PROVISIONAL ASSESSMENT OF THE RIVER TEES BARRAGE FISH PASSAGE.

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July 2014

Canal & River Trust

Cefas

Introduction.

The River Tees was a major salmon river in the 19th century and is said to have supported rod catches up to around 1,000 fish per year. Subsequently, the river suffered serious pollution from urbanisation and industrial development, principally in the estuary and lower reaches. Along with the construction of a number of weirs and other obstructions on the river, this resulted in the complete loss of both salmon and sea trout from the catchment between the 1930s and the early 1980s. The upland part of the catchment is dominated by peaty soils and is characterised by steep slopes resulting in a flashy regime that rapidly responds to rainfall events. These reaches have also experienced pressures, principally from metal mining (lead and zinc), and significant quantities of contaminated waste water and fine particles which were discharged into the river. There are also a number of impoundments along the River Tees which have reduced access to upper tributaries, modified river flows and caused sedimentation of spawning gravels. The Tees Salmon Action Plan also highlighted other problems on the catchment, including predation on both juveniles and adult salmonids by mammals, piscivorous birds and other fish species.

Extensive measures were taken to resolve some of these problems in the second half of the 20th century, and the stocks of salmon and sea trout in the river were therefore at a relatively early stage of their recovery when the estuary barrage was constructed at Stockton-on-Tees in 1994. A denil fish pass was included in the design and construction of the barrage and was granted provisional approval under the Salmon and Freshwater Fisheries Act 1976. Such provisional approval applies until such time as the Agency notifies the applicant that the pass is functioning to its satisfaction or revokes the approval. During the period of the provisional approval, evidence should be collected to demonstrate that the pass is working effectively and to support the application for permanent approval. However, assessing whether this pass has been working effectively has been challenging given the transitional status of the salmon and sea trout stocks. Little was known about the numbers of fish trying to enter the river prior to the construction of the barrage and how this number might have been expected to increase. While the neighbouring River Tyne had experienced quite rapid recovery after the estuary was cleaned up, it was not clear that the same recovery rate should be expected from the River Tees stocks, although this was suggested in the Tees Salmon Action Plan (Environment Agency, 2009). This has complicated assessments of whether the fish pass is working effectively and contributed to repeated postponements to the final decision regarding approval.

The purpose of this report is to determine whether the information now available is sufficient to support a new application for approval of the fish pass. It begins by considering briefly the requirements of a fish pass and the normal behaviour of migratory salmon and sea trout in estuaries before assessing available data on the movements of adult salmon and sea trout past the River Tees Barrage collected during a monitoring programme undertaken by the Centre for Environment, Fisheries and Aquaculture Science (Cefas) and additional monitoring by the Environment Agency.

Fish pass approval.

The purpose of a fish pass is to allow the free passage of endemic species of the appropriate developmental stage(s) at the appropriate time(s) of year (Environment Agency 2010). It may be necessary to consider the specific needs of different fish species and life stages, but in the current considerations, the approval process relates only to the upstream and downstream movements of salmon and sea trout.

The Salmon Advisory Committee (SAC, 1997) advised that, '*to be considered totally efficient, a pass would need to found and used by all fish that would otherwise be obstructed by the barrier, without significant delay or exertion'*. However fish may be able to negotiate a barrier by means other than just the fish pass, and so it is reasonable to consider the

efficacy of all the passage facilities at an obstruction, and this may be defined as the ratio of the number of fish passing the obstruction to the number approaching it in both the upstream and downstream directions. In addition, it is important to consider whether the upstream or downstream movements of fish are delayed, whether passage past the obstruction affects the vulnerability of the fish to predation, and whether it affects their subsequent survival or spawning success.

Movement of migrating adult salmon and sea trout in unobstructed estuaries.

Fish passes are generally installed on in-river obstructions; a full tidal barrage such as that on the River Tees not only creates an obstruction to migration but also significantly modifies the tidal cycle and the subsequent migration cues available to the fish. To understand the operation of a fish pass it is therefore necessary to consider the normal behaviour of upstream migrating fish in an unobstructed river system. Telemetry studies have shown that the behaviour of fish changes as they move through an estuary and upstream through the freshwater section of a river and the behaviour is strongly influenced by a range of factors including tidal cycle, river discharge and temperature, and to a lesser extent by other factors such as levels of dissolved oxygen and general water quality.

Movements though the estuary are often influenced by tidal state (Potter 1988; Potter *et al*. 1992; Smith *et al*. 1994; Solomon *et al*. 1999). In most unobstructed estuaries the tidal cycle creates strong upstream currents on the flooding tide and strong downstream currents on the ebbing tide. Returning adult salmon and sea trout therefore tend to use the flooding tide to move up into the estuary, and may drop back downstream or hold position on ebb tides if conditions are not suitable for entry into freshwater. The transition from relatively passive movement through the estuary to active upstream river migration against the current requires a distinct change in behaviour. This change is likely to be influenced by a range of factors including decreasing salinity. All previous studies on returning adult salmon and sea trout have demonstrated that the fish orientate towards the maximum flow.

Many studies have shown that the movement of salmon and sea trout from estuaries into freshwater is related to flow (Milner *et al.* 2012; Bendall & Moore 2012) although as flow and water temperature are often correlated it may be difficult to distinguish the effects of these two parameters. Potter (1988) showed that most salmon on the River Fowey entered fresh water at night, and that these fish moved on lower flows than the smaller number of fish moving during daylight hours. This behaviour may reflect a predator avoidance strategy, with fish gaining protection by moving under the hours of darkness or under turbid conditions.

