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National Rivers Authority
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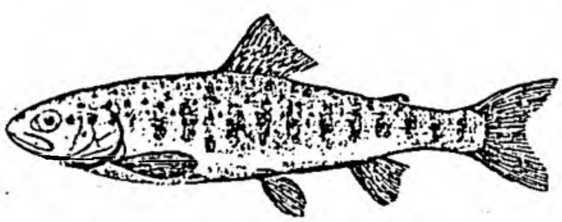
Hampshire Avon Salmon Radio Tracking

1986 – 1990

Final Report

Dr D J Solomon

September 1991



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River Avon Salmon Tracking Investigation Final Report.

Hampshire Avon Salmon Radio Tracking 1986 - 1990. Final Report.

EXECUTIVE SUMMARY.

Introduction.

1. This report describes the findings of a 5-year study undertaken by Dr D J Solomon. The aim of the study was to establish the relationship between salmon migration and catches, and river flow and other environmental variables. This information could then be used to assess the impact of water resource development and to help formulate optimal operating rules. (Sections 1.1, 1.2).

Methods.

2. A total of 437 adult salmon were tagged with radio transmitting tags at the mouth of Christchurch Harbour, and their migration into and up the Avon tracked by portable receivers and automatic recording stations. River flow figures were available from the Authority gauging stations at Knapp Mill Christchurch, and East Mills Fordingbridge. (Section 1.3, 1.4).

Results.

3. A total of 303 (69.3%) of the tagged fish were tracked ascending the Avon. Of the remainder, it was estimated that about 57 (13%) went to other river (about half to the Stour, half to more distant rivers). Twenty eight fish (6.4%) were reported recaptured by the Mudeford nets, and killed. Some of the remainder are explained by death due to tagging and handling trauma, unreported recapture by nets (legal or illegal) in the harbour or estuary, and tag failure. Many however are explained by apparently "natural" mortality in tidal water, amongst fish remaining there at times of low flows. (Sections 2, 3).

4. The patterns of movements exhibited by the tagged fish were closely related to river flow. At a residual flow to the estuary (ie after abstraction) above about 9 m^3/sec, most fish that are going to enter

the Avon do so within a few days of tagging. As flows fall below that level, an increasing proportion of fish remain in the estuary, the survivors entering the river in the autumn (October and November). The estuary fish apparently experience a high mortality rate, which increases with falling flow. Of 25 fish tagged when residual flows were below 5 m^3/sec, only six were recorded entering the river at all, half within 10 days of tagging and half in the autumn. (Section 3.2, Figs 16, 17).

5. After entering the river, fish continue to move upstream, on a discontinuous basis, for up to about three weeks. This initial phase of migration may take them many tens of kilometres, though some fish remain in the lowermost reaches. After this initial phase the fish become quiescent until elevated flows following rain in the autumn stimulate the spawning migration.

6. Movements within the river are also closely linked to flow. At residual flows in excess of 20 m^3/sec, fish having entered the river shortly after tagging continue upstream, some reaching Salisbury and beyond in their initial phase of migration. As flows fall, some fish tend to remain in the lowermost reaches, downstream of the Knapp Mill abstraction point. At a residual flow of 9 m^3/sec, about half the fish entering the river remain here until the autumn. Virtually no fish ascend beyond Knapp Mill on residual flows below $8m^3$/sec.

7. Elevated flows following rain generally had a similar affect to high base flows. In the dry summer of 1989, about half the tagged fish ascending beyond Knapp Mill in their initial migration did so in a few days following a series of thunderstorms that raised residual flows through the critical 8-9 m^3/sec zone.

8. Comparison of the pattern of fish movement with the pattern of angling catches indicates that the early part of the run (and angling catch) was poorly represented by tagged fish, but the main part of the run, which is vulnerable to low flows, was well represented. These observations, plus the timing of recaptures of tagged fish, support the hypothesis that salmon are far more

vulnerable to capture during their initial migration phase ie for 3 weeks or so after entering the river, than after they have laid-up. (Section 6).

The impact of abstraction.

9. Using the tracking results described above, a simple model was developed to predict the pattern of movements that would be shown by the run of fish for any week of the season at any flow. This can be used to predict the likely impact of any scenario of abstraction at any point in the river. It can also be used to demonstrate the impact of existing abstractions. (Section 7).

10. The Matchams and Knapp Mill abstractions are considered together. In years of average to high flows in the summer months these abstractions have minimal impact on salmon movements, as the residual flow does not fall below the 8 m^3/sec critical level. In 1986, for example (a year of average flows - Fig 4) the abstractions averaging a total of 1.4 m^3/sec resulted in a decrease in the numbers of salmon passing Knapp Mill within the angling season of about 6.5%. A greater impact is apparent for a dry year such as 1990. The naturally low flows already have a major impact on salmon movements, and the abstractions increase this. The numbers of salmon ascending past Knapp Mill within the angling season would be reduced by 28% compared to the situation without the abstractions. The numbers remaining in harbour are also higher increasing the number predicted to fail to enter the river from 123 to 441 fish. (Secions 8.1).

11. The Blashford abstraction arrangements are considered to have an insignificant effect on salmon movements. It is suggested that the prescribed flow of 23 m^3/sec for part of the take could be substantially reduced with minimal impact. (Sections 8.2, 8.4.2).

Guidelines for future resource management.

12. A number of options for operating rules for abstractions on the Avon are considered. The following conclusions are drawn:-

- head of tide intakes give much greater scope for modulation of abstraction to reduce impact eg diurnal. (Section 8.4.1).

- a straightforward prescribed flow rule for direct supply abstraction to protect salmon movements is quite unrealistic. (Sections 8.4.2).

- there could be great scope for the concept of "spared flows", eg stop abstraction at critical windows eg falling flows around 9 m^3/sec and the falling limb of a spate hydrograph. A week of bankside storage could allow significant reduction of impact. (Section 8.4.3).

- consideration of diurnal modulation of abstraction is highly recommended, particularly at critical flows eg 8 - 9 m^3/sec. Stopping abstraction between 20.00 and 08.00 hours could protect the majority of fish movement, but would require 12 hour bankside storage. (Section 8.4.4).

Obstructions to migration.

13. Of the five mills and weirs considered, only Bickton and Breamore appear to represent significant obstructions to movement, and then only late in the year during the spawning migration. The impact at that time in dry years appears to be a serious truncation of spawning distribution. (Section 9).

Population estimates and exploitation rates.

14. Approximate estimates of population size and exploitation rates are made from tag recapture data. In the five years total runs into the river (after the net catch and mortality in tidal water) ranged from 2200 to 5300 fish. Between 70 and 100% of the surviving run enters the river within the angling season, depending upon river flow. Net exploitation rates range from 7.3 to 12.1%, and rod exploitation of fish entering the river in the angling season from 15.6 to 19.3%. It is stressed that these estimates are approximate. (Section 10).

1. INTRODUCTION.

1.1. Background.

This is the final report on the conduct and results of a five-year programme of field investigation of the migration of adult salmon in the Hampshire Avon. It was undertaken by Dr D J Solomon, an independent fisheries consultant, under contract to the Wessex Water Authority. Responsibility for the programme passed to the National Rivers Authority (Wessex Region) in October 1989, but the work continued without change. The requirement for the work arose because further water resource development is likely to be required in the area within the next few years, and it was felt that inadequate information was available concerning the relationship between salmon migration and catches, and the discharge pattern of the river.

1.2. Terms of Reference.

The agreed objective of the overall programme was to provide answers to the following questions:-

a) What is the current pattern of movements, in space and time, of salmon into and through the estuary, into fresh water and up the river and how is this influenced by river flows and other environmental variables?

b) What will be the effect of any proposed changes in the pattern of abstraction?

c) Is it possible to suggest guidelines for the management of abstraction which are acceptable to the water supply undertakings and protect the pattern of movements detailed by (a) above?

In addition, it has been recognized throughout that the investigation could provide further information of value to fisheries management eg identification of particular barriers to migration, exploitation rates and total population estimates.

1.3. Approach.

The approach adopted for this study was the tracking of the migratory behaviour of individual adult salmon by radio tagging. Tags were inserted into the stomach of fish captured as they entered Christchurch Harbour, and their progress into and up the river was followed for several months until they spawned. The pattern of behaviour observed were then linked with environmental conditions, in particular river flow. In addition, detailed catch statistics for the period of the study were reviewed and analysed in terms of effect of river flow.

It had been hoped that an electronic fish counter, installed at Ringwood Weir but having proved ineffective, could be refurbished by the Authority so that results could be integrated into this study. In the event the problems of the site could not be overcome during the study period.

1.4. Methods.

The general technique of tagging and tracking salmon with radio tags is described fully by Solomon and Storeton West (1973) and the description here is limited to a brief summary plus detail of local aspects.

The radio tags were developed by the Lowestoft Fisheries Laboratory of the Ministry of Agriculture, Fisheries and Food. The tag is contained in a small waterproof capsule which is inserted into the fishes stomach via a tube pushed down the oesophagus; the fish is anaesthetised for this procedure. A small "message" external tag is also fitted to the back of the fish so that recaptures are reported.

Each tag transmits a unique signal (up to twelve pulse rates on ten radio frequency channels) which emerges from the water above the fish and is then detected remotely by a receiver and aerial system. The range varies according to a number of factors. Salt and brackish water is effectively opaque to radio signals, so the fish is only detectable while it is in fresh water. If the fish lies in deep water under an overhanging bank it may only be detected with the portable tracking equipment for range of about 200 metres. However, listening from a high vantage point eg hilltops a range of up to 1.5 km may be achieved. Similarly, tracking from an aircraft can give a range in excess of 1 km.

Most recording of fish movements however was effected using a total of 17 automatic scanning stations (hereafter referred to as "scanners") sited at selected points throughout the catchment. The scanners listen to each of the ten radio frequency channels every five minutes, and if a tag is detected, details are printed out on a paper tape and recorded on audio tape. The scanners were again developed at the MAFF fisheries Laboratory, and the concept is described by Pearson (1985).

During two two-week periods in 1988 and 1989, a total of 34 fish were fitted with tags that transmitted both a radio signal and an acoustic signal (combined acoustic and radio tags - CARTs). This allowed tracking of movements in salt and brackish water, giving useful indications of detailed patterns of movement within the harbour. The method and results are described in section 3.4. The 34 CART tagged fish are included in the total of 437 tagged salmon, and are included in all analyses.

Fish were obtained for tagging entirely by purchasing from the commercial netsmen operating at the "Run" at the mouth of Christchurch Harbour (Fig 3). This involved developing a close working relationship with the netsmen, who modified their method of landing fish so that they could be obtained in "untouched" condition for tagging. Without exception the netsmen were unfailingly cooperative and took a great interest in the progress of the project.

When the seine net with a captive salmon was drawn into very shallow water, the netsmen ceased hauling so that the fish could be guided and crowded into a tubular bag, manufactured from waterproof plastic material, the mouth of which was held open by an integral hoop about 35 cm in diameter. The tube was about 2 metres in length, so that it could be closed-off at both ends by hand, and the fish lifted in a small volume of water. The fish and water were then decanted into a specially designed canvas bag, which was held closed. To the water in the bag was then added an appropriate dose of tranquilliser (phenoxy-ethanol or benzocaine) to ensure that the fish remained placid during further

handling. The fish was then measured (length from nose to fork of tail), tagged, weighed (carefully in a wet polythene sack) and replaced into a second canvas carrier bag containing clean water. The fish was then driven by Land Rover to a point on the harbour just above the netting zone (Fig 2) and released. The fish usually recovered from the tranquilliser during transport to the release point, and swam away strongly. A few (perhaps 5%) returned seawards to be recaught on the same tide in the nets. If they were undamaged they were again released upstream; if they were damaged during recapture, they were killed and the tag recovered.

A total of 437 salmon were tagged and released during the five-year study. It was also intended to tag some sea trout, though problems with tag regurgitation meant that external tags were necessary for this species (Solomon and Storeton West 1983). The tags therefore have to be small, which limits battery life to 30 - 40 days. In the first year (1986) seven sea trout were radio tagged. However, as during the life of the tags none of these fish ascended the river beyond the lowermost reaches, little useful information was obtained. No further efforts were made to tag sea trout during the project.

In the first two years of the project, the lower-most scanner on the Avon was sited at the tidal limit on the Royalty Fishery, Christchurch (4.6 km by river/estuary channel from the "Black House" at Mudeford Run, the tagging and release site - Fig 2). However, as it became apparent that some activity of interest took place downstream of this point, a scanner was sited at a boatyard at the top end of Christchurch Harbour, 3.4 km form Mudeford Run (site known as "Island scanner"). This proved to be a most useful site and passage past this point was taken as entry to the river. A disadvantage with the site was however that on occasions, at high tide, saline influence at this point allowed fish to pass undetected - though they were of course then recorded by other scanners upstream.

Many other sites were used for scanners upstream, some short-term and others continuously. The following were used virtually throughout the study and are used extensively in the description of the results.

Island	3.4 km	Bickton/Fordingbridge	37.1/38.9
Tidal limit	4.6	Breamore	46.2
Knapp Mill G.S.	6.0	Standlynch	54.6
Avon Causeway	13.7	Salisbury	65.0
Severals fishery	24.8	Wilton (Nadder + Wylye)	70.5
Ellingham	30.8		

The distances are km from the netting site measured along the centre-line of the channel. The approximate location of these sites is shown in Fig 1.

Extensive vehicle and foot tracking was undertaken, mainly to locate fish which had "laid up" for protracted periods in their migration, and to establish the spawning areas used. In September 1986 a canoe was used to locate all fish between Salisbury and the sea, and in 1987 and 1988, an aircraft was used in mid-December to locate fish on their spawning grounds.

In the first year of study (1986) a scanner was located at Iford Bridge, near the tidal limit on the Stour (Fig 1), to record any fish entering that river. As several fish passed this station, a more widespread network was used in later years on the Stour including Throop, Canford and Shapwick. During 1988 to 1990, scanners were also deployed on the Dorset Frome and Piddle, rivers draining to Poole Harbour, in connection with separate studies on those river. Several fish tagged at Mudeford were recorded by these stations.

During the investigation, 43 tagged fish were reported caught by anglers on the Avon, and one each on the Piddle and the Test. A reward of £8 was paid for return of the transmitting tag and external tag (£3 for external tag only) and the captors were provided with a record of the fishes known movements between tagging and capture. Netsmen catching a tagged fish at any time after the tide on which the fish was released were paid the same reward for tag returns; a total of 28 salmon were reported caught in this way. In addition, the name of each person returning a tag from 1989 onwards was entered into an international draw sponsored by the North Atlantic Salmon Conservation Organisation (NASCO) and a Ringwood angler won a cash prize equivalent to $100 US.

2. GENERAL DESCRIPTION OF ACTIVITY IN EACH YEAR.

2.1. Hydrometric overview.

The monthly mean flows at Knapp mill Gauging station for the five years of the study are shown in Fig 4, along with the long-term average monthly flow. The gauging station is situated 6.0 km from Mudeford Run, about 600 m upstream of the West Hants Water Company abstraction point at Knapp Mill itself (Fig 2). The residual flow to the estuary is therefore less than the volume shown in Fig 4. The total abstraction here, for both domestic supply and Fawley refinery, averages about 1.0 m^3/sec.

The most critical time in terms of fish movement is the summer months, as most salmon are entering the river at this time, and flows are of course at their lowest level. From Fig 4 it can be seen that May - August 1986 were slightly higher than average flows, 1987 was about average, 1988 slightly below average and 1989 and 1990 well below average. The study period thus covered a good range of conditions with the exception of a very high flow summer. However, from the viewpoint of the impact of water resource development, flows below average are likely to be the most critical, and the coverage of these low-flow years in the investigation was fortunate.

2.2. 1986.

A total of 76 salmon were tagged between April 22 and the end of the netting season on July 31. This represents a little over 11% of the total commercial catch for the season at Mudeford of 685 fish. The distribution of tagged fish was well spread through the catch (Fig 5). The total number of fish tagged was limited by the availability and delivery of transmitting tags - there is no doubt that 100 could have been tagged had the equipment been available.

As described in section 2.1, the summer months enjoyed flows slightly higher than average. A clear pattern of behaviour with respect to river flow emerged that proved to be consistent throughout the whole five-year study. As long as residual flows entering the estuary from the Avon remained above about 12 m^3/sec (ie above about 13 m^3/sec at Knapp Mill G.S. - see section 2.1) fish generally entered the river within about 12 hours of tagging, and continued on up the river on a discontinuous basis for up to three weeks. While some remained in the lower reaches of the river, many continued for many km upstream, some reaching Salisbury (66 km) in this initial migration. The timing of passage through the various scanner stations is shown in Fig 6, illustrating the distances penetrated in the initial migratory phase. As flows fell below 12m^3/sec at the tidal limit, there was an increasing tendency for fish to remain in the short stretch of river between the tidal limit (4.6 km) and the abstraction point (5.4. km). As flows fell further, below about 9 m^3/sec at the tidal limit, there was an increasing tendency for fish to remain in the freshwater tidal zone between Bridge Pool (3.8 km) and the tidal limit (4.6 km). However, at the flows prevailing until the end of the tagging season (31st July) all tagged fish that were going to enter the river (defined as passage past the junction of the two branches of the Avon downstream of Bridge Pool, 3.4 km from Mudeford Run - see Figs 2 and 3) did so within a few days of tagging. Further, even at the lowest flows recorded during the netting season (about 9 m^3/sec at the tidal limit) a few fish continued for considerable distances upstream before stopping.

As already mentioned, fish continued up river sporadically for up to 3 weeks after tagging, and by the middle of August virtually all activity by tagged fish had ceased. A spate caused by over 40 mm of rain at the end of August triggered about five fish to resume upstream migration for a few days (Fig 6) but there then followed several more weeks of complete inactivity. However, a major movement by most fish was triggered about October 20 by increased discharge caused by heavy rainfall. This represented the start of the spawning migration and movements then continued, on a sporadic basis modulated to a large extent by river flow, until spawning occurred in late December and early January (Fig 6).

2.3. 1987.

A total of 86 salmon were tagged between April 16 and July 31. This total represents just over 15% of the total reported catch of 568 fish, and again the tagged fish were well spread through the total catch (Fig 7). Again, however, tag delivery problems meant that the target of 100 fish was not reached.

Flows between May and July were close to average (Fig 4), and a pattern of fish movement with respect to flow very similar to that in 1986 was apparent. Again most fish entering the Avon did so within a few days of tagging. However, two fish that had not been recorded after tagging entered the river in October, along with two others that had been recorded in the tidal Stour. As with the tendency to remain in the tidal reaches of the Avon, this behaviour was associated with lower river discharges at the time of tagging. Again the overall pattern of migration fell into two phases; for up to three weeks after entering the river fish moved upstream, then laid-up apparently totally immobile for many weeks, until rising discharge following heavy rain in early October stimulated large-scale movements (Fig 8).

An event of interest was the elevated discharge following heavy rain in mid-July, which raised Knapp Mill GS flow from about 9.5 to 19.5 m^3/sec. This had the effect of reducing the tendency to residence in the lowermost non-tidal and tidal reaches among fish tagged at the time, a strong indication that it is low discharge per se rather than time of year that is responsible for fish lingering in the lowermost reaches.

2.4. 1988.

A total of 99 salmon were tagged and released between April 20 and July 31, representing 14.8% of the total commercial catch of 667 fish. The spread of tagged fish through the catch is indicated in Fig 9. Of the 99 fish, 69 were recorded entering the River Avon. Twelve entered the tidal Stour, of which five subsequently ascended the Stour and one the Avon. Two fish were recorded ascending the River Piddle (see section 3.5) and nine were recaptured by the nets at Mudeford. Eleven of the fish entering the Avon were reported caught by anglers.

The early part of the season (April to June) exhibited flows well below average, but steady rain in July made that month about average (Fig 4).

The now-familiar pattern again emerged, with fish showing an increased tendency to remain in the lowermost non-tidal reaches or the tidal freshwater reaches as discharge fell (Fig 10). Again the migration fell into two distinct phases, first for up the three weeks after tagging, followed by a long quiescent period until heavy rain elevated discharge in mid-October. As in 1986, a spate in late August associated with 47 mm of rain (measured at Salisbury) stimulated a minor movement of fish (Fig 10).

For the first time in 1988 a scanner was located well below the tidal limit, at the boatyard downstream of Bridge Pool (3.4 km from Mudeford Run - Fig 2). This allowed an accurate assessment of the time elapsed between tagging and entry to the river. Above a discharge of about 9 m^3/sec, nearly all fish entering the river did so within twelve hours of tagging. Below this flow, many fish took several days to pass through the harbour, though some fast passages were still recorded.
Another aspect of the 1988 study was that twenty of the fish were tagged with CART tags (section 1.4) during a two-week period in July. This allowed detailed analysis of the movements of fish within Christchurch Harbour and the tidal Stour and Avon, the results of which are discussed in section 3.4.

2.5. 1989.

Ninety nine salmon were caught and tagged between May 2 and the end of the netting season on July 31 (Fig 11). This represents over 24% of the total reported catch of 406 fish. Two further fish were tagged on August 2 from a specially-arranged netting session. Of the 101 fish, 63 entered and ascended the Avon. Two ascended the Stour, both having first entered the Avon. Single fish were recorded on the Frome and the Piddle, and a tagged fish was caught by an angler on the River Test. Seven tagged fish were reported caught by anglers on the Avon.

Flows in June and July were well below average (Fig 4), and discharge values significantly lower than in earlier years were experienced. This was associated with many fish remaining in tidal water seawards of the Island (3.4 km) scanner. Seven were recaptured by the Mudeford nets and twelve were not detected after release. Seven more "disappeared" after having been briefly recorded by the Island scanner. Seventeen fish were recorded in the tidal Stour, of which nine later entered the Avon (ie in October and November). The remaining eight failed to enter either river. As was expected from earlier years, the low freshwater flows were associated with much slower estuary passage times even among those fish that did enter the river soon after tagging. Again, with the low flows there was a tendency for fish to lay-up in the lowermost reaches within the river. These features are apparent from a comparison of Fig 12 with the equivalent diagrams for earlier years (1986 Fig 6; 1987 Fig 8; 1988 Fig 10).

Although truncated by the low flows, the pattern of migration within the river again fell into two distinct phases, with virtually no activity between three weeks after tagging and mid October when rain raised the flow and stimulated a large scale movement (Fig 12). An important feature was that discharge fell to the extent that migration past the abstraction point at Knapp mill ceased about the end of June. A thunderstorm in early July raised discharge and was associated with significant migration; of the 25 tagged fish passing the abstraction point before October, 11 did so between July 7 and 9th. Thereafter only one more fish passed this point in the next three months, although 41 were tagged between July 10 and August 2.

River flows receded quickly after the rain that stimulated the large-scale movement in October, and remained very low until late December (Fig 12). This resulted in a much reduced penetration of the upper reaches of the river, with only three tagged fish being recorded at Salisbury (cf average of 10 in the previous three years). In particular, fish appeared to be held up for considerable periods at Bickton and Breamore; this discussed further in section 9.

With low flows through the summer and into the autumn, 1989 proved to be a most important year in the study, greatly extending the range of observations made in the rather average preceding years.

2.6. 1990.

Poor net catches in 1990 reflected a general dearth of fish (especially grilse) in most fisheries throughout the UK. Considerable effort was expended in tagging and releasing 75 fish, representing about 24% of the total commercial catch of 312 salmon. The distribution of the tagged fish through the catch is shown in Fig 13.

From April onwards river flow was far below average (Fig 4), the lowest flows since 1976. As in 1989, this had a profound effect upon the movements of fish (Fig 14). First, only 45 fish entered the Avon, and none the non-tidal Stour. Of the fish entering the Avon, 13 (29%) did so in October/November ie after many weeks in the estuary or tidal Stour. Twelve were not detected after tagging, and a further ten disappeared after being briefly recorded by the lowermost scanner or in the tidal Stour ie without entering either river. Two were recorded entering the Frome. Three were recaptured by the Mudeford nets. Second, of the 32 fish entering the river during the summer, more than half remained in the tidal reaches (12 fish) or the short non-tidal reach below the Knapp Mill abstraction point (6 fish). Of the 35 fish recorded passing upstream of the abstraction point, 23 (66%) did so after October 1. The low flows persisted to the end of the year, limiting the distribution of spawning as in 1989. This is discussed further in section 5.

3. MOVEMENTS INTO THE RIVER.

3.1. General Description.

Of the 437 salmon tagged, 298 (68.2%) were recorded entering or having entered the River Avon (entry to the river is taken as being recorded upstream of the Island scanner site 3.4 km from the release point; detection by this station alone is not considered as entry to the river). Two of these fish subsequently returned seawards and were detected ascending the River Piddle, and three the River Stour. The fate of the remaining 139 fish was:-

- 28 (6.4%) known to be recaptured by the Mudeford nets, and killed.
- 12 (2.7%) detected having ascended the River Stour without entering the Avon.
- 6 (1.4%) detected having ascended other rivers without entering the Avon.
- 43 (9.8%) detected in upper reaches of harbour but not within river.
- 50 (11.4%) not seen again.

The 43 fish detected in the upper harbour area were either detected briefly by the Island scanner (Avon) or Iford scanner (Stour) but were not subsequently recorded upstream, or were found by foot/boat search in the tidal reaches of the River Stour. A few were tracked in the harbour having been fitted with CART tags (section 3.3). The eventual fate of these fish, and of the 50 not detected again after release is of course unknown. Tag failure may have been responsible for some "losses", but the fact that few fish "disappeared" at higher river discharges suggests that some other mechanism is involved. Some may have gone to other rivers; although scanners were deployed on the Frome and Piddle for much of 1988 - 1990, and recorded six fish tagged at Mudeford, the only other way in which fish going elsewhere were discovered was by reported capture (two fish, section 3.5). Three fish were reported as being found dead in the harbour, and the conclusion is drawn that many if not most of the 93 "missing" fish died before entry to the river. This is discussed further in section 3.2.

Entry to the river generally occurred within 10 days of tagging, most

commonly within 3 days. However, a small number of fish (29, representing 9.8% of fish recorded entering the river) spent from 3 to 4 months in the harbour area (or out at sea) before entering the river in the autumn. This pattern of behaviour was associated with low river flows at the time of tagging, and is discussed further in section 3.2.

3.2. The influence of river discharge.

The influence of river flow on the likelihood and timing of entry to the river is indicated in Figure 16. The flow figure used here is the residual flow, being the flow gauged at Knapp Mill less the abstraction for Fawley Refinery and domestic supply by the West Hants Water Company just downstream of the gauging station. This figure is considered to be the freshwater flow at the tidal limit.

At flows above 9 m^3/sec, most tagged fish enter the river within 10 days. Of the 281 fish tagged at such flows, 214 (76.2%) entered the Avon within this time. A further 6 (2.1%) entered the river on elevated flows later in the year (October/November), the remaining 61 being distributed as follows:-

13 (4.8%) recaptured in Mudeford nets.
20 (7.3%) not seen again after tagging
15 (5.5%) recorded in the upper harbour but not in a river.
13 (4.8%) recorded in rivers other than the Avon.

Although there are fluctuations in the proportions of fish entering the river at flows above 9 m^3/sec, no clear trends are apparent (Figs 16 and 17). However, at residual flows below 9m^3/sec the proportion of fish entering the river within 10 days of tagging fell away sharply. Increased numbers entered the river in the autumn, but this increase did not make up for the decline in immediate entrants, and the total river entry proportion fell. Of the 156 fish tagged at flows below 9m^3/sec, 55 (35.3%) entered the river within ten days. A further 23 fish (14.7%) entered the river in the autumn. Thus a total of 50% of the fish tagged at flows below 9 m^3/sec eventually entered the river, compared to 78.3% at higher flows. At a residual flow of less than 5 m^3/sec, of the 25 fish tagged only 6 (24%) entered the Avon at any time.

It is reasonable to propose that the "disappearance" rate for fish tagged above $9m^3$/sec represents the rate at which tags fail, fish die as a result of capture and handling, and fish go to rivers other than the Avon. As there is no reason why these rates should increase at low river discharges, it is reasonable to suggest that the increased loss rate at lower discharges is due to mortality of fish while in the harbour or at sea between tagging and river entry, due to factors other than tagging and handling. Thus if we propose that all fish approaching the river at a residual flow in excess of 9 m^3/sec survive to enter the river, the equivalent figures for flows less than 9 m^3/sec and $5m^3$/sec are 63.9% and 30.7% respectively. To put it another way, over a third of the fish entering Christchurch Harbour at residual freshwater flows of less than 9 m^3/sec fail to enter the river, and over two thirds at flows of less than $5m^3$/sec.

This factor operates largely through the increased elapsed time between entry to the harbour and entry to the river at low flows. Figure 18 illustrates the relationship between flow and estuary passage time (defined as the elapsed time between release after tagging and the last record at the Island scanner). This only includes fish from 1988 - 1990 as this scanner was not installed until year 3 of the project. It is clear that, at residual flows in excess of 12 m^3/sec, the great majority of fish entering the river at all did so within 20 hours of tagging. As flows fell, many fish took much longer to make passage, though some fast passage times were still recorded. At 9 m^3/sec, many fish were taking several days. At low flows, increasing numbers of fish did not enter the river until the autumn ie showed an estuary passage time of several months (Fig 16). It is among this group of fish, ie those remaining in the estuary for months, that it is suggested that the increased mortality was manifest.

As flows generally fall steadily through the summer, it may be considered that the gradual change in patterns of fish behaviour could be a seasonal phenomenon rather than being directly affected by river discharge. However, the relatively few occasions on which sufficient rainfall occurred in the summer months to significantly increase discharge indicated that direct influence of river flow as such. Fish behaviour observed at such times was consistent with that expected at the discharge prevailing, with faster estuary passage times than fish tagged, for example, during the preceding weeks at lower discharges.

3.3. Time and tide.

The continuous record of fish arrival and departure times at the Island scanner in 1988-1990 allows a detailed consideration of the effect of time of day and tidal state on movements at this point. The tide state (time after low water) and hour of the day of the first record of each fish arriving at this scanner are shown in Fig 19. Both clearly have an influence. Greatest numbers occur late on the flood tide, and during the hours of darkness. In Fig 20 the two variables are considered together. It is apparent that fish approach this point at night at any state of the tide, but during the day are virtually limited to 3 to 7 hours after low water ie the late flood tide.

3.4. Movements within the estuary.

3.4.1. Description of observation.

In July 1988 and 1989 a total of thirty four fish were fitted with combined acoustic/radio tags (CARTs) as a joint investigation with the MAFF Fisheries Laboratory (Mr E Potter). These tags allow fish to be tracked in salt and brackish water; after a pre-set period (typically 7 days) the power-hungry acoustic transmitter is automatically switched off, leaving the tag operating as a standard radio tag for the remainder of the battery life. These fish were tracked using an array of acoustic receiving buoys which retransmit the signal as a radio transmission which is then monitored by automatic stations on-shore. The location of the equipment deployed is shown in Fig 3. The method and equipment are described by Solomon and Potter (1988).

3.4.2. Description of movements in 1988.

Twenty fish were CART tagged between July 5 and 14. Upon release immediately upstream of the ferry pontoon on Mudeford Sandbank (Fig 2), the tag signal was generally detected by buoy B, (a few were released before this buoy was sited here - it was then downstream towards A).

One fish is believed to have regurgitated its tag nearby, as the only subsequent records were from this point. The other 19 fish moved away fairly briskly, being recorded by other buoys upstream. Only four of the fish moved seawards at any time to the extent that they were within the range of buoy A. Three of these were within a few hours of release. One fish, having moved up the harbour as far as buoy F, returned seawards on the next ebb tide and was recaptured in a net in the Run. Buoy D was added to the array after several days because several fish had passed between C and F without detection. After this deployment, more fish were recorded using the Limekiln channel than the main channel. One fish, having dropped down to buoy A, passed in 20 minutes from buoy A to buoy E without being recorded by buoys B, C or D; presumably this fish used the Hurn Channel.

