Chapter 12
Water Abstraction from the River Itchen, Hampshire, United Kingdom

Jonathan Cox and Ece Özdemiroğlu

Abstract The River Itchen is a classic chalk river arising from the chalk aquifer of the Hampshire Downs in central southern England. It is world famous for its fly fishing for trout and Atlantic salmon and was where the techniques of dry fly fishing were first developed in the early 20th century. The river has been used for centuries as a source of power, to irrigate flood plain water meadows and as a source of drinking water. These various uses have had a range of effects on the river and its associated wetlands but despite these many changes it retains a rich biodiversity. This case considers predicted future impacts of abstraction (extraction) for public water supply. This could be an example of 'imminent threat' as defined in the Environmental Liability Directive (Article 2—'sufficient likelihood that environmental damage will occur in the near future'). The removal of water from the river results in reduced water levels and most importantly, reduced flow velocity. This causes a range of effects on the river including increased temperature, reduced oxygen concentration and increased concentration of plant nutrients, particularly phosphate, and other contaminants. Previous investigations have shown that in naturally dry years water abstraction has the potential to cause damage to the populations of Atlantic salmon and the floating *Ranunculus* habitat of the river. This case study uses habitat and resource equivalency analyses to estimate the damage and select compensatory remediation. The economic value of Atlantic salmon is also presented.

Keywords Habitat equivalency analysis · Resource equivalency analysis
Value transfer · Water abstraction · Salmon · Floating *Ranunculus*

J. Cox (✉)
Jonathan Cox Associates, Fig House, Poles Lane, Lymington
Hampshire SO41 8AB, UK
e-mail: jonathan_cox@btconnect.com

E. Özdemiroğlu
eftec, 4 City Road, London EC1Y 2AA, UK
e-mail: ece@eftec.co.uk

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12.1 Introduction

The River Itchen is a classic chalk river arising from the chalk aquifer of the Hampshire Downs in central southern England. It is world famous for its fly fishing for trout and Atlantic salmon and was the location where dry fly fishing techniques were first developed in the early 20th century. The river has been used for centuries as a source of power, to irrigate floodplain water meadows, and as a source of drinking water. These various uses have had a variety of effects on the river and its associated wetlands. Despite these many changes, the river retains a rich biodiversity.

The river and its associated wetland habitats have been selected as a Natura 2000 site (Special Area of Conservation, SAC) for their representation of the floating *Ranunculus* habitat (listed on Annex I of the European Union Habitats Directive (HD); Fig. 12.1) and for their populations of six species listed in Annex II of the HD, namely:

- Atlantic salmon (*Salmo salar*);
- Bullhead (*Cottus gobio*);
- Brook lamprey (*Lamperta planeri*);
- White-clawed crayfish (*Austropotamobius pallipes*);
- Southern damselfly (*Coenagrion mercuriale*); and
- Otter (*Lutra lutra*).

Fig. 12.1 Floating *Ranunculus* flowering in the River Itchen (copyright Jon Milliken)

The floating *Ranunculus* habitat is characterised by the abundance of water crowfoots *Ranunculus* spp., subgenus *Batrachium* (*R. fluitans*, *R. penicillatus* ssp. *penicillatus*, *R. penicillatus* ssp. *pseudofluitans* and *R. peltatus* and its hybrids). Floating mats of these white-flowered species are characteristic of river channels in early to mid-summer. They may modify water flow, promote fine sediment deposition, and provide shelter and food for fish and invertebrate animals.

Three subtypes of this habitat in the United Kingdom have been described, depending on geology and river type. In each, *Ranunculus* species are associated with a different assemblage of other aquatic plants, such as watercress (*Rorippa nasturtium-aquaticum*), water starworts (*Callitriche* spp.), water parsnips (*Sium latifolium* and *Berula erecta*), water milfoils (*Myriophyllum* spp.), and water forget-me-not (*Myosotis scorpioides*). In some rivers, the cover of these species may exceed that of *Ranunculus* species.

The *Ranunculus* habitat found within the River Itchen provides one of the best examples of subtype 1 in the United Kingdom. Subtype 1 is found on rivers on chalk substrates. The community is characterised by pond water crowfoot (*Ranunculus peltatus*) in spring-fed headwater streams (winterbournes), stream water crowfoot (*R. penicillatus* ssp. *pseudofluitans*) in the middle reaches, and river water crowfoot (*R. fluitans*) in the downstream sections. *Ranunculus* is typically associated in the upper and middle reaches with (*Callitriche obtusangula*) and (*C. platycarpa*).

Water is abstracted from the River Itchen for public water supply at a number of locations in the river's catchment. Seven abstraction licenses have been reviewed by the Environment Agency for England and Wales (EA), with the largest located in the lower Itchen at Twyford, Otterbourne, and Gaters Mill (Fig. 12.2). Water is taken from both the groundwater aquifer and directly from the river (Table 12.1).

Groundwater abstraction at Otterbourne has been shown to have an almost instantaneous impact on river flows due to the close proximity of the wells, adits, and boreholes into the river. Abstraction at Twyford is further away from the river but is likely to have a rapid impact on groundwater flow toward the river.

The HD requires Competent Authorities to review consents considered likely to have a significant effect on Natura 2000 sites. The EA has reviewed consents for water abstraction from the catchment of the River Itchen SAC in accordance with Article 6 of the HD. This has shown that abstraction for public water supply is likely to adversely affect the river's integrity.

For the purposes of this case study, it has been assumed that consents for abstraction for public water supply will be confirmed, despite the negative assessment. As a consequence, compensation would be required to offset adverse effects, in accordance with Article 6(4) of the HD. Alternatively, if the HD did not apply, the anticipated damage due to continued abstraction in the future could be defined as imminent threat under the Environmental Liability Directive (ELD). Article 2 of the ELD defines imminent threat as 'sufficient likelihood that environmental damage will occur in the near future'.

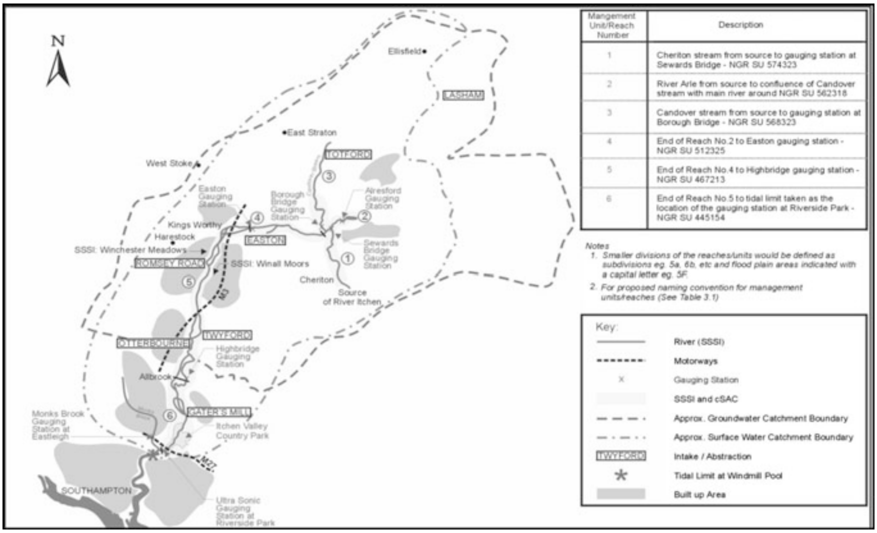

Fig. 12.2 River Itchen catchment showing abstraction points and management units (MUs 1 through 6)

Table 12.1 Water Abstraction, River Itchen—Summary of licensed water abstraction from the catchment for public water supply

	Daily licence (Ml/d)	Annual licence (Ml)
Upper Itchen		
Lasham	27.3	5,455
Totford	4.5	1,659
Easton (Itchen Valley and Winchester)	27.3	6,637
Lower Itchen		
Twyford	36.4	13,320
Otterbourne (including Twyford Moors)	71.6	212,230
Otterbourne surface water	45.5	16,639
Gaters Mill	45.5	16,638

Ml mega liter; *Ml/d* mega liter per day

This short case study demonstrated methods for calculating the magnitude of environmental damage (debit) using two approaches:

- Habitat Equivalency Analysis (HEA) approach using the health of the aquatic macroinvertebrate community as a surrogate for the condition of the floating *Ranunculus* habitat, and
- Resource Equivalency Analysis (REA) approach using predicted numbers of returning Atlantic salmon as a metric.

The economic value of the damage to Atlantic salmon is also shown.

