig. 3) indicates that a limit has been found to the fineness of gravel distributions selected by spawning salmonids in this study and that this limit is the distribution given as highest observed value in Table 3.

The use of the coefficients of equations 1a and 1b (A, B, a and b) enable a distribution to be reconstructed (an operation which is impossible if only the conventional measures of Dg, So and Fi are quoted). The coefficient A is an indicator of the percentage of material finer than 0=0 (1mm) in the entire distribution and therefore has usefulness in monitoring changes in sediment composition due to siltation. The coefficients a and b enable a precise statement to be made of the proportions of sand and silt present in a given sample.

An equation similar to equations 1a and 1b has been proposed by Tappel and Bjornn (1983).

Their equation is of the form

PERCENT= C + K.log Size

where PERCENT=inverse probability transformation of percentage of substrate smaller than a given sieve size,

C=intercept of regression line,

K=coefficient of variable $\log_e$SIZE,

SIZE=sieve size in millimeters

They propose the use of this equation to describe all of that part of a gravel distribution finer than 25.4mm ($\theta = 4.67$). They quote values of r^2 to two decimal places which range from 0.85 to 1.00 with a mean value of 0.97, when these are compared with the values of r^2 quoted in this study for Equations 1a and 1b their somewhat greater accuracy is apparent.

The θ scale used in this study is derived from a $\varnothing$ scale used by sedimentary petrologists (Krumbein and Pettijohn, 1938 and Inman, 1952) where $\theta = -1.\log_2$ sieve aperture. The device of multiplication by -1 was introduced because it was convenient for workers in the field of sedimentary petrology (where the greater proportions of a sample are of sand, silt and clay) to deal with positive numbers. In spawning gravel analysis the great bulk of the particles being studied are coarser than 1mm, therefore the device of multiplication by -1 is illogical and unnecessary.

For division of the various particle size distributions found within the broad range of gravels used by spawning salmon into categories it was decided to use the extreme values and the quartiles as boundaries because this method involved the use of values actually observed rather than estimates e.g. by the use of confidence levels. The choice of the letter A to describe distributions falling within the interquartile range is not meant to imply a superiority of these gravels over those of classes Bf and Bc (indeed gravels of class Bc are obviously more permeable than those of class A). It can however be stated that, in nature, gravels in the narrow range of class A and grade 0 are chosen by spawners 50% of the time against 25% of the time for each of the relatively broad Bc and Bf classes.

ACKNOWLEDGEMENTS

Nigel Bond gave very valuable assistance in the construction of the apparatus used in the study, in field work and in the physical analysis. Patrick McDaid wrote a computer programme for the statistical analysis. Richard Grainger gave advice on significance testing. Miss Eileen Twomey critically read the manuscript and gave valuable advice, it was edited by Christopher Moriarty and typed by Anne McDaid. Members of the staffs of the North-Western, Southern, Eastern and Central Fisheries Boards identified the spawning sites and assisted in the sampling. My gratitude is extended to them all.

REFERENCES

Bogardi, J. (1974). *Sediment transport in alluvial streams* Akademioi Kiado, Budapest.

Harrison, C. W. (1923). Planting eyed salmon and sea trout eggs. *Trans. Amer. Fish. Soc.* 53 191-200.

Inman, D. L. (1952). Measures for describing the size distribution of sediments. *Jour. Sed. Petrol.* 22 (3) 125-145.

Jones, J.W. (1959). *The Salmon,* Collins, London.

Krumbein, W. C. and Pettijohn, F. J. (1938). *Manual of Sedimentary Petrography,* D. Appleton-Century Co. New York.

Lotspeich, F. B. and Everest, F. H. (1981). A new method for reporting and interpreting textural composition of spawning gravel. *Res. Note PNW 369,* 11pp. U.S. Dept. Agric. Forest Serv., Portland, Oregon.

McNeill, W. J. and Ahnell, W. R. (1960). Measurement of gravel composition of salmon stream beds. *College of Fisheries Circ. No. 120,* Univ. Washington Seattle.

