Thames Tideway Tunnel
Thames Water Utilities Limited

Thames Water

Development Consent Order

Application Reference Number: WWO10001

Documents for Certification
September 2014

We, Lindsay Speed and Sarah Fairbrother hereby certify that this is a true copy of the environmental statement referred to in Article 61 (1) (f) of the Thames Water Utilities Limited (Thames Tideway Tunnel) Order 2014.

Lindsay Speed   Sarah Fairbrother

September 2014

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

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Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

APFP Regulations 2009: Regulation **5(2)(a)**

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Appendix B: Air Quality and Odour

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Appendix B: Air quality and odour

B.1 Model verification

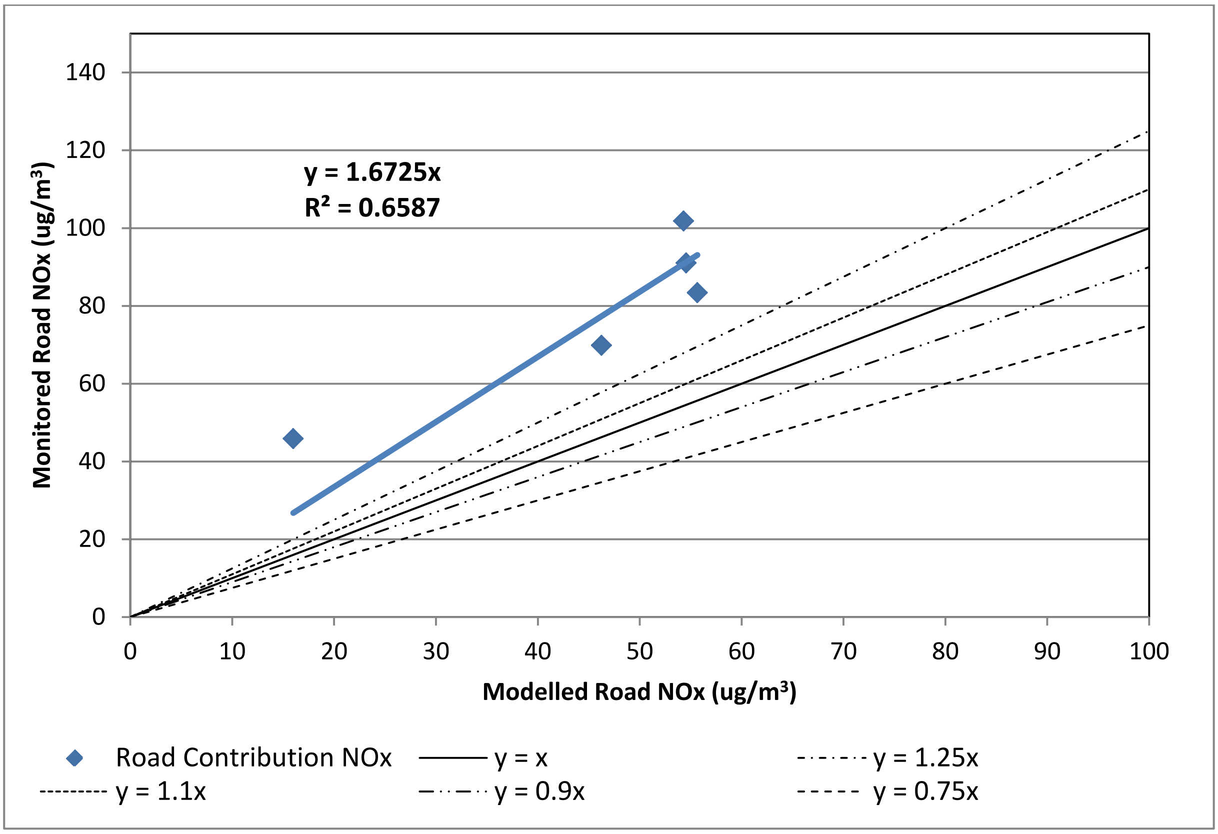
B.1.1 Modelled NO_2 concentrations have been plotted against monitored concentrations at five monitoring sites (GR7, GB6, Bex2, Bex3 and Bex24) as shown in Vol 3 Figure 4.4.1 (see separate volume of figures).

B.1.2 This showed that the modelled results underestimated NO_2 concentrations by between 15% and 27%. As the model has been optimised and no further improvement of the model was considered feasible (such as reducing vehicle speeds or using different pollutant backgrounds, etc), a model adjustment factor was therefore deemed necessary.

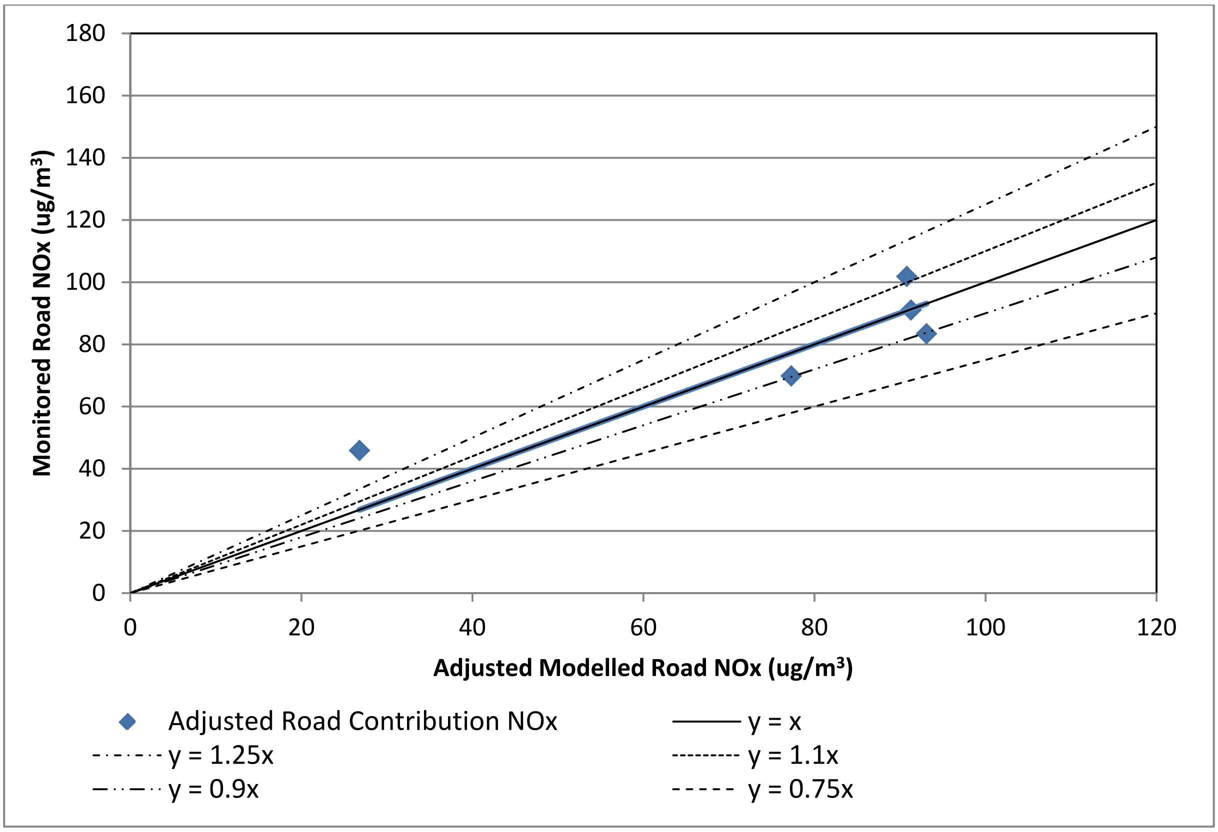
B.1.3 To derive the adjustment factor, modelled road NO_x concentrations were plotted against calculated monitored road NO_x concentrations (see Vol 3 Plate B.1 below). An adjustment factor of 1.67 was calculated for adjusting modelled roadside NO_x concentrations, in accordance with Local Air Quality Management Technical Guidance (Defra, 2009)[1] and subsequently applied. PM_{10} monitoring data were available from one site and were compared with the modelled concentration. The model underestimated concentrations by 2%. An adjustment factor of 1.14 was calculated for adjusting modelled roadside PM_{10} concentrations, in accordance with LAQM.TG(09), and subsequently applied.

B.1.4 Applying the NO_x adjustment factor and then calculating NO_2 concentrations, as shown in Vol 3 Plate B.2, provides better overall agreement between actual and predicted data. The subsequent linear regression calculation for monitored versus modelled total NO_2, as shown in Vol 3 Plate B.3, indicated that four of the five modelled concentrations were within 10% of the measured value and that all five were within 25% of the modelled value.

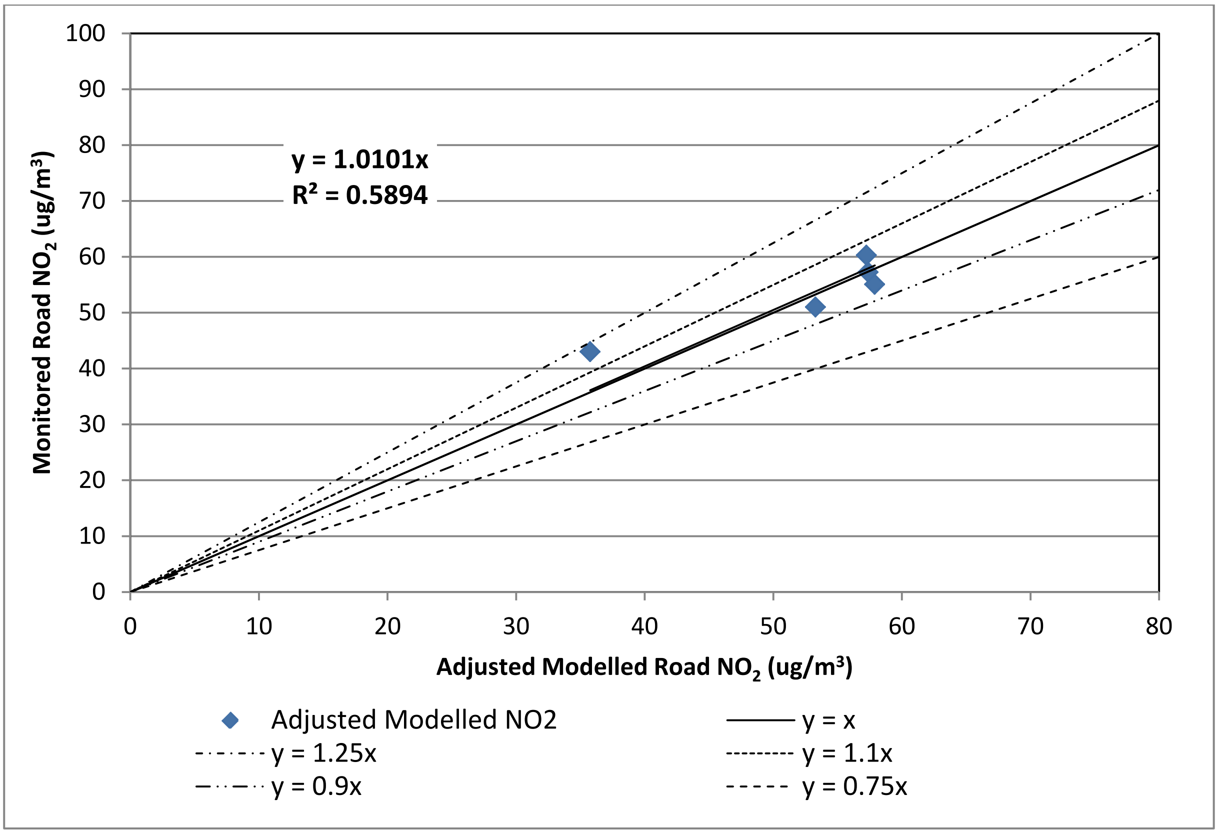
Vol 3 Plate B.1 Air quality – monitored road NO_X vs. modelled road NO_X



Vol 3 Plate B.2 Air quality – monitored road NO_X vs. adjusted modelled road NO_X



Vol 3 Plate B.3 Air quality – total monitored NO_2 vs. total adjusted modelled NO_2



B.2 Traffic data

B.2.1 The traffic data used in the air quality modelling for the project-wide assessment is shown in Vol 3 Table B.1.

Vol 3 Table B.1 Air quality – traffic data model inputs

Source	Road link	2010 baseline AADT*	Baseline % HGV >3.5t	Speed limit (mph)	Model input speed (mph)	Peak construction year AADT	Peak construction year AADT scheme construction HGV (HGV >3.5t)	Peak construction year development case (total AADT)	Peak construction year develop-ment case AADT % HGV (>3.5t)
Transport for London (TfL) HAM**	A2 Greenwich South Street to Maidenstone Hill	29145	5.0%	30	14	31839	256	32133	4.7%
TfL HAM	A2 Maidenstone Hill to Dartmouth Hill	28773	5.0%	30	23	31289	256	31583	4.8%
TfL HAM	A2 Darmouth Hill to Hyde Vale	22994	5.9%	30	22	27513	256	27807	5.1%
TfL HAM	A2 Hyde Vale to General Wolfe Road	39408	4.5%	30	20	44002	256	44361	4.1%
TfL HAM	A2 General Wolfe Road to	43224	4.5%	30	17	48465	256	48824	4.0%

Source	Road link	2010 baseline AADT*	Baseline % HGV >3.5t	Speed limit (mph)	Model input speed (mph)	Peak construction year AADT	Peak construction year AADT scheme construction HGV (HGV >3.5t)	Peak construction year development case (total AADT)	Peak construction year develop-ment case AADT % HGV (>3.5t)
	Goffers Road								
TfL HAM	A2 Goffers Road to Princes Charles Road	39581	4.6%	30	21	42340	256	42698	4.1%
TfL HAM	A2 Prince Charles Road to Maze Hill	35674	5.0%	30	23	38698	256	39054	4.2%
TfL HAM	A2 Maze Hill to Prince of Wales Road	37301	4.8%	30	22	40511	256	40880	4.1%
TfL HAM	A2 Prince of Wales Road to Kidbrooke Park Road	38391	4.4%	30	17	42027	256	42396	3.9%
TfL HAM	A2 Kidbrooke Park Road to Sun in the Sands Roundabout	37156	3.6%	30	13	39659	256	39987	3.2%
TfL HAM	A2 Sun in the Sands	92652	4.1%	50	38	100648	256	100957	3.4%

Source	Road link	2010 baseline AADT*	Baseline % HGV >3.5t	Speed limit (mph)	Model input speed (mph)	Peak construction year AADT	Peak construction year AADT scheme construction HGV (HGV >3.5t)	Peak construction year development case (total AADT)	Peak construction year develop-ment case AADT % HGV (>3.5t)
	Roundabout to Westbrook Road								
TfL HAM	A2 Westbrook Road to Kidbrooke Park Road	92652	4.1%	50	38	100648	256	100957	3.4%
TfL HAM	A2 Kidbrooke Park Road to Westhorne Avenue	78617	4.4%	50	44	84643	250	84954	3.4%
TfL HAM	A2 Westhorne Avenue to Riefield Road	110028	4.2%	50	34	121028	250	121376	3.4%
TfL HAM	A2 Riefield Road to Blendon Road	129724	3.8%	50	36	140753	250	141101	3.2%
TfL HAM	A2 Blendon Road to Lodge Lane	101105	3.9%	50	32	112605	286	112954	3.2%
TfL HAM	A2 Lodge Lane to Upton	134367	3.5%	50	32	145089	286	145439	2.9%

Source	Road link	2010 baseline AADT*	Baseline % HGV >3.5t	Speed limit (mph)	Model input speed (mph)	Peak construction year AADT	Peak construction year AADT scheme construction HGV (HGV >3.5t)	Peak construction year development case (total AADT)	Peak construction year develop-ment case AADT % HGV (>3.5t)
	Road								
TfL HAM	A2 Upton Road to Bourne Road	133682	4.0%	50	31	144277	286	144627	3.4%
TfL HAM	A2 Prince Charles Road Roundabout EB	16924	4.0%	50	21	17672	286	17859	3.9%
TfL HAM	A2 Prince Charles Road Roundabout WB	20704	5.4%	50	23	22847	286	23017	4.4%

** AADT – annual average daily traffic. ** ATC - automatic traffic count.*

References

[1] Defra, *Local Air Quality Management - Technical Guidance, LAQM.TG* (09) (2009)

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Appendix C: Ecology - aquatic

APFP Regulations 2009: Regulation **5(2)(a)**

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Appendix C.1: Baseline report

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Appendix C: Ecology – aquatic

C.1 Baseline report

C.1.1 The following report has its own table of contents.

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Appendix C.1: Baseline report

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Appendix C: Ecology – aquatic

C.1 Baseline report

Introduction

C.1.1 The baseline data supporting the aquatic ecology assessment is based on field survey and background sources. The data has been interpreted and presented in the site specific *Environmental Statement* reports (Volumes 4 to 27) and the Project-wide effects assessment (Volume 3). Information relating to the methodologies used for field survey and assessment; and the range of background data sources is presented in Volume 2 Environmental assessment methodology.

C.1.2 This report presents supporting data and information considered to be relevant to the assessments, but too lengthy to present in the individual *Environmental Statement* assessment reports.

C.1.3 The report does not include raw data held in spreadsheet or database format, such as the Environment Agency (EA) year on year Water Framework Directive fish monitoring programme; or the Thames Estuary Benthic Monitoring Programme for invertebrates. The data is summarised in this report.

C.1.4 The Appendix addresses receptors in the following order:

a. Designations and habitats.

b. Marine mammals.

c. Fish.

d. Invertebrates.

e. Algae.

Designations and habitats

C.1.5 All data obtained for statutory and non-statutory designated sites and for habitats present along the Thames Tideway is presented in the main body of Vol 3 or in site-specific assessments (Vol 4-27), including separate volumes of figures.

Marine mammals

C.1.6 All data obtained for mammals along the Thames Tideway is presented in the main body of Vol 3 or in site-specific assessments (Vol 4-27), including separate volumes of figures.

Fish

Introduction

C.1.7 The following section presents additional supporting information relating to Tideway fish. It includes:

a. An account of the October 2010 field surveys, including species abundances for individual sites, and size composition for individual species.

b. An account of the May 2011 field surveys, including species abundances for individual sites, and size composition for individual species. This is only available on a site-by-site basis for 2011.

c. An account of the 2011 surveys for juvenile fish, including species abundances for individual sites, analysis of effects of water depth, analysis of climatic conditions, records of substrates present, and a summary account for individual fish species.

d. Data for individual EA sampling sites in terms of age composition based on EA multi-method surveys between 1992 and 2010.

e. Age class and length frequency distribution data for selected species through the Tideway based on EA background data.

Baseline fish surveys

C.1.8 Vol 3 Table C.1 presents the raw data collected during the surveys undertaken during October 2010, as numbers of fish recorded for each sample. Except where indicated, all survey sites contribute data that are represented in site-specific assessments (Vol 4-27). Survey methods are presented in Vol 2. Vol 3 Table C.1 summarises the total numbers sampled at each site and provides a picture of variations in the relative abundance of different species along the sampled reach. Vol 3 Table C.2 presents equivalent data for surveys undertaken during May 2011. Photographs of sampled fish are provided in Vol 3 Plate C.64 to Vol 3 Plate C.73 at the end of this document.

Vol 3 Table C.1 Total numbers of fish sampled at each site during October 2010

Thames Tideway Tunnel site	Bream	Dace	Roach	Roach/ bream hybr	Perch	Bleak	3 spined stickleback	10 spined stickleback	Comm smelt	Sand smelt	Sea bass	Flounder	Comm goby	Sand goby	Eel	Total fish
Deptford Church St	12	0	0	0	0	0	2	0	26	1	1	8	18	0	0	68
Kg Edward Mem Park	4	0	2	0	0	0	0	0	50	0	1	4	3	0	0	64
King's Stairs Gardens*	1	0	6	0	0	0	0	0	5	0	0	2	4	0	0	18
Blackfriars Bridge	2	2	1	0	0	0	0	0	9	0	0	13	10	1	3	41
Victoria Embankment	8	0	4	1	0	0	0	0	10	0	0	4	1	0	0	28
Albert Embankment	6	2	1	0	0	0	0	0	8	0	0	0	2	0	0	19
Tideway Walk**	34	4	22	0	0	0	0	0	15	0	2	7	0	0	2	86
Western Pumping Stn	18	3	5	2	1	0	1	0	180	0	0	5	0	0	0	215
Chelsea Embankment	5	7	2	0	0	0	1	0	73	0	0	18	10	0	0	116
Cremorne	81	2	10	0	1	1	0	0	69	0	0	21	61	0	0	246

Thames Tideway Tunnel site	Bream	Dace	Roach	Roach/ bream hybr	Perch	Bleak	3 spined stickleback	10 spined stickleback	Comm smelt	Sand smelt	Sea bass	Flounder	Comm goby	Sand goby	Eel	Total fish
Wharf Depot																
Jews Row***	1	6	7	0	0	0	0	0	14	0	0	43	0	0	0	71
Putney Bridge	4	4	10	0	0	0	0	0	1	0	0	19	0	0	2	40
Dormay Street	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barn Elms	67	6	384	1	3	0	3	1	13	0	2	47	17	0	1	545
Hammersmith Pumping Stn	11	5	11	0	0	1	1	0	3	0	1	6	1	0	0	40
Totals	254	41	465	4	5	2	8	1	476	1	7	197	127	1	8	1597

Note: (2 x 100m x 1m trawls plus 2 x 40m seine hauls)
** Approximately 1km downstream from Chambers Wharf*
*** Adjacent to Kirtling Street and Heathwall Pumping Station*
****Opposite bank of R Thames to Carnwath Road Riverside*

Vol 3 Table C.2 Total numbers of fish sampled at each site during May 2011

	Bream	Dace	Roach	Roach/ bream hybr	Perch	Bleak	3 spined stickleback	10 spined stickleback	Comm smelt	Sand smelt	Sea bass	Flounder	Comm goby	Sand goby	Eel	Chub	Gudgeon	Stone loach	Total fish
Carnwath Road	1	2							1			1							5
Bell Lane Creek*					2		9	1							8	1	3	28	52
Kirtling Street	15	1	46						4			5							71
Heathwall Pumping Station	3		7						2						1				13
Chambers Wharf	3	1	4		2				1										11
Greenwich Pumping Station												19			16	2			37
Intermediate Site 1**			1				1					8			2				12
Intermediate Site 2**	1	1	13									10							25

	Bream	Dace	Roach	Roach/ bream hybr	Perch	Bleak	3 spined stickleback	10 spined stickleback	Comm smelt	Sand smelt	Sea bass	Flounder	Comm goby	Sand goby	Eel	Chub	Gudgeon	Stone loach	Total fish
Intermediate Site 3**												3							3
Cremorne Wharf Depot	9		14		2														25
Putney Bridge		1																	1
Western Pumping Station									4										4
Totals	32	6	85	0	6	0	10	1	12	0	0	46	0	0	27	3	3	28	259

** Relevant to Dormay Street and King George's Park*
*** Potential fish spawning sites*

Fish spawning sites

C.1.9 During May 2011, six sites were sampled in order to seek to determine locations at which common smelt might spawn within the Thames Tideway. The sites surveyed, from upstream to downstream, were Putney Bridge, Intermediate Site 1 (NGR: 524596, 175507), Intermediate Site 2 (NGR: 526550, 176225), Cremorne Wharf, Western Pumping Station (NGR: 528673, 177818), Intermediate Site 3 (downstream of Albert Bridge)

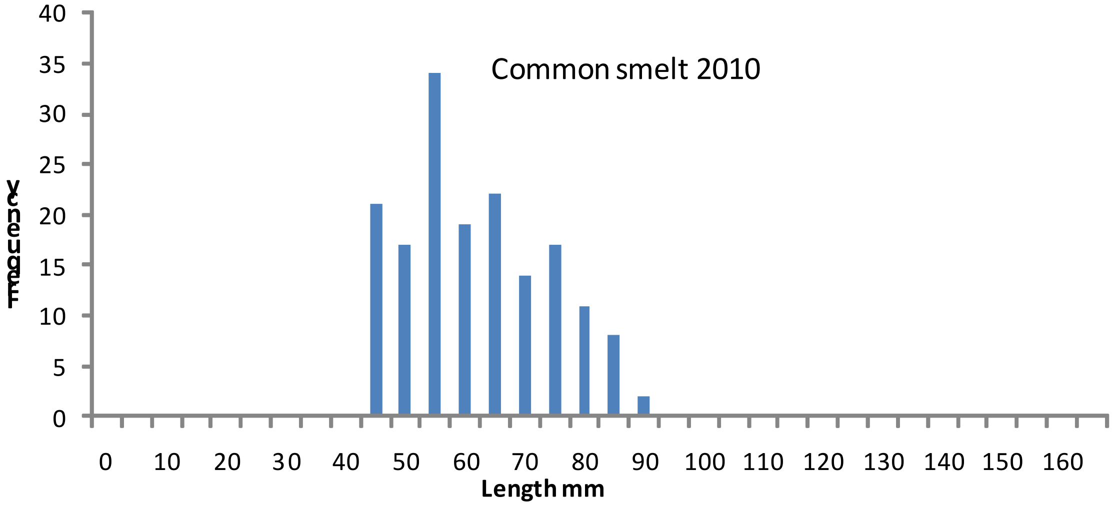
C.1.10 The data from these sites are indicated in Vol 3 Table C.2.

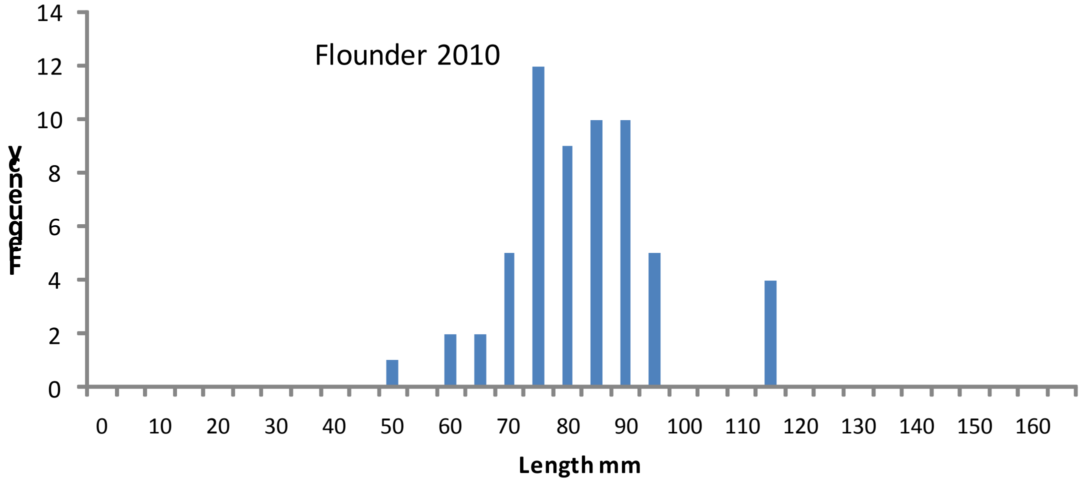
Size composition

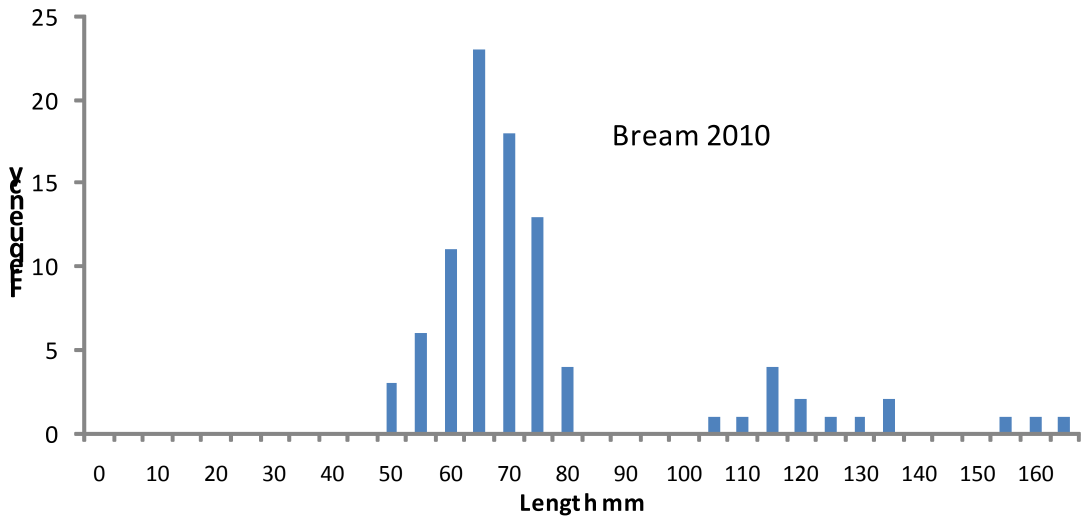
C.1.11 The size composition of the various fish species for both years is illustrated in Vol 3 Plate C.1. The mesh sizes of the two nets (5mm in the case of the seine and 4mm in the trawl) were sufficiently small to ensure reasonable capture rates of young fish from the 2010 year class. At the time of sampling (October) the 0+ year class of roach and bream caught in the nets ranged between 40 and 80mm in length with modal values around 70 mm. Similar capture rates for 0+ smelt showed sizes ranging between 40 and 90mm in length, possibly with a small proportion of escapement of the very smallest young of the year below 40mm in length.

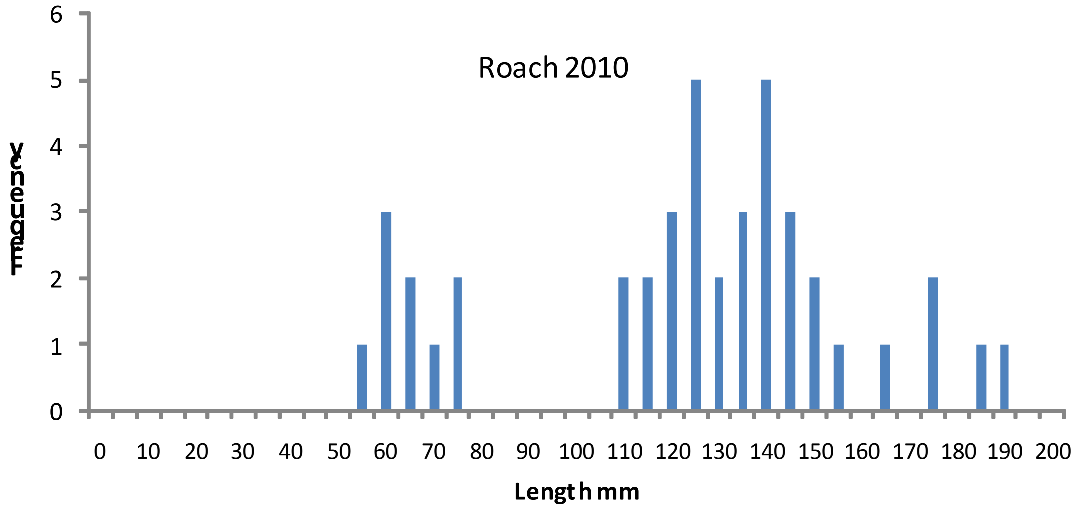
C.1.12 Whereas only a single year class of smelt was present, the size composition of roach and bream indicated multi-aged populations with several year classes. The sampled roach population extended to 230mm and a very large bream of 530mm was sampled at Barn Elms. Other notable fish included two large eels of 870 and 790mm respectively from Blackfriars, and two good sized bass of 650mm each taken at Tideway Walk.

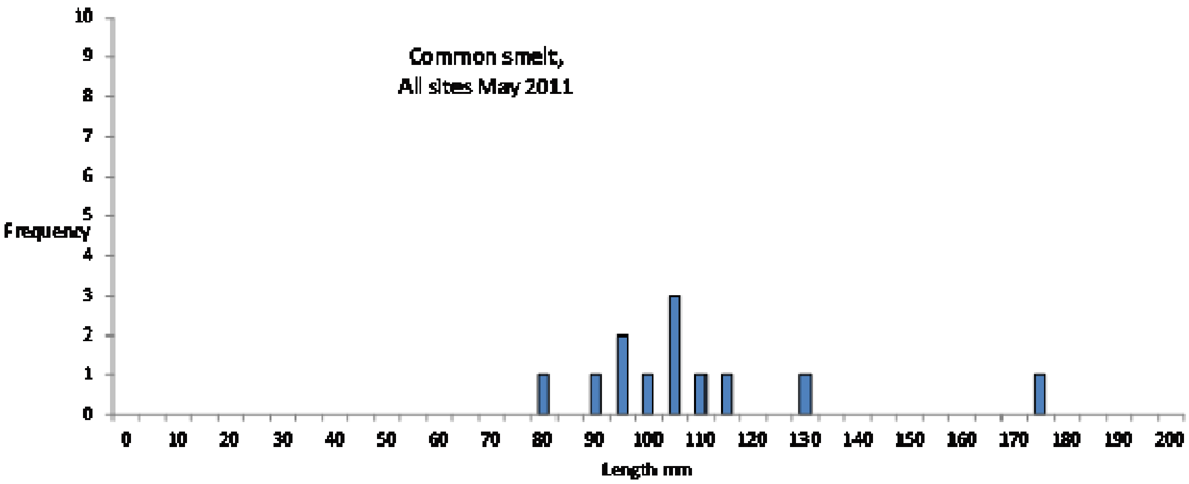
Vol 3 Plate C.1 Length composition of the abundant fish species

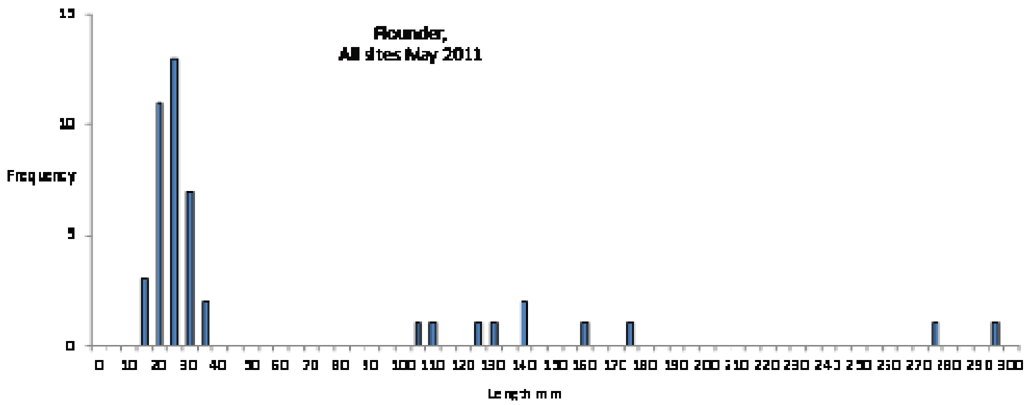


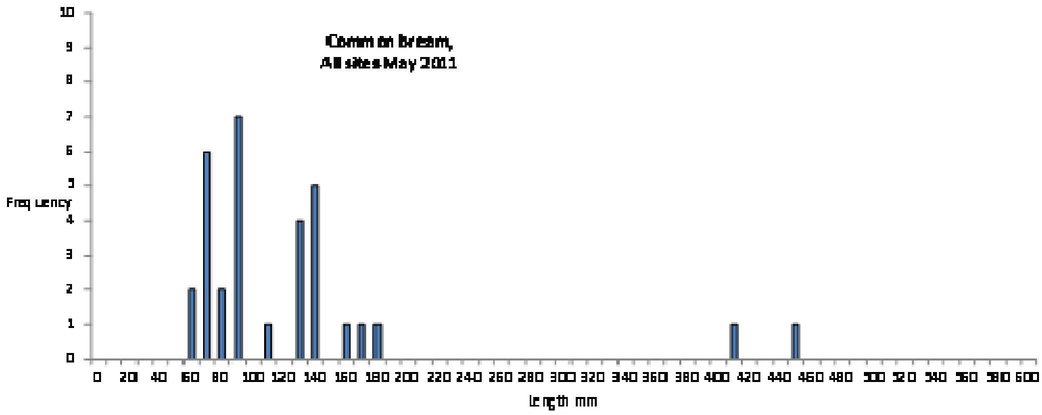


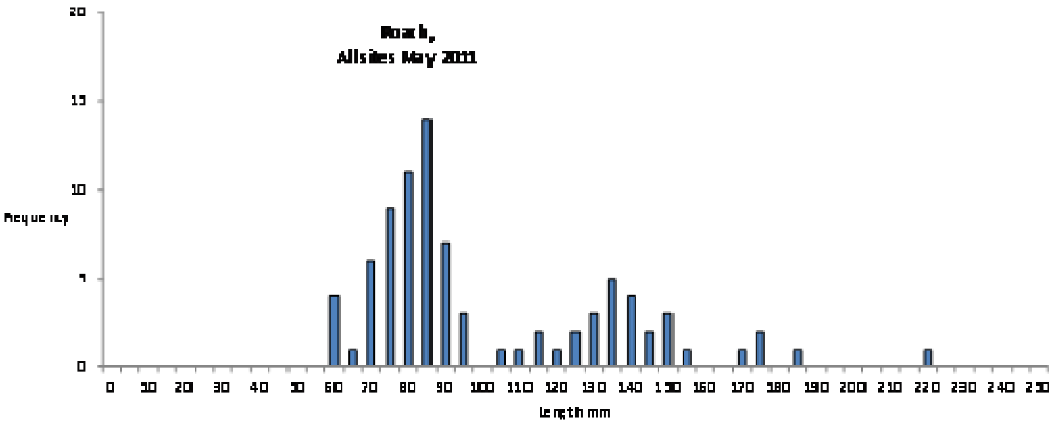

Bream 2010
Frequency
Length mm
0
5
10
15
20
25
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160


Roach 2010
Frequency
Length mm
0
1
2
3
4
5
6
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200


Common smelt,
All sites May 2011
Frequency
Length mm
0
1
2
3
4
5
6
7
8
9
10
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200







Juvenile fish data

C.1.13 Between May and September 2011, five foreshore sites were sampled on six occasions to determine their value for juvenile fish. Methodologies employed are described in Vol 2.