Of the 18 remaining tagged fish, seventeen were recorded arriving at buoy G (the other was subsequently recorded upstream). The fastest time was 1 hour and 16 minutes after release, and the longest delays were about 12 and 48 hours. Most lay between 3 and 8 hours. Once recorded reaching this point, few fish subsequently passed downstream again. Only one was subsequently recorded at buoy F, but quickly returned upstream, being absent from buoy G on this sortie for less than an hour.

The patterns of movement in the upper harbour were more variable. Two fish entered the Stour, after considerable vacillation in the area of buoys H and I, without being detected by the Island scanner on the Avon. Two other fish also ascended the Stour having been recorded on one or more occasions by the Island scanner, again after much vacillation in the area of Clay Pool. Of the twelve radio or CART tagged fish that were recorded during the year reaching the Iford recorder on the Stour, six were first recorded by the Island scanner, 300 m upstream of the junction of the two rivers. Thirteen of the CART tagged fish ascended the Avon. The range of elapsed times between release and the first record at the Island scanner was 1 hour 55 minutes to 53 hours 50 minutes, though only one other was longer than 24 hours. Most lay between 5 and 12 hours. There was often a significant time interval between the first and last records at the Island scanner; the range of reliable records was 30 minutes to 105 hours most lying between 6 hours and 3 days. About half the fish reaching the Island scanner were subsequently recorded on one or more occasions by buoys H and I before finally ascending beyond the station. Once recorded upstream of the Christchurch Town Bridges (Bridge Pool and Waterloo Bridge) no fish subsequently returned downstream to the Island scanner.

Thus the estuary movements can be divided into three zones. Fish generally ascended fairly rapidly (less than 8 hours) to the upper harbour (area of buoy G) and then rarely returned seawards at all. Between here and the first bridges (Waterloo Bridge, Bridge Pool and Tuckton Bridge) the fish tended to move more slowly, with much tidal vacillation. The range of time intervals for Avon fish to pass through this section ranged from 5 hours to 106 hours, with half the records lying between 22 and 49 hours. These three zones were almost entirely separate in that almost no fish passed between them more than once.

Daily mean residual flows for the period of CART tracking lay within a narrow range of 9.1 to 11.5 m^3/sec, and no aspect of movements appeared to be influenced by discharge within this range. A wider range of observations of passage times between release and the Island scanner is of course available as this station recorded all radio tagged fish. These results have already been discused in section 3.2.

3.4.3. Description of movements in 1989.

Fourteen salmon were CART tagged between July 24 and August 2. These fish showed somewhat different patterns of movement to those in 1988. Four fish were released about 2.5 km seawards of the Run; all were recorded re-entering the harbour between 18 hours and 10 days after release. In addition, four other fish dropped out of the estuary seawards to return later. While in some cases the acoustic stage of the CART tag had switched off before movements in the Run area had ceased, these 8 fish between them provided information on 21 passages through the Run and into the harbour. Where one fish provided more than one record, these occurred on separate tides and are thus considered independent events. While these events occurred at all hours of day and night, the majority were on the ebb tide ie the fish were entering the estuary against the tide. It is of interest to note that this coincides with the period fished by the commercial nets at the Run.

Only nine of the 14 were recorded reaching the confluence of the Avon and Stour. Three then entered the Avon within a few hours, but the remaining six entered the tidal reaches of the Stour. Only one was subsequently recorded entering the Avon (after 100 days) and none the non-tidal Stour. This pattern is consistent with the behaviour of radio tagged fish at times of such low flows (section 3.2); residual flows prevailing during the 1989 CART study period lay between 5.4 and 6.3 m^3/sec.

The results of the two years CART tracking have been written-up for publication (Potter, Solomon and Buckley, In Press).

3.5. Fish going to other rivers.

3.5.1. Introduction.

Fish returning to rivers other than the Avon, which are caught and tagged at Mudeford, are of two distinct groups. First, fish homing the Stour are "on course" as the river shares its lower estuary with the Avon. Fish homing to other rivers eg the Test and the Frome are to some extent off course, though tagging studies are increasingly indicating that such "searching and overshooting" behaviour is widespread and does not indicate that the fish are necessarily lost or confused.

3.5.2. River Dorset Stour.

At times, a high proportion of the fish tagged at Mudeford entered the tidal reaches of the Stour, often penetrating as far as Iford Bridge about 3.5 km for the confluence with the Avon estuary at Clay Pool. Many of these fish subsequently returned downstream and entered the Avon, or failed to enter either river (see section 3.1 and 3.2). Some fish ascended the freshwater Stour, however, and were recorded by scanners there or by spot checks. Only these dedicated Stour fish are considered here.

In 1986, three tagged fish were located well up the Stour system by spot checks. Five others were recorded at or just seawards of Iford Bridge, and in the absence of scanner upstream of Iford it is not possible to say whether any or all ascended the river. Given the limited scale of the search that located three fish, it is likely that more had in fact ascended the river. In 1987, five tagged fish were recorded in the river by the five scanners located there. Again in 1988, five fish were recorded having penetrated well into the system. In 1989, only two were recorded well up the Stour, both having first ascended some way up the Avon. No fish were recorded in the river above the tidal limit in 1990, though many fish were recorded in the tidal reaches from Iford Bridge downstream.

The small numbers of observations preclude detailed analysis, though generally the pattern of movements in the Stour appears to be broadly similar to that on the Avon. Some fish ascend the river to the Wimborne area in their initial migration in the summer, but many do not enter the river until the autumn. The river has a lower baseflow than the Avon, and Stour fish appear even more vulnerable to the problems of low flow and associated poor survival in the estuary. The low numbers of fish entering the river in the dry years of 1989 and 1990 were, it is suggested, as a result of virtually the whole run being denied access to the river during the summer. Of the two ascending in 1989, one had in fact spent the summer/early autumn in the Avon, upstream of Knapp Mill. In October it continued up the Avon to Ringwood area, before returning seawards and ascending the Stour, where it was recorded by successive scanners up to Shapwick (between Sturminster Marshall and Blandford, Fig 1).

It appears that the potential run up the Stour is of the order of 100-300 fish per annum. In average to wet years, many of these fish ascend the river in the summer, and exhibit a high survival. At lower flows, an increasing proportion appear to remain in tidal water through the summer, where they experience a high mortality in the same manner as the Avon fish exhibiting the same behaviour (section 3.2). However, as the Stour is more prone to low flows in dry years, the impact on the well-being of the stock appears to be greater, with an overall very low survival in 1990. Summer passage past Throop gauging station was associated with flows in excess of $5m^3$/sec. It is stressed that these observations are based on relatively few data.

Although the scanner array gave a fair picture of the dispersion of fish through the Stour system, the small numbers involved did not justify extensive foot searches to locate spawning areas. Of the fifteen fish, five were recorded passing/having passed upstream of Shapwick, five more passed Canford, four more passed Throop, and one remained downstream of Throop. In addition to the main river, the main spawning tributaries are considered to be the Tarrant (upstream of Shapwick - two tagged fish were located here in 1986), the Allen (between Canford and Shapwick - one tagged fish was located here in 1986) and the Moors River (downstream of Throop).

3.5.3. Other rivers.

Eight tagged fish (about 1.8% of the total) are known to have ascended rivers other than the Avon and Stour. These observations were made in two ways. First, single tagged fish were caught and reported by anglers on the Piddle (1987) and Test (1989). Second, scanners and spot checks on the Piddle and Frome in 1988 - 1990 in connection with tracking programmes there recorded six tagged fish, three in the Piddle and three in the Frome. Of these eight fish, six were not recorded by any of the Avon scanners before these returned seawards and ascended the other river. Two of the fish which were recorded on the Piddle, however, ascended the Avon the area of the tidal limit, remaining there for considerable periods before returning seawards. One did so in response to a minor spate in late August/early September 1988, and the other remained in the Avon until at least December 8 1989 when it was recorded by a spot check. It passed the tidal limit on the Piddle on December 14.

A fish tagged in the Frome estuary in July 1989 was briefly recorded as present in the tidal Avon at Bridge Pool about two weeks later before it again returned seawards.

In view of the fact that many fish going elsewhere after tagging at Mudeford would be unreported and undetected, it is fair to assume that a number of the fish that "went missing" after tagging did in fact go to other rivers. In section 7.2 the proportion of the Mudeford net catch comprising fish going to rivers other than the Avon is proposed as 13%.

for the purposes of modelling the run; about half of this proportion would be Stour fish, and half (say 6.5%) from other rivers.

4. SUMMER MOVEMENTS WITHIN THE RIVER.

4.1. Baseflow movements.

In this section the movements within the river of the fish entering the river within 10 days of tagging are considered. Almost no fish entered the river more than 10 days after tagging except in the autumn in response to increased discharge.

Fish entering the river in the summer generally continue their migration for up to three weeks or so on a discontinuous basis before laying-up for several months until the autumn. This pattern is apparent from the almost total lack of scanner records of migrating fish between mid August and mid October in Figs 6 - 14. Some fish remain in tidal water within the river, while the initial migration phase (the 3 weeks or so) of more active fish may take them 70 km or more upstream.

At residual flows in excess of 20 m^3/sec, most fish, having entered the river very shortly after tagging, continued on upstream beyond Knapp Mill (ie the abstraction point). As flows fell, however, an increasing proportion laid-up between the Knapp Mill weirs (5.5 km) and Island scanner (3.4 km); at 9 m^3/sec, about half the fish entering the river remained in this zone until autumn (Fig 21). At flows below 8 m^3/sec, only one of the 21 fish entering the river proceeded beyond Knapp Mill before the autumn. As the proportion of fish remaining downstream of Knapp Mill increased, there was an increasing tendency for fish to remain downstream of the tidal limit. From Fig 21 it can be seen that, at flows below 8 m^3/sec, about three quarters of fish entering the river remained until the autumn in the 1.2 km reach between the tidal limit and the Island scanner (Fig 3).

As already described, virtually no fish ascended beyond Knapp Mill abstraction point at residual flows below 8 m^3/sec. In Figure 22, the summer destination (=laying-up location) of fish ascending beyond Knapp Mill is indicated. It appears that the distance travelled upstream by those fish ascending beyond Knapp Mill is virtually unaffected by river flow within the range that fish utilize to enter this zone of the river. It should be noted that Knapp Mill gauged flow in used in this graph as this is upstream of the abstraction point.

4.2. Time and tide.

As was done for arrival at the Island scanner (3.4km) in section 3.2, the state of tide at time of first record at the scanner at the tidal limit (4.6 km) and hour of the day of arrival at the scanners at the tidal limit, Knapp Mill Gauging Station (6.0 km) and upstream (all other scanners combined) are shown in Fig 19. Only records for April to July are used, representing the initial migratory phase before the fish laid-up until the Autumn.

It is apparent that tidal state does not influence the time of arrival at the tidal limit. The tidal signal that was apparent in the records for the Island scanner, 1.2 km seawards, has disappeared. The time of day signal is greatly enhanced, with peaks after dark and in the first hours of light and very low numbers throughout most of the day.

At the Knapp Mill G.S. Scanner (6.0 km) the pattern is again different, with numbers sharply concentrated in the first hours of daylight. This station is just a few hundred metres upstream of the obstructions at Knapp Mill and the Great Weir (Fig 3). It is likely that fish arriving at these points during the hours of darkness await dawn to ascend; it is likely that vision is important to orientation while negotiating falls and weirs.

The pattern of arrival time at scanners at various points upstream is different again, with movement more evenly spread throughout the 24 hours. There would appear to be a definite trough in activity in the late afternoon/early evening, however.

4.3. The influence of freshets.

4.3.1. Background.

On four occasions during the study, one in each of the first four years, enough rainfall occurred in a short period at a time of otherwise low flows to have a significant effect upon river flow. As the effects on fish were somewhat different it is useful to consider each in some detail. The events here described are all during the period July to early September; the effects of heavy rainfall in October are described in section 5.

4.3.2. August 25 1986.

The remains of "Hurricane Charlie" crossed Southern England on August 25 1986, and a total of 46.4 mm of rain was recorded at Salisbury. This led to increased discharge throughout the catchment, eg DMF at Amesbury (catchment area 323.7 km^2) rose from 1.8 m^3/sec on August 24 to 2.8 on August 26; single 09.00 reading at Knapp Mill (catchment area 1706 km^2) rose from 9.0 m^3/sec on the 25th to 23.9 on the 27th.

As this event took place more than 3 weeks after the last fish was tagged, none were still in the "initial migration" phase described in section 4.1, and there had been virtually no activity recorded at any of the scanners during the previous two weeks (Fig 6). However, five fish which had been "laid up" for some time were stimulated to migrate upstream by this event. Three of these fish were downstream of the Knapp Mill abstraction point and migrated between 6.5 and 20.0 km over the next two days. The other two stimulated fish were downstream of Ringwood, but as their exact starting points were not known the distances migrated cannot be calculated. The five fish represented a wide range of tagging dates from June 25 to July 30. They were tagged in week numbers 11, 13, 14(2) and 16. Comparison with the weekly distribution of tagging in Fig 5, indicates that the latter half of the tagged population was well represented but not the first half.

4.3.3. July 17-18 1987.

Over 25 mm of rain was recorded at Salisbury on these two days. The 09.00 flow reading at Knapp Mill rose from 9.5 on July 17 to 19.3 on July 19, staying above 10 m^3/sec for a further week. Although no fish that had been in the river for more than a week or so were stimulated to move, the increased discharges had exactly the effect of a higher baseflow on fish entering the river at the time. There was thus a greatly reduced tendency for new entrants to lie-up in the tidal and lowermost non-tidal reaches of the river, and an increased tendency for fish to migrate for some distance up river (Fig 8).

4.3.4. Aug 30 - Sept 1 1988.

Regrettably neither rainfall records and flow records are available in detail for this event, due to equipment failure. On the Frome, a river with broadly similar characteristics to the Avon, the flow was doubled.

As no fish had been tagged for over a month, all had finished their initial migration stage. Five "laid up" fish were stimulated to migrate, however. Four moved upstream, having been located at approximately 4, 9, 30 and 30 km from the tagging site. The fifth fish, located near the tidal limit, returned seawards and was recorded ascending the River Piddle. The fish had been tagged between April 20 and July 26. They represented week numbers 2, 11, 13(2) and 16. Comparison with the weekly distribution of tagging in Fig 9 indicates that this was a fairly representative sample of the tagged population.

4.3.5. July 6 1989.

A series of thunderstorms on the evening of July 6 resulted in rainfall of the order of 25 mm over much of the catchment. Astonishingly, both the Salisbury rain gauge and the Knapp Mill flow gauge were not operational at the time so again the information is incomplete. The dmf estimated at Knapp Mill rose from 9.6 on July 5 (ie residual flow about 8.6) to 10.8 m^3/sec (residual flow 9.8) on July 7, but it is suggested that the real change may have been greater.

The flow before this event was falling through the critical zone for fish migration (see section 3.2) and numbers passing Knapp Mill were falling. The storms kept the residual flow above 9 m^3/sec for several days, and eleven tagged fish passed the Knapp Mill scanner between July 6 and July 10. All these fish had been tagged within the previous 17 days and are therefore considered to have been still in the initial migration phase. These eleven fish represented 44% of the 25 tagged fish passing Knapp Mill before October. Flows fell again quickly, and only one more tagged fish passed this point during the summer in spite of 41 being tagged between July 10 and 31. This highlights the tremendous importance of spates at times of otherwise low flow.

4.3.6. Conclusions.

Summer spates thus appear to affect fish differently according to the timing of the event and the length of time fish have spent in the river. First, they operate in the manner of raised baseflow in influencing the pattern of movements of fish still in their initial migration phase, ie within about three weeks of entering the river. The July flow events described above operated in exactly this manner.

Second, the increased flow may stimulate movement of fish that had been in the river for some time, and were thus considered to have ended their initial phase of migration. The timing of the event appears to have a bearing here; while events in late August stimulated the movement of small numbers of laid-up fish, those in July, although of similar hydrological magnitude, did not. In turn, the flow events which stimulated large-scale movements in October (see section 5) were again of similar or lesser magnitude hydrologically to those initiating only a minor response in late August. Thus a similar flow event has an increasing effect on fish behaviour as the season progresses. This pattern of behaviour therefore appears to be linked to the physiological state of the fish, and may be considered a precursor of the spawning migration phase described in section 5.

4.4. Artificial freshets.

In view of the conclusion that freshets in the summer operate at least partly by simulating an elevated baseflow, it is reasonable to consider that an artificial freshet manufactured by release of stored water might be effective at stimulating movement of fish still in their initial phase of migration.

On August 4 1989, a flow manipulation experiment was conducted in the lower reaches. The aim was to modify the pattern of flow at the tidal limit, over a period of several hours, to attempt to simulate the effect of raised base-flow on migrating salmon. This was achieved by closing hatches at Winkton (5 km above the tidal limit), to reduce flows and impound water for several hours. Hatches were then opened and the impounded water released in a controlled manner. It was hoped that it might be possible that the abstractions at Knapp Mill might also stop for a few hours, to enhance flows further. In the event the critical nature of the supply at these very low flows precluded this, and further limited the extent to which the flow could be impounded. Another problem was that the Knapp Mill gauging station was not operational at the time. Mr Frake and his team arranged the impoundment and release, and also the detailed temporary gauging.

The impact of the experiment on flows near the tidal limit is shown in Fig 23. A temporary near-doubling of the discharge was short-lived with flows back to base levels within a few hours. No fish were stimulated to move by this manipulation. Two factors may have been involved. First, the event is likely to have been too short-lived to stimulate fish. Second, because of a delay in obtaining the necessary approval for the work, it took place a week later than planned, and there were relatively few "fresh" tagged fish available to be stimulated.

The problems involved in mounting this trial and the difficulties posed for the abstractors at Knapp Mill meant that it was not possible to undertake a larger-scale experiment attempting to increase flows for a longer period. In order to be useful such a trial must of course be conducted at times of low flow, when river conditions are critical for all users. It is still considered that this approach might have potential for dispersion of fish at times of low flows.

5. THE SPAWNING MIGRATION.

5.1. General description.

In each of the five years studied, rainfall during October leading to a significant increase in discharge triggered a major movement of fish throughout the river which then continued on and off until the fish spawned at the end of the year. The general level of activity through this period, and the distribution of spawning was considerably influenced by discharge, with long dry periods leading to reversion almost to the quiescent state that predominated in August and September.

5.2. Relationship with flow.

5.2.1. 1986.

Daily records of tagged fish passing scanners and discharge for October, November and December 1986 are shown in Fig 24. Several features are worthy of note. First, many fish were stimulated to move by a small elevation in discharge, in the region of 50% from 8.5 m^3/sec to 13 m^3/sec. Some were stimulated very early on the rising hydrograph and indeed some fish in the lower reaches started to become "restless" before the river level rose. This supports the idea proposed in section 4.3 that increasing physiological readiness towards spawning time means that fish respond more positively and to smaller flow events than in earlier months.

Activity fell away somewhat in late October as flows fell back, but increased again on much greater flows in mid November. This resulted in effective dispersion of fish to the general spawning areas, with little long-distance movement being recorded after mid-November despite high flows prevailing.

5.2.2. 1987.

Elevated discharges occurred earlier in October in 1987, with much of the spawning dispersion being effected between October 7 and 20 (Fig 25). A period of low flows in late October was associated with virtually zero activity, with two spells of elevated discharge triggering further activity, especially in the higher reaches, during November. As in 1986, little long-distance movement was recorded after mid November.

5.2.3. 1988.

The pattern was again similar in 1988, with a spell of elevated flows between October 6 and 24 resulting in widespread migration throughout the river system (Fig 26). A long period of low flows then ensued, with relatively little activity. However, it appears that most fish had reached their target destination during October spates and a further spell of elevated flows in early December was associated with minimal activity.

5.2.4. 1989.

While heavy rainfall causing an increase in discharge in mid October once again triggered large-scale movement of fish, the situation in 1989 was rather different to earlier years. First, because the flows during the summer had been very low, the fish were generally distributed further downstream in early October than in earlier years. Second, flows did not exceed about 15 m^3/sec before falling back to almost summer levels for several more weeks (Fig 27). Thus while large-scale activity was triggered in October, relatively few fish dispersed into the upper river (eg above Fordingbridge) at this time. High flows then occurred again from mid-December, once more triggering activity. However, few fish penetrated beyond Breamore and the distribution of spawning appears to have been severely truncated by the low flows.

The exact mechanism of this reduced spawning dispersion is not known. However, a major build-up of tagged fish immediately below Bickton in early December and below Breamore in late December suggests that fish may have had difficulty in gaining access past these mill weirs at the flows prevailing. This is considered in detail in section 9.

5.2.5. 1990.

The final year of study was similar to 1989. Once again, elevated flows in late October initiated a major movement of fish (Fig 28), but as in the previous year this was mainly centred in the lower river for the same reasons. A very protracted period of low flows then persisted until late December. Again, large numbers of fish were gathered below Bickton, and few eventually penetrated beyond Breamore.

5.2.6. Conclusions.

It thus appears that elevated flows are necessary to trigger large-scale movement towards the spawning grounds in the autumn. It is also apparent that fairly high flows or regular flow elevations are required throughout the autumn for optimal dispersion of spawning. Dry years with few spates and a rapid return to base flows, appear to be associated with severe truncation of the spawning distribution.

The level of flows required to stimulate movement is not high. Major migration was triggered in October 1989 by a flow event with a peak DMF (measured at Knapp Mill) of only 12.8 m^3sec. Fully effective dispersion of spawners appears to require somewhat high flows or at least flows maintained for many days. Sub-optimal dispersion may be associated with particular problem obstructions however, rather than a lack of stimulating flows.

5.3. Spawning distribution.

Numbers of tagged fish still being followed at spawning time (late December - early January) were generally considerably reduced from the numbers tagged. Fish were lost to legal and illegal capture, and increasing numbers of transmitting tags were failing as the year progressed. Nevertheless, numbers tracked each year gave a good indication of the general pattern of spawning distribution.

The first three years of the study represented "unremarkable" years in terms of river flow (section 2.1), and showed similar patterns of spawning distribution. The table below shows the distribution of the most upstream record of each fish being tracked near spawning time each year.

Area	Location km	1986	1987	1988	1989	1990
Wylye	70.5 ->	1	2	0	1	0
Nadder u/s Wilton	70.5 ->	5	5	6	0	0
Nadder d/s Wilton	64.9 - 70.5	4	2	1	1	2
Avon u/s Salisbury	64.9 ->	2	1	3	1	0
Stanlynch-Salisbury	54.6 - 64.9	8	8	7	4	(4
Breamore-Standlynch	46.2 - 54.6	2	3	4	1	(
Fordbge-Breamore	38.8 - 46.2	2	1	1	8	1
Ellingham-Fordbge	30.8 - 38.3	5	1	(8	11	(16
Ringwood-Ellingham	24.8 - 30.8	3	3	(	5	(
Causeway-Ringwood	13.7 - 24.8	3	-	2	10	7
d/s Causeway	0 - 13.7	1	-	-	1	1

Combining the figures for 1986-88 indicates that 58.5% of spawning activity took place upstream of Standlynch Mill. In the two years of low flow, 1989 and 1990 (see section 5.2), less than 15% of spawning took place upstream of Standlynch, with all zones downstream of Breamore more heavily used than in the earlier years. The impact on salmon stocks of this limited spawning dispersion is not yet apparent as grilse catches in 1992 will be the first yearclass possibly affected in the fishery.

It was hoped that the tracking might indicate any differential spawning distribution of the various age classes of fish. In fact there proved to be no discernible pattern. One possible exception is that the small numbers of 3 sea-winter fish tracked appeared not to migrate beyond the Fordingbridge area, but it is stressed that the numbers are too small for this to be a firm conclusion. The largest fish tagged, a 31 lb male, spawned in the Avon Tyrrel area in 1991.

The furthest upstream that tagged fish were found were West Amesbury on the Avon, Steeple Langford on the Wylye and downstream of Dinton Mill on the Nadder.

6. SALMON ANGLING AND RIVER FLOW.

6.1. Tagged fish caught by anglers.

A total of 43 radio tagged fish were reported caught by salmon anglers in the Avon in the year of tagging. Another was caught two years following tagging, ie as a second-time spawner. Details of the 44 fish are given in Table I.

It is apparent that twenty of the 43 (46.5%) same-year recaptures were made within 10 days of tagging, and 67% within 20 days of tagging. Thus most recaptures were made within the three-week period during which the initial migration phase is contained (section 4). It is generally considered that fish are most vulnerable to capture while resting during migration and for a few days after arrival in a lie, though fish actually travelling are less prone to capture. These recapture results support this view.

Fishery	Location	Catch 1986-90	Number of tag returns Expected	Actual
Royalty	3.8 - 6.0	783	12	23
Winkton	6.0 - 9.5	27	0	0
Avon Tyrell	9.5 - 17.0	99*	2	1
Bisterne	17.0 - 22.0	215	3	2
Severals	22.0 - 26.1	133	2	4
Ringwood	26.1 - 27.0	28*	0	2
Somerly	27.0 - 33.4	488	7	1
N. End	33.4 - 35.5	410	6	1
Bickton	35.5 - 37.1	361*	6	7
Breamore	46.0 - 50.0	127	2	2
Trafalgar	52.3 - 60.0	93	1	0

*Includes one or more years estimated.

In the table above the numbers of recaptures reported on the main fisheries are compared to the total reported catches on those fisheries during the five years 1986 to 1990. Given that 43 recaptures were made, we can then allocate the 43 in proportion to the total catches to give an "expected" number of recaptures for that fishery. Generally there is fair agreement between the expected and actual numbers for each fishery with the following exceptions:

- the Royalty fishery is over-represented by actual recaptures.
- Somerley and N.End are under-represented.

In view of the fact that the fisheries upstream of N.End are fully represented, these discrepancies do not appear to be due to any modified behaviour due to tagging (eg tendency to remain well down the river). The apparent over-representation on the Royalty may be due to

- under-reporting of total catch
- tagged salmon being caught and reported by coarse fishermen who would otherwise return and not record salmon catches.

It is likely that both these factors contribute to the situation.

The under-representation at Somerley and N.End could be due to:

- non-reporting of recaptures of tagged fish
- the catches being largely comprised of a run of fish which is under-represented in the tagged sample.

There is no evidence that the former mechanism is responsible. In some years at least, there is a tendency for Somerley catches to peak earlier than (say) Breamore and Severals up and downstream respectively. This is apparent in 1987 (Fig 30) and 1990 (Fig 33). The earlier run is known to be less well-represented in the tagged sample than the later run.

Generally, however, the distribution of recaptures of tagged fish, being well spaced through all the main fisheries, supports the view that the tagged fish are behaving in a similar manner to un-tagged fish.

6.2. Fish movement and angling success.

In Figs 29-33, the weekly angling catches from mid April to the end of August are shown for 1986 to 1990 for several of the main Avon fisheries. When super-imposed on the weekly pattern of movements of the tagged fishing the two patterns can be compared.

The pattern of catches in the lower fisheries is generally bi-modal, with a peak around week five and a larger peak between weeks ten and fifteen. The tagged fish are poorly represented in the early peak, but generally the pattern of movements of fish from week five onwards closely matches the catches up the river. Catches falling-away two to three weeks after the number of tagged fish movements have fallen is consistent with the observation that fish remain vulnerable to capture for only a short time after migrating, (section 6.1) and with the suggestion that relatively few fish enter the river after the end of the netting (and tagging) season at the end of July (section 7.4).

In dry years (eg 1989 and 1990) penetration of the upper river by summer migrants is poor, with commensurate poor catches at Breamore and Trafalgar (Figs 32 and 33). In an average year (eg 1986) penetration is much better, with steady catches at Breamore and Trafalgar throughout the season (Fig 29). Catches on the lowermost fishery, the Royalty, are very much less influenced by river discharge. This is consistent with the observations on the movement of the tagged fish.

Generally these observations confirm the view that the tagged fish behave in a manner that is fully representative of the population from which they have been drawn. The under-representation of tagged fish in the early part of the season is believed to be due to two factors:

- relatively few of the early fish were tagged. No fish were tagged before mid-April, and the net exploitation rate (and hence tagging rate) is believed to have been relatively low for some weeks thereafter.

- rod exploitation rates of the early fish are believed to be higher than on the summer fish. This would lead to a greater catch relative to the population.

In the context of this study this under-representation of early-running fish is considered of little consequence as it is later in the season that low river flows, and abstraction, have a significant influence of fish movements. This is discussed further in section 7.

7. DEVELOPMENT OF A MODEL OF FISH MOVEMENT AND FLOW.

7.1. Introduction.

From the data discussed in section 3 and 4 it is now possible to propose a simple model linking fish movement and river flow. By incorporating an estimate of the numbers of fish approaching the river at any time, based upon net catch returns and estimated exploitation rates (see section 10), the model can then be used to indicate the impact of any abstraction on numbers of fish passing various points.

7.2. Inputs to the model.

In section 3.2, it is noted that at residual flows (flows to the estuary) in excess of about $9m^3$/sec, the pattern of entry to the river appears to be independent of discharge. For 281 fish tagged at such flows, the following pattern of behaviour was observed

214	(76.2%)	entered the Avon within 10 days
6	(2.1%)	entered the Avon in the Autumn
13	(4.8%)	were recaptured in the Mudeford nets
20	(7.3%)	were not seen again after tagging
15	(5.5%)	were recorded in the upper harbour, but not in a river
13	(4.8%)	were recorded in rivers other than the Avon

A number of assumptions/decisions are now necessary. Of the 20 fish not "seen" again after tagging, some are explained by tag failure, some by tagging/ handling mortality, some by natural mortality, some by unreported capture in the harbour (legal or illegal) and some will have gone to other rivers. It should be noted that, although 13 fish were reported in other rivers, most fish going elsewhere will be undetected unless captured or entering a river which is also instrumented for a tracking programme (eg Stour, Frome and Piddle 1988-1990). Similarly, the 15 fish only recorded in the upper harbour area will be explained by the same range of factors. As the total numbers involved (35 fish = 12.5%) is limited the allocation of these fish is not too critical; the following is adopted:-

Of the 35 "missing" fish -

- 20 went to rivers other than the Avon;
- 5 were caught but unreported by the legal net fishery
- 10 are explained by tag failure.

It is assumed that the fish recaptured by the nets and the tag failures would have shown a distribution similar to the remainder. Thus for each 1000 fish evading capture by the nets at Mudeford Run at residual flows in excess of $9m^3/sec$:-

- 846 are Avon fish, and enter the river within 10 days
- 24 are Avon fish, and enter the river in the Autumn
- 130 are fish from elsewhere, which will return elsewhere

The estimated mean exploitation rate of the Mudeford nets for the four years for which estimates were available at the time of writing (ie 1986 - 1989) was 11.9% (see section 10).

At lower flows, the behaviour and fate of fish is increasingly influenced by residual freshwater flow (Fig 16). As flows fall, increasing numbers of fish are either not seen again or are last seen in the harbour, and increasing numbers of fish delay entry to the river until the Autumn. Of fish entering the river, increasing numbers remain for the summer in the tidal reach or downstream of the Knapp Mill abstraction until the Autumn (Fig 21).

As discussed in section 3, it is suggested that the steady "disappearance" rate for fish tagged at flows in excess of $9m^3/sec$ represents the rate at which tags fail, fish die as result of capture and handling, and fish go to rivers other than the Avon. The same allowance is therefore made in the proportion of "disappearing" fish at lower flows, and they are re-apportioned as above. The excess "disappearance" rate is assumed to be caused by death in the harbour, or return seawards without subsequent entry to the river.