Sensitivity of the debit calculation was investigated using different metrics of invertebrate community structure to measure changes caused by consented maximum water abstraction rates. Credits to compensate for the impact of abstraction were calculated using river restoration works as a chosen remediation method.

The quantum of remediation required was calculated using, both HEA and REA, as done for debit calculation. Differences in the magnitude of compensation estimated through different equivalency approaches to are discussed and compared with economic value of Atlantic salmon (using value transfer of existing evidence —see Chap. 8 for definition of value transfer).

12.2 Initial Evaluation: The Impact

Unlike *ex post* cases considered under the ELD, this case considers predicted future impacts of abstraction for public water supply, as illustrated in Table 12.1. These impacts were not yet observed, as the license holders had not found it necessary to abstract the full volume permitted by their licenses. However, with growing demand for water, it is expected that abstraction quantities will increase in future years. In addition, it is predicted that damage to river biodiversity will become increasingly evident.

The effects of water abstraction on the river ecosystem are complex. Water is taken from the river either directly as surface water or from natural groundwater reservoirs or aquifers. In places, the groundwater abstraction points are immediately adjacent to the river; hence there is hydrological continuity between groundwater and surface water.

The removal of water from the river results in lowered water levels and, most importantly, reduced flow velocity. This causes a range of effects on the river including increased temperature, reduced oxygen concentration, and increased concentration of plant nutrients, particularly phosphate and other contaminants.

The impacts of low flows on the river ecology were investigated as part of the Itchen Sustainability Study (River Itchen Study Group 2004) and subsequently as part of the Review of Consents undertaken by the EA. These investigations have shown that, in naturally dry years, water abstraction has the potential to cause damage to the populations of Atlantic salmon and the river's floating *Ranunculus* habitat.

Impacts to the salmon population will result from reduced numbers of salmon returning from the marine environment, as well as reduced spawning success and survival rates.

Impacts on the habitat were measured by reference to changes in the aquatic macroinvertebrate community. This type of community is typically rich and diverse in chalk rivers and is characterised by a number of species that are dependent on highly oxygenated, swiftly flowing water. Flow thresholds were identified by reference to observed changes in the invertebrate community in high- and low-flow years. The use of invertebrate community data to assess the quality of rivers in general and chalk river habitats in particular was well investigated (Exley 2003; Extence 1981; Extence et al. 1999; Nijboer et al. 2005).

12.3 Determining the Debits

In this section, we consider the baseline situation in the SAC by reference to both the floating *Ranunculus* habitat and the Atlantic salmon population. Because this case study addresses an *ex ante* damage event, baseline conditions are defined as the conditions expected to prevail at the time that full licensed abstractions are initiated. We used current (and recent past) conditions in the river to quantify this baseline. We then considered the impact of full licensed water abstraction on predicted flows in the river. The modelling results were used to estimate the number of salmon that might be expected to fail to return to the river as a consequence of abstraction. Aquatic macroinvertebrate sampling data were analysed in order to identify target flows, below which damage can be expected to occur to the floating *Ranunculus* habitat.

12.3.1 *Floating* Ranunculus *Habitat in the River Itchen*

Baseline—floating Ranunculus habitat

The river's *Ranunculus* habitat occurs throughout its length and can be assumed as being ubiquitous. However, the condition of the habitat within the river varies and, in some instances, is not in Favourable Conservation Status (FCS). The aquatic macroinvertebrate community present in the river can be considered 'typical species' as defined by Article I of the HD and provide a good indication of the ecological structure and function of the river. As such, they can be used to assess the conservation status of the *Ranunculus* habitat and of the general health of the river (Environment Agency 2004). Analyses of macroinvertebrate survey results related to data on flow provided a powerful tool by which the impact of flow on the aquatic macroinvertebrate community can be predicted and hence act as a surrogate for the conservation status of the habitat.

Summer low flow is a natural feature of the river, and the habitat is able to recover from these natural events[1] (Atkins 2006). However, low-flow events increase in frequency and severity as a consequence of water abstraction for public

[1]Low-flow events occur where flow drops below the long-term Q95 flow (the flow that is exceeded 95% of the time; measured in megalitres/day, or Ml/d). The Q95 is established by creating a flow-frequency curve for the river. Q95 is the flow that is exceeded 95% of the time.

water supply. Using the invertebrate model, a series of low-flow thresholds were set for the six management units in the river. Damage to the protected *Ranunculus* habitat is likely to occur if these are exceeded.

Table 12.2 shows the relationship between long-term flows and target flows for the six management units in the river using the target flow of 0.861 standardised units.[2] Figure 12.2 shows the locations of the management units (MUs); MU1, MU2, and MU3 are all tributaries of the main river. Upper and lower 95% confidence intervals (CI) are also shown.

Abstraction for public water supply that caused flows to fall below the target flow would result in damage to the *Ranunculus* habitat. Due to effects of river augmentation from non-consumptive water users (watercress and fish farms) and because most of the abstraction (83%) takes place in the lower river, the significant effect of abstraction is detectable only in the lower reaches of the river within MU5 and MU6.

To measure the effect of water abstraction on the *Ranunculus* habitat, the extent of the habitat within the river was calculated (Table 12.3). Due to the natural variation in macrophyte cover and composition, this was not considered a good indicator of the extent of the habitat. A better measure involved reference to river flow and bed character. Key flow-dependant invertebrate groups have been described for chalk rivers by Extence et al. (1999), namely, *Baetidae* (mayflies) (Fig. 12.3), *Elmidae* (riffle beetles), *Ephemerellidae* (mayflies), and *Ephemeridae* (mayflies). Invertebrate sampling in relation to habitat has shown that this group of flow-dependant invertebrates is most closely associated with certain river micro-habitats, described as *Ranunculus*, other submerged macrophytes, gravel, and sand.

These flow-dependent habitat types (or micro-habitats) have been used as components of the wider *Ranunculus* habitat for which the SAC has been selected. The EA (Exley 2006) mapped the extent of these micro-habitats in the river. Table 12.4 shows the distribution of *Ranunculus* across the MU5 and MU6 management units, and in total. To provide an area of habitat related to these percentages, the area of each section of river was measured from Geographic Information System (GIS) maps of the designated SAC.

Calculating the debit—floating Ranunculus habitat

Low-flow targets have been set for the two potentially affected sections of the river (MU5 and MU6) based on the invertebrate/flow model. Three targets or rules were established for each management unit. However, for ease of calculation in this case study, only the third rule was used to determine years when adverse effects on the integrity of the River Itchen SAC (damage) is likely to occur, as follows:

[2]Standardised flow units were established for the river by relating recorded flows to the long-term mean summer Q95 flow. Flows above the long-term mean scored >1 and flows below the long-term mean summer flow scored <1.

Table 12.2 Water Abstraction, River Itchen—Management unit specific summer Q95 flow thresholds (Ml/d) and target flows

Management unit as in Fig. 12.2	Long-term average summer Q95 (Ml/d)	0.861 Target		
		Lower confidence limit 0.719	Mean 0.861	Upper confidence limit 0.951
1	27.6	19.8	23.8	26.2
2	96.6	69.4	83.2	91.9
3	26.7	19.2	23.0	25.4
4	256.2	181.8	217.9	240.7
5	275.4	197.9	237.3	262.0
6	270.2	194.2	232.8	257.1

Table 12.3 Water Abstraction, River Itchen—Percentage cover of *Ranunculus* habitat per management unit of the River Itchen

	MU5 Main River	MU5 Navigation	MU6
Cover of *Ranunculus* habitat (%)	3	8	3

Fig. 12.3 Larvae of mayfly (*Baetidae*) (Courtesy of Kevin Exley, Environment Agency)

Table 12.4 Water Abstraction, River Itchen—Distribution of *Ranunculus* habitat within MU5 and MU6

	Total area of River (ha)	Percentage of *Ranunculus* habitat	Area of *Ranunculus* habitat (ha)
MU5	35.82	77.9%	27.90
MU5 navigation	10.37	77.5%	8.04
MU6	24.47	72.5%	17.74
Total area of habitat			**53.68**

Management Unit 5
Flow should not fall below 198 ML/d for any period of time
Management Unit 6
Flow should not fall below 194 ML/d for any period of time

Data were obtained for a 20-year period during which flows were monitored within the two MUs of the river that are threatened by water abstraction. Years in which low flows are predicted to exceed the target levels were identified within this period. For both MUs, the same years caused the target flow to be exceeded, providing a pattern of eight low-flow years during the 20-year period, as shown in Fig. 12.4.