Estuarial movements are also strongly affected by the topography of the estuary and the availability of holding areas (Potter *et al.* 1992). Thus, in larger rivers salmon may migrate to the head of tide under all but the lowest flows, whereas in smaller rivers they may not even enter the estuary unless flows are above average levels. In larger estuaries, fish may also be able to find holding areas where they can wait for suitable conditions for upstream migration (Milner *et al.* 2012), but in smaller rivers they may have to drop back out to sea (Potter 1988) or find refuge in larger rivers nearby (Clarke *et al*.1991;Stewart *et al*. 2009). In the southern part of England, salmon that are delayed for more than about ten days within the estuary tend not to migrate into the river until the autumn (Solomon *et al.* 1999). Fish thus delayed have been shown to suffer significant losses, and Solomon and Sambrook (2004) suggested that half the stock may fail to enter the river at all in hot dry summers. Further north there is less evidence of losses of salmon delayed in estuaries, suggesting perhaps that temperature is implicated in this phenomenon (Milner et al. 2012).

The construction of the River Tees Barrage will have created an unusual situation, where the upstream and downstream tidal movements have been greatly reduced and a relatively abrupt transition from saline to freshwater has been created. In addition, the reduced tidal flow may also increase the temperature of the estuary particularly during the summer

months. This transition therefore requires a more abrupt and potentially unnatural change in behaviour. Evaluation of the behaviour of the fish at the Barrage must therefore be viewed in the context of these changes.

Salmon and sea trout monitoring

Ideally, to assess the efficacy of a fish pass it is necessary to know the numbers of fish approaching the obstruction and the proportion of these that successfully negotiate the barrier. This is best achieved by utilising established telemetry/tracking techniques, and these have been successfully employed over a number of years in a range of in-river and estuary research programmes (Hawkins & Smith 1986; Potter 1988; Webb & Hawkins 1989; Potter *et al*. 1992; Clarke *et al*. 1994; Bendall *et al*. 2005; Moore *et al.* 2012 *).*

In 2008, 2009 and 2013, Cefas was contracted by British Waterways and subsequently the Canal and River Trust to conduct tracking studies to investigate the movements of adult salmon and sea trout in relation to the River Tees Barrage. The principle objectives of the programme were:

1. Determine the movements of salmon and sea trout around the barrage under river conditions (flows and temperatures) considered to be normal.
2. Investigate the impact of seal predation on adult salmon and sea trout residing downstream of the barrage and management opportunities for mitigation.
3. Use the data from the above studies to support an application for Final Consent for the Fish Pass (and Barrage Scheme of Operation) to the Environment Agency or recommend alternative management action as appropriate.
4. (During the final year) The operation of an echo-sounder upstream of the barrage during the main run of the River Tees salmon and sea trout to provide additional information of the number of fish passing the barrage.

Standard methodologies were used to handle and tag the fish and to monitor their subsequent movements (see Moore *et al*. 2014). These methods have been successfully applied in other estuaries, including the adjacent River Tyne which can be considered to be a partial control to the River Tees monitoring study. However, it is not possible to say whether the fish tagged in the study were entering the estuary for the first time or had already been held up by the barrage nor whether tagged fish were more vulnerable to predation immediately after release than fresh run fish.

Full details of the results have been reported in the annual reports presented to British Waterways and subsequently the Canal and River Trust (see also Moore *et al*., 2014).

The principal findings of the fish monitoring research were:

- A total of 237 fish (199 salmon and 38 sea trout) were tagged with acoustic transmitters and released into the lower estuary below the River Tees Barrage. Eleven fish negotiated the barrage, 10 moving over the barrage gates and 1 passing upstream through the fish pass. This represents 4.6% of tagged fish passing the barrage. In 2009, no fish were recorded passing the barrage.
- The majority of the fish that successfully negotiated the barrage generally approached it immediately prior to high water (+ 2hours). The fish that passed over the gates did so at around high water when the height difference between downstream and upstream of the barrage was minimal.
- Eighty fish (33.7%) approached the barrage after tagging and release. A small number of these fish made a number of approaches to wards the barrage.

- Eighty one fish (34.1%) are known to have left the estuary after tagging and release.
- Thirteen fish (5.4%) were subsequently recorded entering adjacent river systems (Rivers, Wear, Tyne and Coquet. This is unlikely to represent the total number of tagged fish returning to other rivers, including Scottish east coast systems, and it is hoped that further clarification will be provided by genetic studies that are currently underway.
- Thirty five fish are known to have been eaten by seals (14.7%). Predation by a seal was indicated by an increase in the recorded temperature from the acoustic transmitter's temperature sensor to ~37°C. However, it is considered that a larger number of fish may have been predated by seals although the acoustic transmitter was not ingested by the seal. Seventy transmitters (31.6%) were recorded for long periods in the same position on the bed of the estuary indicating that they were no longer in live fish.
- The remaining tagged fish were last recorded in the lower estuary but their subsequent fate is not known.
- Trials of a seal acoustic deterrent device (ADD) were undertaken and observations suggested a range of responses from seals, with some individuals initially moving away from the area, but others rapidly habituating to the noise and continuing to feed. Operation of the ADD close to the barrage did suggest a reduction in foraging behaviour.
- The behaviour of tagged fish indicated that the fish pass trap was a deterrent to the upstream passage of returning salmon and sea trout, and underwater video surveillance confirmed that the trap was causing fish to move back downstream. It was therefore was decided that the trap would be removed in June 2011 and replaced by a Logie resistivity fish counter.
- The deployment of the echo sounder up-stream of the barrage did not provide any accurate information regarding fish passage. Although, the echo-sounder had the capability to detect targets with a very high precision within the impoundment, the combination of fish orientation, debris and high densities of coarse fish made the accurate resolution and quantification of salmon and sea trout not possible.