Mills, D. H. (1973). Preliminary assessment of the characteristics of spawning tributaries of the River Tweed with a view to management. *International Atlantic Salmon Foundation Special Publication.* (M. W. Smith and W. M. Carter eds.) 4 (1) 145-155.

Mundie, J. H. (1971). Sampling benthos and substrate materials down to 50 microns in size in shallow streams. *J. Fish. Res. Bd. Can.* 28, (6) 849-860.

Peterson, R. H. (1978). Physical characteristics of Atlantic salmon spawning gravel in some New Brunswick streams. *Fish and Marine Service Report No. 785,* Biological sta., St. Andrews, New Brunswick.

Phillips, R. W., Lantz, R. L., Claire, E. W. and Moring, J. R. (1975). Some effects of gravel mixtures on emergence of Coho salmon and Steelhead trout fry. *Trans. Amer. Fish.Soc.,* 104, 461-466.

Shirazi, M. A., Seim, W. K. and Lewis, D. H. (1981). Characteristics of spawning gravel and stream system evaluation. Washington Resource Research Centre, Pullman, Washington, *Report No. 39*

Tappel, P. D. and Bjornn, T. C. (1983). A new method of relating size of spawning gravel to salmonid embyro size. *N. Amer. Jour. Fish. Man.* 3 (2) 123-135.

Vanoni, V. A. (1977). *Sedimentation Engineering,* American Society of Civil Engineers, New York.

Wendling, F. L. (1978). Final report on gravel porosity studies along the trans-Alaska pipeline. *Special Report No. 18.* Alaska Department of Fish and Game.

Wilkinson, C. V. (1983). *An investigation of potential spawning sites for salmon in the Thames catchment.* M.Sc. Thesis Plymouth Polytechnic, 160pp.

Table 1. The three scales used in this study (θ = log sieve aperture to base 2.)

Sieve Aperture (mm)	θ scale	American Geophysical Union Descriptive Scale
256 to 512	8 to 9	Small boulders
128 to 256	7 to 8	Large cobbles
64 to 128	6 to 7	Small cobbles
32 to 64	5 to 6	Very coarse gravel
16 to 32	4 to 5	Coarse gravel
8 to 16	3 to 4	Medium gravel
4 to 8	2 to 3	Fine gravel
2 to 4	1 to 2	Very fine gravel
1 to 2	0 to 1	Very coarse sand
0.5 to 1	−1 to 0	Coarse sand
0.25 to 0.5	−2 to −1	Medium sand
0.125 to 0.25	−3 to −2	Fine sand
0.063 to 0.125	−4 to −3	Very fine sand
0.032 to 0.063	−5 to −4	Coarse silt

Table 2. Comparison betwen the means and standard deviations (in parentheses) of particle distribution in 79 Atlantic salmon and 81 Pacific salmon spawning sites.

Particle diameter (mm)	Percentage finer than stated diameter Atlantic salmon	Pacific salmon
128	98.17 (4.54)	97.85 (7.15)
64	91.10 (10.70)	79.59 (17.81)
32	64.14 (15.47)	53.00 (21.27)
16	42.38 (11.41)	32.57 (16.23)
8	27.79 (8.16)	19.04 (10.66)
4	18.24 (6.80)	10.95 (6.87)
2	12.56 (5.22)	7.48 (5.21)
1	7.61 (3.85)	4.94 (4.05)
0.5	3.49 (2.39)	2.54 (2.51)
0.25	1.07 (0.78)	0.61 (0.66)
0.125	0.38 (0.21)	0.14 (0.14)
0.063	0.14 (0.09)	— —
Average Dg (mm)	15.1	22.6
So (mm)	4.4	4.0
Fi	3.4	5.6

Table 3. Observed "percentage finer" values extracted from ranking the observations from 79 samples taken from sites used by spawning Atlantic salmon. Percentages finer than the stated sizes in θ units.

