Southern Water

Technical note on the effects of the Test drought permit on salmon in the River Itchen

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Project reference:	**P00011264**
Date of issue:	**July 2025**

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Revision and Amendment Register

Version Number	Date	Section(s)	Page(s)	Summary of Changes	Approved by
1.0	June 2024	All	All	First draft for client comment	NT
2.0	June 2025	All	All	Draft for client comment and circulation as draft to EA	PD, DB
2.1	July 9th 2025	All	All	Amended Draft for client comment and circulation as draft to EA	PD
2.2	July 15th 2025	All	All	Amended after EA comments	PD
2.3	July 16th 2025	All	All	Reviewed after EA comments	PD

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1. Introduction

An important issue for the River Test Drought Permit (DP) Habitat Regulations Assessment (HRA) is its potential impact on the Atlantic salmon (*Salmo salar*) feature of the River Itchen SAC. The River Meon, draining to the southeast shore of Southampton Water also has a salmon population but it is very small and lacks data suitable for assessment. It is noted here because the Rivers Itchen, Test and Meon are adjacent; their estuaries lying within Southampton Water and therefore have close salmon population connections which are discussed in this Technical Note with a focus on the Itchen and Test.

The DP potential environmental impacts within the Test Estuary and lower Test River could be felt by whatever component of the Itchen salmon run strays into the Zone of Influence (ZoI), coupled with impacts on Test-origin salmon that may deliver contributions to the Itchen production. Assessment of DP impact involves *inter alia*:

- Description of salmon stock status and trends in the two rivers;
- Descriptions and understanding of how salmon populations exchange between the two rivers and their relative interdependencies;
- Estimation of Itchen salmon straying rates into the ZoI that might, because of DP-related effects, be prevented from spawning or spawn less effectively on return to the Itchen;
- Estimation of Test salmon that might normally through straying contribute to spawning in the Itchen;
- Impact pathways and exposure risk resulting from the DP in the ZoI; and
- Estimation of consequences of DP-related impacts on the River Itchen SAC salmon population feature.

The points above are covered in this Technical Note based on evidence. The focus of is on those factors and processes that have the potential to cause *in situ* losses and sublethal effects within the ZoI and those that have the potential to cause migration delay, displacement and loss from the ZoI and the Test-Itchen system.

A relevant consideration is that a Test DP will operate when natural drought conditions already apply. In the summer months of peak salmon run, such low flow conditions are normally accompanied by high water temperatures, related poor water quality (WQ) and habitat deterioration, with attendant risks of disease, predation and poaching which will exert impacts on salmon. Thus, the relevant assessment is of the additional potential risk posed by DP-related environmental changes above those expected in natural droughts.

A background to the River Test DP HRA is a major reduction in the abundance of salmon in most regions of the North Atlantic over the last 40 years that has been attributed to a combination of factors. Some are local, due to human activities within rivers and estuaries and coastal waters; but a common factor is the influence of climate change altering salmon habitats and survival at sea and in freshwater through changing flow and temperature regimes (NASCO, 2020; Olmos et al 2019; Thorstad et al 2021; Sundt-Hansen and Hatfield, 2023) although the governing processes are complex, not fully described and variable across domains and in some cases contested (Dadswell et al 2022; Tyldesley et al 2024).

1.1 Zone of Influence

Details of the DP Zone of Influence (ZoI) physical features are given in the HRA. The principal geography and zonation are shown in Figure 1-1 and Figure 1-2. This is the habitat template on which potential DP impacts would be played out and crucial questions are: how are the fish hazards (environmental and other pressures) as affected by the DP distributed through the ZoI?; and how are the fish distributed within the ZoI and thus exposed to these hazards? The spatial organisation of environmental risk and fish guides this evaluation of the DP impacts.

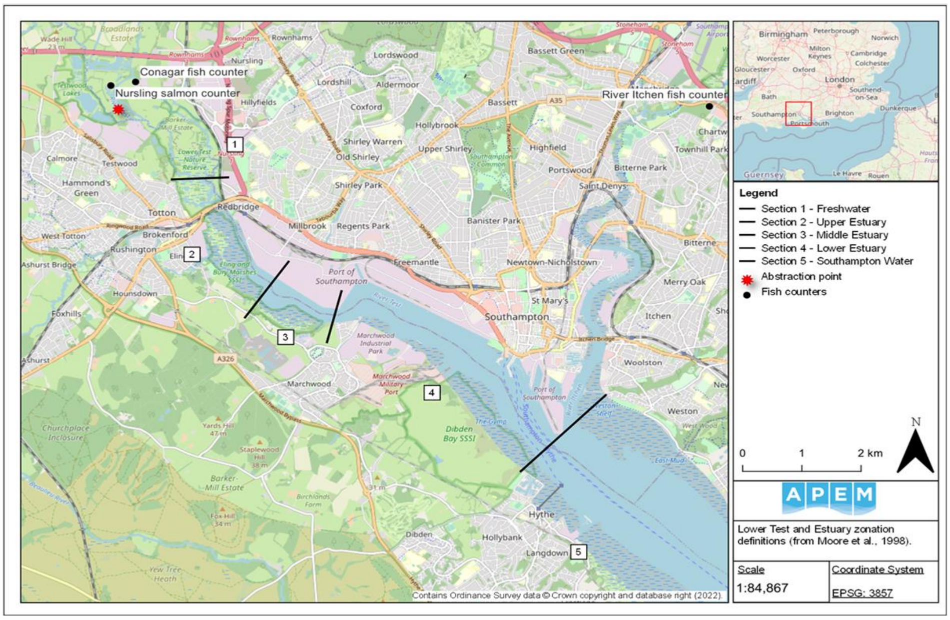

Figure 1-1 Map of the ZoI (adapted from Moore *et al*., 1998) showing four main zones, which exclude the Itchen estuary and the main body of Southampton Water.

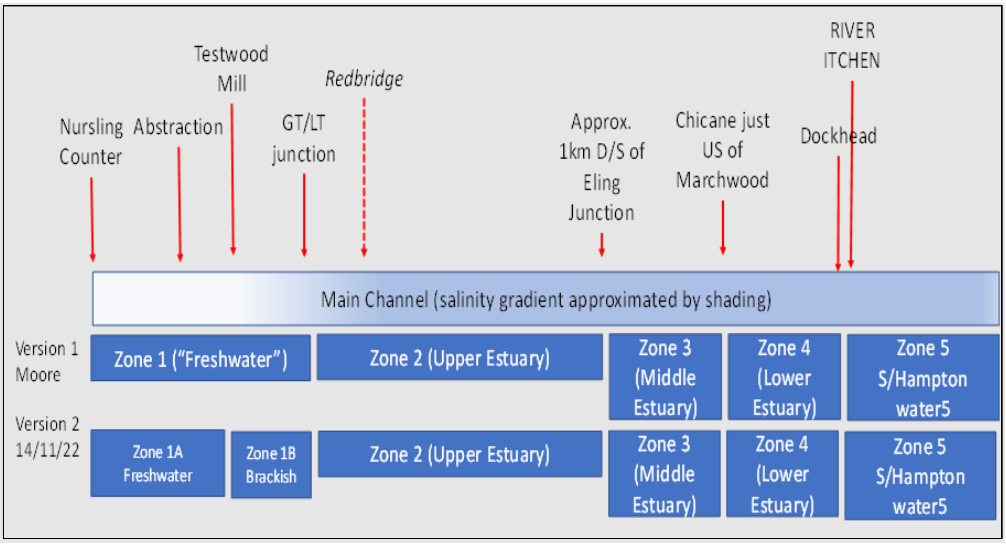

Figure 1-2 Diagrammatic representation of the ZoI, showing principal geographical locations and zones referred to in the text (not to scale).

2. Salmon populations in the Itchen and the Test

2.1 Stock status

This section describes the baseline condition of salmon in the River Itchen and River Test relevant to the Scheme. The Meon is not evaluated because of limited information. The Meon Valley Partnership (https://meonvalleypartnership.org.uk) has noted that "Sea trout and occasionally one or two salmon come into the river from the sea to spawn". There may be a few more than that and juvenile salmons are recorded by electrofishing (King and Stevens, 2021) but no adult data are available. This description draws on data provided by the Environment Agency (EA), some of which contributes to assessments of stocks by the Working Group on North Atlantic Salmon (WGNAS) on behalf of The North Atlantic Salmon Conservation Organisation (NASCO). The national assessments inform negotiations on catch levels in high seas fisheries (currently regulated to very low levels) and conservation management in member countries. Assessments are made at key stages in the adult salmon life at sea and some terms are relevant to this Technical Note. *Pre-fishery abundance* (PFA) is the estimated abundance a 1st January in their first winter at sea (after about 7 months post-smolt life). *Returning Stock Estimate* (RSE) is the abundance estimated prior to coastal home-water fisheries (no-longer in existence in England since 2019, and already much reduced from former times by then). *Spawners* are the salmon that make it through to spawner after loss from natural mortality and post release mortality of angler caught and released fish.

Salmon remain at sea until they mature at different ages, prompting their return. Thus one-sea winter fish mature in their first year at sea and return to rivers as 1SW fish (=maturing salmon on the first 1st Jan after they smolt), mainly over summer months. Others return after two (2SW) or more sea winters, collectively called multi-sea-winter (MSW) salmon (=non-maturing salmon on 1st Jan) and they include the large spring fish much valued by anglers. PFA, RSE and spawners are variously partitioned into 1SW, MSW or expressed as total according to purpose (details in ICES 2025 and references therein).

Atlantic salmon were reassessed in 2023 for the IUCN Red List of Threatened Species (Darwell and Noble, 2023) and reclassified from 'Least Concern' to 'Endangered' in Great Britain (as a result of a 30-50% decline in British populations since 2006 and 50-80% projected between 2010-2025), and from 'Least Concern' to 'Near Threatened' in terms of global populations as a result of global population declines of 23% since 2006.

Catches in salmon rod and net fisheries in England and Wales have been collated with varying degrees of accuracy since 1951 (Russell et al, 1995). Stock data, that is metrics that describe stock status have been assessed since 1994 and reported annually since 1997, jointly by the Centre for Environment, Fisheries and Aquaculture Science (Cefas), the EA in England, and Natural Resources Wales (NRW) for Wales (Cefas, EA/NRW, 2024a). These stock assessments inform baseline conditions in the River Itchen SAC and in the River Test and supported by further information provided by the EA. The data comprising variously of rod catches, counter data (from Nursling on the Test and Gators Mill on the Itchen) and Returning Stock Estimates (RSEs) are used to derive annual egg depositions, using various adjustments. This account focuses on adult returns because they are the population component that would potentially be directly affected by any DP-related impacts. The number of salmon entering a river each year is defined as the RSE. Juvenile abundance estimates from electrofishing programmes are also relevant but are less precise and have a complex and comparatively indirect relationship with DP effects on adults.

Annual total egg deposition is the principal metric used nationally and internationally to describe the status of salmon stocks under the Precautionary Approach (NASCO, 1998). Within England and Wales, Conservation Limits (CL) are set for each of the 64 Principal Salmon Rivers according to a nationally agreed protocol (NASCO, 1998; Cefas / EA / NRW, 2024b). The CL is a Biological Reference Point (BRP) that defines a lower threshold of total annual egg deposition in the river above which a stock is judged to be self-sustaining with an acceptable margin of safety and is equivalent to the Maximum Sustainable Yield (MSY) (Potter *et al*., 2003). The EA protocol also describes how egg depositions are calculated each year from rod licence catch returns (usually, but on a few rivers fishery owners' returns are used and on others counter or trap-based run estimates are used instead of catches).

In association with the CL, each river has a Management Objective (MO) that seeks to ensure that the stock is above the CL in 4 years out of 5 (i.e. at least 80% of the time on average), based on the previous 10 years' performance (Cefas / EA / NRW, 2023). Further, a statistical compliance procedure (introduced in 2004) derives a probabilistic statement of the chance that the river is meeting its MO (i.e. only a 20% chance that the median population is less than CL) in (1) the year of assessment and (2) its projected compliance in 5 years' time, based on a linear regression of the last ten years' trend (Cefas / EA / NRW, 2024b). The categories of compliance are shown in Table 2-1.

Table 2-1 Categories of annual salmon compliance.

Compliance category	Probability of not meeting MO
Not at Risk (NaR)	< 5%
Probably Not at Risk (PNaR)	5 – 50%
Probably at Risk (PaR)	50 – 95%
At Risk (AR)	> 95%

In 2022 the Itchen stock was at its lowest compliance (22%) since CL assessment began. The most recent published assessment (for 2023) classified both river stocks as *At Risk* (of failing to meet their Management Objectives) in 2023 and projected to be *At Risk* in both the Test and Itchen, respectively, in 2028. In 2023, stocks were at 43% and 42% of the CL in the Test and Itchen, respectively (Cefas / EA / NRW, 2024a). Unpublished provisional statistics for 2024 give the Test at 48% and Itchen at 37% of CL, with both stocks remaining *At Risk*.

The CL process has sources of error in the derivation of the Conservation Limit Reference Point and in the annual assessment. For example, salmon abundance and egg deposition are subject to annual variation, therefore the use of a linear regression based a period in which annual variance and fluctuations are substantial may not be the most appropriate for projection because it oversimplifies future trends which may not change at constant proportional rate. These shortcomings and uncertainties in the assessment are recognised by the EA and the CL procedure is currently under review by the EA, Cefas and NRW and refinements are in hand (Gregory et al. 2023)

In assessment it is important to identify the long-term trends and fluctuations in stock status, because these signals can point to factors affecting stock estimates. Egg deposition data from the annual assessment reports (Cefas / EA / NRW, 2024a) show the trend of the salmon in the Test and Itchen (Figure 2-1), illustrating increases in both rivers over the period 1990 to around 2015, followed by reducing deposition (Figure 2-1). Comparisons are more easily shown with standardised data. Standardised annual eggs (z-scores) were calculated as follows:

$$z = (x - \mu) / \sigma$$

Where ***z*** = z-score, ***x*** = the annual egg deposition (millions), ***μ*** = the population mean, and ***σ*** = the population standard deviation.

Standardised data show more clearly that over the long-term the rivers tracked each other in most years, with minor fluctuations and between-river differences that may indicate river-specific factors or sampling errors (Figure 2-1), which cannot be distinguished with these data.

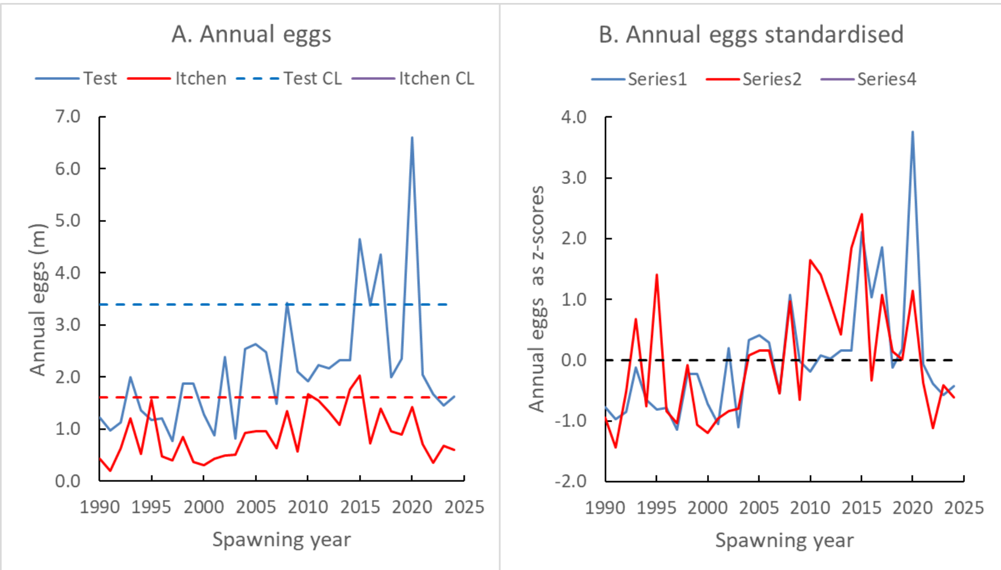

Figure 2-1 (A) Long-term trends (1990 to 2024) in salmon egg deposition (millions) in the Test and Itchen with respective CLs shown by dashed lines. (B) Standardised values (as z-scores) that allow direct comparison of the trends and fluctuations, the dashed line is the period mean

The increases in total egg depositions from late 1990s have been partly attributed to the onset of catch and release between 1996 and 2003 in the Test and Itchen. Total stock indices such as egg deposition hide a more complex and informative pattern of differential changes in salmon of different sea ages (1SW, 2SW etc). In the Test, Itchen and other chalk rivers 1SW stock increase from 2000 followed by decline since 2015 contrasts with a more common pattern across English and Welsh rain-fed rivers of an earlier onset of decline around 2010. 2SW salmon showed a similar temporal pattern with wider fluctuations. Both sea ages have reduced sharply in the last 10 years, with the total runs and egg deposition driven by the 1SW group change. Test and Itchen populations are dominated by 1SW salmon, but this proportion has reduced from around 80-90% of RSE in 1990s to about 40-60% in the last few years (Appendix Figure 1; Appendix Figure 2).

Records show a long-term decline in total rod catches since 1954 (Appendix Figure 2), especially on the Test. The comparative stability in Itchen catch over the period is hard to explain; it may be genuine (which would be surprising if the Test ad Itchen stocks are performing similarly) or could reflect some recording artefact. Both rivers experienced a brief catch upturn between 2000 and 2015 before the recent decline to very low levels, following stock changes.

The reduction in total salmon numbers has been accompanied by a reduction in post-smolt survival rates of between x3 and x5 since 1980 estimated by life cycle modelling (ICES 2025) (Appendix Figure 3), which explains much of the RSE decline over the period. However, the timings are not fully synchronous which points to more complex processes acting throughout the life cycle including freshwater production. This emphasises the importance of robust assessment based on life cycle models (Mangel and Satherthwaite, 2008; Massiot-Granier et al, 2014; Bull et al, 2023). Marine return rates directly measured by recaptures of tagged smolts on index rivers are more variable. The nearest Index River to is the Frome (also an aquifer-fed chalk river) which is currently recording return rates of around 1% and 3% for 1SW and 2SW salmon respectively (Cefas / EA / NRW, 2024).

While there are common salmon stock trends amongst most English and Welsh rivers, due to broad scale climate drivers (Olmos at al, 2019) there are also trend and status variations that reflect a hierarchy of factors acting at oceanic, regional or finer scale, down to individual rivers. Therefore, it is important to review any river against the performance of others at relevant scale. A more detailed review is in progress for Southern Water (SWS).

Comparison with Southwest and Southern EA Region rivers suggests that, while stocks on all rivers are low, the Test and Itchen have performed similarly and at about average across all the rivers over the last 10 years (Figure **2**-**2**). The wide between-river variation in median %CL compliance suggests a need for caution in over-interpreting such variation in a ratio (deposited eggs / CL). It is possible that they represent real differences in stock performance; but it is also possible, given the difficulty and uncertainty in deriving CLs, that that some proportion of the variation is simply due to errors in CL estimates. In comparison with neighbouring chalk rivers for which there are suitable data, time trends in the Test and Itchen were most like the Hampshire Avon, but those three were at poorer condition than the Frome (Figure 2-3).