Although the three year tracking study has produced extremely valuable information on the behaviour of salmon and sea trout in relation to the barrage and the environmental cues necessary to permit the passage of fish over the barrage, Moore *et al.* (2014) concluded that the information was not sufficient to form the basis for an application for Final Fish Pass Consent. However, it had previously been agreed by the River Tees barrage Steering Committee that additional information from a number of other sources should be considered together with the tracking study in order to determine the status of the River Tees barrage fish pass. This additional information has been provided by the Environment Agency and is considered below.

Fish pass trap and fish counter records.

Counts of the numbers of fish entering the River Tees have been collected by means of a trap and a counter over the period 1995 to 2013. Between 1995 and June 2011, a conventional upstream fish trap, with an in-scale entrance, was operated at the top of the denil fish pass at the barrage. The numbers of sea trout caught each year increased rapidly from 1995 to 2001 but declined thereafter until 2010, falling to their lowest levels in 2009 and 2010 (Figure 1). The numbers of salmon, on the other hand, remained relatively stable between 1995 and 2001, but have been somewhat higher, although also more variable, from 2004 until 2010. The increase in counts of salmon may reflect, at least in part, the substantial reduction in the number of drift nets operating off the NE coast in 2003, which

greatly reduced the commercial catch of salmon and to a lesser extent sea trout. The effect of this on the numbers of salmon entering the River Tees is not known but should become clearer when the results of current genetic studies are available. However, it remains unclear why the counts of sea trout should have declined as this does not reflect trends in other rivers in the region. The increased salmon counts may reflect continued improvement in the status of the salmon stock and changes in the operation of the barrage, but this cannot be confirmed from the available data and again is not consistent with the changes in sea trout counts.

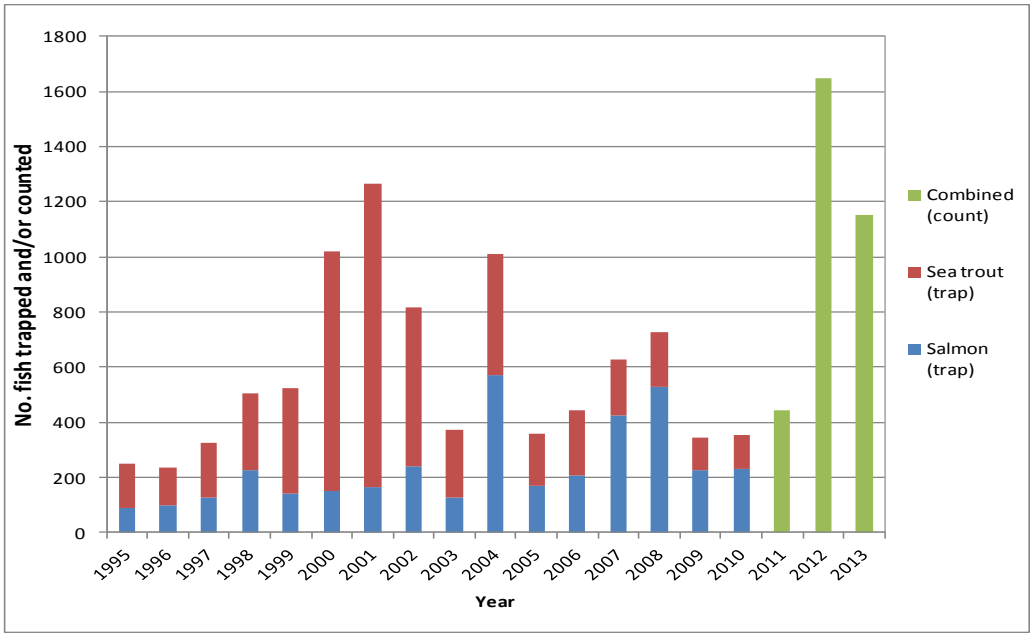

Figure 1. *Number of salmon and sea trout caught in the River Tees fish pass trap (1995-2010) and combined numbers counted (2011-13) [NB In 2011 the trap operated from January to June and the counter for the remainder of the year.]*

The tracking studies conducted by Cefas (see above) showed that the fish trap was deterring fish from moving upstream, and so it was removed in June 2011. From that time, counts of fish entering the River Tees have been obtained from an electronic fish counter operated at the same location in the fish pass. At present, only total counts of salmon and sea trout combined are available, although it is understood that the Environment Agency is examining the counter records to determine whether it is possible to estimate the size of the fish, and hence the stock composition. More fish were recorded passing over the counter in 2012 and 2013 than were trapped in any year between 1995 and 2010, except 2001, and the mean count for 2012 and 2013 was nearly three times the mean number trapped in the five years from 2005 to 2009. It seems likely that these increases are mainly due to the removal of the trap, although it is not clear whether they reflect an increase in the proportion of fish successfully getting past the barrage or just a change in the route used by fish to achieve this.

There have also been marked changes in the annual timing of the runs following the removal of the trap (Figure 2). Throughout the monitoring period, the majority of the run has occurred between July and November. Between 1995 and 2001, the median run date was in October (6 yrs) or November (1 yr), but this advanced to August (2 yrs) or September (7 yrs) between 2002 and 2010. This change may partly reflect the significant reduction in the coastal fishery which operated from June to August, but may also reflect changes in river flows and in the operating procedures at the barrage.