C.1.14 Vol 3 Table C.3 indicates the substrate and general river environment at each of the sampling sites.

Vol 3 Table C.3 Juvenile fish survey sites 2011

Survey location	Site description
Kew (TQ 19097787)	The river corridor at this site is *c.* 120 meters wide. It is characterised by a mixed substrate, with a predominance of coarse gravel (32-64 mm). No macrophyte beds are present at the site, but there is widespread moss and algal growth. Water velocities throughout the site appear fairly homogenous. Boat traffic is minimal, compared to more downstream sites, typically consisting of small rowing boats and occasional powered craft. Water clarity at the site is relatively good for the Tideway (typically ≥ 30 cm visibility, estimated by eye).
Putney Bridge (TQ 23947582)	The river corridor measures ca. 180 m across. Substrate is typically uniform gravel (16-32 mm), with some silted shallow gravel bars. Due to the presence of busy slipways in the area and several active rowing clubs, the river is kept relatively clear of debris, which may have improved netting efficiency at this site. The substrate here is comprised largely of gently-sloping gravel beds; no macrophyte stands are present within the sampled area.
Chelsea (TQ 28277781)	Substrates are mixed and characterised by coarse gravel (32-64 mm) and larger cobbles (> 20 cm). Velocities appear generally homogenous, however, during large spring tides, gravel banks form slacker areas of water which are favourable for seine netting around low water. At this site the river channel measures ca. 220 m in width.
Blackfriars Bridge (south bank) (TQ 31248051)	The immediate foreshore is characterised by a sand bank, leading to a coarse gravel area which stretches to the low water tidal limit. The site experiences marked wave-wash, generated by passing large vessels and, as a result, turbidity is usually relatively high. No macrophyte beds are present. At this point the river corridor width measures around 280 m.
Bermondsey (TQ 34577975)	Characterised by a fairly uniform coarse gravel bank, with some large woody debris and larger boulders. No macrophyte beds are present; water currents at this site appear faster compared to upstream sites. The river corridor measures 252m in width.

C.1.15 The first set of samples was taken during the week commencing May 9th 2011. The sites were sampled on the following dates: Putney May 9th, Kew May 10th, Chelsea May 11th, King Edward May 12th and Blackfriars May 13th. Vol 3 Table C.4 provides the numbers of fish species caught along the Tideway in Survey 1.

Vol 3 Table C.4 Numbers of various fish species caught at Tideway sampling sites in Survey 1

Species	Kew	Putney	Chelsea	Blackfriars	Bermondsey
Smelt	17	2	0	0	1
Dace	1	74	2	4	0
Flounder	134	813	10	37	1
Goby	3	1	0	0	0
Perch	14	36	0	3	0
10-spined stickleback	1	0	0	0	0
3-spined stickleback	1	6	0	0	0
Eel	0	10	3	2	0
Roach	0	5	0	0	0
Barbel	0	0	0	0	0
Bass	0	0	0	0	0
Gudgeon	0	0	0	0	0
Stone loach	0	0	0	0	0
Bream	0	0	0	0	0
Zander	0	0	0	0	0
Bleak	0	0	0	0	0
Bullhead	0	0	0	0	0
Sand smelt	0	0	0	0	0
Chub	0	0	0	0	0
Mullet	0	0	0	0	0
TOTAL	171	947	15	46	2

C.1.16 The second set of samples was taken during the week commencing May 23rd 2011. The sites were sampled on the following dates: Putney May 23rd, Kew May 26th, Chelsea May 25th, Bermondsey May 24th and Blackfriars May 27th. Vol 3 Table C.5 provides the numbers of fish species caught along the Tideway in Survey 2.

Vol 3 Table C.5 Numbers of various fish species caught at Tideway sampling sites in Survey 2

Species	Kew	Putney	Chelsea	Blackfriars	Bermondsey
Smelt	162	3	0	1	2
Dace	81	30	2	0	2
Flounder	803	3698	375	325	7
Goby	1	0	0	0	0
Perch	72	52	25	4	0
10-spined stickleback	0	0	0	0	0
3-spined stickleback	1	0	0	0	0
Eel	2	10	2	0	3
Roach	0	18	0	2	0
Barbel	0	0	0	0	0
Bass	0	0	0	0	0
Gudgeon	0	0	0	0	0
Stone loach	0	0	0	0	0
Bream	0	0	0	0	0
Zander	0	0	0	0	0
Bleak	0	0	0	0	0
Bullhead	0	0	0	0	0
Sand smelt	0	0	0	0	0
Chub	0	0	0	0	0
Mullet	0	0	0	0	0
TOTAL	1125	3811	404	332	14

C.1.17 The third set of samples was taken during the week commencing June 20th 2011. The sites were sampled on the following dates: Putney June 22nd, Kew June 20th, Chelsea June 21st, Bermondsey June 24th and Blackfriars June 23rd. Vol 3 Table C.6 provides the numbers of fish species caught along the Tideway in Survey 3.

Vol 3 Table C.6 Numbers of various fish species caught at Tideway sampling sites in Survey 3

Species	Kew	Putney	Chelsea	Blackfriars	Bermondsey
Smelt	0	1	0	0	0
Dace	8	177	1	0	0
Flounder	101	1301	98	86	102
Goby	0	5	38	0	2
Perch	15	33	3	0	0
10-spined stickleback	1	20	0	0	0
3-spined stickleback	12	52	5	0	1
Eel	3	4	5	1	2
Roach	92	67	30	10	25
Barbel	0	1	0	0	0
Bass	0	97	6	5	0
Gudgeon	0	2	0	0	0
Stone loach	0	2	0	0	0
Bream	0	0	0	0	0
Zander	0	0	0	0	0
Bleak	0	0	0	0	0
Bullhead	0	0	0	0	0
Sand smelt	0	0	0	0	0
Chub	0	0	0	0	0
Mullet	0	0	0	0	0
TOTAL	232	1762	186	102	132

C.1.18 The fourth set of samples was taken during the week commencing July 25th 2011. The sites were sampled on the following dates: Putney July 26th, Kew July 27th, Chelsea July 25th, Bermondsey July 29th and Blackfriars July 28th. Vol 3 Table C.7 provides the numbers of fish species caught along the Tideway in Survey 4.

Vol 3 Table C.7 Numbers of various fish species caught at Tideway sampling sites in Survey 4

Species	Kew	Putney	Chelsea	Blackfriars	Bermondsey
Smelt	0	0	0	0	0
Dace	80	21	0	0	0
Flounder	7	26	3	13	16
Goby	0	283	472	168	262
Perch	2	3	0	0	7
10-spined stickleback	0	1	0	0	0
3-spined stickleback	8	60	1	0	0
Eel	0	1	1	8	4
Roach	1	19	0	0	1
Barbel	0	0	0	0	0
Bass	17	72	162	126	247
Gudgeon	0	1	0	0	0
Stone loach	0	0	0	0	0
Bream	3	1	3	3	7
Zander	0	0	0	0	2
Bleak	0	0	0	0	0
Bullhead	0	0	0	0	0
Sand smelt	0	0	0	0	2
Chub	0	0	0	0	0
Mullet	0	0	0	0	0
TOTAL	38	488	643	318	548

C.1.19 The fifth set of samples was taken during the week commencing August 22nd 2011. The sites were sampled on the following dates: Putney August 23rd, Kew August 22nd, Chelsea August 24th, Bermondsey August 26th and Blackfriars August 25th. Vol 3 Table C.8 provides the numbers of fish species caught along the Tideway in Survey 5.

Vol 3 Table C.8 Numbers of various fish species caught at Tideway sampling sites in Survey 5

Species	Kew	Putney	Chelsea	Blackfriars	Bermondsey
Smelt	0	0	0	1	0
Dace	4	2	0	0	0
Flounder	1	7	1	1	1
Goby	7	851	369	382	457
Perch	0	0	0	0	0
10-spined stickleback	0	0	0	1	0
3-spined stickleback	6	26	0	0	0
Eel	0	1	1	3	1
Roach	0	11	0	0	0
Barbel	0	0	0	0	0
Bass	161	67	149	57	14
Gudgeon	0	1	0	0	0
Stone loach	0	0	0	0	0
Bream	0	0	0	0	0
Zander	0	0	0	0	2
Bleak	0	0	0	0	0
Bullhead	0	0	0	1	0
Sand smelt	0	1	2	0	1
Chub	2	0	0	0	0
Mullet	0	0	0	0	0
TOTAL	181	967	522	446	476

C.1.20 The sixth set of samples was taken during the week commencing September 26th 2011. The sites were sampled on the following dates: Putney September 26th, Kew September 27th, Chelsea September 28th, Bermondsey September 30th and Blackfriars September 29th. Vol 3 Table C.9 provides the numbers of fish species caught along the Tideway in Survey 6.

Vol 3 Table C.9 Numbers of various fish species caught at Tideway sampling sites in Survey 6

Species	Kew	Putney	Chelsea	Blackfriars	Bermondsey
Smelt	0	0	2	0	0
Dace	0	2	0	0	0
Flounder	0	0	2	9	10
Goby	220	995	470	25	330
Perch	0	0	0	0	0
10-spined stickleback	1	1	0	0	0
3-spined stickleback	9	17	2	0	0
Eel	3	0	2	0	3
Roach	0	3	1	0	1
Barbel	0	0	0	0	0
Bass	137	28	23	4	4
Gudgeon	0	0	0	0	0
Stone loach	0	0	0	0	0
Bream	0	0	4	2	5
Zander	0	0	0	0	1
Bleak	0	0	0	0	0
Bullhead	0	0	0	0	0
Sand smelt	0	1	0	0	0
Chub	0	1	0	0	0
Mullet	6	14	0	0	10
TOTAL	376	1062	506	40	364

Use of marginal Tideway habitats at Putney by juvenile fish on a rising tide

C.1.21 An extended Riley netting sampling effort was carried out at Putney in order to determine use of the foreshore at states of the tidal cycle by juvenile fish. The three paired Riley nettings as described in Vol 2 were undertaken on the dropping tide, and a total of five extra paired ‘shallow’ and ‘deep’ Riley runs were carried out on the afternoon rising tide. Current velocity profiles were also measured during the afternoon in order to inform subsequent hydrodynamic computer simulation modelling of Tideway fish movements, which is also described in Vol 2. The results of fish catches from the survey are shown in Vol 3 Table C.10.

Vol 3 Table C.10 Putney Riley net catches June 22nd 2011

Netting Ref. and Time	Catches in 'Deep' Riley net @ 60cm	Catches in 'Shallow' Riley net @ 30cm
Riley 1: 12.58 hr	Flounder 105, Eel 3, Three spined stickleback 1, Perch 1.	Bass 2, Gudgeon 1, Goby 1, Barbel 1, Perch 4, Eel 1, Flounder 217, Ten spined Stickleback 1, Three spined Stickleback 13.
Riley 2: 13.20 hr	Flounder 79, Three spined stickleback 1.	Bass 3, Perch 5, Flounder 264, Three spined Stickleback 2, Roach 5, Dace 12, Stone loach 1.
Riley 3: 13.50 hr	Flounder 35.	Bass 1, Perch 3, Flounder 67, Gudgeon 1, Dace 4.
Low tide: 14.33 hr		
Riley 4: 15.31 hr	Flounder 1.	Roach 2, Flounder 19, Perch 1.
Riley 5: 15.50 hr	Flounder 32.	Stone loach 1, Roach 10, Bass 5, Flounder 37, Three spined stickleback 1.
Riley 6: 16.15 hr	Flounder 40, Roach 1.	Perch 9, Dace 5, Roach 6, Three spined stickleback 6, Bass 6, Flounder 64.
Riley 7: 16.45 hr	Flounder 65, Perch 1.	Bass 8, Roach 4, Three spined stickleback 1, Ten spined stickleback 1, Flounder 19.
Riley 8: 17.08 hr	Perch 1, Flounder 86, Dace 1, Goby 1.	Bass 23, Roach 4, Dace 7, Perch 1, Flounder 44.
High tide: 19.29 hr		

C.1.22 Key findings from this extended set of Riley nettings were:

a. At all stages of tide sampled the 'Shallow' Riley nets, working in water of <30cm captured a greater range of species and, very often, greater numbers of individuals, than 'Deep' nets.

b. It would appear, particularly from numbers of flounder captured, that the falling tide concentrates fish close to the water line.

c. Re-distribution up the intertidal zone with the advancing tide appears to be rapid and to occur in shallow water of <30cm.

Climatic conditions during 2011 juvenile fish sampling

C.1.23 UK Meteorological Office data show that spring 2011 was the warmest on record and that rainfall in South-East England and East Anglia was the lowest for 100 years. This combination of climatic events led to high springtime water temperatures in the upper Tideway – for instance 21.4° Celsius at Kew on May 10th 2010. It seems likely, therefore, that 2011 was an early spawning year for fish which respond to water temperature as a cue for reproductive activity. Springtime growth rates may also have been faster amongst thermophilic species than those more normally seen on the Tideway. The warm water temperatures and low riverine flows also made the Tideway particularly vulnerable to dissolved oxygen sags imposed by organically-polluted combined sewer overflow (CSO) effluent events, such as that recorded in May/June 2011.

Tideway juvenile fish community structure

C.1.24 A complete list of fish species caught during all surveys and their representation at sampling sites is presented in Vol 3 Table C.11 below.

Vol 3 Table C.11 Fish species caught during juvenile sampling program

Common name	Scientific name	Kew	Putney	Chelsea	Black-friars	Bermond-sey
Bass	*Dicentrarchus labrax*	Y	Y	Y	Y	Y
Mullet	*Chelon labrosus*	Y	Y	N	N	Y
Goby	*Potamoschistus sp*	Y	Y	Y	Y	Y
Sand smelt	*Atherina presbyter*	N	Y	N	N	Y
Common smelt	*Osmerus eperlanus*	Y	Y	Y	Y	Y
Flounder	*Platichthys flesus*	Y	Y	Y	Y	Y
Ten-spined stickleback	*Pungitius pungitius*	Y	Y	N	Y	N
Three-spined stickleback	*Gasterosteus aculeatus*	Y	Y	Y	N	Y
Eel	*Anguilla anguilla*	Y	Y	Y	Y	Y

Common name	Scientific name	Kew	Putney	Chelsea	Black-friars	Bermond-sey
Dace	*Leuciscus leuciscus*	Y	Y	Y	Y	Y
Chub	*Leucuscus cephalus*	Y	Y	N	N	N
Roach	*Rutilus rutilus*	Y	Y	Y	Y	Y
Barbel	*Barbus barbus*	N	Y	N	N	N
Gudgeon	*Gobio gobio*	N	Y	N	N	N
Bream	*Abramis brama*	Y	Y	Y	Y	Y
Bleak	*Alburnus alburnus*	N	N	Y	N	N
Bullhead	*Cottus gobio*	N	N	N	Y	N
Stone loach	*Barbatula barbatula*	N	Y	N	N	N
Perch	*Perca fluviatilis*	Y	Y	Y	Y	Y
Zander	*Sander lucioperca*	N	N	N	N	Y

Summary of distribution of juvenile fish during 2011 surveys

C.1.25 Observations made during the present study indicate that a gradually-sloping intertidal foreshore, such as that found at Putney, is a preferred condition, with consistently high overall juvenile fish biodiversity and abundance recorded at this site. Shallowly-sloping shorelines allow juvenile fish to remain in the relative safety of shallow, slower-moving water, throughout the tidal cycle. It is not clear to what extent the consistently higher catches here may have been influenced by favourable sampling conditions.

C.1.26 When species occurrences at the various sampling sites were compared for association (using Chi-squared statistical tests), the following results were obtained:

a. Strong positive associations occurred between bass and gobies, bass and bream, mullet and chub;

b. Strong negative associations (i.e. species rarely found associated with each other in the dataset) occurred between flounder and chub, flounder and mullet, barbel and bleak, stone loach and bleak, bullhead and bleak, bullhead and stone loach, bullhead and barbel.

C.1.27 The above associations appear likely, in many cases to be due to sampling artefacts, but a strong association between bass and gobies is predictable from their respective biology and negative associations between, for instance, flounder and chub, and bullhead and bleak may also be ecologically explicable in terms of, for instance, differing water quality requirements in the former case and microhabitat selection in the latter.

Species accounts for juvenile fish surveys

Flounder

Survey 1

C.1.28 Examination of size frequency for flounder produces a valuable history of early immigration of larvae and post-larvae, clustering around the top of the Tideway at Kew and Putney and extending downstream to Bermondsey in small numbers. This early spring influx of marine-spawned flounders represents the settlement of vast numbers of flatfish larvae, settling out of the open water plankton to explore the shallow water estuarine habitats where they will spend their first summer of life. Access to this habitat removes fish from the wider range of predatory species lower in the estuary and provides access to abundant food resources where there is limited competition from other demersal fish. It was notable that juvenile flounders usually had stomachs bulging with food, visible through the body wall. In Week 1, the overall modal size class for sampled flounder was 12-14mm and most fish were caught at Putney in Riley nets.

Survey 2

C.1.29 By Survey 2, the overall modal size class had increased to 18-20 mm and the pattern of predominantly larger flounders occurring downstream at Chelsea, Blackfriars and Bermondsey becomes further established. At the latter three sites, flounders of 30-32mm were already well represented in the local population whilst, at the same time, many Kew and Putney flounders measured 15-20mm. Most fish were caught by Seine or Riley net.

Survey 3

C.1.30 By Survey 3, the overall modal size class had risen to 33-35 mm and the samples were dominated numerically by the local Putney population. At this time the tendency for larger flounders to occur downstream is still present, but less marked. Most fish were caught by Riley net.

Survey 4

C.1.31 By Survey 4, the overall modal flounder size class had risen to 42-44mm. The now-characteristic split between predominantly small fish upstream and larger fish downstream was maintained, with perhaps a 10mm difference in average sizes between the two groups. Most fish were caught by Seine net.

Survey 5

C.1.32 By Survey 5, flounder catches in the estuarine margins had fallen to low levels and it seems likely that this reflects a switch in microhabitat use, from the upper shoreline ‘sampled zone’, down the slope and further out into the estuarine channel. This view is supported by catches of flounder made by THA whilst trawling deeper mid-channel locations in the upper

Tideway for another project. Most juvenile fish were caught by Riley and Seine net.

Survey 6

C.1.33 Survey 6 flounder samples continue the expected predominantly downstream distribution of relatively large fish (mode 66-68mm): this September data set may mark the progressive movement of flounder to over-wintering outer estuary feeding grounds. Most juvenile fish were caught by Riley and Seine net.

Bass

Surveys 1 and 2

C.1.34 Surveys 1 and 2 produced no juvenile bass, at this time the species is still drifting inshore from spawning grounds in the North Sea/English Channel.

Survey 3

C.1.35 In Survey 3, bass larvae of predominantly 16-18mm appeared in catches at Putney, with smaller numbers of fish caught as far downstream as Bermondsey. Most juvenile bass were caught in Seine nets.

Survey 4

C.1.36 By Survey 4, the early-arriving upstream (Kew/Putney) component of the bass population had grown to a modal size of around 33-35 mm, whilst newer arrivals downstream from Chelsea to Bermondsey were typically 18-23mm. Most juvenile bass were caught in Seine nets, with a progressive increase in catch per individual netting moving downstream.

Survey 5

C.1.37 By Survey 5, the pattern of predominantly larger bass upstream is maintained, with Kew/Putney fish of around 36-44 mm and Blackfriars/Bermondsey fish of around 10 mm less, on average. Catches tended to be larger upstream on this occasion.

Survey 6

C.1.38 By Survey 6, the sampled bass population was centred largely around Kew and ranged widely in size, with a middle band of 40-50 mm fish, once again Seine netting was the most successful sampling method.

Common smelt

Survey 1

C.1.39 Larval smelt were present from the first sampling, the population being concentrated at Kew, modal size was 15-17mm, with most fish being caught by Seine net.

Survey 2

C.1.40 Sampling in Survey 2 emphasised this pattern, with few smelt caught downstream of Kew. Modal size had increased to 30-32mm and most were caught by Seine net.

Survey 3

C.1.41 Survey 3 sampling occurred after a documented CSO incident(s) and produced only one 30mm smelt at Putney.

Survey 4

C.1.42 No smelt were caught at any site.

Surveys 5 and 6

C.1.43 During the final two surveys, three juvenile smelt were caught in Survey 5 and just one in Survey 6.

Dace

Survey 1

C.1.44 Young-of-the-year dace were centred almost entirely around Kew and Putney, indicating, perhaps that the prime natal habitat is the lower Thames or upper Tideway. In Survey 1, modal size dace of 18-20 mm were caught at Putney, with a smaller catch component at Bermondsey; fish which may have originated in the River Wandle. Very small dace were caught either by Riley or Seine net.

Survey 2

C.1.45 By Survey 2, Kew and Putney dace were typically 18-23 mm, smaller numbers of 15-17mm fish were caught at Chelsea and most fish were caught by seining.

Survey 3

C.1.46 By Survey 3, the modal size of Putney fish had risen to 39-41mm: rapid growth. Very few dace were caught elsewhere.

Survey 4

C.1.47 By Survey 4, numbers of dace caught were declining, but size had increased at Putney to typically 60-70mm: once again, rapid growth.

Surveys 5

C.1.48 By Survey 5, Kew and Putney dace had continued to grow rapidly, reaching 75-85mm; numbers caught were broadly comparable to Survey 4.

Survey 6

C.1.49 By Survey 6, five months after appearing in early May samples, dace of the 2011 year class were 100 mm-plus in length and had predominantly disappeared from the shallow littoral zone, presumably to shoal in deeper water.

Perch

Survey 1

C.1.50 In Survey 1, perch larvae were caught widely in the Tideway, with a modal size of 15-17 mm and the population having an upstream distribution, possibly originating largely from the known abundant Lower Thames perch stock. Most fish were caught by seining.

Survey 2

C.1.51 Survey 2 perch fry show a similar distribution to Survey 1, with a modal size increase to 21-23mm.

Survey 3

C.1.52 Survey 3 perch samples show a wide size-range, once again concentrated in the upper Tideway. The largest young-of-the-year fish were 54-56mm.

Survey 4

C.1.53 Perch were now much larger, having shown rapid growth and catches indicate an increased range to include Bermondsey, although the numbers caught were small. The warm water temperatures recorded in the early spring of 2011 meant that, provided adequate food supplies were present, 0 group perch would have grown at optimal rates.

Surveys 5 and 6

C.1.54 By August, 2011 year class perch had disappeared from sampled Tideway foreshore habitats, possibly to shoal in deeper water.

Distribution of juvenile fish with respect to depth

C.1.55 The results of the 2011 juvenile fish survey show that a wide range of species occur consistently in Tideway habitats of one metre or less and that many young fish live routinely in water of less than 30 cm, i.e. the shallow margins.

Environment Agency monitoring data

C.1.56 Data from the ongoing EA Thames Tideway annual survey program are used for assessment of likely impacts of a range of water resources, water quality, flood defence and wider development proposals on fish populations and communities using the lower River Thames and Thames Estuary.

C.1.57 EA fish surveys have used a combination of shore seine netting with both 35x2m and 50x2.5m nets, 2m beam trawling adjacent to seining sites and kick-sampling of suitable substrate areas. Surveys were conducted around the low-tide phase when current velocities are at their lowest and habitats at their most accessible. 8m beam trawling has also been conducted in the lower estuary and samples of fish collected from power station screens have been analysed to produce additional fisheries data.

C.1.58 The data were assessed for potential to produce trends in abundance of particular species at given sites, over time, but such analyses proved unsuitable due to the small numbers of each species caught in any particular year. The range of sampling techniques used (beam trawling, beach seining and hand net kick-sampling) each have their particular associated biases and target differing fish species groups. Sampling effort using these varying techniques was modest in any given year because of the large geographical scale and varied nature of the Thames Tideway, plus inevitable financial resource constraints. Overlain is the additional challenge which fish migratory patterns impose on the sampling program: differing species change in distribution and abundance with the seasons.

C.1.59 Upper Thames Tideway fish species recorded in EA samples between 1998-2008 can be split into a series of guilds (Elliott and Taylor, 1989; Elliott and Hemingway, 2002) relating to preferred salinity and life cycle habitat parameters in Vol 3 Table C.12 below.

Vol 3 Table C.12 Species recorded within the Upper Thames Tideway

Scientific name	Vernacular	Ecological guild
Abramis brama	Common bream	Freshwater
Alburnus alburnus	Bleak	Freshwater
Anguilla anguilla	European eel	Diadromous (migrating from freshwater to sea to spawn)
Atherina boyeri	Big-scale sand smelt	Estuarine Resident
Atherina presbyter	Sand smelt	Estuarine Resident
Barbus barbus	Barbel	Freshwater
Chelon labrosus	Thicklip grey mullet	Estuarine Resident
Cottus gobio	Bullhead	Freshwater
Cyprinus carpio	Common carp	Freshwater
Dicentrarchus labrax	European seabass (bass)	Marine Juvenile
Gasterosteus aculeatus	Three-spined stickleback	Diadromous (spawning in a range of salinities)
Gobio gobio	Gudgeon	Freshwater
Leuciscus cephalus	Chub	Freshwater
Leuciscus leuciscus	Dace	Freshwater
Liza ramada	Thin lip grey mullet	Estuarine Resident
Osmerus eperlanus	Smelt	Diadromous (spawning upstream in lower salinities)
Perca fluviatilis	European perch	Freshwater
Phoxinus phoxinus	Minnow	Freshwater
Platichthys flesus	Flounder	Estuarine Resident
Pomatoschistus microps	Common goby	Estuarine Resident
Pomatoschistus minutus	Sand goby	Estuarine Resident
Rutilus rutilus	Roach	Freshwater
Rutilus rutilus x Abramis brama	Roach x Bream hybrid	Freshwater
Salmo trutta	Sea trout	Diadromous (spawning in freshwater after feeding to

Scientific name	Vernacular	Ecological guild
		maturity at sea)
Sander lucioperca	Zander	Freshwater

C.1.60 The data for the 7 sites which lie within the study area are summarised in Vol 3 Table C.13 below.

Vol 3 Table C.13 Summary of fish at Environment Agency sites on Thames Tideway

EA monitoring site	Period in which site was sampled	Species	Age classes
Hammersmith	1998 to date	Bass Bream Dace Flounder Roach Sand smelt Common smelt Gobies Thin-lipped grey mullet Eel	0+ 0+,3+,4+ 0+,1+,2+,3+ 0+, 1+ 0+, 1+, 4+ 0+, 1+ 0+ 0+ NA NA
Fulham	1992	Low fish diversity & abundance: occasional mullet, eels.	NA
Putney	1992, 1993	Dace Flounder Roach Sand smelt Eels	1+,4+ 0+,1+ 0+,1+ 0+,1+,2+ NA
Battersea	1993-2010	Dace Flounder Bream Roach Smelt Gobies Thin-lipped grey mullet Eel	range of age classes 0+,1+ range of age classes range of age classes 0+,1+ 0+) NA NA
Chelsea	1992,1993	Dace	0+,1+

EA monitoring site	Period in which site was sampled	Species	Age classes
		Flounder Roach Bass Bream Thin-lipped grey mullet Eel	0+,1+ 0+ 0+ 0+,1+,8+ NA NA
Vauxhall	1992, 1993	Low fish diversity & abundance. Dace Bass	 0+, 1+ 0+
Greenwich	1993-2010	Bream Dace Roach Bass Flounder Smelt species Thin-lipped grey mullet Eel	0+,1+ and older age classes 0+,1+ and older age classes range of age classes 0+ 0+,1+ largely 0+,1+) NA NA

Note: available information on well-represented estimated year classes (1992-2010)

Examples of fish population structures

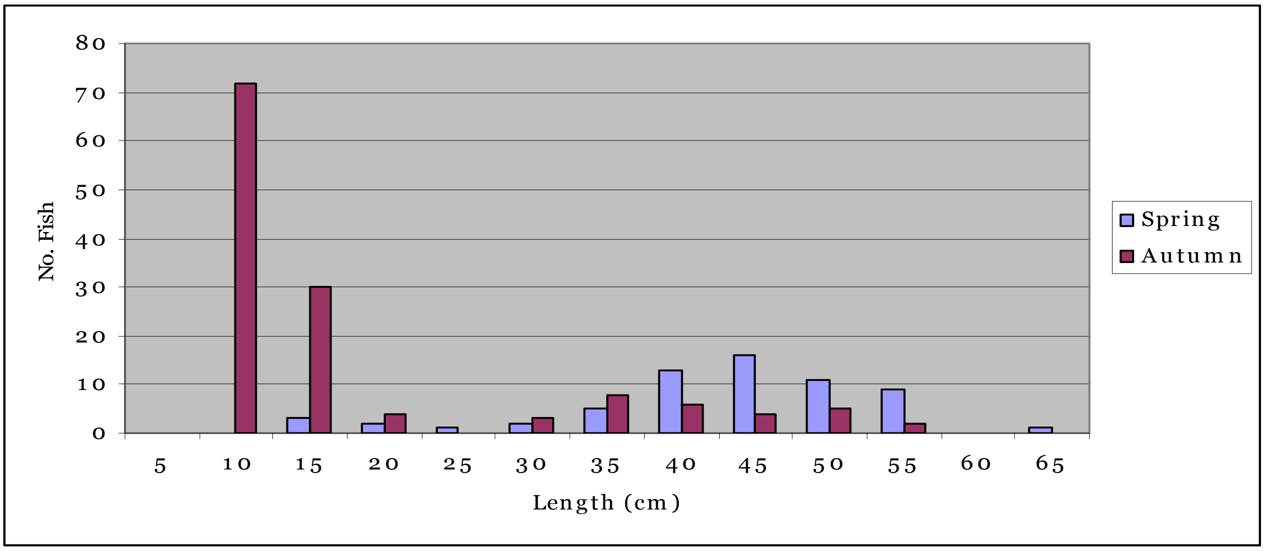
C.1.61 The following information drawn from the EA data provides a summary of the age structure of selected fish species within the Tideway. The species (common bream, dace, roach and flounder) have been selected on the basis of the most abundant species for which there is sufficient data for each year class to conduct a robust analysis.

Common bream

C.1.62 The common bream is widespread throughout the Tideway extending from West Thurrock to Teddington. Specimens were caught at Richmond, Kew, Chiswick and Battersea during each of the sampling seasons (between 1998 and 2008). The mean fork lengths for specimens sampled during the spring and early summer monitoring programme (between 1998 and 2008) was 377mm (n = 63, SE = 13.2). The maximum recorded fork length was 618 mm (range 539 mm). During the autumn sampling programme the mean fork length fell to 133.9 mm (n = 134, SE = 10.8) reflecting recruitment. The maximum fork length recorded during the autumn was 517 mm (range 477 mm).

C.1.63 Vol 3 Plate C.2 and Vol 3 Plate C.3 below, show the length and age-frequency distributions of bream recorded in both the spring and autumn surveys.

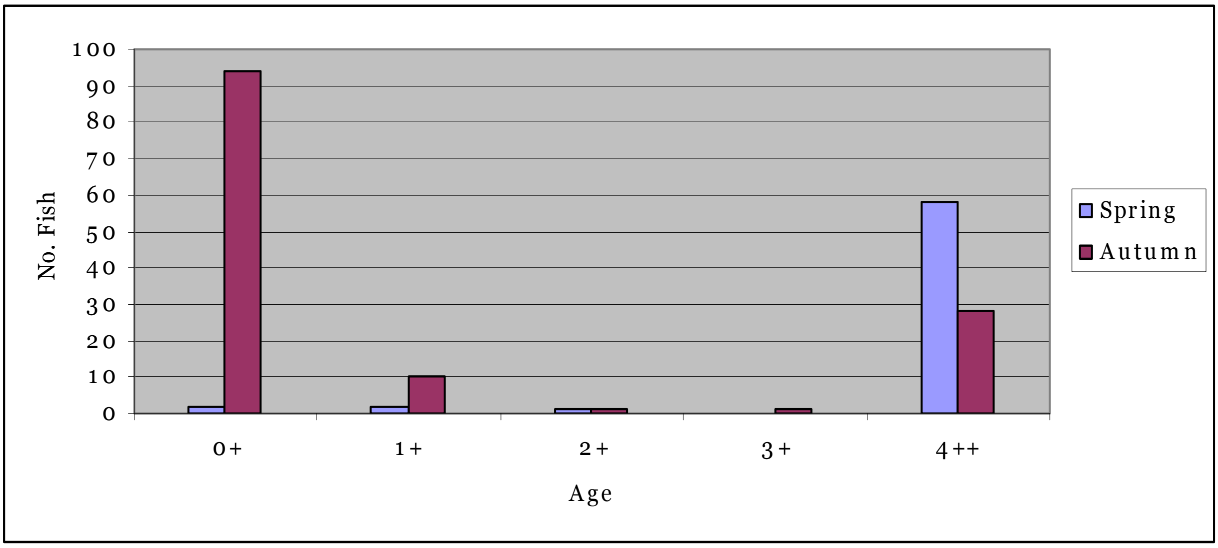
Vol 3 Plate C.2 Length-frequency distribution for common bream in Upper Tideway



Note: (1998 – 2008).

C.1.64 Throughout the Tideway common bream age classes have been recorded at between an estimated 0+ to 8+ years (O'Keeffe, 2005). Within the Upper Tideway, age classes (from length) were recorded between 0+ and 4+ (A.3 below).

Vol 3 Plate C.3 Age distribution of common bream within Upper Tideway

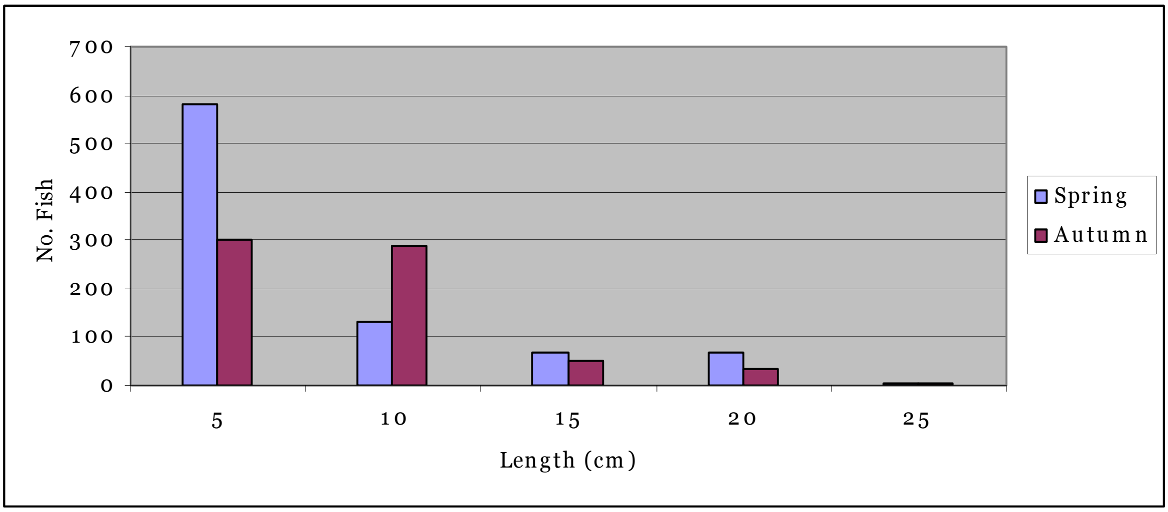


Note: (1998 – 2008)

Dace

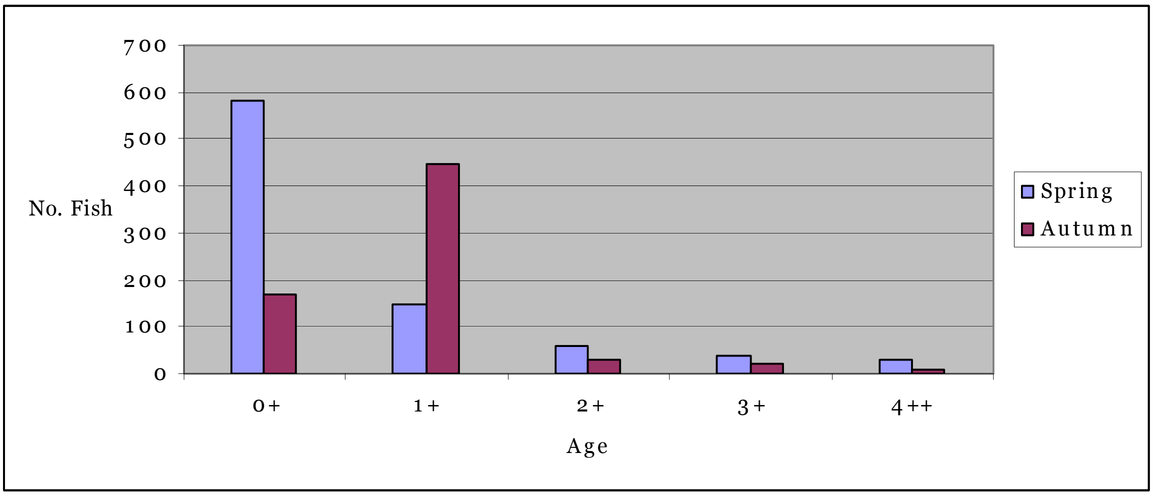
C.1.65 The mean fork lengths for dace sampled during the spring sampling programme was 63.4 mm (n=854, SE = 2.03). The largest specimen measured 246 mm and the sample range was 237 mm. The mean fork length for specimens recorded during the autumn sampling programme was 86.2 mm (n=676, SE = 1.4). The largest specimen recorded was 231 mm and the sample range was 201 mm. Vol 3 Plate C.4 below presents the length frequency distribution and Vol 3 Plate C.5 the estimated age frequency distribution of dace within the Upper Tideway between1998 and 2008.