This pattern was then projected forward to predict potential low-flow patterns over the next 20 years using 2008 as the base year. There are clearly a number of assumptions in this approach, perhaps most importantly, no account was taken of potential changes in the frequency of low-flow years due to climate change. To take these additional factors into consideration in the prediction of future low-flow events is beyond the scope of this case study. However, if such an equivalency analysis were to be performed in an actual situation, Competent Authorities may wish to consider future environmental states under climate change scenarios.

To estimate the magnitude of damage to the invertebrate community (and by implication the habitat) during low-flow years, comparison was made between four sets of variables (Exley 2004):

- Number of taxa (richness);
- Evenness (measured using the Shannon-Weaver index);
- Total invertebrate abundance; and
- Abundance of flow-dependent invertebrate groups in MU5 and MU6.

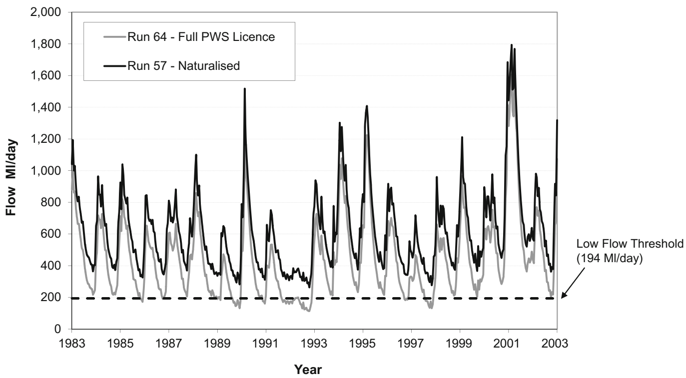

Fig. 12.4 Hydrograph for the lower River Itchen (1983–2002) for MU6 showing the frequency of modelled, naturalised low-flow years and the effects of public water supply licenses on breaching the low-flow threshold

Significant flow-related responses of the invertebrate community do not occur progressively with declining flow. However, they have been shown to occur only below a threshold flow band. All four variables were subjected to analysis of variance (ANOVA) tests and showed significant differences between above- and below-flow threshold years, as shown in Table 12.5. More details of the identification of the threshold flow are given in Appendix to this chapter.

ANOVA: analysis of variance

The percent change in both richness and evenness is of similar magnitude, while the abundance of individuals (both flow dependent and total invertebrate abundance) shows a much greater effect. To illustrate the effect of these two measures on the total damage and hence compensation requirement, an analysis was made using both the change in number of taxa (12.5%) and the change in the abundance of key invertebrate species (71%).

Having calculated the total area of habitat in the damaged sections of the river, the years when damage is predicted to occur (by projecting frequency and pattern of low-flow years from historic hydrograph), and the magnitude of the damage that occurs in low-flow years, it is possible to calculate the damage caused to the habitat each year. For the purposes of this case study, the two most extreme rates were used to calculate the annual loss of habitat service in low-flow years (12.5 and 71%). Other rates of change in the range, shown in Table 12.5, could also have been used and a mean taken. However, the change in flow-dependent species was considered

Table 12.5 Water Abstraction, River Itchen—Results of ANOVA tests comparing the diversity (richness and evenness) and total abundance of invertebrates collected in samples above and below the flow threshold

Criterion	Mean in samples collected above flow threshold	Mean in samples collected below flow threshold	ANOVA Result, *p* value	Change	% Change
Richness (number of taxa)	40	35	<0.001	Significant decrease	12.5
Evenness	0.62	0.73	0.001	Significant increase	17.7
Total invertebrate abundance	4,549	1,024	0.001	Significant decrease	77.5
Abundance of flow-dependent invertebrates	414.2	121.1	0.001	Significant decrease	70.9

Note The natural question about this comparison is, how much is above and how much is below the low-flow thresholds? Ideally, one would think about a continuous scale: sufficient flow would equal 100% of invertebrate services. Wholly insufficient flow (dry, or close to it) would yield 0% service. There would then be a continuous relationship (maybe concave and exponential) where reduced flow would be mapped against invertebrate impairment. This could not be estimated for this case study, which used the above simplified relationship most likely to reflect changes to the *Ranunculus* habitat. As noted above, the strict ‘threshold’ concept probably is an oversimplification. Although this is reasonable for a simple case study, it is unlikely to be defensible in a full ELD implementation.

Because the predicted damage to the river will continue for an indefinite period into the future, a period of 100 years has been used over which to calculate damages, with a 3% discount rate to express the changes over time in present value terms (Discounted Service Hectare Years, DSHaYs).

The calculations showing the total DSHaYs over 100 years using both a 12.5 and 71% annual rate of damage are shown in Tables 12.6 and 12.7.

It was assumed that the habitat will recover in one year after a low-flow year, providing flows return to above-threshold levels. However, when there are a series of low-flow years (as between 2013 and 2016), there is no recovery between years and hence the damage is compounded over this time. It might be expected that the rate of recovery would be longer than one year following a series of damaging low-flow years. However, the data available did not appear to support this prediction. If data were available, it would be possible to develop a more complex modelling approach that uses different recovery rates for different degrees of flow reduction and to consider multiyear conditions to identify any increased levels of damage following a series of low-flow years.

Comparison of annual damage rates—floating Ranunculus habitat
The change in abundance of key invertebrate groups of 71%, which was used to calculate annual service losses in Table 12.6 and Fig. 12.5, gave a total habitat-service loss over 100 years of 623 ha of floating *Ranunculus* habitat. By comparison, the use of the change in species diversity of 12.5%, shown in Table 12.7 and Fig. 12.6, gives a habitat service loss over the same period of only 165 ha of floating *Ranunculus* habitat.

This raises the obvious question of which of these two damage rates most accurately reflects the impact of reduced river flow, caused by abstraction for public water supply, on the protected habitat of the River Itchen. Ecologically, it might be assumed that the macroinvertebrate fauna is adapted to low river flows, as is demonstrated by the rapid rate of recovery after low-flow years. Low flow, therefore, has a limited impact on species diversity because most species survive the low-flow events in localised sections of the river or patches of river bed where flow conditions remain tolerable. However, changes in abundance of the key flow-dependent invertebrate groups reflect more accurately the change in extent of suitable habitat within the river during these low-flow events. Also, it is considered a better measure of the impact of water abstraction on the condition of the protected riverine habitat in this case. Note that abundance is typically a less sensitive indicator of contaminant effect.

Table 12.6 Water Abstraction, River Itchen—Debit calculation: 71% annual service loss, change in abundance of key chalk river macroinvertebrate species, years in which the minimum flow threshold is exceeded

Low-flow year	Year	Service years available pre abstraction (ha)	Service years available post abstraction (ha)	Annual service loss (%)	Year, base year	Discount factor	Loss	Discounted loss (DSHaYs)
(A)	(B)	(C)	(D) = (C) × (1 − (E))	(E) = 71.0%	(F)	(G) = 3.00%	(H) = (C) − (D)	(I) = (G) × (H)
No	2008	53.68	53.68	0.00	0	1.00	0.00	0.00
No	2009	53.68	53.68	0.00	1	0.97	0.00	0.00
Yes	2010	53.68	15.57	71.00	2	0.94	38.11	35.92
Yes	2011	53.68	4.51	91.59	3	0.92	49.17	44.99
No	2012	53.68	53.68	0.00	4	0.89	0.00	0.00
No	2013	53.68	53.68	0.00	5	0.86	0.00	0.00
Yes	2014	53.68	15.57	71.00	6	0.84	38.11	31.92
Yes	2015	53.68	4.51	91.59	7	0.81	49.17	39.98
Yes	2016	53.68	1.31	97.56	8	0.79	52.37	41.34
Yes	2017	53.68	0.38	99.29	9	0.77	53.30	40.85
No	2018	53.68	53.68	0.00	10	0.74	0.00	0.00
No	2019	53.68	53.68	0.00	11	0.72	0.00	0.00
No	2020	53.68	53.68	0.00	12	0.70	0.00	0.00
Yes	2021	53.68	15.57	71.00	13	0.68	38.11	25.95
Yes	2022	53.68	4.51	91.59	14	0.66	49.17	32.50
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
No	2107	53.68	53.68	0.00	99	0.05	0.00	0.00
No	2108	53.68	53.68	0.00	100	0.05	0.00	0.00

Notes
53.68: 100% service provision in hectares in the baseline
3.0%: Discount rate
71%: Annual percent loss of services (based on decline in abundance of key macroinvertebrate groups)
2008: Base year (the year the analysis occurs in)
DSHaYs: Discounted Service Hectare Years
To shorten the table, some of the results were omitted and substituted by the ellipsis

Table 12.7 Water Abstraction, River Itchen—Debit calculation: 12.5% annual service loss, change in macroinvertebrate species diversity, years in which the minimum flow threshold is exceeded