Size	Highest observed value	Upper quartile	Median value	Lower quartile	Lowest observed value
−4	.55	.18	.12	.08	.02
−3	1.42	.45	.37	.24	.06
−2	4.17	1.28	.87	.58	.14
−1	11.54	4.28	2.95	1.97	.57
0	22.87	9.07	6.91	5.27	1.00
1	30.11	15.71	12.01	9.04	2.19
2	35.81	23.1	18.22	13.31	4.65
3	49.52	32.3	28.03	23.00	9.19
4	72.49	49.79	43.71	36.32	15.39
5	91.17	75.55	65.63	55.11	28.01

Table 4. Constants and coefficents of determination of the regression lines of Figure 4.

Distribution range	θ0 to θ5			θ−4 to θ−1		
	A	B	r^2	a	b	r^2
Highest observed	22.12	0.28	.9903	31.78	1.02	.9994
Upper quartile	9.71	0.41	.9958	11.41	1.06	.9962
Median	7.32	0.44	.9979	7.94	1.05	.9959
Lower quartile	5.42	0.47	.9982	5.3	1.05	.9965
Lowest observed	1.12	0.66	.9941	1.51	1.09	.9907

Table 5. Categorisation of constants for spawning gravel based on the data of Table 4.

	Values of A		Values of B	
	Range	Class	Range	Grade
Beyond the limit of fineness	>22.12	C_f	<0.28	−2
Used by spawning salmon but of fine tendency	9.71 to 22.12	B_f	0.28 to 0.41	−1
Category most used by spawning salmon	5.42 to 9.71	A	0.41 to 0.47	0
Used by spawning salmon but of coarse tendency	1.12 to 5.42	B_c	0.47 to 0.66	+1
Beyond the limit of coarseness	<1.12	C_c	>0.66	+2

Table 6. Basic characteristics of salmon spawning gravels; mean values where more than one sample was taken. (r^2 = coefficient of determination in Equation 1a)