Vol 3 Plate C.4 Length-frequency distribution for dace in Upper Thames Tideway



Note: (1998 – 2008).

Vol 3 Plate C.5 Age distribution of dace within Upper Tideway



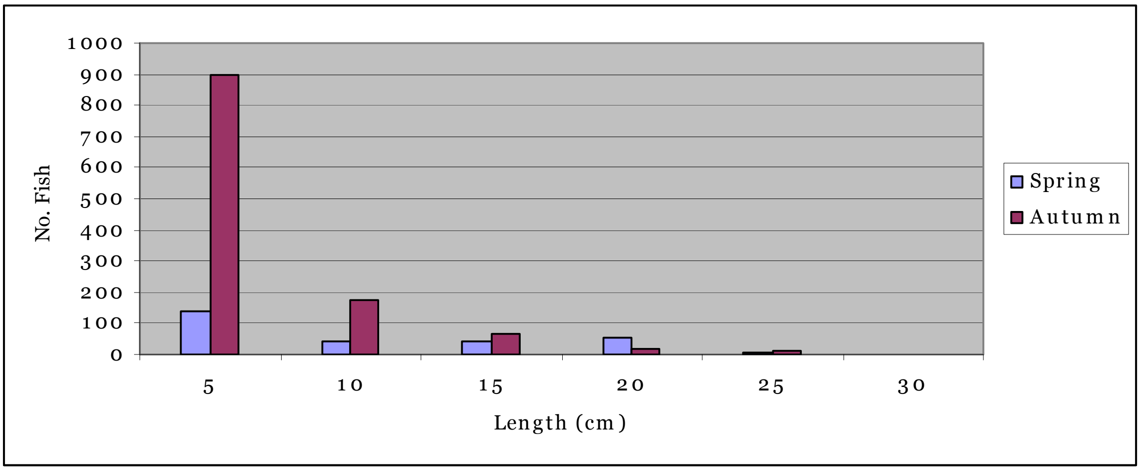
Note : (1998 – 2008)

Roach

C.1.66 Roach are known to be present in the Thames Tideway from Teddington to Thamesmead. From an earlier review of roach distribution (O'Keeffe, 2005) the species appears to extend further down the Tideway during the autumn months, with the downstream limit of roach in the spring being recorded as Greenwich. The mean fork length for roach sampled in the spring survey was 104.4 mm (n = 285, SE = 3.9). The largest specimen recorded during the spring was measured at 275 mm with a sample range of 253 mm around a mode of 70 mm. During the autumn sampling programme the mean length fell to 68.4 mm (n = 1167, SE 1.04) probably as a result of recruit of 0+ fish. The largest fish recorded during the autumn was 272 mm with a sample range of 268 mm around a mode of 52 mm.

C.1.67 Vol 3 Plate C.6 and Vol 3 Plate C.7 present the length and age-frequency distributions for roach in the Upper Tideway between 1998 and 2008.

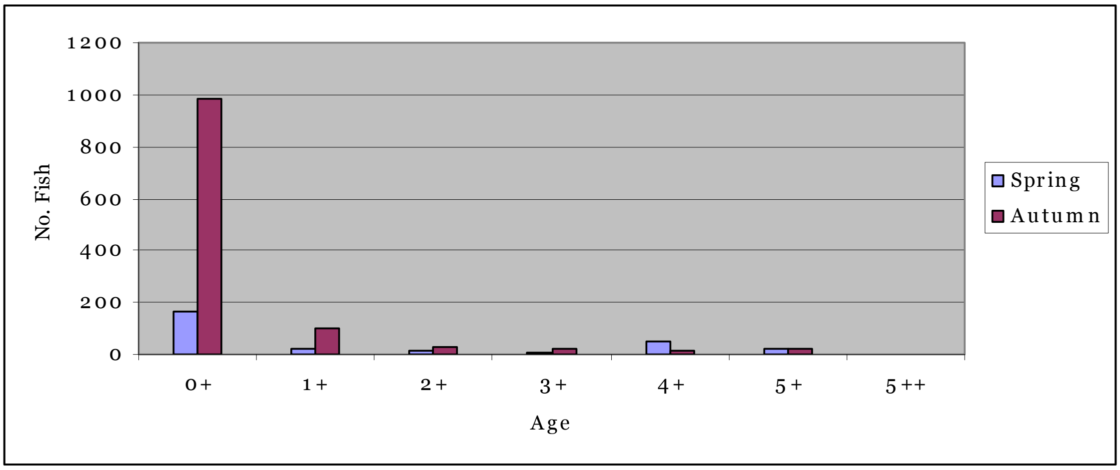
Vol 3 Plate C.6 Length-frequency distribution of roach within Upper Tideway



Note: 1998 – 2008

C.1.68 Roach are typically found in the Upper Tideway in the estimated age range 0+ to 5+.

Vol 3 Plate C.7 Age class distribution of roach within upper estuary

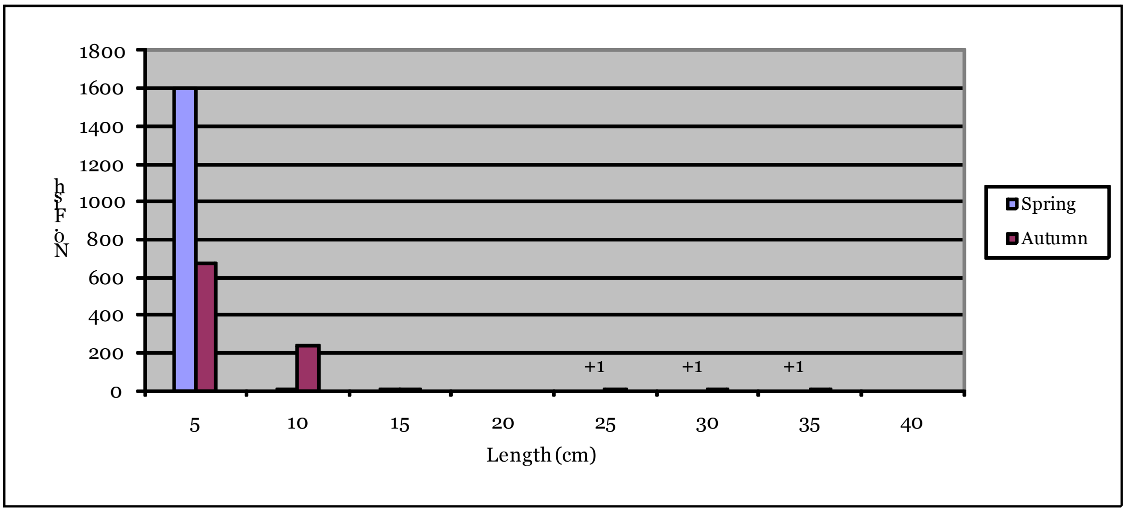


Note: 1998 – 2008

Flounder

C.1.69 The mean total length of flounder recorded within the spring sampling programme was 27.2 mm (n = 1613, SE = 0.28). The largest specimen recorded was 157 mm and the sample range was 150mm around a mode of 22mm. During the autumn sampling, the mean total length increased to 68.3 mm (n=913, SE = 0.72). The largest specimen recorded had a total length of 340 mm with a sample range of 310 mm around a mode of 60 mm. Vol 3 Plate C.8 and Vol 3 Plate C.9 show the length and age-frequency distributions for flounder in the Upper Tideway.

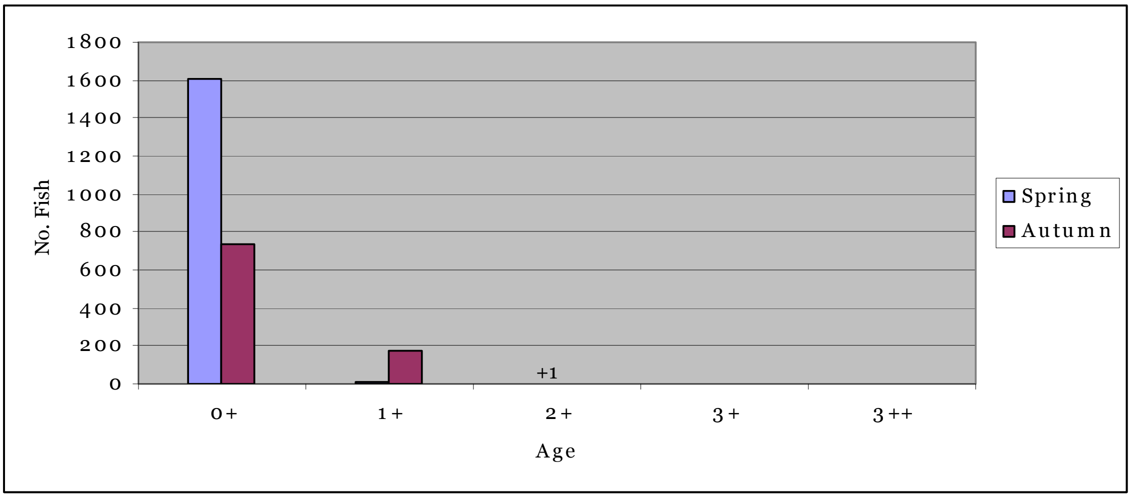
Vol 3 Plate C.8 Length-frequency distribution for flounder in Upper Tideway



Note: (1998 – 2008)

C.1.70 Flounder within the Tideway are caught in the estimated age range 0+ to 4+ with the older specimens typically being caught in the Lower Tideway to West Thurrock. Fish within the Upper Tideway are typically in the 0+ and occasionally 1+ and 2+ cohorts. Vol 3 Plate C.9 shows the distribution of age classes within flounder populations of the Upper Tideway between 1998 and 2008.

Vol 3 Plate C.9 Age class distribution of flounder within upper estuary



Note: 1998 – 2008

Invertebrates

Introduction

C.1.71 The following section presents additional supporting information relating to Tideway invertebrates. It includes:

a. An account of the October 2010 and May 2011 field surveys, including species abundances (in terms of number of invertebrate taxa) for individual sites;
b. The abundance of individual species and taxa considered to be sensitive to polluted conditions, and taxa considered to be indicative of polluted conditions based on the October 2010 survey data;
c. The distribution of invasive species based on the October 2010 survey data; and
d. Data for individual EA sampling sites in terms of age composition based on EA multi-method surveys between 1992 and 2010.

2010 Field Survey Data

C.1.72 Raw invertebrate data are provided in Vol 3 Table C.14 below.

2011 Field survey data

C.1.73 Raw invertebrate data are provided in Vol 3 Table C.15 below. Lots Road Pumping Station, Western Pumping Station, and Deptford Storm Relief were included as ‘improvement’ sites, described in Vol 2. These sites were sampled in 2010, but further ‘control’ samples outside of the reach of influence of relevant CSOs were considered necessary and were collected in 2011.

Vol 3 Table C.14 Invertebrate survey October 2010

	CCI Score	Borthwick Whf AL Drag	Borthwick Whf AL1	Borthwick Whf AL2	Borthwick Whf AL3	Borthwick Whf AL4	Borthwick Whf ALA	Borthwick Whf ALB	Borthwick Whf Beam	Borthwick Whf SW1	Borthwick Whf SW2	Borthwick Whf Vertical	Kg Edward Mem Pk AL1	Kg Edward Mem Pk ALA	Kg Edward Mem Pk ALB	Kg Edward Mem Pk Quad	Kg Edward Mem Pk SW1	Kg Edward Mem Pk SW2	King's Stairs Gdns AL1	King's Stairs Gdns AL2	King's Stairs Gdns AL3	King's Stairs Gdns AL4	King's Stairs Gdns KS1	King's Stairs Gdns KS2	King's Stairs Gdns Quad	Blackfriars Br AL1	Blackfriars Br AL2	Blackfriars Br Quad	Blackfriars Br SW1	Blackfriars Br SW2	Victoria Embkt AL1	Victoria Embkt AL2	Victoria Embkt AL3	Victoria Embkt S2	Victoria Embkt SW1	Victoria Embkt SW2	Albert Embkt AL1	Albert Embkt AL2	Albert Embkt Quad	Albert Embkt SW1	Albert Embkt SW2	Tideway Wk AL1
Empty Gasteropoda																										250			100	33												
Unidentified Gasteropoda																																										
Theodoxus fluviatilis	3							120																							10	2	2				11	5				2
Theodoxus fluviatilis empty																																										5
Viviparus viviparus empty																																										
Potamorpyrgus		15																													20		216	1		1	235	22		16	17	
Potamopyrgus empty																																										
Potamopyrgus antipodarum	1						100	350																50			6					3			2							24
Cochliopidae (?)	2						20																																			
Cochliopidae empty																																										
Peringia ulvae	1						10																																			
Peringia ulvae empty																								200													4					
Ancylus/ Acroloxus empty																																					1					
Radix balthica	1							110						18											1		1					3	2					32			2	1
Radix empty																																										
Planobidae empty																																										
Ancylus fluviatilis	1																																									
Ancylatus fluviatilis empty																																										
Uniondae empty																																										
Sphaeridae (empty)																										4																
Sphaeridae								100																																		
Sphaerium damaged																																										
Sphaerium (*corneum* ?)	1																																									
Pisidium spp.																																										
Dreissena polymorpha	2																																									
Dreissena polymorpha (empty)																																										
Corbicula fluminea																																1										5
Polychaeta																																									2	
Nereis diversicolor							40			8																						2	2		2							
Oligochaeta		2				3	145	1500		2		110	12	30	80		8	150	150	12	28		35	80		20	5		6	2	500	1000	2000	3	13	3	230	80		25	75	59
Oligochaeta (ringed tail)																																										
Glossiphonia complanata	1																																1									
Helobdella stagnalis	1																														1							1				
Hirudinea																																						1				
Erpobdella sp.														1												1	9											10			1	
Erpobdella damaged																																										1
Erpobdella testacea	5						1	12											1														1				17					
Hydracarina																																										
Palaemon longirostris	5																									3					1										1	
Crangon crangon		6	6	6			45		1		1				16			1	15	3	5	10				1	1									2		3		1		
Eriocheir sinensis							1									2											1						2							1		
Asellus aquaticus	1																															1										
Lekanesphaera hookeri	2						1			3													1	63		1																
Apocorophium lacustre	8	20	145	8	7	85	350					5	11					1	150		4	14		25		200	700	3				112	80		3		107	80				2
Corophium volutator	3	1					3								1																											
Gammarus sp							2																			20			1													
Gammarus zaddachi	1	6					100	140			1			50	8			1	60		1		250	420	1	135	120				25	15	12				47	40		350	65	1
Diptera pupae																	1																		13							
Chironomidae																																			1							
Diptera larvae																																			1							
Tipulidae																																										

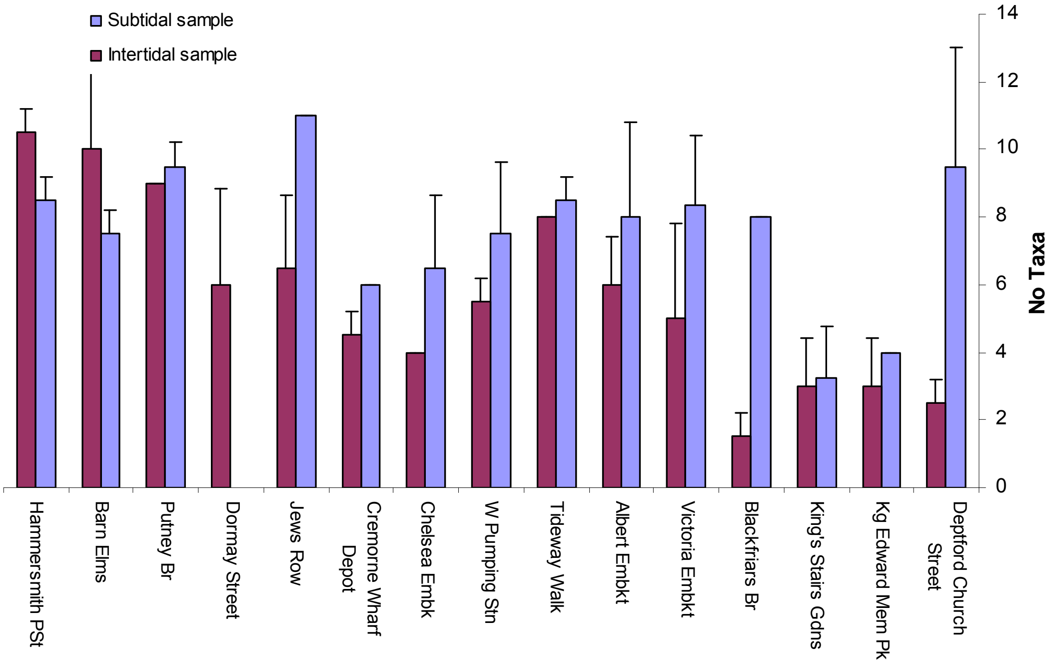
	CCI Score	Tideway Wk AL2	Tideway Wk Quad	Tideway Wk SW1	Tideway Wk SW2	W Pumping Stn AL1	W Pumping Stn AL2	W Pumping Stn Quad	W Pumping Stn SW1	W Pumping Stn SW2	Chelsea Embk AL1	Chelsea Embk AL2	Chelsea Embk Quad	Chelsea Embk SW1	Chelsea Embk SW2	Cremorne Whf AL1	Cremorne Whf AL2	Cremorne Whf Quad	Cremorne Whf SW1	Cremorne Whf SW2	Jews Row AL1	Jews Row AL2	Jews Row Quad	Jews Row SW1	Jews Row SW2	Bell La Crk Quad	Bell La Crk SW1	Bell La Crk SW2	Putney Br Al1	Putney Br AL2	Putney Br Quad	Putney Br SW1	Putney Br SW2	Barn Elms AL1	Barn Elms AL2	Barn Elms Quad	Barn Elms SW1	Barn Elms SW2	Hammersmith PSt AL1	Hammersmith PSt AL2	Hammersmith PSt Quad	Hammersmith PSt SW1	Hammersmith PSt SW2
Empty Gasteropoda																																			100+								
Unidentified Gasteropoda																																											
Theodoxus fluviatilis	3		2	2	5	4					16		3			1					36	35		3					38	20	2	4	8	120	25	4	8	12	20	150	10	35	20
Theodoxus fluviatilis empty																																											
Viviparus viviparus empty																				2																							
Potamorpyrgus						500	150		2	70	60	1																															
Potamopyrgus empty																				1																							
Potamopyrgus antipodarum	1	750		22	42										4	200	160				1610	53		42	20		80	200	45	40		1	90	350	32		14		1	2		85	30
Cochliopidae (?)	2																																										
Cochliopidae empty																												3															
Peringia ulvae	1																																										
Peringia ulvae empty																																											
Ancylus/ Acroloxus empty																																									1		
Radix balthica	1	8	1	15	34	1300	104	3	2	82	63	5	2	40	11	1	12	6	1		400	450		100	36	18		3	65	90	2	260	200	110	8	7	140	100	25	120	150	290	150
Radix empty																											15																
Planobidae empty																			2									1															
Ancylus fluviatilis	1																					1																					
Ancylatus fluviatilis empty																					2																						
Uniondae empty																				1																							
Sphaeridae (empty)																																											
Sphaeridae																					70								3		1									3	1	1	
Sphaerium damaged																																				1							
Sphaerium (*corneum*?)	1																					10								2		1	1	150	1		12	18					1
Pisidium spp.																						14		1				7										1					
Dreissena polymorpha	2																			2										1							1						
Dreissena polymorpha (empty)																																			1								
Corbicula fluminea		1		1		1														2																							
Polychaeta																																											
Nereis diversicolor																																											
Oligochaeta		85	8	650	1000	3000	5000		1160	300	25	150		200	120	300	350		20000	3000	100	55	1	1500	55		1000	1200	20	100	16	120	3000	1500	1550		1000	3000	40	13		1500	1300
Oligochaeta (ringed tail)																																	1										
Glossiphonia complanata	1													1							1										1						1					2	8
Helobdella stagnalis	1																																				1			1		1	1
Hirudinea																																											
Erpobdella sp.					2					3																								12									
Erpobdella damaged																																											
Erpobdella testacea	5	1		1?	5	2	5				7						3		1		21	4		2	1			40	27	32	2	10	8		3		12	10	8	1		23	70
Hydracarina																																											
Palaemon longirostris	5																																										
Crangon crangon		17		2		1			1		1									1	1	2								1		4	37				125	10					
Eriocheir sinensis		2																			2	1		1					1		1	1									1		1
Asellus aquaticus	1									1																	4	420	1										1			1	
Lekanesphaera hookeri	2																																										
Apocorophium lacustre	8	300		60	280	500	200				140	65			1	2	8				60	60							7	3							1		1	2			
Corophium volutator	3																																										
Gammarus sp																															1				2								
Gammarus zaddachi	1	97	5	300	350	160	11		2	7	295	36	5	6		140	644		9		77	320	1	175	7		3		750	400	8	240	85	140	28	12	250	110	120	90	65	90	300
Diptera pupae																																										1	
Chironomidae																																											
Diptera larvae																																											
Tipulidae																												1															

Vol 3 Table C.15 Invertebrate survey May 2011

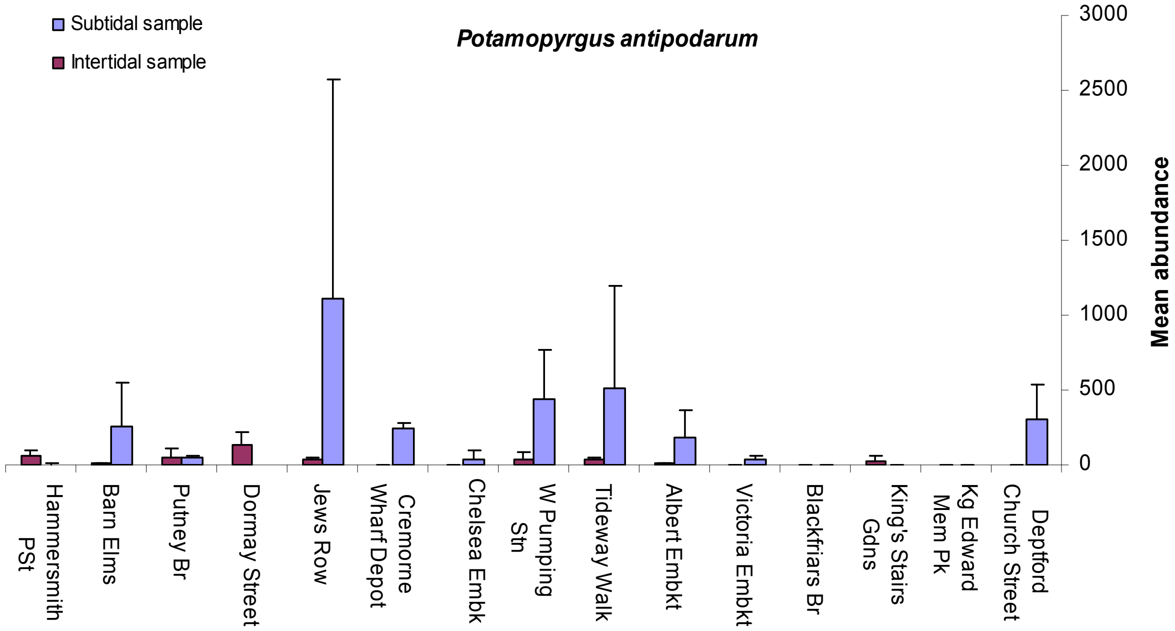
	CCI score	Carnwath Road AL1	Carnwath Road AL2	Carnwath Road kick	Carnwath Road SW 1	Carnwath Road SW 2	Kirtling Stree AL1	Kirtling Street AL2	Kirtling Street kick	Kirtling Street SW 1	Kirtling Street SW 2	Heathwall PS AL1	Heathwall PS AL2	Heathwall PS kick	Heathwall PS SW 1	Heathwall PS SW 2	Chambers Wharf AL1	Chambers Wharf AL2	Chambers Wharf kick	Chambers Wharf SW 1	Chambers Wharf SW 2	Lots Road PS AL1	Lots Road PS AL2	Lots Road kick	Lots Road PS SW 1	Lots Road PS SW 2	Western PS AL1	Western PS AL2	Western PS kick	Western PS SW 1	Western PS SW 2	Deptford Storm Relief AL1	Deptford Storm Relief AL2	Deptford Storm Relief kick	Deptford Storm Relief SW 1	Deptford Storm Relief SW 2	Greenwich PS SW 1	Greenwich PS SW 2	Greenwich PS SW 3	Greenwich PS SW 4	Abbey Mills PS AL1	Abbey Mills PS AL2	Abbey Mills PS AL3	Abbey Mills PS AL4
Theodoxus fluviatilis	3	1	7					1				2	2	5		3	2				1	10	16				2	3			6													
Potamopyrgus antipodarum	1	60	600				1	38		3	2	165	30	2	80	31	92	8	1	8	80	180	430		30	7	120	150		40	15					2	170	45	40	20			20	40
Radix balthica	1	1	1				2	1				13	1	1	10							60	150	2	20	7	110	1400	4	45	55													
Pisidium amnicum	3	1																																										
Pisidium spp.																																						20						
Pisideum casertanum	1																																				3							
Pisidium nitidum	3																																				1							
Corbicula fluminea			9					1						5			5																											
Polychaeta			1		30		5	1		90				1			127	35	35	185	80									1		84	2	3	150	100		10		3				
Oligochaeta		250	600	5	250	1500		380	3	52	26	10	150		200	58	99	80	5	23	100	300	110	220	308	1000	350	400	50	2500	100		4		50	75	90	270	200	300	1300	4000	400	1300
Helobdella stagnalis	1		1									1																																
Erpobdella sp.					1										1								2					1			5													
Erpobdella octoculata	1											9																																
Erpobdella testacea	5		2										3	1											1	2	20		1								2		1					
Palaemon longisrostris	5					2							2															2																
Gammarus sp.				1			16			5	5																					1												
Gammarus zaddachi	1		2200		40	3		140				1700	2000	30	1300	948	33	20		218	450	2000	1700	2	516	700	450	1400	50	1500	1000		1		40	30			20	8	1		150	40
Gammarus tigrinus	1																							7											1									
Ancylus fluviatilis								1																																				
Crangon crangon										1	8				1						1		1		9							1			2	1								
Cochliopidae sp.															2						1																							
Pisidium sp.																1																												
Apocorophium lacustre	8											1					2	2																				1						
Chironomidae																1								1													50	45	10		10		100	10
Neomysis integer	1																			77																								
Asellus aquaticus	1																								2	1				2							5		1				10	
Lekanesphaera hookeri	2																														1						4							
Trochaeta bykowskii	5																																				2	1						
Haemopsis sanguisuga	5																																					1						
Cyarthura carinata																																					1							
Corophium multisetosum	2																																							1				
Diptera larvae																																					20		6					
Ceratopogonidae (biting midges)																																							2					

C.1.74 The mean number of taxa per sample is shown in Vol 3 Plate C.10 below. This illustrates that diversity is generally quite low in all samples, and that there was variability between samples taken in subtidal and intertidal areas.

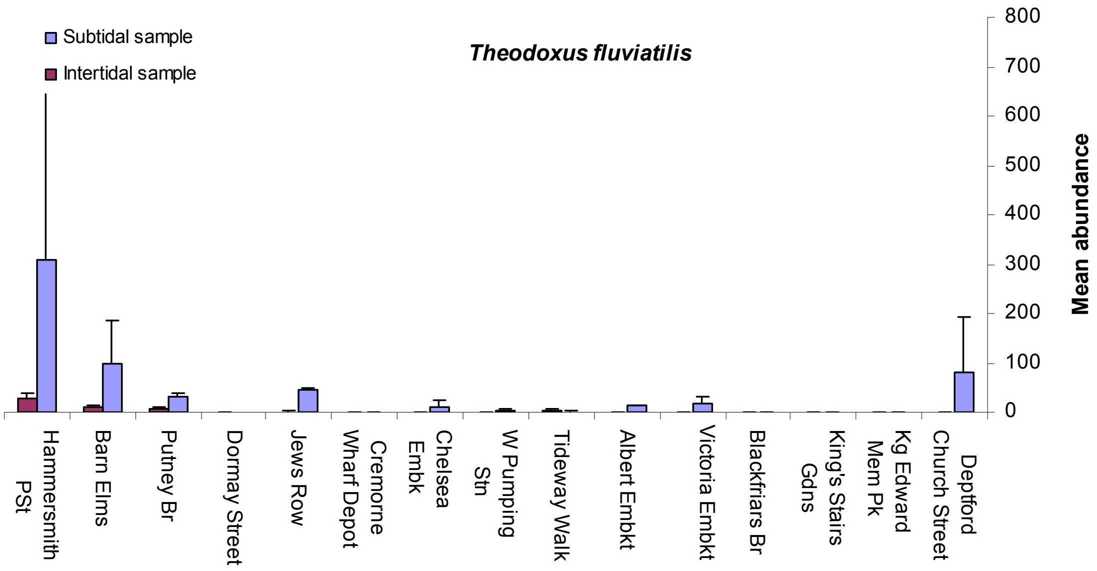
Vol 3 Plate C.10 Mean diversity of intertidal and tidal samples and mean abundance of key invertebrate taxa

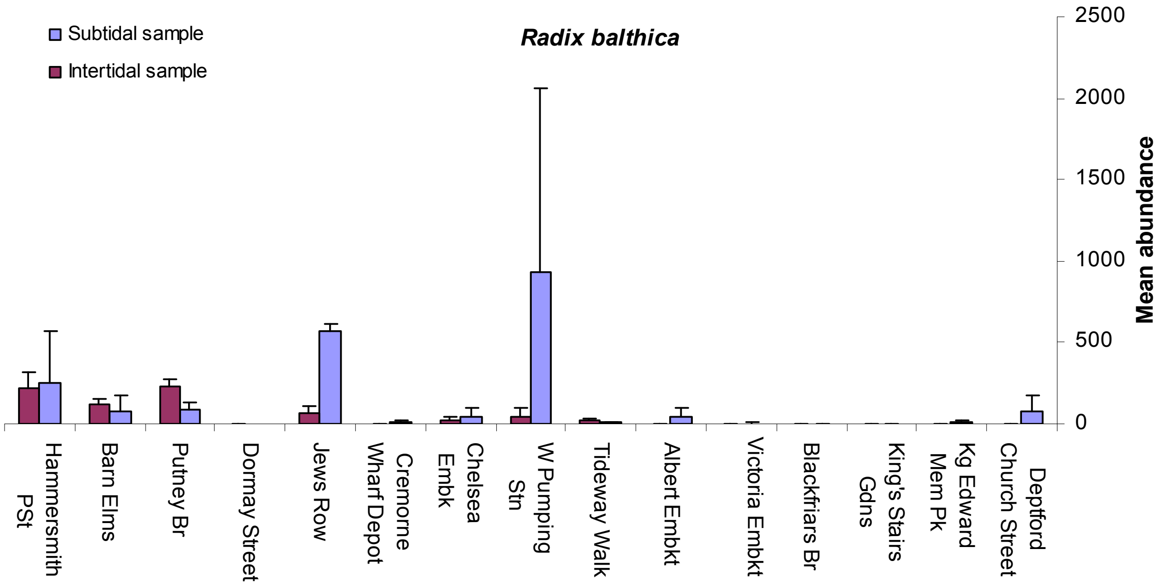


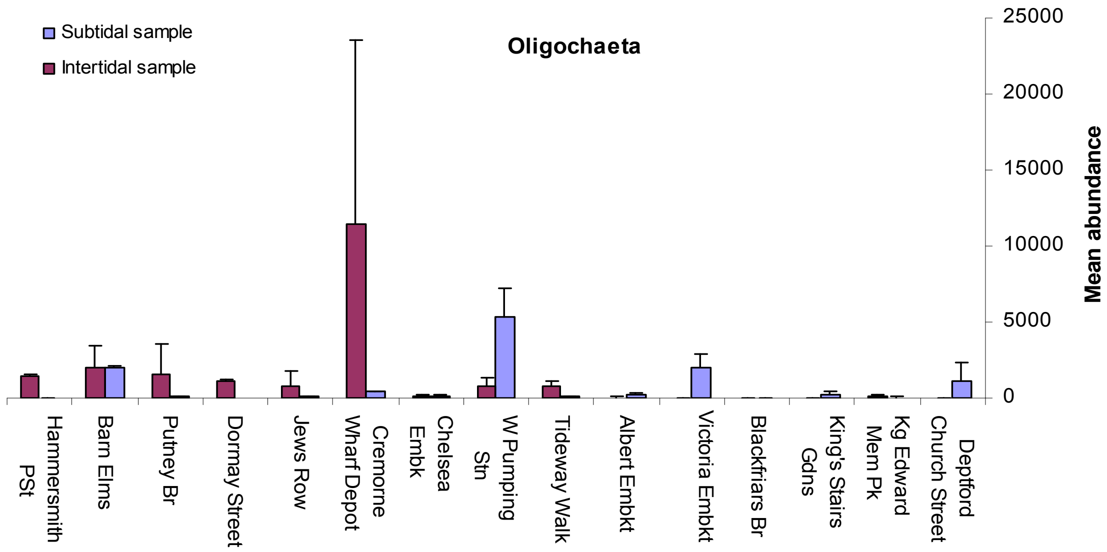
Note: (No taxa per sample + standard deviation)

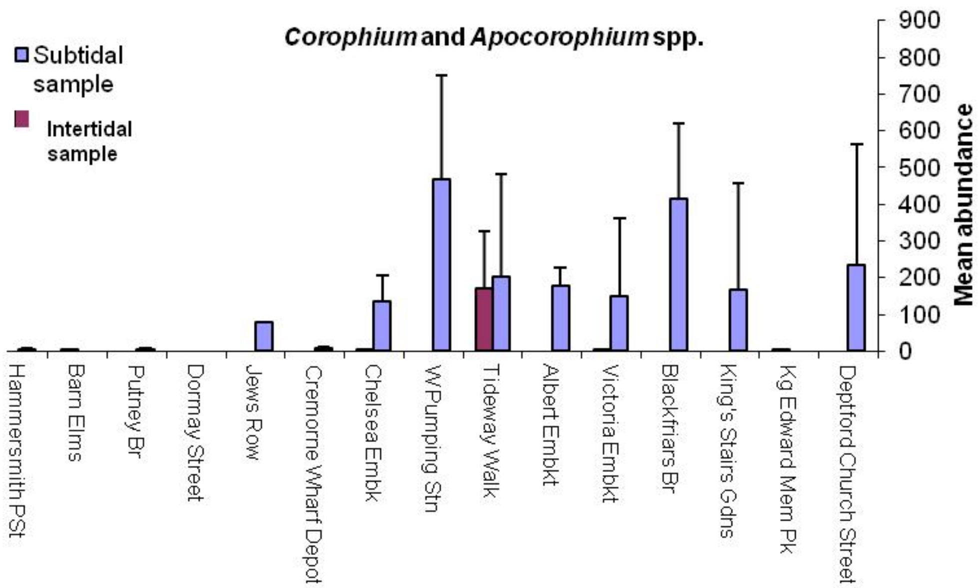


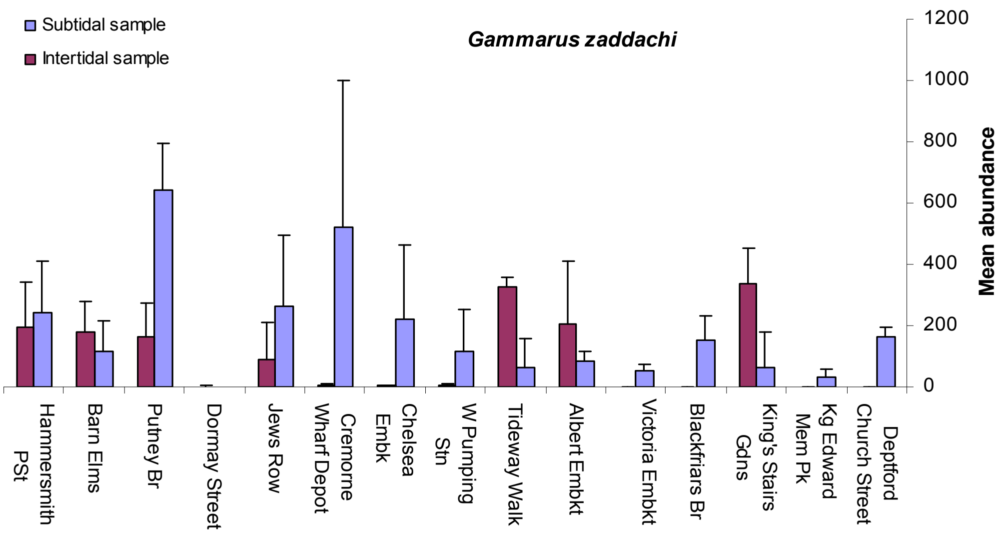
Mean abundance of key invertebrate taxa


Theodoxus fluviatilis
Subtidal sample
Intertidal sample
Mean abundance
0
100
200
300
400
500
600
700
800
Hammersmith PSt
Barn Elms
Putney Br
Dormay Street
Jews Row
Cremorne Wharf Depot
Chelsea Embk
W Pumping Stn
Tideway Walk
Albert Embkt
Victoria Embkt
Blackfriars Br
King's Stairs Gdns
Kg Edward Mem Pk
Deptford Church Street


Radix balthica
Subtidal sample
Intertidal sample
Mean abundance
0
500
1000
1500
2000
2500
Hammersmith PSt
Barn Elms
Putney Br
Dormay Street
Jews Row
Cremorne Wharf Depot
Chelsea Embk
W Pumping Stn
Tideway Walk
Albert Embkt
Victoria Embkt
Blackfriars Br
King's Stairs Gdns
Kg Edward Mem Pk
Deptford Church Street


Oligochaeta
Subtidal sample
Intertidal sample
Mean abundance
0
5000
10000
15000
20000
25000
Hammersmith PSt
Barn Elms
Putney Br
Dormay Street
Jews Row
Cremorne Wharf Depot
Chelsea Embk
W Pumping Stn
Tideway Walk
Albert Embkt
Victoria Embkt
Blackfriars Br
King's Stairs Gdns
Kg Edward Mem Pk
Deptford Church Street





Note: in subtidal and intertidal samples
((+ standard deviation) subtidal sample abundance: No of individuals/m2, intertidal sample abundance: No of individuals/sample)

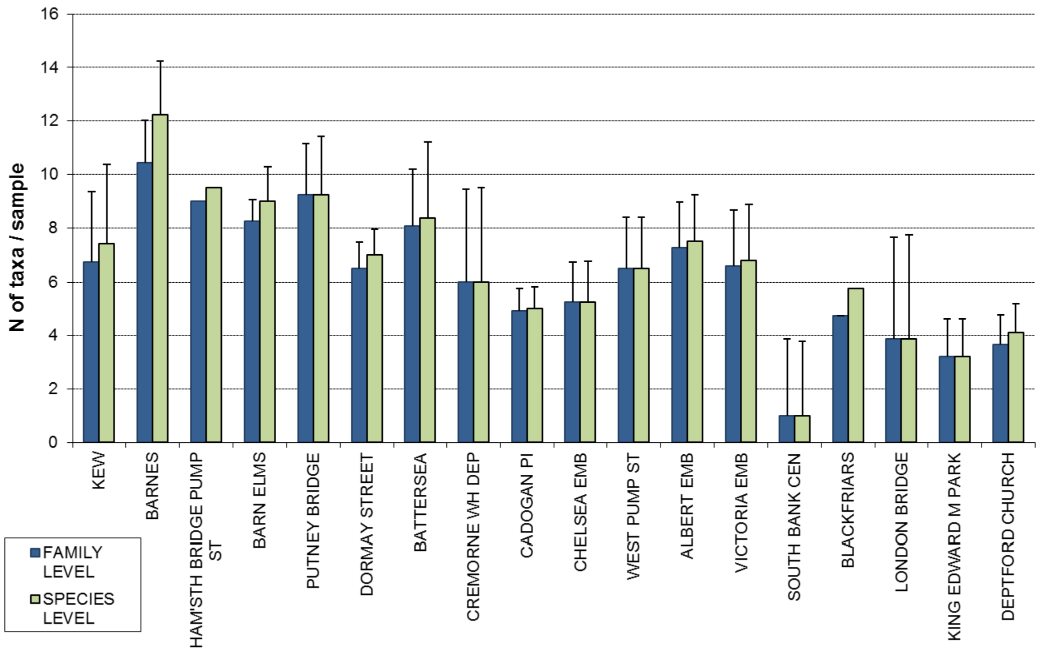
Overview of Thames Tideway Invertebrate Community

C.1.75 The following section presents a summary of the baseline data collected during invertebrate surveys of intertidal and subtidal habitats in the vicinity of the proposed CSO construction sites collected by the EIA team during autumn 2010, and EA background data for a number of sites in the Thames Tideway collected between 1992 and 2010.