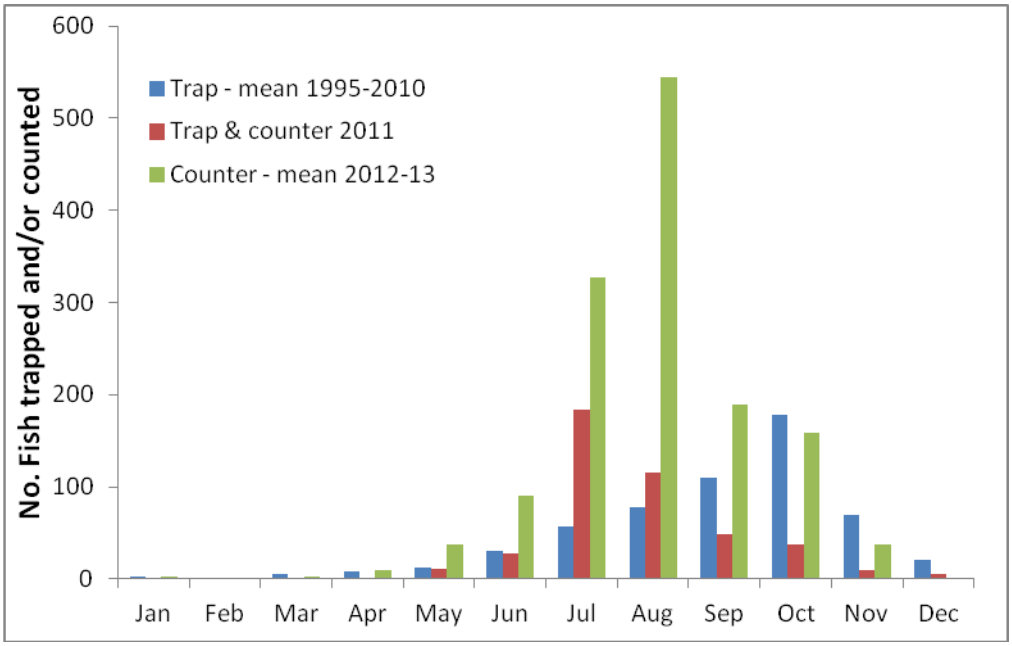

Figure 2. *Mean numbers of salmon and sea trout caught per month in the River Tees fish pass trap (1995-2010) and combined numbers counted per month (2011-13) [NB In 2011 the trap operated from Jan to June and the counter for the remainder of the year.]*

Following the removal of the trap in 2011, there was a large increase in the numbers of fish counted in July, immediately after the removal of the trap, but counts then declined steadily until the end of the year (Figure 2). However, in 2012 and 2013, the runs increased from April to a peak in August before declining again until November. While care is required in interpreting these limited data, they are consistent with passage through the pass being greatly improved by the removal of the trap, particularly during the summer months during the summer months.

One factor that might affect the interpretation of these data is possible changes in the relative proportions of salmon and sea trout in the runs. The trap catches between 1995 and 2010 indicate that although the average runs of salmon and sea trout both peaked in October (Figure 3), the median migration date was in September for salmon compared with October for sea trout. There are no data on the separate timing of the runs of salmon and sea trout since the removal of the trap in 2011, and so changes in the timing of the combined run since the trap was removed in 2011 might have been affected by changes in the stock composition.

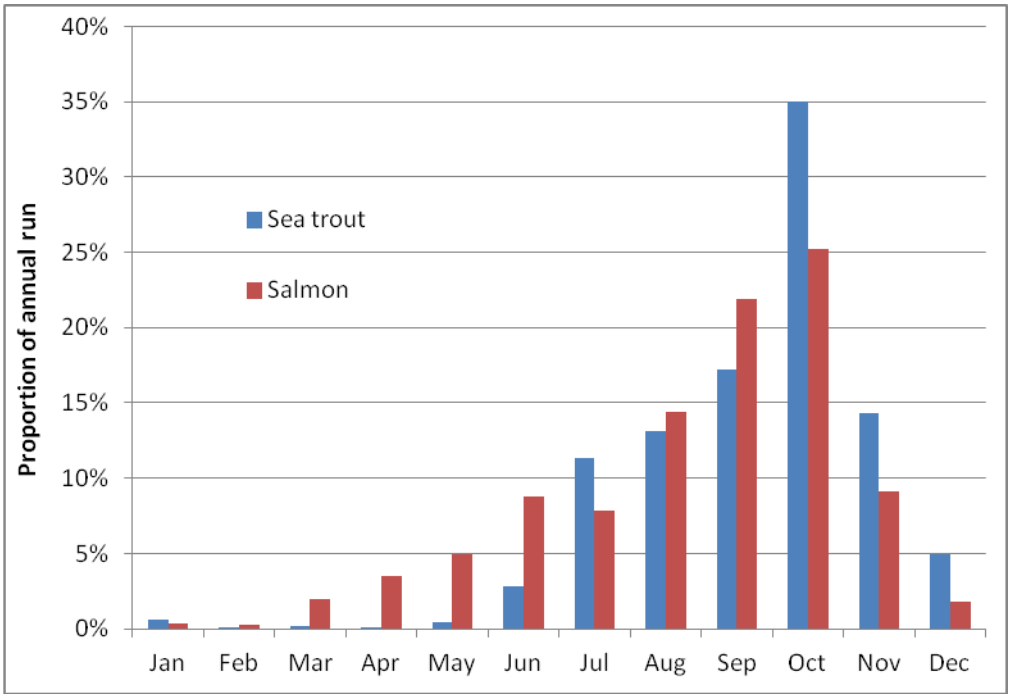

Figure 3. *Proportions of the mean annual run of salmon and sea trout for 1995 to 2010 caught in the River Tees fish pass trap each month (1995-2010).*

Rod catches.