River System	Site on main river or name of tributary (T)	Dg	So	Fi	a	b	A	B	Category	r^2	Number of samples N
Drumcliff	Drifreen Br.	21.17	3.77	5.62	3.19	1.09	4.22	0.51	B_c+1	0.9852	1
Bonet	McKeown's Ford	12.29	4.67	2.63	17.03	1.14	10.99	0.36	B_f-1	0.9922	5
Bonet	Daisy's Ford	22.68	4.50	5.04	9.58	1.13	8.25	0.30	A−1	0.9855	6
Bonet	New Bridge	16.09	3.12	5.16	4.42	0.99	3.55	0.60	B_c+1	0.9955	4
Bonet	Upr. Gortinar	10.69	4.82	2.22	37.31	1.43	12.07	0.35	B_f+1	0.9938	6
Bonet	Glenade	12.55	3.24	3.87	11.84	1.23	4.51	0.59	B_c+1	0.9950	4
Bonet	(T) Strawbrick	8.56	4.56	1.84	19.20	1.22	14.06	0.35	B_f-1	0.9986	1
Bonet	Toothfield	14.56	3.35	4.35	6.24	1.10	4.76	0.55	B_c+1	0.9988	1
Bunree	Glenree	11.33	4.31	2.63	6.93	1.19	9.81	0.42	B_f 0	0.9653	1
Glenisland	Glenisland	29.46	5.94	4.96	10.31	1.16	8.84	0.30	A_f-1	0.9911	2
Erriff	Upr. Drummin	17.02	3.33	5.11	4.10	0.73	4.79	0.52	B_c+1	0.9962	3
Erriff	(T) Cross R.	31.13	3.50	8.89	4.07	0.88	3.84	0.43	B_c 0	0.9944	2
Erriff	Glendavock	21.13	3.98	5.31	2.90	0.99	6.04	0.43	A 0	0.9927	2
Boyne	(T) Mattock	14.17	4.45	3.18	2.91	1.06	7.90	0.45	A 0	0.9800	1
Boyne	(T) Murmod	19.67	3.41	5.77	2.80	0.67	4.31	0.50	B_c+1	0.9964	2
Boyne	(T) Trimblestown	16.95	4.64	3.65	5.63	0.89	6.61	0.47	A 0	0.9970	1
Boyne	(T) Blackwater	17.00	4.57	3.72	12.50	0.96	9.04	0.36	A −1	0.9971	4
Liffey	(T) Rye	14.59	3.97	3.68	9.62	1.10	7.36	0.43	A 0	0.9991	1
Liffey	Athgarvan	12.70	3.31	3.84	1.66	1.06	5.94	0.53	A +1	0.9871	1
Liffey	(T) Morrell	11.26	4.27	2.64	7.74	0.89	9.41	0.42	B 0	0.9919	2
Slaney	(T) Bora	26.66	4.73	5.64	5.76	1.11	5.11	0.38	B_c-1	0.9985	1
Slaney	(T) Urrin	16.71	6.09	2.74	8.24	0.93	12.41	0.30	B_f-1	0.9640	1
Slaney	Rathvilly	11.53	5.29	2.18	2.25	1.31	12.09	0.36	B_f-1	0.9833	1
Slaney	Baltinglass	20.85	5.40	3.86	8.84	1.04	8.10	0.38	A −1	0.9768	1
Slaney	Carrigrower	21.06	4.90	4.30	4.23	0.82	6.95	0.41	A 0	0.9742	1
Slaney	Glen of Imaal	11.14	4.18	2.67	6.80	1.00	9.36	0.43	A 0	0.9452	2
Slaney	(T) Glashavey	14.59	5.62	2.60	12.65	1.14	11.91	0.33	B_f-1	0.9989	2
Slaney	(T) Douglas	11.82	5.01	2.36	16.80	1.50	13.60	0.31	A 0	0.9997	1
Nore	(T) Kings	12.83	4.26	3.27	3.72	0.72	8.50	0.45	A 0	0.9931	2
Nore	(T) Munster	9.92	4.01	2.47	8.71	0.99	10.08	0.43	B_f 0	0.9916	2
Nore	(T) Dinin	17.43	3.59	4.88	2.50	0.71	4.79	0.53	B_c+1	0.9920	2
Nore	Castletown	11.31	3.93	2.88	8.89	1.02	8.73	0.44	A 0	0.8954	2
Suir	(T) Linguan	15.30	4.47	3.43	6.38	0.96	8.31	0.40	A −1	0.9839	2
Suir	(T) Anner	13.90	3.76	3.96	7.55	1.12	5.78	0.50	A +1	0.9927	2
Suir	(T) Tar	19.07	6.71	2.84	12.62	1.18	10.89	0.34	B_f-1	0.9979	1
Suir	(T) Clashawley	11.91	4.51	2.64	12.03	1.04	9.54	0.41	A 0	0.9816	2
Suir	(T) Multeen	15.58	3.92	3.97	9.07	1.10	6.08	0.49	A '1	0.9987	4
Mean of all 79 samples		16.18	4.38	3.80	9.64	1.07	7.88	0.42	A 0		79
Standard Deviation		5.31	0.85	1.41	6.54	0.18	2.78	0.08			
95% confidence limits		17.35	4.57	4.11	11.08	1.03	8.49	0.40	A −1		
		15.01	4.19	3.29	8.20	7.27	6.27	0.44	A 0		

Table 6 Basic characteristics of spawning gravel at 37 sites on 10 salmon bearing rivers

Means and standard deviations calculated by summing the data from each of the 79 individual samples taken

(T) denotes a tributary

N number of samples taken at the site

r^2 refers to coefficient of determination of Eqn 1 for A and B

Table 7. Basic characteristics of sea trout spawning gravels; mean values where more than one sample was taken. (r^2 = coefficient of determination in Equation 1a)

River Catchment	Site or Tributary	Dg	So	Fi	a	b	A	B	Category	r^2	N
Cummeragh	Waterville	16.86	3.29	5.12	1.41	0.84	3.05	0.65	B_c+1	0.9960	1
Doohalla	Roundstone	16.83	3.39	4.96	1.41	0.74	3.40	0.65	B_c−1	0.9965	2
Ballinahinch	Inagh	14.41	3.99	4.38	24.70	1.19	14.25	0.48	A +1	0.9965	2
Erriff	Glendavock	12.29	3.81	3.23	2.62	0.61	6.34	0.52	A +1	0.9738	1
Glenisland	Glenisland	14.22	4.92	3.03	8.51	0.84	10.56	0.35	B_f−1	0.9929	3
*Means		14.92	4.07	3.94	9.09	0.87	8.60	0.49	A +1		9
*Standard Deviations		6.21	0.86	2.07	15.06	0.27	7.77	0.18			
95% confidence		9.69	4.73	5.53	20.69	1.09	14.58	0.35	B_f−1		
		0.15	3.41	2.35	−2.51	0.06	2.62	0.63	B_c+1		