C.1.76 The average number of taxa recorded per sample using kick and airlift sampling methods at 18 sites between Kew and Deptford Church Street is presented in Vol 3 Plate C.11. The graph illustrates that there is a clear decrease in the number of taxa per sample, from a peak of 12 at Barnes to a minimum of 3.2 at King Edward Memorial Park Foreshore. This can largely be attributed to increasing salinity from the freshwater to brackish zone, since only a relatively small number of invertebrate taxa are able to tolerate the fluctuations in salinity that occur within the brackish zone.

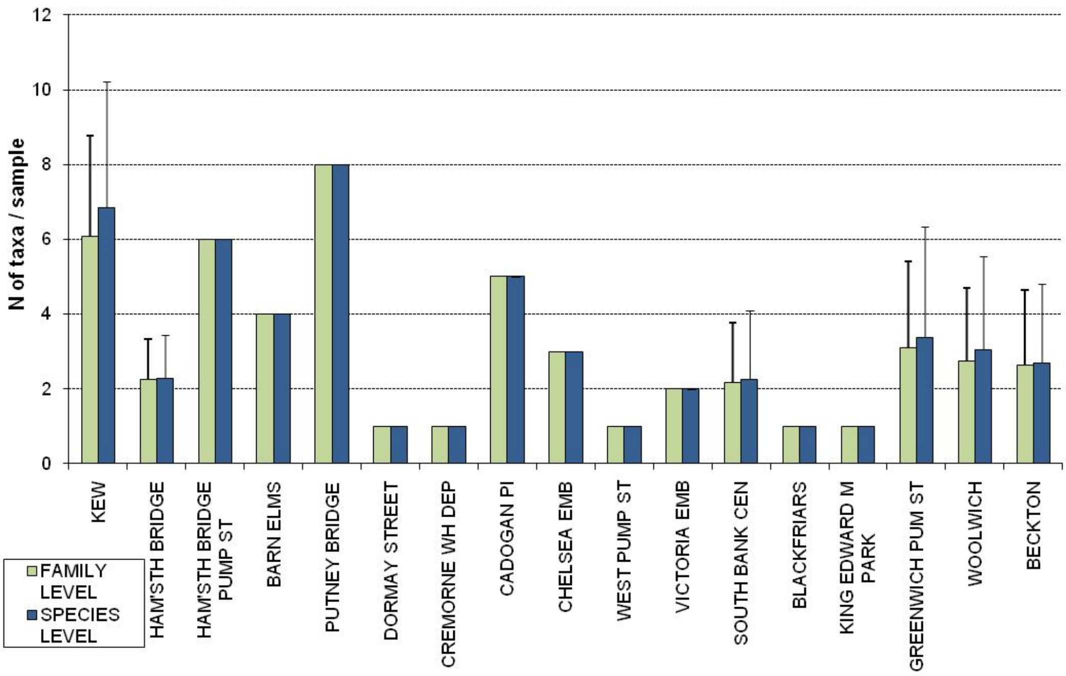
C.1.77 However, the transition is not without interruption, and there are clear exceptions to the trend. These are likely to represent differences in distribution of habitat and substrate at sampling stations, local sources of pollution and sampling variation.

Vol 3 Plate C.11 Mean number (+ standard deviation) of invertebrate families and species recorded using airlift and kick sampling methods in the tidal Thames using data from 1989 to present



C.1.78 The mean number of taxa recorded per sample using core, grab and quadrat sampling methods at 16 sites between Kew and Beckton is shown in Vol 3 Plate C.12 below. These results show the same general trend as data obtained using kick and airlift methods, with upstream freshwater sites being characterised by a higher level of diversity. However, there is a greater number of exceptions and very low taxa numbers. This reflects the different sampling method and low number of comparable samples taken at many of the sites, notably those sampled using the quadrat method as part of field surveys undertaken in 2010.

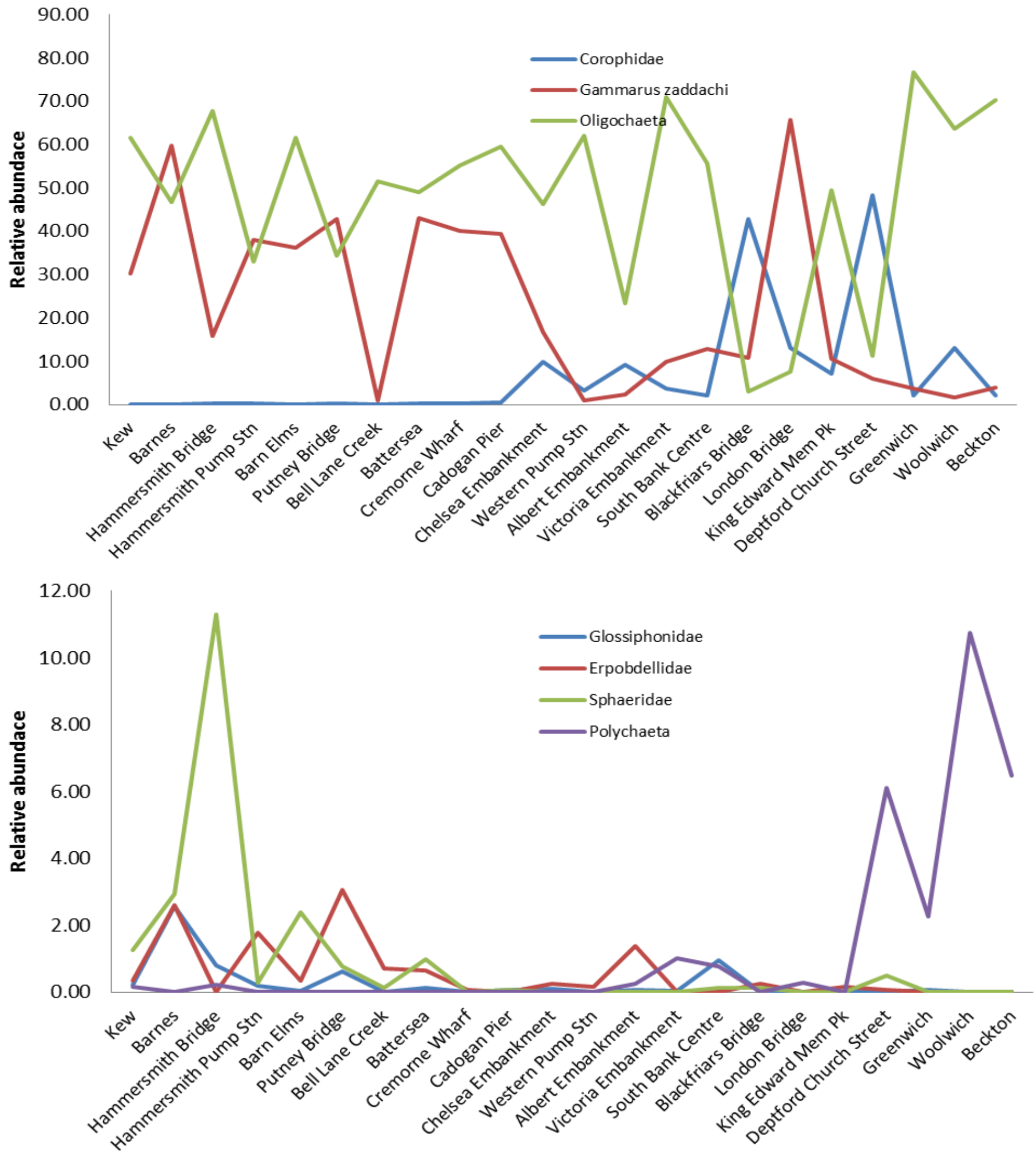
Vol 3 Plate C.12 Mean number (+ standard deviation) of invertebrate families and species recorded using core, grab and quadrat sampling methods in the tidal Thames using data from 1989 to present



C.1.79 In addition to the trends in the number of taxa, the invertebrate communities are characterised by different types of animals in samples as one moves downstream through the Thames Tideway.

C.1.80 Vol 3 Plate C.13 shows a "snapshot" of how certain key taxa change with distance downstream. The data set illustrated combines all data from each year using all of the different methods, including those collected during our field surveys undertaken in 2010. Relative abundance has been used to avoid bias brought about by the different sampling methods used. The figure demonstrates how mostly freshwater groups such as leeches (Erpobdellidae, Glossiphoniidae), insects and pea mussels (Sphaeridae) are replaced by groups such as worms (Polychaeta) and mudshrimp (Corophiidae). Estuarine taxa such as Gammaridae (mostly represented by *Gammarus zaddachi*) are fairly ubiquitous due to their tolerance of saline fluctuations although they eventually decrease at sites downstream of King Edward Memorial Park Foreshore. Oligochaeta appear to mostly ubiquitous throughout the length of the tideway considered, although there are three sites (Deptford Church Street, Blackfriars Bridge and London Bridge) where they are significantly less abundant.

Vol 3 Plate C.13 Distribution of key invertebrate taxa through the tidal Thames



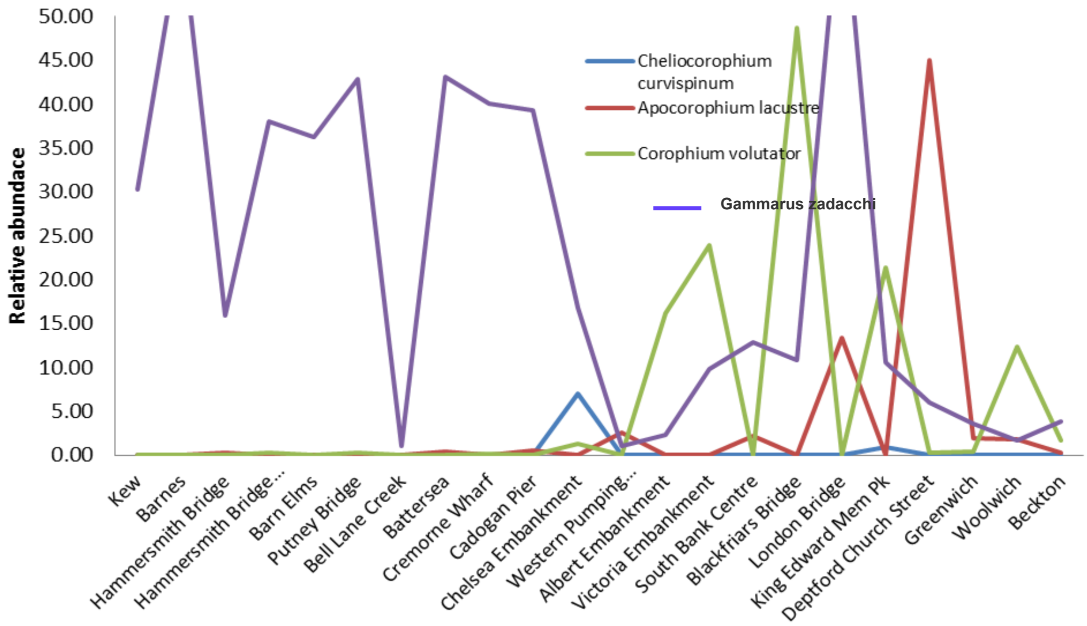
C.1.81 The importance of distance downstream and resulting differences in saline influence and habitat is further demonstrated in Vol 3 Plate C.14 which show the distribution of different species Amphipoda (crustaceans: shrimps and mudshrimps. This illustrates the succession of species, as one moves further into the estuary.

C.1.82 *Gammarus pulex* is limited to the most freshwater extreme of the Thames tideway, and is most abundant at Barnes and Kew, but is intolerant of even highly infrequent saline intrusion, and is not present further downstream as the water becomes more brackish. *Gammarus zaddachi* on the other hand is fairly ubiquitous and is abundant at most sites between Kew and London Bridge, but decreases at sites downstream of King Edward Memorial Park Foreshore. The three species of Corophiidae

(*Cheliocorophium curvispinum*, *Apocorophium lactructre*, *Corophium volutator*) on the other hand are mostly abundant in more brackish parts of the Thames, with *A. lacustre* and *C. volutator* appearing to have a more saline preference compared with *C. curvispinum*.

C.1.83 However, what is also clear is how variable these indicator groups are and that the transition is not smooth. This may be due to localised variations in habitat and substrate, although freshwater inputs (e.g. from CSOs, STW and nearby tributaries) and point source discharges are likely to be significant.

Vol 3 Plate C.14 Distribution of key species of Amphipoda through the tidal Thames



C.1.84 The varying level of salinity and saline fluctuations appear to be a dominant factor determining the diversity and structure of benthic invertebrate assemblages. Generally, invertebrate communities were dominated by species tolerant of fluctuations in salinity. The community is characterised by a larger proportion of worm taxa (Oligochaeta and Polychaeta), Crustacea and snails, compared with the freshwater environment where insect taxa tend to dominate in terms of species diversity and abundance. Even at the most upstream site Kew, few obligate freshwater species or taxa were sampled.

C.1.85 The majority of species present are considered to be relatively tolerant of organically polluted conditions, with few 'clean' water indicators present. The species generally considered to be most sensitive to organic pollution is the river neritid, *Theodoxus fluviatilis* (Neritidae) (as shown in various studies, for example Walley and Hawkes (1996) Walley and Hawkes (1997)), which is a species found in freshwater and brackish waters.

C.1.86 This species was most abundant in upstream sites and appears to have colonised many of the sites relatively recently. The relatively low abundance of *Theodoxus* in many of the downstream sites may be, in part, due to increased salinity lower down in the Tideway. However, the presence of this invertebrate at Deptford Church Street suggests that the low water quality or habitat availability in some of the mid-Tideway sites may also be a limiting factor.

C.1.87 The initial data analysis has highlighted the significant changes that occur through the Thames Tideway, from freshwater through the brackish to the marine zone. However, it is important to point out that even in the most upstream 'freshwater' part of study area, there is a low diversity of invertebrate animals compared with the true freshwater Thames and other similar freshwater rivers and obligate freshwater animals are poorly represented.

Cluster Analysis

C.1.88 The following section presents the principal findings of cluster analyses of invertebrate assemblages collected from throughout the Thames tideway, between 1989 and 2011. Given the large size of the cluster dendrograms, these are not reproduced here, but the main relevant findings are summarised below.

C.1.89 The cluster analysis of the whole data set (mixing the different sampling methods) showed that the main parameter defining the structure of the data set (or split between samples in different clusters) was the sampling method. Core, grab, gulley dredge and quadrat samples tended to cluster together, as did three-minute kick and airlift samples, whichever measure of abundance (presence absence, abundance class etc) was used. That confirms the results of other analyses, for example the comparison of the mean taxa diversity, that the sampling methods are not equivalent. Core, grab, gulley dredge and quadrat sampling methods appear to be significantly less efficient in collecting a high diversity of invertebrates and give less taxa rich samples than three-minute kick and airlift samples methods.

C.1.90 Therefore, the interpretation of clustering analyses of two different data sets (the two groups of sampling methods, described above) is presented in further detail in the following section.

Three-minute Kick and Airlift Sampling Methods

C.1.91 Results of the clustering analysis analysed presented below are based upon abundance classes, relative abundances, and presence-absence data, as set out in the Methodology. The actual abundance data sets did not provide visually satisfactory outputs.

Relative Abundances

C.1.92 The cluster analysis of relative abundance data separates the samples into five main clusters, each of them characterised by a single dominant taxon:

a. Oligochaeta, a cluster formed by 219 samples, mostly from freshwater sites, but without any temporal homogeneity.

b. Gammaridae, a cluster comprising 129 samples, with a trend for samples in the freshwater zone and early years of monitoring.

c. Hydrobiidae, a cluster comprising 17 samples, mostly from the brackish zone, but with no temporal pattern.

d. Corophiidae, a cluster comprising 13 samples from the brackish zone.

e. Nereidae (1 sample).

C.1.93 The two main clusters (Gammaridae and Oligochaeta) were not well separated (i.e. the ‘branches’ that joined the two clusters were short, relative to many of the ‘twigs’ joining the different samples within the same cluster), indicating relatively small statistical differences between the two clusters of samples. There did not appear to be any pattern of years or samples sites within the groups identified in this analysis. However, the distribution of Oligocheata and Gammaridae within these two clusters appeared to be mutually exclusive, in that the samples tended to have high relative abundance of Gammaridae or Oligochaeta, but not both.

C.1.94 These results indicate that by far the greatest contribution to variability of the data set (in terms of relative abundance) is due to the amount of Gammaridae or Oligochaeta present in samples. Given the lack of any clear pattern, it is not clear why such an apparent dichotomy exists; high relative abundances of either Oligochaeta or Gammaridae might be due to habitat or variations in water chemistry.

Abundance Classes

C.1.95 Cluster analyses of the abundance classes set out in the Methodology (rather than relative abundance) decreases the influence of the overpowering abundance of Oligochaeta and Gammaridae.

C.1.96 Based on abundance classes, no clearly defined ‘discrete’ clusters were revealed, and the data appeared to be quite continuous between potential clusters. Several loose clusters could, however, be defined. Two large clusters were identified, one of which could be further split into two sub-clusters, as shown in Vol 3 Table C.16 below.

Vol 3 Table C.16 Main groups identified with the clusters analysis and their characteristics

	Cluster A	Cluster B1	Cluster B2
N samples	60	89	202
Taxa	Oligochaeta	Oligochaeta	Oligochaeta
	Gammmaridae	Gammaridae	Gammaridae
	Hydrobiidae	Hydrobiidae	Hydrobiidae
	Sphaeriidae	Sphaeriidae	Sphaeriidae
	Glossiphonidae	Glossiphonidae	
	Erpobdellidae	Erpobdellidae	
	Neritidae	Neritidae	
	Lymnaeidae	Lymnaeidae	
Main sampling	Barnes 2005 to	Kew 1995 to	Kew 1989 to

	Cluster A	Cluster B1	Cluster B2
sites	2010 (35)	2004 (35)	2004 (56)
	Kew 1995 to 2001 (9)	Battersea 2005 to 2010 (18)	London Bridge (76)

C.1.97 Examination of the heat maps (see Vol 2 Environmental Statement methodology for definition) showed that Cluster A is made up of more diverse, recent samples taken in the freshwater (upstream) zone.

C.1.98 Cluster B is divided into two smaller sub-clusters. Cluster B1 includes small marginal groups within Cluster B (89 samples). The samples in this cluster are characterised, in comparison to B2, by higher numbers of samples from the freshwater (upstream) zone. The cluster is as taxon-rich as samples clustered in the Cluster A, but with lower abundance classes of Sphaeriidae, Glossiphonidae Erpobdellidae, Neritidae and Lymnaeidae. The most common samples within this group include samples from Battersea (2005 – 2010) and Kew (notably from 1995 - 2004). Most of the samples were therefore relatively recent and from the freshwater zone of the tidal River Thames.

C.1.99 Cluster B2 is the largest sub-cluster within Cluster B (202 samples). The cluster is characterised by less diverse samples and the absence of taxa such as Glossiphonidae, Erpobdellidae, Neritidae and Lymnaeidae. It is made up of samples from both the brackish (downstream) zone (76 samples) and the freshwater (upstream) zone (126 samples). These included samples from Kew (mostly from 1989 – 2004) and London Bridge.

C.1.100 It is interesting to note that for the Kew samples, samples taken between 1989 and 1995 are not present in the most diverse groups, Cluster A and Cluster B1, but exclusively in the Cluster B2. This suggests that an improvement in biological quality may have occurred at some samples sites between 1989 and 2010.

C.1.101 In addition to the main clusters described above, 12 small clusters were also identified, each containing only 1 – 3 samples. These clusters did not reveal any particular trend in the data set, and appear to be the result of poor samples (due to very low numbers of animals), or the presence of one single taxon. Therefore, the potential for more interpretation is much reduced.

C.1.102 Despite the difficulties in identifying clusters (due to the apparently continuous nature of the data set), the analysis of the cluster and accompanying heat map show that:

a. samples tend to cluster together according to their longitudinal location in the Tideway (with more diverse sites generally present in the freshwater zone); and

b. some sites appear to be in different clusters, separated by years, with clusters containing more relatively recent samples characterised by higher taxa richness.

Presence Absence

C.1.103 Nine small groups and two large clusters were identified by the cluster analysis of presence-absence data.

C.1.104 The cluster analysis shows that, as with other clusters, the main parameter leading to the separation of samples is the presence of the taxa Oligochaeta, Gammaridae and Hydrobiidae. The presence of taxa such as Erpobdellidae, Glossiphonidae, Neritidae, Sphaeridae and Asellidae also appear to be important factors.

C.1.105 The nine small groups were defined mainly by the absence of one of the following key taxa: Oligochaeta, Gammaridae, or Hydrobiidae.

C.1.106 As described above, two large clusters were identified. The first is notably more diverse than the second, due to the presence of Erpobdellidae, Neritidae, Glossiphonidae, Sphaeridae and Asellidae, which were absent from the second cluster. The more diverse cluster mostly comprises samples from the following sites: Barnes, Barn Elms, Battersea and Kew from 1996 to 2005 (i.e. relatively recent samples from the freshwater zone). The less diverse cluster comprises mainly samples from the following sites: London Bridge, Cadogan Pier and Kew from 1989 to 2005 (i.e. generally samples from the brackish zone, with the exception of a few slightly less recent samples from Kew).

C.1.107 As with the abundance classes, this analysis therefore indicates that samples cluster together and show similar characteristics, based on the location of the site (freshwater or brackish zone). Samples from Kew seem to be separated in two types of groups (earlier less diverse and later more diverse samples), suggesting some improvement; however, there are many exceptions to this trend.

Other Sampling Methods

C.1.108 As described above, the actual abundance datasets did not provide satisfactory outputs (clusters not clearly defined and difficult to interpret). Therefore, only results from the analysis of abundance classes, relative abundances, and presence-absence data are presented below.

Abundance classes

C.1.109 Cluster analyses of the abundance classes set out in the Methodology (rather than relative abundance) decreases the influence of the overpowering abundance of Oligochaeta and Gammaridae on the data.

C.1.110 Based on abundance classes, no clearly defined ‘discrete’ clusters were revealed, and the data appeared to be quite continuous between potential clusters. Several looser groupings could, however, be defined. There were 22 small clusters (each containing 1 to 14 samples) and two larger groups. The smaller clusters generally contained more recent samples (post 1996), from both freshwater and brackish zones, and were characterised by higher diversity. The two larger clusters were:

a. Cluster A: comprising 47 samples, dominated by samples taken at Woolwich after 1996, and which can be characterised as the more diverse samples (Spionidae, Corophidae, Hydrobiidae, Oligochaeta, absence of Gammaridae); and

b. Cluster B: comprising 600 samples, dominated by low diversity samples. Within this cluster, small sub-groups (18 samples, mainly late samples from the freshwater and brackish zones), comprise samples of slightly higher diverse relative to the other samples of this cluster. The main (largest) group was characterised by samples showing less diversity, and coming mostly from the brackish zone of the tidal River Thames. No clear temporal pattern exists within this group.

C.1.111 While no clear pattern of discrete clusters emerges from this analysis and accompanying heat map, it appears that recent samples from both brackish and freshwater zones tend to cluster together (in Cluster A and other samples) and were generally more diverse than the samples, present in Cluster B. This trend suggests that there has been some improvement in biological quality between 1989 and 2010.

Relative abundances

C.1.112 The cluster analysis of the relative abundances data set identified seven groups, each of them defined by taxa dominating the samples:

a. Cochliopidae, Grapsidae, Lymnaeidae, clusters comprising 1 to 6 samples mostly taken at South Bank Centre, King Edward and Greenwich in the late years of monitoring

b. Gammaridae, a cluster comprising 39 samples mostly from hammersmith Bridge, South Bank Centre and Beckton in the early years of sampling.

c. Hydrobiidae, a cluster comprising 71 samples mainly from South Bank Centre, Woolwich and Greenwich, with no particular temporal trend.

d. Oligochaeta, a cluster comprising 557 samples, with no homogeneity of sampling sites or time.

e. A cluster of samples characterised by the dominance of either Corophiidae or Spioniidae: two sub-clusters of respectively 34 samples taken mostly at Woolwich in the early years and 39 samples taken mostly at Woolwich in the late years of monitoring.

Discussion of Key Findings

C.1.113 The cluster analysis reveals a number of patterns within the Thames tideway dataset. However, the findings of the analysis varied significantly depending on (a) different measures of abundance or presence/absence data; and (b) the sampling method with which the invertebrates were collected. Separating samples into two groups based on sampling methods provided more interpretable clusters than when all methods were mixed.

C.1.114 However, for all sampling methods and measures of abundance or presence/absence it was generally difficult to identify distinct clusters of samples, suggesting that the data was generally ‘continuous’ over relatively large distances and time periods.

C.1.115 With data collected using three minute kick and airlift sampling relative abundances of two taxa, Oligochaeta and Gammaridae, determined where in the cluster the samples were organised. This did not appear to be influenced by the position in the Thames Tideway. Therefore the invertebrate assemblages were quite clearly influenced by factors other than salinity. Gammaridae are known to prefer complex, well aerated habitats in contrast to Oligochaeta, which are typical of simpler, silty, less well-aerated habitats. Although habitat data were not recorded by the EA, it is strongly suspected that habitat, rather than location or time, is the strongest influence on these two dominant groups. However, temporal factors (such as water quality) may also play a role.

C.1.116 By allowing for the influence of habitat, patterns obscured by this apparent dominance may be revealed in any future analyses undertaken on the Thames Tideway similar exercises (e.g. by the EA or water companies). It would clearly be valuable for future surveyors of the River Thames for the EA or other purposes to collect habitat data alongside fish data in the future, so that its influence can be allowed for and thus much better resolution of changes with time and distance can be achieved.

C.1.117 The analysis of presence/absence and abundance classes revealed other patterns within the data set. The cluster analysis of three minute kick and airlift samples identified clusters of higher diversity and abundance which were distinct from more taxon-poor clusters. On the whole, samples in the brackish zone were within the ‘less diverse’ clusters compared with samples taken in the freshwater zone. This concurs with previous research into the invertebrate community of the River Thames and other estuaries, which show diversity decreasing downstream as the saline influence increases. This is generally attributed to the fact that relatively few invertebrates are adapted to significant fluctuations in saline concentrations, although other factors, such as poor water quality in downstream areas of the Thames and lack of habitat diversity in areas near central London are also likely to contribute somewhat. By contrast, following the drop in invertebrate taxa in the brackish zone, taxon richness is known to increase as you get further out into the estuary (Remane and Schlieper, 1971), however, this was outside (downstream) of the zone covered by the current study and therefore this phenomenon was not observed.

C.1.118 The exception to the above ‘rule’ was that a number of samples from the freshwater zone did not cluster with the ‘high diversity’ group, but in the low diversity brackish sample-dominated cluster. These were generally earlier (1989 - 2005) freshwater samples from Kew, suggesting taxon-richness was poorer in these samples. Although changes to sampling method or sampling efficiency cannot be ruled out (especially given the length of time covered by the analysis), these may reflect real changes associated with improved water quality in this area. One of the taxa that ‘appeared’ in later samples is Neritidae, the only species being *Theodoxus fluviatilis*, the river neritid. This animal one of the most pollution sensitive molluscs (in term of BMWP score) present in the data provided (Walley and Hawkes, 1996).

C.1.119 The analysis of 'other' sample methods produced poorer, less easily interpretable clusters. However, position in the tideway seemed to significantly influence where samples were placed in the analysis (with samples from the brackish zone in clusters of 'low taxa diversity'). However, there were some unusual results (such as clusters characterised by samples containing a single taxa). This is likely to be due to the poor efficiency of these sampling methods compared to three minute kick and airlift samples. Core sampling produces results with confidence limits compared with kick and airlift sampling.

Multivariate Ordination (PCA) of Thames Invertebrate Data

C.1.120 The following section presents the principal findings of the PCA analyses of invertebrate assemblages collected from throughout the Thames tideway, between 1989 and 2011.

C.1.121 As invertebrate data collected using three-minute kick sampling and airlift sampling were not comparable to the 'other' sampling methods (e.g. core, dredge sampling etc), these two groups of data were analysed separately. The PCA of the three-minute kick and airlift sample data are presented in the first instance, followed by the PCA of data collected using 'other' methods. For both sampling methods, we present the principal findings from the PCA of abundance data, as well as PCA of presence-absence data.

Analysis of All Invertebrate Data - Kick and Air Lift Samples

Abundance Data

C.1.122 In total, 378 samples from 20 sites were analysed using invertebrate abundance data. All sample methods other than three-minute kick and airlift sampling were excluded from this analysis, as they had already been shown not to be comparable.

C.1.123 The results of the principal components analysis carried on invertebrate abundances data collected from throughout the Thames tideway between 1989 and 2011, using three-minute kick and airlift sampling is presented in Vol 3 Plate C.15 and Vol 3 Plate C.16 below.

C.1.124 The PCA axes PC1 and PC2 (which express respectively 47.7% and 19.1% of the total variability of the data set) are presented in Vol 3 Plate C.15. The taxonomic groups that contribute most significantly to the variability in the abundance of the invertebrate assemblages of the tidal Thames are Oligochaeta and Gammaridae. The first principal component axis (PC1) contains a high proportion (47.7%) of the total variability, and abundances of Oligochaeta and Gammaridae dominate this axis. The abundances of these taxa appear to be strongly and negatively correlated with each other, while other taxa are not well represented on this axis.

C.1.125 On the other axes (PC2 and PC3), abundances of Corophiidae and Hydrobiidae are better represented (Vol 3 Plate C.15 and Vol 3 Plate C.16). However, there does not appear to be a correlation between the abundances of these groups.

C.1.126 The sample projection on the factorial maps in Vol 3 Plate C.15 and Vol 3 Plate C.16 shows that there are no clear, distinct groups of samples or sites and that the variations in the data are along continuous gradients.

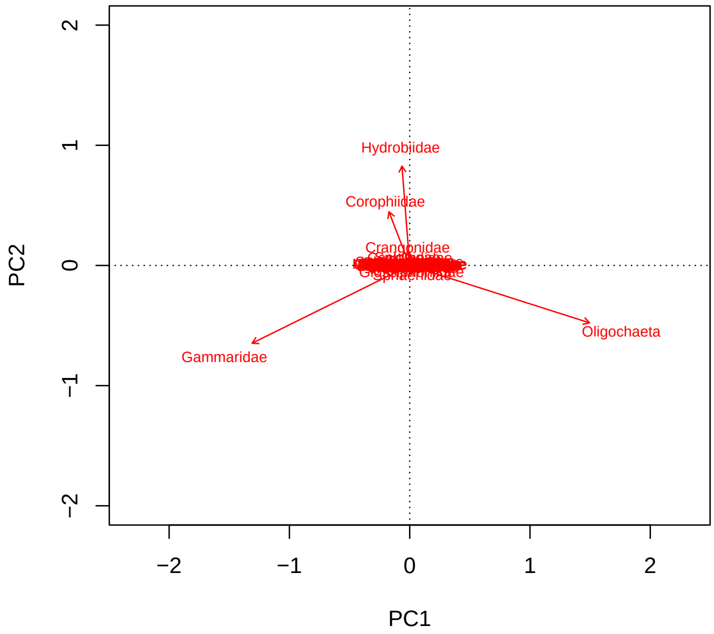
C.1.127 These results and projections suggests (a) that the invertebrate communities from different sites and years in the areas of the tidal Thames sampled are not highly heterogeneous; (b) that most of the variation that does exist is between two extremes - ‘Gammaridae’ and ‘Oligochaeta’ dominated assemblages; (c) that the variation between these two extremes is continuous; and (d) that the influence of other taxa is more subtle. These general findings mirror the findings from the cluster analysis. The variation between Gammaridae and Oligochaeta dominated samples was inferred to be strongly dominated by habitat, due to the typical habitat preferences being respectively gravels and silts. Until actual habitats are recorded when samples are taken, this supposition cannot be verified.