7.3. Relationship between flow and fish movement.

Using the inputs discussed in 7.2 (above), the following figures are suggested:-

% of Avon fish evading net capture which:-

Residual flow m^3/sec	Fail to enter	Enter Avon <10 days	enter Avon Autumn	lie-up tidal Avon	lie-up d/s Knapp	ascend beyond Knapp in season
20+	0	97.2	2.8	0	0	97.2
16-20	0	97.2	2.8	0	12	85.2
14-16	0	97.2	2.8	0	12	85.2
13-14	0	97.2	2.8	5.4	12	85.2
12-13	0	97.2	2.8	8.8	17.7	70.7
11-12	0	97.2	2.8	10.5	18.4	68.3
10-11	0	97.2	2.8	16.2	24.3	56.7
9-10	0	97.2	2.8	14.5	29.0	53.8
8-9	8.5	70.2	21.3	19.1	14.9	36.2
6-8	17.5	49.5	33.0	38.5	8.9	2.1
5-6	45.5	37.7	16.8	29.3	6.3	2.1
4-5	60	20.0	20.0	13.3	6.7	0

While the figures follow closely the actual results of tracking, some arbitrary "smoothing" of the trends has been applied, particularly where single fish in a small batch have resulted in points lying off the general trend. The model is illustrated in Fig 34.

It is of interest to note that, among the tagged fish ascending beyond Knapp Mill in the initial phase of migration ie within the fishing season, there appeared to be no relationship between distance travelled and discharge (Fig 22, section 4.1). However, analysis of angling results (section 6) indicates that the fisheries in the upper river ie upstream of Bickton are dependent to a large extent on high flows to enjoy good fishing. This is likely to be because fish do ascend further at high flows; the reason why this is not indicated by the tracking results is probably because of the preponderance of dry summers (and poor upper-river catches) during the investigation, and the small numbers of fish reaching far up river in their initial migration.

7.4. The numbers of fish.

The final part of the model is the numbers of fish approaching the Avon. In the table below, the mean net catches by week for 1986 to 1990 are shown. By applying the estimated mean exploitation rate of 11.9% by this fishery, an estimate of the mean run by week is given. A further calculation adjusts for the mean estimated proportion of the Mudeford net catch that comprises Avon fish (see above, 88.1%), and to allow for the fact that part of the run enters the harbour outside the netting season (see below).

Week	Net catches in Year					Mean	Mean	Avon	Escape	adjusted
No.	'86	'87	'88	'89	'90	catch	run	total	nets	escape
1	8	6	3			3.4	29	26	23	18
2	10	4	6		1	4.2	35	31	27	22
3	6	2	2		2	2.4	20	18	16	13
4	16	5	9	2	4	7.2	61	53	47	38
5	14	19	10	2	4	9.8	82	72	63	50
6	26	19	11	2	4	12.4	104	90	79	63
7	21	28	14	3	9	15.0	126	110	97	78
8	52	24	22	5	22	25.0	210	183	161	129
9	58	25	34	13	25	31.0	261	227	200	160
10	65	25	34	33	19	35.2	296	258	228	182
11	74	57	55	55	33	54.8	461	401	353	282
12	84	90	76	56	33	67.8	570	496	437	350
13	87	92	124	59	44	81.2	682	593	522	418
14	77	103	106	57	59	80.4	676	588	518	414
15	50	56	117	68	32	64.6	543	472	416	333
16	23	46	28	48	21	33.2	279	243	214	171

The adjustment for the proportion of the run occurring outside the netting season is necessary because the overall estimated exploitation rate by the nets is 11.9% of fish entering the harbour between the start of the run (February ?) and the end of the angling season on September 30 (see section 10). Thus the weekly run sizes in the table are over-estimates by a factor equivalent to the proportion of the run which enters the harbour outside weeks 1 - 16 ie before about April 14 and after July 31. It is believed that only a limited proportion of the run occurs at such times, and a 20% adjustment is made to account for this.

Using the "whole season" estimate of exploitation rate for individual weeks is of doubtful validity, as it is certain that effective fishing effort is much lower in the early part of the season when fish are few. Thus the exploitation rate is likely to be much lower in the early weeks than at the peak of the fishery (possibly as little as a quarter of the peak) and, higher than the average in the peak weeks. This would lead to the numbers of fish running in the early weeks being a major underestimate. For example, if the exploitation rate were only one quarter for the first five weeks what it was for the remaining 11 in the table above, the runs in the first five weeks would be underestimates by 75% and the remaining weeks would be over-estimates by only 20%. As the weeks of greatest impact of abstraction are indeed the later ones, and in the absence of reliable effort figures, the values derived in the table are used.

Using these inputs, we can now calculate the expected numbers and behaviour patterns for any week, and indicate the different results obtained using the natural flow record, the actual flow record, or any predicted residual flow for a new scenario of abstraction. We can thus indicate the impact on salmon movement, and to a some extent angling success, of existing and proposed abstraction patterns.

8. THE IMPACT OF ABSTRACTION.

8.1. Knapp Mill and Matchams.

Using the model developed in section 7, we can now "predict" the pattern of movements of salmon for some sample years, for both the actual residual flow pattern and the calculated flow pattern that would have occurred without, for example, the Matchams and Knapp Mill abstractions.

Table II and Fig 35 illustrate the model output for 1986, a year with average discharge in May, June and July. Because residual flows remained just above the critical level of 9 m^3/sec, the impact of the average abstraction at Matchams and Knapp Mill (domestic plus Fawley) of 1.4 m^3/sec was small. Numbers of fish entering the river within ten days and in the autumn were unaffected, though entry of some fish may have been delayed by a day or so (see section 3.2). The main impact is upon the proportion of fish that ascended beyond the abstraction point at Knapp Mill in the initial phase of migration. Of the 2651 fish which the model suggests entered the river between weeks 1 and 16, 580 remained in the Royalty Fishery, between Knapp Mill and the Island scanner, and 2071 ascended beyond Knapp Mill. Had the abstractions not been operating, the figures would have been 437 remaining in the Royalty Fishery and 2214 ascending beyond. Thus the abstraction resulted in a reduction in the numbers of fish ascending beyond Knapp Mill in the season of 6.5%. The numbers remaining in the Royalty Fishery were increased by 32.7%. There was also a slight shift in the proportion of the Royalty "resident" fish which laid up in the tidal zone ie the lower fishery from 20% at "natural" flows to 26% with abstraction.

Thus while the abstraction in 1986 would have had almost no impact upon the wellbeing of the stock of salmon, it would have led to a minor redistribution of fish during the angling season and thus, presumably, of angling success.

The picture for 1990, a very dry year with low flows, is rather different (Table III, Fig 36). Numbers of fish entering the river within ten days of entering the harbour would have been lower than in 1986 even with natural flows, at 2300 fish. Abstraction, increasing the period when residual flows were below 9 m^3/sec and taking flows eventually below 5 m^3/sec, decreased the numbers entering the river during the season to 1858 fish ie a reduction of 19%. Some of the "delayed" fish would have entered the river in the Autumn (414 such fish compared to 303 under a natural flow regime) but the numbers failing to enter the river was increased from 123 to 441 ie an additional 318 losses. Numbers laying-up in the Royalty Fishery were increased by abstraction from 953 to 1040, an increase of 9%; it should be noted that these numbers are much greater than in wetter seasons such as 1986 described above. The numbers ascending beyond Knapp Mill within the angling season, already low at 1257 with the natural flow, were reduced to 904 ie a reduction of 28%.

Thus abstraction in 1990, impacting on a situation of already very low flows, had a significant effect on both stock well-being (increased mortality due to delay in the estuary) and distribution of stock for angling. In particular, it brought forward by about 10 days the flow below which there is virtually no penetration by fresh fish beyond the Knapp Mill abstraction point. In respect of this latter effect, abstraction beyond week 15 was of little consequence because the natural flows would by then have fallen below this critical level.

In conclusion, the Matchams and Knapp Mill abstractions are having a negligible effect in years when summer flows are above average. At average flows there is a minor effect on distribution of fish for angling, but no impact on stock well-being. However, in years of below average discharge the present abstraction is having a significant, but not overwhelming, impact on both stock well-being and on dispersion of fish for angling.

It will be noted that the figures quoted above for the numbers of fish entering the river within 10 days and in the autumn are somewhat different to those actually observed in 1986 and 1990 (see section 10). This arises because the above calculations are based upon an average, smoothed run of fish so that the model can be used for years for which there is no tracking data. In fact the run of fish in 1986 was rather above average, and that in 1990 rather below. While this would change absolute numbers of fish affected by abstraction it would not change the proportions.

8.2. Blashford.

The licence to abstract water at Ibsley for replenishment of Blashford Lakes and direct supply allows the following maximum daily takes:-

20 Ml/d, to count towards Knapp Mill daily total. Plus:-
30 Ml/d, subject to a prescribed flow of 23 m^3/sec at East Mills G.S.

The switching of 20Ml/d of take from Knapp Mill to Blashford makes no difference to the residual flow to the estuary, but would result in a minor reduction in flow between Ibsley and Knapp Mill. In section 4 it is concluded that discharge in this reach has little influence upon the migration of fish at the range of flows when fish are proceeding above Knapp Mill ie above 9 m^3/sec at Knapp Mill G.S. It is unlikely that a reduction of 20 Ml/d (0.23 m^3/sec) would change the situation.

The abstraction of a further 30 Ml/d (0.35 m^3/sec) subject to a prescribed flow of 23 Ml/d at East Mills will be of no consequence to salmon movement, as at such high flows fish move throughout the river freely. Indeed, a greater take or significantly lower prescribed flow could be applied with minimal impact; this is discussed further in section 8.4.

The only unquantifiable potential impact of the Blashford scheme concerns the extent to which draw-down of the lakes in times of low flows may deplete stream flow in adjacent water courses by intra-gravel seepage and local lowering of the water table. If this does result in a significant reduction in flow in the Avon this could in turn have an impact on salmon movement. In all other respects, however,the Blashford scheme appears to be very acceptable in environmental terms.

8.3. Groundwater abstraction.

Consideration of groundwater abstraction in detail is beyond the scope of this report. Clearly, however, any abstraction within the catchment that causes a reduction in dry-weather flow of the river will be contributing to the impact on salmon migration. A classically designed groundwater abstraction scheme, however may be having the opposite effect; if the boreholes are situated away from the stream, the cone of depression should not affect stream flow in the summer, and should be recharged during the winter. Much of the abstracted water is likely to be discharged to the river via sewage treatment works, enhancing summer flows. The other side of the coin however, is that there is then a delay in the aquifer contributing to elevated stream flow in the autumn/winter period. In dry years, low autumn flows are implicated in a significantly reduced dispersion of spawning fish.

8.4. Guidelines for the future.

8.4.1. Introduction.

The aim of this section is to consider a range of options for water resource development in the future, involving both new schemes and modifications to existing schemes. This is of course driven by consideration of the requirements for migrating salmon, and some of the ideas may be impracticable or not economically viable in resource management terms. On the other hand, adoption of some of the ideas may not involve significant inconvenience or cost, and may be realistic in the longer term. Some suggestions may indeed represent a bonus or economy in resource terms.

8.4.2. Location of abstraction points.

The first consideration concerns the location of abstraction points. Other things being equal, the lowest possible point downstream is the obvious choice; this limits any impact to the least possible length of river, and in relative terms the take will be a lower proportion of the flow. However, the lowest practical point for abstraction may still result in a significant reduction in salmon movement. For example, abstraction at Knapp Mill still leaves about 2 km of river downstream where, at times of low flow, large numbers of salmon are held up. Many other fish remain in the estuary or even return seawards. The situation in 1990 is illustrated in figure 36 and Table III. Had all the Matchams and Knapp Mill abstraction been taken at the tidal limit (ie at 4.6 km) the migration model suggests that an extra 87 salmon would have ascended past Knapp Mill within the fishing season (taking the total from 904 to 991 ie an increase of 9.6%). As the same number of fish remained in the tidal river under both natural and residual flows, moving the abstraction further downstream into the tidal zone would, in 1990, have made no further difference. This would still leave an impact on movement in terms of fish delayed in the estuary which either enter the river in the autumn (111 fish) or fail to enter the river (318 fish). Thus while exact location of the abstraction point does influence the impact, any realistic site still leaves a significant potential impact.

In section 7.3 it is concluded that, within the range of flows that fish use to pass Knapp Mill, the actual value of the flow has little impact on subsequent movement. This suggests that moving the Matchams licence, or indeed any other existing and fully utilized licence from upstream, to Knapp Mill would be of little benefit to fish movement. However, the scope for diurnal modulation of abstraction to reduce the impact on fish movement is greatly increased for downstream sites. This is discussed further in section 8.4.4.

8.4.3. Prescribed flows.

The licensed abstractions at Knapp Mill and Matchams are fairly unusual in UK terms, being such large takes without any prescribed flow requirement. The impact is of course limited by the large dry-weather flow of the river (Q95 at Knapp Mill GS, 1975-88 = 6.9 m^3/sec). However, as movements of salmon at low flows are influenced by abstraction, would application of a prescribed flow rule help the situation?

The answer is undoubtedly "yes" if the prescribed flow could be set high enough. There are, of course, major operational problems posed by such an approach. Using Q95 as a starting point (a commonly adopted level for prescribed flow) immediately indicates a peculiarity of rivers with a high groundwater contribution to baseflow compared to surface-water fed rivers. The distribution of flows below Q95 is highly clumped, with many years passing without flows falling to such a level, followed by a year with perhaps months of such flows. Since Knapp Mill gauging station records began in 1975 only six years have shown flows below Q95. These are 1975 (16 days), 1976 (238 days), 1984 (38 days), 1987 (1 day), 1989 (80 days) and 1990 (95 days). Thus an alternative source would be used only infrequently, but then perhaps for a considerable period. A storage reservoir, for example, to ensure a maintained drought-reliable yield would have to be inordinately large, and would remain unused for long periods.

A second major problem is that, in order to protect salmon migration, a prescribed flow rule would have to protect the critical flow of about 9 m^3/sec (section 7.3). Such flows occur far more often, and for longer periods, than Q95 flows. Clearly, the approach of a straightforward prescribed flow rule to protect salmon migration is inappropriate for direct-supply abstraction from the Avon.

The concept is more viable for abstraction for storage reservoirs, however, and has of course been applied to part of the take for replenishment of the Blashford Lakes (section 8.2). It is suggested however that the p.f. in that case has been set unnecessarily high at 23 m^3/sec. From section 7.3 it will be noted that salmon movements into and through the river are virtually unaffected by residual flows to the estuary in excess of 13 m^3/sec. If adoption of a prescribed flow for the 30 Ml/d abstraction at Blashford of 13 m^3/sec to the estuary could in turn allow reductions of other Avon abstractions at critical flows, such an option would be recommended.

8.4.4. The concept of "spared flows".

A more realistic approach to at least partially protecting salmon movements is to target particular flow ranges and events that are critical for fish movement. Two such events are immediate candidates - falling flows around 9 m^3/sec, and summer spates.

The salmon movement model suggests that the Knapp Mill plus Matchams abstractions caused an overall reduction in the numbers of salmon migrating upstream of Knapp Mill within the season in 1990 of 354 fish (section 8.1, Fig 36). Abstraction in a single week (week 14) was responsible for 141 (40%) of these, mean flows being reduced from 8.4 to 6.7 m^3/sec. Abstraction in week 15 was responsible for only 7 fish failing to ascend above Knapp Mill. There would thus appear to be scope to target a fairly short time period for protection of flows to maximise benefit. In some other years, of course, where natural flows fell to around 8.5 m^3/sec and held there for several weeks, the impact of abstraction would be relatively greater and more prolonged, and targeting a particular week, though perhaps protecting the same number of fish, would not have such a great relative effect compared to the whole-years impact of abstraction. The timing of the falling hydrograph relative to the run is also important - falling through the critical levels in early July will have a much greater impact than a similar event in mid August.

The other obvious candidate for flow sparing is the falling limb of a spate hydrograph in June or July, especially if previous base flows were below 9 m^3/sec. Just a few days of sparing could be very effective here - for example, in 1989 44% of tagged fish ascending beyond Knapp Mill before October did so in the four days following the peak flow resulting from thunderstorms (section 4.3.4). Had this event occurred a week or two later, abstraction would have rendered it virtually valueless for salmon movement.

It is therefore suggested that bankside storage equivalent to seven days abstraction (totalling about 1000 Ml), to be used to avoid direct abstraction from the river at critical times, would represent a significant reduction in the impact of existing abstraction on fish movement. Once the supply was depleted, direct abstraction could then resume and the storage would only be replenished once flows rose again above (say) 13m^3/sec.

8.4.4. Modulation of abstraction.

The idea here is to consider the possibility of modulating abstraction at critical times eg by state of tide, time of day or perhaps one day on/one day off. Clearly this would involve taking more water when abstraction was allowed, and having bankside storage for supply when abstraction ceased.

From the observations made in sections 3.3 and 4.2, it seems there is little to be gained from the idea of modulation on a tidal basis. However, there would appear to be a strong case for diurnal modulation, based upon the patterns apparent in Fig 19. Cessation of abstraction for 12 hours from 20.00 to 08.00 BST, even at the cost of doubled abstraction for the other twelve hours, is likely to greatly reduce the overall impact. The would only be of major benefit when Knapp Mill gauged flows lay between about 8 and 11 m^3/sec. Therefore the modulation would not be required at very low flows, when the doubled rate of take during the day might have a much greater relative impact. This option would require bankside storage of the order of 65 Ml. It also pre-supposes that the Matchams abstraction could also be switched off and that the effect of this would be apparent almost simultaneously at the tidal limit - clearly this is not the case. Alternative options could include moving the Matchams licence to Knapp Mill, or operating this concept based upon Knapp Mill abstractions alone.

Day on/day off operation might be desirable if it were found that the protected time of 12 hours proposed above were too short to be fully effective. It would of course require twice the bankside storage capacity.

9.0. OBSTRUCTIONS TO MIGRATION.

9.1. Introduction.

Observations on obstructions to upstream passage were of course routinely made in the course of the project. In addition, the Fisheries Department invested in some additional equipment for the project from 1987, to extend the range of study including additional observations on obstructions. There are five sites between the estuary and Standlynch where delays may occur; these are now discussed in turn.

9.2. Knapp Mill.

The large numbers of fish remaining downstream of Knapp Mill at times of low flow (section 7.3) suggests that the mill and its associated weirs are a severe obstacke to movement. Is this in fact the case?

The situation is complicated by the fact that there are two upstream routes past Knapp Mill. A fairly constant flow of water passes through the mill itself, regulated by the requirements of the turbine pumps and the fish pass. All excess water passes over the Great Weir and down the main channel. The abstraction points are upstream of Knapp Mill itself (Fig 2). The flow through Knapp Mill is generally of the order of 5 m^3/sec. Thus the flow via the Great Weir represents the great majority of discharge at high flows, but at very low flows only the fishpass operates there taking less than 0.5 m^3/sec. As long as a good flow is passing over the Great Weir (total residual flows in excess of 14 m^3/sec) almost all fish pass via this route, and can procede upstream without delay. Between residual flows of the order of 9.5 and 14 m^3/sec, fish pass by either route, and again appear to experience no delay. At residual flows below 9.5 m^3/sec, almost all fish passing upstream do so via Knapp Mill itself. The situation is illustrated by results obtained in 1986 (Fig 37) when scanners were sited at Knapp Mill and Great Weir during the summer. This phenomenon of fish starting to use the Knapp Mill route only as flows fall is well known to the salmon anglers on the Royalty fishery, with the "Parlour" Pool below Knapp Mill being a noted summer salmon location.

As residual flows fall below about 8 m^3/sec, very few fish ascend beyond Knapp Mill (section 7.3). However, this appears unconnected with the mill itself and any impediment to movement that it might represent for the following reasons:-

- While a scanner was installed at Knapp Mill and Great Weir in 1986 and 1987, few fish laying-up downstream were recorded by these scanners beforehand ie they had not experienced the situation at the mill or weir.

- Although the Parlour Pool is a good holding area, at no time was there evidence of large numbers of tagged fish crowded at this spot.

- Fish laying-up downstream of the mill and weir were well distributed in the 1.5 km between the Parlour and Bridge Pools.

- Few of the fish laying-up in the tidal zone of the river (ie between the tidal limit, 4.6 km and the Island scanner at 3.4 km, Fig 2) were recorded beforehand at the tidal limit scanner ie their decision to remain was not influenced by conditions at Knapp Mill.

Thus although Knapp Mill and the Great Weir both cause minor delay to movements, with many fish remaining for a day or two in the pools below, there is no evidence that they represent a serious impediment to migration under conditions when fish are in any case inclined to move.

9.3. Bickton Mill.

Although no scanners were deployed at Bickton between 1986 and 1989 some observations are possible based upon spot-checks and rates of travel between downstream and upstream recorders. Two scanners were sited there in 1990.

Twenty seven radio tagged salmon reached Bickton Mill during the angling season (ie before September 30) in the five years (numbers each year were 10, 8, 6, 1 and 2). The great majority of passage past this point has taken place later, generally mid to late October.

Of the 27 fish, seven were reported caught by anglers fishing at Bickton. Three remained in the Bickton area until October. The remaining 17 passed on upstream generally after only a short delay. These fish were generally recorded by the scanner at Fordingbridge (38.5 km) within a few days of passing the next downstream scanner at Ellingham (30.8 km) or being recorded by spot checks at Bickton (36.0 - 37.1 km)

Thus although the high apparent exploitation rate (26%) might suggest a significant obstruction to movement, fish mainly remained at Bickton for only a few days before moving on. Those caught had on average passed the scanner situated 7 km downstream less than four days previously (range 2 to 9 days) and had been tagged at the estuary mouth (37 km downstream) on average eleven days before capture (range 7 to 25).

Thus during the angling season Bickton Mill does not appear to have been a significant impediment to movement. Fish will only be reaching this far up the river on flows in excess of 9 m^3/sec (at Knapp Mill - flows similar at Bickton) at which discharge passage does not appear to be a problem.

The situation appears rather different later in the year under dry conditions, however, when fish appear to be willing to migrate on lower flows. In 1989 and 1990 a major build-up of fish occurred here in November and December. Fish appeared to get through with the minimum of delay in October, on flows (measured at East Mills) above about 6.7 m^3/sec. As flows fell below 6.5 m^3/sec no fish appeared to pass, and numbers built up immediately downstream. At times up to ten tagged fish were present, indicating a build-up of several hundred fish. In both years heavy rain later in December allowed fish to ascend once again.

It is important to note that it does not appear to have been the weirs themselves that caused the obstruction. The fish were generally held up downstream below the fish farm outfalls, rarely being detected by the scanners located at the weirs themselves. It thus appears that it was the depletion of flow in the main channels by the fish farm abstraction that represented the obstruction. For this reason caution must be exercised in interpreting the above flow rates in terms of fish passage as the volume and proportion of flow passing through the fish farms at any time is not known.

9.4. Burgate Weir.

In 1986 and 1988-90 no recorder was sited here. In 1987, at the request of the Fisheries Department, a station was deployed at the upper weir here from July to October 30. In 1986, five fish passed Burgate during the fishing season. Time taken to run from Fordingbridge to Breamore recording stations (7.25 km) ranged from 22 hours to 38 days, though four of the five made the journey in less than 3 days. One of the fish reached Breamore Mill before returning downstream to Burgate Lower Weir (where it spent three months, with another excursion up to Breamore and down again, before migrating upstream in the Autumn to spawn in the Nadder).

In 1987 only three tagged fish reached Burgate during the angling season, all before the recorder was installed in late July. One passed from Fordingbridge to Breamore in just over 24 hours. One remained nearby Burgate Weir from arrival in July to departure in October. The third fish passed from Fordingbridge to Breamore in 6 hours 20 minutes. It than dropped downstream to Burgate Weir area, where its presence was recorded until July 31. It then passed upstream through Breamore Mill the next day.

Thus although two of the three fish remained sometime in the Burgate area, one had already passed upstream and had returned. In fact on detailed checking on July 31 both fish were located just upstream of the upper weir.

Thus this area appears to be attractive to those few fish reaching this weir on their "initial" migration up river. Fish appear to remain in, or return to this area voluntarily rather than because the weirs represent an obstacle to movement.

Eleven more tagged fish passed the recorder during October 1987. Seven were either recorded for a single 5 minute scan, or were missed altogether. This suggests that they had ascended the lower weir and were passing the recorder site at the upper weir without pausing. The other four were recorded intermittently for 2 to 10 hours, indicating minor delay in their migration. Three of the four "arrived" during darkness and reluctance of fish to ascend weirs at this time has been noted throughout the study. It is therefore concluded that the weirs at Burgate do not represent a serious impediment to migration.

9.5. Breamore Mill.

Twelve tagged fish reached Breamore Mill during the angling season in the five years; five in 1986, two in 1987, five in 1988 and none in 1989 and 1990. These records were between May 18 and September 3. Of the twelve, eight passed straight on upstream with total presence recorded at the Mill ranging from ten minutes to three days. Of the four not passing straight on upstream one remained in the area for three weeks, during which time it was recorded 1 km upstream of the Mill before returning downstream. It was subsequently caught by an angler in Breamore Mill Pool. Two others, having been recorded for a short time at Breamore Mill dropped downstream to the Burgate area. These fish later passed upstream again (one on August 1 1987, period of presence at Breamore Mill 8 hours, and one in October 1986). The fourth fish remained in the vicinity of Breamore Mill for several weeks.

The flows prevailing when the eight fish passed this point lay between 7.4 and 11.4 m^3/sec, measured at the East Mills gauging station about 6 km downstream. The flows prevailing when the remaining four fish arrived at Breamore were also in this range.

Most fish passed this point from October onwards. Flows prevailing during known successful passage lay between 6.0 m^3/sec and 15.7 m^3/sec. Fish arriving at the mill in October and November showed a similar distribution of delay times in each year, so the figures are combined:-

	<30 min	30-60 min	1-6 hr	6-24 hr	1-3 days	3 days+
number of fish	13	9	22	11	2	3

In 1986-88, virtually all upstream passage past Breamore Mill was complete by the end of November (see Figs 24-28). However, in the dry autumns of 1989 and 1990 a high proportion of fish reaching here did so in December and demonstrated considerable delay in passing the mill, many remaining downstream. In 1989, seven fish arrived between December 17 and 24, and only one was known to have passed upstream. In 1990, four fish arrived between December 19 and 25, and remained in the area for many days. One is known to have eventually passed on upstream, but it is not known if any of the other three eventually succeeded.

Three possible explanations for the passage problems in December 1989 and 1990 are immediately apparent.

- The fish were close to spawning, and may have found it impossible to ascend the weir or may have been disinclined to do so because of their condition.

- Flows in late December 1989 were higher than the range previously associated with successful passage. From December 17 1989 flows remained in excess of 17 m^3/sec until well into the New Year. The single fish passing here in December 1989 did so on the 14th on a flow of 15.7 m^3/sec.

- Flows in December 1990 were lower than those associated with successful passage. Flows on the day of arrival lay between 4.8 and 6.8 m^3/sec; what passage took place did so many days later on higher flows.

- The loss of weed growth late in the year would have lowered the tail-water level in the weir pool, exposing a sill below the hatches. This would make passage more difficult. Dredging downstream undertaken in 1989 is also likely to have exacerbated this problem.

Whatever the reasons, Breamore weir appears to have been a significant impediment to migration in December 1989 and 1990, and is likely to have been implicated in the truncated dispersion of spawning activity in those years. At other times it does not appear to have been a serious obstacle to movement.

9.6. Standlynch Mill.

Four tagged fish reached Standlynch during the angling season, three in 1986 and one in 1987. The three fish in 1986 passed the mill before a scanner was installed so no details of their passage are available. The fish in 1987 was recorded for a total of 3hr 10 minutes on July 30, when the dmf at East Mills GS was 7.8 m^3/sec.

Most fish passed here from October onwards. New fish passes were commissioned at the mill and weir in 1988, so comparison of the delays demonstrated by fish before and after installation is of interest.

	<30 min	30-60 min	1-6 hr	6-24 hr	1-3 days	3 days+
Numbers of fish						
1986+7	0	2	9	12	4	5
1988+9	0	1	9	11	1	1

Although the faster passage times have remained similar, there does appear to have been a reduction in the incidence of delays in excess of 24 hours. Numbers of observations are small, however, and this should be taken as an indication rather than proof that the passes are effective.

Only two tagged fish are known to have passed Standlynch in 1990, and equipment problems meant that no details of their passage are available.

10. POPULATION ESTIMATES AND EXPLOITATION RATES.

The number of tagged fish entering the river within the angling season, the numbers of tagged fish caught by anglers and the total reported angling catch each year can be used as inputs to a mark/recapture population estimate. This estimates the total run entering the river before the end of the angling season. From a consideration of how many fish each marked fish represents, one can estimate the total river run and the total number of fish entering Mudeford Run. In turn, exploitation rates can be computed. The inputs and results are tabulated below.

	1986	1987	1988	1989	1990
1. No. tagged	76	86	99	101	75
2. Tagged fish enter river in season	57	65	68	52	32
3. Rod catch	1025	600	708	441	295
4. Net catch	685	568	667	406	312
5. Tag recaps by rod	10	10	11	7	5
6. Estimated run into river in season	5317	3551	4017	2873	1579
7. 95% CL + or -	1953	1015	1105	949	591
8. Each tagged fish represents	93.3	54.6	59.1	55.2	49.3
9. Total run at Mudeford to 30 Sept.	7091	4696	5851	5580	3698
10. Total run into river	5317	3877	4078	3481	2219
11. Exploitation rate by nets	9.7%	12.1%	11.4%	7.3%	8.4%
12. Exploit. of available fish by rod	19.3%	16.9%	17.6%	15.6%	18.7%
13. Exploit. of whole river run (rod)	19.3%	15.5%	17.4%	12.7%	13.3%

The estimated run into the Avon before September 30 each year ranged from 1579(1990) to 5317(1986), but the confidence limits are wide. This suggests a rod exploitation of available fish (ie those entering the Avon before September 30) ranging from 15.6 to 19.3%. The range of rod exploitation rates on the whole stock entering the river including in the Autumn (ie the extent to which the spawning stock is reduced) ranged from 12.7% to 19.3%.

Estimates of the total number of fish entering Mudeford Run ranged from 3698 (1990) to 7091 (1986), but it must be borne in mind that a proportion of these are not Avon fish. In section 7.2, a total of 13% of the catch at Mudeford (and therefore the run of fish) is estimated to have originated from, and be returning to, rivers other than the Avon. The estimated exploitation rate by the nets on the whole run passing through Mudeford Run range from 7.3% to 12.1% between years.

It is stressed that the confidence limits on these estimates are large, and only the extreme values are significantly different from one another. They are presented here because they give a useful picture of the levels of stocks and exploitation rates. Great care should be exercised in considering the differences between years.

While the rod catches are partly a reflection of the size of the salmon stock approaching the coast, as in all rivers flow conditions play a major part. However, in the case of groundwater-fed rivers such as the Avon, rainfall and recharge during the preceding winter are the critical factor. In surface-water fed rivers, summer rainfall is generally more important. Thus the best catch on the Avon during this study was in 1986, when a strong stock coincided with good baseflow conditions. However, throughout the UK 1988 was generally an exceptionally good year, with ideal flows following rain through July and August which had a much smaller impact upon Avon catches.

The poor rod catch in 1989 was due mainly to low flow conditions, and was reflected throughout the UK. In 1990, drought conditions coincided with a weak adult stock, producing very poor catches throughout the UK, including the Avon. The weak adult stock in 1991 also is a cause of concern but is beyond the scope of this study.

The exploitation rates calculated above are unexceptionable by UK standards. A fish-counter based study on the Test and Itchen conducted by the NRA indicates significantly higher levels; of the order of 40% by rods alone on the Test, and 70% by rods and net on the Itchen.

11. REFERENCES.

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12. ACKNOWLEDGEMENTS.

Throughout this project I have received a vast amount of help and support from the Mudeford netsmen, the riparian owners and anglers on the River Avon, and the Staff of Wessex Water Authority and the National Rivers Authority.

I do not wish to list all those who have helped individually as they are so many that I fear some would be missed inadvertently. However, special mention must be made of the netsmen,

> Mr Norman Derham, Mr Doug Bursey, Mr Tony Stride, Mr Mike Wilson, Mr Binkie Hunt and Mr Alf Wills, and their endorsees.

Their unfailing support, cooperation and interest in the whole programme has been most encouraging. Without their whole-hearted cooperation this project would have been very much more difficult, and less successful.