Low-flow year	Year	Service years available pre abstraction (ha)	Service years available post abstraction (ha)	Annual service loss (%)	Year, base year	Discount factor	Loss	Discounted loss, (DSHaYs)
(A)	(B)	(C)	(D) = (C) × (1 − (E))	(E) = 12.5%	(F)	(G) = 3.00%	(H) = (C) − (D)	(I) = (G) × (H)
No	2008	53.68	53.68	0.00	0	1.00	0.00	0.00
No	2009	53.68	53.68	0.00	1	0.97	0.00	0.00
Yes	2010	53.68	46.97	12.50	2	0.94	6.71	6.32
Yes	2011	53.68	41.10	23.44	3	0.92	12.58	11.51
No	2012	53.68	53.68	0.00	4	0.89	0.00	0.00
No	2013	53.68	53.68	0.00	5	0.86	0.00	0.00
Yes	2014	53.68	46.97	12.50	6	0.84	6.71	5.62
Yes	2015	53.68	41.10	23.44	7	0.81	12.58	10.23
Yes	2016	53.68	35.96	33.01	8	0.79	17.72	13.99
Yes	2017	53.68	31.47	41.38	9	0.77	22.21	17.03
No	2018	53.68	53.68	0.00	10	0.74	0.00	0.00
No	2019	53.68	53.68	0.00	11	0.72	0.00	0.00
No	2020	53.68	53.68	0.00	12	0.70	0.00	0.00
Yes	2021	53.68	46.97	12.50	13	0.68	6.71	4.57
Yes	2022	53.68	41.10	23.44	14	0.66	12.58	8.32
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
No	2107	53.68	53.68	0.00	99	0.05	0.00	0.00
No	2108	53.68	53.68	0.00	100	0.05	0.00	0.00
								164.79

Notes
53.68: 100% service provision in hectares prior to impact (Sect. 3.2.1)
3.0%: Discount rate
12.5%: Annual percent loss of services
2008: Base year (the year the analysis occured in)
DSHaYs: Discounted Service Hectare Years
To shorten the table, some of the results were omitted and substituted by the ellipsis

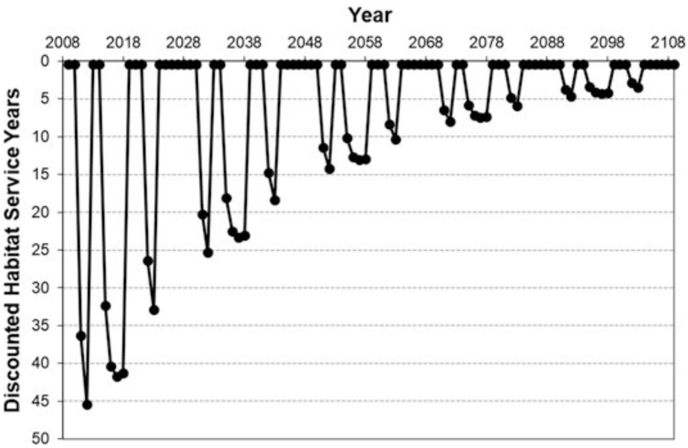

Fig. 12.5 Present value habitat service loss over 100-year period and a 71% annual habitat service loss showing the influence of discounting

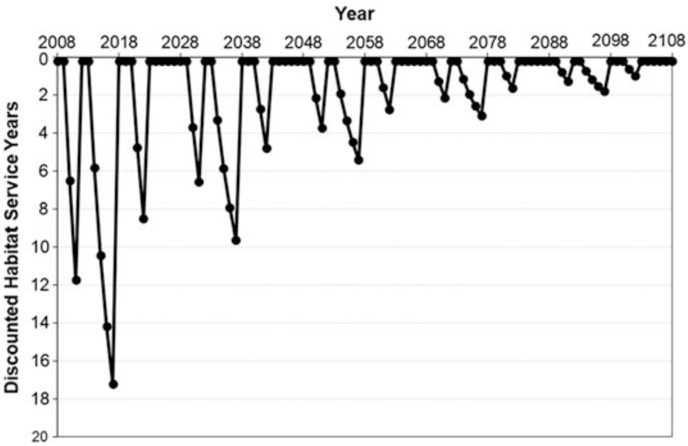

Fig. 12.6 Present value habitat service loss over 100-year period and a 12.5% annual habitat service loss showing the influence of discounting

12.3.2 The Atlantic Salmon in the River Itchen

Baseline—the Atlantic salmon

Atlantic salmon have been a feature of the River Itchen since the last ice age. It is likely that they contributed to the siting of early settlements in the area of Winchester, because prior to agricultural development, salmon were a good source of protein in the winter months. Private rights of net fishing were granted by the

King before Magna Carta, and many documents exist in the Hampshire Records Office of leases of salmon fishing rights by the Bishop of Winchester from the 16th century onward (Solomon 2002).

Taking into account a number of factors, the EA has calculated the egg deposition and consequently the approximate minimum number of adult salmon required for a self-sustaining population in the River Itchen. This ‘conservation limit’ equates to approximately 660 spawning salmon, or three and a half times the spawning escapement observed between 1999 and 2001. This low population size is thought to be due to several important factors including poor egg survival and poor marine survival.

Several studies have shown that spawning gravel areas of the River Itchen are in poor condition (Scott and Beaumont 1993; Riley et al. 1998; Solomon 2004), with egg survival rates often less than 5%. Riley et al. demonstrated that mitigation methods such as channel modification, gravel reinstatement, and gravel cleaning can increase egg survival.

Identifying a baseline Atlantic salmon population for the River Itchen is problematic. Evidence from the 1990s suggests a declining population. However, more recent data for the period 2001–2006 suggest something of a recovery in population, with approximately 400 returning fish, as illustrated in Fig. 12.7. If this recovery is sustained, it is possible that the population can be restored to a favourable condition.

To simplify this case study, it was assumed that the numbers of salmon returning to the river from the Woodmill Pool equate to the numbers spawning—this is something of an oversimplification because a degree of mortality is to be expected between entering the river and spawning. It was also assumed that the conservation

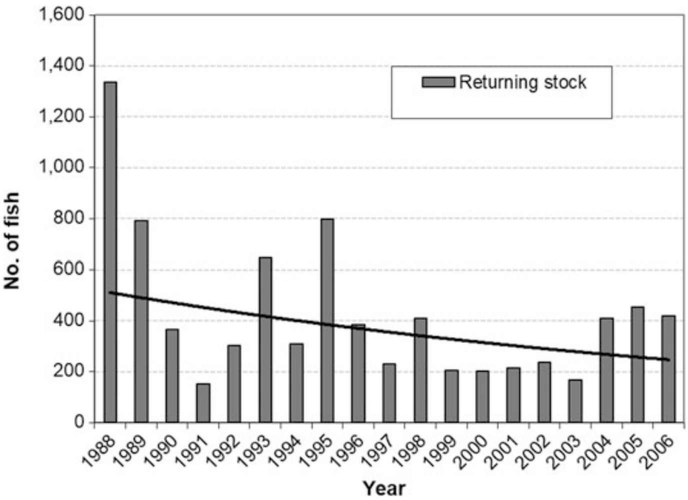

Fig. 12.7 River Itchen returning Atlantic salmon (1988–2006) (Environment Agency and CEFAS 2006)

limit of 660 spawning fish represents the minimum number to achieve FCS, as defined by Article 1 of the HD. Once this population has been reached, Competent Authorities could assume that compliance with Natura 2000 had been achieved. However, it could also be argued that FCS is not reached until a theoretical carrying capacity for the river has been reached. This could be based on reconstruction of historic population size from rod catch returns or on habitat-quality assessments.

The number of salmon returning to the river showed signs of recovery, rising to 419 fish in 2006. It was not possible to determine if this trend was sustainable and likely to continue. However, for the purposes of this case study, it was assumed that recovery will continue at approximately the rate of 6% per annum seen between 2001 and 2006.

To illustrate the effect of choosing different rates of recovery, a 2.5% recovery rate was also used for comparison. This was based on estimates of smolt survival published in United States literature.

It was assumed that there is no longer an adverse effect on site integrity once the baseline reaches the conservation limit for the river of 660 fish. The baseline was therefore considered to be recovering until the conservation limit equating to FCS is reached. In reality, it is hoped and presumed that salmon populations will continue to increase beyond this level. However, these additional fish should not be subject to further remediation once the population has been restored to FCS.