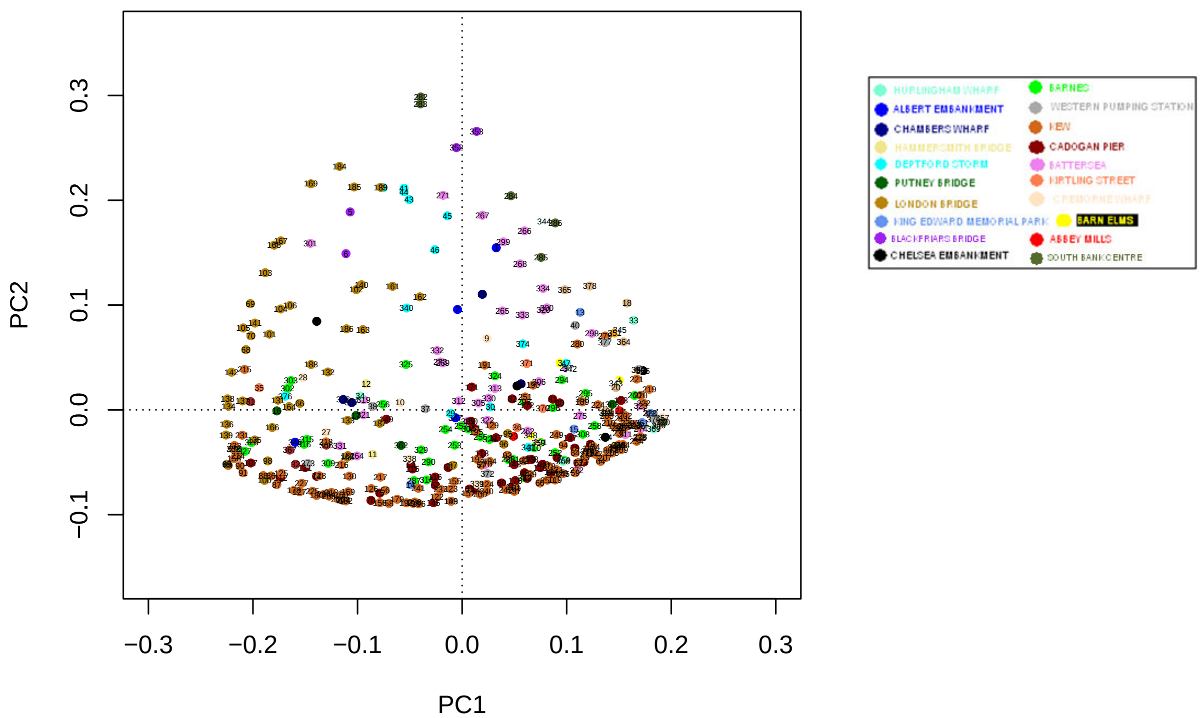
C.1.128 However, although there are no ‘distinct’ groups of sites, some different sample sites tend to be grouped closer together along the continuous gradients, as with the London Bridge samples (high Gammaridae, low Oligochatea and moderate Hydrobiidae, on the left hand side of the projection) and the Battersea samples (high Oligochaeta, low Gammaridae, moderately high Hydrobiidae, on the upper left of the projection). Samples from other sites, such as Kew or Cadogan Pier, tend to be split along the gradient formed by abundances of Oligochaeta and Gammaridae, but do not appear to be characterised by high abundances of other taxa.

C.1.129 No clear temporal pattern within the different groups is revealed by this initial analysis. However, it is important to note that some of the sites described above were sampled at different times from others (some sites were sampled during early years, while others were sampled later) therefore any temporal trends may be hidden. Habitat differences between samples and sites are likely to constitute a key determining factor, but on which, with the exception of the EIA team samples taken on 2010 and 2011, we have no information.

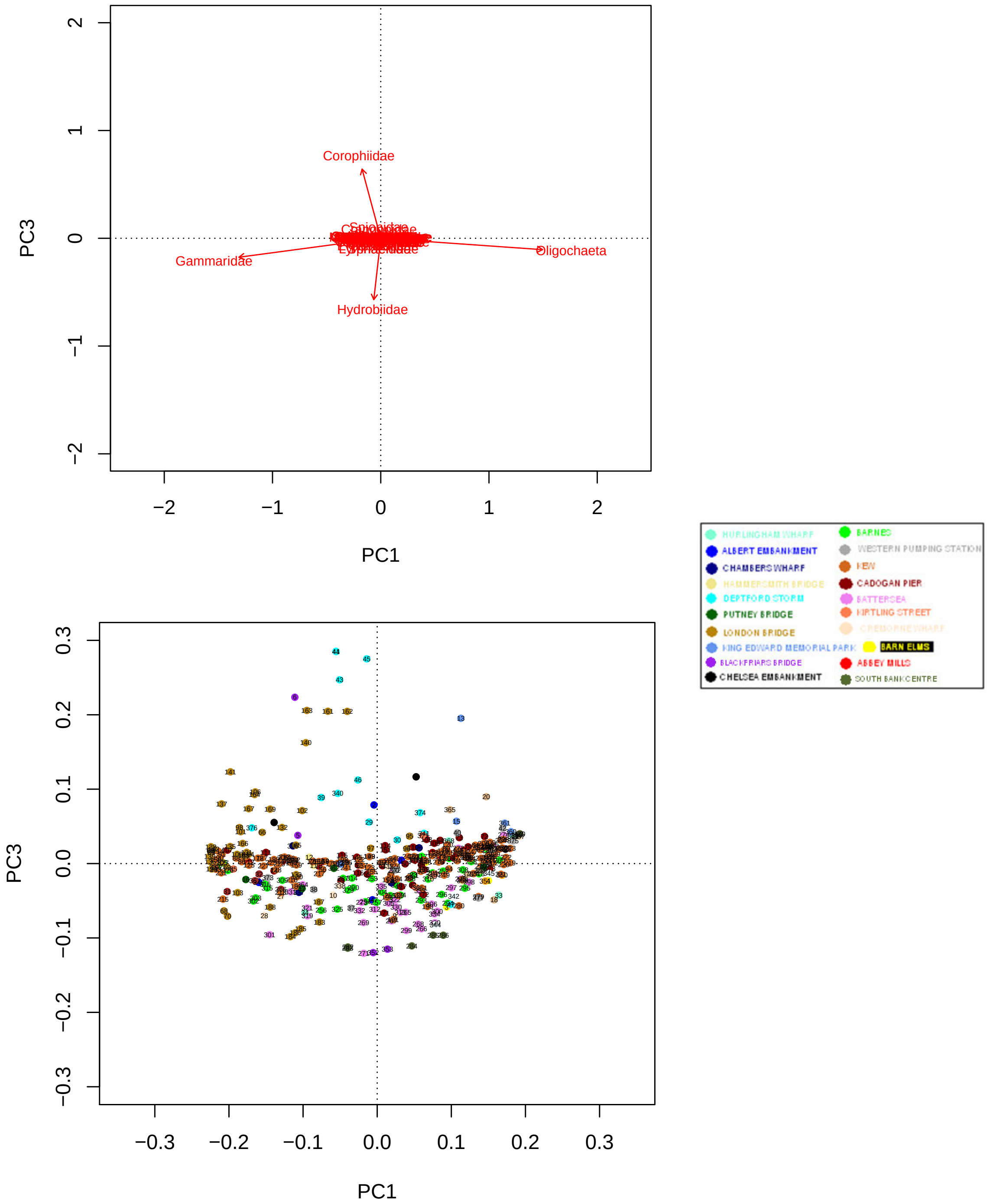
C.1.130 Although the potential saline gradient (based on the brackish/freshwater indicator species and position of sites in the Thames) has not been identified as the key determining factor defining the invertebrate communities, this is largely due to the lack of sites from the brackish zone included in this analysis. Sites in the brackish zone have not traditionally been collected using kick or airlift sampling methods (but core and other methods, excluded from this analysis). The only exceptions are sites such as London Bridge (at the upper extreme of the brackish zone) and sites such as Deptford Storm relief, which were sampled in 2010 and 2011. The projection of axes PC3 and PC1 indicates that these sites were characterised by groups such as Corophiidae and Spionidae, two typical estuarine groups.

Vol 3 Plate C.15 PCA plots of Thames invertebrate sample abundances between Kew and Beckton (1989 – 2011) collected using kick and airlift sampling. Correlation map (above) and distances map (below) for the invertebrate data, where PC1 and PC2 explain 48.7% and 19.1% of the variability





Vol 3 Plate C.16 PCA plots of Thames invertebrate sample abundances between Kew and Beckton (1989 – 2011) collected using kick and airlift methods. Correlation map (left) and distances map (right) for the invertebrate data, where PC1 and PC3 explain 48.7% and 10.0% of the variability



Presence-absence data

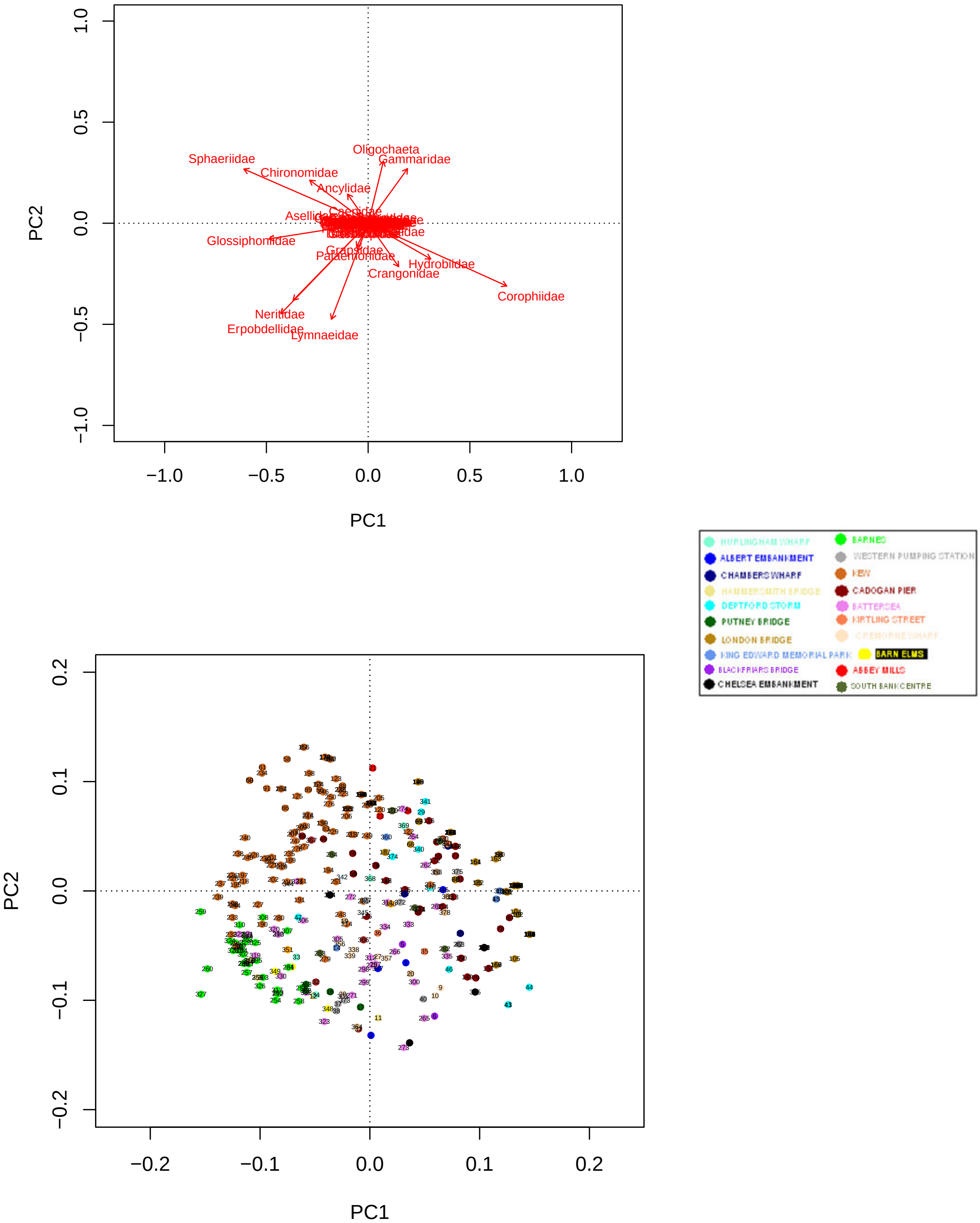
C.1.131 In order to pick out more subtle differences in the invertebrate community of the tidal Thames, without the preponderant influence of abundant groups such the Gammaridae or Oligochaeta abundance gradient, PCA was also carried out on the invertebrate presence-absence data. The PCA of the presence-absence dataset for samples collected from throughout the Thames tideway between 1989 and 2011, using 3-minute kick and airlift sampling is presented in A.17, below.

C.1.132 The PCA axes PC1 and PC2 contain respectively 18.5% and 11.5% of the variation and therefore do not represent a significant proportion of the total variability in the data. Ten taxa most significantly contribute to axes PC1 and PC2, and their projection suggests they tend to be correlated into a number of groups: (a) Neritidae, Lymnaeidae and Erpobdellidae; (b) Sphaeriidae and Chironomidae; (c) Oligocaheta and Gammaridae; (d) Corophiidae, Crangonidae and Hydrobiidae.

C.1.133 The projection of samples on the factorial maps indicates that samples are distributed continuously along the different gradients, suggesting that there are no distinct groups. However, samples from some sites, such as Kew (characterised by the presence of Sphaeriidae, Chironomidae), Barnes or Battersea (characterised by the presence of Erpobdellidae, Lymnaeidae, Neritidae) tend to be grouped together in the same area of the factorial chart. Again, as for the analysis of invertebrate abundances, no significant temporal pattern or trend associated has been identified, although this may be due to the data used, as discussed above.

C.1.134 In terms of the position of the site along the length of the tidal Thames (and the associated saline gradient), the analysis indicated how this factor was important in determining the structure of invertebrate assemblages. A significant observation is the apparent correlation between typically brackish taxa Corophiidae and Crangonidae, which are negatively correlated with the mainly freshwater families Sphaeridae, Chironomidae and Ancyclidae on axes PC1, PC2 and PC3. The projection of sample sites indicates that the ‘brackish’ animals were most frequently sampled at sites in the brackish zone, notably London Bridge, King Edward Memorial Park Foreshore and Deptford Storm Relief, while generally freshwater taxa, including Sphaeridae, Glossiphoniidae, Neritidae, Erpobdellidae and Lymnaeidae were most frequently sampled at sites such as Kew and Barnes.

Vol 3 Plate C.17 PCA plots of Thames invertebrate samples between Kew and Beckton (1989 – 2011) collected using kick and airlift methods. Correlation map (left) and distances map (right) for the invertebrate data (presence/absence) where PC1 and PC2 explain 18.5% and 11.5% of the variability



Other Sampling Methods

Abundance Data

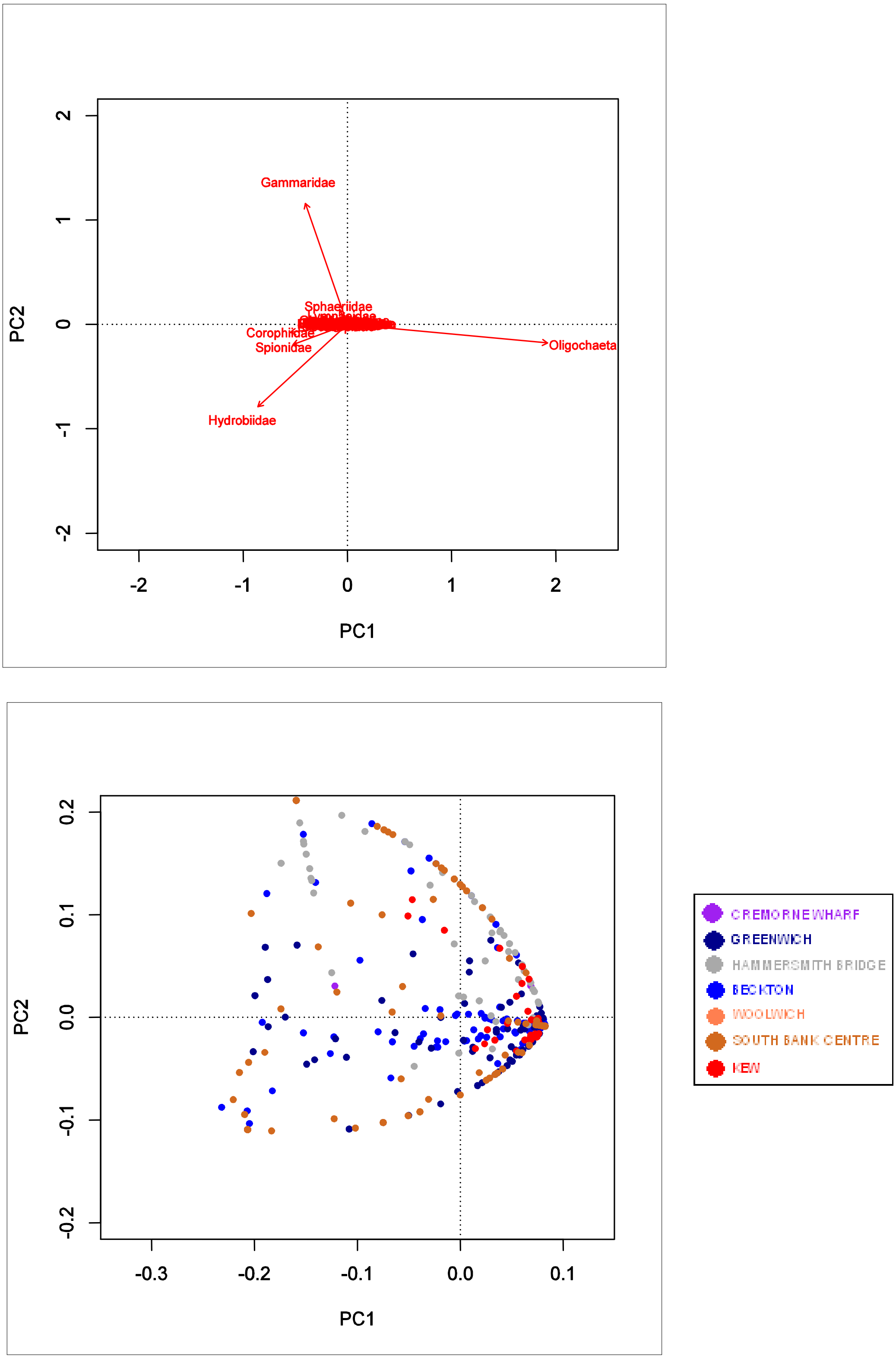
C.1.135 750 samples from 7 sites were analysed based on abundance data collected using ‘other’ sampling methods, which comprised 0.1 m and 0.01 core samples, gulley dredge samples, quadrat samples and 0.01 grab methods, as they were shown to provide similar taxon-richness data in preceding analyses. The results of these analyses are presented in Vol 3 Plate C.18 and Vol 3 Plate C.19. The first principal component is dominated by Oligochaeta, although other groups also contribute significantly, including Corophiidae, Spionidae, Gammaridae and Hydrobiidae. These four taxa are on the opposite side of the axes, which suggests that they tend to be in low abundances when Oligochaeta is dominant.

C.1.136 Analysis of other axes (PC2 – 4) indicate that differences in Corophiidae, Spionidae, Gammaridae and Hydrobiidae abundances contribute significantly to the total variation in the structure of the data set. However, there does not appear to be correlation between the abundances of these groups.

C.1.137 Although the samples are spread continuously over the axes and there are no true ‘discrete groups’ of samples, different areas of the gradients represented on the factorial map are dominated by specific sample sites. The following sites can be seen to dominate different areas: Woolwich (characterised by high abundances of Spionidae and Hydrobiidae), Beckton (high abundance of Oligochaeta) or Hammersmith Bridge (high abundance of Hydrobiidae). As discussed elsewhere, the habitat availability at the different sites is likely to contribute significantly in determining the animals present.

C.1.138 Another significant observation from Vol 3 Plate C.19 (showing PC1 and PC3) is that the samples where Spionidae is most abundant generally are those from the brackish zone and exclude samples from the freshwater zone (Kew and Hammersmith Bridge). Spionidae is the only exclusively brackish taxon whose abundance variations are significant enough to contribute to the PCA. The contribution of this group to axes PC2, PC3 and PC4 (and its relative abundance in brackish and freshwater zone samples) is therefore indicative of the importance of the saline gradient on the invertebrate communities of the Thames.

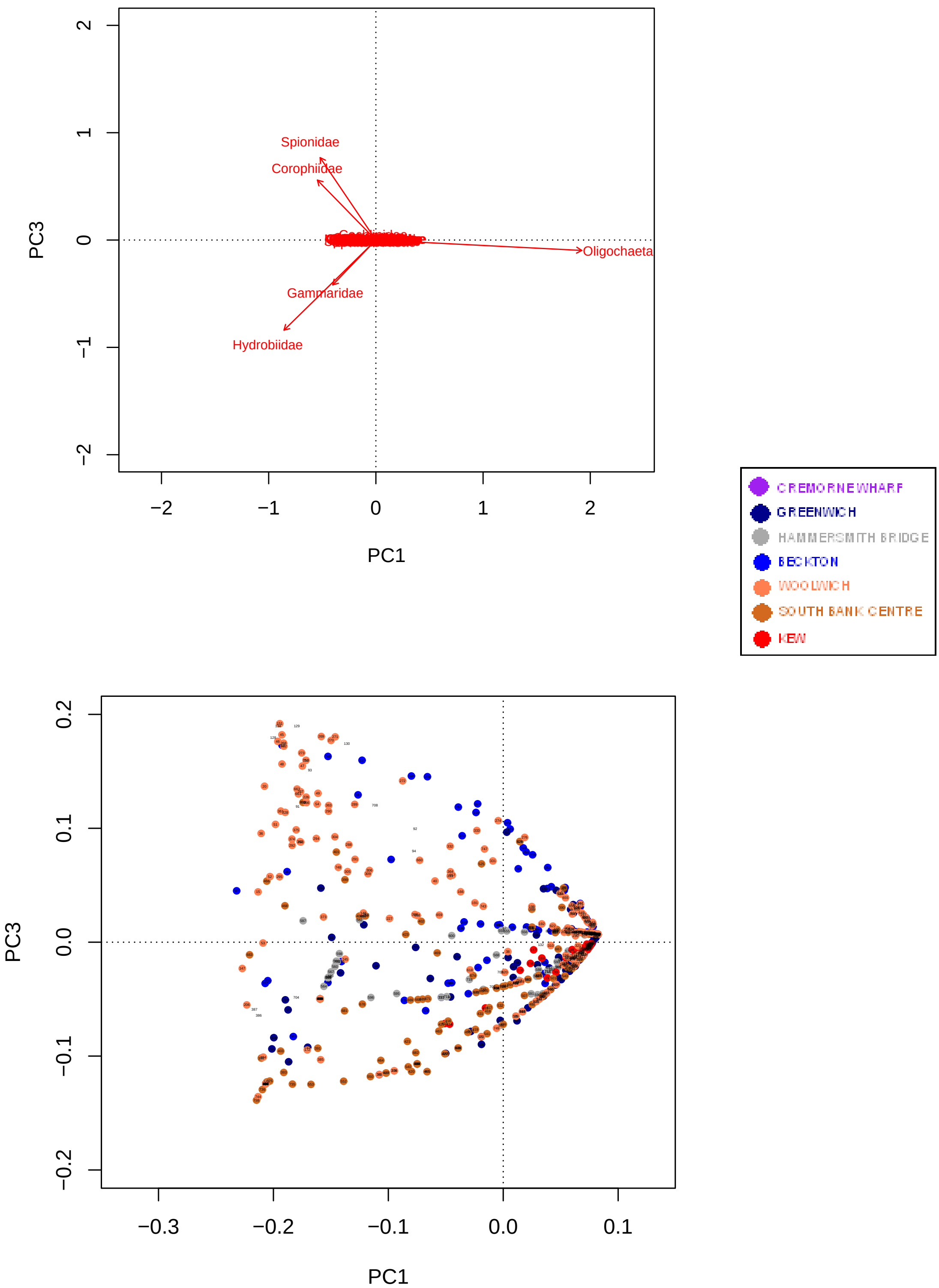
Vol 3 Plate C.18 PCA plots of Thames invertebrate sample abundances between Kew and Beckton (1989 – 2011) collected using other sampling methods. Correlation map (left) and distances map (right) for the invertebrate data (abundances), where PC1 and PC2 explain 40.1% and 16.2% of variability



C.1.139 Some temporal variation (seasonal and yearly) also seems to be revealed by those distances maps, which suggest that higher abundances of Gammaridae are present in summer samples, while Hydrobiidae tend to be more abundant in autumn and that Gammaridae tend to be more abundant in the early years of sampling (1989-1994), while Hydrobiidae more abundant in the latter samples (2000-2011). However, it is important to note that the some of the sites described above were sampled at different times from others (some sites were sampled during early years, while others were sampled later) and therefore some of the variation described above may, in part, be explained by seasonal or year on year trends.

C.1.140 Additionally, there appear to be some differences between the sampling methods (core samples collect lower numbers of Gammaridae compared with all other methods), which may further influence the data distributions.

Vol 3 Plate C.19 PCA plots of Thames invertebrate sample abundances between Kew and Beckton (1989 – 2011) collected using other sampling methods. Correlation map (left) and distances map (right) for the invertebrate data (abundances), where PC1 and PC3 explain 40.1% and 13.9% of variability



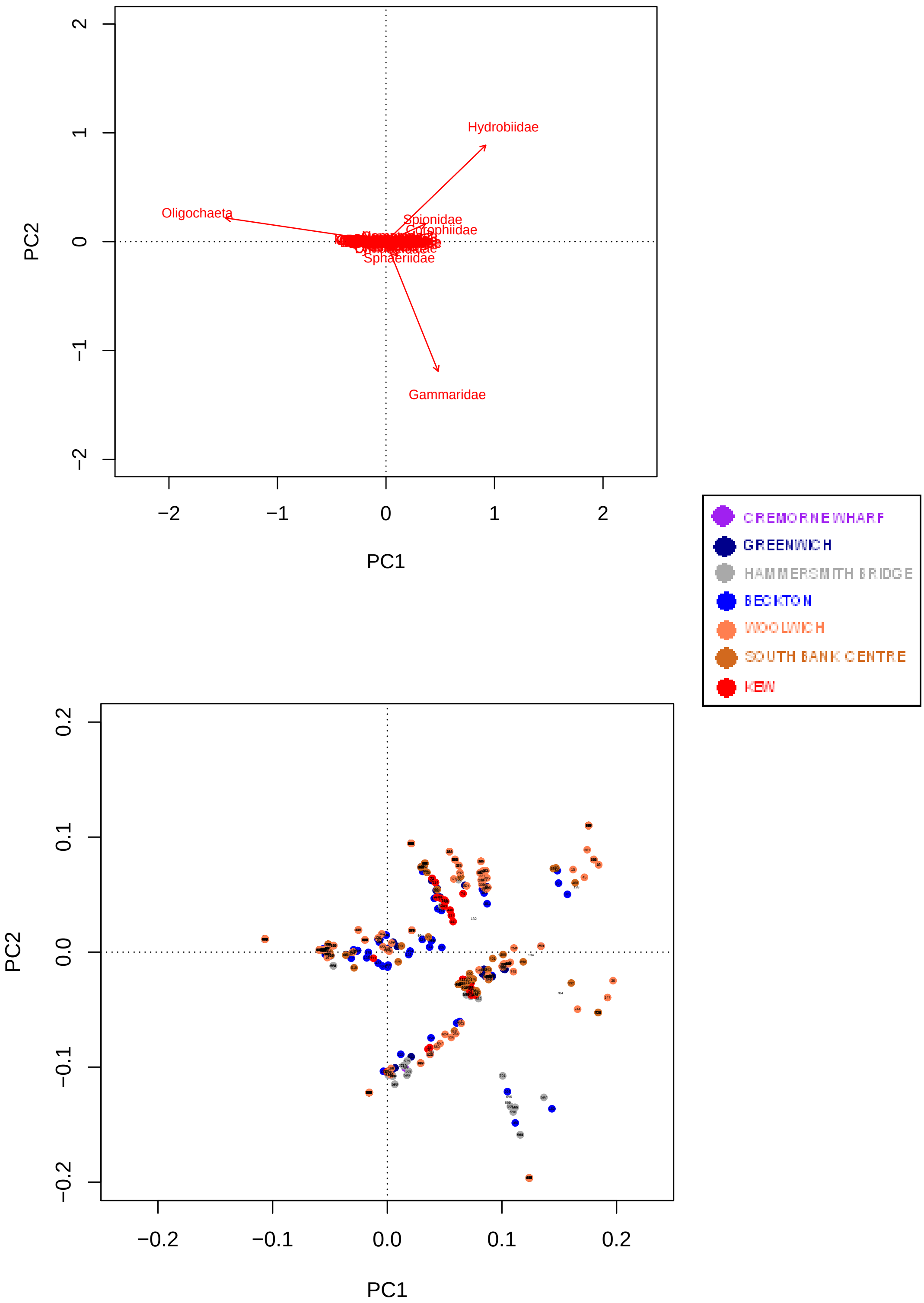
Presence-absence Data

C.1.141 The PCA of the presence-absence data for the samples collected from the tidal Thames between 1989 and 2011 are presented in Vol 3 Plate C.20 and Vol 3 Plate C.21 below. The analysis exclude samples collected using three-minute kick and airlift sampling methods.

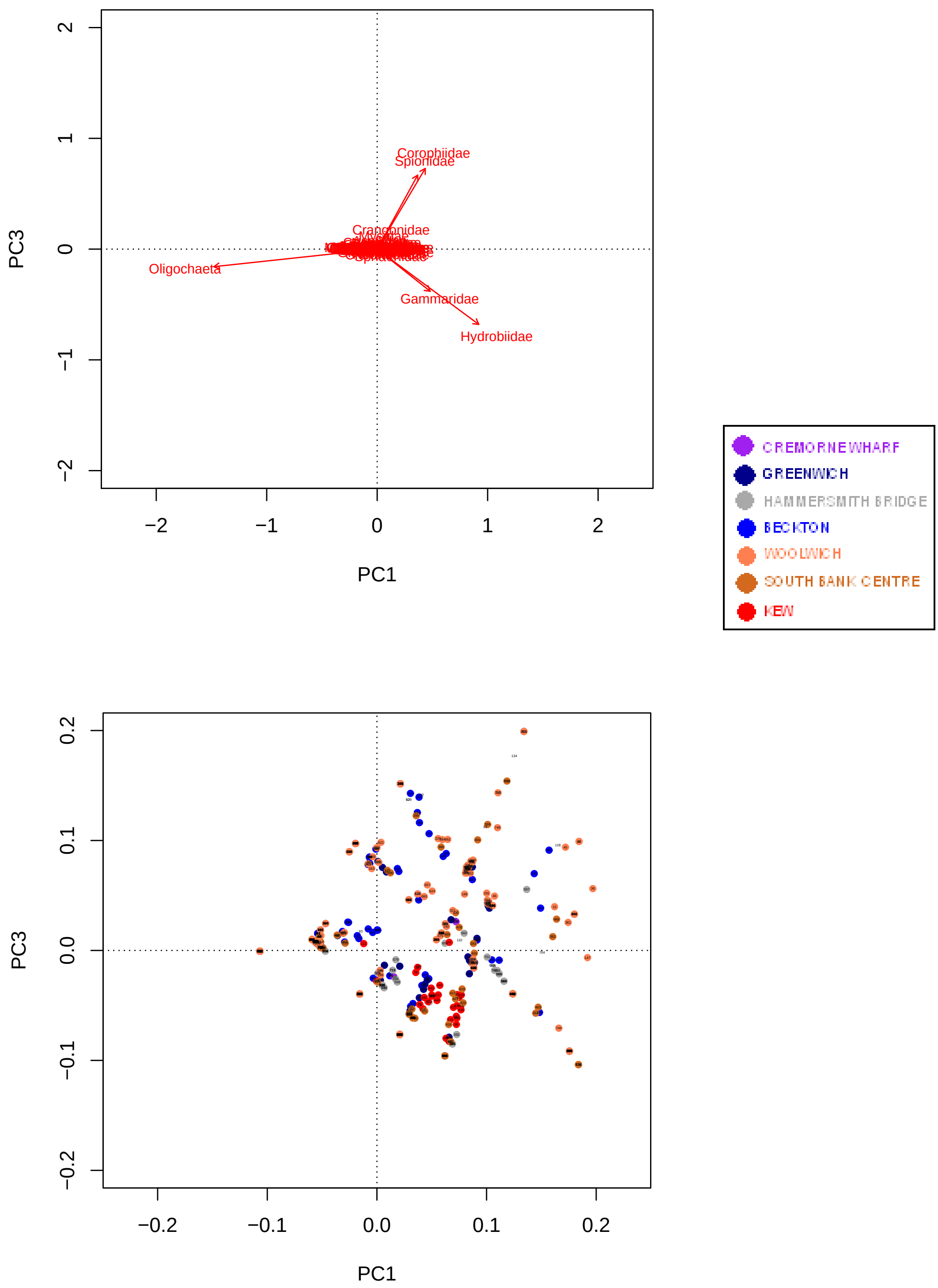
C.1.142 The correlation maps show that the best represented taxa on the various axes on the analysis are Oligochaeta, Gammaridae and Hydrobiidae. Corophiidae and Spionidae are moderately well represented on the axes of the analysis. No clear relationship between the presence-absence of those taxa is revealed here, except a slight positive correlation between Corophiidae and Spionidae.

C.1.143 The sample projection on the factorial maps indicates that there are a number of distinct groups of samples, but no clear pattern to explain these groupings has been identified. The only key observation is that Spionidae and Corophiidae are generally most associated with the brackish zone and samples from the freshwater zone (Kew and Hammersmith Bridge) are excluded from this area of the factorial map. This, as discussed previously, is indicative of the saline influence on the invertebrate communities.

Vol 3 Plate C.20 PCA plots of Thames invertebrate samples between Kew and Beckton (1989 – 2011) collected using other sampling methods. Correlation map (left) and distances map (right) for the invertebrate data (presence/absence), where PC1 and PC2 explain 25.4% and 16.2% of the variability



Vol 3 Plate C.21 PCA plots of Thames invertebrate samples between Kew and Beckton (1989 – 2011) collected using other sampling methods. Correlation map (left) and distances map (right) for the invertebrate data (presence/absence), where PC1 and PC2 explain 25.4% and 11.6% of the variability



Summary and Discussion of Key Findings

C.1.144 The PCA analyses of the tidal Thames invertebrate communities between Kew and Beckton STW shows that, despite the significant length of the estuary covered, the invertebrate community is dominated by a handful of taxa based on family level data. At species level, diversity would increase significantly and more spatial and temporal tends would probably be apparent. The data are relatively homogenous over significant longitudinal distances and no discrete groups of samples or sites are apparent.

C.1.145 This is likely to be due to the 'homogenising' nature of a tidal system. The tide moves water up and downstream for several kilometres twice daily, carrying with it a saline 'wedge', and associated differences in temperature, silt, organic matter, and other materials. The distance this saline 'wedge' travels up and downstream is variable (depending on freshwater flow, tide etc) meaning that the at any given site there is considerable variability in minimum/maximum salinity between seasons and years; thus in terms of its saline profile, no given site or area of the Thames is 'unique' and the fauna is likely to reflect this. This is likely to be a significant factor that explains the lack of 'discrete' groups along the profile of the Thames. During hot summers and low flows, tidal movements also move oxygen sags and other poor water quality problems with it. Thus a 'step' change in water quality and invertebrate fauna cannot be expected between sites upstream and downstream of significant discharges, such as CSOs or STW.

C.1.146 Also, the tidal nature of the estuary, combined with the disturbed (engineered) nature of a waterbody in a highly urban setting, means that to find significant differences in habitat and associated invertebrate communities, it is necessary to cover a great longitudinal distance (compared, for example, to a non-tidal and freshwater system). For example, habitats such as pebble bottoms are ubiquitous throughout intertidal areas of the upper estuary, and it is not until near to Greenwich where areas of mudflat become more dominant.

C.1.147 Another important factor is that the analysis was only carried out on taxonomic data to family level (with all Oligochaeta combined under a single order). Because of this, it is likely that some more subtle variations between up and downstream have not been identified. There are approximately 20 species of Oligochaeta that have been identified in the Thames, some of which are limited to the upper estuary, others are only found in the brackish zone and others throughout much of the tideway. For example, sites for which species level data were available indicated that the freshwater zone are dominated by the tubficids *Tubifex tubifex*, *Limnodrilus* spp., *Psammoryctides barbatus*, *Potamothrix hammoniensis*, *Brachiura sowerbyi* and the Naididae *Nais elinguis* and *Chaetogaster crystallinus*, while in the brackish zone *Heterochaeta costata* and *Tubifex pseudogaster* become more common. Another example is the mudshrimp family Corophiidae, of which there are several species. Vol 3 Plate C.14 illustrates how *Apocorphium lacustre* is more associated with the upper tideway and replace by *Corophium volutator*, downstream of Greenwich.

C.1.148 Within the upper estuary (including sites from London Bridge to Kew), the most dominant taxa were Oligochaeta and Gammaridae, whose abundances tended to be negatively correlated with one another throughout the estuary, as was suggested by the cluster analysis. Hydrobiidae also contributed significantly to the variation observed, although the analyses showed that this taxon was not correlated with either Oligochaeata or Gammaridae. The abundance of these groups does not appear to be associated with any specific sites along the tideway. The use of binary (presence-absence) data provided a clearer understanding of the distribution of other less abundant groups, such as freshwater taxa including leeches and river neritids (which characterised the Barnes sample site); Sphearidae (most dominant Kew sample site). These groups were more characteristic of upstream sample sites.

C.1.149 Within the brackish zone (downstream of London Bridge to Beckton), taxa such as the polychaete family Spionidae and mudshrimp Corophiidae significantly contributed to the invertebrate community structure, although taxa such as Oligochaeta, Gammaridae and Hydrobiidae also appeared to be significant. Spionidae are a brackish family of polychaete worms not found freshwaters. Their abundance, which was highest at downstream sites (notably Woolwich), is indicative of the saline influence on the invertebrate community of the River Thames. Corophiidae, on the other hand, have been found to be present throughout the tideway, notably in stable deeper waters. However, it is likely that sampling efficiency for this group is compromised in upstream areas. They are present in large numbers in mud burrows on pebbles in subtidal areas (Attrill 1998), which are not easily collected by the three-minute kick sampling (which only sample shallow waters), while in deeper waters the pebbles get stuck in the jaws of grab sampling apparatus.