Particular mention must also be made of Mr Allan Frake of the Regional Biology Unit of Wessex WA and now of the Wessex Region NRA. He has been the project officer throughout, and his support and encouragement in the formative stages of the work were warmly appreciated. Throughout he has been a most effective liaison officer and a totally reliable colleague.

Finally, I should also mention an ex colleague at MAFF, Trevor Storeton West. He was responsible for the development of the radio tracking system which made this project possible. Throughout the execution of the project he has been most supportive in terms of advice and technical expertise.

Table I. Details of tagged fish recaptured by anglers.

Year	Tag no	Weight lbs	Date tagged	Date caught	Days elapsed	Where caught
1986	A367	11.50	May 27	June 29	33	Royalty
	A385	5.20	June 6	June 16	10	Bickton
	A401	8.20	June 18	June 28	10	Bickton
	A313	6.50	June 20	July 15	25	Bickton
	A424	11.50	June 23	July 19	26	Breamore
	A309	7.50	June 25	July 5	10	Royalty
	A429a	7.25	July 4	July 11	7	Bickton
	A440	8.50	July 8	Aug 10	33	Royalty
	A439	8.25	July 8	July 24	16	Bisterne
	A429b	8.25	July 29	Aug 4	8	Royalty
1987	B1/1	20.50	April 16	April 22	6	Ringwood
	B2/2	14.25	May 27	June 27	31	Royalty
	B10/2	10.75	June 5	June 14	9	Severals
	B10/3	7.25	June 23	July 2	10	Bickton
	B2/3	5.25	June 23	June 30	7	Bickton
	B5/4	7.00	June 26	Sept 7	73	Royalty
	B6/4	6.00	June 26	Aug 8	43	Avon Tyrell
	B10/5	6.25	July 2	Aug 3	32	Royalty
	B10/6	5.25	July 7	July 9	2	Royalty
	B5/8	6.00	July 20	July 31	11	Royalty
1988	C9/1	15.50	May 20	May 30	10	Royalty
	C5/1	11.00	May 25	June 1	7	Severals
	C6/1	10.00	May 31	June 4	4	Royalty
	C2/6	13.50	June 16	July 1	15	Royalty
	C10/8	7.00	June 20	July 12	22	Bisterne
	C8/7	13.00	June 20	July 12	22	Severals
	C8/9	7.50	July 4	July 17	13	Somerly
	C1/9	8.50	July 4	July 12	8	Royalty
	C7/9	6.00	July 4	Sept ?	60+	Royalty
	C2/10	8.00	July 5	Sept 22	78	Breamore
	C3/7	8.25	July 6	July 25	19	Ringwood
1989	?	?	?	July ?	?	Royalty
	D9/2	10.00	June 14	June 28	14	North End
	D2/1	11.25	June 20	June 23	3	Royalty
	D1/5	13.00	June 26	July 3	7	Royalty
	D5/5	15.00	June 28	July ?	?	Royalty
	D3/10	5.00	July 17	Sept 17	62	Royalty
	D5/12	7.75	July 28	Sept 12	46	Royalty
1990	E3/4	6.25	June 25	July 13	18	Severals
	E6/1	11.50	June 5	June 18	14	Royalty
	E4/1	8.00	June 6	June 12	6	Royalty
	E6/3	5.00	June 15	June 25	10	Bickton
	E3/3	8.00	June 14	June 26	12	Royalty

Table II Migration model output for 1986.

a) Natural flows (Knapp Mill gauged flow plus Matchams abstraction)

Week No.	Flow	Total Run	Fail to Enter	Enter <10d	Enter Autumn	Tidal River	Lower River	u/s Knapp
1	27.4	17	0	17	0	0	0	17
2	29.0	22	0	21	1	0	0	21
3	19.7	13	0	13	0	0	3	10
4	20.5	38	0	37	1	0	0	37
5	23.0	50	0	49	1	0	0	49
6	31.8	63	0	61	2	0	0	61
7	20.1	78	0	76	2	0	0	76
8	18.2	129	0	126	3	0	15	111
9	18.2	166	0	162	4	0	20	142
10	15.6	182	0	177	5	0	22	155
11	16.4	282	0	274	8	0	34	240
12	14.3	350	0	340	10	0	42	298
13	15.8	418	0	406	12	0	50	356
14	12.5	414	0	402	12	35	71	296
15	11.9	333	0	324	9	35	61	228
16	11.1	171	0	166	5	18	31	117
Totals				2651	75	88	349	2214

b) Residual flows (Knapp Mill gauged flow less Knapp Mill abstractions).

Week No.	Flow	Total Run	Fail to Enter	Enter <10d	Enter Autumn	Tidal River	Lower River	u/s Knapp
1	26.0	17	0	17	0	0	0	17
2	27.6	22	0	21	1	0	0	21
3	18.3	13	0	13	0	0	3	10
4	19.1	38	0	37	1	0	5	32
5	21.6	50	0	49	1	0	0	49
6	30.4	63	0	61	2	0	0	61
7	18.7	78	0	76	2	0	9	67
8	16.8	129	0	126	3	0	15	111
9	16.8	166	0	162	4	0	20	142
10	14.2	182	0	177	5	0	22	155
11	15.0	282	0	274	8	0	34	240
12	12.9	350	0	340	10	31	62	247
13	14.4	418	0	406	12	0	50	356
14	11.1	414	0	402	12	43	76	283
15	10.5	333	0	324	9	54	81	189
16	9.7	171	0	166	5	25	50	91
Totals				2651	75	153	427	2071

Notes. Week 1 ends April 20, week 16 ends August 3.
Flow = peak dmf for week.
Total run = see section 7.4.
Enter = pass Island scanner (3.4 km).
Tidal = lay up in tidal river 3.4 - 4.6 km
Lower = lay up in lower river, 4.6 - 5.6 km
u/s Knapp = ascending beyond Knapp Mill before laying up

Table III Migration model output for 1990.

a) Natural flows (Knapp Mill gauged flow plus Matchams abstraction)

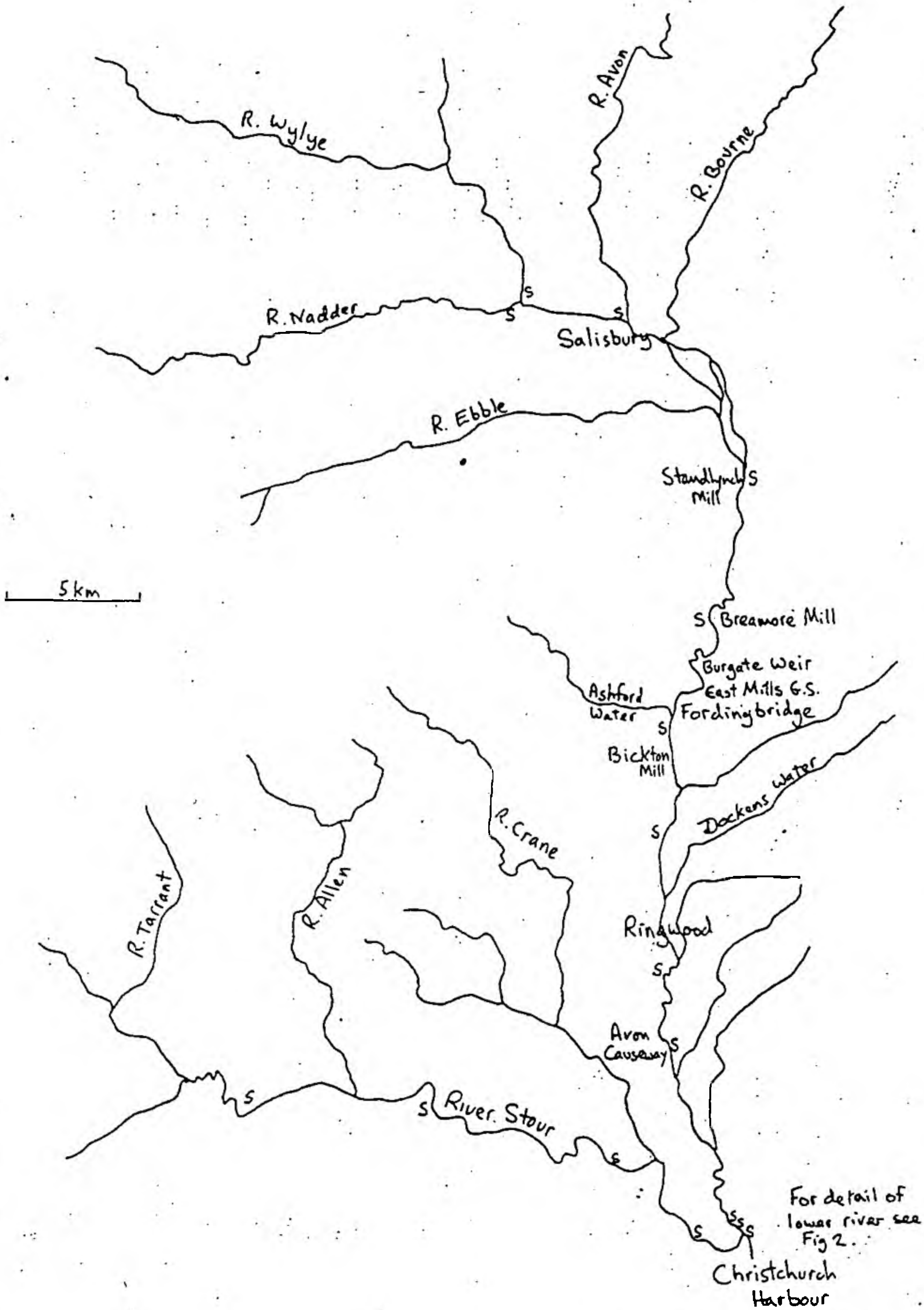
Week No.	Flow	Total Run	Fail to Enter	Enter <10d	Enter Autumn	Tidal River	Lower River	u/s Knapp
1	23.0	17	0	17	0	0	0	17
2	22.4	22	0	21	1	0	0	20
3	18.9	13	0	13	0	0	2	11
4	16.4	38	0	37	1	0	5	31
5	15.0	50	0	49	1	0	6	42
6	14.3	63	0	61	2	0	8	53
7	12.0	78	0	76	2	7	14	55
8	10.9	129	0	126	3	21	31	74
9	11.0	160	0	162	4	17	29	116
10	10.6	182	0	177	5	29	44	104
11	10.6	282	0	274	8	46	69	159
12	9.5	350	0	340	10	51	102	187
13	9.2	418	0	406	12	61	118	227
14	8.4	414	35	291	88	79	62	150
15	6.7	333	58	165	110	128	30	7
16	6.1	171	30	85	56	66	15	4
Totals		2720	123	2300	303	505	535	1257

b) Residual flows (Knapp Mill gauged flow less Knapp Mill abstractions).

1	21.7	17	0	17	0	0	0	17
2	21.2	22	0	21	1	0	0	21
3	17.6	13	0	13	0	0	2	11
4	14.7	38	0	37	1	0	5	32
5	13.7	50	0	49	1	3	6	40
6	12.8	63	0	61	2	6	12	43
7	10.3	78	0	76	2	13	19	44
8	9.4	129	0	126	3	19	37	70
9	9.5	166	0	162	4	24	48	90
10	9.2	182	0	177	5	26	53	98
11	9.2	282	0	274	8	41	82	151
12	8.2	350	30	246	71	67	52	127
13	8.0	418	36	293	89	80	62	151
14	6.7	414	72	205	137	159	37	9
15	4.7	333	200	67	56	44	22	0
16	4.5	171	103	34	34	23	11	0
Totals		2720	441	1858	414	505	448	904

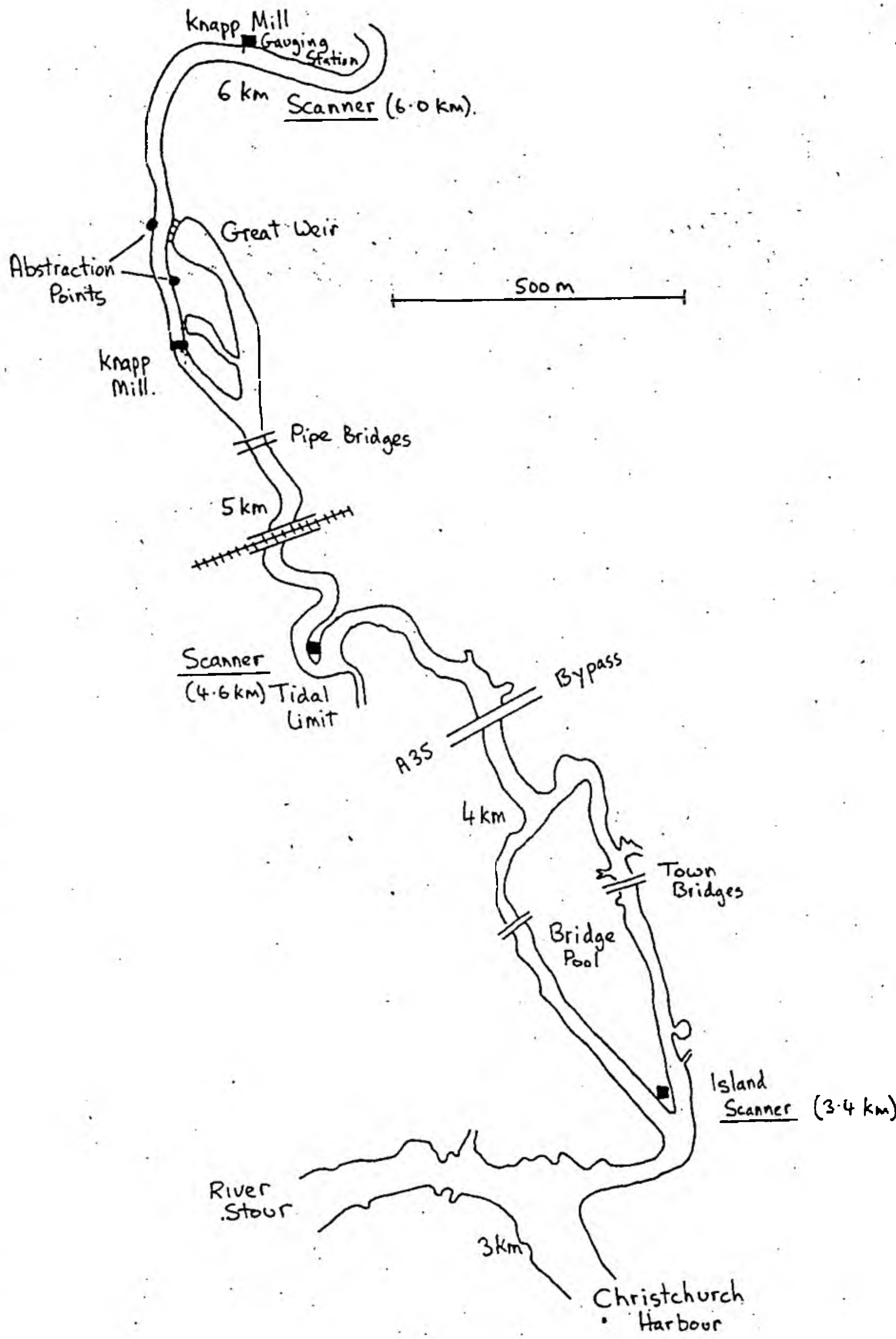
Notes. Week 1 ends April 15, week 16 ends July 29.
Flow = peak dmf for week.
Total run = see section 7.4.
Enter = pass Island scanner (3.4 km).
Tidal = lay up in tidal river 3.4 - 4.6 km
Lower = lay up in lower river, 4.6 - 5.6 km
u/s Knapp = ascending beyond Knapp Mill before laying up

Figure 1

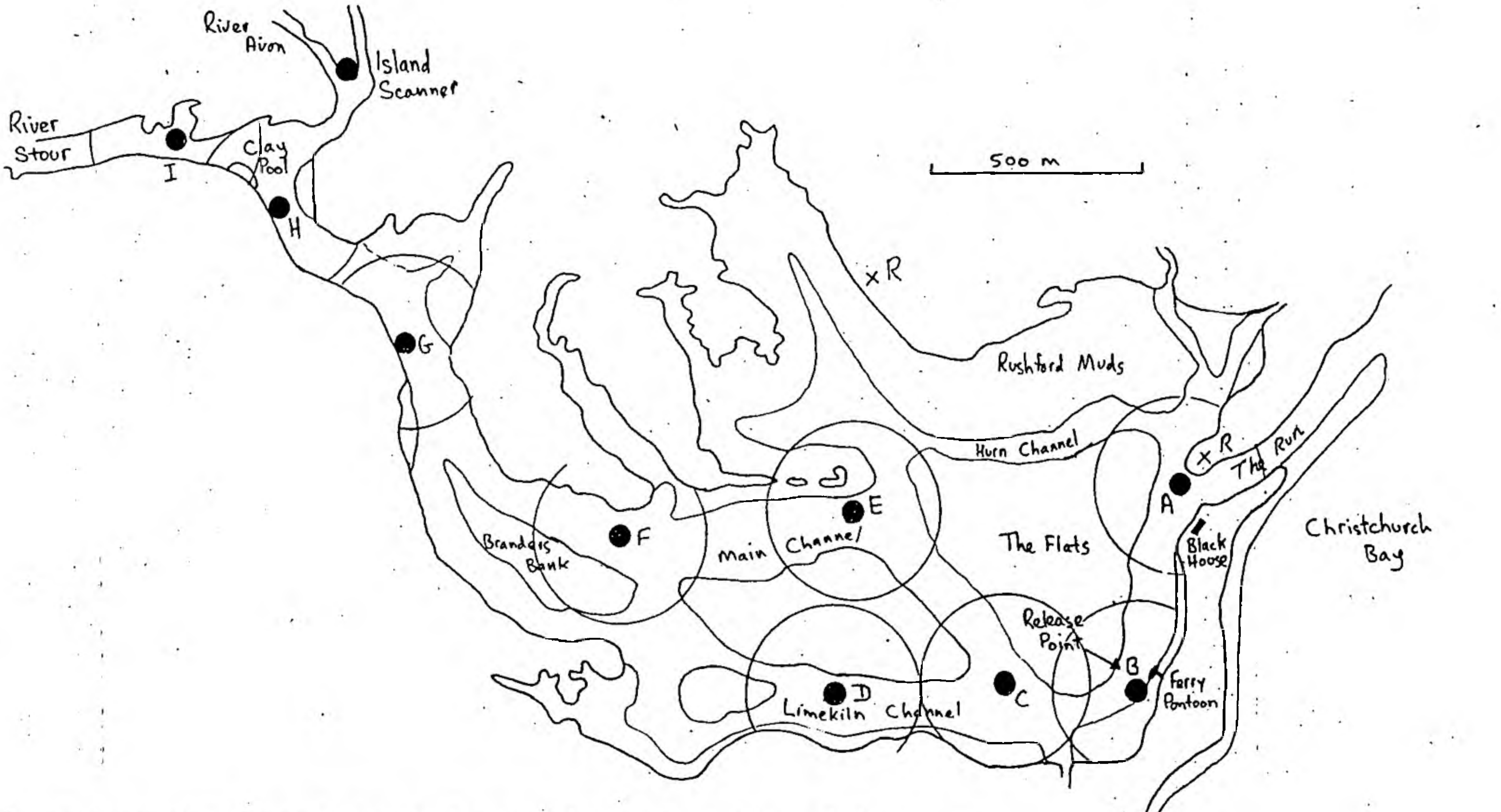


The Avon and Stour systems, showing the most-often used scanner sites, and other locations mentioned in the text.

Figure 2



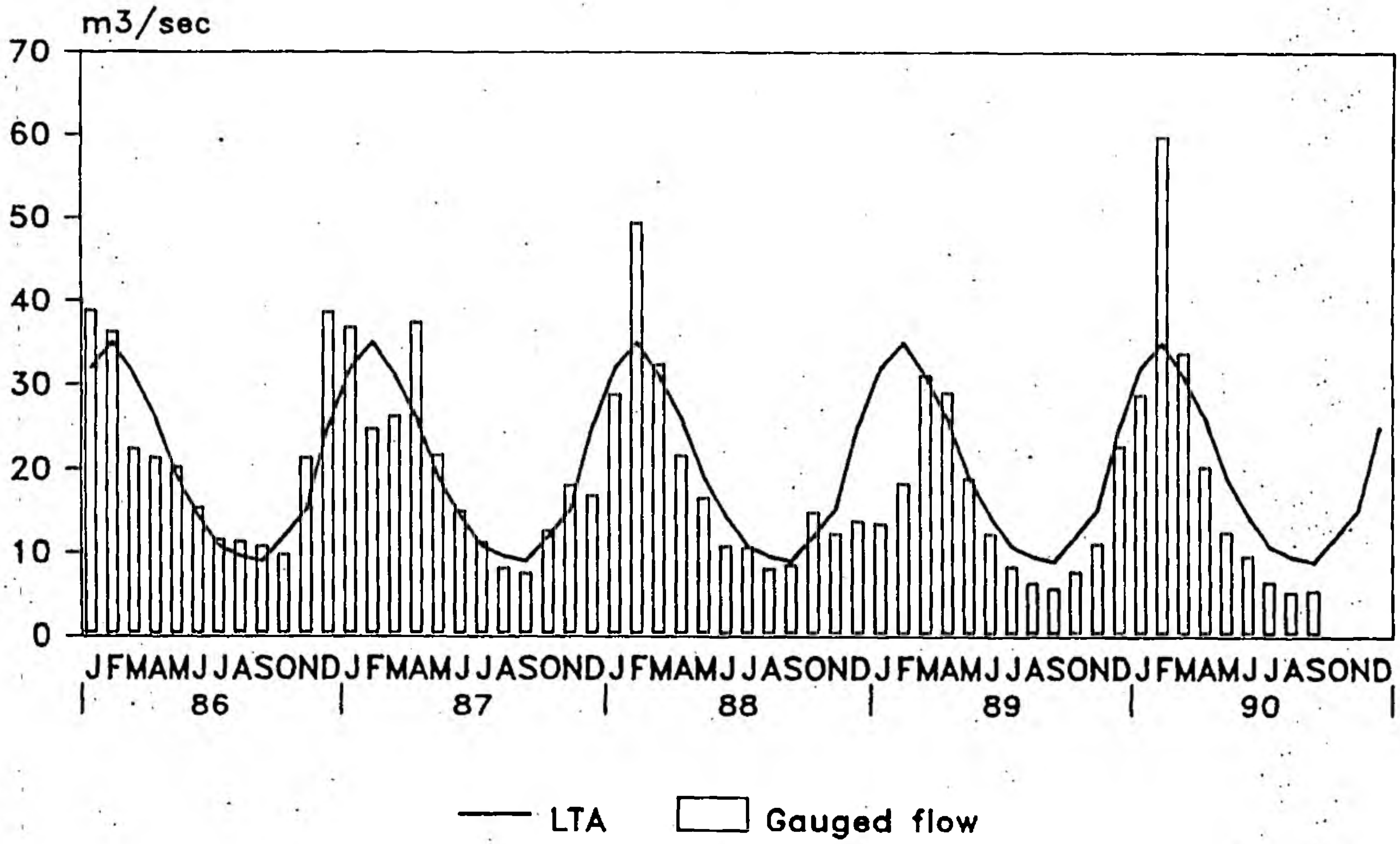
The lower Avon between Knapp Mill Gauging Station and the confluence with the Stour. Sites mentioned in the text are marked.



Christchurch Harbour, showing the location of the release point and the sites used for the CART tracking buoys in 1988 and 1989. The circles indicate the approximate range of tag detection of each buoy. Points R indicate the sites used for CART land stations.