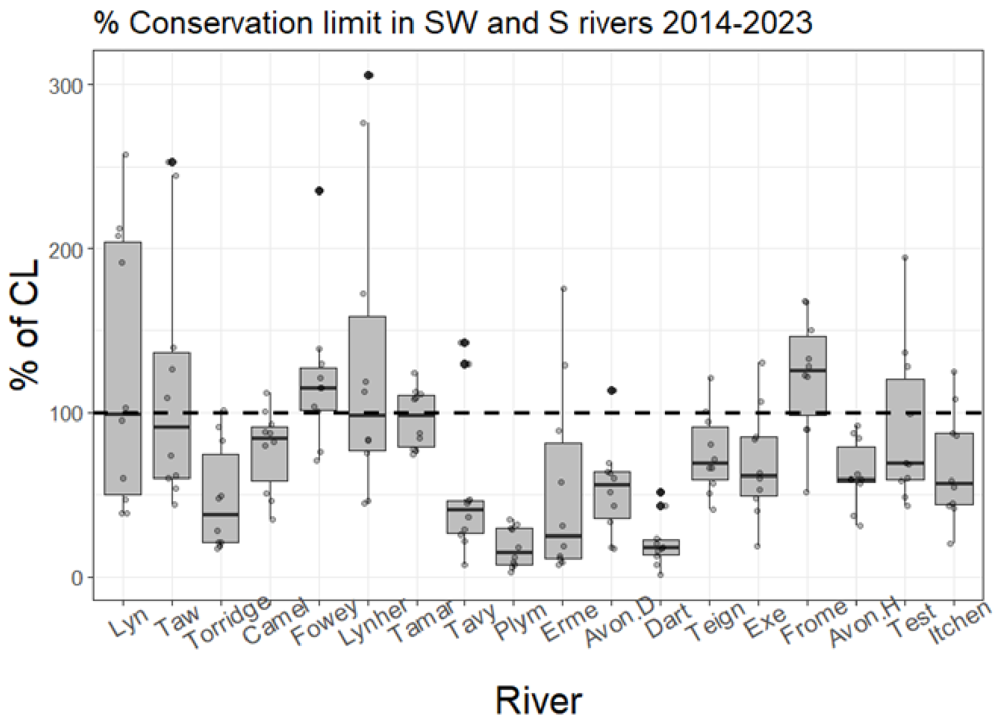

Figure 2-2 **Boxplots of ten-year (2014 - 2023) variation in CL compliance for SW and S EA regions rivers, ordered west to east, showing median (horizontal line) quartiles and outliers. Dashed line is 100% of CL, Data from Cefas / EA / NRW (2024).**

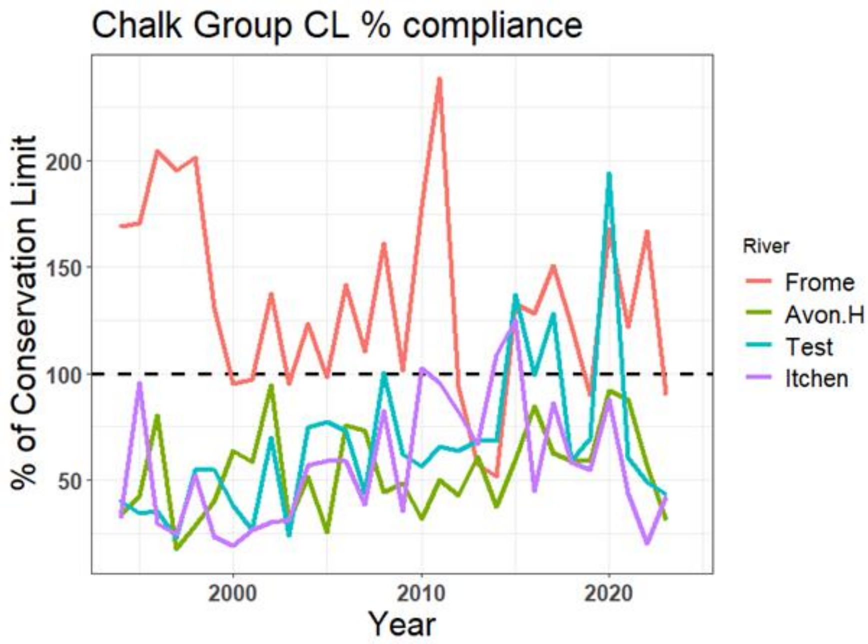

Figure 2-3 Time series (1994 - 2023) of egg depositions as % of river conservation limit for Test, Itchen, Hampshire Avon and Frome. Dashed line is 100% of CL. Data from Cefas / EA / NRW (2024).

The significant correlation (r = 0.59, p<0.05, df = 33) between the Test and Itchen time series in egg deposition contrasts with lower correlations with neighbouring chalk rivers although the Test and Avon are also correlated (Figure 2-4) and illustrates the association between them. The data were not adjusted for autocorrelation (which was low in the Test for example) but are indicative of the relative associations between the time series. The correlation does not demonstrate a functional link, but it is probable that the proximity of the rivers their, common unique habitats, common evolutionary origin and selection pressures of the populations (see Section 3.4) mean that they are likely to show similar trends. notwithstanding transient river-specific factors described above.

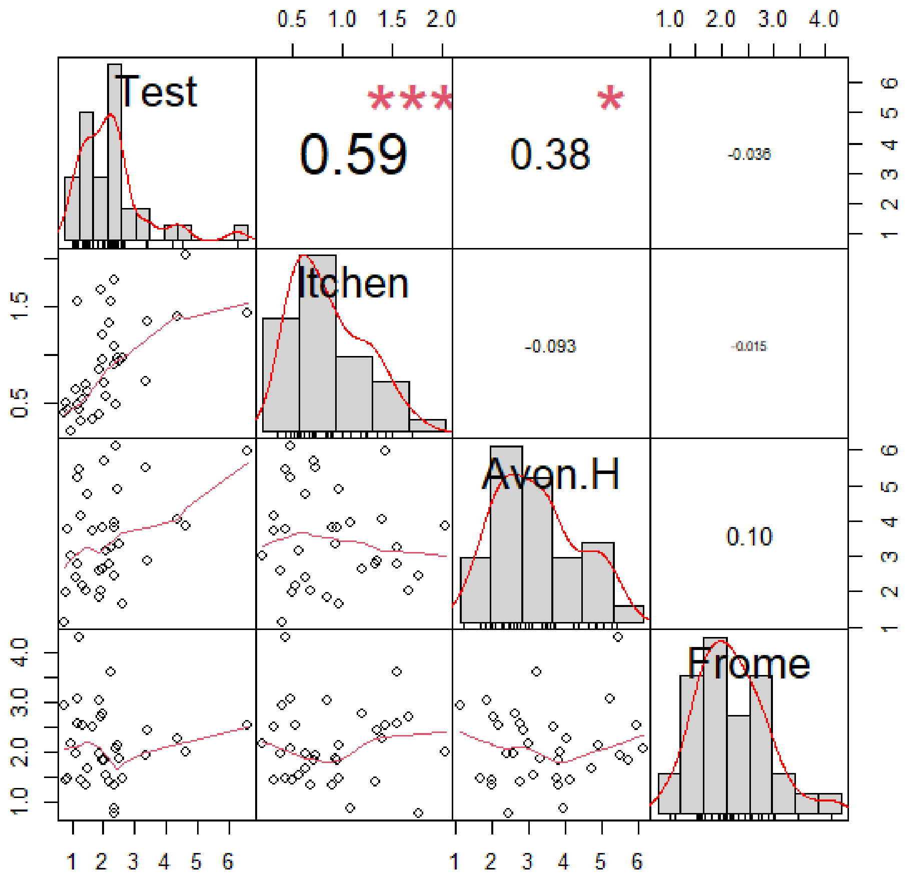

Figure 2-4 Pearson correlation coefficients (*r*) and plots, with smoothers between annual (1990 - 2024) egg deposition in four chalk rivers. Data not adjusted for autocorrelation. The frequency distributions of egg depositions (millions) are on the diagonal, with x and y axes labelled with deposition values. r values and significance (* <0.001, ** <0.05) between river pairs are shown above the diagonal and smoothed bivariate plots below.**

2.2 Overview of factors affecting salmon stocks

Many factors affect salmon stocks throughout their life cycle in freshwater and at sea (NASCO, 2024; Thorstad et al 2021). Changes in the marine ecosystem affecting salmon growth, maturation and survival are thought to be important factors behind trends in almost all stocks (Chaput, 2012; Olmos et al 2019). Anthropogenic factors and broad scale climate-driven pressures also act in freshwater, through unfavourable flow and temperature regimes, changing land use and aquatic habitats, biodiversity and ecosystem function (Russell et al 2012; NASCO, 2023). The Cefas / EA / NRW 2021 assessment report noted the effect of a widespread juvenile recruitment crash in 2016, attributed by Gregory et al (2020) to high spawning temperatures in 2015 and higher flood frequencies during emergence in 2016, which is thought to have had knock-on effects in smolt output (Cefas / EA / NRW, 2021). In the cases of the Itchen and Test (having a mixture of 1SW and MSW returners and mainly 1 year-old smolts) this means that effects on returning adults would have been expected in 2018 and 2019 (other factors being equal) and RSE dips in those years may be due to that event (Figure 2-1). In addition, many anthropogenic factors affect salmon including flow regimes modified by abstraction and river regulation, invasive species, habitat loss, diffuse and point source pollution and sedimentation. An example of combined impacts may be evident in the trend of reducing juvenile salmon on the River Test during 2010 to 2016, a period of increasing egg deposition (Longley, 2018). Some factors must have caused this loss of recruitment, reflecting reduced egg to parr survival, but the data are few and may be insufficient to explore links between adult and juvenile abundance. It is notable that Southern Water's abstraction regime on the River Itchen and within the River Itchen catchment has not significantly changed since 1990 over a period of substantial long-term increase to 2015 and more recent decline (Figure 2-1) with short-term fluctuations in RSE. This does not demonstrate that total river flow has no influence on RSE, but there has been no detectable link with historic abstraction.

Salmon fishing by anglers is mostly contained as a problem because 100% catch and release operates on both rivers, although rod fishing exploitation rates (the proportion of the run that is caught by anglers) are exceptionally high on these rivers, particularly the Itchen: the mean rates (1990-2021) were 27% (range 12 - 52%) and 47% (range 21 - 88%) in the Test and Itchen respectively. These are the highest rod exploitation rates reported for rivers in England and Wales. Currently the EA assume that mortality of released rod caught salmon is 20% and the impact on RSE has been assessed as "minor" (Longley, 2018). However, this likely underestimates the rod fishing impact because significant additional effects of stress-induced reduced spawning effectiveness of survivors have recently been shown to result from catch and release (Bouchard et al 2022). Due to the high exploitation rates, this is a potentially important contributory pressure in the Test and Itchen. Some respite for salmon could be offered by anglers ceasing to fish at elevated water temperatures. Poaching is a reported problem in the lower Test and upper Test Estuary. Predation on resident juveniles and smolts by birds and on adults by mammals is not quantified on the Test but is commonly regarded as important and figures highly in national ranking of pressures on salmon in England (NASCO 2025). Marine illegal fishing and bycatch on other fisheries in coastal and high seas waters is also regarded as potentially important (Dadswell et al 2022), although not yet quantified they are subject to current urgent research.

Disturbance and impaired migration can arise through high sound levels from shipping, port maintenance and construction (Nedwell, 2001; Gilson et al 2022). Southampton Water is a busy commercial and recreational port and shipping movements give an index of potential disturbance to migrating adult salmon that is increasing (Figure 2-5, inset). There is a range of industrial and domestic contaminant inputs to the estuary such as thermal effluent, combined sewage outfalls (CSOs) and sewage treatment works.

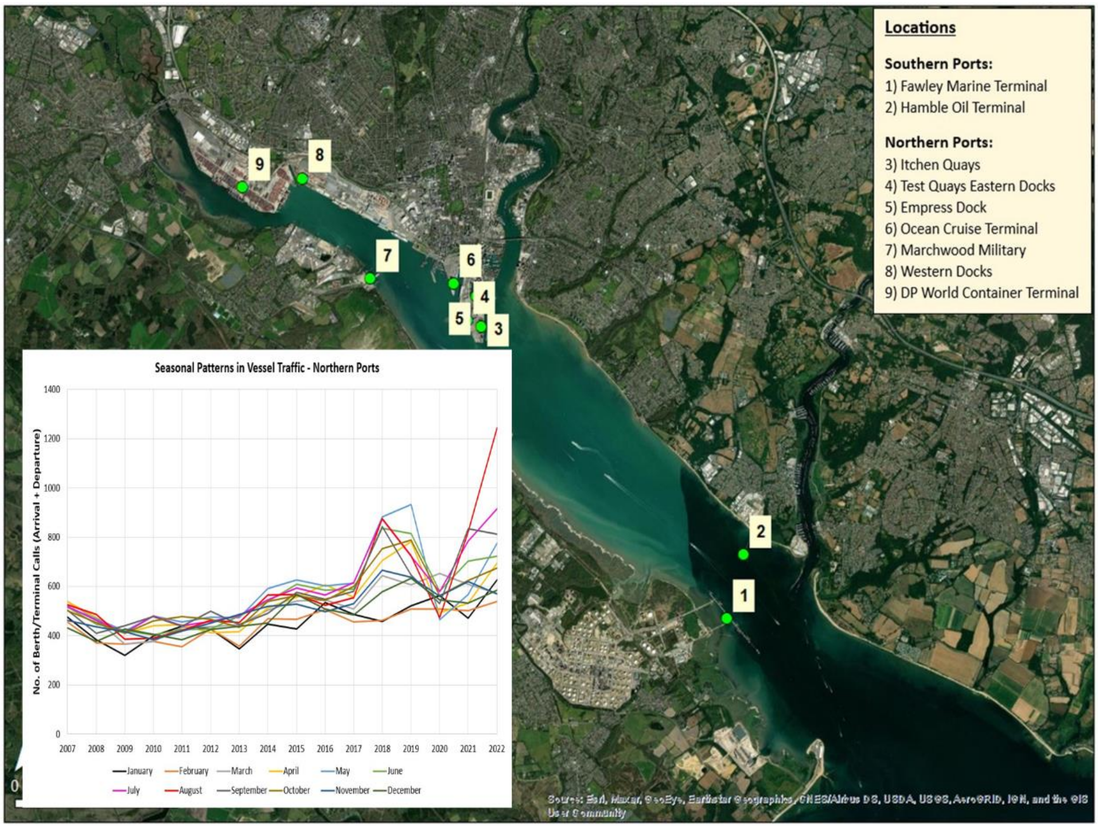

Figure 2-5 Trends in monthly shipping traffic at ports within Southampton Water. Source: To be confirmed.

High water temperature, high biological oxygen demand (BOD) and ammonia concentrations (that depending on duration would be harmful to salmon and would lead to avoidance), displacement and delay, have recently been demonstrated in the Itchen and attributed to the Portswood Sewage Treatment Works (STW) (Longley, 2024). At critical times these conditions could present temporary barriers to salmon entering the river and could exacerbate the effects of deleterious environments (high temperature and low DO) when they occur during droughts.

3. Salmon return migration through estuaries, river entry and holding

3.1 General principles

Salmon returning from sea feeding grounds generally home with considerable accuracy to their natal rivers to spawn. The mechanisms of their navigation and orientation change as they move from ocean to coastal waters, into estuaries and finally into and up rivers. The details are not fully understood, but oceanic migration appears to involve navigation by orientation to earth magnetic fields, but closer to home they adopt olfaction to detect chemical signals from their natal rivers. These are thought to be homing cues (pheromonal (kin recognition) and/or geochemical) imprinted in juveniles prior to and during smolting.

Numerous reviews on this subject are available (e.g. see Hasler and Scholz, 1983; Hansen et al 1993; Thorstad et al 2011; Keefer and Caudill, 2014). Estuarine passage and river entry are the most relevant phases for the River Test DP HRA and the consensus is that fish initially orientate to their estuary through general freshwater discharge and as they get closer home switch to the imprinted responses to the river-specific cues. Behaviourally, as they near their estuary, they tend to swim closer to the surface, possibly to better detect freshwater signals in the stratified upper layer. Davidsen et al (2013) reported that mean swimming depth in a Norwegian Fjord reduced from 2.5m to 0.5m and that in the estuary salmon slowed down, before increasing speed again once in freshwater. Although such habitat is different from Southampton water, but the general searching principles are likely to apply.

Numerous behavioural variations reflect location-specific variations probably influenced by local topography, hydrography of the estuaries, prevailing conditions and season (Milner et al 2012). The diversity may have a genetic basis through adaptation to specific estuarine conditions (Jonsson *et al*., 2007), but in the absence of any reported observations for the Test / Itchen / Southampton Water, there are some general patterns that are likely to apply. These involve an interaction between (i) the fish physiological state (e.g. maturation state and adaption to moving from hypertonic sea water to hypotonic freshwater) and (ii) the potential to move without obstruction into freshwater.

Active tracking has demonstrated that within estuaries a typical pattern applies of tidal transport, moving up and down on flood and ebb flows (Potter, 1988; Priede et al 1988), with flood ground speeds often only slightly faster than tidal velocities, which could be interpreted as searching behaviours. Intermittent holding occurs on flood and ebb flow, reportedly more on the ebb and at low water, akin to selective tidal stream transport tending to move fish upstream. Individuals that move into freshwater on a particular flood tide have been reported to swim faster than those which continue to vacillate (Potter, 1988). The discrete phase of river entry is influenced more by freshwater discharge in small rivers (Jonnson et al 2007) than in large ones and shows considerable variation according to river/estuary boundary conditions, season, environmental conditions, age, size and maturation state of the fish (see reviews: Banks, 1969; Thorstad et al 2011; Milner et al 2012).

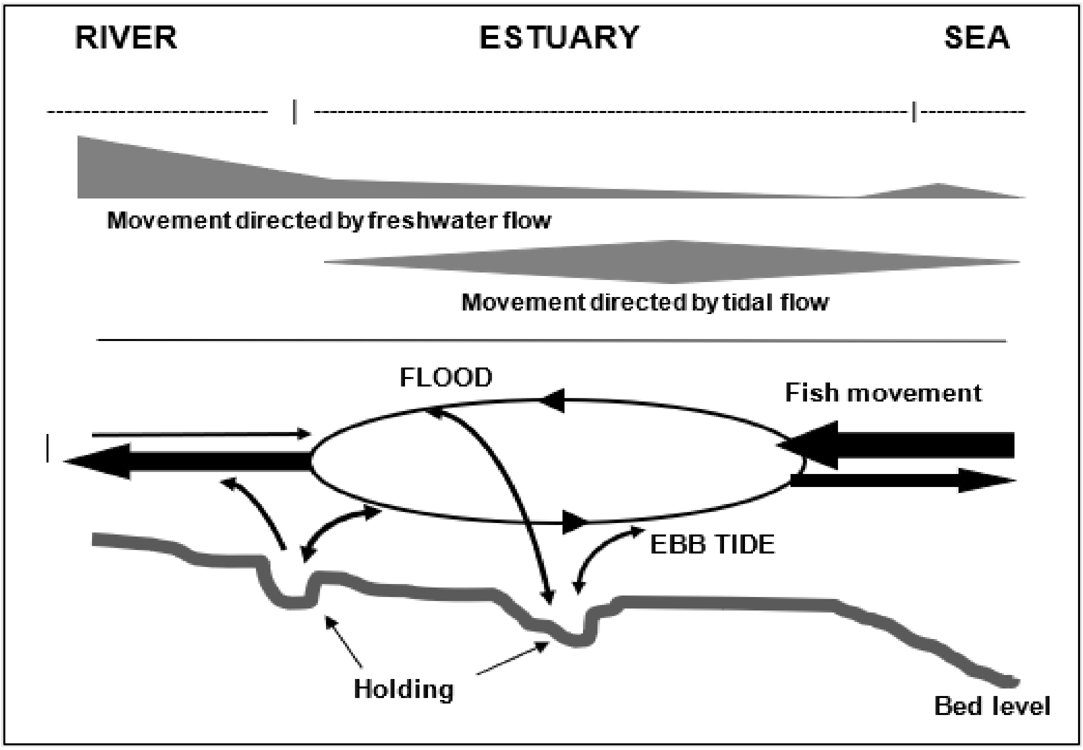

Figure 3-1 Diagrammatic representation of salmon movement through an estuary in relation to tide cycle and position in estuary. Horizontal arrows represent direction and intensity of movement. Fish may hold up in in deeper parts if available and river flow has a progressively important attraction as the tidal limit is approached. From Milner et al. (2012).