C.1.150 Although no habitat data were provided with the invertebrate data, the type of habitat sampled is likely to play a significant role in determining which taxa dominated the assemblages. Oligochaeta, for example, are generally more abundant in finer sediment, such as anoxic silts, while Gammaridae prefer well oxygenated and slightly larger sediments, such as gravels.

C.1.151 Sampling method is also likely to influence the invertebrate communities present. Methods such as core sampling cannot sample coarse habitats and therefore favour soft silt habitats and Oligochaeta tend to dominate.

C.1.152 Temporal variations are not easily picked out by the above data analysis. In particular the lower diversity identified in the cluster analysis for some samples (notably Kew) was not picked up by the PCA of presence-absence data. It is important to point out that only a relatively small amount of the total variability is explained by the first four axes, and other subtle trends (such as differences in diversity between earlier and later samples) may be hidden. Temporal changes are, however, likely to be significant, due to the biological rhythms of species or populations (reproductive cycles, migrations etc) and seasonal or annual environmental variations (flow, water quality, salinity etc).

Assessment of Temporal Trends

C.1.153 The following section presents the findings from the assessment of how changes or fluctuations in the invertebrate communities (seasonal or year on year) of the Thames are influenced by chemical, physical and other factors. The biological data have therefore been combined with chemical and other relevant and available data. In order to eliminate significant factors for which we have no or little data (such as habitat differences between sites), a number of key sites were analysed individually (Kew, Cadogan Pier, Greenwich and Beckton).

Kew

C.1.154 Biological (invertebrate sampling) and water quality sampling data were available from the Kew sampling site from between 1989 and 2005. The biological data were collected using three-minute kick sampling. Other sampling data were available from core sampling, but given the differences in data from the different sampling methods, these additional data were not included in the analysis.

Environmental Variables

C.1.155 Environmental variables were calculated for 6 month time periods preceding the dates that biological samples were taken at Kew, as set out in Vol 2.

C.1.156 The results show positive correlations between high flow at Teddington Weir and high DO concentrations, which tend to be negatively correlated with low flow, low DO, high water temperature and high salinity.

C.1.157 Parameters associated with low DO (number of events < 3 mg/L DO, number of events < 1.5 mg and duration of these events) appear to be correlated with low flow at Teddington Weir and high water temperatures. The spring samples tended to show higher DO concentrations and higher flows at Teddington Weir.

C.1.158 Concerning ammonia, high concentrations were positively correlated with low flow parameters and negatively correlated with high flow and low salinity. There were only weak (negative) correlations observed between certain high DO and the ammonia measures considered and no apparent correlation between ammonia and temperature or high salinity.

C.1.159 In summary, the results indicate that lowest water quality (frequent low DO events, frequent high ammonia concentrations) tends to be associated with low flows and high temperatures in summer.

Invertebrate Abundances

C.1.160 Invertebrate abundances from 117 three-minute kick samples from Kew (1989 – 2005 data) were analysed using PCA. The graphical results of these analyses are presented in

C.1.161 A.22, below, which illustrates axes PC1 and PC2. The projection of these axes express a total of 87.0% of the variation of the data set (81.3% and 5.8% respectively, for axes PC1 and PC2).

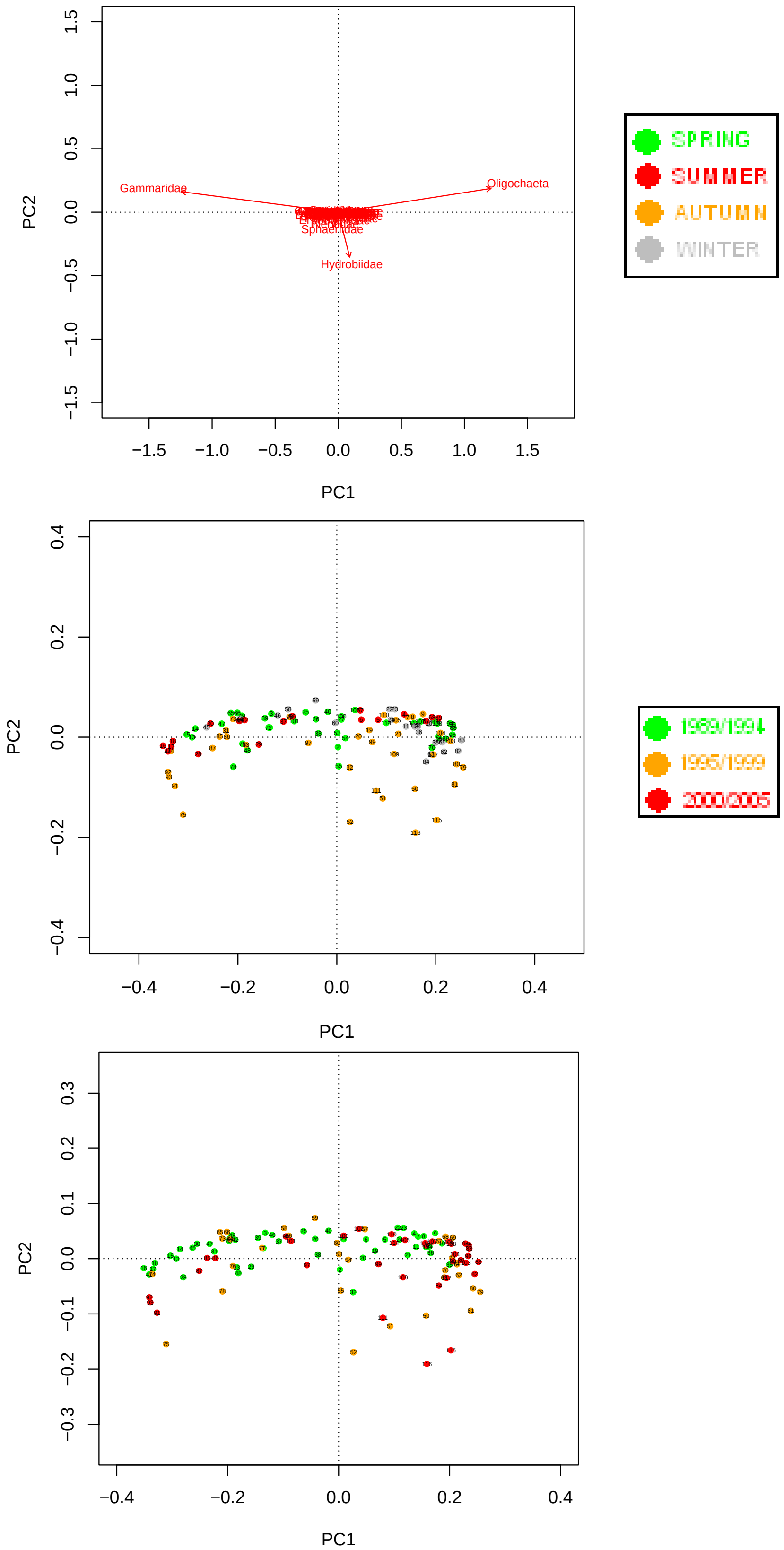
C.1.162 The first principal component axis (PC1) expresses a high proportion of the total variability, and abundances of Oligochaeta and Gammaridae contribute most highly to this axis. This indicates that these two taxonomic groups that contribute most to the differences in the invertebrate abundances at Kew. The abundances of these taxa appear to be strongly and negatively correlated to each other, while other taxa are not well represented on this axis. As discussed elsewhere, habitat is a significant factor in determining whether Oligochaeta or Gammaridae are dominant.

C.1.163 The projection of samples on the factorial maps indicates that there are no distinct groups of samples and the data appear to be fairly continuous. However, the figure shows that autumn and winter samples appear to be on the extreme of axis PC1 associated with high abundances of Oligochaeta worms and low abundances of Gammaridae. These may reflect seasonal differences in water quality; DO sags tend to be most common in later summer and would affect the composition of subsequent autumn and winter invertebrate samples. There are exceptions to these trends: for example, samples 73 – 75 (October 1998), 85 – 87 (September 2000) and 91 – 93 (September 2001) appear on the PC1 gradient associated with high Gammaridae and low Oligochaeta. These samples followed summers where water quality (in terms of DO concentrations) remained relatively high.

C.1.164 It also appears that samples taken in later years (2000 – 2005) are mostly associated with the extreme of axis PC1, characterised by high abundances of Oligochaeta and low abundances of Gammaridae. Water quality data show that DO sags were frequent during this time period, with the exception of 2000 and 2001. Indeed, the samples that were taken in 2000 and 2001 (for example samples 85 – 93) were generally associated with that part of the chart associated with higher Gammaridae and low Oligochaeta.

C.1.165 The removal of the highly dominant Gammaridae and Oligochaeta from the analysis reveals significant variations in Sphaeridae, Erpobdellidae, Glossiphonidae and Chironomidae at Kew. Of particular note is that Chironomidae were most dominant in samples taken in spring, while samples in which Glossiphonidae and Erpobdellidae were dominant in autumn. Most Chironomidae are sensitive to raised levels of salinity, which might explain their dominance in spring (decreased tidal influence of the winter period). Further analysis of the influence of chemical quality on the invertebrate community of Kew is described later in this section.

Vol 3 Plate C.22 PCA plots of Thames invertebrate samples at Kew (1989 – 2011). Correlation map (top) and distances map (middle and bottom) for the invertebrate data (abundances), where PC1 and PC2 explain 81.3% and 5.8% of the variability



Invertebrate Presence Absence Data

C.1.166 The PCA of presence absence data at Kew revealed few other trends that were not shown by the abundance data and is therefore not discussed further.

Redundancy Analysis (RDA)

C.1.167 RDA of Kew data illustrates correlations between the invertebrate community and the variations in environmental variables (flow and water chemistry) in this area of the Thames, described above.

C.1.168 The RDA of the invertebrate dataset constrained by the environmental dataset described above shows that only 24.8% of the variability existing in the invertebrate data set is explained by the environmental variables used. This means that 75.2% of the variability in the data is explained by other factors, such as sampling variation, habitat and other chemical measures not available.

C.1.169 Although 25% may not appear to be a significant proportion of the total variability in the data, it is quite typical of this type of ecological data, especially given the absence of data on habitat and other environmental parameters and the fact that samples have been collected and analysed by a number of different people between 1989 and 2011. Ecological data tends to be very ‘noisy’, and significant variations of invertebrate abundances, due to sampling and other natural variations, means that it is common for the multivariate models based on environmental parameters not to explain a majority of biological variability.

C.1.170 Different projections of axes RDA1 – RDA4, shown in Vol 3 Plate C.23 below illustrate the relationships between environmental variables and abundances of invertebrate taxa.

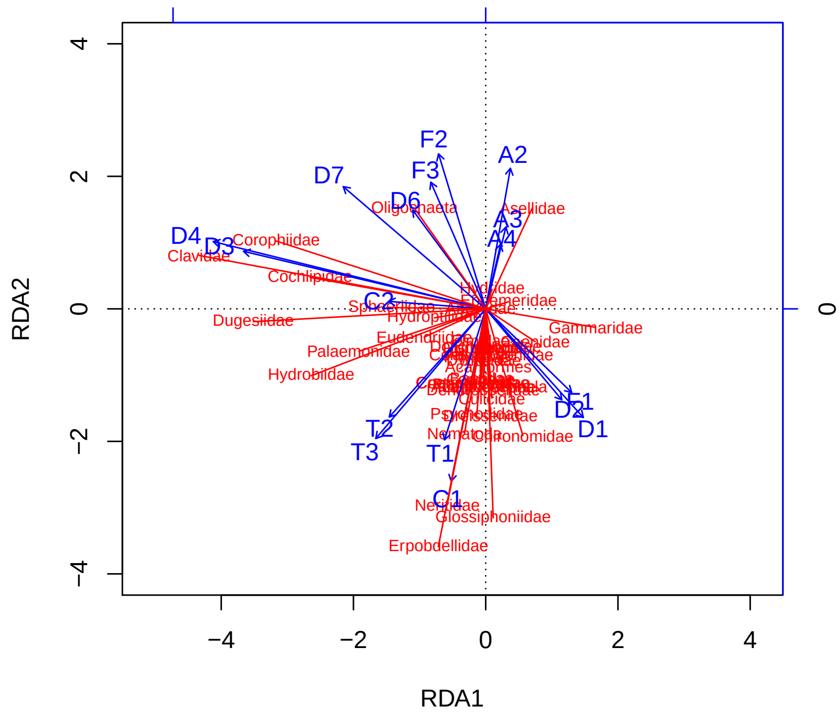
C.1.171 These charts indicate that a large group of invertebrates are negatively correlated with low DO events, notably the number of DO events < 3 mg/L (D6) and the maximum duration of these events (D7). Although these are not visible on the charts, the output from the analysis shows that this group includes Caenidae, Ephemerillidae (mayfly), Gammaridae (shrimps), Planariidae, (flatworms), Neritidae (river neritids), Physidae (bladder snails), Dreissenidae (zebra mussel), Glossiphoniidae, Erpobdellidae (leeches), Leptoceridae, Psychodidae (caddis) and various Diptera (truefly) taxa (Chironomidae, Culcidae). Many of these invertebrates also tend to be positively correlated with mean six-monthly DO concentrations (D1) and DO 95%ile values (D2), as well as high flow at Teddington Weir (F1) and low (5%ile) saline (chloride) concentrations (C1), suggesting that they may be affected by saline and/or chlorine concentrations. The above invertebrate groups are characterised by different tolerances to salinity and hypoxia, as considered further in the discussion. The invertebrates that are most strongly correlated with high flow at Teddington Weir (F1) and high DO parameters include Caenidae, Chironomidae, Neritidae and Gammaridae. Other taxa, notably (river neritids), Glossiphoniidae and Erpobdellidae (leeches) appear to be most strongly correlated with low chloride concentrations (C1) and are therefore most likely to be influenced by increases to salinity during low flows.

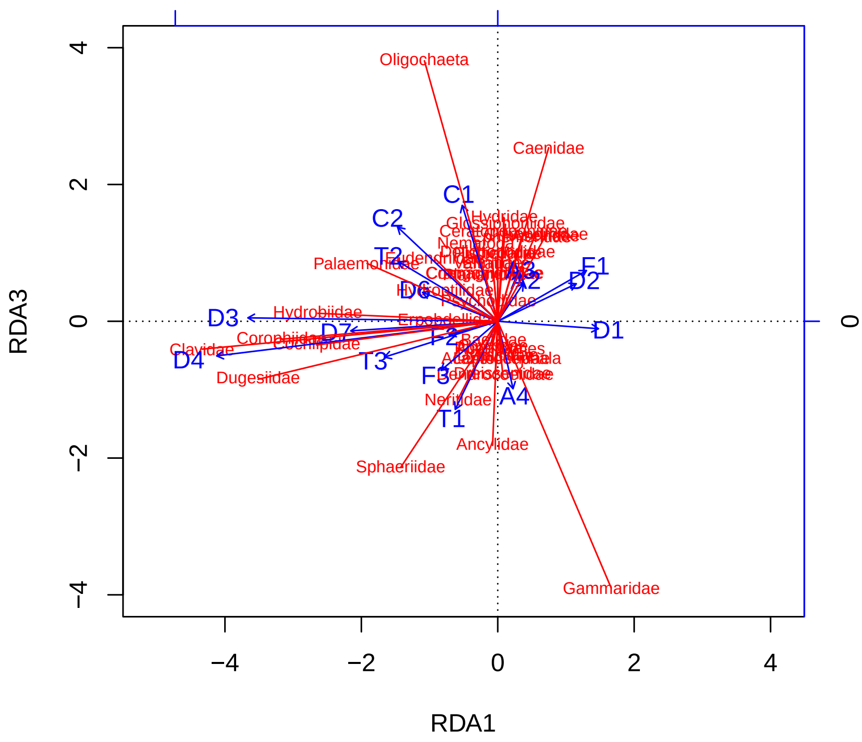
C.1.172 On the other hand, some taxa appear to be positively correlated with low flow, low DO events, low mean DO (D1) and low DO 95%ile (D2) values. These include a group comprising Corophiidae, Cochliopidae and Clavidae, which appear to be associated with parameters D3 and D4 (number and maximal duration of DO events < 1.5 mg/l). These taxa are all brackish, and therefore the variations may be, at least partly, due to increased distribution from downstream due to saline intrusion during low flows, which have allowed these animals to increase their distribution.

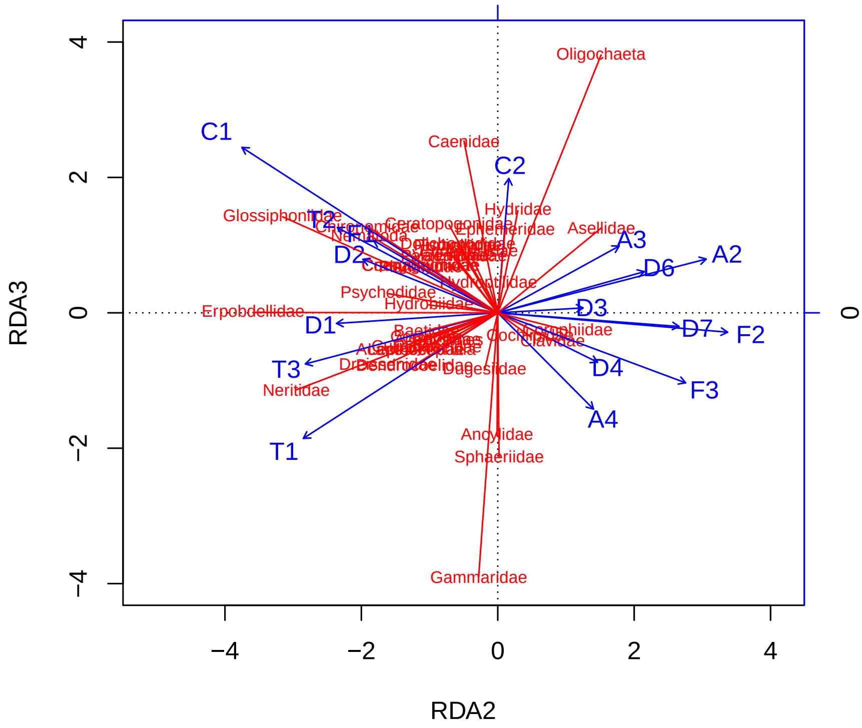
C.1.173 Another group, which includes Oligochaeta and Hydrobiidae appear to be correlated with D6 and D7 (number and maximal DO events < 3 mg/L).

C.1.174 Inspection of axes RDA1, RDA2, RDA3 and RDA4 indicates that correlations between ammonia concentrations (A2, A3 and A4) and invertebrate taxa are complex. Asellidae and Oligochaeta are the only taxa that are associated with high ammonia concentrations, while certain taxa (notably Glossiphonidae and Erpobdellidae) are generally negatively correlated. However, inspection all four axes presented suggests that these correlations are not highly significant.

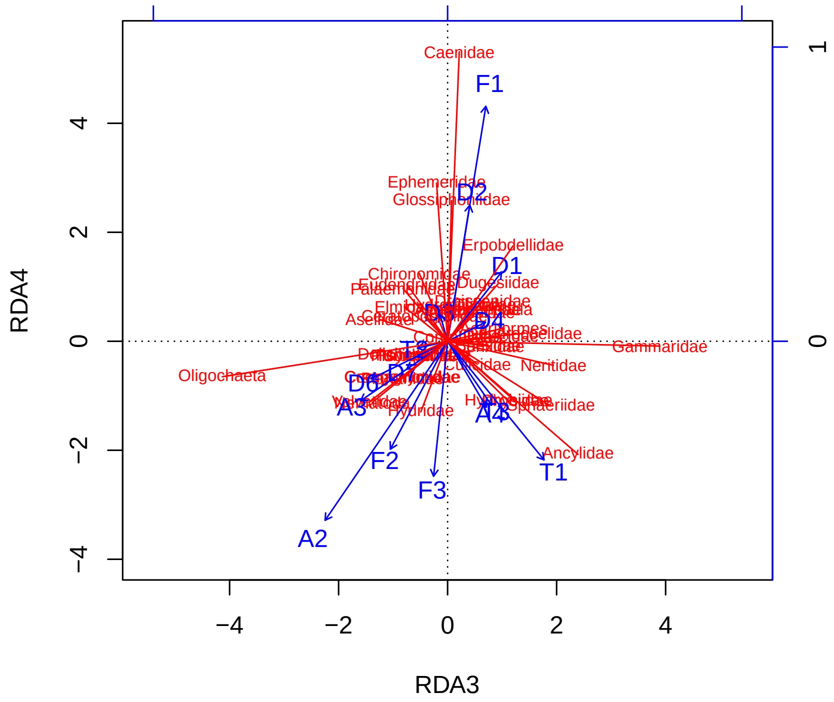
Vol 3 Plate C.23 RDA plots of Kew (1989 – 2010) invertebrate samples where PC1, PC2, PC3 and PC4 explain 25.0%, 16.8%, 14.8% and 12.1% of the variability constrained by chemical parameters







RDA3
RDA2
4
2
0
−2
−4
−4
−2
0
2
4
0
Oligochaeta
Caenidae
C1
C2
Hydridae
Glossiphoniidae
T2
Ceratopogonidae
Ephemeridae
Asellidae
A3
A2
D2
D6
Hydrobiidae
Psychodidae
Erpobdellidae
D3
D1
D7
F2
Baetidae
Clavidae
T3
Neritidae
Dugesiidae
D4
F3
A4
Ancylidae
T1
Sphaeriidae
Gammaridae



RDA4
RDA3
4
2
0
−2
−4
−4
−2
0
2
4
1
0
Caenidae
F1
Ephemeridae
D2
Glossiphoniidae
Erpobdellidae
Chironomidae
D1
Dugesiidae
Asellidae
Gammaridae
Oligochaeta
Neritidae
D6
A3
Hydridae
A4
Sphaeriidae
F2
Ancylidae
T1
F3
A2

Cadogan Pier

C.1.175 Biological and environmental data available from the sampling site at Cadogan Pier from between 1989 and 1993 were used in the subsequent analysis.

Environmental Variables

C.1.176 PCA was undertaken on various six monthly measures of chemistry and flow parameters, from available AQMS and spot sampling chemical data at Cadogan Pier.

C.1.177 As at Kew, the PCA indicates correlations between high flow at Teddington Weir and high DO concentrations. Parameters associated with low DO appear to be correlated with low flow at Teddington Weir and high water temperatures.

C.1.178 There were some significant differences compared to the Kew data, notably that high ammonia concentrations and events were positively correlated with high DO and low salinity and negatively correlated with low DO events in Cadogan Pier samples (while at Kew no such trends was apparent).. This may reflect the sampling period (Kew samples: 1989 – 2010, Cadogan Pier: 1989 – 1993) and degradation rates of organic compounds and ammonia (temperature dependent), as discussed later in this section.

Invertebrates

C.1.179 The main findings of the PCA analysis of invertebrate abundances (47 samples) from Cadogan Pier (1989 – 1993 data) are presented below.

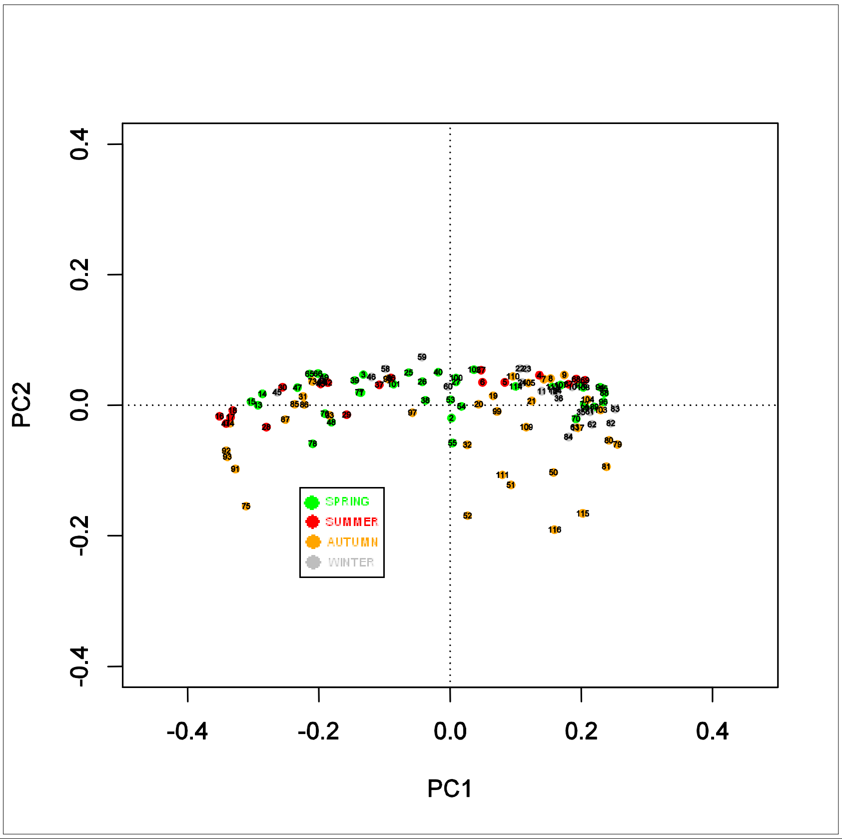
C.1.180 The PCA axes PC1 and PC2 (which describe respectively 80.1% and 10.3% of the total variability of the data set) are presented in Vol 3 Plate C.24.

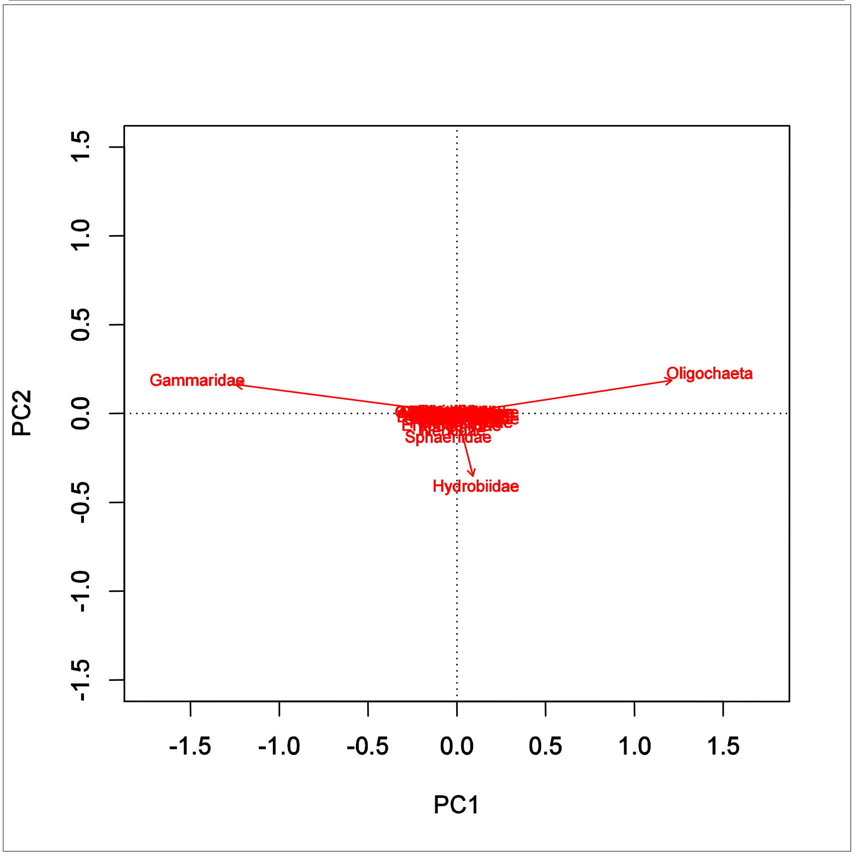
C.1.181 As at Kew and other sites, the most significant proportion of the variability is due to the differences in abundances of Oligochaeta and Gammaridae, which are expressed the first principal component, axes PC1, and appear to be negatively correlated. Hydrobiidae also contributes significantly to the axis PC2, but other taxa are not well represented on either axis. As discussed elsewhere, habitat is likely to be a key factor in determining which taxa is most dominant.

C.1.182 The sample projection on the factorial maps indicates that although there are no distinct groups of samples, the ‘Gammaridae’ extreme of the PC1 axis is dominated by samples taken in the spring, while at the ‘Oligochaeta’ extreme, summer and winter samples are more frequent. The area of PC correlated with high abundances of Hydrobiidae was dominated by winter and summer samples only, excluding all spring samples. These may reflect seasonal differences in water quality, as water quality is generally better (less DO sags) during the period preceding the spring sample collection.

C.1.183 Further interpretation of the influence of chemical quality on the invertebrate community of Cadogan Pier is discussed as part of the RDA analysis, below.

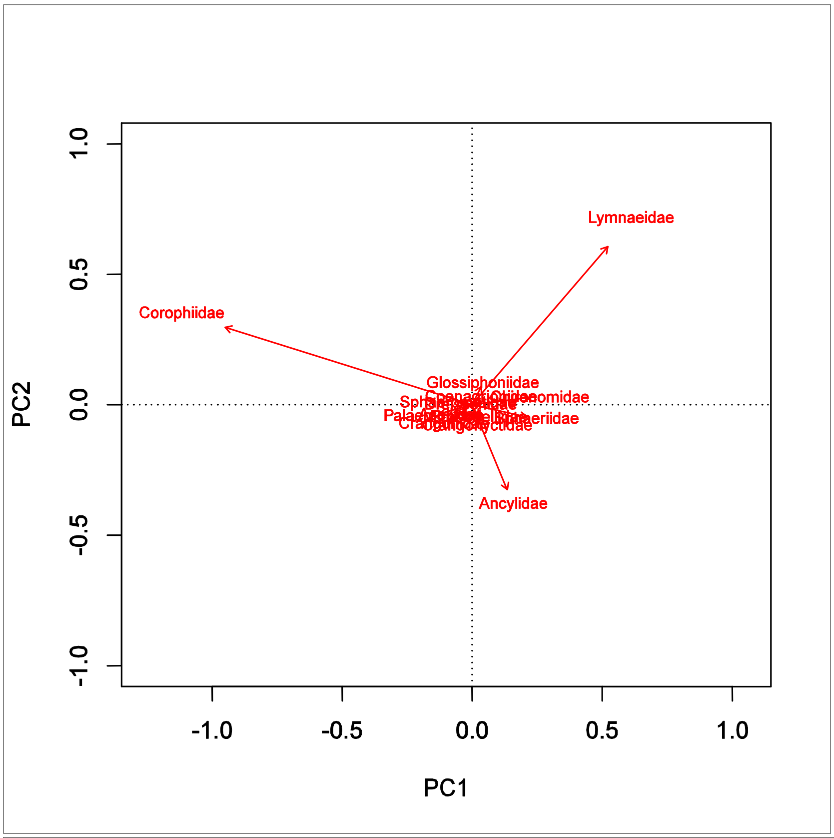
Vol 3 Plate C.24 PCA plots of Thames invertebrate samples at Cadogan Pier (1989 – 1993). Correlation map (left) and distances map (right) for the invertebrate data (abundances), where PC1 and PC2 explain 80.1% and 10.3% of the variability

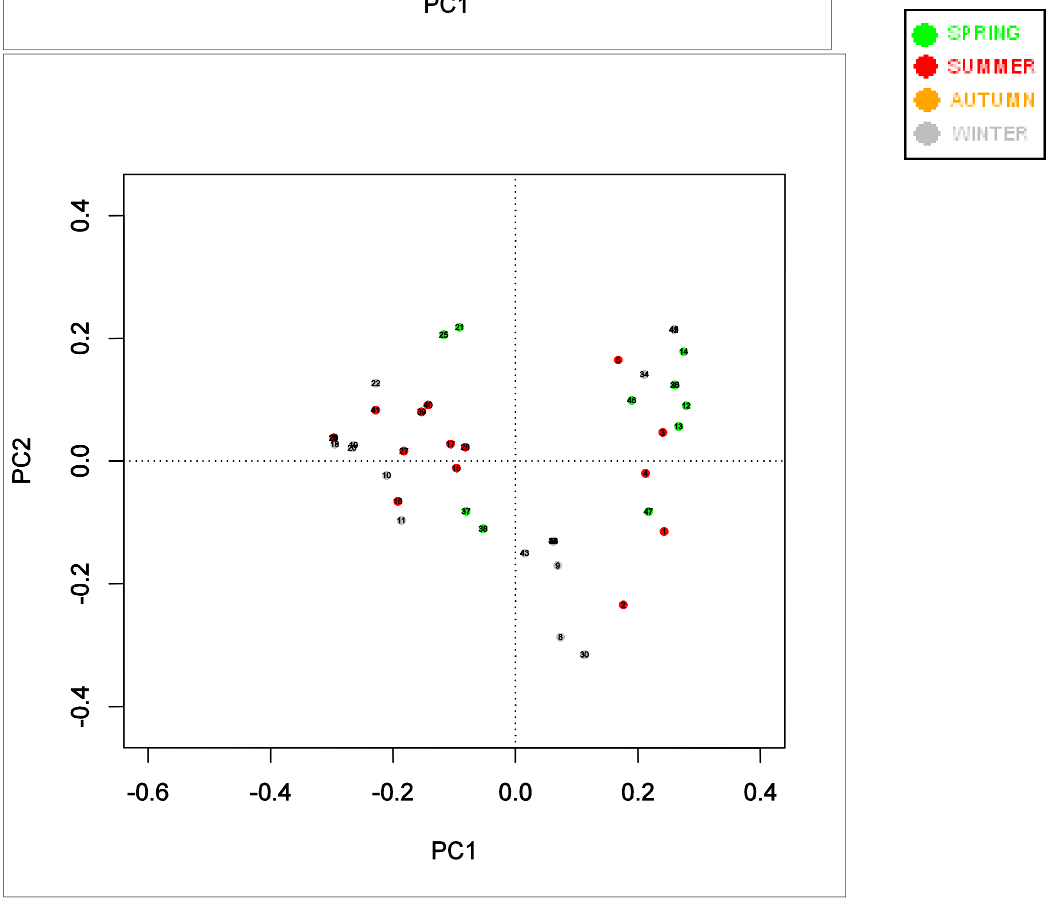




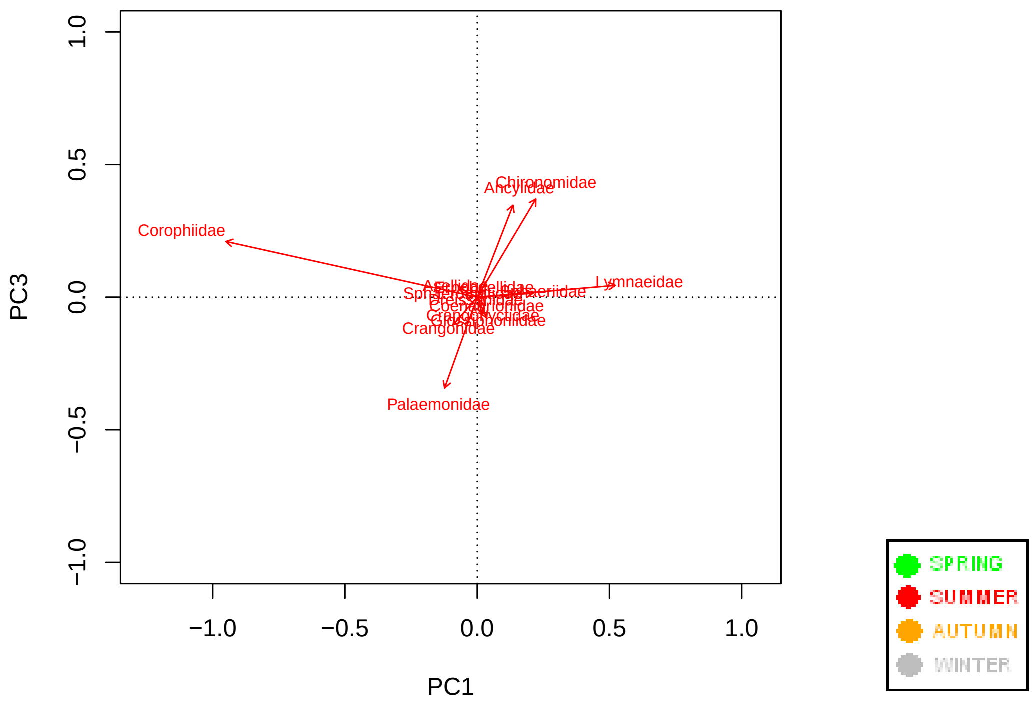
C.1.184 The results of a further PCA analysis on the invertebrate data, which was carried out on the invertebrate abundances data set without Oligochaeta, Gammaridae and Hydrobiidae, the most influential taxa, are provided in Vol 3 Plate C.25 and A.26, below. These charts indicate that after Oligochaeta, Gammaridae and Hydrobiidae, other taxa appear to be significant, notably Corophiidae, Lymnaeidae and Ancylidae. The projection of sample sites onto axes PC1 and PC2 indicate seasonal differences between the abundance patterns of these three taxa: Ancylidae and Corophiidae appear to appear to be most abundant in summer and winter samples, while Lymnaeidae was generally found to be in higher abundances in spring samples. Again, seasonal differences in flow, water quality (or salinity) and/or breeding patterns are likely to explain these trends.