*Means and standard deviations calculated by summing values for individual samples

Table 8. Basic characteristics of sites within spawning areas but avoided by spawning salmonids. (Samples 1-4 defined as coarse, 5-13 as fine)

Sample No.	Dg	So	Fi	a	b	A	B	Category	r^2
1	73.63	3.359	20.51	1.532	0.80	1.43	0.55	B_c+1	0.9930
2	37.22	5.02	7.41	1.94	0.92	4-05	0.49	B_c+1	0.9620
3	28.98	4.12	7.03	6.32	1.19	5.10	0.40	B_c−1	0.9974
4	9.16	3.55	2.58	2.29	1.01	8.03	0.55	A +1	0.9181
Means	37.25	4.07	9.38	3.02	0.98	4.40	0.50	B_c+1	
Standard Deviations	26.96	0.68	7.74	2.22	0.16	2.33	0.07		
5	14.27	6.49	2.20	20.50	1.19	17.30	0.20	B_f−2	0.9952
6	15.09	5.46	2.76	21.02	1.13	11.16	0.33	B_f−1	0.9992
7	6.68	4.40	1.52	28.86	1.60	16.91	0.34	B_f−1	0.9957
8	14.80	5.46	2.71	12.84	1.20	12.80	0.30	B_f−1	0.9925
9	10.63	4.48	2.37	4.15	0.87	10.86	0.40	B_f−1	0.9967
10	8.76	4.27	2.08	25.16	1.09	9.84	0.44	B_f−1	0.9948
11	8.45	4.77	1.77	17.66	0.90	13.94	0.35	B_f−1	0.9948
12	10.05	4.54	2.21	14.64	1.15	12.11	0.37	B_f−1	0.9915
13	18.74	4.55	2.54	7.37	1.06	8.49	0.35	A −1	0.9875
Means	11.94	4.93	2.24	16.91	1.13	12.61	0.34	B_f−1	
Standard Deviations	3.94	0.73	0.41	8.04	0.21	3.02	0.07		
95% Confidence	4.98	5.49	2.56	23.10	1.29	14.94	0.29	B_f−1	
	8.90	4.37	1.92	10.72	0.97	10.20	0.39	B_f−1	

Table 9. Mean percentages and standard deviations (in parentheses) of gravel and cobble present in distributions selected for spawning.

	Pacific salmon	Atlantic salmon	Sea trout
Cobble	23% (15)	11% (10)	9% (9)
Very coarse gravel	26% (11)	33% (11)	35% (12)
Coarse gravel	25% (9)	26% (8)	24% (7)
Medium gravel	17% (7)	18% (6)	19% (6)
Fine gravel	9% (5)	12% (4)	13% (5)
Number of samples	81	79	9

IRISH FISHERIES INVESTIGATIONS SERIES A (Freshwater)

1. (1965) I. Review of the Irish Salmon Industry.
A. E. J. Went.
II. Salmon of the River Shannon (1957 to 1962).
Eileen Twomey.
III. The effects of Arterial Drainage works on the salmon stocks of a tributary of the River Moy.
E. D. Toner, Ann O'Riordan, Eileen Twomey.
IV. Recaptures of Irish tagged salmon off Greenland.
A. E. J. Went.

2. (1967) The movement of salmon *Salmo salar* through an estuary and a fish-pass.
P. A. Jackson and D. I. D. Howie.

3. (1968) "Specimen" brown trout and sea trout from Irish waters.
A. E. J. Went.

4. (1968) The early life of brown trout *Salmo trutta* L.
M. Kennedy and P. Fitzmaurice.