A number of models were developed to predict the impact of water abstraction on the River Itchen Atlantic salmon population. The model that provided the best indication of the effect of abstraction on the numbers of salmon returning to the river was the salmon migration model. This model was based on work undertaken by the EA (2006) and Fewings (2004) on salmon migration related to river flow. It was based on the premise that salmon require certain flow characteristics in order to return from the estuary to the river. Salmon that remain in the estuary for longer periods due to inadequate river flow are vulnerable to fishing activity and natural predation.

The migration model was used to predict the effects of different scenarios on the number of salmon returning past the tidal limit during a high-flow year (2000), average-flow year (1987), and low-flow year (1992), as illustrated in Table 12.8.

Dry years with full licensed abstraction result in a 48.5% reduction in the numbers of salmon returning to the river at Woodmill Pool. Unremarkable years result in 11.3% reduction in numbers of returning salmon, while in wet years there

Table 12.8 Water Abstraction, River Itchen—Loss of salmon (% of run returning to Woodmill Pool) due to two abstraction scenarios compared to naturalised flows

	Naturalised (scenario 9)	Contemporary (scenario 1)	Full entitlement (scenario 10)
Wet year (2000)	0	1.4	3.5
Unremarkable (near-average) year (1987)	0	4.2	11.3
Dry year (1992)	0	30.9	48.5

Note As per Table 12.5, a simplifying set of assumption is used here would be a 3.5% reduction. The number returning to the river at Woodmill is not necessarily the same as the number of spawning salmon because a further reduction in salmon numbers can be predicted in the river due to mortality. However, for the purposes of this case study, the number of salmon returning to the river at the tidal limit (Woodmill Pool) was taken as equivalent to the number of spawning salmon.

Calculating the debit—the Atlantic salmon

The salmon migration model was used to calculate the percentage of salmon unable to return to the river under high-, average-, and low-flow years, as shown in Table 12.5. Hydrological data from the 20-year period 1983–2002 were used to identify the number of years it might be reasonable to expect these three levels of flow. This is illustrated in Fig. 12.8. The results from the analysis in Fig. 12.8 are shown in Table 12.9, which assigns each year to a high-, average-, or low-flow category.

Comparison of recovery rates—the Atlantic salmon

Table 12.10 shows the results of the debit calculation using a 6% recovery rate to baseline. It gives a total of 4142 Discounted Atlantic Salmon Service Years (DASSYs) lost over a 100-year period. By comparison, using a 2.5% recovery rate, losses are reduced to 3,841 DASSYs over the same period (Table 12.11). This is not a significant difference and reflects the assumptions about recovery back to baseline of 660 fish and discounting. The more the attenuated recovery rate scenario generates losses further in the future, the less is the difference between the two scenarios.

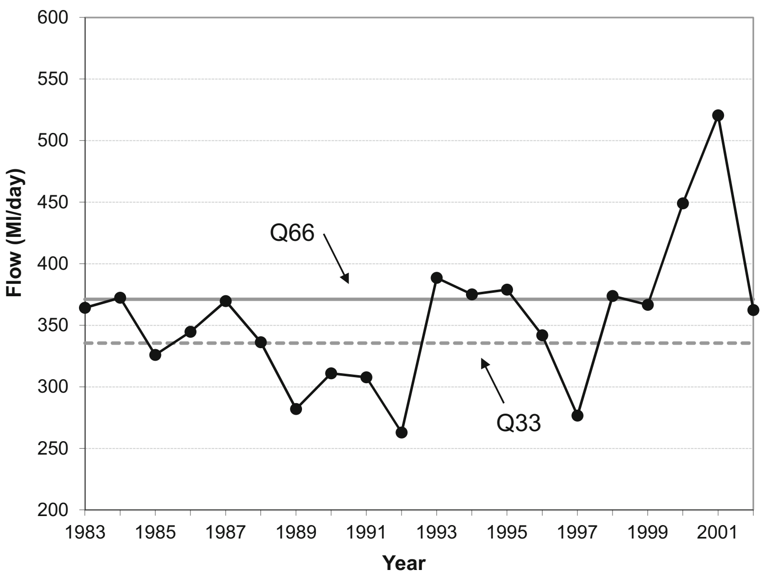

Fig. 12.8 River Itchen minimum annual flows 1983–2002 showing Q33 and Q66 flow thresholds used to identify high-, average-, and low-flow years

Table 12.9 Water Abstraction, River Itchen—Allocation of years to flow category

Year	Minimum recorded flow (Ml/d)	Flow category
1983	364.3	Average
1984	372.4	High
1985	325.9	Low
1986	344.7	Average
1987	369.6	Average
1988	336.2	Average
1989	282.0	Low
1990	311.0	Low
1991	307.8	Low
1992	263.0	Low
1993	388.6	High
1994	375.1	High
1995	379.0	High
1996	341.9	Average
1997	276.6	Low
1998	373.8	High
1999	366.7	Average
2000	449.1	High
2001	520.5	High
2002	362.4	Average

In both of the above calculations, a long time period of 100 years was used to calculate debits. This was done so that credit, in terms of compensatory habitat, can be calculated to maintain the integrity of the Natura 2000 network in perpetuity. Figure 12.9 illustrates the reduction in annual loss over time using discounting and the two recovery rates.

Estimating the debit in monetary terms—the Atlantic salmon

The aim of this section is to estimate the economic cost of the decline in the population of Atlantic salmon in monetary terms and to illustrate the value-to-value and value-to-cost approaches. The economic cost is calculated as the discounted sum of annual economic loss, which is, in turn, the number of salmon lost multiplied by the economic value of one salmon. While economic value could include both market and non-market components (see Chap. 8), the intention is not for the responsible party to make monetary compensatory payments to the affected parties for commercial (market) loss. The principle that money exchange in the context of the ELD must be to compensate the damage resources and their services is retained, even if the metric used to measure damage and remediation is money.

Various economic valuation methods can be used to obtain a unit value for salmon in the River Itchen. One can either undertake a valuation study at the River Itchen site or use previous estimates from the available literature. For the purposes of this case study, we implemented the second approach, which is called value

Table 12.10 Water Abstraction, River Itchen—Debit calculation: 6% annual recovery, changes in Atlantic Salmon, years 2017–2106

Year	Recovery to baseline, number of fish	Baseline +	Fish lost due to water abstraction (%)	Number of fish lost	Number of fish returning to river	Year, base year	Discount factor	DASSYs
	(A)	(B) = 6%	(C)	(D) = (B) × (C)	(E) = (B) − (D)	(F)	(G) = 3%	(H) = (D) × (G)
2008		400	11.30	45.20	354.80	0	1.00	45.20
2009	24.00	424.00	3.50	14.84	409.16	1	0.97	14.41
2010	25.44	449.44	48.50	217.98	231.46	2	0.94	205.47
2011	26.97	476.41	11.30	53.83	422.57	3	0.92	49.27
2012	28.58	504.99	11.30	57.06	447.93	4	0.89	50.70
2013	30.30	535.29	11.30	60.49	474.80	5	0.86	52.18
2014	32.12	567.41	48.50	275.19	292.21	6	0.84	230.47
2015	34.04	601.45	48.50	291.70	309.75	7	0.81	237.18
2016	36.09	637.54	48.50	309.21	328.33	8	0.79	244.09
2017	38.25	660.00	48.50	320.10	339.90	9	0.77	245.33
2018	0.00	660.00	3.50	23.10	636.90	10	0.74	17.19
2019	0.00	660.00	3.50	23.10	636.90	11	0.72	16.69
2020	0.00	660.00	3.50	23.10	636.90	12	0.70	16.20
2021	0.00	660.00	11.30	74.58	585.42	13	0.68	50.79
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2106	0.00	660.00	3.50	23.10	636.90	98	0.06	1.28
2107	0.00	660.00	11.30	74.58	585.42	99	0.05	4.00
Sum				**12,745**	**51,911**			**4,142**

Notes

Baseline is assumed to have been reached at 660 returning fish; 3.0%: Discount rate; 6%: Annual recovery of population to baseline; 2008: Base year (the year the analysis occurs in); DASSYs: Discounted Atlantic salmon service years; Sums rounded

To shorten the table, some of the results were omitted and substituted by the ellipsis

Table 12.11 Water Abstraction, River Itchen—debit calculation: 2.5% annual years of recovery to baseline, Atlantic salmon, years 2017–2107