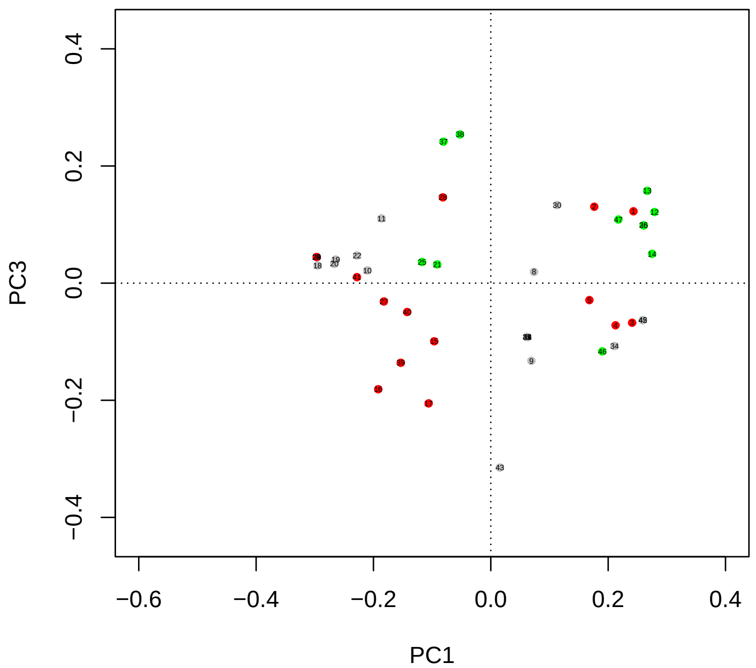
Vol 3 Plate C.25 PCA plots of Thames invertebrate samples (excluding Oligochaeta, Gammaridae and Hydrobiidae) at Cadogan Pier (1989 – 1993). Correlation map (left) and distances map (right) for the invertebrate data (abundances), where PC1 and PC2 explain 34.4% and 15.2% of the variability





Vol 3 Plate C.26 PCA plots of Thames invertebrate samples (excluding Oligochaeta, Gammaridae and Hydrobiidae) at Cadogan Pier (1989 – 1993). Correlation map (left) and distances map (right) for the invertebrate data (abundances), where PC1 and PC3 explain 34.4% and 11.6% of the variability





Redundancy Analysis (RDA)

C.1.185 The finding of RDA analysis undertaken on Cadogan Pier invertebrate abundance data, to illustrate correlations between the invertebrate community and the variations in water chemistry are presented in Vol 3 Plate C.27 below.

C.1.186 The RDA of the invertebrate dataset constrained by the environmental data shows that 59.4% of the variability existing on the invertebrate data set is explained by the environmental variables used. This means that 40.6% of the variability in the data is explained by other factors, such as sampling variation, habitat and other chemical measures not available.

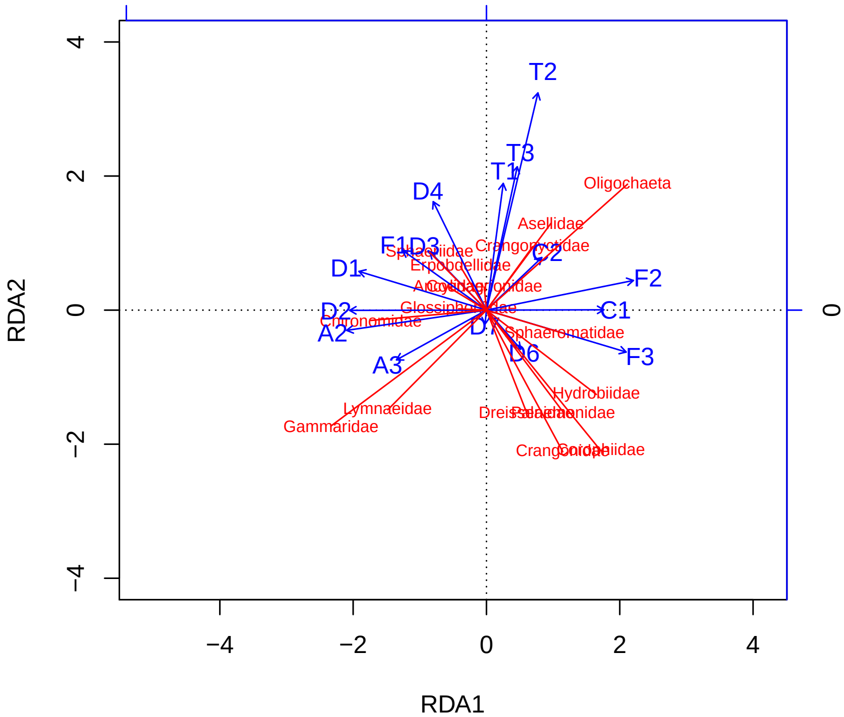
C.1.187 Different projections of axes RDA1 – RDA4 are presented in Vol 3 Plate C.27 below and illustrate the relationships between environmental variables and abundances of invertebrate taxa.

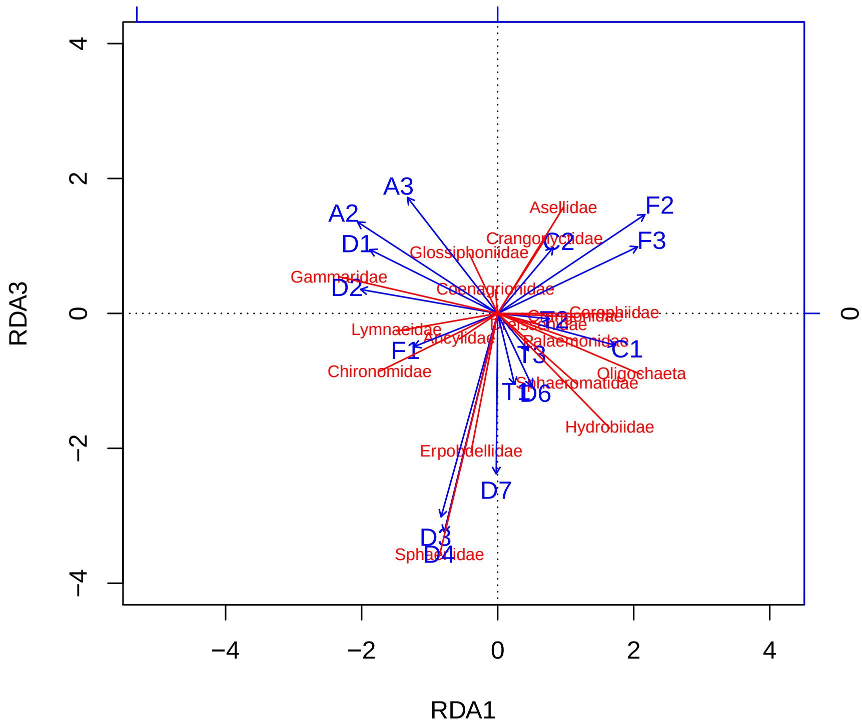
C.1.188 These charts indicate various positive and negative correlations between environmental variables (low DO events, mean DO 95%ile DO) and abundances of invertebrate taxa. Vol 3 Plate C.27 indicates that there are correlations between the abundances of the most variable taxa (Oligochaeta and Gammaridae) and various environmental variables included in the analysis. Abundances of Oligochaeta seem to be negatively correlated with mean DO (D1) 95%ile DO (D2), high (95%ile) ammonia concentrations (A2) and events above ammonia quality thresholds (A3 and A4). There is also a positive correlation between Oligochaeta abundances and low flows (F2 and F3) and low salinity (C1, 5%ile chloride concentrations).

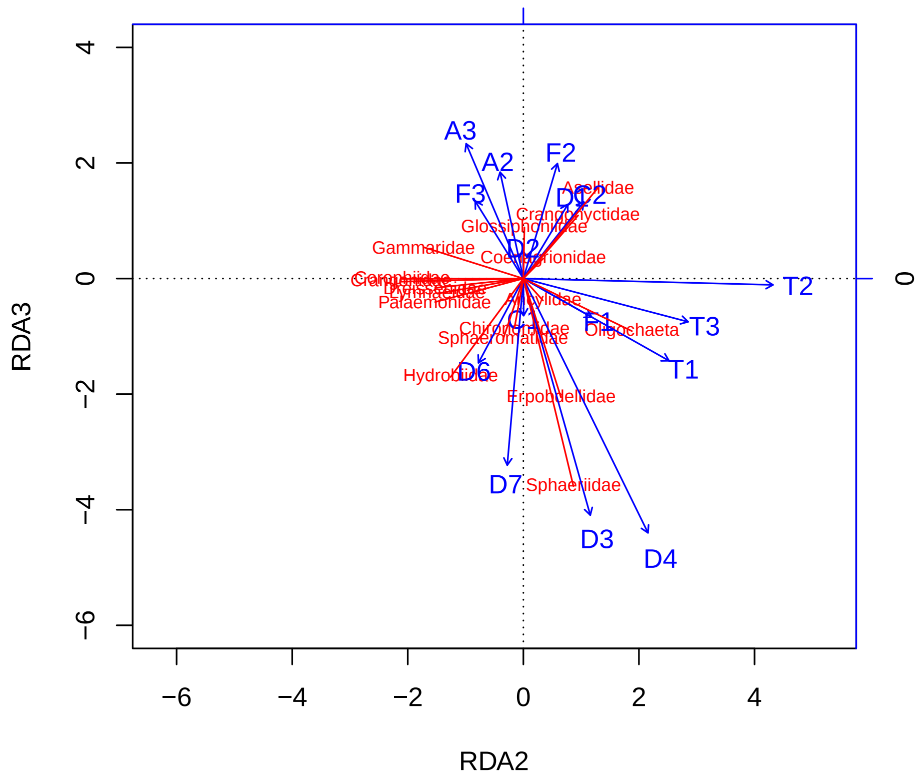
C.1.189 Abundances of Gammaridae, Chironomidae and Lymnaeidae seem to be positively correlated with mean DO (D1) 95%ile DO (D2), high ammonia (A2 and A3) and mean daily flow (F1). However, this group is relatively small, compared to the large group of taxa that are negatively correlated with low DO and low DO events at Kew.

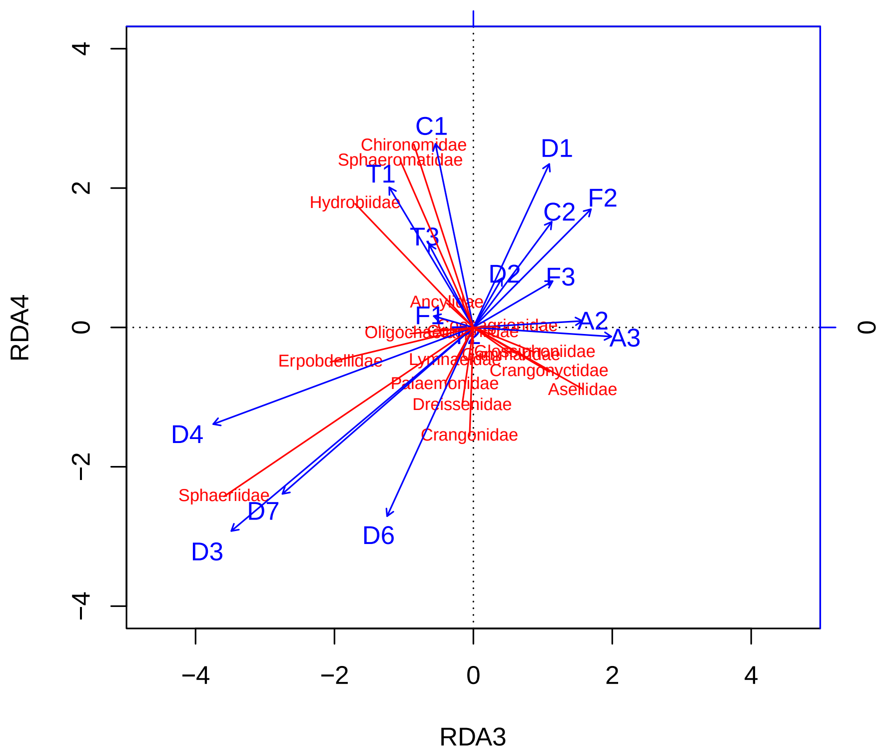
C.1.190 The projection of axes RDA1 and RDA2 suggest that another group of animals (including Hydrobiidae, Cororphidae, Crangoniidae) are negatively correlated with mean DO (D1) and positively correlated with low flow (F2 and F3). However, axes RDA3 and RDA4 show that the only groups positively correlated with low DO events < 1.5 mg/L (D3, D4 and D5) and < 3 mg/L (D6, D7, D8) are Sphaeridae and Erpobdellidae.

Vol 3 Plate C.27 RDA plots of Cadogan Pier (1989 – 1993) invertebrate samples where PC1, PC2, PC3 and PC4 explain 23.7%, 21.0%, 11.2% and 10.36% of the variability constrained by environmental parameters.






RDA2
RDA3
A3
A2
F2
F3
T2
T3
T1
D7
D3
D4
Gammaridae
Asellidae
Crangonyctidae
Oligochaeta
Erpobdellidae
Sphaeriidae
Hydrobiidae
Palaemonidae


RDA3
RDA4
C1
D1
C2
F2
T1
T3
F3
A2
A3
D4
D7
D3
D6
Chironomidae
Sphaeromatidae
Hydrobiidae
Ancylidae
Erpobdellidae
Palaemonidae
Dreissenidae
Crangonidae
Crangonyctidae
Asellidae
Sphaeriidae

Greenwich

C.1.191 Biological (invertebrate sampling) and water quality sampling data were available from the Greenwich sampling site from between 1989 and 2007. The biological data were collected using various sampling methods (gulley dredge, 0.01 m^2 core samples, quadrat samples).

Environmental Variables

C.1.192 PCA was undertaken on various chemical parameters, which were calculated from available AQMS and spot sampling chemical data at Greenwich.

C.1.193 As at other sites, the results indicate correlations between high flows at Teddington Weir and high DO concentrations. Parameters associated with low DO are positively correlated with low flow at Teddington Weir and high water temperatures. High ammonia concentrations were positively correlated with low flow and negatively correlated with high temperature. There is also a weak negative correlation between DO events above the given quality thresholds and high ammonia. Unlike upstream sites, salinity (chloride) concentrations could not be used, given the unreliability of the data set.

Invertebrate Abundances

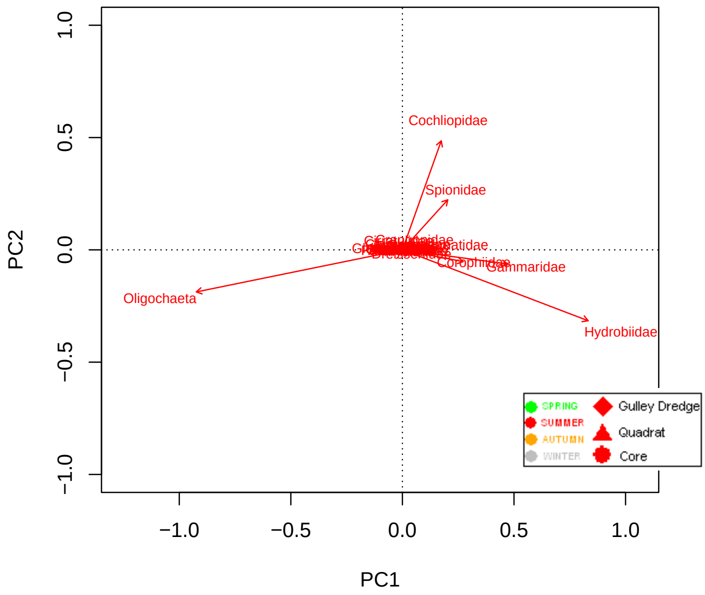
C.1.194 Invertebrate abundances from Greenwich (1989 – 2005 data) sampled using various methods were analysed using PCA. The PCA axes PC1 and PC2 (which express 58.4% and 13.0% of the total variability of the data set) are presented in Vol 3 Plate C.28 below.

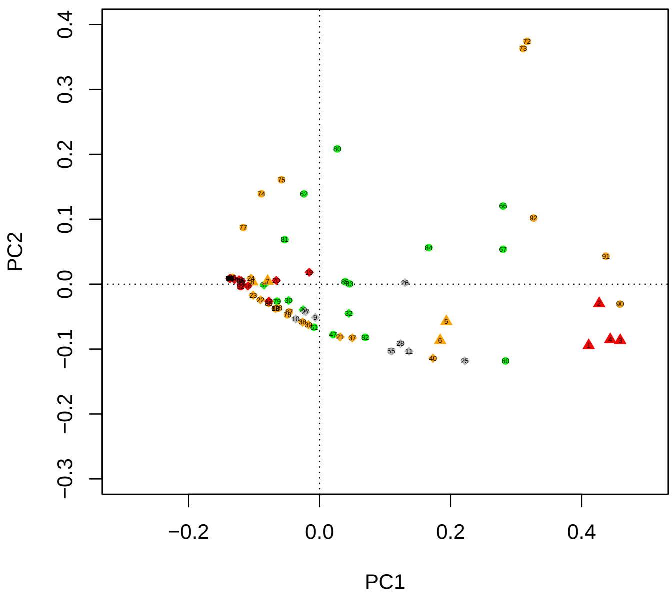
C.1.195 The taxonomic groups that contribute most to the differences in the invertebrate abundances at Greenwich are Oligochaeta, Cochliopidae, Spionidae, Gammaridae, Corophiidae and Hyrdrobiidae. The greater importance of Cochliopidae, Corophiidae and Spionidae compared with freshwater sites Kew and Cadogan Pier can be attributed to a number of factors: (a) the greater saline influence of the site (Cochliopidae and Spionidae are brackish taxa); (b) difference in habitat (further into the estuary there finer sediment are more comment); and (c) difference in sampling method.

C.1.196 On the whole, Cochliopidae and Spionidae were strongly correlated, as were Gammaridae and Hydrobiidae (although there did not appear to be a strong correlation between these two groups of taxa). Oligochaeta appeared to be negatively correlated to all of the above). The projection of other axes (PC3, PC4) demonstrates similar correlations.

C.1.197 The projection of samples on factorial maps indicates a number of ‘loose’ groups of samples. These maps of samples indicates that quadrat sampling tends to favour taxa such as Hydrobiidae (pulmonate snails) over Oligochaeta, which is typical, given the habitat favoured by these groups and the efficiency of sampling using this method. There did not, however, appear to be significant differences between the other sampling methods (gulley dredge and core sampling). The analysis also indicates that, with the exception of quadrat samples, Oligochaeta were most abundant in summer and autumn samples.

Vol 3 Plate C.28 PCA plots of Thames invertebrate samples at Greenwich (1989 – 2005). Correlation map (left) and distances map (right) for the invertebrate data (abundances), where PC1 and PC2 explain 58.4% and 13.0% of the variability





Redundancy Analysis (RDA)

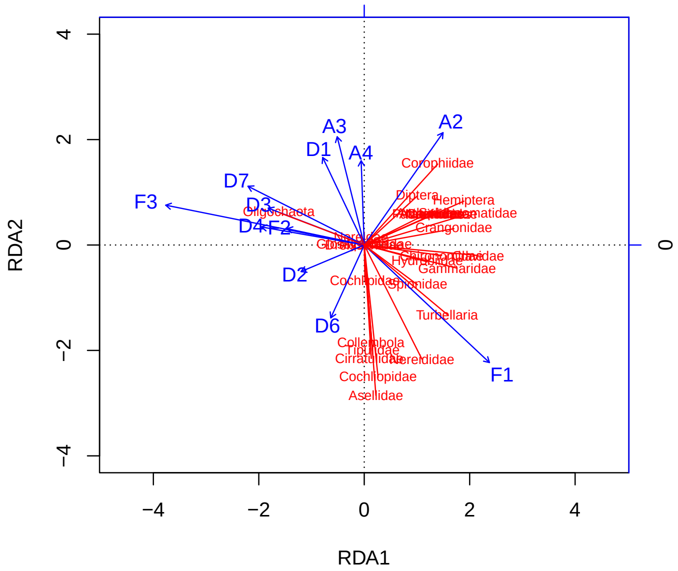
C.1.198 RDA of Greenwich data showed that 21.5% of the variability in invertebrate abundances was explained by the environmental variables used. As discussed elsewhere, although 21.5% may appear to be a low, explaining high proportions of ecological variability by given environmental variables should not be expected.

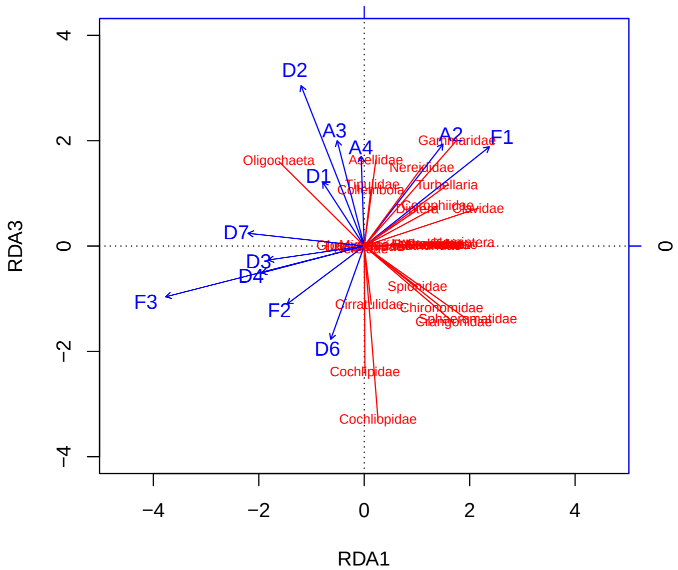
C.1.199 The results of the analysis are illustrated in Vol 3 Plate C.29 below for various projections of axes RDA 1 to RDA4.

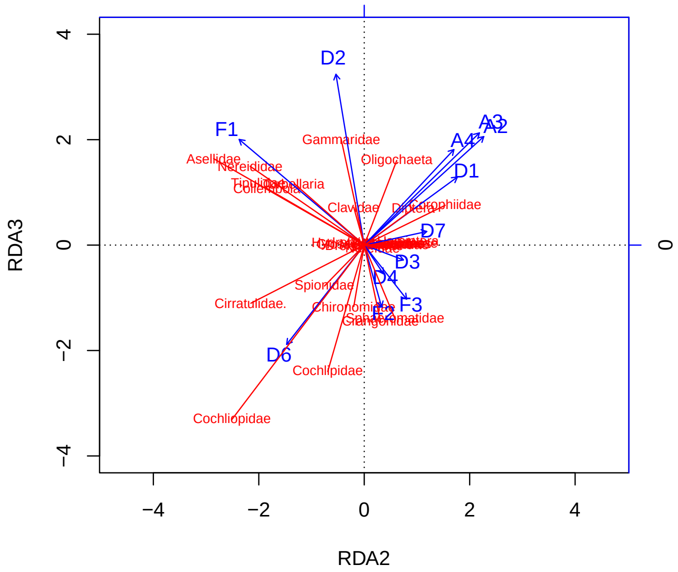
C.1.200 The projection of RDA1 and RDA2 (Vol 3 Plate C.29) indicates that flow at Teddington Weir is the most important factor determining invertebrate assemblages at Greenwich, notably the mean flow (F1) and the number of days < Q90 during the sixth month period. However other factors associated with dissolved oxygen also appear to be significant. Reliable chloride concentrations were not available for Greenwich throughout the period for which biological sampling data were available. However, as chemical data from other sites have indicated, freshwater flow parameters are a useful proxy for salinity levels.

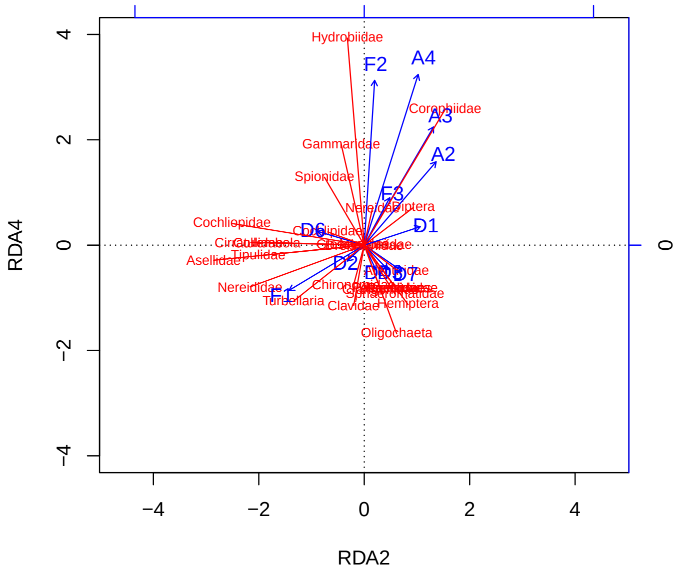
C.1.201 The projection of axes RDA1 and RDA2 identifies four ‘loose’ groups of taxa vectors and relationships to environmental factors. Firstly, a single taxon, Oligochaeta, is the only group that is positively correlated with F3 (number days flow < Q90). Oligochaeta is also positively correlated with environmental factors D7 (max duration of DO < 3 mg/L) and D3 (number of events DO < 1.5 mg/L). Curiously, Oligochaeta is also correlated with high mean and 5%ile DO concentrations (D1and D2) on axes RDA1 and RDA3, although examination of RD2 shows this correlation is not high.

Vol 3 Plate C.29 RDA plots of Greenwich (1989 – 2005) invertebrate samples where PC1, PC2, PC3 and PC4 explain 47.8%, 19.4%, 14.2% and 7.3% of the variability constrained by environmental parameters









C.1.202 There are two groups of animals correlated with RDA1, the first of which are positively correlated with high mean daily flow at Teddington (F1), which include Turbellaria (flatworms), Gammaridae, Hydrobiidae, Chironomidae and Clavidae (hydrozoa). This group appears to be negatively correlated with the low flow factor F3 (days <Q90) and low DO factors such as D7 (max duration of DO < 3mg/L) and D3 (number of events <1.5 mg/L). The second group that is highly correlated with the RDA1 axis comprises a large collection of taxa including Corophiidae, Crangonidae, Diptera, Sphaeromatidae (brackish water louse), Nuculidae (saltwater clams), Anthuridae (marine isopod), Caenidae and Palaemonidae. For these taxa, there is no correlation with F1, although the group is negatively correlated with F3 (number days flow <Q90) and

low DO factors such as D3 (number events <1.5 mg/L) and D4 (max duration events <1.5 mg/L), suggesting this group is also intolerant to low freshwater flows (salinity) and/or low DO. The projection of RDA1 and RDA2 suggests the group is also negatively correlated with 5%ile DO (D2), however, further inspection of RDA3 suggests that the correlation is weak. A confounding factor is that this ‘low DO sensitive’ group is positively correlated with 95%ile ammonia concentrations (A2), as is demonstrated on RDA axes 1, 2 and 3. This site shows no correlation between ammonia and temperature or DO, hence it is suspected that this potential relationship is spurious (it would be unusual to find animals that are favoured directly by high ammonia levels).

C.1.203 The final group comprises Cochliopidae, Cirratulidae and Nereididae and appears to be associated with D6 (number of DO events < 3 mg/L) and negatively correlated with high mean DO (D1) and high 95%ile ammonia concentration (A2). This ‘low DO tolerant’ group do not appear to be affected by freshwater flow at Teddington Weir. The RDA2 and RDA3 projection is most useful in interpreting how this group relates to environmental factors and shows that the relationship between Nereididae and factors D1, A2 and D6 is not as strong as other members of the group.

Beckton

C.1.204 Biological data available from the sampling site at Beckton from between 1989 and 2005 (collected using core, gulley dredge, quadrat and grab sampling method) were used in the analysis, along with chemistry data from Erith.

Environmental Factors

C.1.205 PCA was undertaken on various environmental parameters, which were calculated from available flow (at Teddington) data along with AQMS and spot sampling chemical data at Erith (the nearest sample site).

C.1.206 As at other sites, the results indicate correlations between high flow at Teddington Weir and high DO concentrations, which were generally in the spring and winter. Parameters associated with low DO are positively correlated with low flow at Teddington Weir and high water temperatures (more frequent in summer and autumn periods).

C.1.207 As for Cadogan Pier, temperature is negatively correlated with both high ammonia concentrations and high DO, suggesting that temperature is an influencing factor in the biological breakdown of ammonia and the organic load from Beckton STW. Unlike upstream sites, salinity (chloride) concentrations could not be used, given the unreliability of the data set.

Invertebrates

C.1.208 PCA charts of invertebrate abundances (132 samples) from Beckton (1989 – 2005 data) are presented in Vol 3 Plate C.30 and Vol 3 Plate C.31 below.

C.1.209 The projection of axes PC1 and PC2 (which describe respectively 34.6% and 17.8% of the total variability of the data set) indicate that at Beckton, the variability in abundance data are explained by three taxa: Oligochaeta, Spionidae and Gammaridae   However, inclusion of PC3 (10.7% of the variation) also indicates how Hydrobiidae, another statistically important invertebrates, relates to the above. Overall, it appears that Oligochaeta is negatively correlated with Spionidae, Gammaridae and Hydrobiidae, which are, given the near orthogonal angles between each other, have a correlation close to 0.

C.1.210 The position of the sample sites on the factorial maps of axes PC1 and PC2 shows how sample sites are split along the gradients into a number of loose groups:

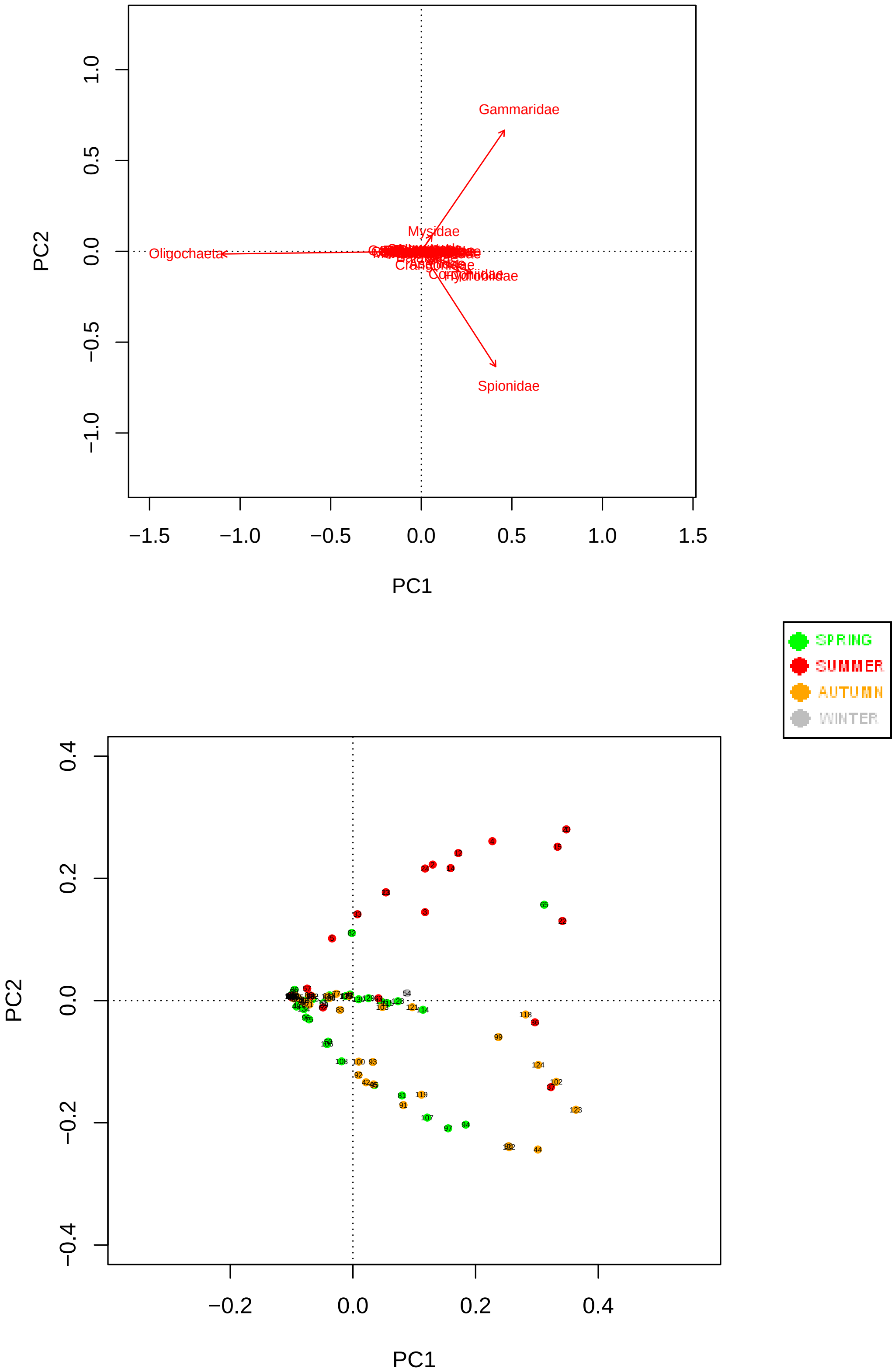
a. The upper and upper left area of the chart, with samples characterised by high abundances of Gammaridae (mostly summer samples from 1989 - 1994)

b. The left and central region of the chart, with samples characterised of high and moderate numbers of Oligochaeta, and not particularly high numbers of other taxa (mixed seasons, but generally later – 2005 and 2006 – samples)

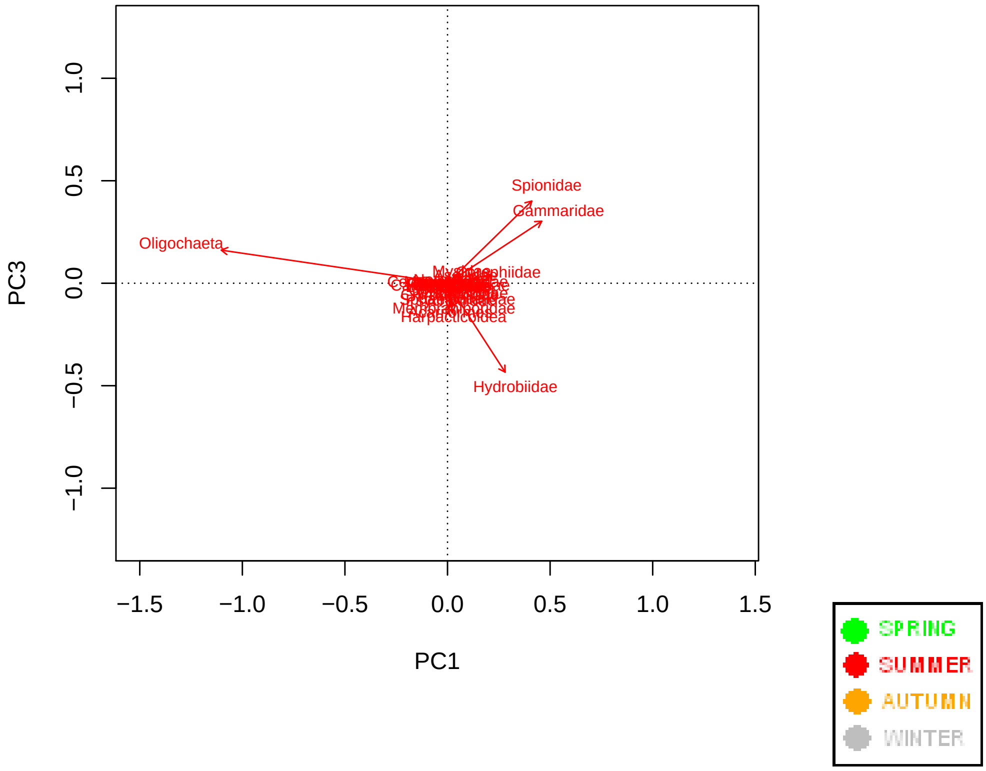
c. The central and lower right region of the chart, with two distinct groups, characterised by a decreasing gradient of Oligochaeta and high abundances of Spionidae (mostly autumn samples, no annual patterns)

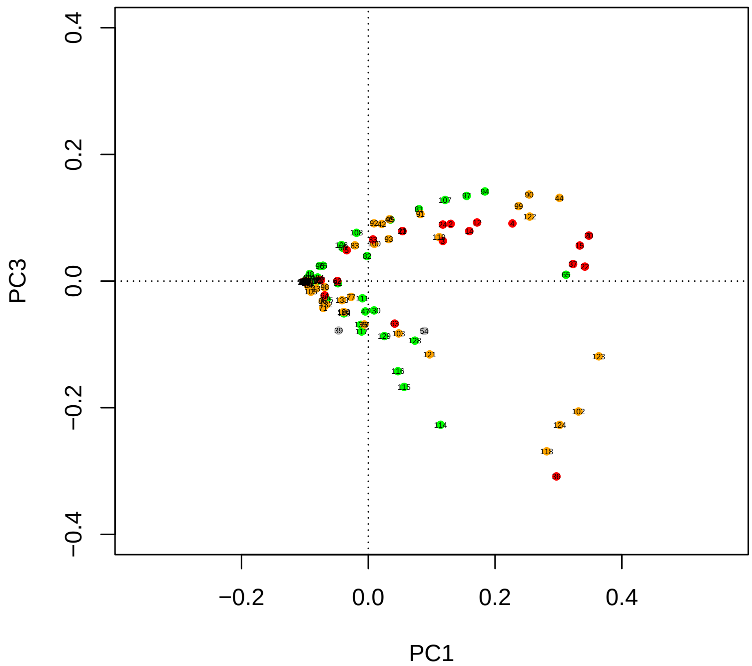
C.1.211 Additionally, examination of the chart that describes PC1 and PC3 indicates another group characterised by abundant Hydrobiidae, to the lower right of this chart (autumn samples).