Another indicator of changes in the numbers of fish entering the river may be provided by the catches in the rod fisheries in the River Tees upstream of the Barrage. Rod catches of both salmon and sea trout have been recorded since the early 1980s, although there may be some uncertainty about the sea trout catches because data presented by the Environment Agency in their stock status review (Environment Agency, 2012; Figure 2.48) differ markedly from the published catch statistics (Environment Agency 2004 and 2013).

Since the construction of the barrage catches of both species have been fairly variable (Figure 4). Salmon catches showed a general increasing trend until they peaked in 2008 at 267 fish, but they then fell to below 100 between 2009 and 2011, increasing again to 211 in 2012. Sea trout catches also increased initially, peaking at 143 in 2004, but have declined reasonably steadily since then.

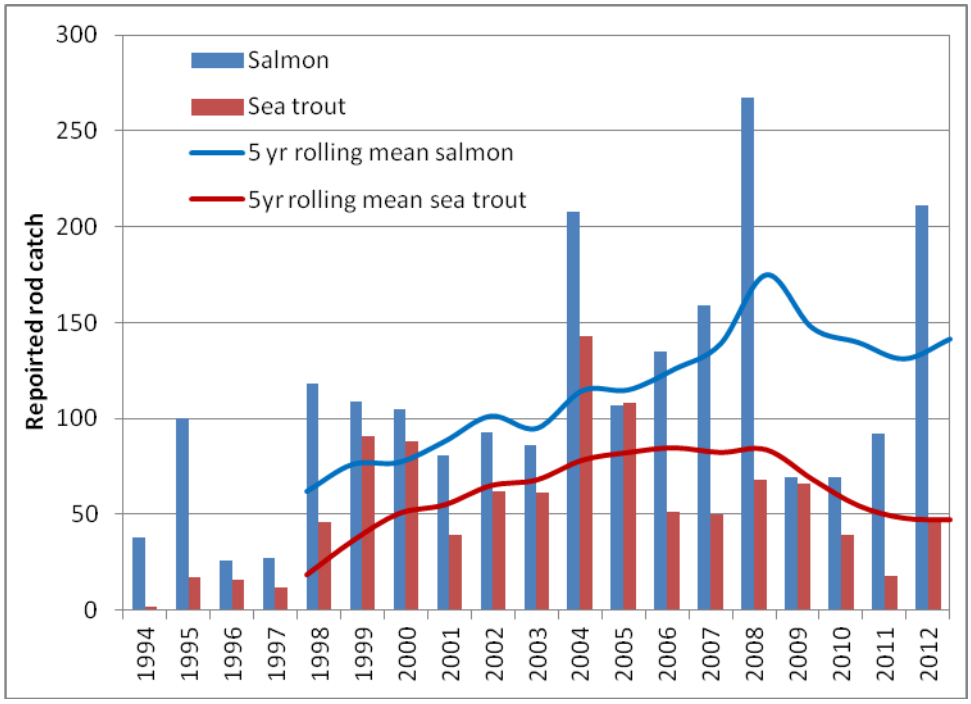

Figure 4. *Reported rod catches of salmon and sea trout on the River Tees, 1994-2012 with 5yr rolling means.*

In 1995, the reported rod catch of salmon was approximately equal to the number of fish counted at the trap, although in the two following years the catch was only about 20% of the trap count (Figure 5). (NB: this ratio should not be regarded as an estimate of the exploitation rate because the trap count is known to be an incomplete count of the numbers of fish entering the river.) Subsequently, the rod catch declined from a peak of about 77% of the trap count in 1999 to about 30% in 2009 and 2010. The sea trout rod catches have shown the opposite trend, however, with the declared catch being only around 10% of the trap count between 1995 and 2002 but varying between 22% and 58% between 2003 and 2010.