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
Year	Recovery to baseline (number of fish)	Baseline +	Fish lost due to water abstraction (%)	Number of fish lost	Number of fish returning to river	Year, base year	Discount factor	DASSYs
	(A)	(B) = 2.50%	(C)	(D) = (B) × (C)	(E) = (B) − (D)	(F)	(G) = 3.00%	(H) = (D × G)
2008		400	11.30	45.20	354.80	0	1.00	45.20
2009	10.00	410.00	3.50	14.35	395.65	1	0.97	13.93
2010	10.25	420.25	48.50	203.82	216.43	2	0.94	192.12
2011	10.51	430.76	11.30	48.68	382.08	3	0.92	44.54
2012	10.77	441.53	11.30	49.89	391.63	4	0.89	44.33
2013	11.04	452.56	11.30	51.14	401.42	5	0.86	44.11
2014	11.31	463.88	48.50	224.98	238.90	6	0.84	188.42
2015	11.60	475.47	48.50	230.61	244.87	7	0.81	187.50
2016	11.89	487.36	48.50	236.37	250.99	8	0.79	186.59
2017	12.18	499.55	48.50	242.28	257.27	9	0.77	185.69
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
2106	0.00	660.00	3.50	23.10	636.90	98	0.06	1.28
2107	0.00	660.00	11.30	74.58	585.42	99	0.05	4.00
Sum				**12,358**	**50,654**			**3,841**

Notes

Baseline is assumed to have been reached at 660 returning fish; 3.0%: Discount rate; 2.5%: Annual recovery of population to baseline; 2008: Base year (the year the analysis occurs in); DASSYs: Discounted Atlantic salmon service years; Sums rounded

To shorten the table, some of the results were omitted and substituted by the ellipsis

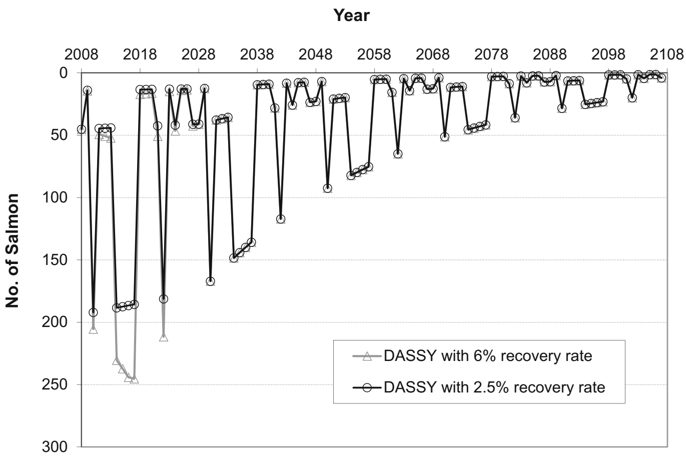

Fig. 12.9 Interim loss calculations (discounted Atlantic salmon service years) using 2.5 and 6% recovery rates to baseline

(benefits) transfer because a value estimate in the literature is transferred to the case study site and time period of the current analysis. The transfer could be unadjusted (using the same estimate found in the literature) or adjusted (adapting the estimate found in the literature to the factors at the case study site – as much as the data allow).

The most extensive database for economic value estimates that is publicly available online and that can potentially be used in this context is the Environmental Valuation Reference Inventory (EVRI).[3] As a searchable database of empirical studies, EVRI is a very useful source for a value transfer exercise.

We searched EVRI for this case study and found one study to be particularly relevant, namely, the report by Radford et al. (2001). The overall objective of that report was to estimate the total market value for inland fisheries in England. The estimate was part of a project aimed at determining the benefits or value provided by inland fisheries in order to inform policies in this area, notably regarding fishing rights.

One component of that study was an estimate of monetary value for each salmon caught in privately owned recreational inland fisheries in England.[4] The value was estimated through a hedonic pricing model, which seeks to establish how the market value of a private fishery varies with its characteristics, for example, its facilities (e.g., nearby parking), the population living in the surrounding area, and the number of salmon caught. The relationship between the number of salmon caught at a particular fishery and the value of a fishery is an indication of the value of the salmon population—the implicit price per salmon caught.

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[3]www.evri.ca.

[4]Radford et al. (1991) note that almost all the inland fisheries in England are private properties and hence can be bought and sold on the market.

The market value of the fisheries was obtained through a survey of fishery owners, along with other information such as the number of salmon caught in the five preceding years and the other facilities available on the site. With that data, a statistical relationship between the market value of the property and its attributes was estimated to establish the effect of the number of salmon caught on the value of the property. This provided market price information on the value of the salmon population.

Thus, Radford et al. (2001) find the average value per salmon in fisheries in England to be £7,791 in 2001 prices, or £8,790 in 2007 prices. The authors note that this value is in line with earlier estimates by Radford et al. (1991). Note that the hedonic pricing methodology does not account for the non-use value of salmon and is therefore a lower bound of the total economic value.

In order to relate the number of fish lost each year due to the water abstraction scheme to an estimation of the implicit price per salmon caught, an estimate of the catch rate is needed, that is, the percentage of salmon population that is caught. This was done by compiling figures on the yearly salmon population and number of

Table 12.12 Water Abstraction, River Itchen—debit calculation: 6% annual recovery rate, Atlantic salmon, monetary value, years 2021–2106

Year	Number of fish lost	Catch rate (%)	Loss of salmon caught	Value per fish caught (£)	Discount factor	Discounted loss (£)
	(A)	(B)	(C) = (A) × (B)	(D)	(E)	(F) = (C) × (D) × (E)
2008	45.2	51	23.1	8,790	1.00	202,627
2009	14.8	51	7.6	8,790	0.97	64,589
2010	218.0	51	111.2	8,790	0.94	921,082
2011	53.8	51	27.5	8,790	0.92	220,853
2012	57.1	51	29.1	8,790	0.89	227,286
2013	60.5	51	30.8	8,790	0.86	233,906
2014	275.2	51	140.3	8,790	0.84	1,033,172
2015	291.7	51	148.8	8,790	0.81	1,063,264
2016	309.2	51	157.7	8,790	0.79	1,094,233
2017	320.1	51	163.3	8,790	0.77	1,099,790
2018	23.1	51	11.8	8,790	0.74	77,055
2019	23.1	51	11.8	8,790	0.72	74,810
2020	23.1	51	11.8	8,790	0.70	72,631
2021	74.6	51	38.0	8,790	0.68	227,666
⋮	⋮	⋮	⋮	⋮	⋮	⋮
2106	23.1	51	11.8	8,790	0.06	5,716
2107	74.6	51	38.0	8,790	0.05	17,918
Sum			12,745.5			**£18,569,352 (~ €25 million)**

Notes Column A is the same as Column D of Table 12.10
To shorten the table, some of the results were omitted and substituted by the ellipsis

Table 12.13 Water Abstraction, River Itchen—debit calculations, 2.5% annual rate of recovery, Atlantic Salmon monetary value, years 2017–2106

Year	Number of fish lost	Catch rate (%)	Loss of salmon caught	Value per fish caught (£)	Discount factor	Discounted loss (£)
	(A)	(B)	(C) = (A) × (B)	(D)	(E)	(F) = (C) × (D) × (E)
2008	45.2	51	23.1	8,790	1.00	202,627
2009	14.4	51	7.3	8,790	0.97	62,456
2010	203.8	51	103.9	8,790	0.94	861,260
2011	48.7	51	24.8	8,790	0.92	199,691
2012	49.9	51	25.4	8,790	0.89	198,721
2013	51.1	51	26.1	8,790	0.86	197,756
2014	225.0	51	114.7	8,790	0.84	844,657
2015	230.6	51	117.6	8,790	0.81	840,557
2016	236.4	51	120.5	8,790	0.79	836,477
2017	242.3	51	123.6	8,790	0.77	832,416
⋮	⋮	⋮	⋮	⋮	⋮	⋮
2106	23.1	51	11.8	8,790	0.06	5,716
2107	74.6	51	38.0	8,790	0.05	17,918
Sum			12,358.6			**£17,220,964 (~ €23million)**

Notes Column A is the same as Column D in Table 12.11
To shorten the table, some of the results were omitted and substituted by the ellipsis

salmon caught published by the EA (2006). The average catch rate over the period 1996–2006 was projected over the next 100 years. Of course, this is a simplification, and a more sophisticated approach could be used to reflect, for example, the impact of the size of the stock on the catch rate. Using the lost salmon estimates from Tables 12.10 and 12.11, Tables 12.12 and 12.13 provide annual breakdowns of the calculations that were used to obtain the value lost over 100 years with 6 and 2.5% recovery rates.

The first step was to estimate the number of salmon that cannot be caught at fisheries along the River Itchen as a result of the reduction in the salmon population (column C in Tables 12.12 and 12.13). Thereafter, the loss of salmon caught was multiplied by the value of the salmon and then discounted back to the base year. Finally, the annual losses were summed over 100 years to obtain the total monetary loss due to the water abstraction scheme.