Figure 3

Avon Knapp Mill Flows
1986 – 1990 and LTA

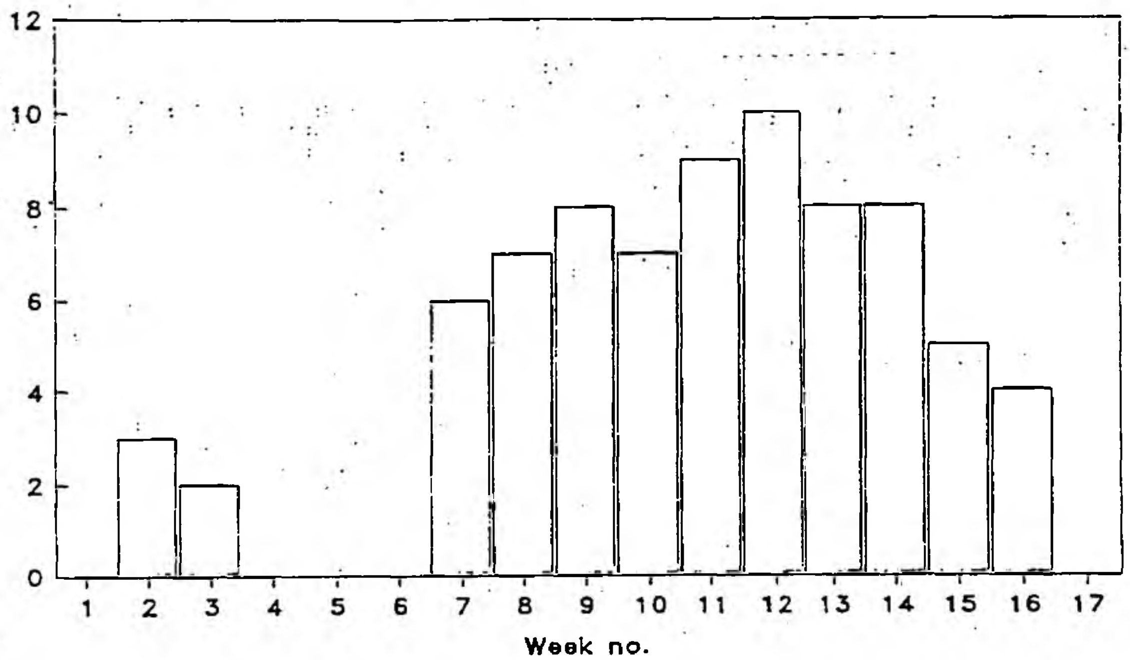


D J Solomon, January 24 1990
hgavon/flowmon

Figure 4

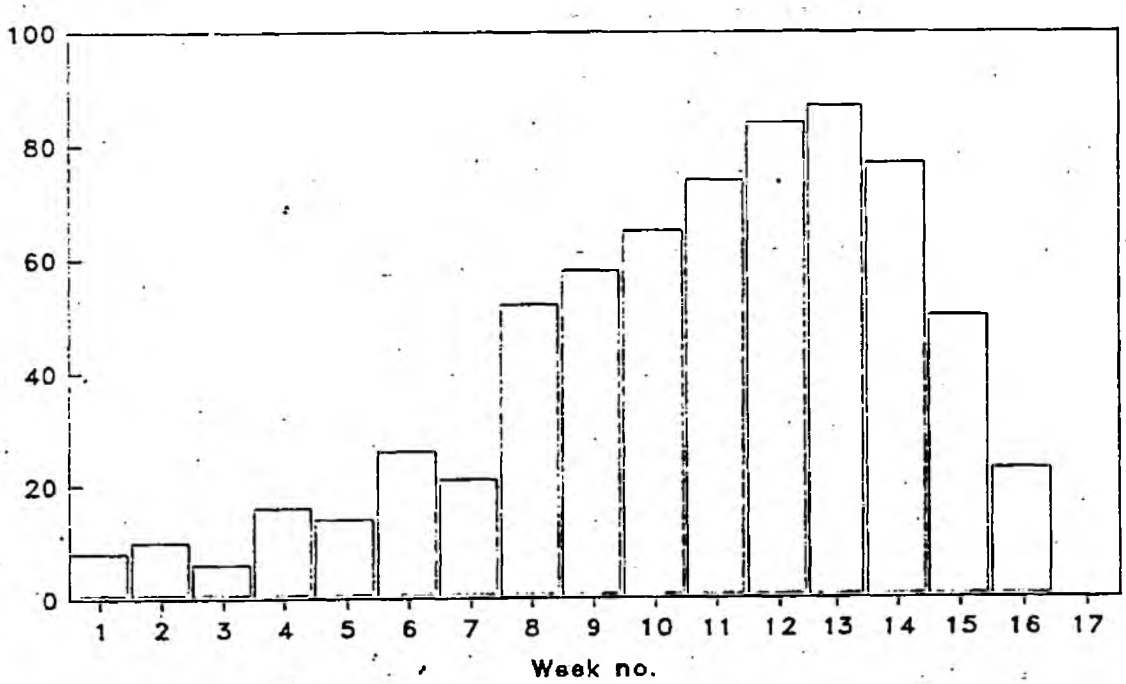
Figure 5

Fish tagged in 1986
Numbers by week



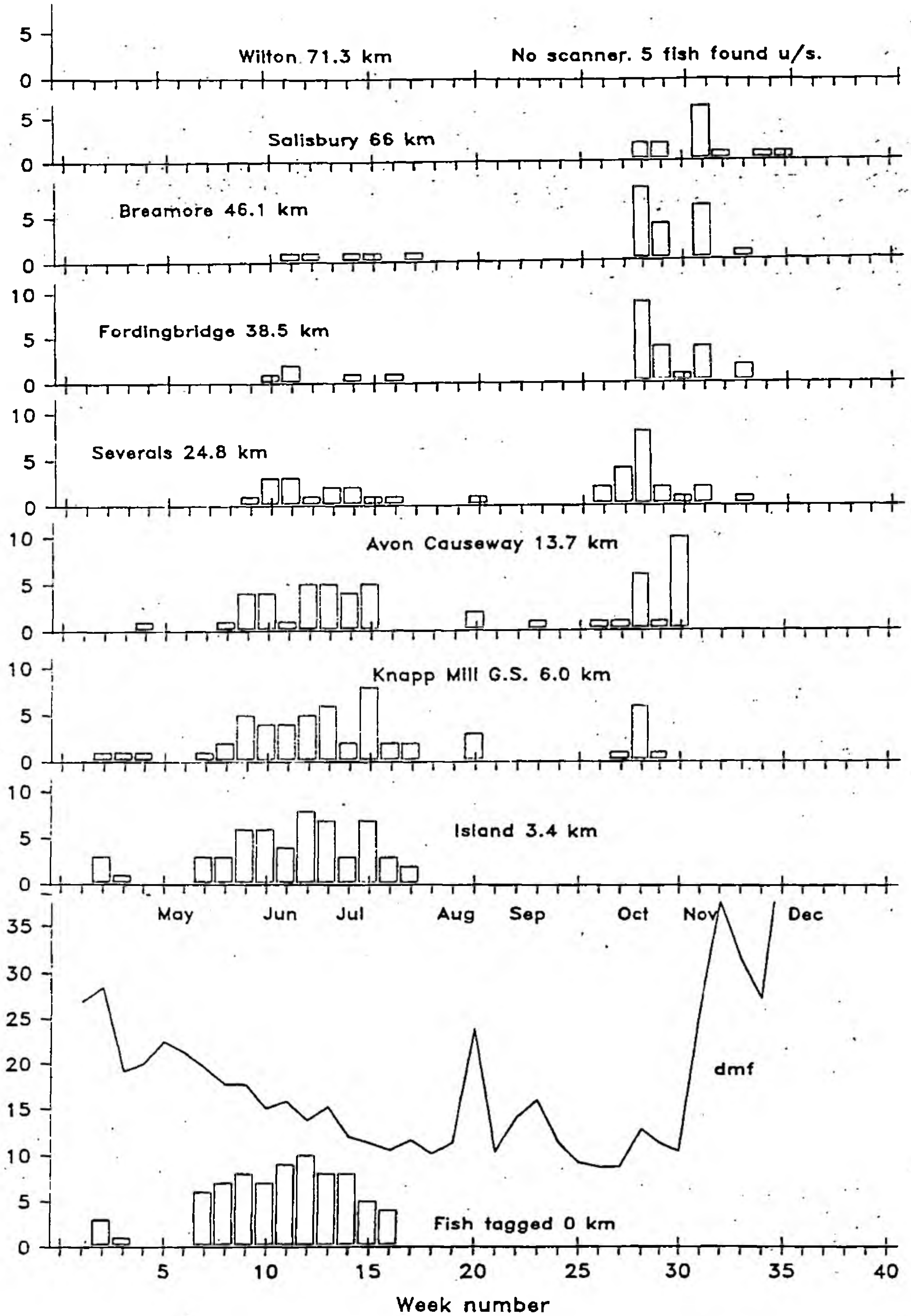
D J Solomon, March 11 1991
hgavon/tag86

Commercial catch in 1986
Numbers by week



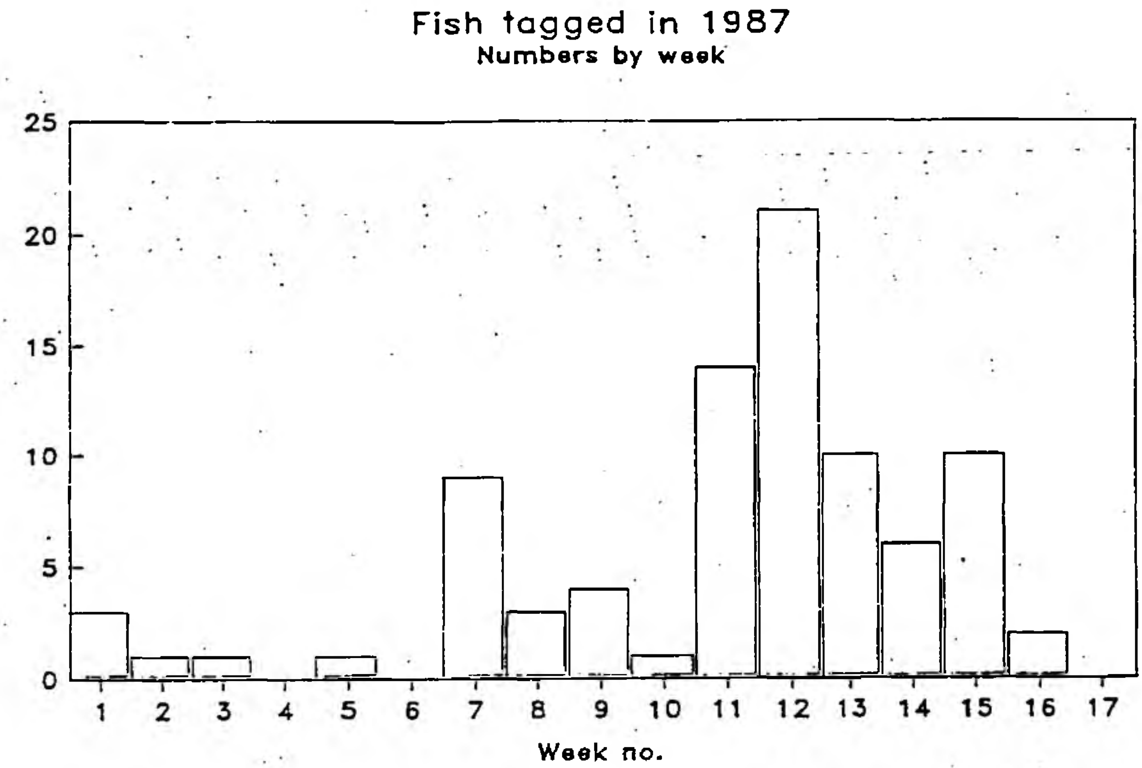
D J Solomon, March 11 1991
hgavon/cat86

Figure 6

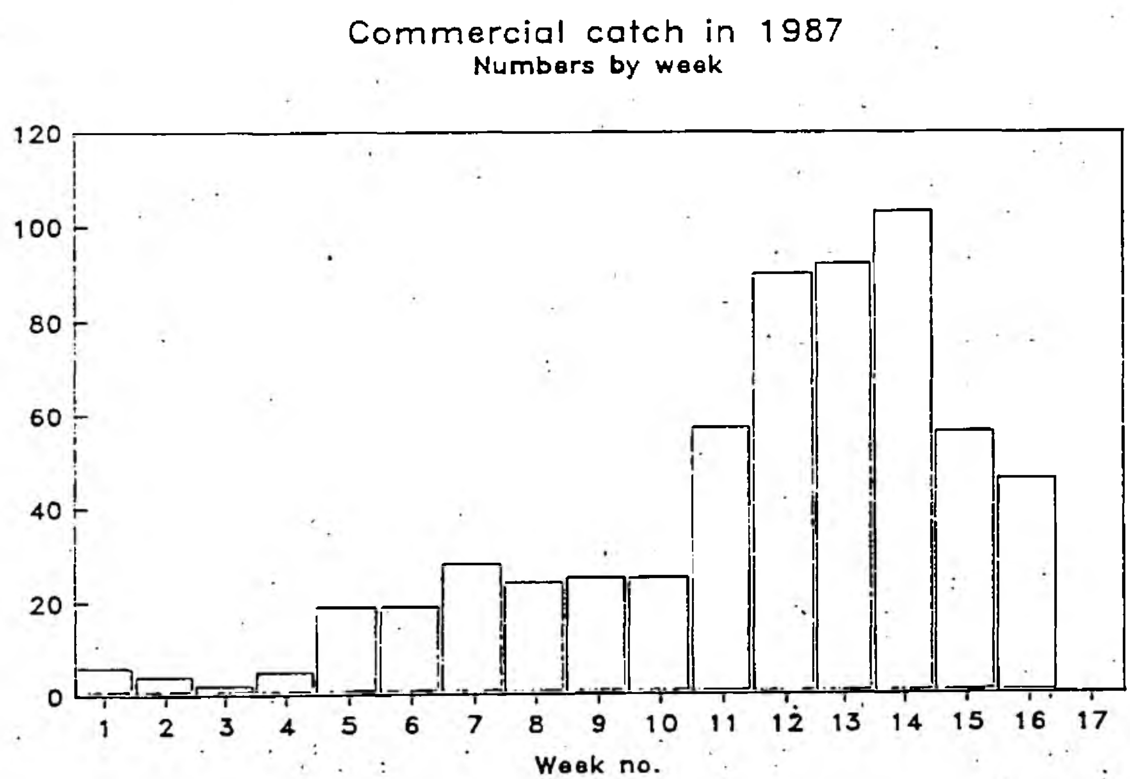


1986 weekly distribution of fish tagged, and tagged fish passing the scanner sites on the Avon. The dmf figures represent the peak daily mean flow for the week. The distances are by channel centre from the tagging site at Mudeford Run. Week one ends on April 20.

Figure 7

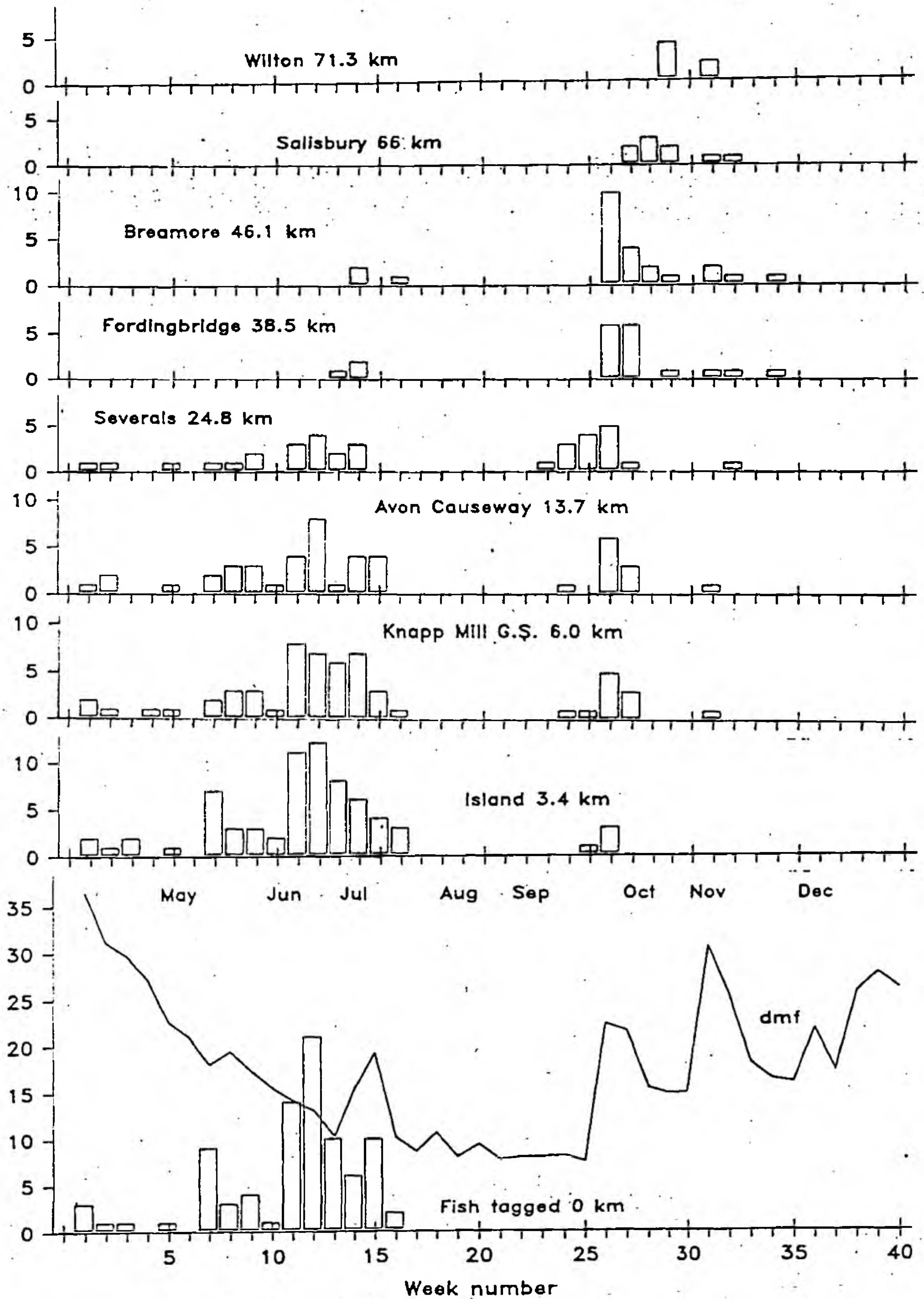


D J Solomon, March 11 1991
hgavon/tag87



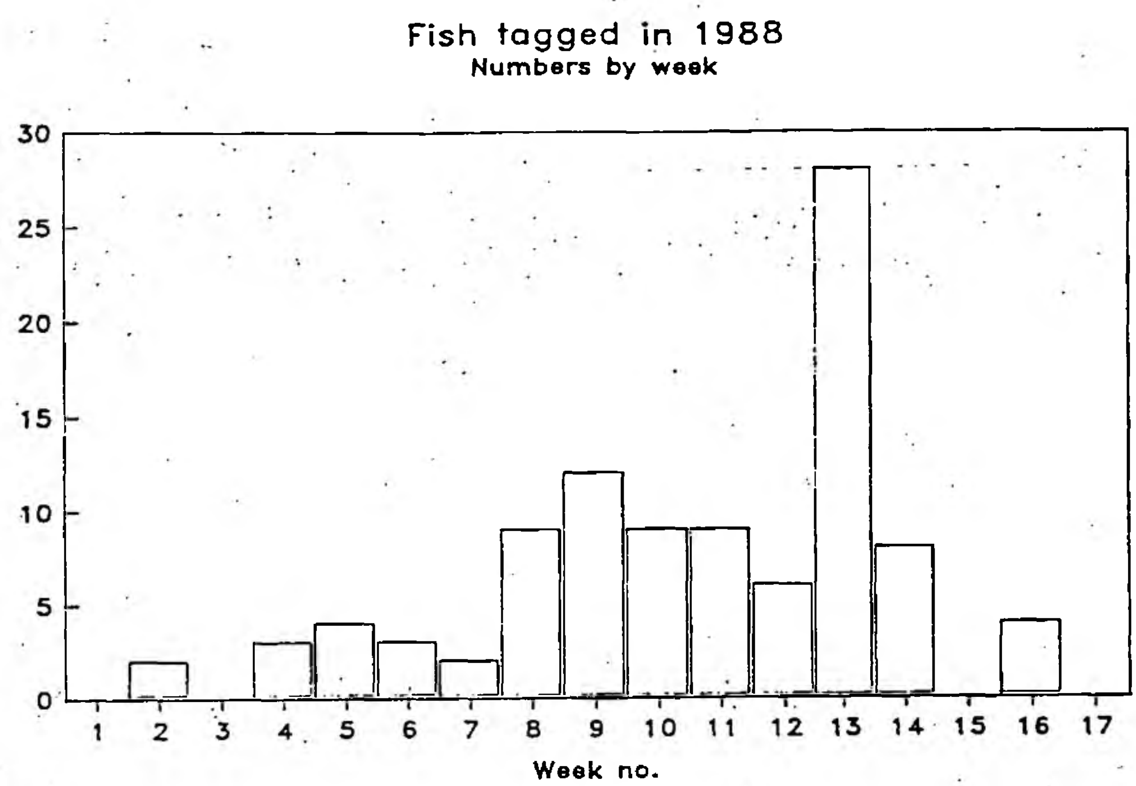
D J Solomon, March 11 1991
hgavon/cat87

Figure 8

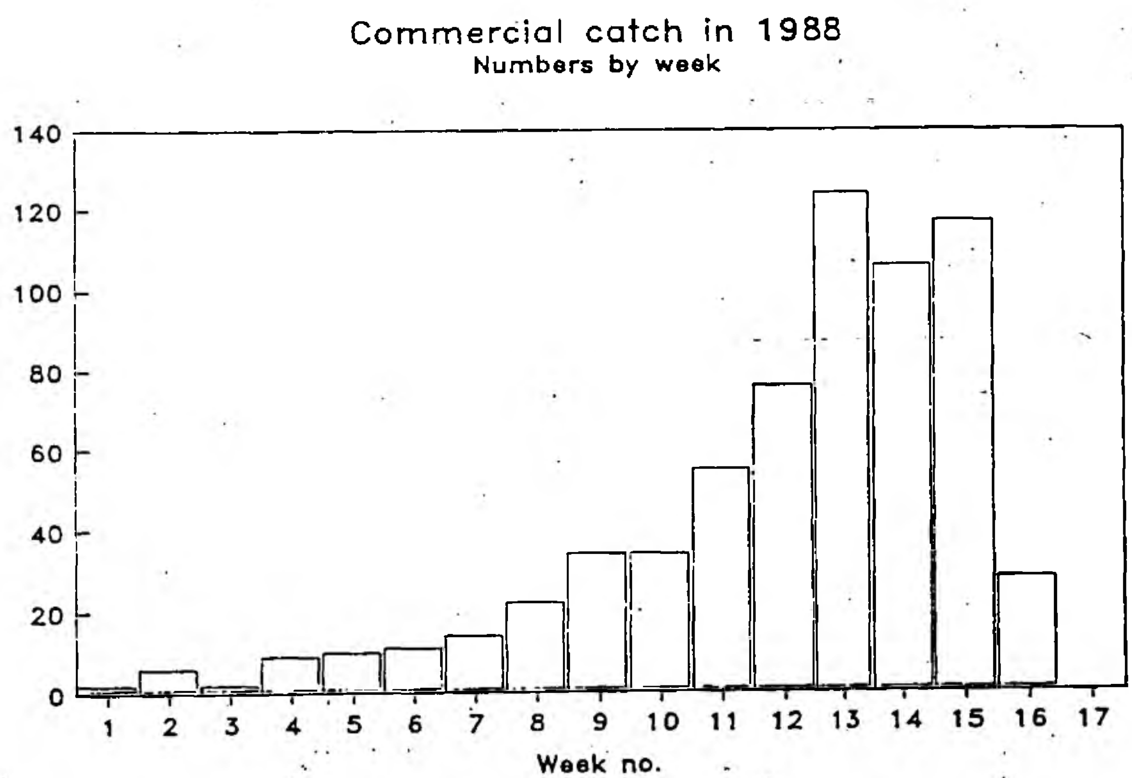


1987 weekly distribution of fish tagged, and tagged fish passing the scanner sites on the Avon. The dmf figures represent the peak daily mean flow for the week. The distances are by channel centre from the tagging site at Mudeford Run. Week one ends on April 19.

Figure 9

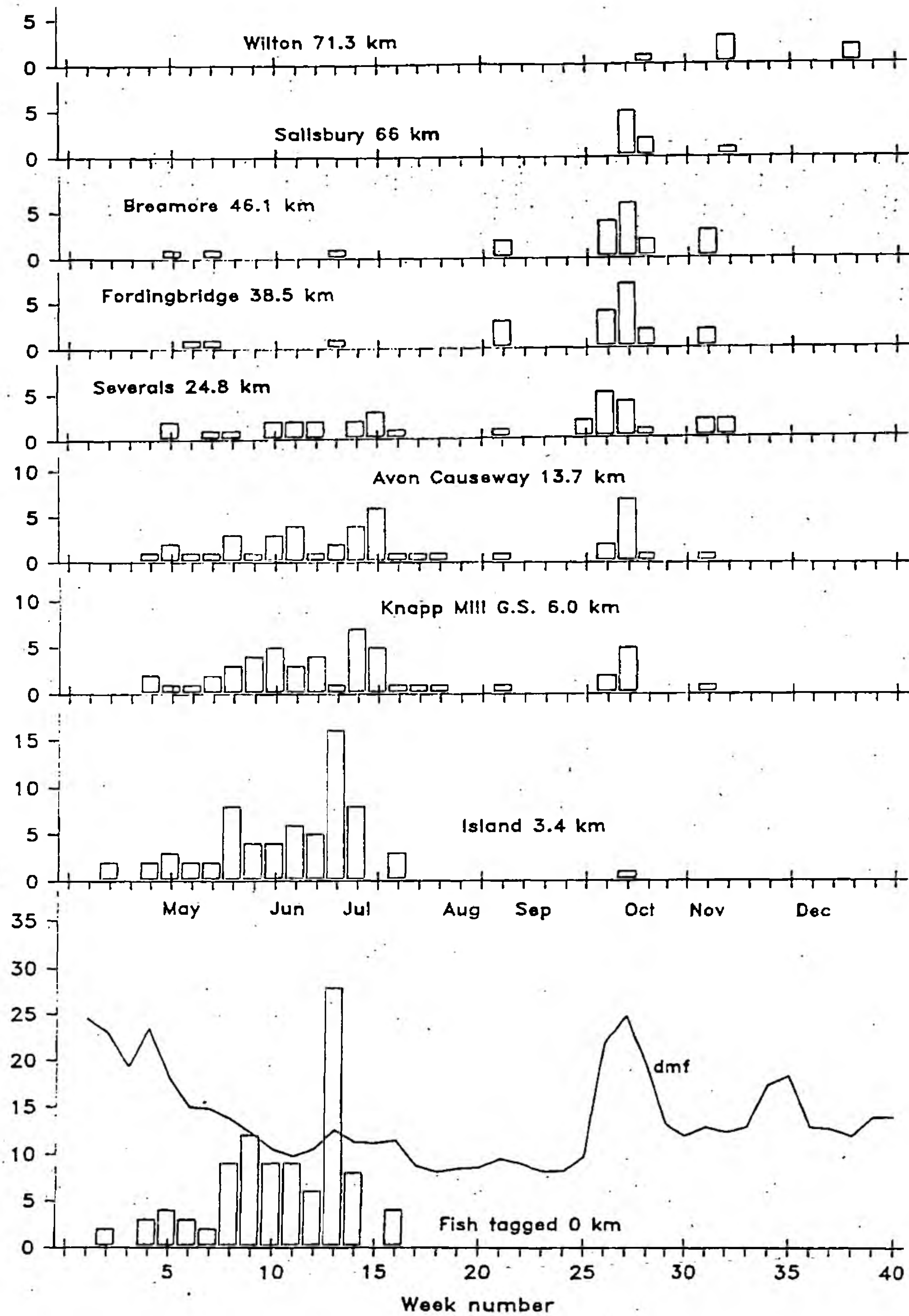


D J Solomon, March 11 1991
hgavon/tag88



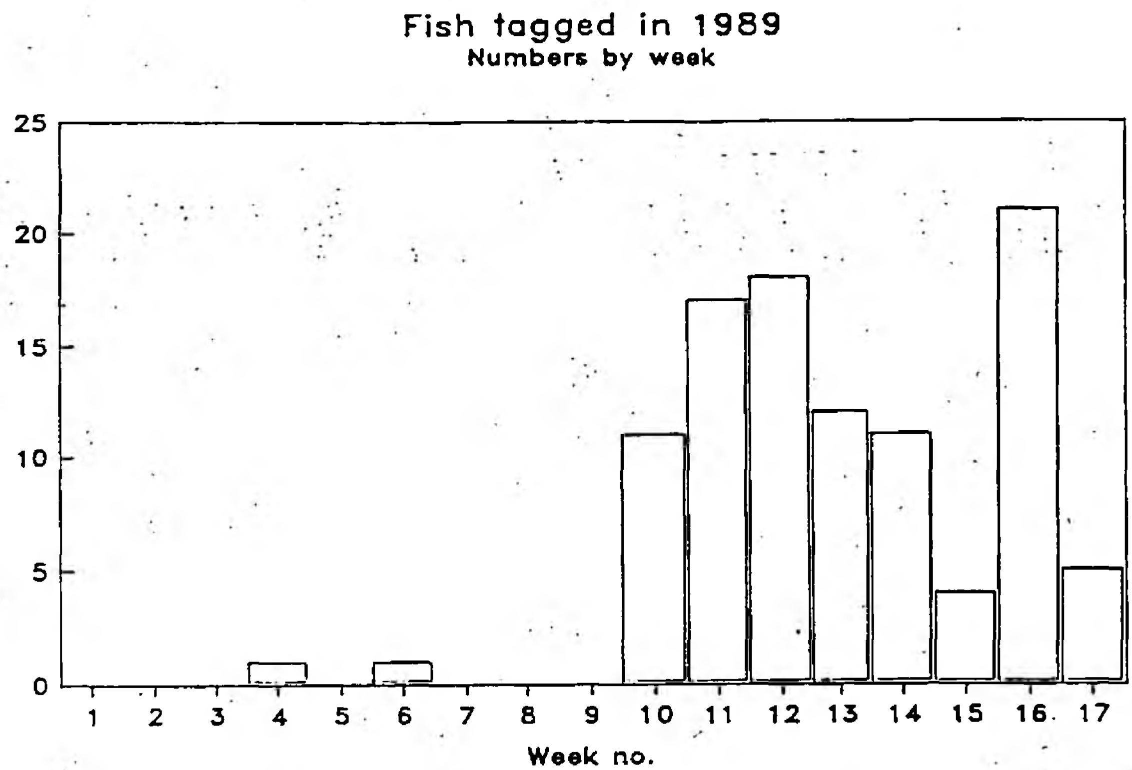
D J Solomon, March 11 1991
hgavon/cat88

Figure 10

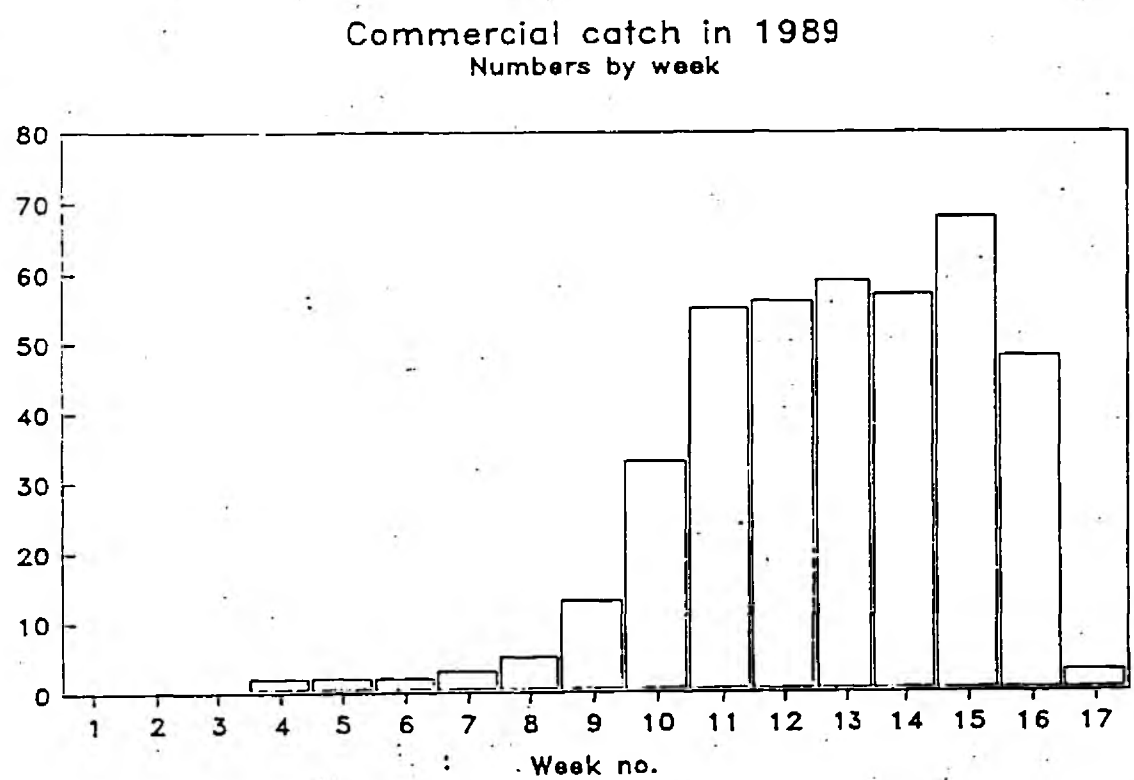


1988 weekly distribution of fish tagged, and tagged fish passing the scanner sites on the Avon. The dmf figures represent the peak daily mean flow for the week. The distances are by channel centre from the tagging site at Mudeford Run. Week one ends on April 17.

Figure 11

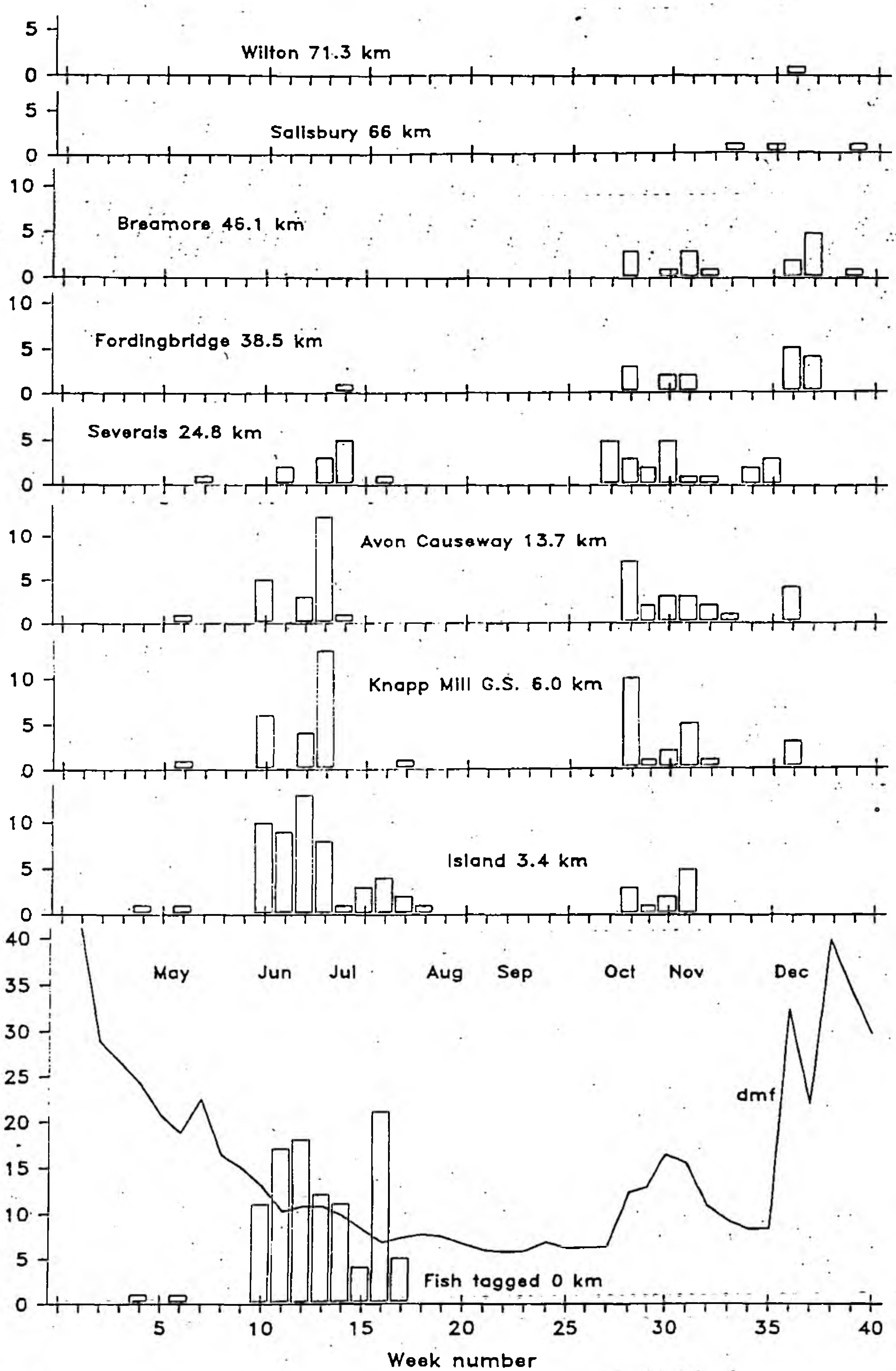


D J Solomon, March 11 1991
hgavon/tag89



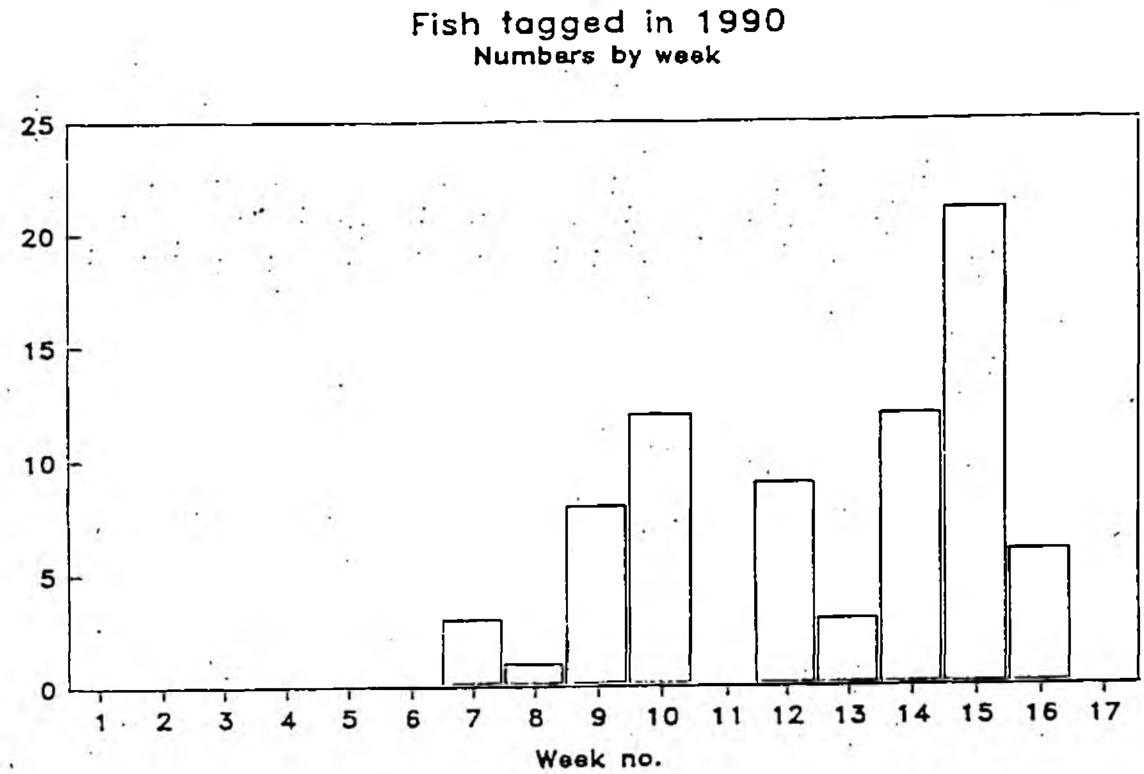
D J Solomon, March 11 1991
hgavon/cat89

Figure 12

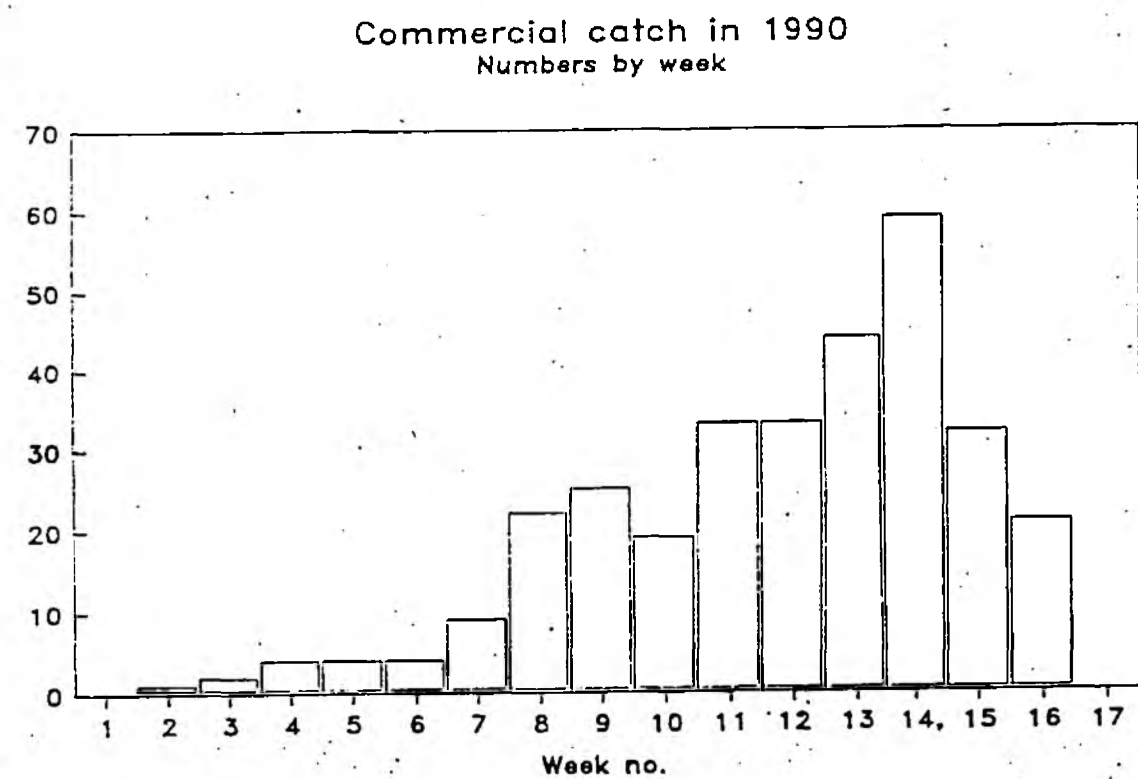


1989 weekly distribution of fish tagged, and tagged fish passing the scanner sites on the Avon. The dmf figures represent the peak daily mean flow for the week. The distances are by channel centre from the tagging site at Mudeford Run. Week one ends on April 16.