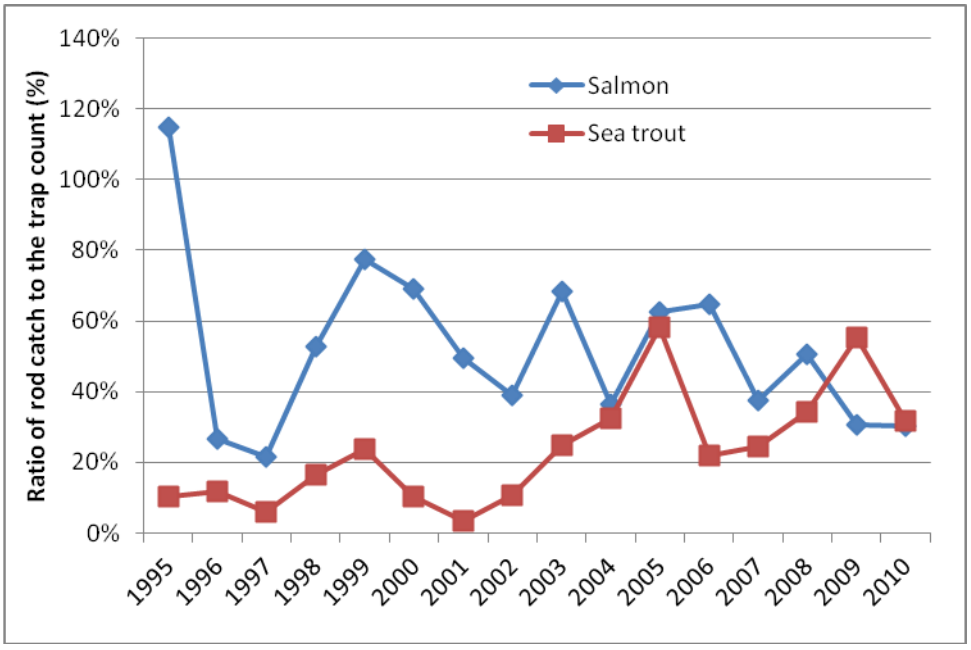

Figure 5. *Rod catches of salmon and sea trout on the River Tees expressed as a proportion on the counts in the Tees Barrage fish trap, 1995-201.*

If the exploitation rates and catch reporting rates in the rod fishery have not changed over time, the rod catch would be an indicator of the stock size and the trap count divided by the rod catch (i.e. the inverse of Figure 5) would provide an index of the proportion of the fish entering the Tees that migrated upstream via the fish pass. This would suggest that an increasing proportion of the salmon, but a decreasing proportion of the sea trout entered the river in this way over the period between 1995 and 2010. In practice, however, the exploitation rates and catch reporting rates may have changed as the fisheries developed making it impossible reliably to interpret changes in the behaviour of the fish in this way.

Timing of fish movements

The Environment Agency has provided more detailed data on the time of day that fish were counted at the top of the barrage fish pass in 2012. The total counts indicate that runs occurred throughout the day and night between May and November (data are not provided for other months), but at all times of year the run peaked in the afternoon, between 14:00 and 17:00) (Figure 6). Overall, runs were at their lowest between 06:00 and 07:00, increased steadily to peak between 15:00 and 16:00 and then declined again to 18:00. Runs were relatively stable between 18:00 and 06:00. While there was some variation between months, there was no evidence of a consistent trend.

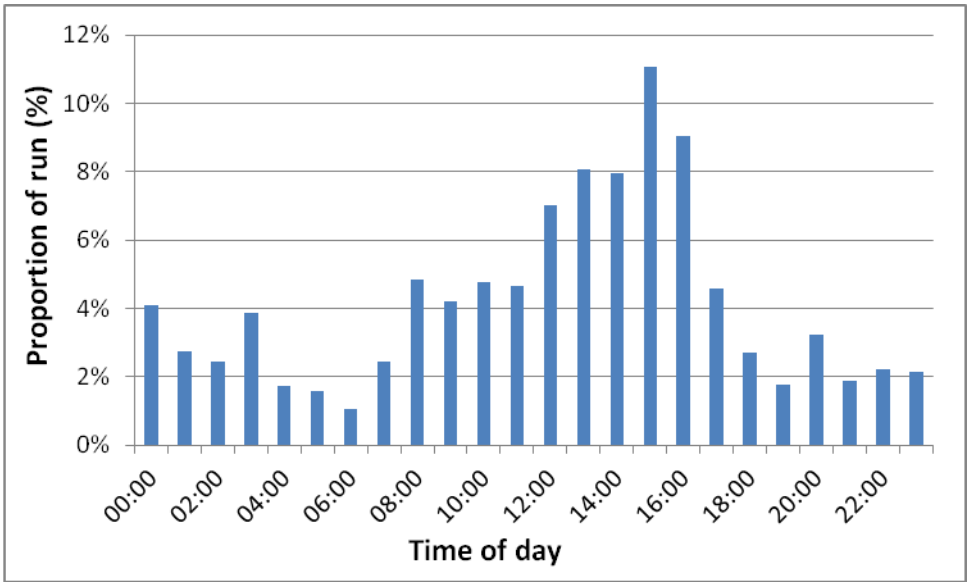

Figure 6. *Time of day of upstream movements of salmon and sea trout combined past the River Tees barrage between May and November 2012.*

This behaviour is not consistent with the timing of movements generally seen in other, unobstructed estuaries. Tracking studies have generally shown that movements in the lower estuary are dominated by the tidal cycle and occur at all times of day and night. However, fish tend to move into freshwater during the night, except during periods of increased flows. The daily movements therefore appear to reflect the way the gates are operated at the barrage or discharge when the canoe slalom is operating. This suggests that it may be possible to improve the night-time operation of the gates and/or canoe course to improve the passage of fish past the barrage during the hours of darkness.

The Environment Agency provided data on the timing of fish movements relative to the state of tide for the 14 days with the largest runs between June 30th and 15th November. Data have been extracted for one full tidal cycle (starting at low water) on each of these days and summed to provide an estimate of the run timing relative to the state of the tide (Figure 7). This suggests that the counts tended to increase to a peak around the 4th hour after low water, remained relatively high until the 7th hour after low water and then fell to minimal levels towards the next low water. Additional monitoring using a DIDSON imaging sonar, also indicated that fish were passing over Gate 1 predominantly 1-2 hours before high tide (Figure 8). Therefore, most fish are detected passing the barrage at around high water which agrees with the results of the fish tracking research.