Salmon moving to the upper estuary on a flood tide can pass immediately into freshwater, if river flows and their preconditioning permit, where they may hold in secure locations for long periods (weeks to months) before further upstream passage. However, if the fish are not predisposed or flows are not suitable for entry then holding in the estuary often occurs, sometimes with displacement back to coastal waters, that may be followed by approaches to other rivers. Holding durations vary from hours to weeks depending on season, discharge, estuary size, topography and safety (from predators, poor water quality and currents) of holding locations. probably also influenced by the prior migratory history of tagged fish and their migratory intentions. Salmon can delay for long periods in lower estuarine reaches. Solomon and Potter (1988) reported that in the River Fowey estuary some salmon held up in deep water (>10m at low water) in the lower estuary near dock areas. Otherwise, salmon typically made long distance (5+ km) tidal excursions and avoided holding in the shallow upper estuary. In an extension of that study, Potter (1998), confirmed the predominance of tidally-directed movements in the upper and middle estuary. He reported that low flows delayed the migration of salmon which subsequently waited in the lower estuary - an observation described for other rivers by Solomon and Sambrook (2004), which in more extreme cases involved complete loss from the estuary, sometimes permanently in times of drought. Clarke *et al*. (1991) reported that, at times of low flow, tracked salmon delayed entry into the River Tywi, South Wales, by many weeks, and that probability of eventual entry was greatly reduced, suggesting that this was due to increased exposure to netting. They also found that salmon moved more slowly from estuaries into the river at times of low river flows.

Priede et al (1988) found that salmon on the River Ribble, a shallow estuary characterised at the time by an extensive low DO sag due to sewage discharge, made extensive (10kms) upstream and downstream tidal excursions. They reported that 75% of tagged salmon left the estuary, which they interpreted as evidence that 75% of the fish they had tagged being from other rivers making exploratory straying movements and rapid ebb-tide retreat if the freshwater cues did not match their natal river. Their oxygen tags showed that salmon avoided DO < 5.5 mgl^{-1}. Like the observations of Potter (1988) and Solomon and Sambrook (2004) they found that in summer drought conditions fish did not enter the river, behaviour attributed to low flows; or, as Solomon and Sambrook proposed, in response to co-correlated factors, mainly high temperature and low DO that act as a barrier deterring salmon. Solomon *et al.* (1999) found that on the Hampshire Avon, salmon tagged at low flows that did not enter the river within 10 days of tagging spent 3 to 4 months in the harbour area or moved out to sea. Some returned, but up to 50% of tagged fish did not return to the river. The problem was more prevalent on the River Stour (having a shared estuary with the Avon) which is more prone to low flows than the Avon, due to relative base flow effects. Deep water holding sites can offer saltwater sumps that may consequently be exposed to low DO. Solomon and Sambrook (2004) noted such a sump in the Stour estuary, where DO of 2.4 mgl^{-1} was reported, but they noted that salmon made vertical movements to the higher oxygenated surface water and no mortalities were attributed to that cause there.

In contrast, the Tamar Estuary appears to offer particularly challenging conditions for holding salmon at times of drought and substantial estuarine mortalities have been reported in drought years (1975, 1976, 1983, 1984 and 1989). The mechanism in those cases appeared to be high BOD / chemical oxygen demand (COD) of sediments resuspended by big spring tides coincident with low river flows, leading to mortalities when the salmon are unable to avoid these rapidly deteriorating conditions. Longley (2022) considers that "*The acute upper estuary water quality pressures on salmon described in this document closely reflect experiences of EA colleagues regarding serious salmon mortalities on the River Tamar over several years*" at Redbridge and in 2022 critical temperature and DO conditions were reported (Longley, 2022), but without reported salmon mortalities. Such a process may apply in the Test, but so far there is no clear evidence that the Test salmon risk is the same as presented by the Tamar, a spate river, which Solomon and Sambrook noted was quite different from the other rivers they examined in terms of salmon behaviour in response to flow at the tidal limit.

Summary

1) Salmon passage from sea through estuaries and river entry is a key and sensitive transition.
2) Behaviours and movements are river- specific. River entry is positively influenced by freshwater discharge, with a general pattern under normal flow ranges of tidally directed movement, vacillation and holding thought to be determined by fish internal state.
3) Behaviour changes under conditions of low flow and high temperature which deter estuary and river entry of all salmon (those homing to natal river and exploratory strayers) which can lead to loss of spawners by permanent displacement from the system, or reduced breeding effectiveness of survivors.

3.2 Application to the Test and Itchen

3.2.1 Holding in the Test ZoI

Environmental conditions in the lower River Test are generally good for holding adult salmon and are well-described in Atkins (2013) and Solomon (2005). Holding locations are deeper, shaded, often with surface turbulence and instream shelter offering thermal and predation refuges. The Great Test freshwater reaches (Zone 1A) and the upper part of the tidally influenced section above the Little Test confluence (Zone 1B) are believed to be the major holding areas downstream of the Nursling counter and a large proportion of the run of salmon into the Test is believed to spend much of the summer around the tidal limit of the River at Testwood Mill, congregating and staying there until autumn flows stimulate further upstream passage (Solomon, 2005, and anecdotal information from river keepers, see Figure 3-2). Others will hold elsewhere but the locations are uncertain.

There will be other holding locations in the lower parts of Zone 1B and in Zones 2, 3 and 4, but these are not well-described. Moving downstream these sections are increasingly tidally influenced and in Zone 2 particularly, and upper end of 3, are highly dynamic, with varying depth and salinity and mostly shallow tidally exposed sections, which in warm weather droughts offer a high likelihood of high temperatures and low DO that, based on reported tracking studies, salmon would tend to avoid (see Section 3.1). Fish moving to the optimal holding areas must pass through these zones, obviously, and some may hold for short periods, but they are unlikely to be important holding areas. Further downstream again, Zone 4 and much of 3 lies in modified port channels with deeper water and is probably environmentally safer than Zones 2 and top of 3, although holding there may be comprised by disturbance from port maintenance and shipping activities. Zone 4 and lower part of Zone 3 will be less influenced by any DP-related effects through dilution of river flow by tidal volume. On the Itchen Woodmill Pool is a well-known holding location. However, the upper Itchen estuary channel is narrow and tidally influenced and may be less likely to offer long-term major holding opportunity, although there are doubtless holding opportunities within the lower estuary. Inferences can be drawn from observed salmon behaviour in shallow tidal channels elsewhere, but In both rivers, with a few exceptions, there is no direct evidence on where salmon hold in the estuaries and fish location is a major knowledge gap.

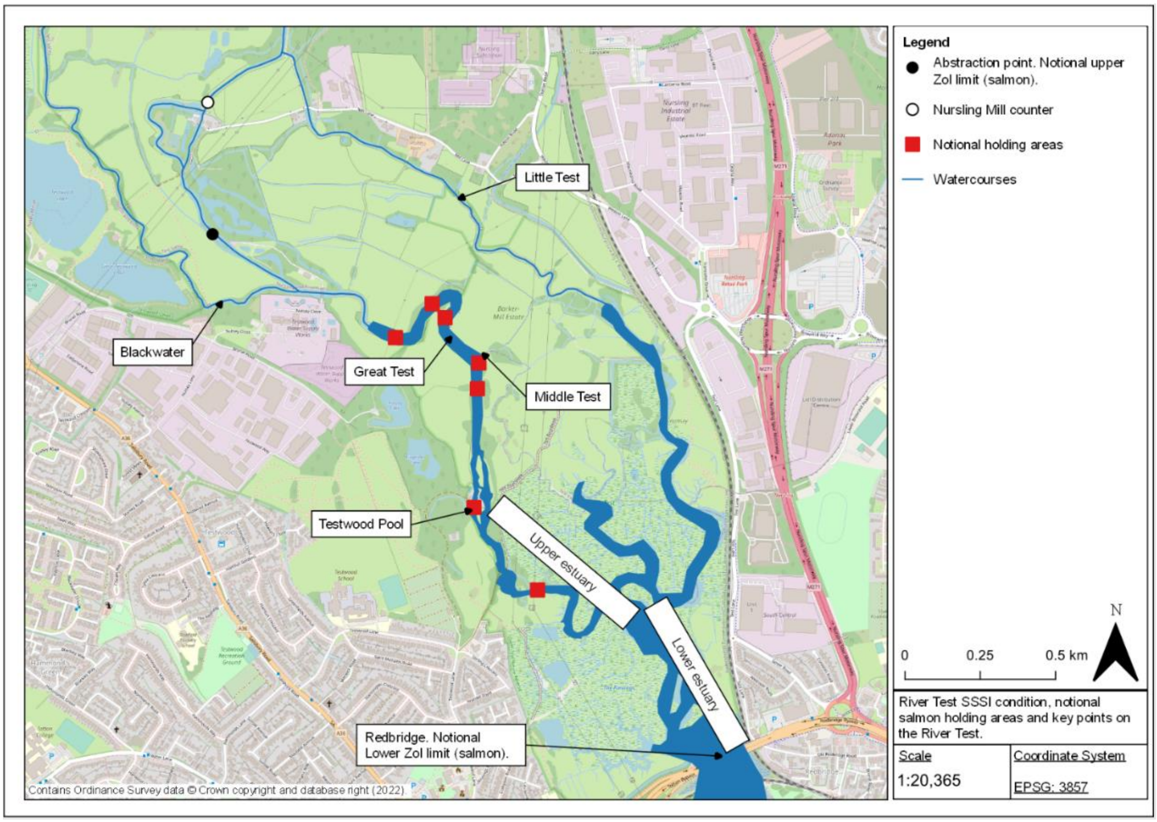

Figure 3-2 Known salmon holding areas as indicated by Little River Management Fishery.

3.2.2 Timing of salmon presence in the Test ZoI

Counter studies (mainly from Great Test counts at Nursling) have demonstrated the bimodal migration pattern in the lower freshwater Test, typical of southern chalk rivers, in which a proportion of early arriving salmon (mainly MSW fish in May to June) move over the counter and continue upstream. However, many early arrivals and most later summer entrants are believed to hold up in deep water holding sites in the lower Test (Figure 3-2), Zones 1A and 1B, such as in Testwood Pool, until further upstream movement is resumed normally in October and November as rains stimulate the fast flow component of the hydrograph to which salmon appear responsive (more so than changes in base flow). There may be holding areas elsewhere, but no information is available. This is also a time when salmon appear to become more sensitised to flow due to physiological and behavioural changes accompanying maturation (Thorstad et al 2008).

Movements over the Nursling counter do not reflect timing of arrivals from sea for most salmon because most fish holding in the lower river or estuary do not move over the counter until the Autumn. The seasonal presence and abundance of salmon in different parts of the ZoI has not been directly studied and is a key knowledge gap, but arrivals in the angled sections of Zones 1A and 1B (i.e. areas from which salmon later move upstream over Nursling counter) have been inferred from angler catches in the vicinity of Testwood Mill analysed in Atkins (2013) and latterly by John Lawson in various reports to the Salmon Working Group (SWG, 2015) on behalf of the Hampshire and Isle of Wight Water Resources Steering Group.

The catch data were complemented by limited recording of sea lice. These external parasites of salmon at sea are lost after about 3 days in freshwater, so their presence infers fish freshly arrived from saltwater.

In addition, arrivals in the Test "estuary" have been equated with the timing of Mudeford net catches at the entrance to the River Avon's Christchurch Harbour which represent arrivals from open coastal water into the outer estuary of the River Avon (Solomon *et al*., 1999) (Figure 3-3).

From the net data (NB when it operated, the net season began in May) and the cumulative rod catches (Figure 3-4) it is likely that "entry" to the upper estuary (say for example, at the Eling/Test confluence, Figure 1-2) can begin in March, peaks probably during July to September (earlier for MSW fish) and is mostly over by the end of October. Lawson considered that salmon entry to the Test (presumed to mean Zone 1A mostly, with some in 1B) was over by the middle of August.

The timing pattern will vary somewhat each year, depending on prevailing flows and marine factors. Further variation arises because salmon runs comprise different sea ages having different run timings: MSW fish tend to arrive earlier in the season than 1SW, and sea ages shift over time, possibly through changes at sea (Section 2.1). In the southern part of the North-East Atlantic Commission (NEAC) there has been an increase in MSW from 2000 to 2015, tending to bring forward average arrival time, and some reduction since, tending to set back average arrival time (NASCO, CNL(24)06), in addition to the potential for shifts in return timing within sea age groups.

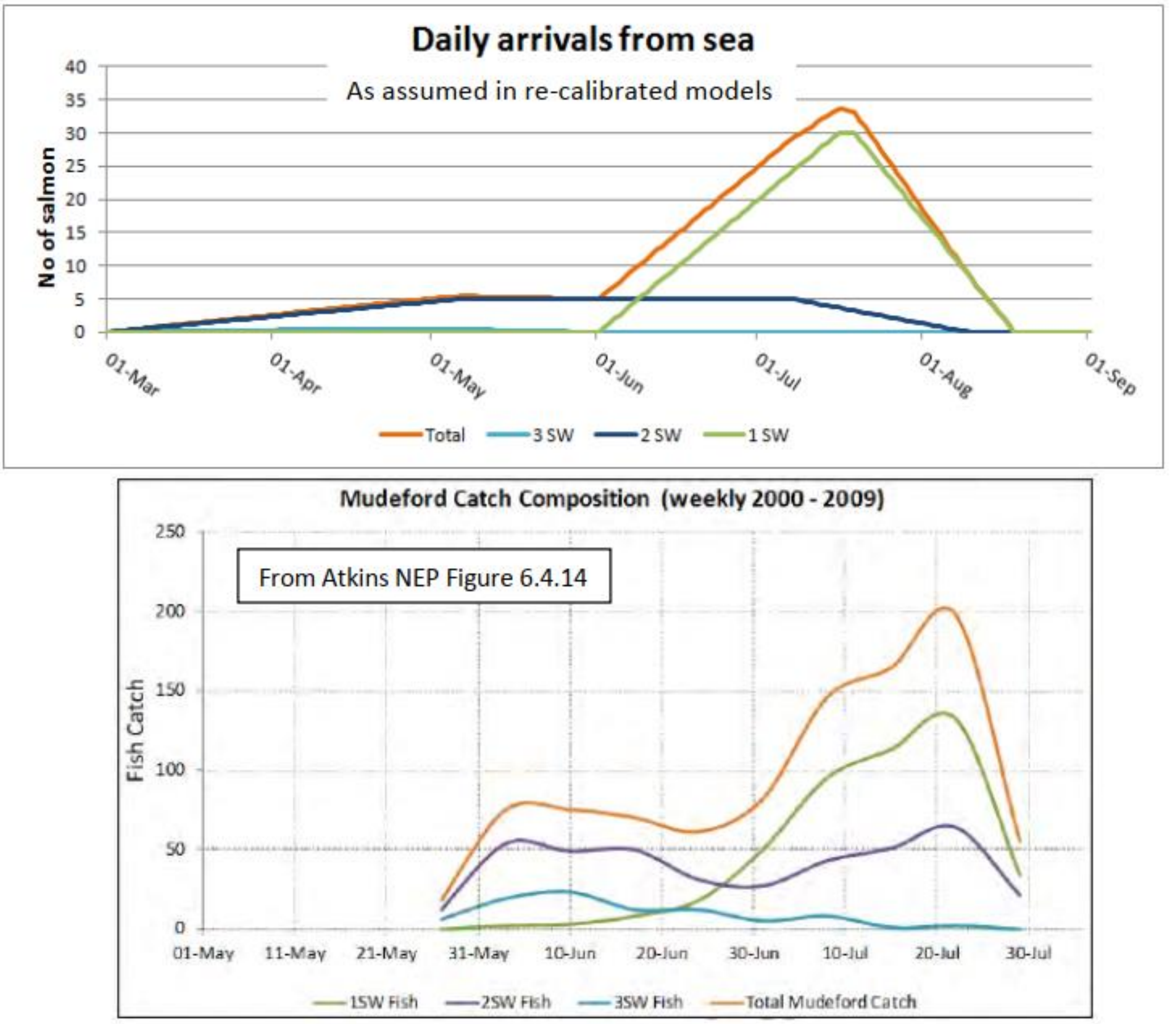

Figure 3-3. Estimated arrivals in lower river (assumed U/S of normal tidal limit), from sea, based initially on net catches at Mudeford (lower plot) and adjusted for rod catches and sea lice presence at Testwood (upper plot). From Discussion Paper on Test Salmon Migration modelling 23/08/2015. See also Summary Report of the Salmon Working Group, 30 September 2015 (Appendix Figure 1).

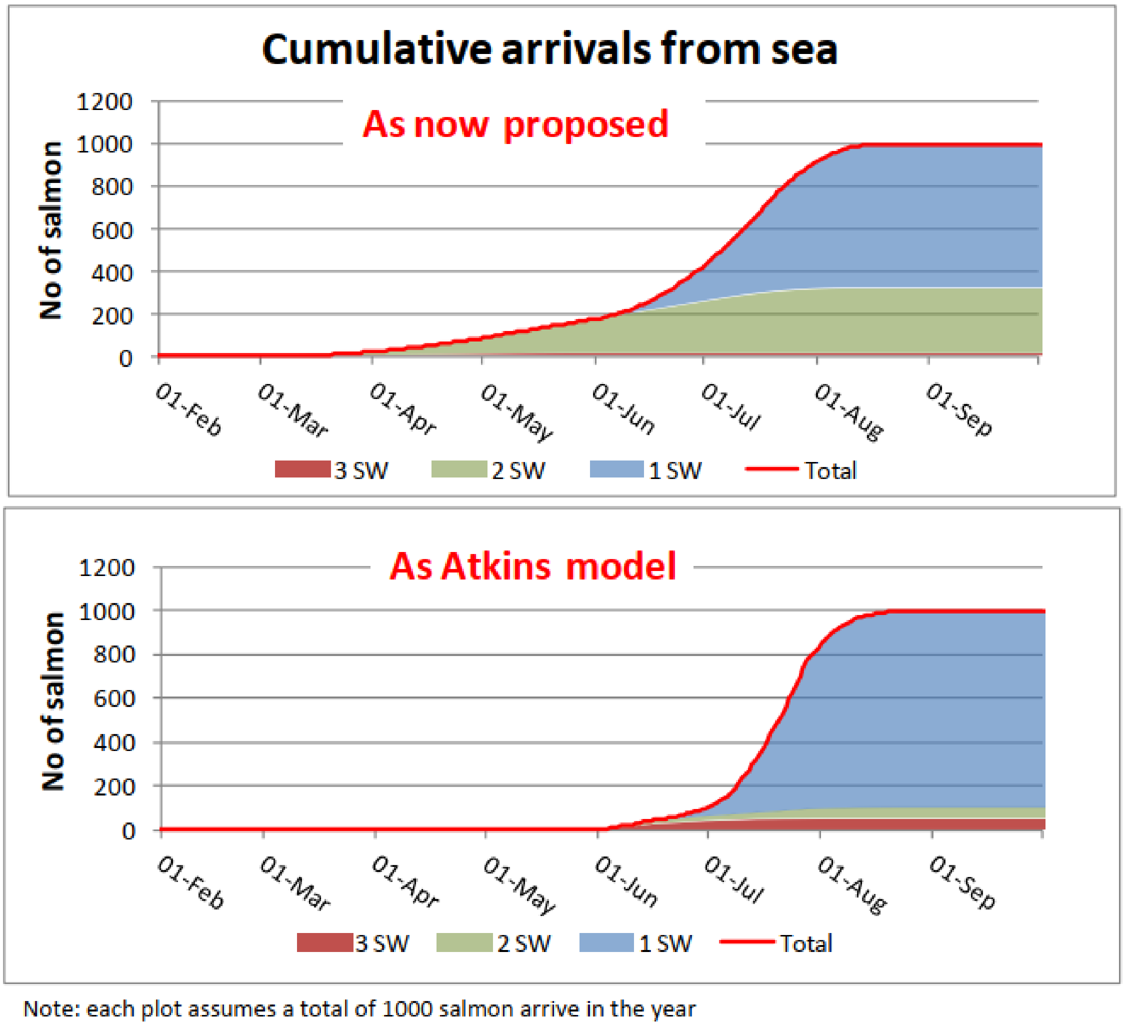

Figure 3-4 Salmon arrival patterns (assumed into the Zone 1A and 1B) based on J Lawson model (top panel) adapting the original pattern in lower panel (Atkins NEP1B, 2013).