Figure 13

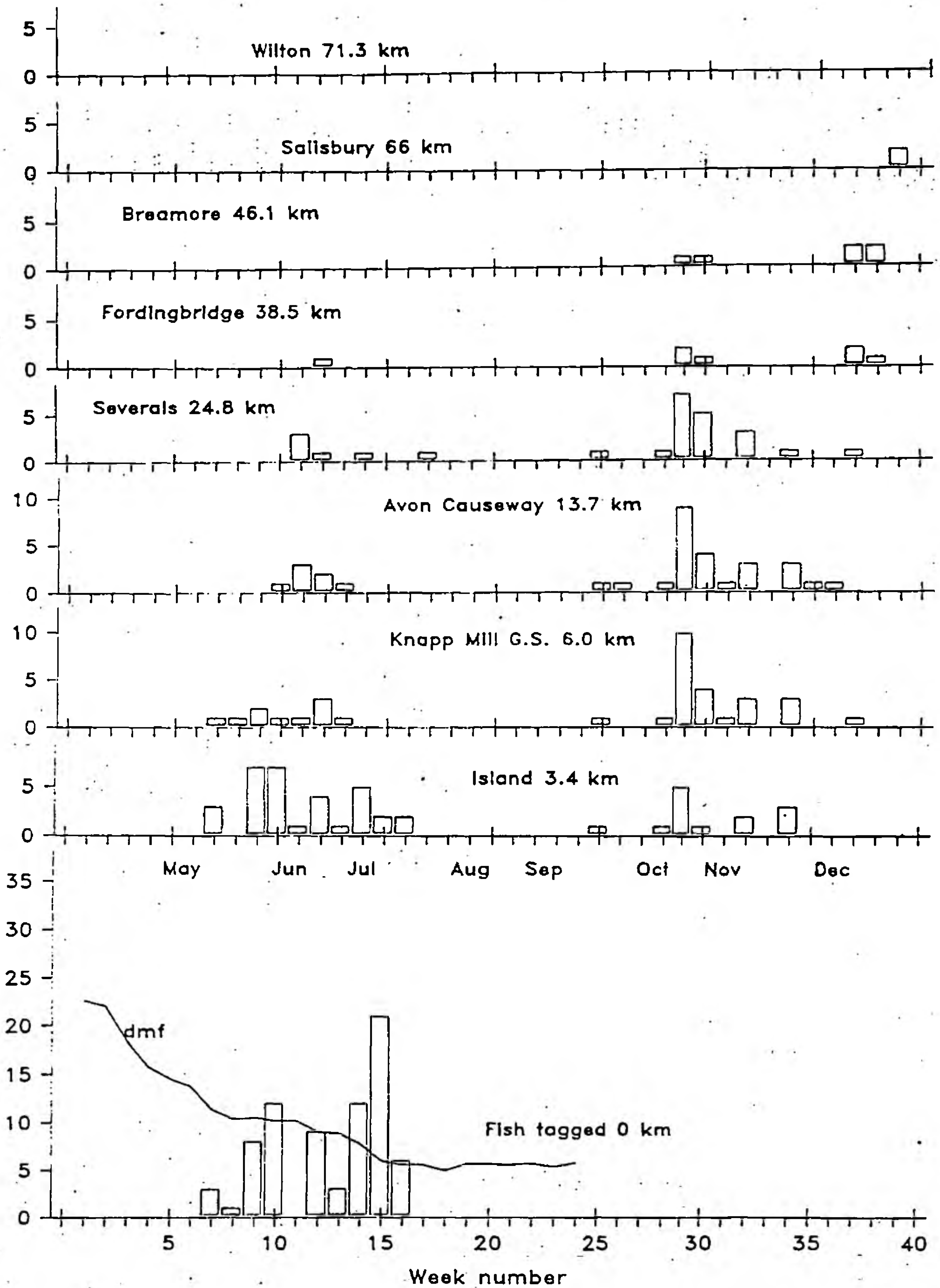


D J Solomon, March 11 1991
hgavon/tag90



D J Solomon, March 11 1990
hgavon/cat90

Figure 14



1990 weekly distribution of fish tagged, and tagged fish passing the scanner sites on the Avon. The dmf figures represent the peak daily mean flow for the week. The distances are by channel centre from the tagging site at Mudeford Run. Week one ends on April 15.

Explanation of Figures 16, 17, 21 and 22.

In Figures 16, 17 21 and 22 the patterns of migratory behaviour of all the tagged fish from the five years are combined and viewed in relation to river flow.

Most fish are allocated to the flow band appropriate to the day of tagging, even though the flow on the day they exhibited the particular behaviour pattern may have been slightly different. However, some fish exhibited the behaviour on flows significantly higher than that on the day they were tagged, when heavy rainfall in July 1987 and July 1989 (see sections 4.3.3 and 4.3.5) raised flows and stimulated migration. For fish migrating under such circumstances the flow on the day of demonstrating the behaviour pattern is used.

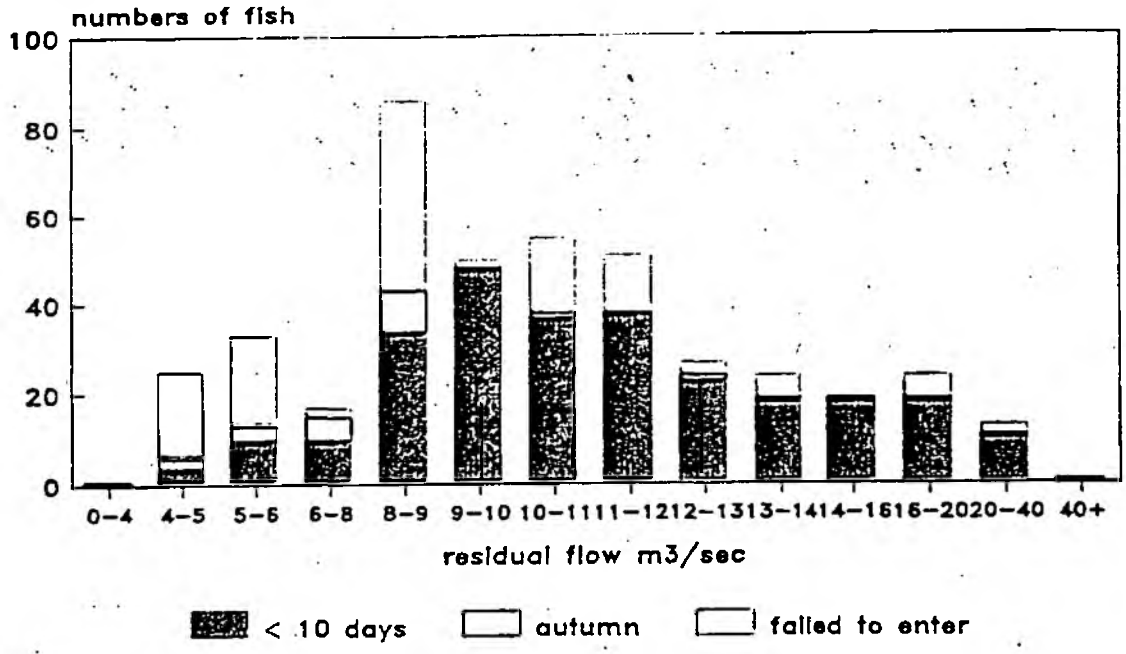
In Figures 16, 17 and 21 the residual flow (ie Knapp Mill gauged flow less Knapp Mill abstraction) is used as the behaviour patterns being considered took place downstream of the abstraction point. In Figure 22 Knapp Mill gauged flow is used as the behaviour patterns took place upstream of the abstractions.

In Figures 16 and 17 all tagged fish are considered. In Figure 21 only those fish entering the river within 10 days of tagging are considered, and in Figure 22 only those migrating beyond the Knapp Mill abstraction points in their initial migration are included.

The upper and lower graphs show the same information in absolute numbers (upper) and percentage of all fish allocated to that flow band (lower).

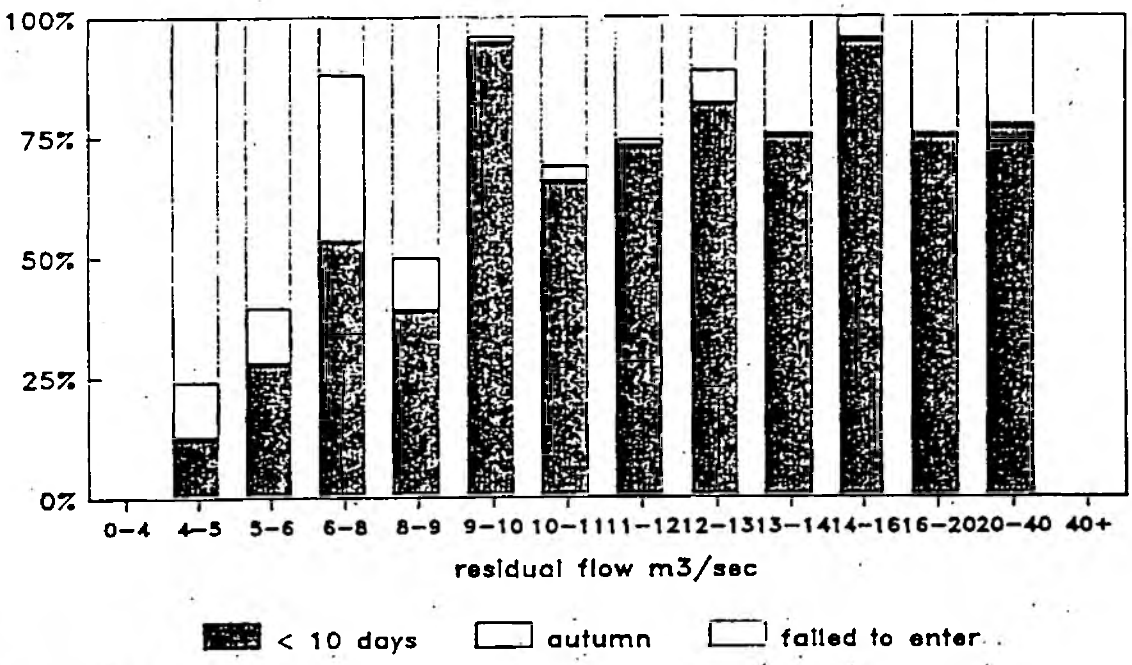
Figure 16

Effect of Flow on Entry to River
All years combined



D J Solomon, February 2 1991

Effect of Flow on Entry to River
All years combined

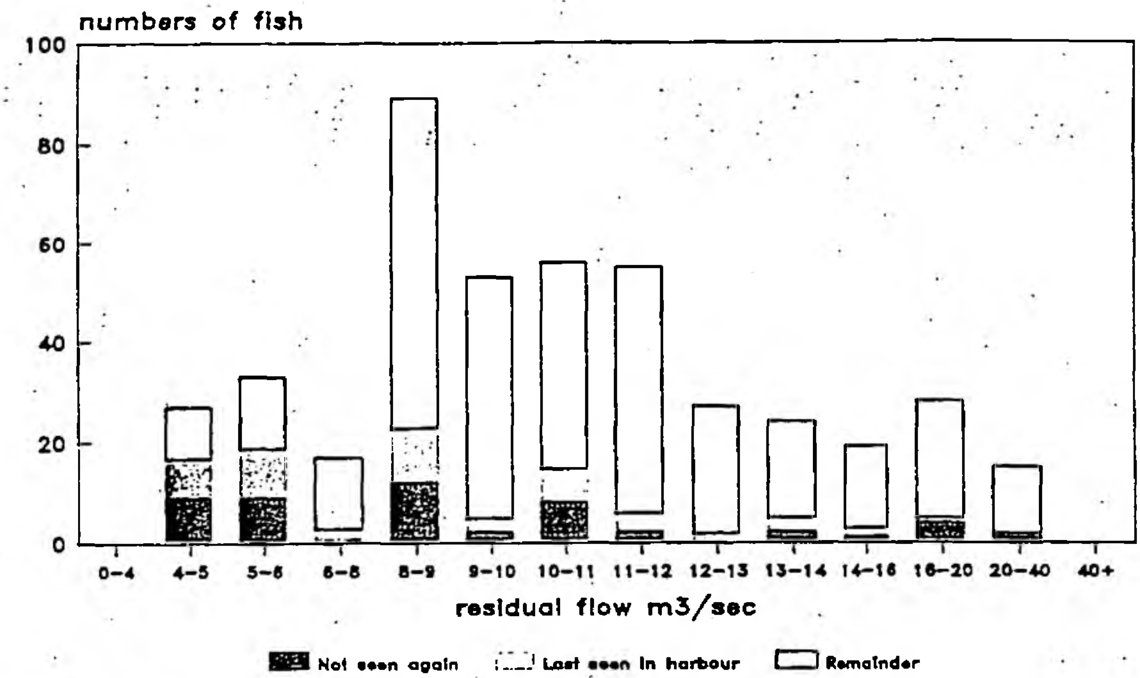


D J Solomon, February 2 1991

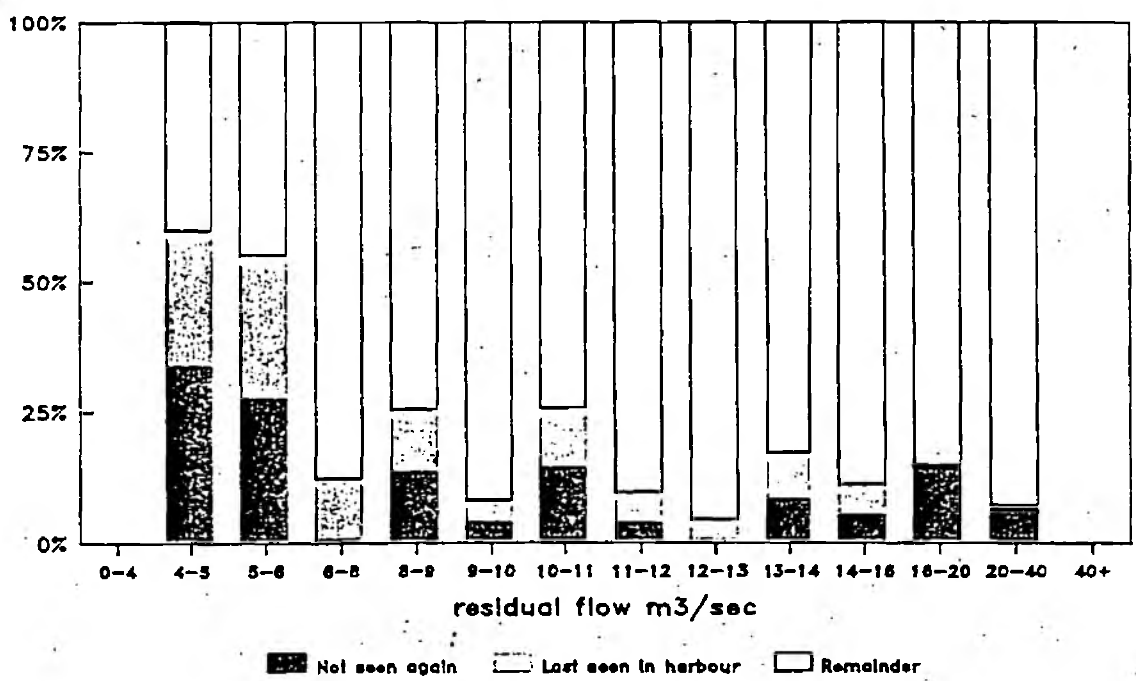
For explanation see Figure 15.

Figure 17

Flow and Fish Lost
All years combined – numbers



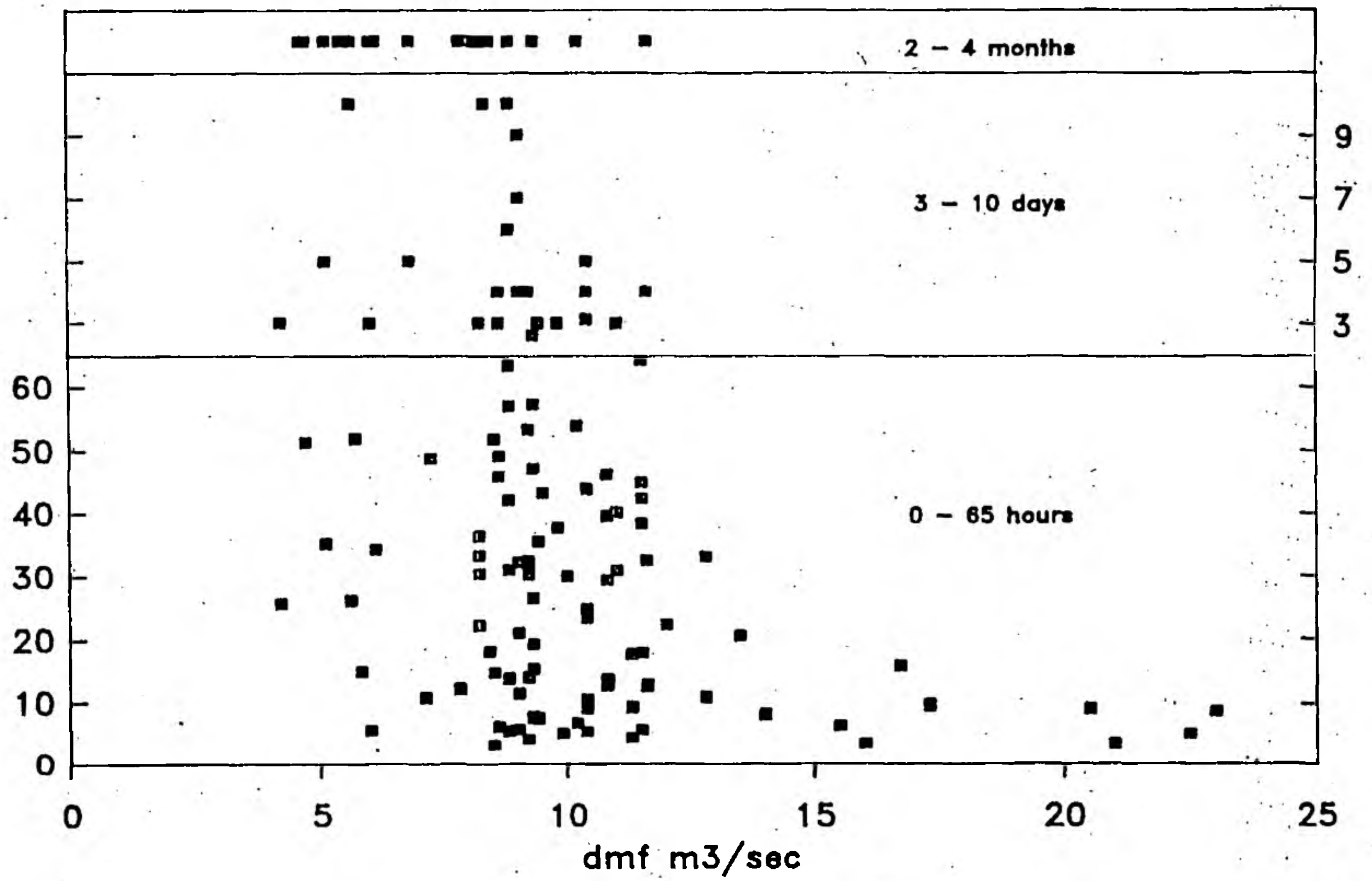
Flow and Fish Lost
All years combined – %



For explanation see Figure 15.

Estuary passage time 1988 – 1990

Relationship with residual flow



D J Solomon, April 21 1991
hgwessex/avon/est

Figure 18

Fish movements – time of day and state of tide.
April – July only

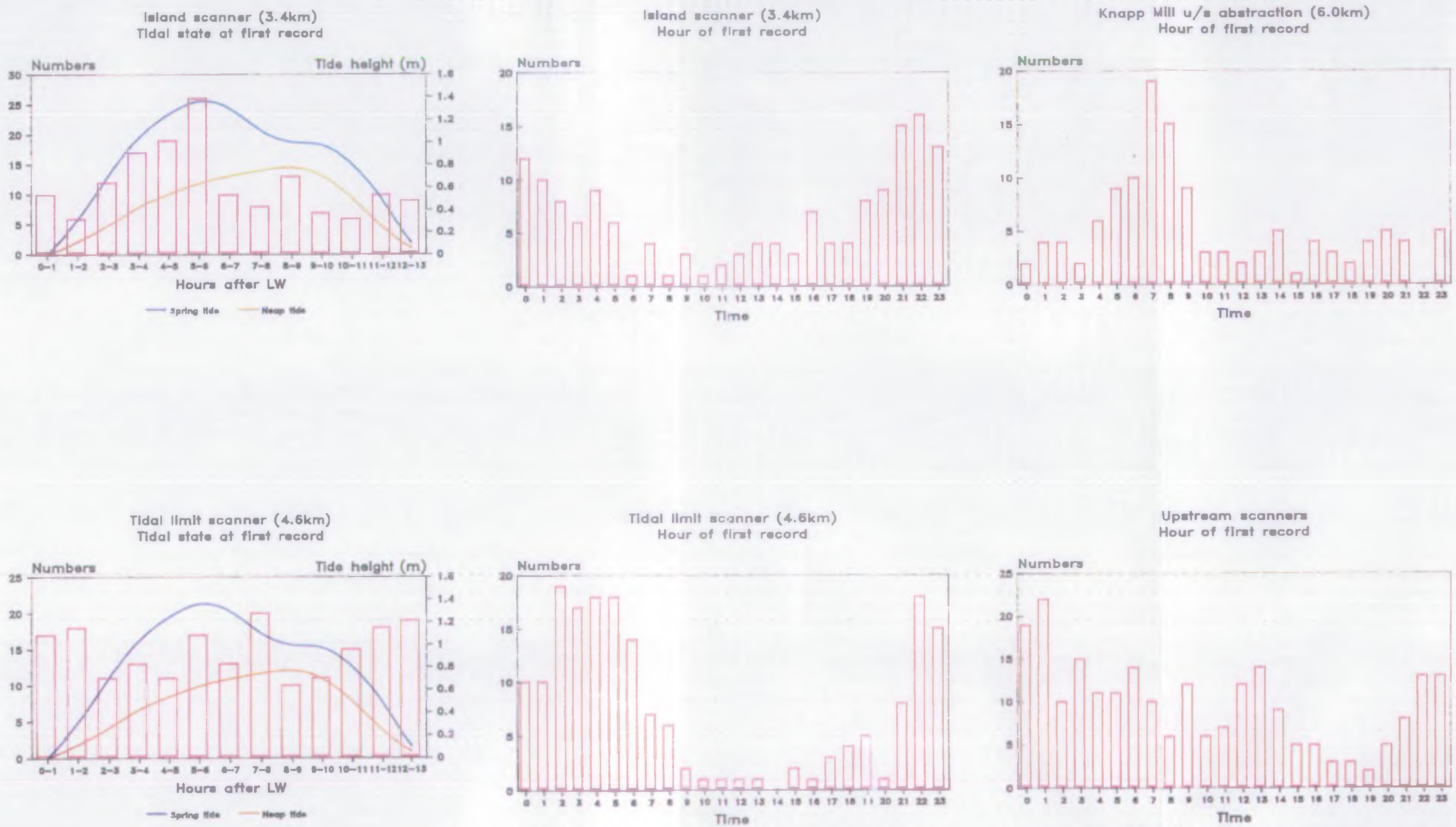
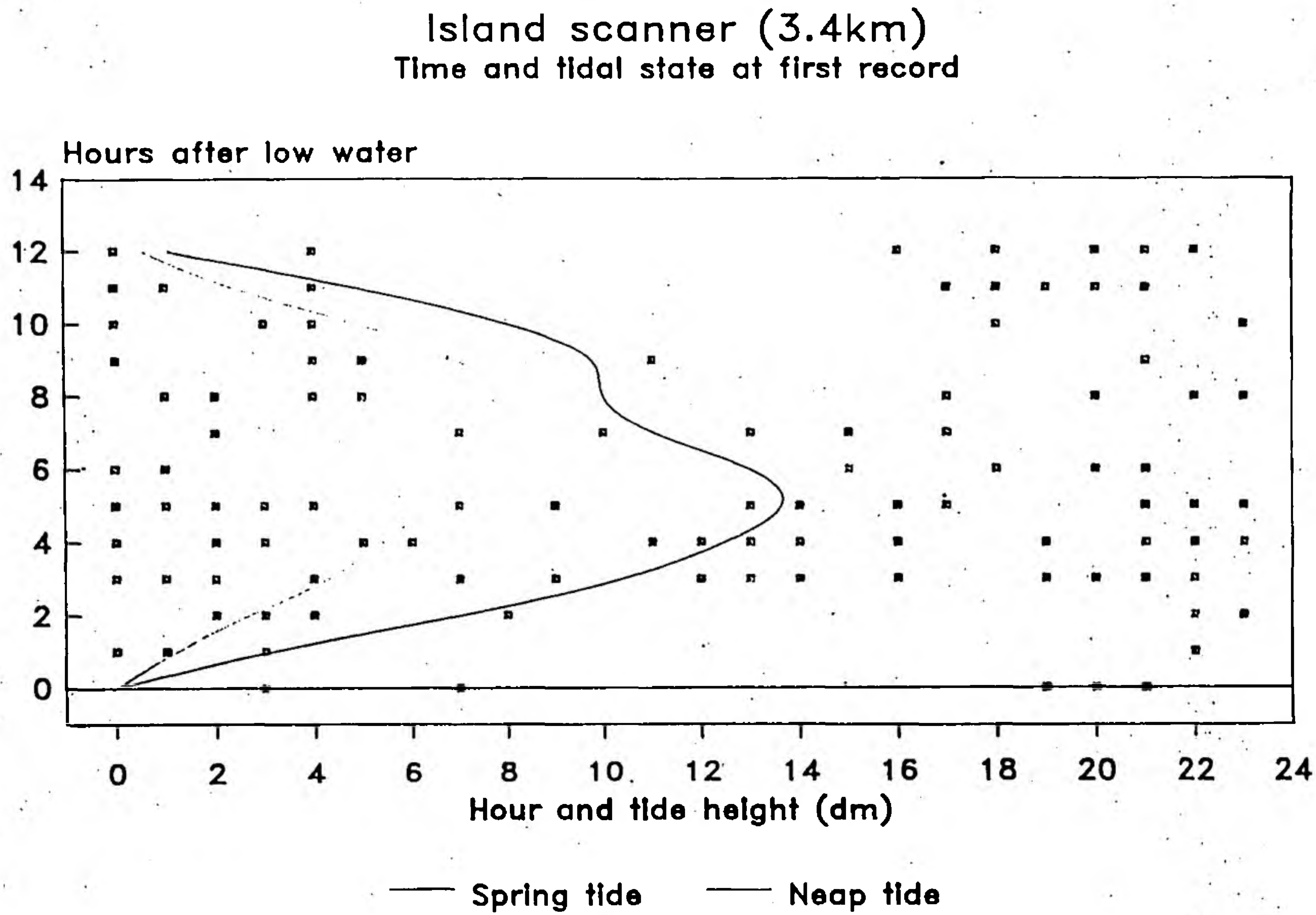