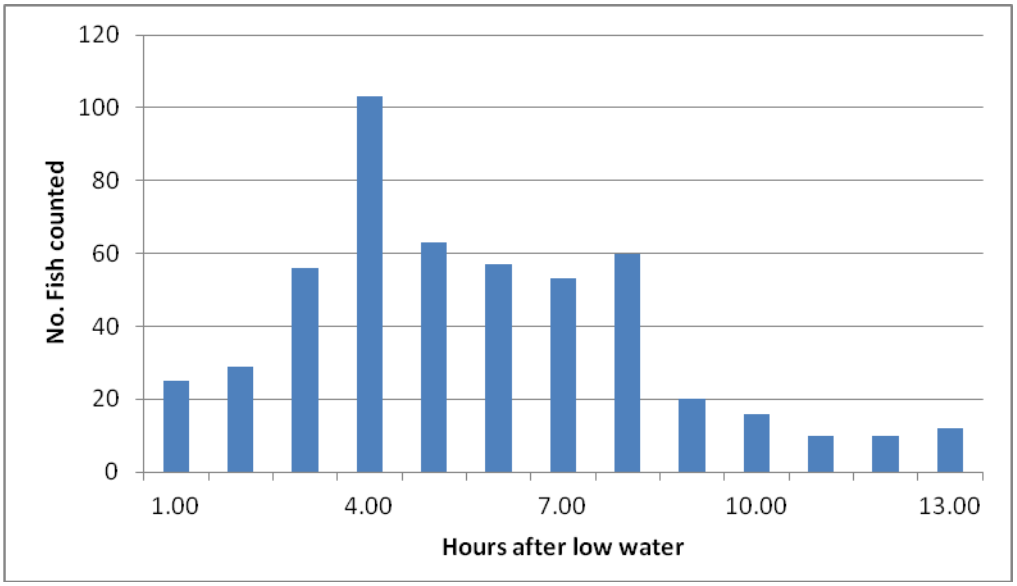

Figure 7. *Timing of movements of salmon past the River Tees barrage relative to the tidal cycle observed on 14 days in 2012.*

This is consistent with the behaviour of migratory salmon and sea trout observed in unobstructed estuaries, in which they generally move into and up the estuary on a flooding tide and may then either begin swimming against the current, hold position or drop downstream again on the flooding tide.

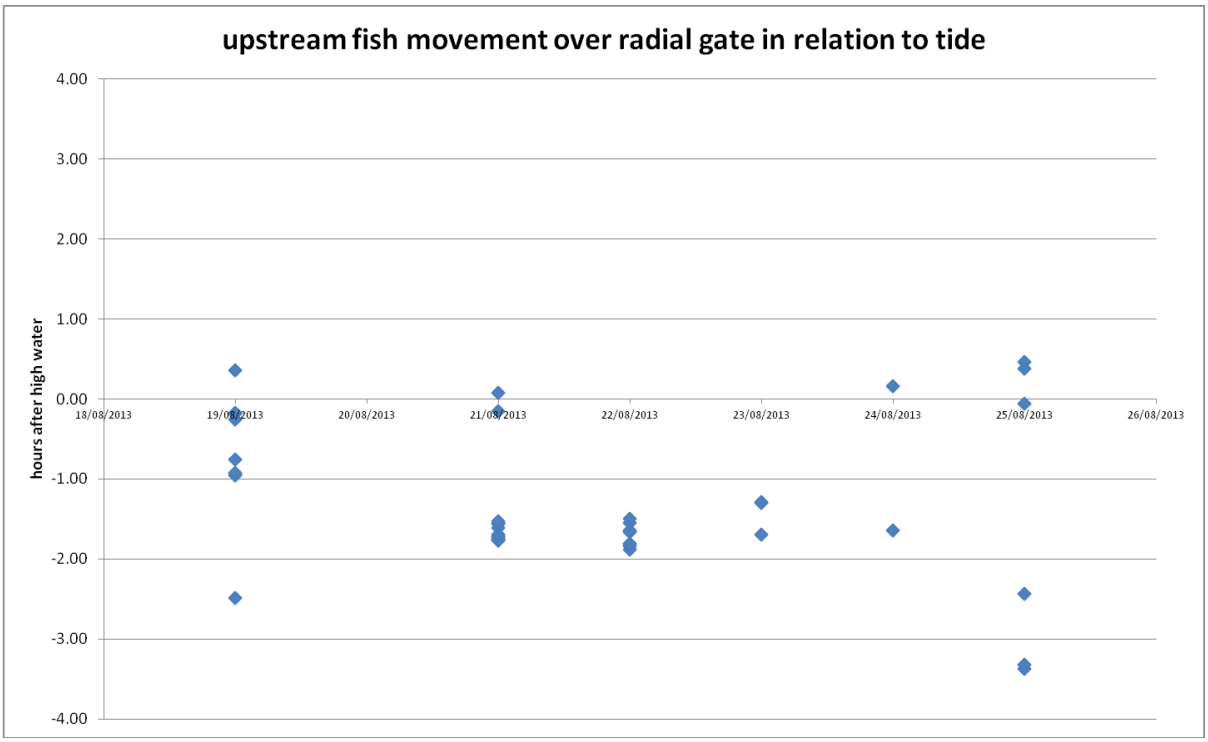

Figure 8. *The upstream movements of adult salmonids over the barrage gate in relation to the tidal cycle monitored by the Environment Agency using a DIDSON imaging sonar.*

Downstream movement of smolts and kelts.