Following this approach, the estimated monetary loss over 100 years, which is implied by the water abstraction scheme, is between £17 and £18.5 million for an assumed recovery of 6 and 2.5%, respectively.

12.4 Determining the Credits

12.4.1 Remediation Alternatives

The objective for the complementary remediation needed to balance the damage calculated in the previous section is determined by the HD. This must ensure that the overall Natura 2000 network is protected, as defined by Article 6(4) of the HD.

Damage to the *Ranunculus* habitat should be addressed by remediating the same habitat type—'like-for-like remediation.' Guidance from the European Commission (2007) states that compensatory measures can consist of:

- Recreating a habitat on a new or enlarged site, to be incorporated into Natura 2000;
- Improving habitat on part of the site or on another site, proportional to the loss due to the project; and
- In exceptional cases, proposing a new site under the HD.

Within the chalk river system of southern England, there are numerous rivers that have significant reaches that are damaged or degraded and are not part of Natura 2000. Indeed, The State of England's Chalk Rivers (Environment Agency 2004) states that 31% of chalk river sites monitored were in poor or very poor condition and 57% had been 'significantly modified or worse.' One option for remediation would be to restore these rivers such that they could be incorporated into Natura 2000. An alternative would be to undertake restoration on the River Itchen or another chalk river SAC in England that is 'equivalent to the loss' calculated in Sect. 12.3.

Simply designating a new chalk river SAC in its current state would not seem to represent any gain in biodiversity and would not be an addition to what the United Kingdom should be contributing to the Natura 2000 network as part of its responsibilities under the HD. In other words, designation of SAC would not generate additional credits.

A similar approach could be taken to remediate the Atlantic salmon population. It would be possible to improve salmon habitat on another chalk river in England or to enhance habitat on the River Itchen provided this work can be shown to be additional to what the United Kingdom would have had to contribute to be in compliance with the HD as for instance proposed by Holmes (2003).

12.4.2 Selecting Remediation Projects

Techniques for river restoration have been developed over recent decades throughout Europe and much of the world. These restoration techniques involve renaturalising rivers by removing impediments to natural processes of erosion and deposition, reconnecting lost meanders and braided channels, replacing natural riverine features such as woody debris, and recreating channel features such as pool-riffle sequences, gravel bars, and islands. These types of restoration schemes have been shown to have dramatic effects on the macroinvertebrate community, macrophyte growth, and fish populations, particularly on the spawning success of salmonid species.

The effects of such river restoration projects on chalk rivers and on the metrics used in this case study (macroinvertebrate and Atlantic salmon populations) has not been quantitatively monitored. However, there are some examples that can be used to scale the benefits of river restoration projects using these metrics.

To gain an understanding of the relative improvement (service gain) from river restoration on the invertebrate community, a reference site approach was taken. Data regarding a silted section of the River Itchen upstream of an impoundment were used to compare this section with similar reaches of the river where flow was good and the floating *Ranunculus* habitat was typical.

To evaluate improvements to salmon spawning habitat, data relating to restoration of two reaches of a headwater stream in the River Avon were obtained from the Environment Agency (2007).

12.4.3 Calculating the Credit

Macroinvertebrate community metric

The first step in remediation is to calculate the area of the length of river that would need to be restored in order to remediate the effects of water abstraction calculated in Sect. 12.3. It was first necessary to obtain information on the percentage service gain, measured in terms of both the abundance of key flow-dependent invertebrate species and the overall diversity of species within both a silty, degraded reach of the river and a healthy reach of the river. These were the two invertebrate metrics considered in Sect. 12.3. Data showing improvement differences between the invertebrate community in good-quality chalk river habitat and degraded chalk river habitat were obtained from the EA. Data showed a 90% difference in species abundance between the degraded and the healthy river sections. Species diversity indices showed a less dramatic change, with only a 16% increase in species diversity between degraded and good-quality habitats.

Although the percentage habitat damage (debit) using invertebrate abundance was large (71%) compared to the change in species diversity (12.5%), the amount of potential service gain from river restoration was roughly comparable (90 and 16%, respectively). Consequently, the area of habitat needed to be created in order to provide the necessary remediation (credit) over a 100-year period was not significantly different. Assuming a 90% service gain accumulates over a 5-year recovery period and 100 years of benefits, 1 ha of habitat restoration will provide just over 27 DSHaY. Assuming a 16% service gain accumulates over a 5-year recovery period and 100 years of benefits, 1 ha of habitat restoration will provide 4.88 DSHaY. Provision of 165 ha of habitat service years would require restoration of 165/4.88 = 33.8 ha of river in present value terms.

Table 12.14 Water Abstraction, River Itchen—Calculation of increase in salmon fry density following river restoration

Sites	Density, salmon fry/100 m^2
Site 1	
2003	15.0
2006	10.7
2007	45.3
Site 2	
2003	10.8
2006	11.3
2007	128.4
Mean 2003	**12.9**
Mean 2006–2007	**48.9**
Increase in number of salmon fry	**36.0**
% increase	**279**

Atlantic salmon metric

Information on Atlantic salmon spawning success from the River Wyle, a tributary of the River Avon, was obtained before and after a 2003 river restoration project. The project consisted of two restored reaches of the river. Numbers of juvenile salmon (fry) were recorded in 2003, prior to restoration, and again in 2006 and 2007 (Table 12.14). Calculations of the increase in numbers of salmon fry from improved spawning success need to be translated into predicted numbers of returning adult fish because this was the metric used to calculate damages or debits.

Salmon are subject to significant levels of mortality at each stage of their life cycle. Some simple relationships between numbers of fry, par, smolts, and returning adults were calculated from the literature Baglinièrea et al. (2005), as follows:

- Fry—par: 50% survival;
- Par—smolt: 10% survival; and
- Smolt—returning adult: 5% survival.

From the increase of 36 fry/100 m^2 of river restoration, one can expect: $36 \times 0.5 \times 0.1 \times 0.05$ returning adults = 0.09 returning adults.

12.5 Scaling Remediation

12.5.1 Macroinvertebrate Community Metric

Given 27 DSHaYs per hectare of restoration (see Sect. 12.4.3), provision of 623 DSHaYs (see Table 12.6) would require the restoration of 623/27 = 23 ha of river restoration in present value terms. Assuming a river width of 10 m, this is equivalent to 23 km of river restoration (1 km of restoration = 1,000 m × 10 m = 10,000 m^2 = 1 ha).

Using the same assumptions about river width, the 16% service gain assumption (see Sect. 12.4.3) equates to 33.8 km of river restoration. Thus, despite the significant differences in the percentage losses and gains using the different invertebrate metrics, these balance each other out so that the area of habitat restoration needed is similar.

12.5.2 Atlantic Salmon Metric

The number of returning salmon needed to compensate for the damage caused by water abstraction was calculated in Sect. 12.3 using two rates of baseline recovery. The larger one (4,142 discounted Atlantic salmon service years from Table 12.10) was used for the purposes of this case.

Assuming a 6-year recovery period, 100 years of benefits, and a 3% discount rate, the 100 m^2 of river restoration will provide 2.63 DASSYs, as illustrated in Table 12.15. The rate of service gain from the river restoration project was assumed to provide increasing amounts of service (in terms of numbers of returning salmon) over the first six years following the restoration, with a 10% service gain in year 1, 25% in year 2, 50% in year 3, 70% in year 4, 90% in year 5, and 100% in year 6. In other words, the 100-m^2 area reaches its full capacity of facilitating returning fish (0.09 fish/100 m^2) by year 6, at 100% of service provision. Assuming a river width

Table 12.15 Water Abstraction, River Itchen—Calculation of credit over 100 years assuming a 6-year recovery period and 3% discount rate

Year	Year, base year	Discount factor	Returning fish (number/100 m^2)	Discounted credit (DASSYs per 100 m^2)
(A)	(B)	(C) = 3%	(D)	(E) = (C) × (D)
2009	1	0.97	0.009	0.087
2010	2	0.94	0.022	0.084
2011	3	0.92	0.045	0.082
2012	4	0.89	0.063	0.079
2013	5	0.86	0.081	0.077
2014	6	0.84	0.09	0.075
⋮	⋮	⋮	⋮	⋮
2104	96	0.06	0.09	0.0052
2105	97	0.06	0.09	0.0051
2106	98	0.06	0.09	0.0049
2107	99	0.05	0.09	0.0048
2108	100	0.05	0.09	0.0046
Total				**2.63**

Notes Provision of 4,142 DASSYs would require 4,142/2.63 × 100 m^2 = 15.75 ha of restored river

To shorten the table, some of the results were omitted and substituted by the ellipsis

of 10 m, this is equivalent to 15.75 km of river restoration (1 km of restoration = 1000 m × 10 m = 10,000 m^2 = 1 ha).