Given the observed behaviours of salmon in estuaries, it is likely that they experience tidal excursions in Southampton water and more so as the estuary narrows at Dockhead. Some fish will have made it straight into the Test freshwater Zone 1A beyond the normal tidal limit (NTL) (Testwood Mill) to take up holding residence, some of which may have moved further over the Nursling Counter. Others may hold up in Zone 1B, upstream of the Great / Little Test junction, and the upper part of Zone 2 (Figure 1-2), both considered by the EA to be of “obvious importance” as salmon holding areas (Longley, 2022). At low flows, if the general pattern of S3.1 applies, salmon are likely to drop back to Zones 3, 4 or to Southampton Water. Some may be displaced into fully coastal water and a significant proportion may be lost from the system (Solomon and Sambrook, 2004).

3.3 Straying and exchange of salmon in estuaries and rivers

This section establishes the general principles of salmon behaviours before moving on to consider in the next section how they might apply to the Itchen /Test. Although salmon home with great accuracy to their natal rivers (Thorstad et al 2011) a low level of straying is an essential adaptive feature to colonise or recolonise other rivers and to buffer against environmental variation acting differentially across rivers (Keefer and Caudill, 2014).

The level of straying of returning Itchen origin salmon into the DP ZoI is an important question for the Test DP HRA. If none stray from their route to the Itchen none will be exposed to the DP effects in the ZoI; if they all do, then they will all be exposed. Some intermediate level would be expected and that is reviewed in this section, considering the evidence and scale of straying generally in salmon. Note that salmon from the Test also figure strongly in Itchen sustainability through straying to the Itchen, which is discussed in later sections. Expanding slightly on the definition above, straying can be of two broad types:

- *Functional straying*, in which fish enter and spawn in non-natal rivers. This is the conventional type of straying referred in much of the literature (Quinn 1993, Keefer and Caudill 2014). It results in lost spawners from the donor river and increased spawners to the recipient river. Whilst this category does not contain all the salmon that are exposed to DP pressures it has consequences for the HRA in the context of reciprocal straying and source-sink dynamics between the Test and Itchen as outlined below.
- *Exploratory straying*, in which salmon wander inadvertently and temporarily into non-natal estuaries and rivers during their return journey. This represents "mistakes" in searching as fish home to their natal river. Exploratory strays normally back track to their intended natal river, sometimes from far into the freshwater zone of the non-natal river into which they have strayed. From many tagging studies such straying is known to be common, but it has no direct effect on breeding and recruitment in the recipient river other than possible targeting of fishing mortality. It is logical to expect the frequency of explorers to decrease moving upstream through estuarine to freshwater reaches as "mistakes" get recognised and corrected by back tracking; but the spatial distribution of the fish will be influenced by the topography of the channel and suitability for passage and holding. There will also be seasonal variation in their presence linked to run timing. The recognition that estuaries are frequently occupied by salmon from many rivers is why estuarine mixed stock fisheries were regulated against.

The distinction is made because although functional straying is true reproductive "straying", in tagging studies (which provide most of the straying information) such fish cannot be distinguished from explorers in the lower parts of river/estuary systems because there is no way of knowing at that point why and for how long a stray salmon will be in a non-natal system. If tracked for long enough, a minority of explorers may end up spawning and therefore be functional strayers. Functional strays therefore form a component within exploratory strays. A further distinction should be made between strays *from* a river going to one or more rivers and straying *to* a river (from one or more donor rivers) and it is not always clear which is being discussed in the literature, most of which refers to functional straying

The two main sources of evidence for straying are: (i) tag recapture and tracking studies which, depending on design, can demonstrate exchange of fish between sites and if monitored for long enough, evidence of functional straying, and (ii) genetics, theoretical and observational, which establishes the genetic similarity or divergence of the populations and thus information on gene flow, the common ancestry, evolutionary pressures, effective population size and shared exchange of spawners.

The evidence on straying in Atlantic salmon is inconsistent reflecting variations in methods, terminology, life histories and ecological circumstances of different studies. Thorstad et al (2011) suggested that "*Usually less than 3-6% of mature wild salmon return to rivers other than the one they were hatched in*". The context of this quote implied functional straying, but this was not explicit. Pess et al (2014) quoting Hendry (2004) noted that on average 92% of salmon home leaving 8% as functional strays (but of course more may be explorers). Potter and Russell (1994) reviewed returns of micro-tagged parr in north-east England rivers and reported that about 2% of wild salmon recoveries and 3% of hatchery salmon recoveries were strays from non-natal rivers, but there were likely biases in reporting rates that could not be reliably assessed, and these were thought likely to have been underestimates. The recovery sources were varied and the data probably referred to functional straying. For wild salmon on the Imsa (Southern Norway) a particularly well-studied system using genetics, the average straying rate from the Imsa was 5.8% (Jonsson et al 2003).

Telemetry tracking studies can be more informative than micro-tagging. Solomon et al (1999), reviewing their adult tracking programme in six southern English rivers, concluded that salmon entering a non-natal estuary temporarily was "widespread and common". This refers to exploratory straying. On the Taw/Torridge system having intimately connected estuaries, of 255 salmon tagged in the lower Taw estuary, 122 were subsequently recorded in the Taw and 42 in the Torridge. Thus, of the known returners to these two rivers (164 fish) Torridge fish had formed 25.6% (42/164) of salmon in the neighbouring estuary, at the time of tagging.

On another system with closely linked joint estuaries, the Tamar and Tavy, Solomon et al (1999) found there was exchange of fish into the adjacent estuary. 7.6% (25 of 330 tagged) of salmon tagged in the Tamar estuary entered the Tavy and 13.8% (24 of 174 tagged) of Tavy estuary fish entered the Tamar. The sources (natal rivers) of these fish were not known, and neither were their final spawning destinations, and it is likely that exploratory straying within estuarine zones downstream of the recording locations would have been higher. Nevertheless, it illustrates that exploratory straying occurs in co-located rivers and estuaries (such as the Test/Itchen), even though it does not inform about the level of functional straying which will be less than these percentages, because almost certainly some fish will not have originated in the river of their capture and tagging, nor will they necessarily spawn in the rivers in which they were last reported.

Keefer and Caudill (2014) in their review of functional straying in many salmon rivers concluded that "*ideal estimates of straying from a population…are rarely if ever possible*". They caution against usage of general "appropriate" straying rates. While they note that donor straying rates can exceptionally be more than 20% in some years, in most cases the median values are much less. Nevertheless, while heeding their caution regarding specific values, ranges are more consistent, and theirs and other reviews and specific studies quoted here (which is not an exhaustive list) suggest that for Atlantic salmon functional straying is less than 10% in most rivers but can, rare cases reach 20%.

For DP HRA purposes the natural focus is on the exploratory straying of Itchen-origin salmon into the ZoI, because their reduction in numbers would be a direct loss to Itchen RSE which, coupled with non-lethal effects on breeding efficiency, would reduce recruitment with consequences for the SAC population dynamics. But exploratory and functional straying are expected to be reciprocal, and some Test-origin salmon will stray into the Itchen and breed, with possibly important effects if they are reduced through impacts in the ZoI. This depends on the source-sink interactions of the two populations (Crozier et al, 2003) which are discussed in Section 3.4.

Summary

1) In most situations, salmon display strong homing to their natal river but a small proportion (usually <10%, up to about 20%) stray to breed in other rivers.
2) Straying is of two types: *Functional* in which salmon breed in non-natal rivers and *Exploratory* in which by mistake they wander into non-natal estuaries and rivers during normal homing. This is reversed by back tracking to the natal river.
3) Both types increase with proximity of donor and recipient rivers
4) Explorers are more prevalent than functional strays and are common in estuaries.
5) Most Itchen salmon exposed in the ZoI will be exploratory strays.
6) Frequency of explorers will decrease moving upstream from lower estuary to freshwater, but location will be influenced by channel topography.
7) In the context of the DP HRA, Itchen explorer presence on average is likely to decrease moving upstream through the ZoI from lower estuary to freshwater, with variation due to channel features.

3.4 Straying and exchange of salmon between the rivers Test and Itchen

Section 3.3 outlined the current knowledge background on Atlantic salmon straying. This section considers how that understanding applies to or should be modified for the Itchen / Test situation.

Following current evidence on migration across the species range, Itchen salmon are more likely to home to the Itchen than to the Test, because that is their natal river and because it is the first big freshwater influence they encounter in Southampton Water. Although the Itchen has the smaller freshwater flow, the ratio of the Test to Itchen flows is at its lowest during times of drought and in the typical low flow months of July, August and September (Appendix Figure 5). Moreover, the Test discharge at Dockhead has been diluted by the larger, deeper estuarine channel in its lower estuary (Zone 4, Figure 1-1)

Nevertheless, some Itchen salmon will overshoot to the ZoI and of some of those will eventually enter the Test freshwater system. However, following conventional understanding, most will drop back to the Itchen, as reported for Avon-tagged fish that dropped back downstream having spent a considerable time in the River Piddle (Solomon et al 1999) and similar behaviour was reported in the Itchen (Horsfield 1992) and other examples (see Section 3.3). A proportion will breed in the Test, as evidenced by genetic studies (Ikediashi et al 2018; King and Stevens, 2021), expanded on below. These are true functional strays which if impacted by the DP would not be part of the annual "losses" from the Itchen, although they contribute to Test production and thus in the long term (3-4 years, salmon generation time in these rivers) to Itchen via subsidy of Test-origin fish. These proposed behaviours cannot be demonstrated or quantified and there will obviously be some exceptions, but under normal conditions this is a reasonable and uncontentious model.

"Overshooting", i.e. carrying on past the natal river until the homing "mistake" is realised, is one of two options by which salmon can enter other rivers: the other is by entering a river it encounters before it reaches the natal river. For example, it is likely that some Itchen and Test salmon enter the Meon and doubtless some other chalk rivers west of Southampton Water. Hawkins *et al* (1979) reported overshooting in salmon making directed movements in coastal waters but was soon corrected. Their swimming in the top 5m of the water column (with intermittent diving) may assist in detection of homing cues (Davidsen *et al*., 2013; Godfrey *et al*., 2014). Some overshooting past the Itchen is inevitable. Solomon (1973) reported an extreme example based on tagged smolt to adult returns in the Severn estuary but is an unusual situation that is not representative of what is likely in the Test / Itchen / Southampton Water context (Longley 2024), because of the tidal forces in the two locations. The Severn estuary has one of the highest tidal ranges in the world (14m-15m), with corresponding high tidal excursion and tidal stream velocities (see Appendix Table 1), and its high tidal energy contrasts strongly with Southampton Water which is one of the lowest tidal energy areas in the British Isles (tides range between 5m spring tides and 1.5m neap tides). Accordingly, flood tide velocity in the Severn estuary is x4 and x6 greater than the Southampton water on spring and neap tides respectively, for example 2.5ms^{-1} vs 0.5ms^{-1}, on spring tides. Salmon entering the Bristol Channel waters will be transported upstream and past the Usk and Wye entrances (if those are natal rivers) to a greater extent in the fast moving, high energy, highly turbid environment of the large Severn estuary than would be the case in Southampton Water. Therefore, it is not appropriate to compare overshooting in the Severn with the Itchen / Test situation. Overshooting of Itchen salmon will occur but likely at much lower levels than in the Severn. In all reported cases of salmon exploratory straying, eventual homing to their natal river is high, as it was (92%) in the case of the Bristol channel rivers.

Evidence of exchange between the Itchen and Test based on tracking is limited to one study which, although it had a small sample size with associated uncertainties, because of its location bears closer examination. Uncertainty. Radio tracking of adult salmon and a few sea trout tagged in the Test and Itchen was carried out in 1990 (small samples, but unspecified) and 1991 (Horsfield, 1992). Note that incidence rate is the incidence (proportion) of donor salmon in a recipient river; it is not the rate of straying from the donor river. The report focused on 1991, a year of low flow (Appendix Table 2) and the tagging was on both rivers with more fish being tagged on the Itchen. 58 fish, including 3 sea trout, were tagged at Woodmill on the Itchen at the upper tidal limit netting station. Of these, 5 were later recorded in the Test upstream of Testwood Mill and 3 were thought to have spawned in the Test. If the other 2 were also Test origin fish that gives a 9.1% (5/55) incidence of exploratory strays of Test fish in the Itchen (at Woodmill) in 1991. The 95% confidence interval on this estimate is 3% to 20% (using Wilson score interval method).

If only the known spawners were Test-origin fish, thereby meeting the definition of exploratory stays by being identified as Test spawners, having returned from straying, then a lower estimate of stray incidence rate (from the Test into the Itchen) is 5.4% (3/55), 95% interval 2% - 15%). the RSEs for Test and Itchen were 538 and 152 respectively. Considering for now, that upper limit incidence rate of Test salmon was between 15% and 20% in 1991 and if they were representative of the year, then the number of Test salmon in the Itchen was between 23 (0.15 x 152) and 30 (0.20 x 152), giving straying rates FROM the Test to the Itchen at Woodmill of 4% (23/538) and 6% (30/538).

These may significantly underestimate straying because of the comparatively small sample (55 fish), because stray rates may have been different later in the year (the fish were tagged 4th Jine to 20th August) and because some of possible mortality of some the Test strayed salmon recorded in the Itchen. Horsfield (1992) noted that "A*n additional 13 fish of the 55 tagged at Woodmill remained in the area for up to several months before dropping out of the system. This suggests that up to 31% of the catch in the Woodmill Net may be of non-native fish*". This may or may not be a correct conclusion, but unfortunately there were no listening stations downstream of Woodmill so the fate of the fish is unknown. Accepting the value, it is line with the findings reviewed above regarding salmon straying, but as there is no attribution to rivers it is uninformative about Itchen-Test exchange.

On the Test in 1991 only 9 fish were tagged, 4 salmon and 1 sea trout at Redbridge and 4 salmon at Romsey, well upstream. Of the fish tagged at Redbridge one fish moved downstream but was not recorded after that, and the remainder moved further upstream, but none were recorded in the Itchen: on face value indicating no exploratory straying from the Itchen into the freshwater zone. However, with such a low sample size the Test observations are uninformative. Note that these are fish recorded in freshwater (Zone 1A, Figure 1-2) but still within the ZoI, there will be others that stray only into lower parts of the ZoI, because as noted above for tracking studies elsewhere, the incidence of exploratory trays is likely to be higher in areas downstream of the receivers and in the respective estuaries.

Regarding functional straying, genetics also offers important additional evidence for the Test and Itchen. Ikediashi et al (2018) in a microsatellite study demonstrated that five rivers with chalk geologies (Frome, Piddle, Avon, Test, and Itchen) have remarkably similar and distinctive genetic compositions suggesting common origins and adaptations to the unique environmental conditions of groundwater-fed chalk rivers, hypothesising that the distinctive similar geologies, may cause homing to the group as much as to individual rivers. They showed also that isolation by distance applied, i.e. closer populations have higher similarities induced by gene flow caused by breeder exchange, than those further apart. In a further study including the River Meon, King and Stevens (2021) supported Ikediashi's account. They demonstrated that the strongest association amongst the chalk rivers was between the Test and Itchen, which together with the Meon formed a distinct cluster within the "chalk" group and that the chalk group (including Hant Avon, Piddle and Frome) constituted a metapopulation. Metapopulations work because they have a level of asynchrony in the component populations, thereby bringing stability to the whole by straying and re-colonisaton from donor rivers that offset intermittent declines in member populations from whatever local causes (Schtickzelle and Quinn, 2007).

The lack of discernible genetic discrimination between the Test and Itchen does not on its one demonstrate a single population. They may be, but that is not shown at this stage. There is clearly strong gene flow, that makes a strong genetic connection and is sufficient to obscure establishment or continuity of genetic signatures of salmon in either river – they are in effect indistinguishable. It does not mean there is no homing, but homing will be less and straying more, but by how much cannot be determined from the genetics data. The similarities also imply common local adaptations maintained by the common ancestry and present-day selection pressures in the unique common chalk stream habitats (King and Stevens, 2021).

The genetic studies are important evidence and influence the way that breeding exchange in Test and Itchen should be viewed, they show that functional straying will be higher than reported elsewhere, but some caution is advised in extrapolating the results. For example, it cannot be assumed that salmon originating from Test or Itchen have an equal probability of homing to either river on their return to spawn. The principle of homing to natal rivers is not invalidated by metapopulation status.

The interpopulation dynamics are further influenced by river population size through source-sink processes as illustrated by a simple example. Over the period 1990-24 the average RSEs in Test and Itchen were 944 and 439 respectively. Thus, at an equal functional straying rate, the Test would contribute more fish to the Itchen than vice versa. If for example 20% functional stray rate (from the donor river-origin salmon) applied equally then, adjusting for mutual exchange, annually 178 Test-origin (born in the Test) salmon from Test would add to the Itchen RSE and breed in the Itchen and 52 Itchen-origin fish would add to the Test RSE and breed in Test, giving 41% more Test immigrants to the Itchen and 6% Itchen immigrants to the Test. Assuming a stray rate of 30% gives Test / Itchen immigrant rates to the Itchen of 61% and to the Test of 5%. A lower stray rate of 10% still gives 21% Test strays to the Itchen RSE and 4% Itchen strays to the Test RSE. This marked asymmetry in contributions is simply a function of relative populations sizes, but an important relative difference in their respective source (Test) and sink (Itchen) roles.

Therefore, reduction of the Test population would be a significant factor in Itchen recruitment and sustainability. Hence the relevance of functional straying. This simple example makes assumptions about stray rates, characteristics of spawners, relative population sizes, breeding success in non-natal rivers and effective population sizes, but it illustrates the principle of a likely effect to consider in the Testwood DP impact and the importance of the Test to the Itchen. The ratio of Test to Itchen RSE has fluctuated since 1990, ranging from x0.74 to x4.38 (median = 2.18) but only once (in 1995) has the Itchen RSE been larger than the Test (Appendix Figure 4**Error! Reference source not found.**). The same principle would apply to the Meon and its interdependencies with the Test and Itchen, but the exchange would be far more asymmetric, with the Meon almost entirely dependent upon the other two much larger populations. It illustrates how plausible stray rates can result in large breeder contributions to the recipient river (the actual amount is dependent on relative population size) and would predict strong gene flow, which the genetics supports and in this example is sustained even with homing of an indicative 70% (in the 30% stray rate example).

Overall, it is reasonable to infer a greater level of stray rates than normal between the Test and Itchen because of their proximity, with important effects on breeder exchange.

Unfortunately, it is not yet possible to state how much greater. Therefore a robust analysis of the interpopulation dynamics of these populations that rationalises census size (*Nc*, e.g. the RSE) with effective population size (*Ne*) in a demo-genetic model (Frank et al 2011; Piou and Prévost, 2012), is recommended.