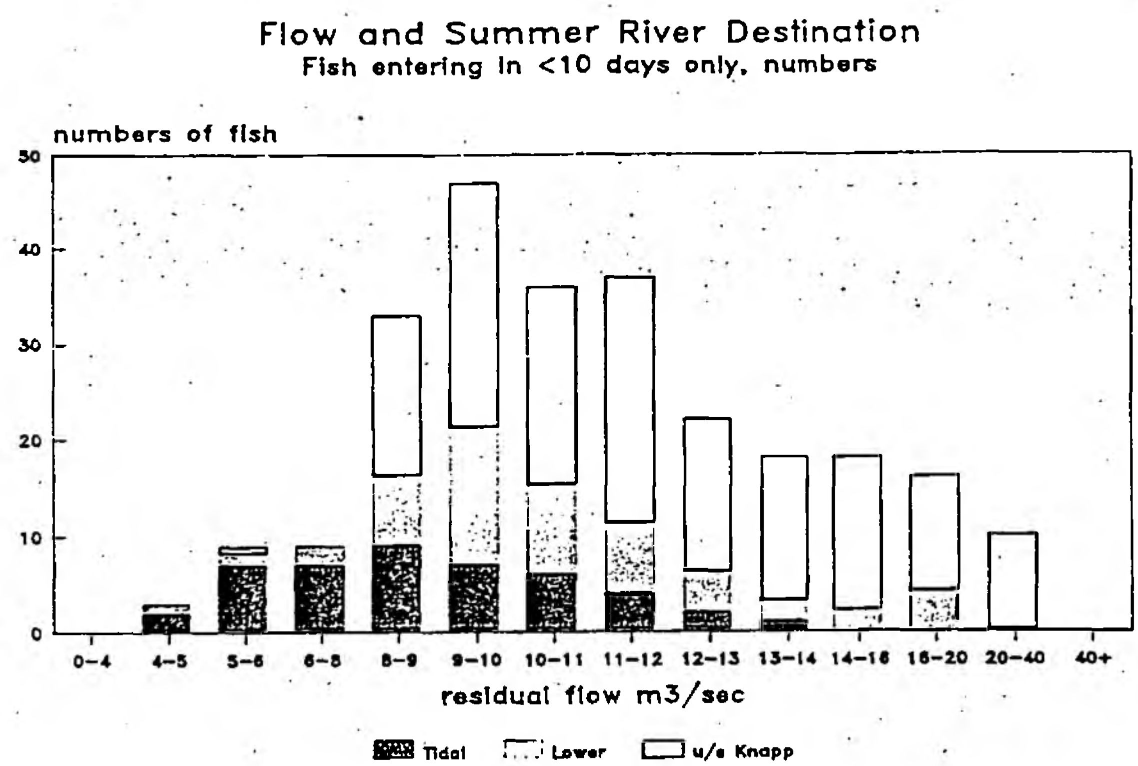
Figure 19



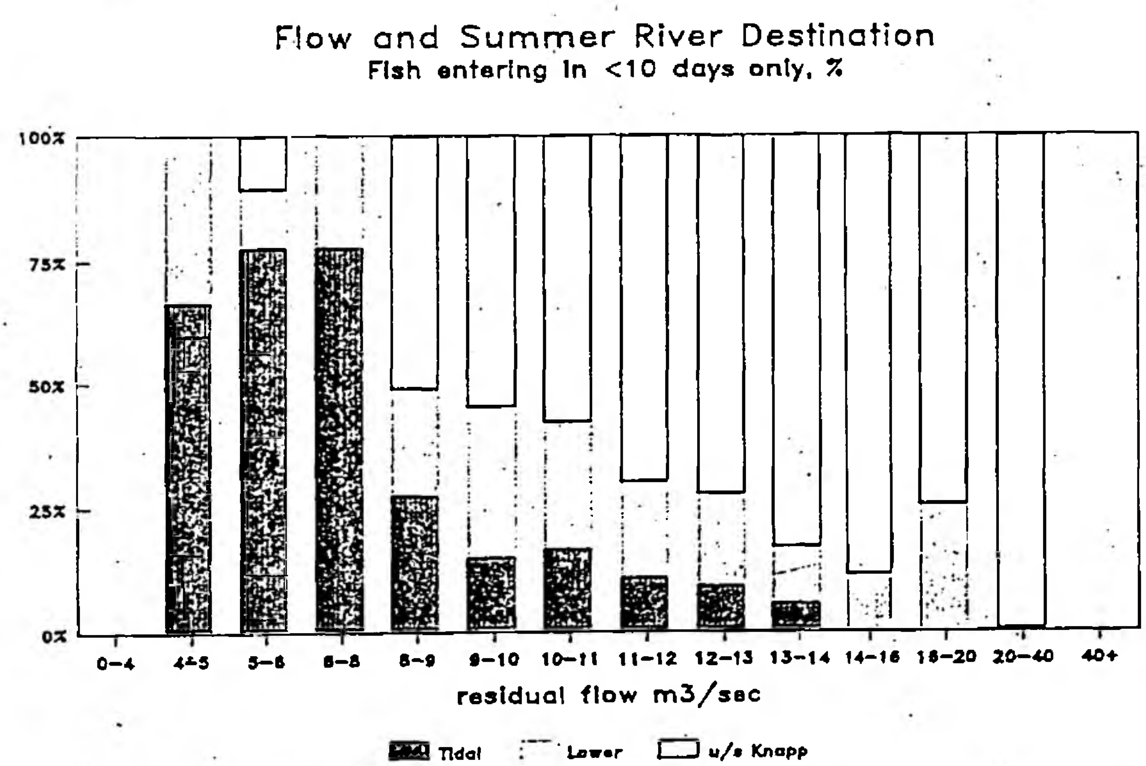
D J Solomon, March 15 1991
hgavon/timtid0

Figure 20

Figure 21



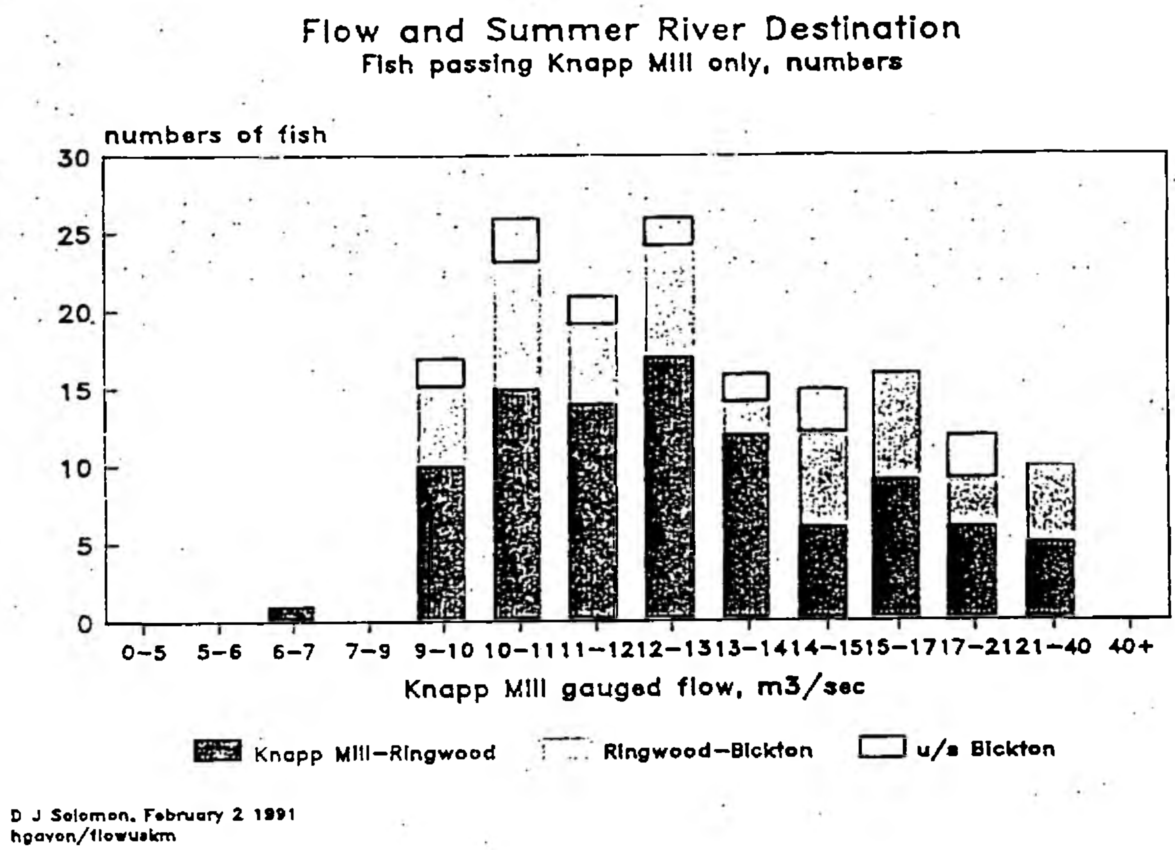
D J Solomon, Febraury 2 1991
hgavon/flowdestn

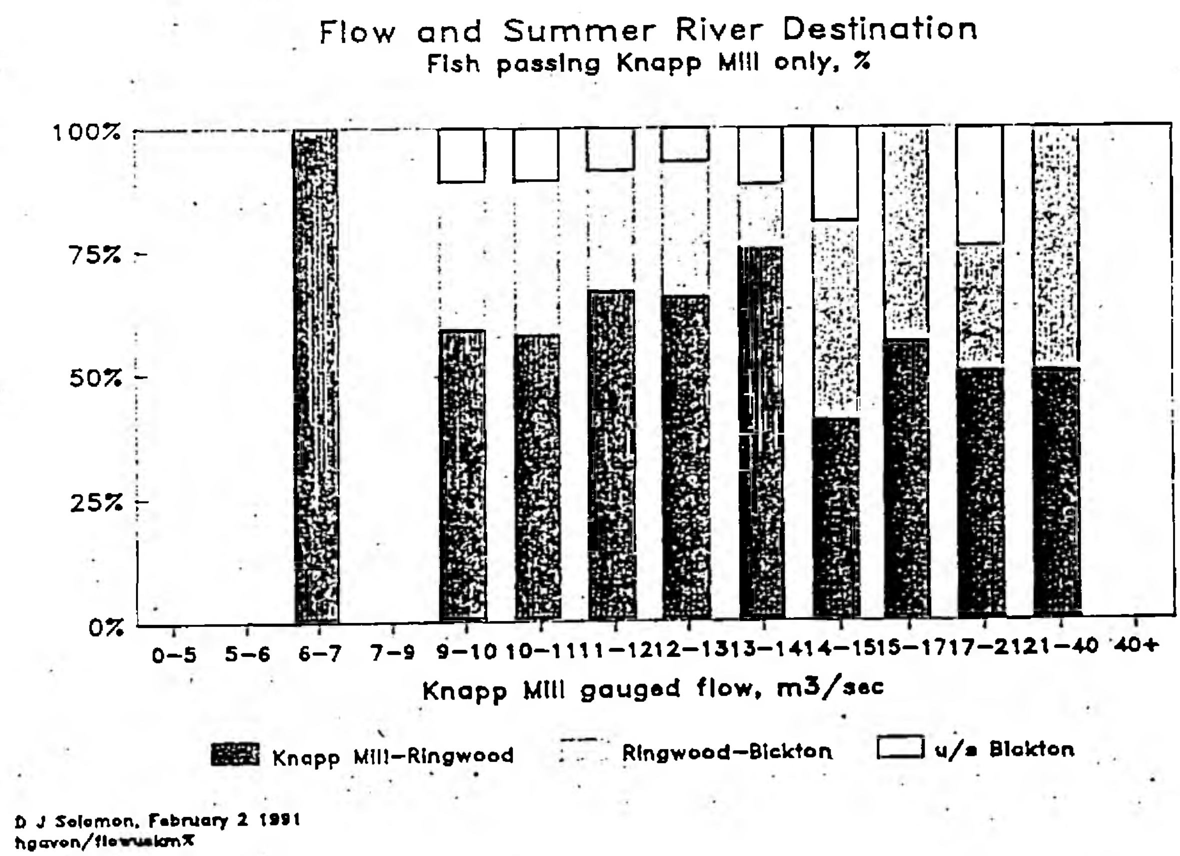


D J Solomon, Febraury 2 1991
hgavon/flowdest%

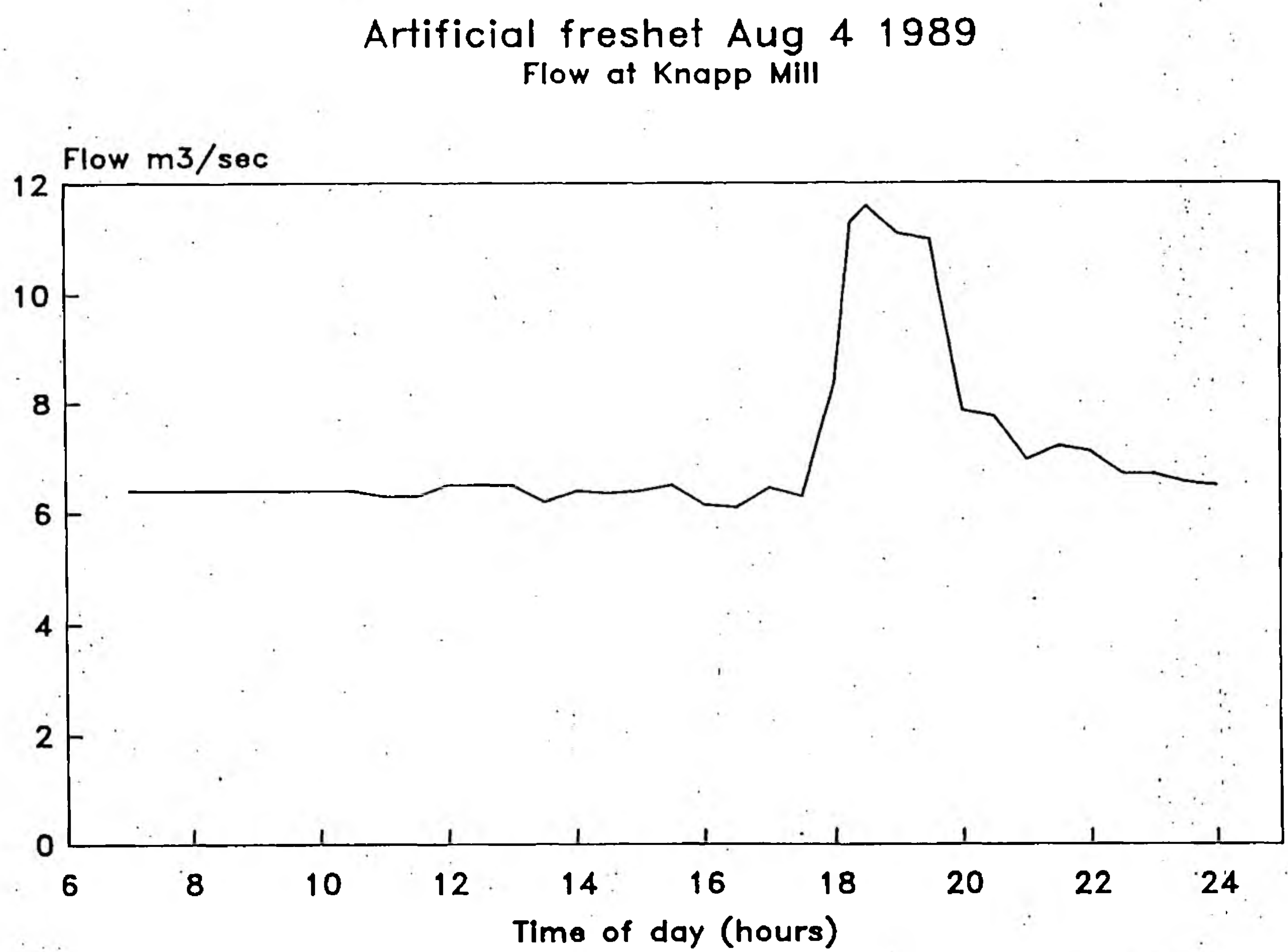
For explanation see Figure 15.

Figure 22





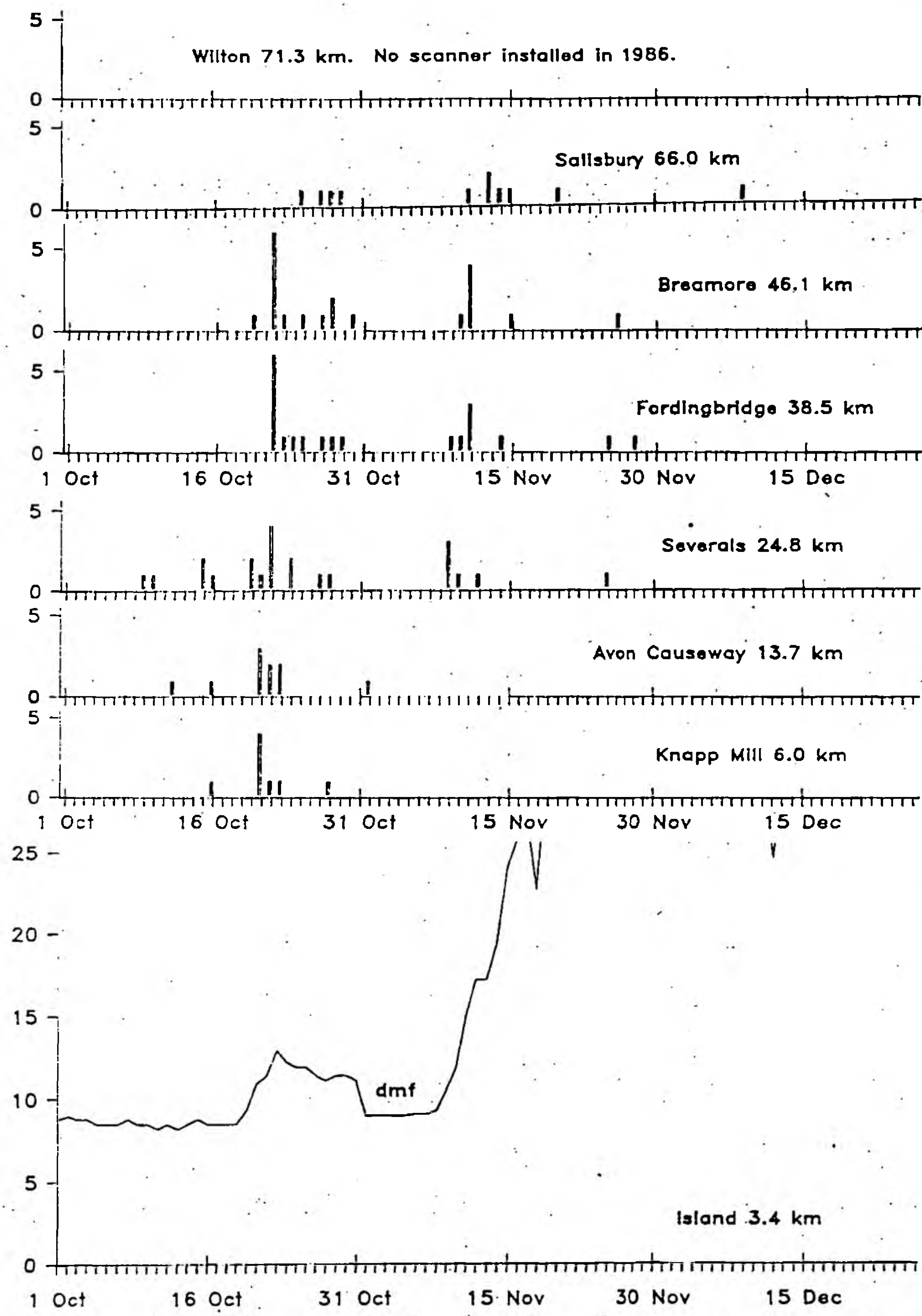
For explanation see Figure 15.



D J Solomon, April 27 1991
hgwessex/avon/fresh

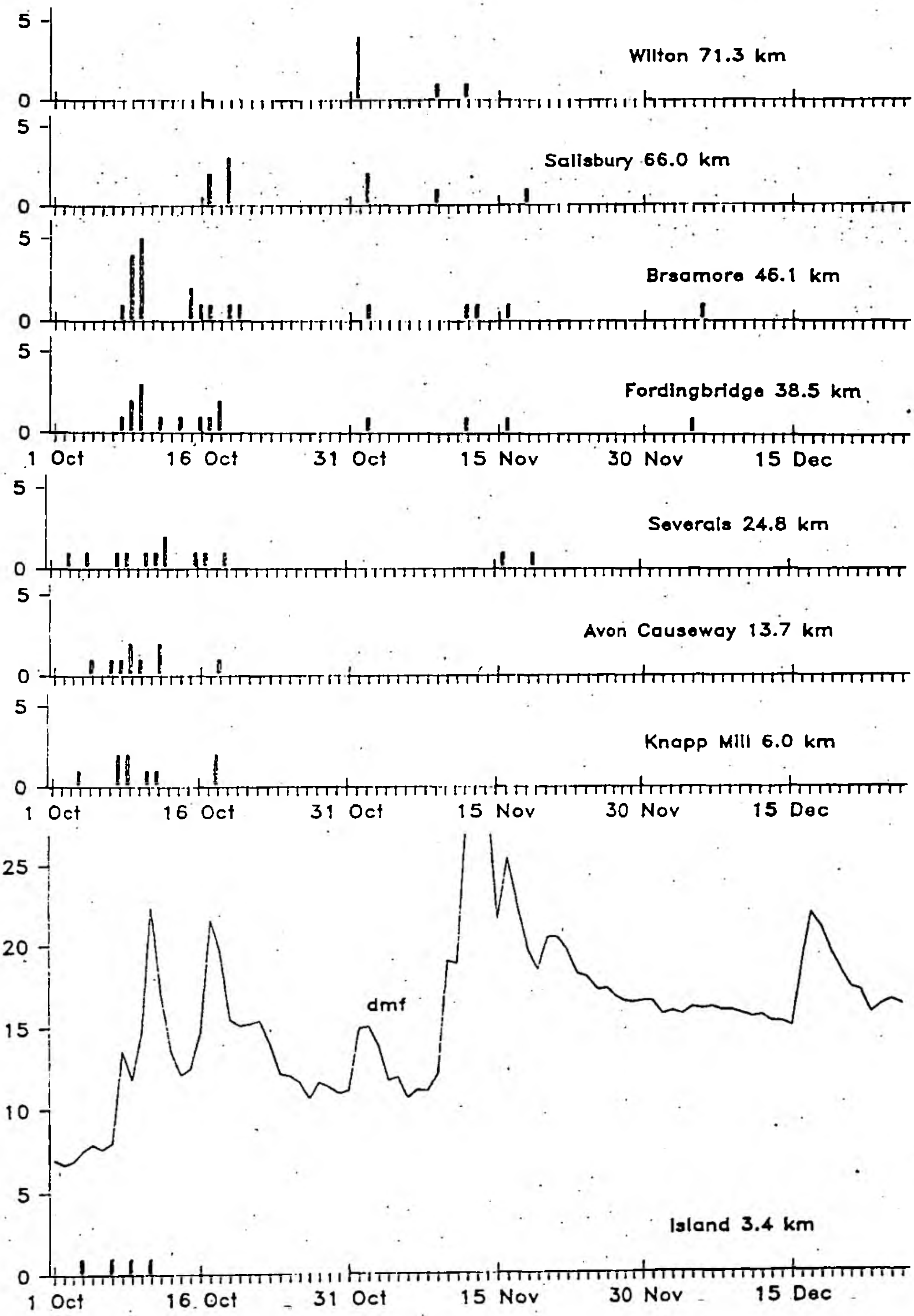
Figure 23

Figure 24



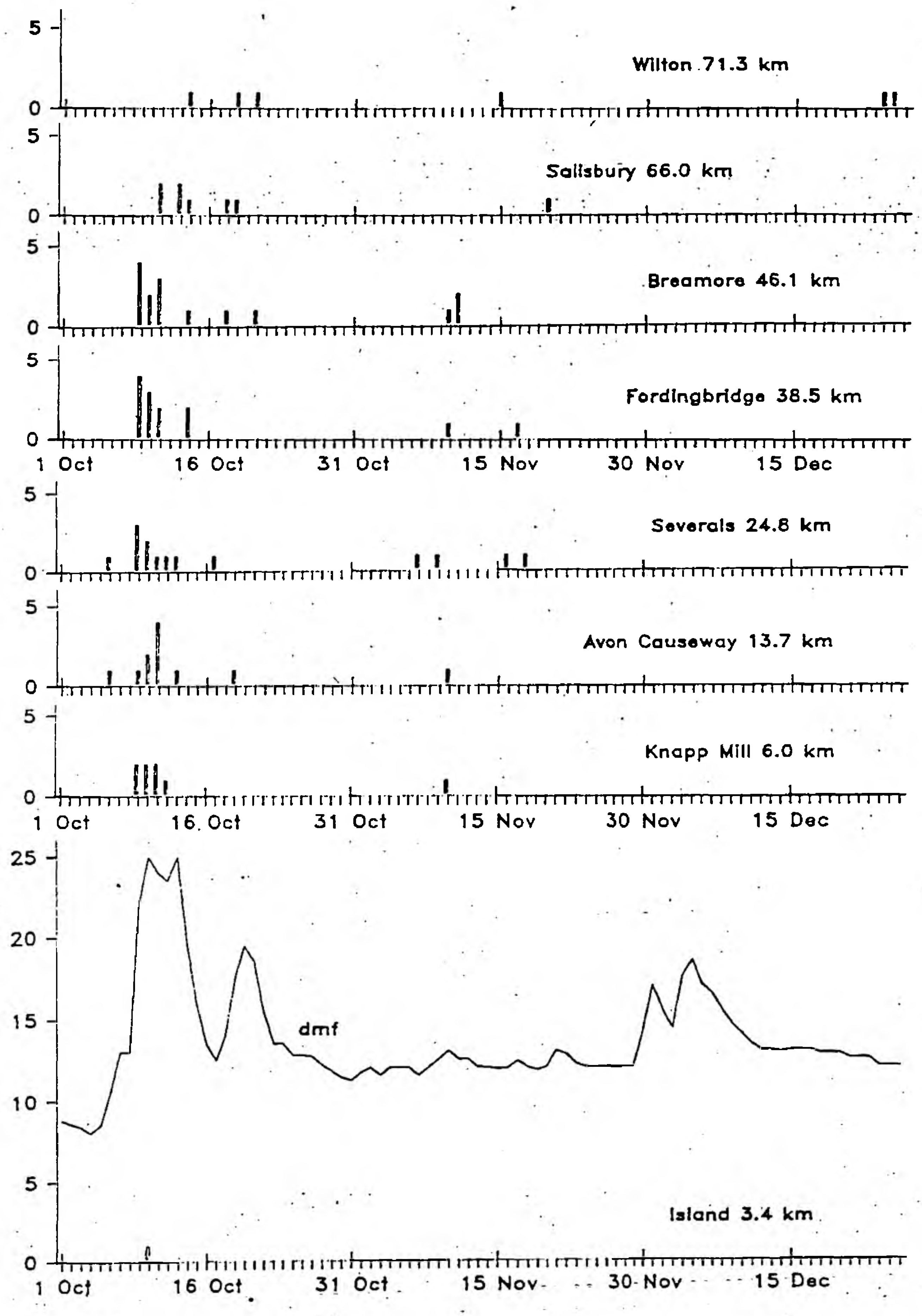
Daily scanner records of fish passage and Knapp Mill dmf, Oct - Dec 1986

Figure 25



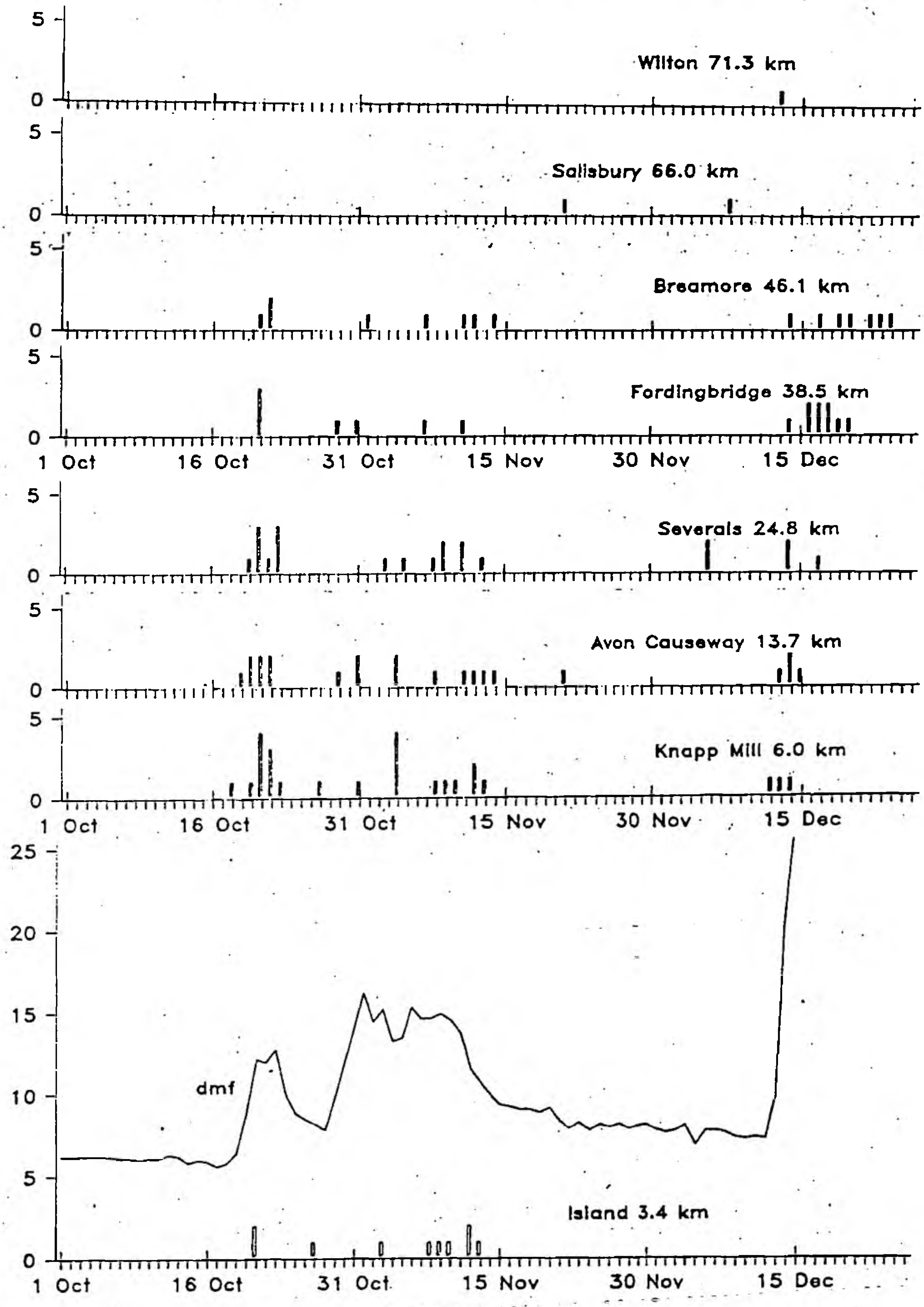
Daily scanner records of fish passage and Knapp Mill dmf, Oct - Dec 1987

Figure 26



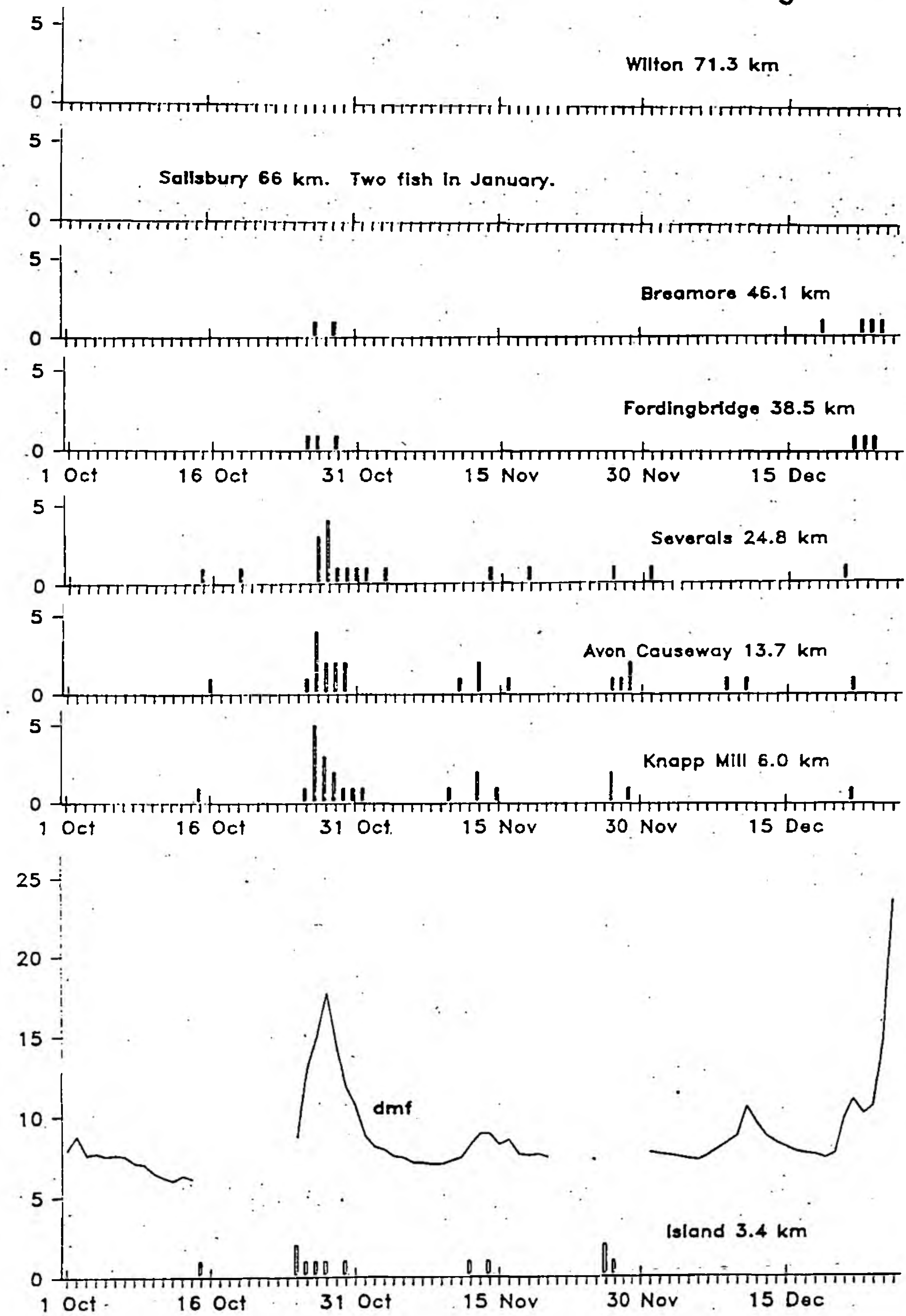
Daily scanner records of fish passage and Knapp Mill dmf, Oct - Dec 1988