In evaluating the passage of salmon and sea trout past an obstruction, it is also important to consider the downstream movements of emigrating smolts and kelts. However no data have been made available on these life stages and it is therefore not possible to assess the adequacy of the fish passage facilities for their movements. It is important to note that there is a very brief "optimal window" for the migration of smolts into the marine environment and any significant delay to downstream migration has been shown to reduce their survival in the sea and reduce the numbers of returning adults. Further studies on the temporal and spatial behaviour of these stages of the life cycle of salmon and sea trout in relation to the barrage are required.

Conclusions and recommendations.

The Environment Agency has four options regarding the future of the River Tees Barrage Fish Pass:

1. Approve an application for Final Fish Pass Consent based on the evidence collected to date from the fish tracking and other monitoring studies.
2. Revoke the existing Provisional Fish Pass Consent as insufficient fish are negotiating the barrage.
3. Agree to continue with the existing Provisional Fish Pass Consent but implement key recommendations and monitor the effects of these improvements. Write key recommendations into the barrage scheme of operation.
4. The "do-nothing" option. Do not implement any recommended changes to barrage operation and discontinue the monitoring of fish negotiating the barrage.

It is considered that the evidence from both the 3 year tracking study and the information provided by the Environment Agency is not sufficient to form the basis of a successful application for Final Fish Pass Consent. However, conditions are clearly improving in the River Tees and the modifications to the canoe course, removal of the fish pass trap and changes to the operation of the barrage would suggest that revocation of the existing Provisional Fish Pass Consent would be difficult to support given that fish are negotiating the structure. The "do-nothing" option is clearly unacceptable as there is a requirement to improve fish passage past the barrage. It is considered too early to fully assess how the recent changes to the barrage have improved the passage of fish and therefore, it is recommended the third option is accepted. For the continuation of Provisional Fish Pass Consent, further monitoring will need to be undertaken and that the evidence on the behaviour of the fish, produced as a result of the Cefas fish monitoring research and additional monitoring from the EA is used to modify and refine the operation of the barrage to further improve the passage of returning fish. The Cefas fish monitoring study provided strong evidence for significant interactions between the returning salmon and sea trout and resident seals which must be minimised to ensure that fish delayed by unfavourable conditions for passage below the barrage are not predated.

The following are the recommendations for future monitoring, operation of the barrage to assist upstream migration and methodologies to reduce interactions between seals and fish necessary to support the continuation of Provisional Fish Pass Consent.

1. *Interactions between fish and seals.*

- Significant numbers of tagged salmon and sea trout were predated by seals downstream of the barrage. Methods need to be developed to minimise the interactions between fish and seals. Trials of an acoustic deterrent device (ADD) were undertaken with mixed results. Seals rapidly habituated to the device particularly during the netting of the fish for the monitoring study. Previous research by Cefas on the management of pisciverous birds and fish has shown that underwater refuges can reduce the predation of fish by cormorants. It is recommended that similar refuges are trialled at "survival bottlenecks" in the estuary where fish are often delayed and eaten by seals. Such sites would be at the entrances of the fish pass and canoe course. A similar temporary structure could be installed and trialled during periods when the navigation lock was being operated to assist upstream migration of fish during low flows. The structures would be in the form of metal cages that would allow fish to freely enter but with a mesh size that would prohibit the entry of resident seals.

2. *Monitoring of fish passage past the barrage*.

- The Environment Agency to continue with the operation of the fish counters within the fish pass and the canoe course in order to assess the numbers of returning fish during years of variable river flows and conditions. In addition the Environment Agency to continue with hydro-acoustic monitoring to support any changes to barrage flow management.
- The deployment of appropriate technology to assess the numbers of fish moving upstream over the barrage gates. This could include side-scan sonar, DIDSON imaging sonar or a dedicated Passive Integrated Transponder (PIT) system on top of the barrage gates to detect PIT tagged fish.

- A monitoring programme to assess the downstream movements of salmon and sea trout smolts and kelts. The programme should provide temporal and spatial information on the movements of the fish in order to understand how barrage operation could assist escapement of these fish to the lower estuary and marine environments.

3. *Operational changes to the barrage*.

- Further investigations are required regarding the operation of the canoe course to assist upstream passage of salmon. Clearly, the restructured canoe course has the potential to operate as a suitable fish pass in itself and operation during the afternoon, flood tides and hours of darkness would permit returning fish to move rapidly from the lower estuary and into freshwater above the barrage.
- Returning adult salmon and sea trout move upstream by detecting and orientating towards the principal flow. During much of the tidal cycle the flow of water being discharged over Gate 1 attracted the fish away from the entrance to the fish pass and canoe course. Therefore, it is recommended that water is not discharged over the gate closest to the fish pass in order for returning fish to be able to detect the flows from the fish pass and the canoe course. The fish tracking study together with hydro-acoustic data collected by the Environment Agency demonstrated that the majority of fish that did move upstream did so over the gates, close to high water when they were able to literally jump from the lower estuary and into the impoundment. Except during a short period 1-2 hours either side of high water, the height difference between the estuary and impoundment was too great for the fish to negotiate the barrage by this route and the fish were delayed in the estuary. Therefore, it is recommended that water is constantly discharged during a 2 hour period either side of high water maintaining a jump of 50cm or less to allow fish approaching the barrage to move rapidly and continuously upstream.
- Previous studies have indicated that the barrage navigation lock can be a suitable means of moving fish from the estuary and into the impoundment. Further work is required to refine how the lock is operated to attract fish into the structure and permit their movement upstream. It is considered that the use of the navigation lock would be important in assisting fish passage during periods of low flows and poor water quality below the barrage.

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