Summary

1) The Test and Itchen are very close genetically, due to high gene flow such that individual signatures for each river are not discernible. As a river pair, and as part of a larger chalk river metapopulation, through their proximity and common selection pressures they will display greater levels of breeder exchange from functional straying than reported elsewhere, but by how much cannot be assessed from existing data.
2) Translation of genetic similarities and gene flow directly to numerical straying of fish needs caution. The notion of natal river homing is not invalidated by the genetic similarity.
3) Strong dependencies of the Itchen population on the Test arise directly from the relative population sizes (e.g. Test RSE is x2.2 the Itchen RSE). Simple calculations, based on RSE numbers and assuming plausible straying rates, point to the Test being the dominant contributor source to the Itchen (sink), even with the maintenance of natal homing, albeit at lower levels than elsewhere. This makes the Test population status crucial to the Itchen SAC feature.
4) There are no data available to comment quantitatively on exploratory Itchen strays in the DP ZoI, other than to note it will be more than functional straying
5) Despite the uncertainties the evidence shows that the Itchen and Test have very close population connections that must be considered in the HRA.

4. Impact pathways

4.1 Rationale, Conceptual model and approach

The chain linking DP impact to SAC salmon population response has multiple pathways, processes, pressures and receptor components, making quantitative assessment unfeasible with currently available information. Nevertheless, some grading of the likely impact is obligatory in an Appropriate Assessment. To aid that this section summarises the processes in the impact pathways to put structure on to this complex problem. The outcome, for the Itchen SAC salmon feature, is determined by a sequence of processes from straying and exchange through potential lost eggs to the impacts on the population dynamics and emergent properties of the SAC feature, as summarised in Figure 4-1.

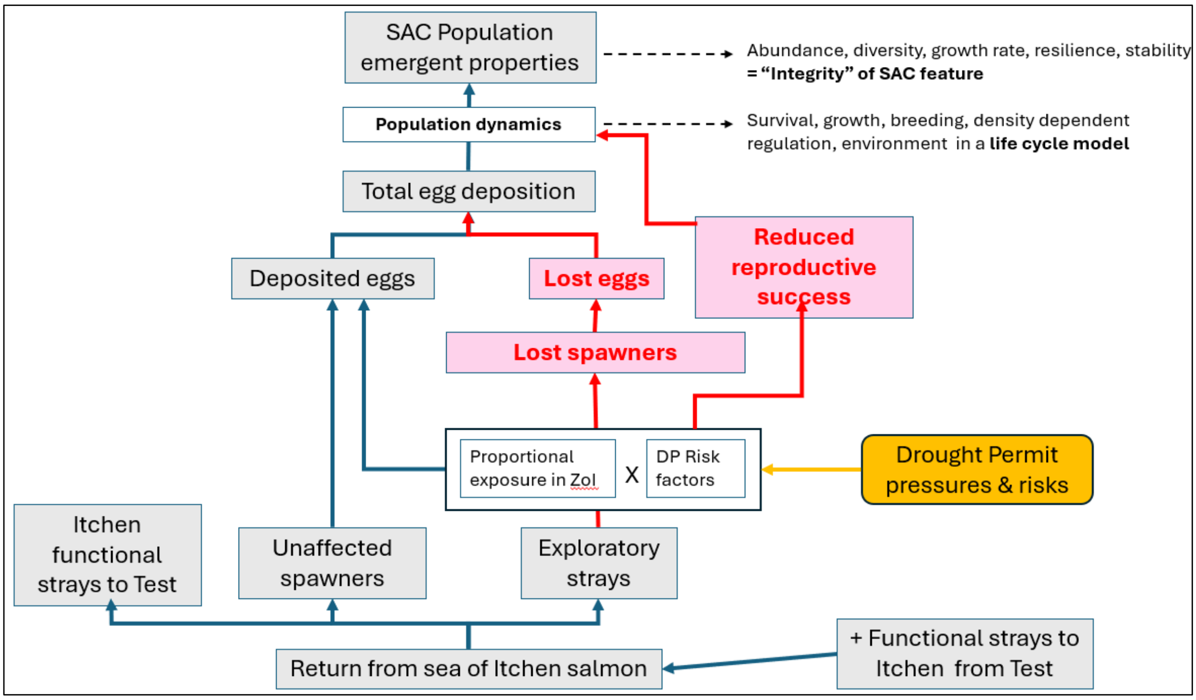

Figure 4-1 Conceptual model of the impact of the Drought Permit on the Itchen SAC salmon feature.

Two categories of DP pressures and risks to salmon apply, both originating and dependent on the scale of DP-related effects on environment:

(i) *in situ* direct effects (lethal or sublethal) on adult salmon through all routes of WQ toxicity, predation; and

(ii) barrier effects from migration delays as salmon encounter conditions somewhere within the ZoI that they avoid. These may result in delayed lethal or sublethal effects.

In both pathways, the ultimate response relevant to the Itchen SAC population is reduced spawning stock and breeding effectiveness with knock-on effects on emergent properties of fitness, resilience and sustainability (Figure 4-1).

There are potentially five categories of returning adult relevant to the overall outcome in Itchen SAC (Figure 4-1).

(i) Itchen exploratory strays: likely to be the largest group of fish potentially affected.
(ii) Itchen functional strays to Test: if affected, could reduce Test breeding and source role to Itchen.
(iii) Test exploratory strays: a neutral category, by definition elsewhere until they become (iv)
(iv) Test functional strays to Itchen: if affected, could reduce Itchen breeding.
(v) Test homing spawners: if affected, could reduce Test population and source role to Itchen.

These reduce to two phase of impact: A). Lost breeding, either as eggs or reduced breeding success, in the same year as the DP is implemented (i, iii, iv); and B) spawners in the Test, originating from the Test or Itchen, that through Test production may contribute breeder subsidy to the Itchen in 3-4 years' time (ii and v) – this is a significant component.

The DP environmental pressures leading to *in situ* and barrier effects within the ZoI have 3 properties: location, timing and intensity. For DP impacts to occur the fish must overlap spatially and temporarily with the pressures, which must cause effects on individual fish, at sufficient severity and in sufficient proportion of the annual breeding stock to affect the dynamics of the SAC salmon.

The DP-related risks vary within the ZoI. For example, in Zone 4 and 3 the likelihood of DP effects will be less than in Zone 1B and 2. In Zone 1A, upstream of the NTL, tidal effects, which have been considered to drive the mechanism of high temperature and low DO, is less likely to apply, and impacts that may be moderated by the optimal holding habitat (outlined in section 3.2.1). These are unknowns that require modelling.

The proportion of the Itchen run that strays into the ZoI, will not be distributed uniformly throughout the zone. Evidence from tracking in estuaries (e.g. Priede et al, 1988; Potter, 1988, and others) show that holding even temporarily over a tide, is restricted to suitable topography, typically deeper, slower water with shelter and from visual appearances that is scarce in lower Zones 1B (there is no hydrography or bathymetry survey data to back this up), 2 and upper 3 dominated at low tide by shallow tidal flats.

The potential fates of stray Itchen salmon (and the principles apply to the other categories listed above) are summarised in Figure 4-2. Following the model in Figure 4-1, they recognise that not all Itchen salmon stray, that not all the strays are in those parts of the ZoI where deleterious DP-related effects occur (influencing LOCATION in Figure 4-2) and of those not all will be equally affected (PROCESS in Figure 4-2). To evaluate DP impacts on salmon all links in this chain of events should be considered.

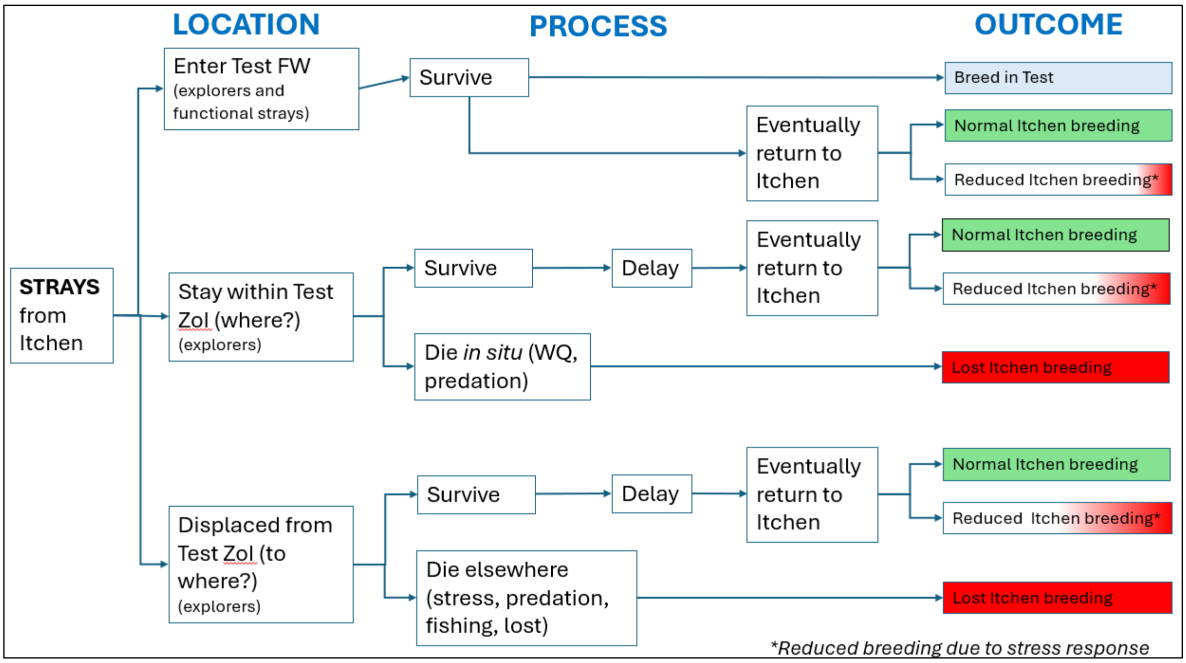

Figure 4-2 Conceptual model of fates of Itchen-destined salmon that stray into the Test ZoI. There are other pathways not shown here, involving the Test population as a source to the Itchen. Green indicates unaffected spawning, red shading indicates lost spawning. Reduced spawning is taken to result from sublethal effects on reproductive success. Not to scale.

DP effects on Itchen salmon will reflect deterioration in environmental conditions from greater abstraction coupled with exposure to them. However, the DP implementation will be on top of or pre-empted by the natural drought conditions that triggered it. If such conditions have already reduced migration and killed or displaced salmon as a natural consequence of droughts and hot weather, by how much and where will the DP further reduce environmental quality and how many salmon will be available to experience that additional pressure?

The assessment task is to evaluate the size and significance of the OUTCOME (Figure 4-2) components for the Itchen SAC salmon feature and to apportion them to the DP and natural effects. The pathways leading to loss of strays and exchanged spawners are many and the population dynamics are complex demanding full life cycle models that cannot be fully parameterised with limited available data. Given the coarseness of the assessment of breeding loss and the low level of knowledge about the populations, would not warrant application or a detailed discussion here. Nevertheless, the risk factors can be outlined, and a qualitative evaluation can be made by considering the range of losses against the Conservation Limit (Section 5).

4.2 Assessing risk factors for salmon in the ZoI

Principal environmental factors likely to act on salmon within the ZoI are localised hydraulic changes, high temperature, low dissolved oxygen concentration, reduced pollutant dilution and hydraulic variables including low velocities and shallower depth. These physicochemical changes can lead to processes including:

1. Reduction in habitat size (defined by area, volume, velocities, overhead shelter and water quality), that affects holding potential and vulnerability to predation and poaching and crowding that could increase pathogen transmission.
2. Reduction in flow-related cues for movements in or out of the holding areas within the ZoI and the connectivity to allow such movements.
3. Exposure to lethal or sub-lethal effects of water quality conditions, including high temperature and low dissolved oxygen concentration.
4. Barriers to river entry through avoidance of poor water quality and high temperatures or other variables leading to displacement from the ZoI and Test/Itchen system that may be permanent or lead to delays and fish missing physiological windows for maturation, or limits distribution of spawners.

These processes may act in synergy causing combined effects. Their occurrence and intensity will vary greatly through the ZoI according to freshwater-estuarine locations, topography, channel form and tidal influence, with a general presumption of reducing effects moving downstream as river flow influence reduces with increasing estuary size and tidal influence.

4.2.1 Habitat changes

The better holding areas in Zone 1A and 1B are regarded as comparatively safe places to be in droughts, exemplified by the Testwood Mill and environs (see Section 1.1). Atkins (2013) modelled flow effects on channel hydraulics and concluded that only minor changes would result from a Hands-off Flow (HoF) of 265 MLd^{-1}. Nevertheless, in tidally effected reaches temperatures and low DO occur there that could lead to hypoxic and thermal stress and at worst conditions the death of fish that are present (Longley 2022). The Atkins model has been challenged by the EA, but the implications of that and the outcome of any revisions are unknown. More detailed modelling with and updated and into the estuarine ZoI is in progress and will inform on this key question

Further down the estuary in Zones 2, 3 and 4, there are no data currently available to report physical changes related to river flow, but on the principle that they are progressively more tidally influenced, they are less likely to be at risk of deleterious physical change from the DP.

4.2.2 Temperature and dissolved oxygen

Salmon are a cold-water species needing well-oxygenated, cool water to survive. They are ectotherms (cold-blooded animals whose body temperature tracks water temperature) and thus their metabolism, physiology, maturation and behaviours are dependent on and responsive to water temperature. Their critical thermal tolerance limits are approached at times in UK rivers: more so in the warmer southern regions; and the frequency of this will increase with climate heating (Webb and Walsh, 2004; Fenkes et al, 2016). Furthermore, DO concentration reduces as temperatures increase, presenting double jeopardy as water warms and fish metabolic rates and oxygen demands increase, a reduction in DO of 1mg/l accompanying an increase in temperature of 4°C (Alabaster et al. 1991). Therefore, the two variables and other chemicals that covary with them should be considered together.

Thermal tolerance thresholds for survival and various behavioural responses vary to some extent with acclimation and adaptation, but some general guidelines are available (Solomon and Lightfoot, 2008). Shephard has suggested mortality occurs at temperatures greater than 23°C, but salmon are often found living at higher temperatures, although will experience levels of physiological stress. Elliott (1991) proposed a physiological tolerance zone of 7.0 - 21.9°C and maximum thermal tolerance (exceedance resulting in death) of 26°C, a value that was used for salmon by Webb and Walsh (2004) to assess the impact of global warming on fish in UK rivers.

Major salmon fish kills have been reported in hot summers and drought conditions where temperature and DO act together. A notorious example was in the River Wye during the 1976 drought (Brooker et al 1977). In this case, mean daily temperature increased from 21.4°C on June 23rd to 26.3°C (maximum 27.6°C that day) on the 28th of June, leading to a massive fish kill on the 29th of June, that was compounded by macrophyte die-off leading to DO concentrations of 2 mgl^{-1} and 1 mgl^{-1} on the 28th and 29th of June, respectively. In 2022 on the River Wye, there has been significant fish mortality from low dissolved oxygen event(s) but, in this case, it is thought to be exacerbated by runoff highly charged with organic matter from agricultural areas.

Alabaster et al (1991) reported that water temperature was an important factor in determining the lethality of low dissolved oxygen concentrations. In laboratory studies salmon were able to survive dissolved oxygen concentrations of 3.2 mgl^{-1} at 15°C; at 22.5°C a dissolved oxygen concentration of approximately 5.7 mgl^{-1} was required and at 25°C the concentration was 7 mgl^{-1} for survival.

Sublethal effects on salmon are observed at lower temperatures. Alabaster et al. (1991) in a statistical analysis of returning stocked fish trapped in the River Thames reported that monthly salmon migration ceased at around a median (50%ile) temperature of 21.5°C in the Thames estuary. They noted that this was a comparatively low threshold compared with studies elsewhere, possibly due to the combined effects of low DO that was prevalent in the Thames, and salmon passage on the Loire proceeded at temperatures up to 24°C, trap catches in the River Axe ceased above a monthly mean of 24.9°C and good runs were maintained in the River Erne, Ireland, at temperatures up to 20°C. (see Alabaster et al 1991 for refs). Clearly, some fish do move at such high temperatures, even on the Thames (Alabaster and Gough 1986). Nevertheless, Alabaster's study demonstrates the interactions and complexities amongst water temperature, DO and river flow that compound to reduce estuarine passage by salmon.

Solomon and Sambrook (2004) reported that high temperatures were implicated in deterring salmon from entering southern rivers (acknowledging that there may have been covarying factors such as oxygen levels and ammonia), leading to delayed entry (in which case physiological windows for salinity transition and reproduction could be missed) or complete failure to return. They suggested that the implied mortality might be due to other factors such as netting (as did Clarke et al 1991) in their tracking studies on the Afon Twyi, Wales. Although legal netting has ceased in Southern England, there may still be bycatch on coastal fisheries. They suggested that temperature was a more important factor than low flow, acknowledging that the two were difficult to disentangle. Low dissolved oxygen can also deter salmon migration. Alabaster and Lloyd have suggested that upstream migration ceases at 5 mgl^{-1} and Priede *et al*. (1988) reported avoidance behaviour of salmon in the Ribble estuary at dissolved oxygen < 5.5 mgl^{-1}.

In some estuaries salmon fish kills have been reported when the combination of high temperatures and low DO brought about variously by hot weather and / or high BOD inputs sometimes coincides with low river flows and spring tide. Oxygen sags can cause significant salmon mortality in estuaries if they coincide with the presence of salmon. The mortality mechanisms appear to vary between estuaries. In some cases (like the River Tyne) they may be exacerbated by high sewage discharge biological oxygen demand (BOD) or other chemical inputs. In others they may be induced or enhanced by spring tides that can mobilise high BOD and chemical oxygen demand (COD) in sediments and bring about upstream penetration of warmer sea water, warmed by tidal flats. This has been reported for the River Tamer (see refs in Solomon and Sambrook, 2004) and a recent analysis by the EA (Longley, 2022) has suggested this mechanism might apply to the Test. Alternatively, neap tides may be sensitive times if limited tidal movement reduces flushing of warm low DO water (Longley, 2024; APEM unpublished). Longley (2022) reported that DO as low as 3.3mg/l and temperatures up to 31^{o}C occurred over spring tides at critical times of tide and day. Such low DO and high temperatures are lethal for even short exposures.

There were no Test salmon mortalities known to Southern Water during 2022 or 2023, although concerns were raised by Little River Management in 2022 relating to polluted runoff from Nursling Industrial Estate to the Lower Little Test. The absence of fish kill observation could be because no fish were present to be killed (quite likely in view of salmon behaviour in a small estuary under such conditions), or they were present, but the conditions were not lethal combinations of level and duration (although sublethal stress effects would occur), or there were mortalities but they were not observed (certainly possible, if in the difficult-to-access reedbed areas), although any significant kill would normally be reported at an accessible location like Redbridge. It is uncertain that the dimensions and shelter attributes of the freshwater deep holding areas will be altered by the Scheme sufficiently to render the fish detectably more exposed to disease incidence, predation or poaching even though these may be increased by the drought itself. Nevertheless, this remains a DP risk factor.

In the Thames estuary in 1984 when major oxygen sags occurred, Alabaster and Gough (1986) inferred that part of the salmon run had passed through a 1km zone when the 5th, 10th and 50th percentile DO values were 1.8 mgl^{-1}, 2.0 mgl^{-1} and 3.5 mgl^{-1} respectively. When considering passage through a 10km zone, the 10th and 15th percentile DOs were 2.2mgl^{-1} and 3.8 mgl^{-1} respectively. Their study inferred fish movements from trap catches and not directly observed fish movements in relation to DO, nor were the number of fish available to move known (they were tagged hatchery fish) so the results must be regarded accordingly.