Figure 27

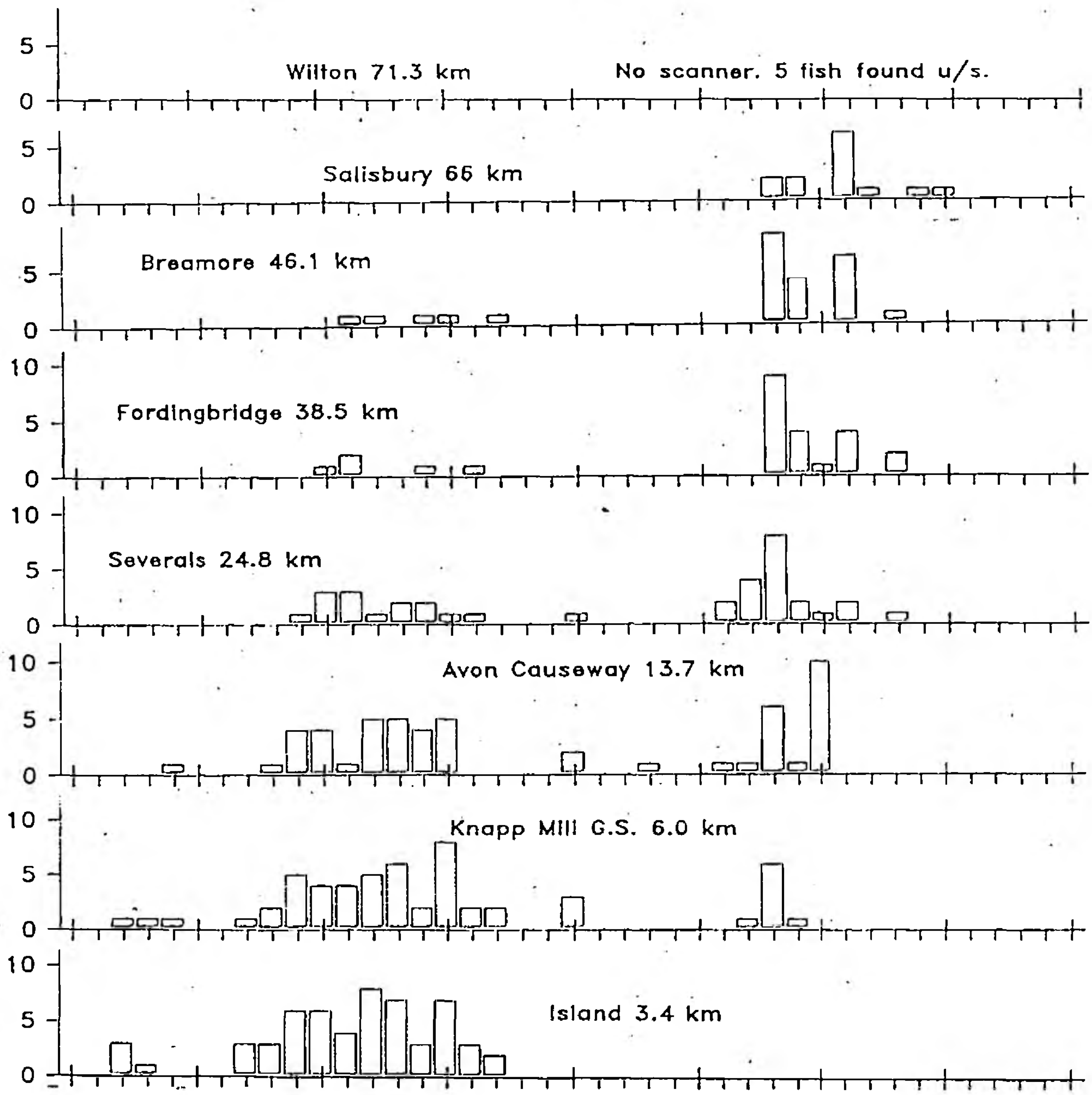


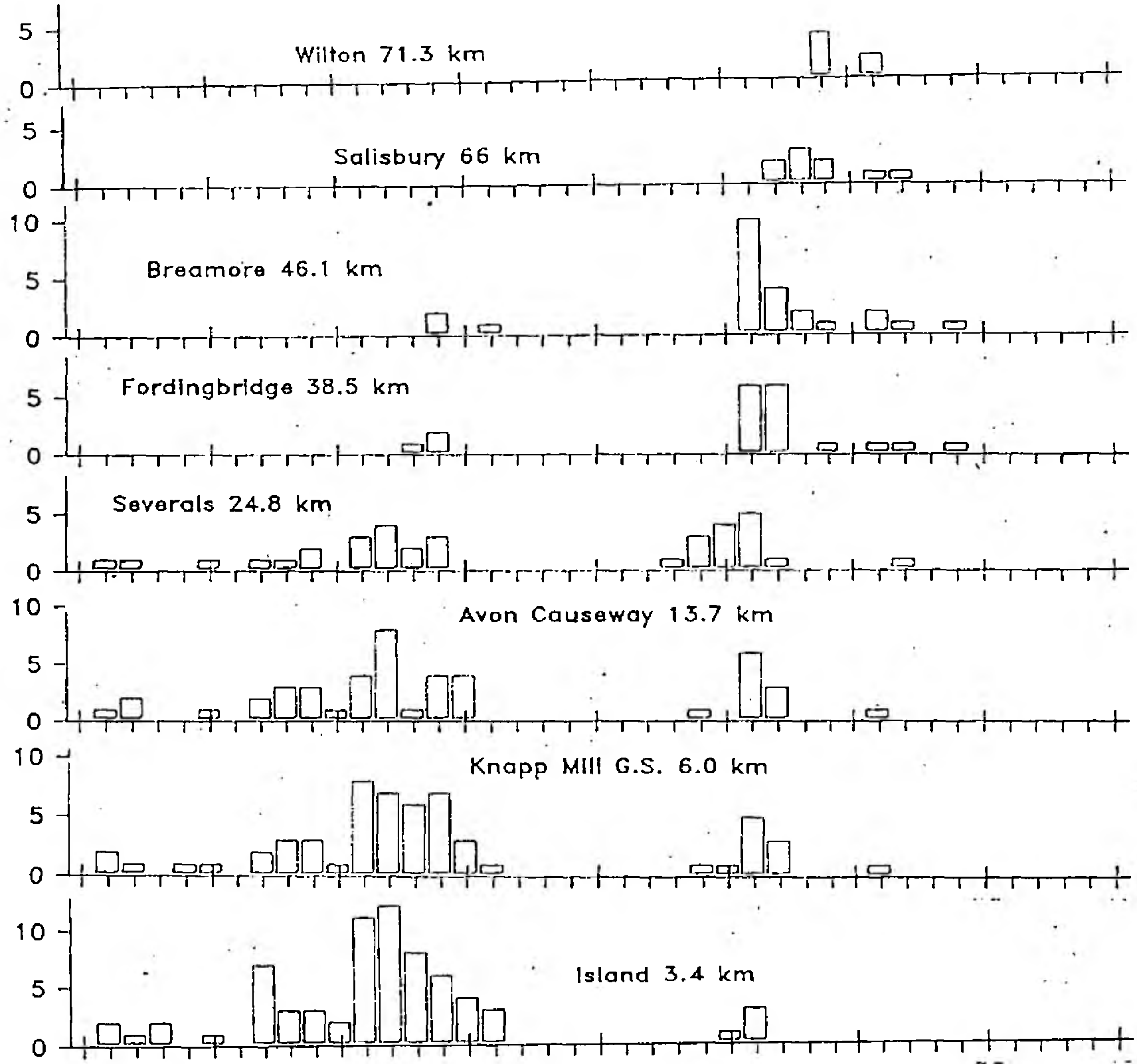
Daily scanner records of fish passage and Knapp Mill dmf, Oct - Dec 1989

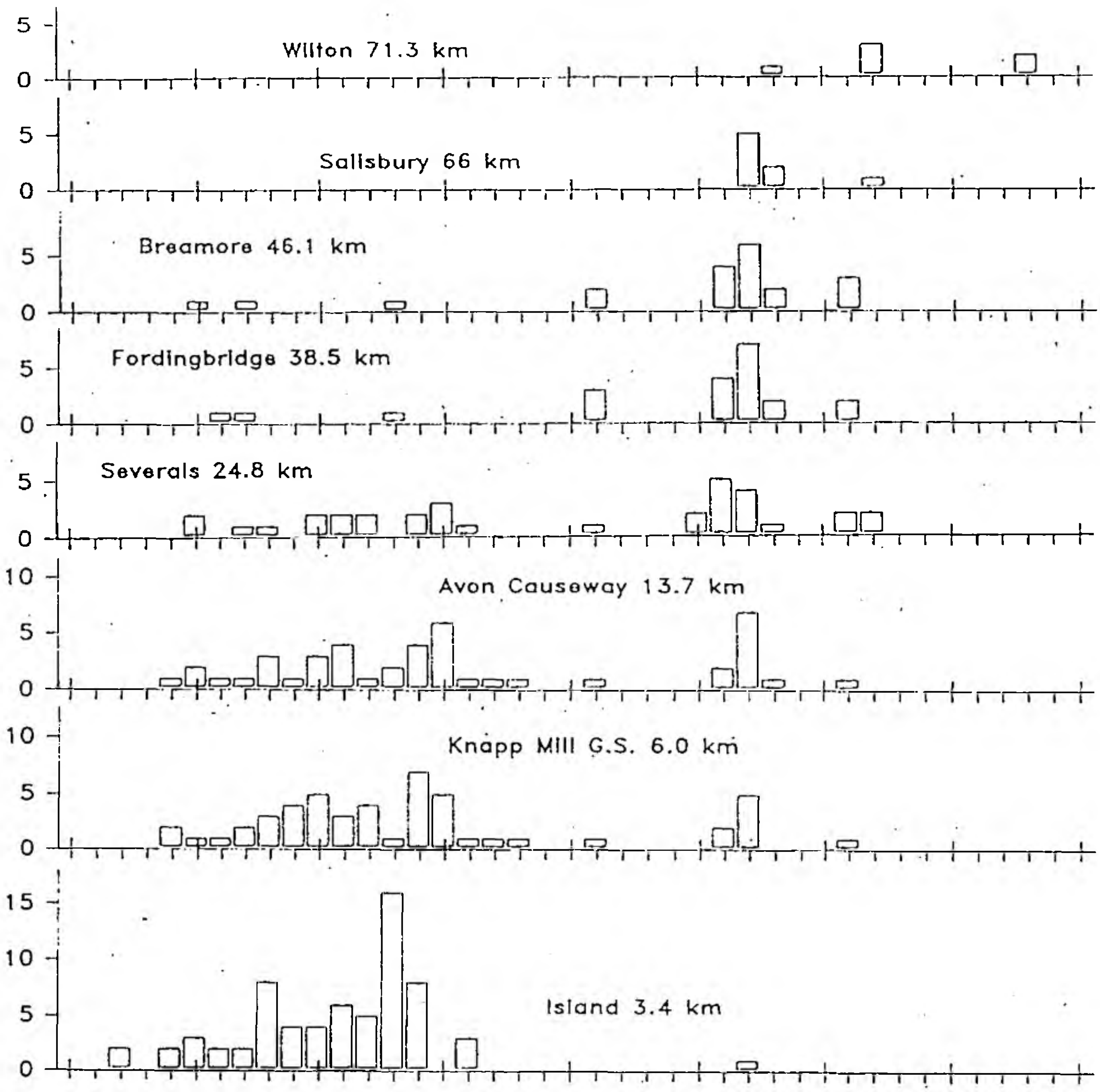
Figure 28



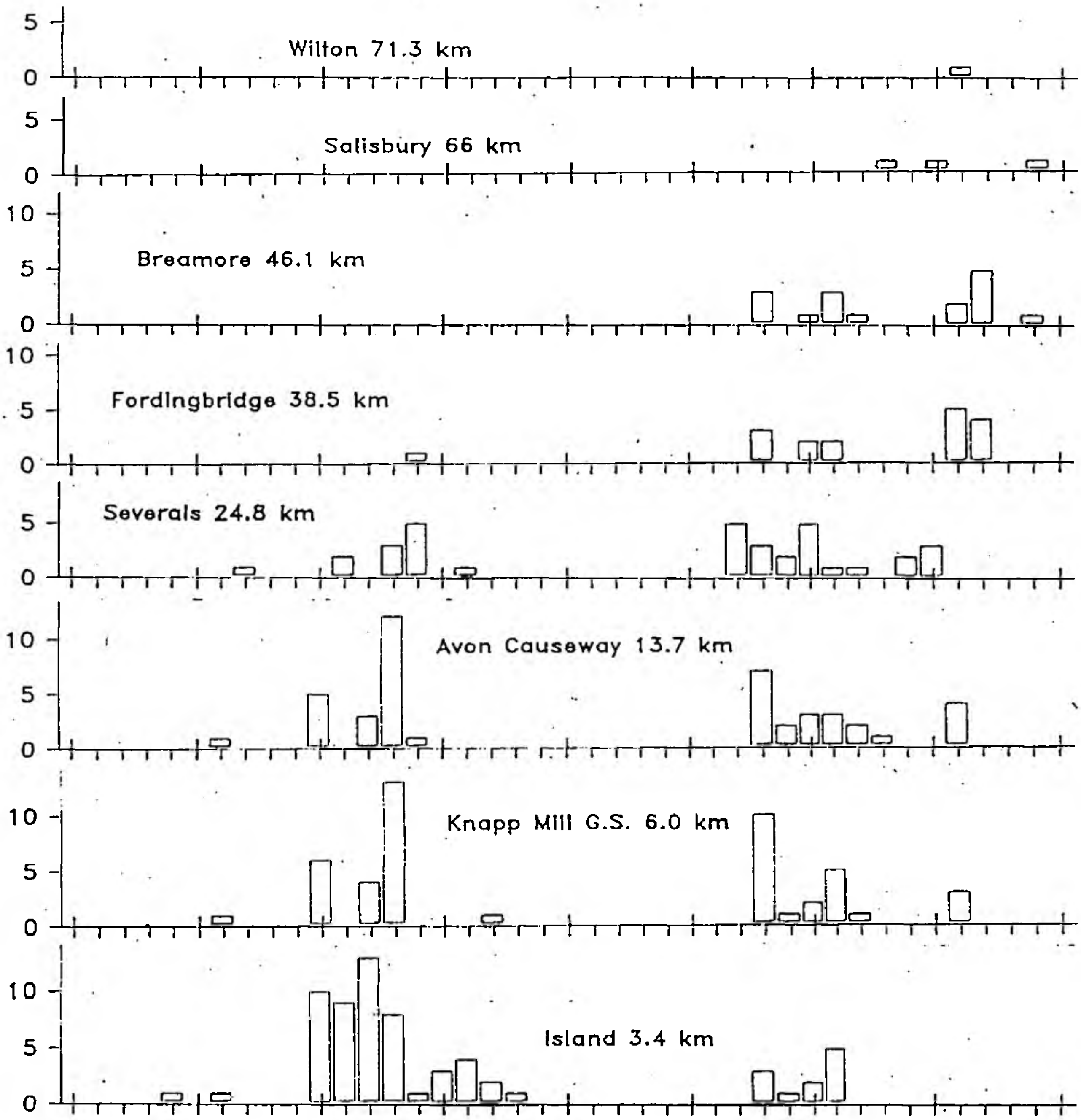
Daily scanner records of fish passage and Knapp Mill dmf, Oct - Dec 1990


Wilton 71.3 km
No scanner. 5 fish found u/s.
Salisbury 66 km
Breamore 46.1 km
Fordingbridge 38.5 km
Severals 24.8 km
Avon Causeway 13.7 km
Knapp Mill G.S. 6.0 km
Island 3.4 km
0
5
10


Wilton 71.3 km
Salisbury 66 km
Breamore 46.1 km
Fordingbridge 38.5 km
Severals 24.8 km
Avon Causeway 13.7 km
Knapp Mill G.S. 6.0 km
Island 3.4 km
0
5
10



Wilton 71.3 km
Salisbury 66 km
Breamore 46.1 km
Fordingbridge 38.5 km
Severals 24.8 km
Avon Causeway 13.7 km
Knapp Mill G.S. 6.0 km
Island 3.4 km
0
5
10
15


Wilton 71.3 km
Salisbury 66 km
Breamore 46.1 km
Fordingbridge 38.5 km
Severals 24.8 km
Avon Causeway 13.7 km
Knapp Mill G.S. 6.0 km
Island 3.4 km
0
5
10

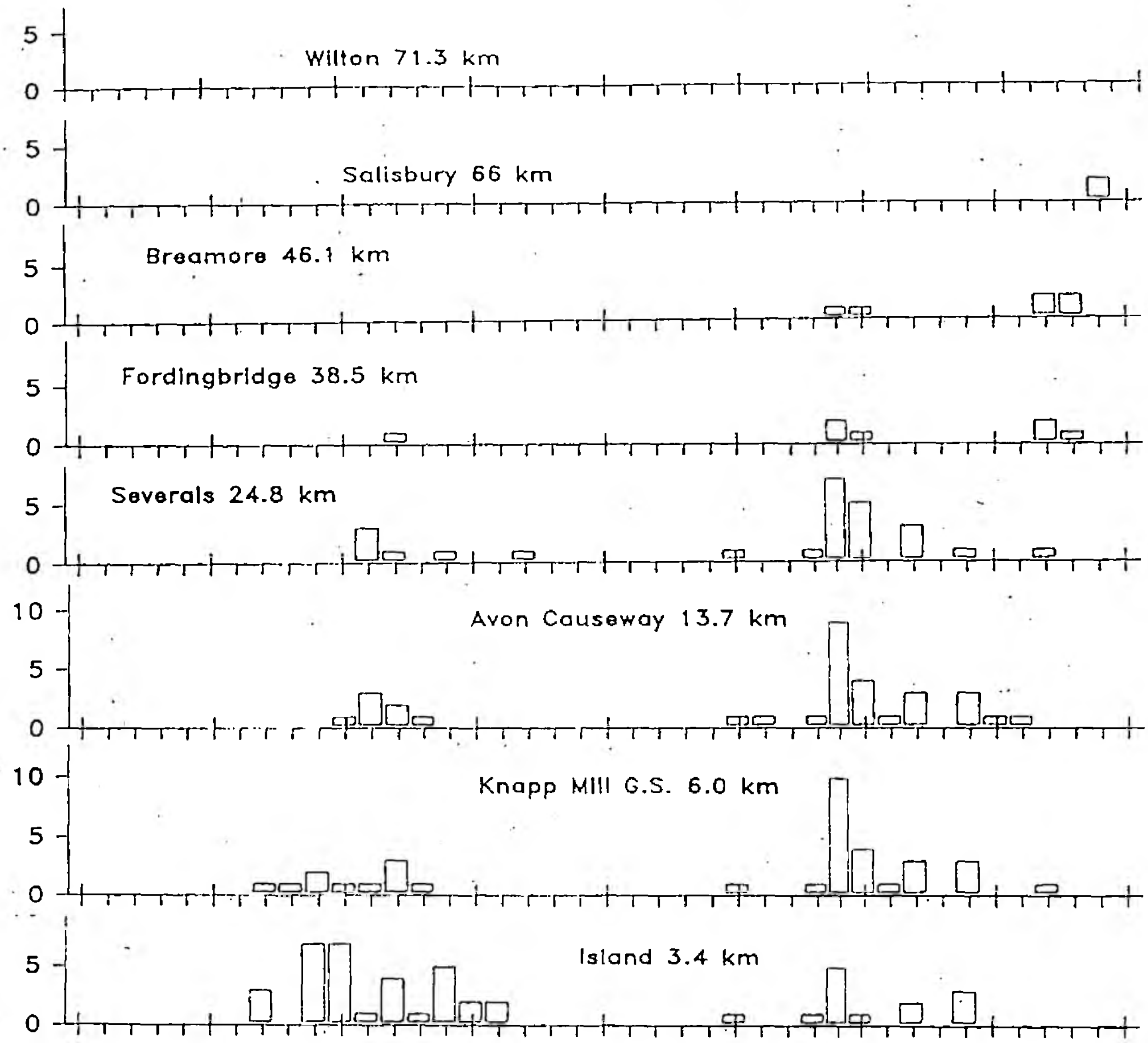
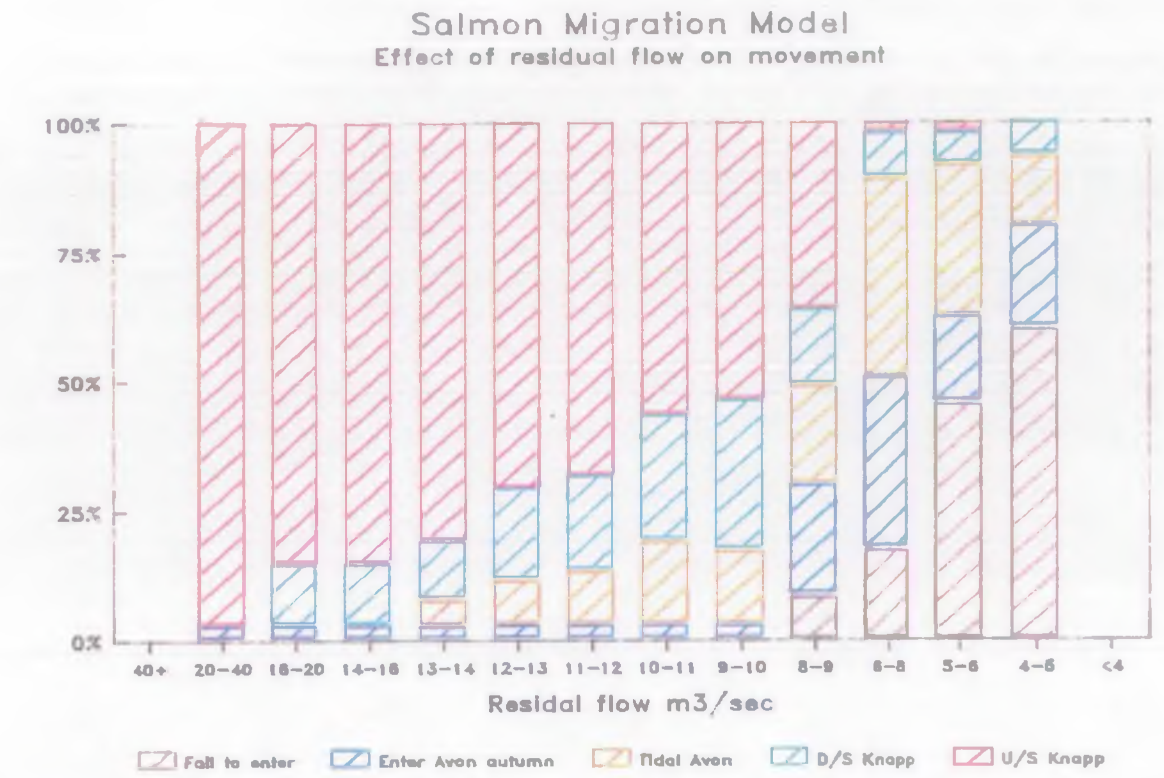
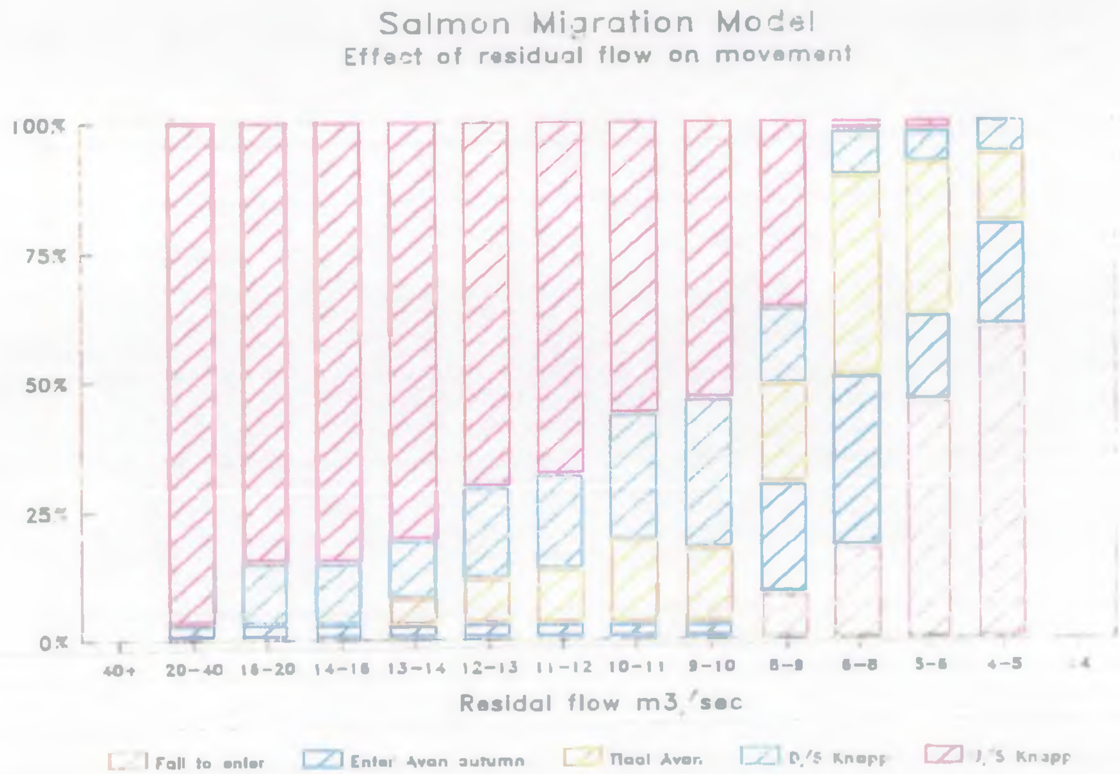

Wilton 71.3 km
Salisbury 66 km
Breamore 46.1 km
Fordingbridge 38.5 km
Severals 24.8 km
Avon Causeway 13.7 km
Knapp Mill G.S. 6.0 km
Island 3.4 km
5
0
10

Figure 34



D J Solomon, March 5 1991
hgavon/mod1



D J Solomon, March 9 1991

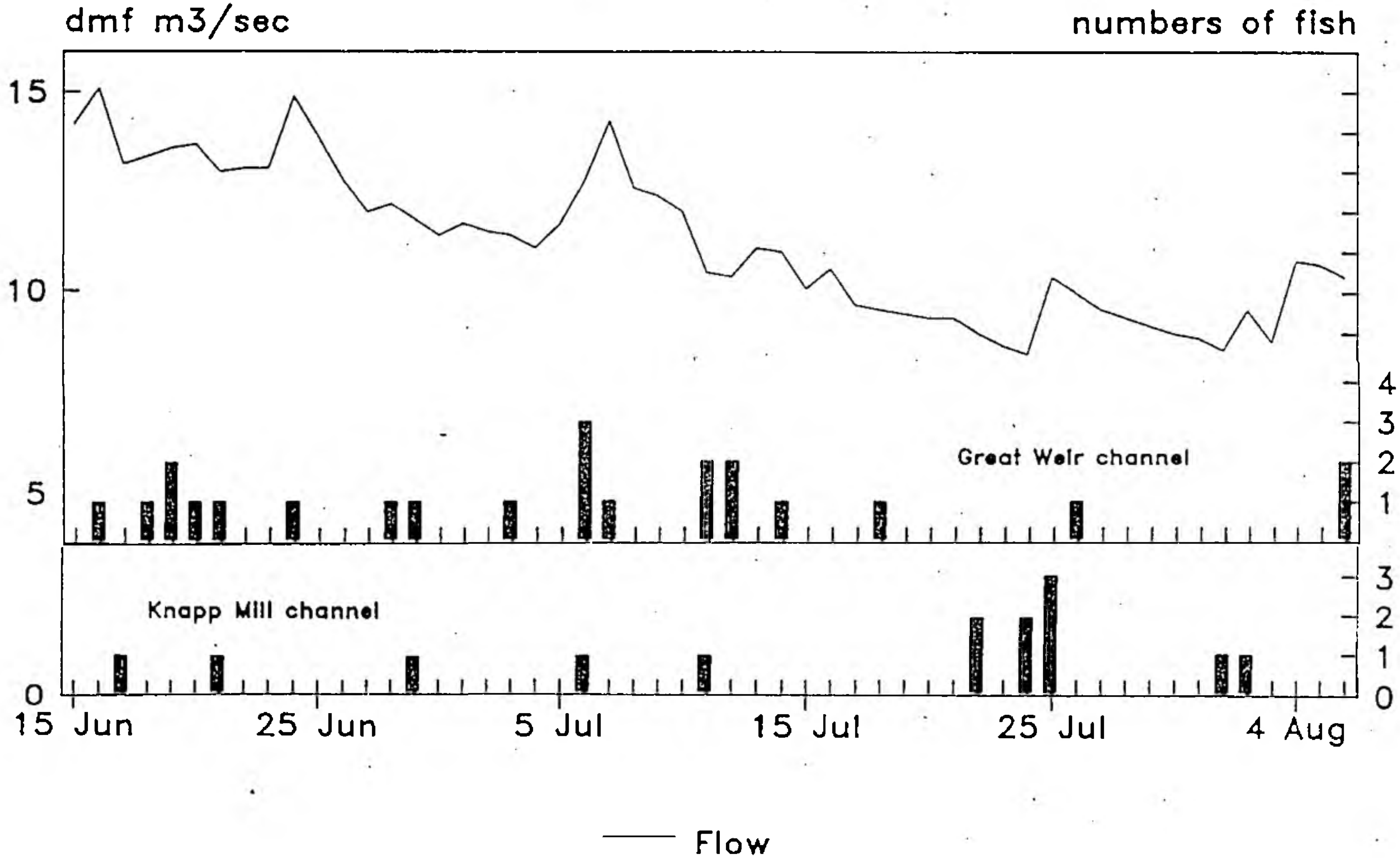
Figure 35

Effect of Abstraction, 1986.

Figure 36

Effect of Abstraction, 1990.

Fish using Mill and Gt weir channels
June – August 1986



D J Solomon, April 26 1991
hgwessex/avon/parl

Figure 37