12.5.3 Consideration of Potential Remediation Projects

Ideally, river restoration takes place on the river that has been damaged, in this case the River Itchen. However, due to the quantity of remediation necessary (between 33.8 and 14.58 km), it may not be possible to identify a sufficiently degraded length in the river to provide sufficient remediation. This is particularly true where the slower-flowing, silty reaches of the river can provide important habitat for a number of typical chalk river species, for instance, juvenile stages of lamprey. Restoration projects must be sensitive to the need for the sufficient conservation of these slow-flowing reaches. Identification of appropriate remediation projects is further complicated by the need to identify projects that provide a substantial increase in service gain, that is, from a highly degraded condition to one of high ecological function. Given these constraints, it seems unlikely that sufficient restoration projects in the River Itchen alone would be identified. If this is the case, it would be necessary to identify one or more additional rivers in England on which to undertake restoration work. The geographical distance between the river(s) and the River Itchen may require addition of a displacement factor to the amount of remediation provided.

12.5.4 Cost of Remediation

Costs of river restoration projects, which are taken from the River Restoration Centre,[5] vary substantially. However, they are limited to the cost of implementing the construction work and do not include associated ancillary costs. Table 12.16 considers potential costs associated with restoration of a 1-km stretch of river. Costs were valid at the time of this case study in 2007.

Using the above unit costs, it was possible to calculate total cost of remediation using the different metrics as shown in Table 12.17. Costs for remediation of floating *Ranunculus* habitat range between approximately €10 and €15 million. The cost for remediation using the Atlantic salmon population as the metric is just over €7 million. These differences in remediation costs illustrate the importance of finding a metric that best reflects a true level of damage to the environment.

[5] www.therrc.co.uk.

Table 12.16 Water Abstraction, River Itchen—Costs of river restoration per kilometre

	£	€
Planning	15,000	21,429
Mobilization	5,000	7,143
Preliminary sampling	5,000	7,143
Implementation	150,000	214,286
Operations and management	50,000	71,429
Oversight by competent authority	15,000	21,429
Monitoring and reporting	25,000	35,714
Overhead	25,000	35,714
Contingency	25,000	35,714
Total	**315,000**	**450,000**

Table 12.17 Water Abstraction, River Itchen—Remediation costs for different lengths of river restoration

	Length of river restoration required (assuming 10-meter-wide river) (km)	Cost (€)
Cost using change in invertebrate species diversity as the metric	23.02	10,359,000
Cost using change in invertebrate abundance as the metric	33.8	15,210,000
Cost using returning Atlantic salmon as the metric	15.75	7,087,500

12.5.5 Value-to-Cost Equivalency Approach

The economic value of damage using the Atlantic salmon metric, as estimated in Sect. 12.3.2, is between €23 and €25 million in present value terms over 100 years of lost services (2007 exchange rate). This is in fact a conservative estimate in that it (a) is only the salmon angling value and hence excludes non-use values and (b) assumes that the unit economic value of salmon caught remains the same over 100 years. Despite this, the damage (debit) is significantly greater than the credit—at least €23 million compared to the cost of just over €7 million. Thus, if remediation using Atlantic salmon was claimed to be disproportionately costly, this comparison could be shown to prove the opposite.

12.6 Monitoring and Reporting

It is important that future monitoring demonstrates the necessary improvement of habitat required to provide sufficient remediation during the first five to six years of restoration implementation. Monitoring should be performed in order to record habitat characteristics, including invertebrate community and Atlantic salmon spawning productivity, in terms of numbers of fry produced.

12.7 Conclusions

This case study illustrates how equivalency analysis can be used to calculate the magnitude of compensation required in an *ex ante* case where damage to a Natura 2000 site is predicted to occur as a consequence of abstraction for public water supply. It is based on a fictitious scenario in which damage to the Natura 2000 site is permitted in accordance with Article 6(4) of the HD. It could also be an example of 'imminent threat' in the context of the ELD, given that if abstraction continues the damage is inevitable.

The magnitudes of damage (debit) and remediation (credit) were calculated using two metrics: changes to the floating *Ranunculus* habitat and Atlantic salmon. Changes in the aquatic macroinvertebrate community were shown to provide a sensitive measure of changes in the conservation status of the European-protected floating *Ranunculus* habitat. Choosing an appropriate method for measuring these changes so as to reflect changes in the quality of the habitat proved to be problematic. Changes in species diversity and in the abundance of key invertebrate groups were investigated as part of this case study. Change in species abundance appeared to provide a better measure of change due to the inherent resilience of faunal diversity to low-flow events.

A second metric, use of numbers of returning Atlantic salmon, was based on a salmon migration model developed by the EA. The result was a calculation of roughly half the quantity of remediation required than when the invertebrate metric was used. However, the calculation of benefits likely to accrue from river restoration schemes for salmon was based on a limited sample from a reach of river where salmon have habitually spawned. It is probably unrealistic to expect similar levels of benefits to arise from restoration of the entire length of river, which would be needed to remediate the calculated damages. In this case, considerably more remediation would be needed.

Although variable, the quantity of remediation required to offset predicted damage is considerable. It is very unlikely that sufficient length within the River Itchen could be restored. Consequently, additional river restoration projects on other similar chalk rivers in southern England would need to be identified. In many instances, these restored rivers would in turn need to be added to the Natura 2000 network. The cost of implementing the necessary river restoration is considerable but low compared to lower-bound estimates of damage of €23 million.

Appendix: Flow Thresholds Set with Reference to Local Investigations on the River Itchen—Summary

A trend linking invertebrate community variation and antecedent summer Q95 flow was identified. Based on multivariate ordination techniques, a statistically and ecologically significant community change was shown to occur as flows fell below 0.861–0.844 standardised flow units. Samples collected when flows were greater than or equal to 0.861 units contained typical chalk stream invertebrate communities, whereas those collected when flows were less than or equal to 0.844 units were already impacted. No samples were available when flows were between 0.861 and 0.844 standardised units. It is therefore not possible to be specific about the impacts of flow within this narrow range.

The community shift that occurs between 0.861 and 0.844 standardised flow units was evident at sites throughout the River Itchen catchment. The shift was primarily caused by a reduction in the abundance of macroinvertebrates that prefer fast-flowing water and are highly characteristic of the typical chalk stream community.

Figure 12.10 summarises the community change that occurs between 0.861 and 0.844 standardised flow units.

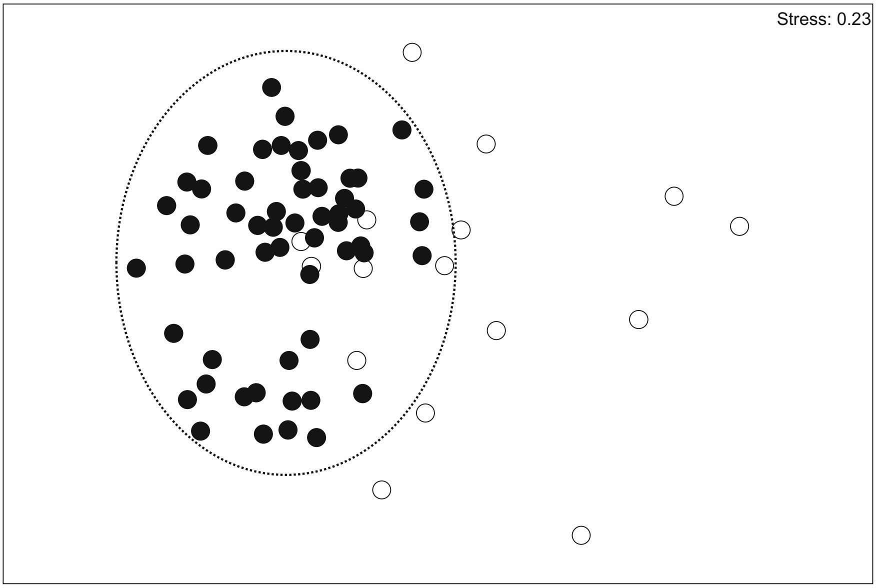

Fig. 12.10 Ordination of River Itchen samples highlighting samples (in black) collected when summer Q95 flow was greater than or equal to 0.861 standardised flow units, and samples (in white) collected when summer Q95 flows were less than or equal to 0.844 units. These sample groups were shown to be significantly different (p = 0.001) (*Source* Exley 2006)

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