An important sublethal consequence of high temperature is on reproductive physiology controlling gamete development and spawning (Solomon and Lightfoot, 2008). King *et al*. (2003) reported experiments (on Tasmanian farm-origin Atlantic salmon) showing that egg size, fertility due to reduced vitellogenesis and egg survival were reduced as continuous temperature treatments increased from 14°C to 22°C over a period equivalent to July to September in the salmon's natural range. King *et al*. (2007) further showed that the sensitive period was equivalent to mid-August to mid-September in UK (Solomon and Lightfoot, 2008) and that comparatively short exposure to high temperatures was as damaging as longer exposure to lower temperature. Continuous exposure to 22°C over a period of 4 – 6 weeks caused fertility to reduce to 70% of control compared with a greater reduction to 45% of the control after 12 weeks. Ova survival was reduced to 40% and 13% of control respectively. The authors noted that shorter durations of lower oxygen could be just as or more harmful. The duration of residence of Itchen stray salmon is not known, but some may remain in warm water for up to several weeks (see above), so while it cannot be quantified, this is an important risk factor in any natural warm weather drought.

Thresholds for temperature and DO (and other determinands such as ammonia, not considered here) are clearly interlinked and dependent upon exposure duration, fish adaptation and genetic variation; but being aware of those caveats one can approximate critical temperatures as follows:

- Lethal >25°C.
- Sub-lethal, inhibited upstream in-river passage >22°C.
- Sub-lethal, thermal stress >20°C.
- Sub-lethal, inhibited river entry (following estuary passage) >19°C.
- Sub-lethal, fertility >20°C (if continuous for >4 weeks).
- Sub-lethal, ova survival >20°C (if continuous for >4 weeks).

These critical temperatures are intended as a guide, they cannot be absolute and there will be variations. Similarly DO thresholds vary, but for river entry a threshold of 5 mgl^{-1} may be appropriate for most temperatures, but noting a higher value may apply at high temperatures (see 7mg/l suggested for 25^{o}C, above). Standards of combined thresholds for interacting DO, temperature and salinity conditions are needed over a range of values (Alabaster et al, 1991). Toxicities of virtually all chemicals are modified by temperature, DO, salinity and other chemicals, and would need to be considered in detail as data become available. These approximate criteria can be compared with the information available on temperatures in the lower Test.

There are extensive data on temperature and DO in the lower Test from long term studies reported in Atkins 2013, continued by Southern Water Services (SWS) and enhanced by recent studies (Longley, 2022 and APEM unpublished). In addition, surveys further downstream (APEM, unpublished) showed changes over tidal cycles at times of hot weather and low flows in 2022 and demonstrated physicochemical stratification driven by saline/ freshwater contrasts. Recently, Longley (2024) described poor oxy-thermal conditions, with reference to other toxicants including ammonia, in the Itchen in relation to operation of Portswood Sewage Treatment Works (STW).

Atkins (2013) modelled the effect of abstraction at Testwood pool for the period between May 1st and October 1st, 2006, reporting average values for cross-sections and noting that some stratification would occur in summer months. If this is the case, cooler deeper water would be sought by salmon, known to make microscale selection of thermal habitat. The Atkins model results (Figure 4-3) suggest minor effects on temperature of full DP vs zero abstraction, the vertical bars illustrating the numerical difference between them, suggesting variations less than 0.5°C, which would present minimal additional pressure on salmon. Atkins noted that the primary driver of water temperature was the prevailing weather, principally air temperature. The Atkins model has been challenged by the EA, but the outcome of any revisions is not known. More detailed modelling of the relationships amongst discharge, tidal state and water quality parameters in the rivers and upper estuary are in progress and will shed more light on this topic.

Water temperatures in the Test Estuary showed maxima of around 22.2°C during July, August and September at the Test Estuary 2 (NGR SU3948011910) and the Test Estuary 3 (NGR SU4119011020) EA sampling points which could be problematical to salmon if deep cool water is not available for refuge. Nevertheless, dissolved oxygen concentrations found in the lower Test Estuary are typically high (EA data show that dissolved oxygen concentration stayed above 6 mgl^{-1} throughout 2022 at both the Test Estuary 2 and Test Estuary 3 sampling points). However, this contrasts with the deterioration in conditions, low DO and high temperature, that occur with tidal and diurnal cycles in the upper Estuary at Redbridge for example (Longley 2022).

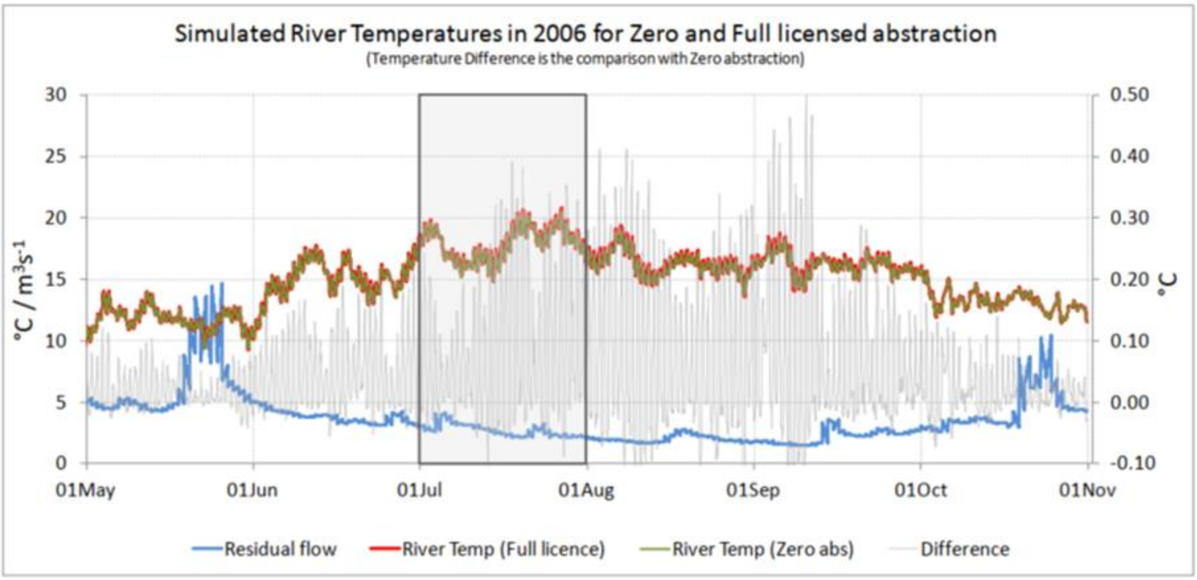

Figure 4-3 Simulated hourly river temperatures upstream of Testwood Pool from May 1st to October 31st, 2006. The predictions are averages for a given cross-section and the vertical bars show difference with full DP abstraction. The residual flow following full licensed abstraction is also shown.

Data in 2022, a hot drought year, show the extreme conditions of high temperature (Figure 4-5) and low dissolved oxygen that prevailed at Redbridge (Figure 4-5). Inspection of data from monitoring sites in the freshwater zone for a recent period when all were recording (31st

August – 4th September 2022) shows that compared with Redbridge, average temperatures were 8% lower at GT5 (Testwood Mill) and 18% lower at GT3 (Testwood Bridge), indicating that Redbridge is a critical section. Temperatures there exceeded notional thresholds often in June and was greatly exceeded after the 7th June, with extreme values of 28.5°C (11th July), 27.8°C (19th July) and 30.8°C (8th August). Salmon are most unlikely to enter this zone under these temperatures, but if present and exposed would experience severe thermal stress and mortality, in addition to the combined effects of depleted oxygen coupled with increased metabolic oxygen requirements. The exposure durations to cause these effects and the sublethal response are not well understood even if as noted above exceptions are reported in which salmon endure such conditions and continue to migrate and survive. Some degree of temperature acclimation is reported (Anttila et al, 2014) which may partly offset the impacts of thermal stress. can arise and there may be behavioural changes apart from basic avoidance (Moore et al, 2012). At times of hot weather salmon entering the Avon appeared to adjust their entry to times of lowest temperatures, in dawn and late evening (Solomon and Lightfoot, 2008). These are relevant to note but the effects in terms of response cannot be predicted.

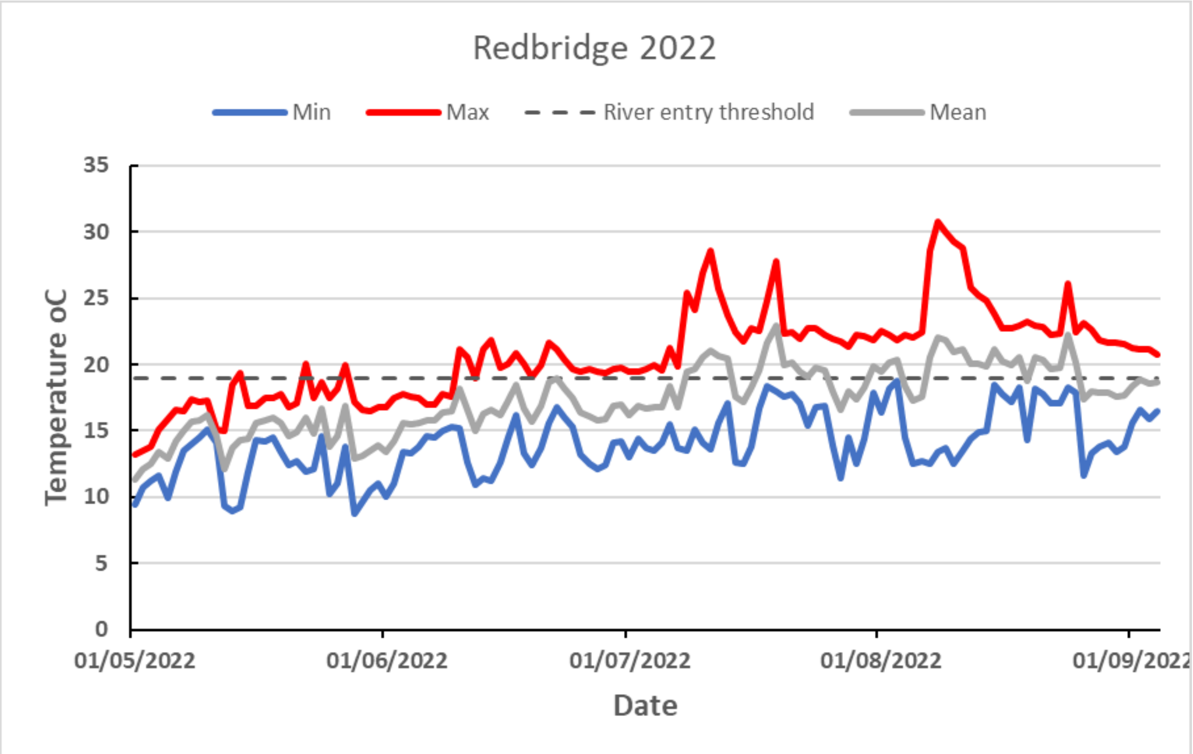

Figure 4-4 Water temperature (mean, minimum and maximum) at Redbridge (logger fixed to road bridge) from 1st May to 4th September 2022. The notional threshold for river entry is shown by the dashed line.

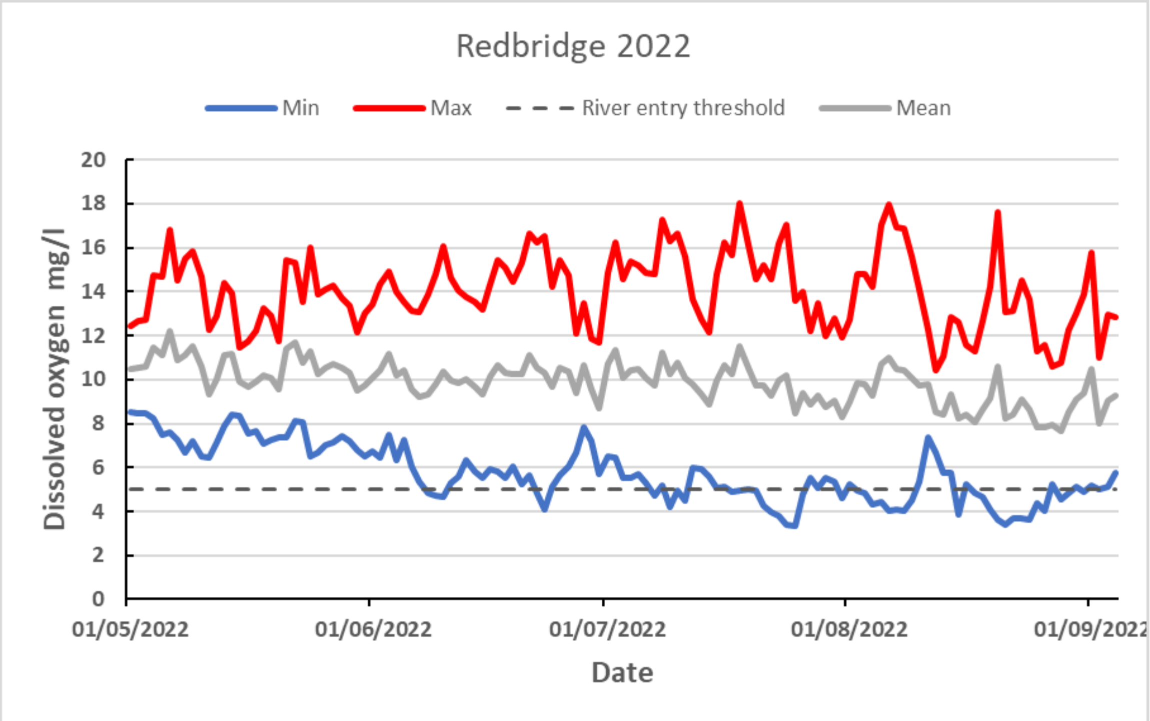

Figure 4-5 Dissolved oxygen (mean, minimum and maximum) at Redbridge (logger fixed to road bridge) from 1st May to 4th September 2022. The notional threshold for river entry (5 mgl^{-1}) is shown by dashed line.

The temperature pattern on top of low flows suggests that salmon entry (strays and natives) to the Test will have been reduced in 2022 in the months June-July when most fish are believed to enter Zones 1A. Fish experiencing such conditions will suffer stress, likely displacement downstream; some may subsequently die and some may spawn elsewhere (Solomon and Sambrook, 2004), but this is a drought-driven impact that would arise without the DP in place. The key questions are:

- how much would water quality be made worse by the lower flows due to the DP, and;
- what proportion of Itchen-to-Test strays would be exposed?

The former question requires appropriate modelling to resolve it, which is in progress. Preliminary statistical modelling suggests a small flow effect over the existing flow range in the current data set (APEM unpublished) and, when validated and strengthened by better understanding of the dynamics of the critical parts of the ZoI, can be used to explore DP oxy-thermal conditions. The modelling should be extended to the estuarine ZoI (Zones 2, 3 and 4) to better understand the impacts of DP conditions on spatial WQ that may lead to in situ direct effects and barriers leading to impaired migration.

The second question can only be addressed by knowing where migrating fish including strays are located against the spatial pattern of the environmental pressures. There is little reliable information on this. Most early entrant Test fish and Itchen strays are believed to hold in the freshwater zone of 1A, Testwood Mill area and the tidally influenced river of upper 1B. For reasons discussed earlier these are among the safest places to be in times of drought within the Test system. The major unknowns are the timing and frequency for salmon in lower zones (lower 1B, 2, 3 and 4). This cannot be resolved at this stage. Based on the reported behaviours in other estuaries, it is unlikely that a large proportion of salmon would hold up in the reaches which by virtue of their topography and tidal influence might be expected to have the most critical temperature and DO conditions that salmon avoid. It is emphasised that the location of critical zones is speculation at this stage and requires better survey data and modelling of season, climate, flow, tidal and diurnal factors to resolve.

Reduced river volume and discharge can lead to increased accumulation and concentration of pollutants during droughts. This has been a well-reported problem in many large industrial rivers where its effects can lead to serious fish kills and loss of salmon runs, for example the Rivers Thames, Tyne, Tees, Ribble and many of the South Wales coalfield rivers. These presented in-combination effects of low flow and often high temperatures with variously industrial contaminants, high BOD and COD substances and sewage discharges. Such industrial impacts are rare nowadays, although sudden sewage discharges are becoming more prevalent as summer rainstorms overload sewerage systems; but in their place have emerged increased organic and other chemical loadings from intensive agriculture and urbanisation. Salmon congregating at high densities in holding areas may pose a risk to survival if they are subjected to pollution events. Previous assessments have indicated that there may be a local risk of pollutant residues entering the river during periods of flash flooding associated with storms, immediately following periods of hot, dry weather. A rapid and concentrated influx of pollutants such as this may have significant impacts on local water quality and, if concentrated in the vicinity of salmon holding pools, may pose a significant risk to fish health and survival.

4.2.3 Predation and poaching

If the holding areas reduce in size (area, depth and flow) due to the Drought Permit, coupled with increased delays in upstream passage this could lead to increased salmon density which could subsequently attract predators, increased poaching and, through secondary stress response or direct transmission, higher incidence of pathogens and disease. As discussed above and in Section 3.2.1 it seems likely that the most important long-term holding areas, where salmon will be vulnerable, are in Zones 1A and 1B.

Predation on large adult salmon will be restricted to large mammals, such as seals, otters and mink. There is anecdotal evidence to suggest predation of adult salmon by seals in the Test may be an issue, though this is likely limited to individuals which have adapted their foraging behaviour to specifically target adult salmon in holding sites, as demonstrated in other river systems (Butler *et al*., 2006). Similar studies have also demonstrated that otters may take adult salmon, particularly as these fish navigate shallow riffles (Carss *et al*., 2006), though mink may be limited to scavenging carcasses as opposed to preying upon living adult fish (Cunningham *et al*., 2002).

Poaching is reported by the EA as a significant problem in the lower river and upper estuary, Zone 1A to 1B, including at Redbridge. It may be that the high value, tightly managed salmon rod fisheries mean that poaching is deterred to some extent, but clearly some risk remains. Any Itchen straying fish would be as equally vulnerable as Test fish. Potential risk would likely increase as low flows cause fish to hold up and aggregate in pools, and EA advice is that this is extensive at Redbridge, in the reedbed zone and lower freshwater zone. No further information is available to develop this mortality factor.

4.2.4 Pathogens and parasites

Reduced physiological resistance brought on by thermal stress coupled with increased density of adults can lead to disease and parasite transmission (Marcogliese, 2001; Fenkes et al, 2016) and is a concern at times of drought. Diseased fish are more susceptible to predation and less able to perform functions such as migration. Specific examples for the River Test are not reported, but furunculosis related to *Aeromonas* infection has been associated with high temperatures in Norwegian rivers (Jonsson and Jonsson, 2009). Ulcerative Dermal Necrosis (UDN) caused major salmon kills in British rivers in the 1960s and 1970s and has occurred sporadically since. Its cause is not fully understood but it is characterised by secondary *Saprolegnia* fungal infection. Its incidence is higher in crowded fish populations at times of warmer, drier springs and may be exacerbated by high UV exposure (Henard *et al*., 2022).

5. Impact assessment

The preceding account shows that a significant proportion of Itchen salmon run will stray into the ZoI and through their various behaviours of tidal excursion, holding for varying periods, avoidance, displacement and recovery of correct migration route, will display a range of exposures and responses to DP-related impacts ranging from none to lethal. Moreover, it is shown above that impacts on the Test population would also have implications for the Itchen SAC as a source of breeders both in years of a DP operation and later (lagged by 3-4 years) if salmon of Test or Itchen origin destined for the Test were affected in the ZoI.