5. (1969) I. Irish Pike investigations. I. Spawning and early life history.
M. Kennedy.
II. Irish kelt tagging experiments 1961/62to 1966/67.
A. E. J. Went.

6. (1971) I. The distribution of Irish char *Salvelinus alpinus.*
A. E. J. Went.
II. The crayfish *Astacus pallipes* of an Irish lake.
C. Moriarty.
III. Temperature and oxygen determinations in some Irish lakes.
Patrick Fitzmaurice.

7. (1971) Fluctuations in the characteristics in Irish salmon.
A. E. J. Went and Eileen Twomey.

8. (1972) Water quality investigations in the River Blackwater and River Martin, Co. Cork — 1966-1969.
P. F. Toner and Clodagh O'Connell.

9. (1972) The ecology of brown trout and salmon in River Ownenea, County Donegal.
D. T. McCarthy.

10. (1972) Studies of the eel *Anguilla anguilla* in Ireland. I. In the lakes of the Corrib System.
C. Moriarty.

11. (1973) Insect emergence data from four small lakes in the south and southwest of Ireland.
J. J. Bracken and D. A. Murray.

12. (1973) The age and growth of pike from four Irish trout rivers.
J. J. Bracken.

13. (1973) Studies of the eel *Anguilla anguilla* in Ireland.
2. In Lough Conn, Lough Gill and North Cavan Lakes.
C. Moriarty.

14. (1974) Studies of the eel *Anguilla anguilla* in Ireland. 3. In the Shannon catchment.
C. Moriarty.

15. (1975) Studies of the eel *Anguilla anguilla* in Ireland. 4. In the Munster Blackwater River.
C. Moriarty.

16. (1977) The effects of drainage on the Trimblestown River.
I. Benthic invertebrates and flora.
D. T. McCarthy.

17. (1978) A comparative limnological study of two Irish lakes (Lough Sillan, Co. Cavan and Lough Dan, Co. Wicklow).
J. P. O'Connor and J. J. Bracken.

18. (1979) Sea trout from the tidal waters of the River Moy.
E. Fahy.

19. (1980) Sea trout from the Currane fishery in 1973 and 1974.
E. Fahy.

20. (1980) An investigation of the chemical and biological effects of pollution in the River Tolka.
M. A. O'Connor and J. J. Bracken.

21. (1981) A list of Rotatoria known to occur in Ireland with notes on their habitats and distribution.
J. P. K. Horkan.

22. (1981) Some direct gillnet selectivity tests for brown trout populations.
M. F. O'Grady.

23. (1984) Advances in fish biology in Ireland.
C. Moriarty (Ed.).

24. (1984) Observations on the Trichoptera of the Killarney lakes, Co. Kerry, Ireland.
J. P. O'Connor and E. J. Wise.

25. (1985) Feeding, growth and parasites of trout *Salmo trutta* L. from Mulroy Bay, an Irish sea lough.
E. Fahy.

26. (1985) Studies on the Minnow *Phoxinus phoxinus* (l.) from an upland Irish reservoir system.
H. A. Dauod, T. Bolger and J. J. Bracken.

27. (1985) Studies on the Three-Spined Stickleback *Gasterosteus aculeatus* L. from an upland Irish reservoir system.
H. A. Daoud, T. Bolger and J. J. Bracken.

28. (1986) Age growth and diet of the Brown trout *Salmo trutta* L. in the Roundwood Reservoir System.
H. A. Dauod, T. Bolger and J. J. Bracken.

29. (1987) The distribution of the crayfish *Austropotamobius pallipes* (Lereboullet) in Ireland.
J. Lucey and M. L. McGarrigle.

30. (1988) A Comparative Study of two tributaries of the River Dodder — Ireland. The Owendoher and the Dundrum Stream.
Mary Kelly-Quinn and J. J. Bracken.

31. (1988) The Currane, Co. Kerry Sea Trout Fishery 1980-1986 Edward Fahy and Ruary Rudd.

32. (1989) An Analysis of the Gravels used by Spawning Salmonids in Ireland. R. D. Fluskey.

Irish Fisheries Investigations Series B (Marine) deals with scientific research into marine fisheries.