The presence of even a small proportion of strays in the ZoI presents a *prima facie* case of potential impact where impacts on SAC integrity from by the Scheme could not be excluded, leading to this Stage 2 assessment. Furthermore, the routine presence of strays in the ZoI makes it an ecological functional habitat for the Itchen SAC. NASCO guidelines on applying the Precautionary Principle (NASCO, 1988) to salmon habitat management (NASCO, 2010) state "*Where salmon stocks have been designated for special protection, there should be a strong presumption against any loss of productive capacity, even where measures to compensate or mitigate for the losses are proposed*". The Precautionary Approach also states "*…managers should demonstrate that they are being more cautious when information is uncertain, unreliable or inadequate...*".

Some scaling of impacts on salmon is necessary to set the DP HRA in the context of Itchen SAC salmon feature. Unfortunately, because of the limited and uncertain information on the processes, the location, timing and exposure of salmon to risks in the ZoI, on the level of environmental or other detriment attributable to the DP at different parts of the ZoI and on the likely individual fish and population responses (i.e. at all stages of the chain in Figure 4-1) it is not possible to quantify the DP outcomes for Itchen salmon across the range of pathways (Figure 4-1) or the contributory effects on Test salmon (Figure 4-1).

However, it is possible to offer a range of values by taking ranges of straying rates into the ZoI, irrespective of where they are in it which could be from Zone 4 to Zone 1A. To these are applied a range of *impacts* (=lost fish) which is a combination of exposure (reflecting when and where fish are in the ZoI) and effects (= outcomes in Figure 4-2) in terms of mortality (there is also includes some lost breeding potential from delayed sublethal effects), to estimate changes in CL compliance and losses of spawners. The result is a lookup table that allows comparison of these parameters against the current stock status indexed by latest conservation limit compliance. This was done by taking a range of values for the proportion of Itchen RSE (NOTE these include Test-origin presumptive spawners in the Itchen, see Section 3.4) salmon that stray (5% to 80%) into the ZoI and assumed "*Impact*" values of 10% to 100%, then estimate egg losses with reference to the 2022 %CL compliance (20%) and estimate what the CL would be under each set of straying and impact values (Table 5-1).

Table 5-1 Example calculation of estimated changes to % CL compliance in the Itchen. CL, RSE (Returning Stock Estimate) and fecundity data from EA.

Variable	Value
Conservation limit (eggs x 10^6)	1.63
Assumed proportion of RSE that are strays	0.2
Assumed proportional loss of the strays	0.2
2022 RSE (number of fish, males and females)	133
RSE lost (number of fish)	5.32
Eggs / RSE	2451
Eggs lost (at eggs / RSE)	13,040
Annual eggs (x 10^6)	0.31296
Revised % compliance with CL	19.2

The calculations are shown in Table 5-1, for illustrative purposes only, the proportion of strays was taken as 0.2 and the proportion of those then exposed to the Scheme caused impacts and killed (or had equivalent impaired breeding success) was 0.2. Under these circumstances the resulting compliance in 2022 becomes 19.2%, compared with 20% with no DP-related losses. Repeating this calculation assuming, for example, 50% stray and of those 50% are lost by virtue of where they stray to and the level of impact they experience gives a compliance reduced to 15%. Ranges of other values were used to cover scenarios (Table 5-2).

Table 5-2 Estimation of Estimated % CL compliance in the Itchen 2022 (observed compliance 20%) attributable to DP-related effects over a range of Itchen straying rates (0.05 to 0.80) and Impacts as loss of breeders or breeding effectiveness (0.1 to 1.0).

Proportion that stary into ZoI	Impact (= proportion of strays lost)				
	0.1	**0.2**	**0.5**	**0.7**	**1.0**
0.05	19.9	19.8	19.5	19.3	19.0
0.10	19.8	19.6	19.0	18.6	18.0
0.20	19.6	19.2	18.0	17.2	16.0
0.30	19.4	18.8	17.0	15.8	14.0
0.50	19.0	18.0	15.0	13.0	10.0
0.60	18.8	17.6	14.0	11.6	8.0
0.80	18.4	16.8	12.0	8.8	4.0

Interpretation of Table 5-2 is qualitative and subjective but it obliges consideration of plausible scenarios. The results do not include the effects of salmon (of Test- or Itchen-origin) lost to Test breeding. The latter impacts would be lagged by 3-4 years and therefore would not figure in the immediate annual losses to which the table refers. We cannot locate with confidence where in the tables the impacts lie, but scenarios can be envisaged and compared. For example, if 50% of Itchen salmon strayed, is it reasonable to assume that all of those will remain are in a ZoI zone where the conditions cause 100% mortality, leading to 10% CL compliance (Table 5-2)? Possibly not, given what is known about avoidance behaviour because barrier effects will trigger the pathway of migration delays and losses from that, but unlikely to be 100%. The question then becomes how intense is the oxy-thermal barrier and where is it? And consider if 80% of the Itchen run strayed but only as far as the top of Zone 4, would they suffer high mortality or experience the barrier effect? From what we know about likely WQ there (which is quite little unfortunately) they probably would not die but might drop back to the Itchen or be prevented from upstream migration in either channel and displaced possibly leading to some loss by that route, or find their way to the Itchen, which route could be also blocked if the WQ deterioration reported there (Longley 2024) was occurring, but not by the DP impacts. The extremes of assumptions can also be made where, say, 80% stray and all are killed, but this stretches to implausibility current understanding of stray rates, salmon behaviour and WQ predictions. In relation to the DP, a further link not covered by this simple model is the contribution that the DP makes to the intensity and distribution of harmful environmental conditions. This remains a critical unknown, but it directly affects the attribution of its impact on SAC salmon feature for the purposes of the HRA.

Salmon populations have natural resilience, i.e. a capacity to recover from perturbations even from levels that are low compared with the population's Conservation Limit (CL). This is a fundamental property of salmon population dynamics and is the basic assumption behind all salmon restoration programmes which, if carried out effectively and remove limiting factors, demonstrably allows salmon populations to recover from sometimes very low levels, well below the CL (Mawle and Milner 2003). However, on the Itchen and on its co-river the Test, other pressures, including the overarching effects of marine climate change have not all been lifted or even satisfactorily identified, so more precaution should be applied to protect salmon.

The CL is an indicative threshold Biological Reference Point recommended by NASCO and adopted by Defra, EA and NRW, below which it is recommended not to go, and should not be interpreted or presented as a point below which populations collapse suddenly, but the risk of collapse increases rapidly as populations decrease below it (Milner and Garcia de Leaniz, 2022). This is recognised in the interpretation of the NASCO Guidance (Cefas / EA / NRW, 2023). The policy interpretation follows the Precautionary Approach adopted by NASCO and its Parties (of which the UK is one) in 1998 and for "At Risk" populations (like the Itchen) require urgent actions of achieving zero exploitation and looking to maintain socio-economic benefits where possible.

A comment on assessment of multiple pressures on Itchen and Test

The DP/DO impacts should be evaluated realistically and in context of multiple pressures in freshwater, estuaries and at sea. For example, impacts on salmon arise every year through angling, which even with 100% catch and release, assuming survival of 80% to spawning, 50% females and recent declared rod catch of 257 (average 2010 - 2021), gives a loss of 26 female salmon on the Itchen. In 2022, with an RSE of 133 the estimated loss was 7 adults. To this can be added the further sublethal loss of reproductive success resulting from the stress of capture and release which can be up to 30% loss (Bouchard et al 2022). This is important in rivers like the Test and especially the Itchen where rod exploitation is high. Rod effects are used only for illustration because they allow some reasonably straightforward estimation. Other pressures in freshwater may be more important and as shown in section 2.1 marine survival rates have decreased by x3 to x5 over the last 40 years almost certainly a signal of marine climate effects. The Itchen/Test status and unique dependencies require a multifactorial approach to protect and restore the populations. Although it has not been possible to assess the Meon population, because it is a very small salmon population it has proportionally higher extirpation risk (Verspoor et al 2007; Schtickzelle and Quinn, 2007). Thus, if major reduction to the Itchen and Test populations occurred for whatever reason (Note: this is not being implied in relation to the DP) that would greatly increase the risk to the Meon population.

6. Summary

1. The Rivers Itchen and Test are adjacent lying within Southampton water and have salmon populations that are genetically very close showing common long-term trends with some river-specific variation.
2. Salmon abundance has declined since 2015 in both rivers and both populations are formally classed by the Environment Agency as being "*At Risk*". The Itchen was at 20% of its Conservation Limit in 2022 and provisionally estimated at 37% in 2024.
3. Any further impacts on population at such low levels are of concern because they already have low resilience and capacity for recovery. This status alone threatens the integrity of the Itchen SAC salmon feature, which is subject to multiple pressures in addition to the DP.
4. There are many causes of this decline, in freshwater and at sea but they are poorly quantified, and their effects are not easily separated. Pan-Atlantic climate change factors have reduced freshwater habitat quality and marine survival in recent decades, and these are widely considered to be major factors in salmon decline in these southern rivers, on top of damage through catchment and water use practices.
5. If DP implementation exacerbates the environmental conditions of droughts and hot weather that would act on the SAC salmon feature through multiple pathways both on Itchen salmon directly and indirectly via the Test population which is shown to have an important role as a source or breeding salmon for the Itchen by virtue of its larger x2.2) population coupled with plausible stray rates.
6. Harm could arise in a year of DP implementation if straying salmon destined to spawn in the Itchen (including any Test-origin salmon as presumptive spawners in the Itchen) were exposed to DP-related risk factors in the ZoI.
7. In addition, lagged effects could arise (3-4 year approx.) if presumptive Test spawners (of mixed Test and Itchen origin) were killed or suffered reduced breeding effectiveness in the year of DP operation.
8. Harm could result from unresolved combinations of (i) *in situ* mortality if severe conditions (principally but not exclusively high temperature and low DO, predation, poaching) coincide with salmon presence; (ii) cessation of migration and sublethal effects through stress-related impacts on health and reproductive biology; (iii) displacement of salmon avoiding poor water quality and high temperatures to the lower estuary or to coastal waters followed by mortality and permanent loss of spawners, or delayed return as spawners, as autumn flows increase, likely to be accompanied by sublethal effects as in (ii). Of these, poor WQ barrier and displacement effects are likely to be the most important.
9. Such losses of salmon occur naturally at times of drought and hot weather in many estuaries and offsite losses of displaced fish can be high (~ 50% annual run) and would arise without a DP and depending on its timing would precede or be concurrent with a DP implementation.

10. DP impacts on ZoI environment are not yet reliably predicted but recent studies indicate that harmful conditions (principally but not exclusively high-water temperature and low oxygen) would arise under certain conditions. The intensity and locations of these effects and the likelihood of simultaneous presence and exposure of salmon are not known.

11. None of the impact pathways connecting DP implementation and SAC salmon population responses can be quantified with any confidence due to the complexity of process and lack of data. However, given the poor state of the Itchen SAC stock and following NASCO guidance on the precautionary principle this would be a potentially significant pressure factor on the population. Therefore, impacts on the integrity of the SAC salmon feature cannot be ruled out without effective mitigation.

7. Conclusions and information needs

1. Assessment of potential impacts of the DP on Itchen SAC salmon feature, given potential straying and exchange levels and risks of exposure to harmful environments in the ZoI, indicates that there is a risk of loss of salmon spawners due to DP-related effects acting on fish of both Itchen and Test origin. Therefore, given the already critical state of Itchen salmon and the necessity to apply the Precautionary Approach, the conclusion is that impacts on the integrity of the SAC salmon feature cannot be ruled out without effective mitigation.
2. It has not been possible to quantify the level of losses potentially attributable to the DP because the assessment has been constrained by lack of data and reliable observations on almost all key questions that it has addressed.
3. Future information needs. The Itchen and test are unusual rivers and, in some respects, may not be well-characterised by studies in other rivers, even neighbouring chalk rivers. Robust assessment needs better data on (i) baseline habitat and WQ environment throughout the ZoI, not just a focus on the upper reaches. (ii) Baseline migration behaviours, timing (at seasonal and diurnal/tidal scales), holding, straying and exchange between Test and Itchen and neighbouring rivers. A specific recommendation is to consider PIT tagging to learn more about exchange and homing. (iii) Modelling of DP effects on WQ and habitat throughout the ZoI. (iv) Behavioural and physiological responses of adults to changes in oxy-thermal conditions. (v) Inventory and assessment of population status and multiple pressures in freshwater, estuary and at sea across the life cycle stages using full life cycle models. (vi) Demo-genetic modelling of the source-sink processes linking Test and Itchen populations is also recommended to combine those two approaches.
4. The DP impact is judged to exert impacts on the SAC integrity so importantly its resolution would remove one risk factor but would not guarantee a recovery or even protection of these vulnerable salmon populations. They are in jeopardy for many reasons outlined in this Technical Note, of which river flow, whilst important, hereto has not been the major factor. Protection of these unique stocks requires a nuanced, objective and detailed evaluation supported by better monitoring, investigation and multifactorial modelling, in a collaborative approach.

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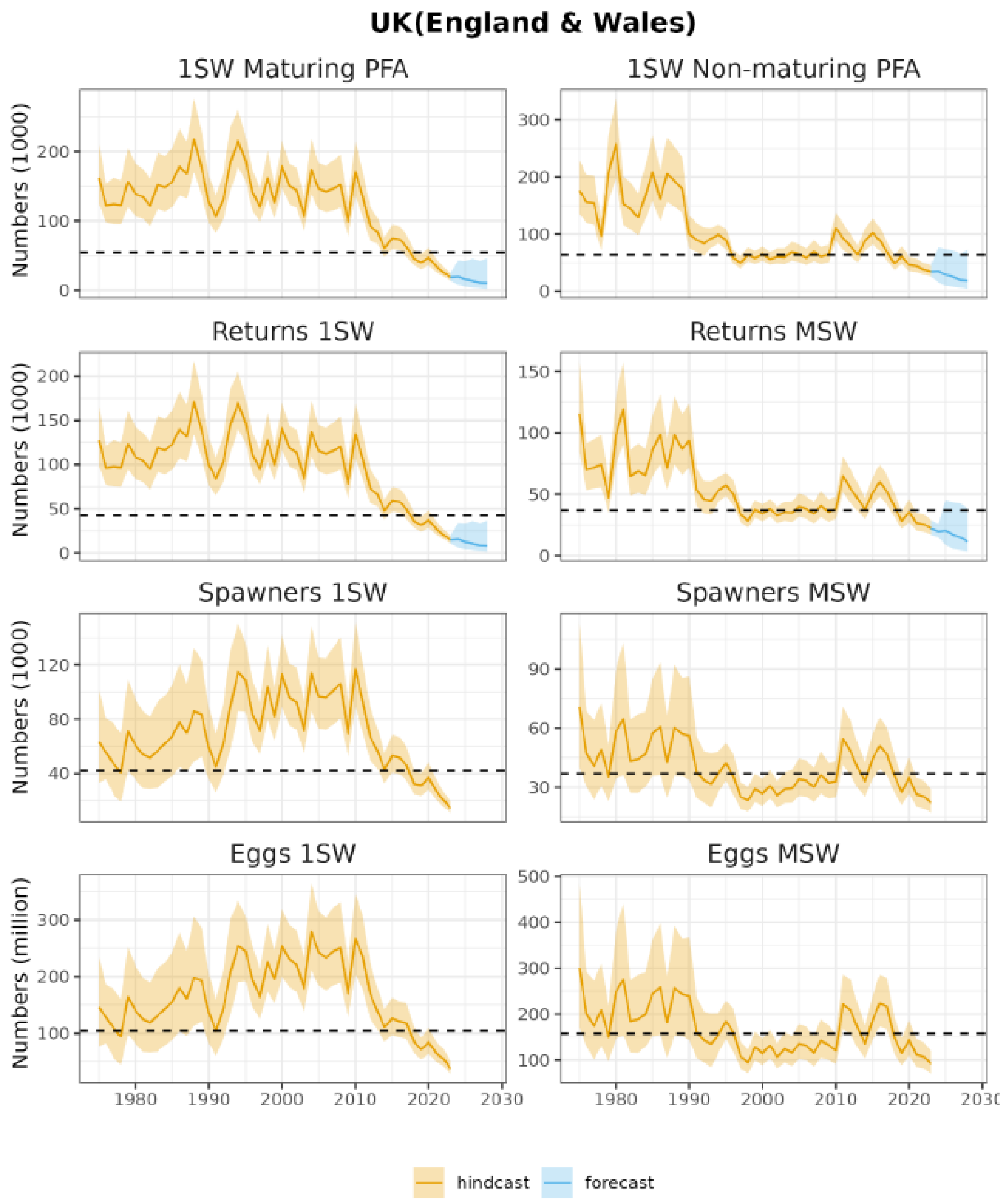
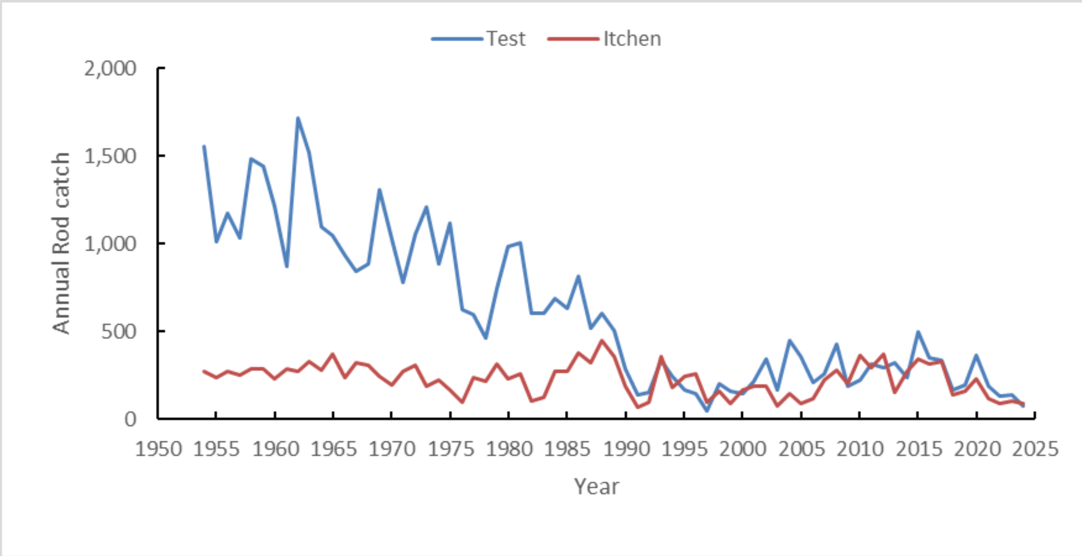
Appendix A

Appendix Table 1 Tidal streams in the Severn estuary (from West Coast Pilot) and off Hythe Pier, Southampton Water, approximately opposite the Itchen estuary

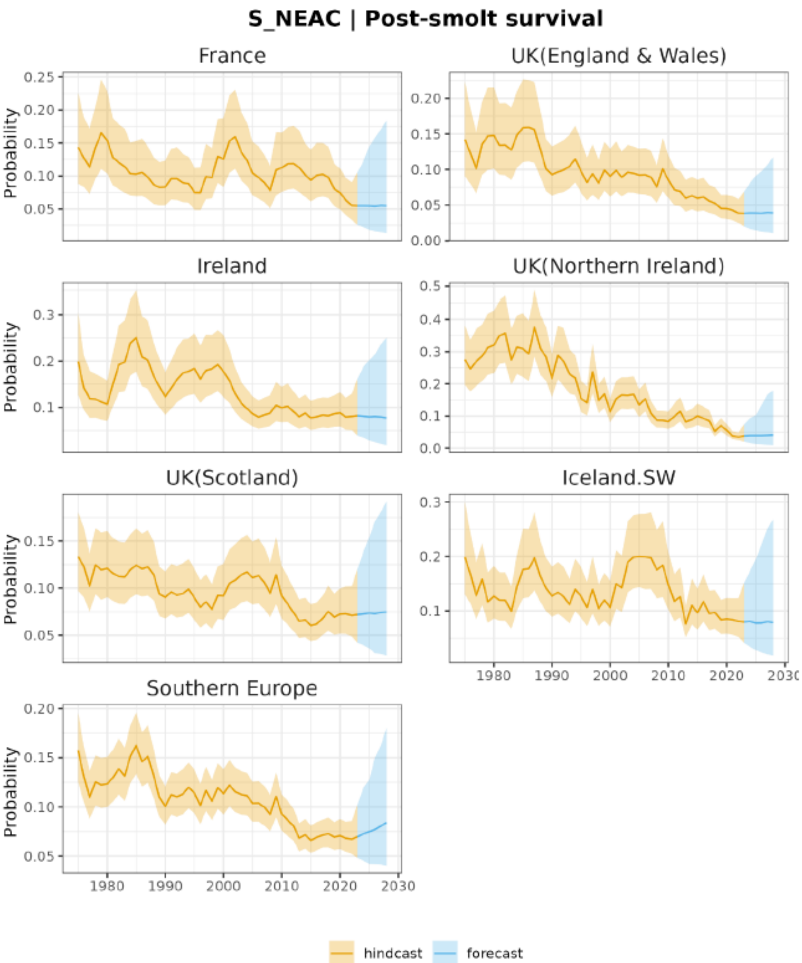
	Spring tide velocity (knots) and direction (degrees)		Neap tide velocity (knots)	
Location	**Flood**	**Ebb**	**Flood**	**Ebb**
Severn				
1ml SW of Middle Ground, approx. opposite Usk entrance	4.0 (048)	3.6 (228)	2.1	1.9
Western approach t¬¬o Kings Road Off Portishead approx. 7ml SW of Wye entrance	4.8 (057)	2.6 (236)	4.0	2.2
Off entrance to River Avon	5.0	4.0	-	-
Southampton Water	1.1	1.9	0.6	0.9



Appendix Figure 1 **Figure and legend from ICES (2025). UK (England & Wales). 1SW maturing and 1SW non-maturing PFA, returns of 1SW and MSW fish, 1SW and MSW spawners, and egg deposition from 1SW and MSW spawners, derived from the LCM. Solid line: median of the marginal posterior distributions. Shaded area: 90% Bayesian credibility interval. Orange shaded area: hindcasting of the historical time-series. Blue shaded area: forecasting obtained under a scenario with zero catches in all fisheries (for PFA and returns). The horizontal dotted black lines are the age-specific SER values (in number of fish; PFA panels), the age-specific conservation limits (in number of fish; spawner and return panels) and the age-specific conservation limits (in eggs; eggs panels). Year refers to year of return with the exception of PFA non-maturing which is year of return minus one.**

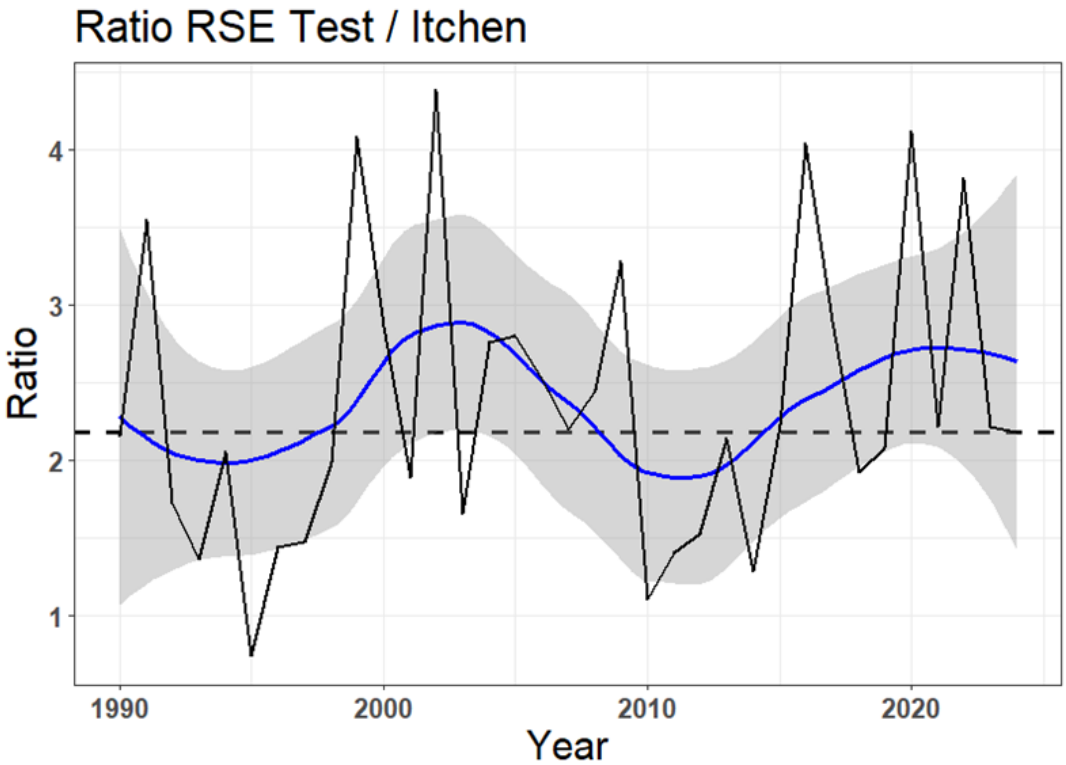


Appendix Figure 2 Declared rod salmon catches in the rivers Test and Itchen 1954 to 2024.

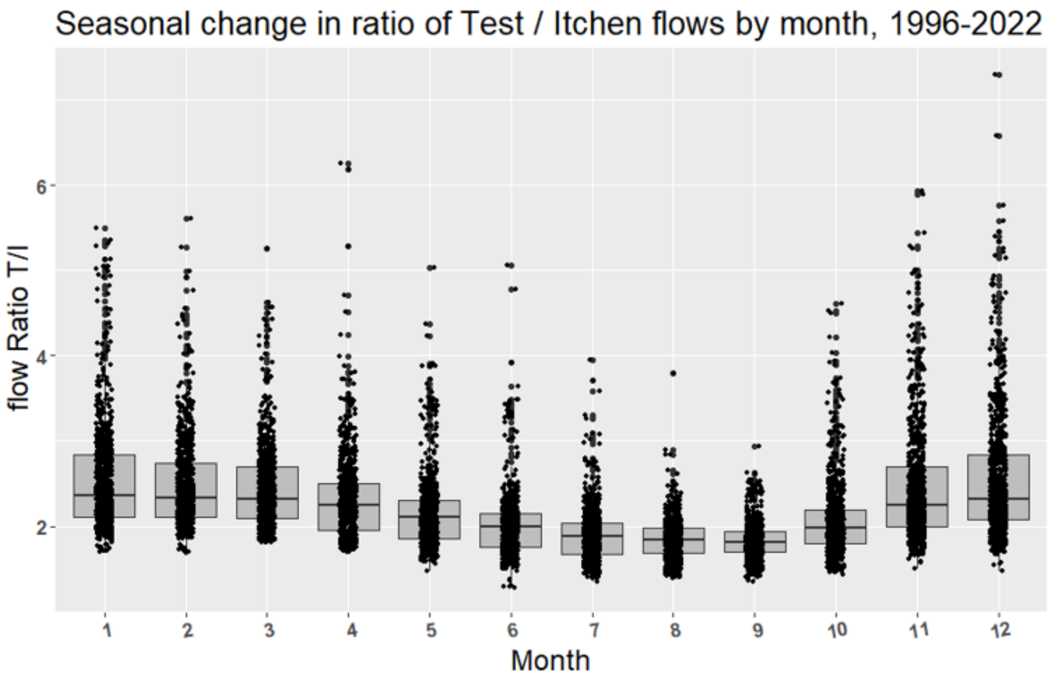


Appendix Figure 3 Figure and legend from ICES (2025). Post-smolt survival for all countries in Southern NEAC and for the Southern NEAC complex, derived from the LCM.

Years are smolt migration years. Solid line: median of the marginal posterior distributions. Shaded area: 90% Bayesian credibility interval.



Appendix Figure 4 Long term (1990 – 2024) variation in ratio of Test RSE to Itchen RSE. Dashed line is long term median = 2.18. Loess smoother is loess, span 0.6) with 95% ci in shaded area.



Appendix Figure 5. Monthly variation in the ratio of Test to Itchen daily mean flows, 1996 to 2022.

Appendix Table 2 **Itchen flows and Central England Temperatures 1990 to 2022. Blue Arrow and block show years of Solomon *et al*. (1999) tracking studies. Itchen/ Test tracking (Horsfield, 1994) was in 1991.**

Itchen flows (Ml/d), red low flow

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	504.9	554.0	543.2	517.0	412.5	354.5	296.4	277.6	288.7	279.0	307.2	342.0
1981	390.8	398.5	426.1	554.8	479.1	420.8	362.4	310.3	297.1	380.9	421.5	462.2
1982	601.7	588.0	599.3	519.4	424.6	360.8	299.1	280.3	258.6	290.0	437.7	687.7
1983	784.9	664.0	564.0	542.5	495.2	424.7	356.9	315.3	298.4	295.0	296.5	323.6
1984	414.2	629.4	548.6	490.8	447.6	349.7	291.2	253.6	256.6	275.4	330.4	457.2
1985	585.6	663.5	563.5	553.2	434.9	387.9	311.1	331.7	302.7	297.1	282.7	324.3
1986	559.8	595.1	541.0	502.4	470.5	357.2	344.9	313.5	288.3	278.1	297.0	441.8
1987	552.4	478.8	464.1	535.4	439.7	355.5	290.2	260.2	248.6	245.5	393.6	467.2
1988	518.0	797.9	685.6	567.8	444.4	331.3	338.2	291.9	294.7	298.7	313.4	315.4
1989	305.3	298.2	402.7	506.4	449.7	279.0	222.2	218.6	227.0	223.0	237.4	222.0
1990	395.9	751.9	629.1	471.0	381.6	328.8	240.2	223.8	225.1	228.5	248.7	258.1
1991	356.5	378.2	416.9	466.2	358.5	315.2	234.5	234.3	236.6	258.0	248.7	297.1
1992	300.8	290.6	300.2	288.9	253.5	205.8	207.2	204.6	247.0	247.6	281.8	561.4
1993	592.5	582.8	471.2	506.9	450.4	356.7	312.4	294.3	284.4	436.2	432.0	509.8
1994	780.8	837.7	692.7	671.8	654.9	431.6	347.5	332.3	332.7	311.0	443.5	471.2
1995	579.0	1000.5	855.8	637.9	488.5	315.2	279.1	245.3	260.8	306.8	298.2	406.6
1996	487.2	538.1	577.9	498.9	425.2	310.5	247.1	255.6	238.2	250.8	285.1	396.5
1997	358.3	358.9	458.4	367.3	291.1	260.9	234.7	222.5	219.3	236.6	240.5	353.7
1998	540.0	513.3	501.5	521.7	448.0	380.2	320.7	280.3	264.2	289.4	430.0	486.9
1999	610.1	713.8	575.5	480.2	410.7	337.8	263.3	261.2	276.7	360.5	397.7	396.3
2000	601.0	583.3	557.0	557.8	660.8	500.4	414.9	348.8	338.8	376.7	670.3	1055.8
2001	1035.1	1122.3	964.2	968.5	687.2	525.5	407.9	379.7	350.0	384.0	433.4	463.1
2002	435.4	570.4	637.2	520.5	485.4	418.3	364.4	338.4	311.3	301.8	381.2	737.9
2003	994.5	783.3	641.7	546.4	439.3	365.0	305.9	274.7	273.6	256.4	292.2	447.8
2004	490.8	667.9	554.7	509.8	440.6	360.3	295.5	279.9	295.5	316.2	412.1	396.6
2005	439.8	425.1	386.2	356.0	298.9	232.4	212.5	220.3	222.9	242.8	332.6	374.1
2006	378.4	368.9	384.5	395.7	362.9	302.4	245.4	231.6	221.2	259.2	307.6	577.2
2007	625.9	717.0	766.5	521.9	435.6	395.1	429.8	441.3	400.0	381.1	355.6	456.5
2008	509.4	606.2	581.1	556.9	469.5	483.3	404.1	394.2	390.3	391.7	428.7	493.1
2009	505.8	669.6	625.0	533.2	412.0	326.0	313.2	289.4	280.1	277.3	315.0	634.1
2010	728.6	760.1	765.8	729.5	578.0	380.8	330.0	325.5	305.1	328.3	328.8	389.8
2011	379.1	491.3	486.1	383.4	346.8	314.8	274.4	266.5	288.6	282.7	288.7	296.5
2012	401.8	375.8	351.2	316.4	413.2	457.8	473.0	454.9	383.3	434.0	581.6	789.0
2013	918.4	889.1	782.6	645.6	538.2	436.8	342.7	317.8	300.8	303.3	375.4	366.0
2014	927.1	1353.0	974.6	804.4	631.8	474.6	352.8	347.2	334.2	334.4	387.9	599.6
2015	654.9	711.9	640.2	527.9	424.2	345.6	328.3	318.0	350.8	356.8	402.6	437.2
2016	588.4	786.2	732.7	681.7	551.2	502.0	403.5	358.6	354.2	326.4	324.9	358.7
2017	368.8	472.6	508.9	432.7	382.1	293.1	288.1	337.8	335.7	327.4	332.9	336.0
2018	506.2	569.7	577.2	738.3	553.9	390.9	312.9	308.4	289.4	284.4	281.5	373.2
2019	446.5	462.2	519.3	491.2	408.9	351.0	286.5	264.4	256.3	333.1	427.2	514.3
2020	823.8	875.2	967.7	740.7	514.3	417.5	338.9	304.0	348.6	389.7	592.4	682.2
2021	796.5	902.2	737.5	577.2	500.4	441.0	454.9	440.9	418.4	457.2	518.6	517.5
2022	568.3	560.6	594.3	522.7	431.4	374.2	289.5	260.6	276.0	294.0	369.1	506.2

Central England Temperature ºC, red high temp

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	2.3	5.8	4.7	8.8	11.2	13.8	14.6	15.9	14.6	8.8	6.4	5.4
1981	4.8	3.0	7.9	7.8	11.2	13.1	15.5	16.3	14.4	8.3	7.6	0.1
1982	2.7	4.8	6.0	8.6	11.6	15.5	16.4	15.7	14.1	9.9	7.7	4.1
1983	6.7	1.8	6.4	6.8	10.3	14.3	19.4	17.4	13.7	10.3	7.4	5.4
1984	3.9	3.4	4.7	8.1	9.9	14.3	16.8	17.7	13.6	11.0	7.8	5.1
1985	0.9	2.2	4.7	8.3	10.9	12.6	16.1	14.7	14.6	10.8	3.9	6.2
1986	3.5	-1.0	5.0	5.8	11.0	14.7	15.7	13.7	11.3	10.8	7.6	6.1
1987	0.8	3.6	4.1	10.3	10.1	12.7	15.8	15.6	13.6	9.5	6.4	5.4
1988	5.3	4.9	6.4	8.2	11.9	14.2	14.6	15.2	13.2	10.3	5.0	7.3
1989	6.1	6.0	7.5	6.6	12.9	14.4	18.1	16.6	14.6	11.5	6.0	4.7
1990	6.5	7.3	8.3	8.0	12.6	13.5	16.8	18.0	13.2	11.7	6.7	4.1
1991	3.2	1.6	7.8	7.9	10.7	11.9	17.1	17.1	14.6	10.0	6.6	4.5
1992	3.6	5.4	7.5	8.7	13.6	15.7	16.1	15.3	13.3	7.7	7.2	3.4
1993	5.9	4.7	6.6	9.4	11.5	15.0	15.1	14.6	12.3	8.3	4.5	5.3
1994	5.3	3.2	7.6	8.0	10.7	14.4	18.0	16.0	12.7	10.0	9.9	6.2
1995	4.8	6.5	5.5	9.1	11.6	14.2	18.5	19.1	13.6	12.8	7.5	2.1
1996	4.3	2.5	4.5	8.6	9.2	14.4	16.4	16.6	13.6	11.5	5.7	2.7
1997	2.4	6.7	8.3	9.0	11.5	14.0	16.6	19.0	14.2	10.0	8.2	5.7
1998	5.1	7.2	7.8	7.7	13.1	14.1	15.4	16.0	14.8	10.4	6.0	5.4
1999	5.5	5.3	7.3	9.4	12.9	13.8	17.5	16.2	15.6	10.6	7.7	4.8
2000	4.9	6.2	7.5	7.7	12.1	14.9	15.3	16.7	14.7	10.2	6.8	5.3
2001	3.2	4.3	5.2	7.7	12.5	14.2	17.1	16.8	13.4	13.2	7.5	3.4
2002	5.5	7.0	7.6	9.3	11.8	14.3	15.8	17.0	14.4	10.0	8.4	5.6
2003	4.5	3.9	7.5	9.6	12.0	15.9	17.4	18.3	14.3	9.1	8.0	4.6
2004	5.2	5.4	6.5	9.4	12.1	15.3	15.7	17.6	14.9	10.4	7.6	5.3
2005	5.9	4.3	7.1	8.9	11.3	15.8	16.8	16.2	15.2	13.0	6.1	4.3
2006	4.4	3.9	5.0	8.6	12.3	15.8	19.8	16.2	16.8	12.9	8.0	6.4
2007	7.0	5.9	7.3	11.2	11.9	15.1	15.3	15.5	13.9	10.7	7.2	4.9
2008	6.6	5.6	6.1	8.0	13.4	13.9	16.4	16.3	13.5	9.6	7.0	3.5
2009	3.1	4.3	7.1	10.0	12.1	14.7	16.3	16.7	14.3	11.4	8.6	3.0
2010	1.5	2.9	6.2	8.9	10.7	15.2	17.2	15.4	13.8	10.2	5.1	-0.7
2011	3.7	6.5	6.8	11.9	12.2	13.7	15.3	15.5	15.1	12.5	9.5	5.9
2012	5.5	4.0	8.3	7.3	11.8	13.5	15.6	16.7	13.0	9.5	6.8	4.7
2013	3.5	3.3	2.8	7.5	10.5	13.6	18.5	17.0	13.7	12.4	6.1	6.3
2014	5.7	6.3	7.7	10.3	12.3	15.1	17.9	15.1	15.1	12.3	8.5	5.1
2015	4.5	4.2	6.5	9.1	10.8	13.9	16.0	16.0	12.7	10.9	9.4	9.6
2016	5.5	5.1	5.8	7.5	12.6	15.2	17.0	17.1	16.1	10.7	5.5	5.9
2017	4.0	6.2	8.8	8.9	13.3	16.0	16.9	15.7	13.6	12.2	6.8	4.7
2018	5.3	3.1	5.0	9.9	13.3	16.1	19.3	16.8	13.7	10.5	8.3	6.8
2019	4.0	6.9	7.9	9.1	11.2	14.2	17.6	17.2	14.3	9.8	6.2	5.7
2020	6.4	6.4	6.8	10.5	12.6	15.3	15.8	17.7	14.0	10.4	8.5	4.9
2021	3.2	5.3	7.3	6.5	10.3	15.5	17.8	16.0	16.0	12.0	7.2	6.3
2022	4.7	6.9	8.0	9.2	13.1	14.9	18.2	18.7	14.5	12.8	9.2	3.4