Vol 3 Plate C.30 PCA plots of Thames invertebrate samples at Beckton. Correlation map (left) and distances map (right) for the invertebrate data (abundances), where PC1 and PC2 explain 34.6% and 17.8% of the variability



Vol 3 Plate C.31 PCA plots of Thames invertebrate samples at Beckton (1989 – 2011). Correlation map (left) and distances map (right) for the invertebrate data (abundances), where PC1 and PC2 explain 34.6% and 10.7% of the variability





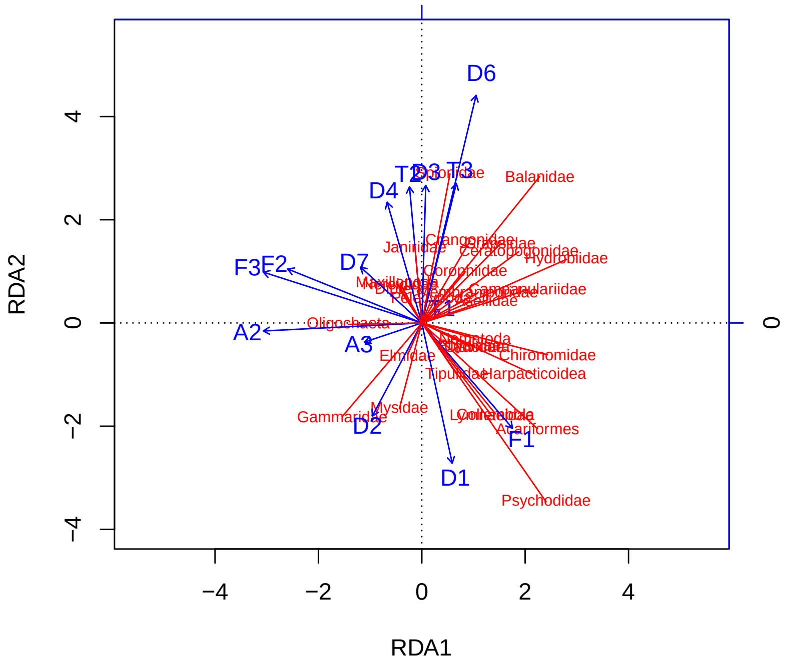
Redundancy Analysis (RDA)

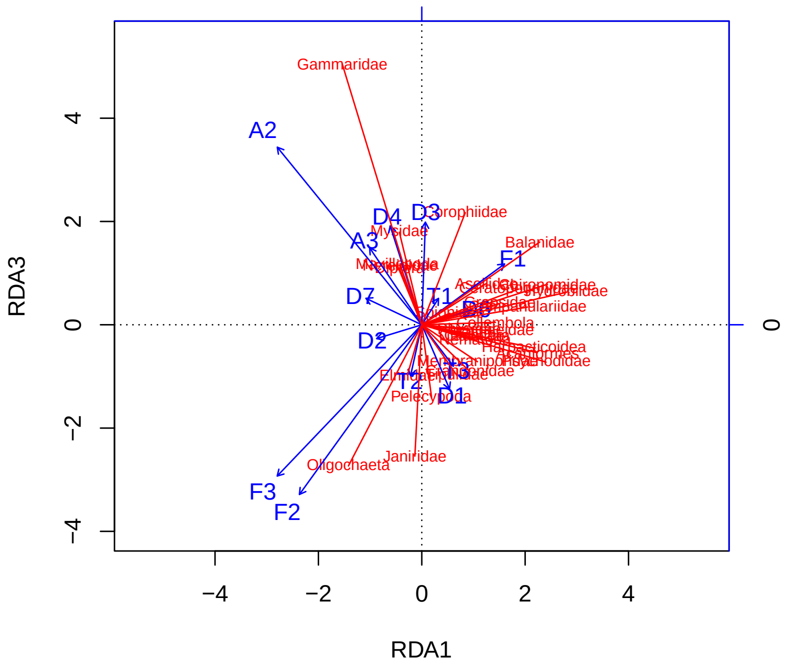
C.1.212 RDA of Beckton data showed that 15.8% of the variability in invertebrate abundances was explained by the environmental variables used. This is lower than the other sites examined suggesting that the environmental variables were less important and that a higher proportion of variability is explained by other environmental factors, such as habitat or other chemical factors associated with Beckton STW discharge. Sampling and sample processing variation may also have a significant influence.

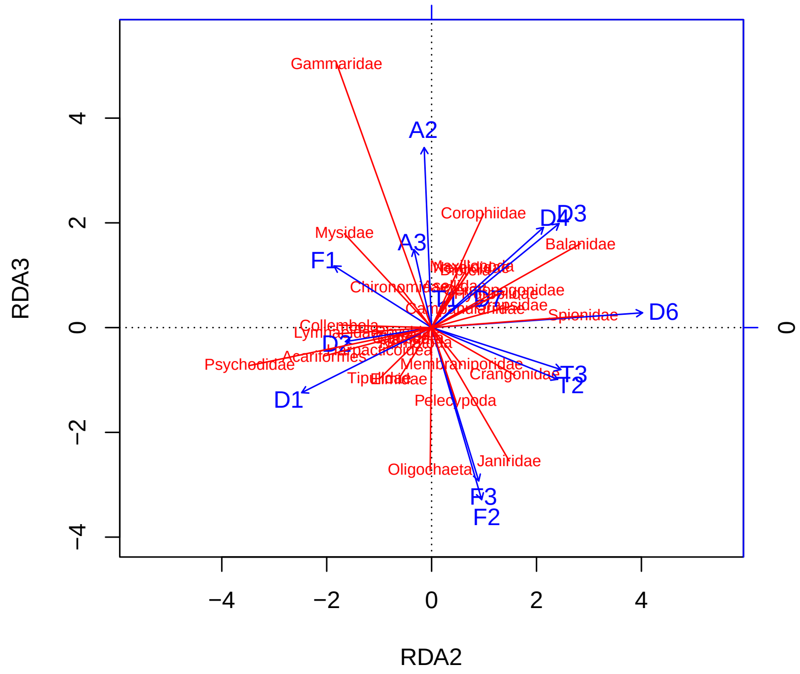
C.1.213 The results of the analysis are illustrated in Vol 3 Plate C.32 below, for axes RDA 1, RDA2, RDA3 and RDA4. These axes express relatively 26.5%, 20.8%, 13.9% and 10.2% of the constrained variation.

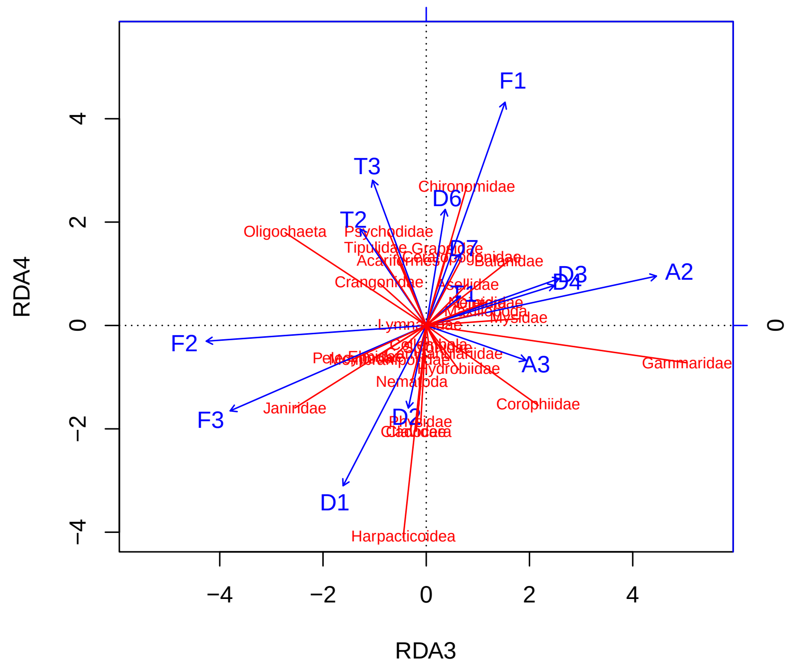
C.1.214 The projection of RDA1, RDA2, RDA3 and RDA4 (Vol 3 Plate C.32) indicates the importance of environmental factors, such as the mean flow (F1), mean and 5%ile DO (D1 and D2) the number of days flow < Q90 and < Q95 during the sixth month period (F2 and F3), . However other factors associated with dissolved oxygen, in D6 (number of events <3 mg/L) and A2 (95%ile ammonia concentration) also appear to be significant.

Vol 3 Plate C.32 RDA plots of Beckton (1989 – 1993) invertebrate samples where PC1, PC2, PC3 and PC4 explain 23.7%, 21.0%, 11.2% and 10.36% of the variability constrained by environmental parameters.









C.1.215 Some significant observations include:

a. Taxa such as Psychodidae, Chironomidae, Lymnaeidae, Harpacticoidea and Acariformes appear to be positively correlated with mean daily flow (F1) and strongly negatively correlated with the number of days < Q95 (F2) and < Q90 (F3), and this group may be positively associated with high flood events..

b. Mysidae appear to be correlated with high mean DO (D1) and 95%ile DO (D2) and negatively correlated with frequency and duration of low DO events.

c. Spioniidae are correlated with low DO events (D6 and D3) and negatively correlated with high DO (D1, D2).

d. A group of animals that include Corophiidae, Campulanaridae, Balanidae and Hydrobiidae are associated with low DO events (D3, D4, D6) but also negatively correlated with mean and 5%ile DO (D1, D2).

e. Gammaridae appear to be correlated with high flow (F1) and 95%ile ammonia concentration (A2).

f. Oligochaeta and Janiridae, on the other hand, appear to be positively correlated with low flows <Q95 and <90 (F2 and F3), although no clear correlation to other chemical variables has been demonstrated.

C.1.216 These charts indicate positive and negative correlations between environmental variables (low DO events, mean DO 95%ile DO) and abundances of invertebrate taxa.

Discussion of Key Findings

Chemistry

C.1.217 The PCA and RDA analyses demonstrate the temporal (year-on-year and seasonal) variations in environmental parameters and invertebrate communities at four key sites on the Thames. The dominant factor affecting the short term and probably long term status of the invertebrate communities appears related to DO concentrations, notably the number and duration of low DO events. A secondary factor was the upstream penetration of saline waters. Ammonia, which was expected to be a significant influencing factor, was found to be of relatively low importance, as it rarely reached toxic concentrations. The relationships observed between these and other physical or chemical variables are discussed below.

C.1.218 Throughout the Thames tideway, the influence freshwater flow at Teddington Weir and climatic/meteorological factors (e.g. temperature) and interaction between physico-chemical variables was clearly demonstrated. During low freshwater flows and high water temperatures, the most significant and frequent DO sags were experienced and mean DO generally remained low. Many of the low DO events are due to the discharge of untreated waste water from storm drains (CSOs) into the Thames, which exert an increased organic load and cause a drop in DO as bacteria decompose the polluting load. Other sources of pollution also contribute significantly to this load, notably Mogden STW and Beckton STW. The sag in DO usually occurs in summer only when flows are low, retention times are longer, and, due to higher temperatures, oxygen is less soluble and organic loads degrade more quickly. This exerts an oxygen demand, using up the oxygen available. CSO discharge to the Thames after relatively little rainfall (<3 mm rain in some areas), therefore there is little or no delay following precipitation to allow increased freshwater to reach the estuary.

C.1.219 The chemical data also demonstrate the correlation between salinity (chloride) and the various measures of DO, both of which are influenced by temperature and/or freshwater flow at Teddington. As high salinity and low DO concentrations are correlated (and thus generally occur during the same six month periods), it is difficult to discriminate between the effects of increased salinity and anoxia on the invertebrate community, which is considered in more detail, below.

C.1.220 The relationship between ammonia/ammonium concentrations is more complex and varies between the different sample sites. At Cadogan Pier and Greenwich sample sites, there is a strong negative correlation between ammonia concentrations (or events) and low DO concentrations (and events). This negative relationship may appear to be counter-intuitive, as both of these environmental factors are positively influenced by discharges from sources such as CSOs and STWs. However, the role of temperature on bacterial metabolism is likely to be important and needs to be considered to understand why this negative relationship can be observed. An increased organic load can only result in low DO and DO sags if the load is broken down by bacteria, which consumes and depletes oxygen in the water. As described above, higher water temperature accelerates bacterial metabolism of both organic compounds and ammonia. Therefore, provided that the organic and ammoniacal load of the water is relatively stable, a negative correlation between low DO and high ammonia would be expected with varying temperatures. This may also be related to the resuspension of fine sediments during high flows and when water temperature is low. It is also important to understand that nitrification is not inhibited provided that DO remains above 1 mg/L.

C.1.221 The PCA of environmental variables from Greenwich and Cadogan Pier (where the correlations between low DO and high ammonia concentrations were observed) clearly demonstrate that ammonia is negatively correlated with high temperature, while at Beckton and Kew (where the correlations between low DO and high ammonia concentrations were not observed) there appears to be little or no relationship between temperature and ammonia concentrations. This suggests that, while in Greenwich and Cadogan Pier samples temperature is the main factor determining the concentration of ammonia and DO, other factors (notably varying discharge rates or concentrations from nearby STW and CSOs) are more influential at Kew and Beckton.

Invertebrates

C.1.222 The PCA and RDA analyses demonstrate the temporal (year-on-year and seasonal) variations in invertebrate communities on sites on the Thames and the influence of environmental factors on their distribution. As described elsewhere, the most significant variations in invertebrate distributions were between the amphipod shrimp Gammaridae and Oligocheata, at all four sites considered. Other taxa (notably Hydrobiidae, Cochliopidae and Spionidae) also contributed significantly to other overall invertebrate variations at one or more of these sites.

C.1.223 The RDA analysis, combining the chemical and invertebrate data, demonstrates the importance of environmental variables in determining the invertebrate communities in the Thames. Indeed it appears that dominance of either Gammaridae (sensitive to hypoxia) or Oligochaeta (more tolerant to hypoxia) is influenced by the DO concentrations and DO sags in the Thames, although, as described below, other factors (habitat etc) are also highly important. Other invertebrate taxa have been identified as being affected by poor water quality (low DO) and/or saline intrusion, notably the insect group (mayflies), while other groups (essentially polychaete and oligochaete worms) were shown to be tolerant of these conditions. Given the contribution of CSO discharges (and interception by the proposed Thames Tideway Tunnel project) to these DO sags, these findings can be considered as significant in terms of understanding how these storm water discharges affect the Thames.

C.1.224 For all sites, a large proportion of the variation was not explained by the model of environmental variables used, but by ‘other factors’. Although it is typical for residual variation to be high (given the type of ecological data analysed), it is clear that other factors that were not included in the model are highly influential, notably habitat, sampling and sorting variation and other chemical measures for which data were not readily available.

C.1.225 It is important to point out that the records show that many invertebrate taxa identified as being influenced by environmental variables (such as low DO) are represented in the data set by a few individuals in a low number of samples and therefore these results taken individually may not be considered as significant. However, the fact that these are ‘grouped’ together is notably and thus is a reason why multivariate analysis is a useful tool for this type of analysis.

C.1.226 For several analyses, certain key taxa (notably Gammaridae) were shown to be positively correlated with high ammonia concentrations. This is likely to be due to the fact that, at many sites, ammonia is negatively correlated with high DO, as discussed above, rather than any direct positive influence of ammonia on any invertebrates. Ammonia levels were generally low (at concentrations that wouldn’t affect invertebrates). Ammonia in its unionised form is toxic to fish and invertebrates at low concentrations. However, most of the ammonia in the Thames is likely to have been ionised in the form of ammonium (given pH levels and existing spot sample records for unionised ammonia analysis).

C.1.227 The variations in the structure of invertebrate communities and the determining environmental factors briefly described above are considered in more detail, in the following sections. Sites within the freshwater zone (Kew and Cadogan Pier) first, followed by those in the Brackish zone (Greenwich and Beckton).

C.1.228 In the upper freshwater zone (Kew and Cadogan Pier sample sites), the most significant variations were the abundances of Gammaridae and Oligochaeta. These two taxa were negatively correlated with each other and demonstrated a pattern of continuous variation between two extremes: Gammaridae dominated samples and Oligochaeta dominated samples, as described elsewhere in this report. Whether Oligochaeta or

Gammaridae is dominant is largely due to the types of habitat sampled (Oligochaeta prefer poorly oxygenated silt while Gammaridae prefer larger stones) and both types of habitat are likely to be present in different areas of the Kew sample site. However, the PCA analysis of Kew and Cadogan Pier demonstrated that there are also seasonal patterns, with Oligochaeta more frequently dominant compared with Gammaridae in summer and autumn samples. The seasonal variation between these two groups has previously been described in studies of the Thames invertebrate communities from the early 1990s (Attril, 1998), which suggests *Gammarus zaddachi* (the dominant species of Gammaridae in the Thames between Kew and Gravesend) is effectively a 'winter' species. No explanation of these trends was provided in this previous study by Attril. However, as discussed below, the RDA analyses of environmental and biological variations at Kew and Cadogan Pier seem to provide some correlations, which may help to explain this and other temporal variations in the upper estuary.

C.1.229 The environmental data appear to explain, at least in part, the variations in biological assemblages sampled on the Thames at Kew and demonstrate how the invertebrate fauna at Kew is affected by DO concentrations and DO sags. The apparent correlations between mean DO concentrations and the frequency/duration of low DO events and the abundance of Oligochaeta and Gammaridae are also notable. The negative correlation between low DO events and reduced Gammaridae is consistent with observations of Gammaridae coming to the surface (for oxygen) during periods of hypoxia (Pers. Comm., Lars Akesson, EA). However, it is likely that other factors (notably local variations in habitat) also play a significant role.

C.1.230 For some observations, it is difficult to determine which environmental parameters are impacting the invertebrate communities the greatest and it is likely that there are in combination effects. As demonstrated by the RDA and preceding PCA, low DO concentrations tend to occur at the same time as low summers flows and thus tend to be associated with slight increases salinity at Kew. Many freshwater invertebrates, notably insects, are intolerant to even the smallest increase in salinity, even when it occurs for a very short duration, and it is therefore difficult to discriminate between variations associated with water quality and those associated with salinity. Therefore, for many of the invertebrates that appeared to be adversely impacted by low DO concentrations at Kew (notably Caenidae, Ephemerillidae, Planariidae, Neritidae, Physidae, Dreissenidae, Glossiphoniidae, Erpobdellidae, Leptoceridae, Psychodidae, Chironomidae) no clear distinction between the effects of increased salinity and low DO could demonstrated by the RDA, as they generally occurred during the same 6 month periods (warm, dry summers). Chironomidae (non-biting midge) includes several saline tolerant species (e.g. *Chironomus* and *Thalassosmittia* spp., Eppy, 1989), some of which are pollution sensitive. However, no data on the species present were available, so it is difficult to conclude whether this change in the abundance of this taxon is correlated with salinity or DO.

C.1.231 However, many of the apparent DO sensitive taxa are tolerant to the levels of saline increases recorded at Kew. The species of the amphipod Gammaridae present in samples from Kew was almost exclusively *Gammarus zaddachi*, a brackish species present as far down in the tideway as Gravesend (Attril, 1998). Therefore the drop in abundances correlated with high flows and DO concentrations/events observed is more likely to be due to changes in DO than any change in salinity. Indeed, inspection of axes RDA1, 2, 3 and 4 indicate that there is little, if any, correlation with chloride concentrations and Gammaridae, although seasonal variations may have an influence. The mayfly family Caenidae is recorded as being almost exclusively *Caenis luctuosa*, a euryhaline (tolerant to varying saline levels) species (Péran et al, 1999). Its presence is therefore likely to be indicative better water quality (high DO concentration) years. Likewise, some other groups that appear to be impacted by low DO during warm summers are similarly tolerant of the highest saline concentrations recorded at Kew, including *Dreissena polymorpha* (the only species of Dreissenidae), and many species of Physidae (Verbrugge et al., 2007; Costil et al., 2001; Dreier and Tranquilli, 1981).

C.1.232 Similar patterns were observed in Cadogan Pier samples. The apparent correlations between mean DO concentrations and the frequency/duration of low DO events and the abundance of Oligochaeta and Gammaridae are also notable. It is likely that other factors (notably local variations in habitat) play also a significant role.

C.1.233 However, although there are clear correlations between low DO events and key taxa, the group of invertebrates that are negatively correlated with low DO (and/or salinity) is much smaller, and comprise mainly Gammaridae, Chironomidae and Lymnaiedae. The reasons for this are not clear. However, it is likely that the following factors are determinant: (a) downstream position of the sample site, subject to greater variations in salinity and therefore lower invertebrate diversity; (b) the reduced period in which samples taken (three years, compared with sixteen years at Kew); (c) the distance from upstream sources of migration; and (d) possible poorer habitat. Thus, the baseline is coarser and less vulnerable to the impacts of low DO.

C.1.234 Another significant difference compared with Kew is that Erpobdellidae appear to be associated with poor water quality. However, and inspection of the data reveals that only a very limited number of Erpobdellidae were recorded at Cadogan Pier (*Erpobdella testacea*), while at Kew several species were recorded in high abundances (including *Erpobdella octoculata*, *E. testacea*, *Trocheta bykowskii*).

C.1.235 Many of our results that identify certain animal groups as being negatively or positively associated with low DO or DO events below given thresholds are consistent with published data on pollution sensitivity of invertebrates. The mayfly Caenidae has a relatively high BMWP (pollution sensitivity) scores, although some studies show that it is less sensitive to increased organic loads than other mayfly taxa (Walley et al, 2001). Likewise, Gammaridae and Neritidae are generally are more sensitive to increased organic loads (Walley and Hawkes, 1996, 1997, Mouthon 1997) than many Oligochaeta taxa, for example *Tubifex tubifex*, a common and highly pollution tolerant worm species in the Thames. The pea mussels Sphaeridae, which were identified as being correlated with low DO, include a wide range of species with varying tolerances to low DO. However, the principal species recorded (for which data were available) included *Pisidium casertanum*, *Pisidium nitidum* and *Pisidium personatum*, which have been demonstrated to have high tolerances to biodegradable pollution (Mouthon, 1996). Likewise, Chironomidae have varying tolerances to both low DO and high salinity, but no species level data were provided for the Thames data set.

C.1.236 Seasonal patterns associated with the ecological and biological traits of the different invertebrates are likely to have been influenced on their temporal and spatial variation, notably for groups such as insects. However, records show that many groups appear to be affected by environmental parameters independently of seasonal patterns. For example, Caenidae were collected consistently in spring samples between 1997 and 2002, but was absent from subsequent samples collected at the same time of year (and sample method) following ‘poor’ water quality (low DO) periods (such as 2003).

C.1.237 The variations in invertebrate assemblages in the brackish zone (Greenwich and Beckton STW sample sites) were dominated by a limited number of taxa, as in the freshwater zone. At Greenwich, the PCA analyses indicated that the greatest variations were between Hydrobiidae, Gammaridae, Cochliopidae, Spionidae and Oligocheata, with the latter (oligochaete worms) dominating summer samples.

C.1.238 Although similar patterns were observed at Beckton, variations in abundances of Gammaridae were more significant than at Greenwich, while Cochliopidae contributed less this variation. This is likely to be explained by differences in habitat, water quality and salinity at the site. Beckton STW discharge is likely to be an important factor, which discharges a constant and significant organic load and freshwater flow into a more saline area of the Thames. The water is therefore locally less saline and frequently deoxygenated at the sample site, compared with Greenwich and other nearby sites, which may explain the above differences.

C.1.239 The associations between environmental factors and invertebrate taxa indicate how water chemistry influences the invertebrate community at Greenwich, as illustrated by the RDA. Again, it is difficult to discriminate between the influence of poor water quality (such as DO sags) and the effects of salinity, as they both tend to occur at the same time (during hot and dry periods of low freshwater flows). However, a number of the taxa apparently impacted by low DO are known to be highly tolerant to variations in salinity, notably the species of Clavidae, Corophiidae, Sphaeromatidae, Hydrobiidae and Anthuridae and the Gammaridae (*Gammarus zaddachi* or *Gammarus salinis* in some years) present. Other groups are more likely to be more sensitive to changes in salinity, notably Chironomidae, while Caenidae (*Caenis luctosa*) are near to the limit of their natural tolerance and therefore more sensitive to other stresses, such as reduced DO than they normally would be. Other taxa freshwater taxa that appear to be associated with high flows (Asellidae, Diptera, Turbellaria, Hemiptera) may have been washed down from nearby watercourses (e.g. Deptford Creek) during high flows.

C.1.240 As at other sites, a number of invertebrates were positively correlated with low DO, notably Cochliopidae (marine/brackish snails), Nereidae, Cirratulidae, Spionidae (polychaete worms) and Oligochaeta worms. This is fairly consistent with scientific research, which suggest that these taxa are tolerant to organically enriched and low DO environments. For example *Hediste diversicolor* (the species of Nereidae present) is a euryhaline species that inhabits littoral muds and sands that have lower oxygen levels than other sediments. *Hediste diversicolor* is resistant to moderate hypoxia (Diaz and Rosenberg, 1995) and smothering by silt (Jones et al., 2000). Likewise, although there are inconsistencies in the data set and different species of Cirratulidae and Spionidae, both of these groups have been shown as positive indicators of a stressed community due to pollution in marine environments (Bailey-Brock, 2002; Bryan, 1984; Dean, 2008).

C.1.241 There are, however, some differences between how the Greenwich community has reacted to low DO. For example Hydrobiidae were shown as being sensitive to low DO events, although at upstream sites the same species (*Potamopyrgus antipodarum* dominated the fauna at all sites) was tolerant. There are a number of possible biological explanations, such as varying DO tolerance in different levels of salinity (the species is tolerant to a broad range of salinity concentrations) or the presence of hypoxia tolerant ‘strains’. Another more simple reason is that in the lower tideway, DO drops more frequently, for longer periods and at different periods in the year compared with upstream, which may exert greater or differing pressures on this species.

C.1.242 The RDA analysis of the Beckton sample site showed that the environmental variables explained a much lower proportion (15.8%) of the invertebrate variations observed compared with all other sites. Although clear relationships with freshwater flow at Teddington have been demonstrated, there are also a number of anomalies (compared with other sites) and DO concentrations and/or events do not clearly and consistently explain the invertebrate assemblages recorded. For example, a number of animals appear to be negatively correlated with both low DO events (frequency/duration of events less than < 1.5 mg/L and/or < 3 mg/L) and high DO concentrations (mean DO). It is likely that elements associated with Beckton STW discharge is highly important and ‘confusing’ the analysis. This has not been included in this investigation as data were not readily available and this assessment was outside the scope of this investigation. Moreover, water quality data were taken from two different sites near to Beckton, which may have somewhat localised differences in DO and other variables.

C.1.243 It is also important to point out that invertebrate community at Beckton is the most impoverished of all sample sites, in terms of invertebrate diversity. In a study of this site on the Thames, Attrill (1998) found that this site had the lowest numbers of species, with low numbers of a single species or no animals at all frequently recorded, despite having similar sediment characteristics to other nearby sites (such as Woolwich), which had higher abundances and invertebrate diversity. Because of this, results from this site need to be considered with prudence.

Species of conservation importance

C.1.244 The only species of conservation importance identified was the amphipod *Apocorophium lacustre* (sometimes referred to as a mud shrimp). It is classed as a Red Data Book 3 (“rare”) species. However, EA data has shown that it is common in the tidal Thames and its distribution appears to have increased since it was classified. It is typically a brackish species that tolerates near freshwaters (Lincoln, 1989).

C.1.245 No other species classified as being rare or threatened were identified.

Invasive species

C.1.246 Invasive species recorded during the October 2010 survey included:

a. The asiatic clam (*Corbicula fluminea*) which was present at Victoria Embankment, Albert Embankment, Tideway Walk and Cremorne Wharf Depot (it is probably present throughout the Thames Tideway);

b. The chinese mitten crab (*Eriocheir sinensis*), which was present at all of the sites except the following: Kings Stairs Gardens, Western Pump Station, Chelsea Embankment and Dormay Street; and

c. The zebra mussel (*Dreissena polymorpha*) which was present at Cremorne Wharf Depot, Putney Bridge and Barn Elms (empty shells were also found at a number of other sites.

C.1.247 The zebra mussel (*D. polymorpha*) can establish in densities that crowd out native invertebrates, and also colonises the shells of native species, thereby reducing the ability of the host to feed and burrow. Asian clams (*C. fluminea*) can also reach high densities, consuming significant amounts of phytoplankton. The increased water clarity caused by their filtration can lead to increases in light penetration, enhanced macrophyte growth, and alteration of fish stocks. Further, the asian clam may also alter the benthic substrate (Elliot et al, 2008).

C.1.248 Chinese mitten crabs (*E. sinensis*) cause bank destabilisation and erosion, and also compete for food resources with other species. The former issue is less of a concern within the study area as much of the river bank comprises hard defences, but competition with other species could occur.

Environment Agency invertebrate background data

C.1.249 Available aquatic invertebrate data for sites within the tidal Thames from 1989 to present were obtained from the EA.

C.1.250 Data has been obtained from the EA for ten sites (see Vol 3 Table C.17 and Vol 3 Table C.18).

Vol 3 Table C.17 Summary of invertebrate sample data sources

Site name	Sample years	Sample methods
Kew TQ 194 777	1989 - 2008	Kick sampling, 0.1 m core, day grab
Barnes TQ 215 766	2005 – 2010	Kick sampling
Hammersmith Bridge TQ 230 780	1989 – 1993	Quadrat sampling, gulley dredge, grab
Battersea TQ 267 768	2005 – 2010	Kick sampling
Cadogan Pier TQ 274 776	1989 – 1993	Kick sampling, gulley dredge
South Bank Centre TQ 308 803	1989 – 1993, 1995 – 2008	Quadrat sampling, gulley dredge, 0.1 m core, grab
London Bridge TQ 327 805	1989 – 1993,	Kick sampling
Greenwich TQ 383 780	1989 – 1993, 2005 – 2007	Quadrat sampling, gulley dredge, 0.1 m core, grab
Woolwich TQ 427 793	1989 – 2008	Quadrat sampling, gulley dredge, 0.1 m core, grab
Beckton TQ 456 815	1989 – 1993, 1995 – 2004, 2008 - 2009	m core sampling

Vol 3 Table C.18 Environment Agency monitoring sites

Environment Agency site	Data collection method and number of samples						TTT site	Distance from Environment Agency site
	2005	2006	2007	2008	2009	2010		
Barnes	11 kicks	9 kicks	3 kicks	4 kicks	5 kicks	6 kicks	Acton Storm Tanks Hammersmith Bridge	1.2 km downstream 2.4 km downstream
Battersea	14 kicks	5 kicks	2 kicks	3 kicks	5 kicks	6 kicks	Cremorne Wharf Depot Chelsea Embankment Putney Bridge Barn Elms Dormay Street King George's Park Hurlingham Wharf Falconbrook Pumping Station Tideway Walk Heathwall Pumping Station	300 m downstream 2.8 km downstream 2.9 km upstream 3.8 km upstream 1.8 km upstream 1.8 km upstream 1.1 km upstream 461 m upstream 3.8 km downstream 3.8 km downstream
South Bank Centre	10, 0.01 cores	6, 0.1 grabs	31, 0.1 grabs	-	-	-	Albert Embankment Victoria Embankment Blackfriars Bridge Chambers Wharf	1.9 km upstream very close 900 m downstream 4.2 km downstream
Greenwich	-	12, 0.01 cores	14, 0.1 cores	-	-	-	King Edward Memorial Park Foreshore Earl Pumping Station Deptford Church Street Greenwich Pumping Station Abbey Mills Pumping Station	4 km upstream 2 km upstream 600 m upstream 100 m upstream 3 km downstream
Beckton							Beckton STW	Adjacent

Note: within the vicinity of construction and improvement survey sites

Barnes

C.1.251 The EA site at Barnes lies downstream of Acton Storm Tanks and Hammersmith Bridge survey sites. The site has been regularly sampled since 2005, using the standard kick method with eleven samples taken in 2005, nine in 2006, three in 2007, four in 2008, five in 2009 and six in 2010.

C.1.252 A total of 23 species were recorded at Barnes in the period between 2005 and 2010. During the period of recording, the Oligochaete worms were the most common group at this site, with other abundant species being *Radix balthica, Gammarus zaddachi*, *Theodoxus fluviatilis* and *Potamopyrgus antipodarum*.

Battersea

C.1.253 The EA invertebrate sampling site at Battersea was the nearest monitoring station to the following sites for which recent (2005-present) data was available: Cremorne Wharf Depot; Chelsea Embankment; Putney Bridge; Barn Elms; Dormay Street; King George’s Park; Hurlingham Wharf; Falconbrook Pumping Station; Tideway Walk and Heathwall Pumping Station.

C.1.254 The monitoring site at Battersea has been regularly sampled since 2005. The samples have been taken using the standard kick method with fourteen samples taken in 2005, five in 2006, two in 2007, three in 2008, five in 2009 and six in 2010. Samples are taken in shallow water from the foreshore.

C.1.255 A total of 46 taxa were recorded at the Battersea site over the six year period in which samples were collected. The taxa Oligochaeta (worms), which is often used as an indicator of organic pollution, was relatively abundant, together with other pollution tolerant species such as the snail *Potamopyrgus antipodarum*. However, *Gammarus zaddachi*, a moderately pollution sensitive species was also highly abundant, and *Theodoxus fluviatilis*, a relatively pollution sensitive river neritid, was also present in most years.

South Bank Centre

C.1.256 South Bank Centre is the EA sampling site which is nearest to Albert Embankment, Victoria Embankment, Blackfriars Bridge and Chambers Wharf survey sites.

C.1.257 The South Bank Centre site was sampled ten times in 2005 using a 0.1 m^2 core sampler, six times in 2006 using a 0.01m^2 grab sampler and 31 times in 2007 using a grab sampler. There are no records for invertebrates at South Bank Centre since 2007.

C.1.258 A total of thirty-eight taxa were recorded at South Bank Centre over the three year period in which samples were collected. Oligochaeta (worms), often used as an indicator of organic pollution, were relatively abundant throughout this sampling period, together with other pollution tolerant species such as the snail *Potamopyrgus antipodarum*. However, *Gammarus zaddachi* (shrimp) was also highly abundant and the river neritid *Theodoxus fluviatilis* was present most years (both of these are considered to be moderately pollution sensitive).

Greenwich

C.1.259 Greenwich is the EA sampling site which is nearest to King Edward Memorial Park Foreshore, Earl Pumping Station, Deptford Church Street, Greenwich Pumping Station and Abbey Mills Pumping Station survey sites.

C.1.260 The Greenwich site was sampled twelve times in 2006 using the 0.01m² grab sampler and fourteen times in 2007 using a 0.1m² core sampler. There are no records for invertebrates at Greenwich since 2007.

C.1.261 The most abundant taxon that were recorded at Greenwich between 2006 and 2007 include Oligochaeta worms (notably *Nais elinguis*), Polychaeta worms (mostly *Boccardiella ligerica*), gasteropod snails (*Potamopyrgus antipodarum* and Cochliopidae) and *Gammarus zaddachi*.

Species of conservation importance

C.1.262 *Apocorophium lacustre*, the rare species of mud shrimp sampled at various sites during the 2010 Thames Tideway Tunnel project targeted surveys, has previously been recorded by the EA at all of the sampling sites considered. This supports our findings that it is widely distributed throughout the tidal Thames.

Invasive species

C.1.263 In addition to the invasive species recorded during the October 2010 surveys, the EA has sampled the amphipod G. tigrinus, of North American origin, at a number of sites. It has been found at the Greenwich, South Bank Centre and Battersea sites.

C.1.264 It is believed that this species of amphipod arrived in English waters via ballast water from ships. It lives in fresh and brackish waters and can expand rapidly, outcompeting local amphipods. However, based on available data, it appears to be much less abundant than the native Gammarus zaddachi within the Tideway.

Algae

C.1.265 Algal surveys of the river walls at foreshore sites along the Thames Tideway were undertaken during 2012, following methodology outlined in Vol 2. Vol 3 Table C.19 illustrates the substrate and aspect of the river walls.

Vol 3 Table C.19 Conditions at algal survey sites

Location	Salinity	Habitat	Aspect	Insolation	Wall height	Beach height
Wapping	4 o/oo	Vertical brick wall	South facing	Insolated	5 m (fro top ledge)	Not recorded
Bermondsey	4 o/oo	Vertical brick wall	North facing	Partly shaded	4.1 m	4 m + C.D.

Location	Salinity	Habitat	Aspect	Insolation	Wall height	Beach height
Blackfriars	4 o/oo	Vertical granite wall	South facing	Insolated	5.2 m (from top plinth)	0.2 m + C.D.
Westminster	4 o/oo	Vertical granite wall	South facing	Insolated	Not measured	0.4 m + C.D.
Vauxhall	3 o/oo	Vertical brick wall	North facing	Partly shaded	3 m	3 m + C.D.
Battersea	3 o/oo	Vertical brick wall	North facing	Partly shaded	Not measured	3 m + C.D.
Chelsea	3 o/oo	Vertical brick wall	South facing	Insolated	5 m	2. 9 m + C.D.
Putney	2 o/oo	Vertical brick wall	North facing	Partly shaded	3.5 m	2 m +C.D.

General observations

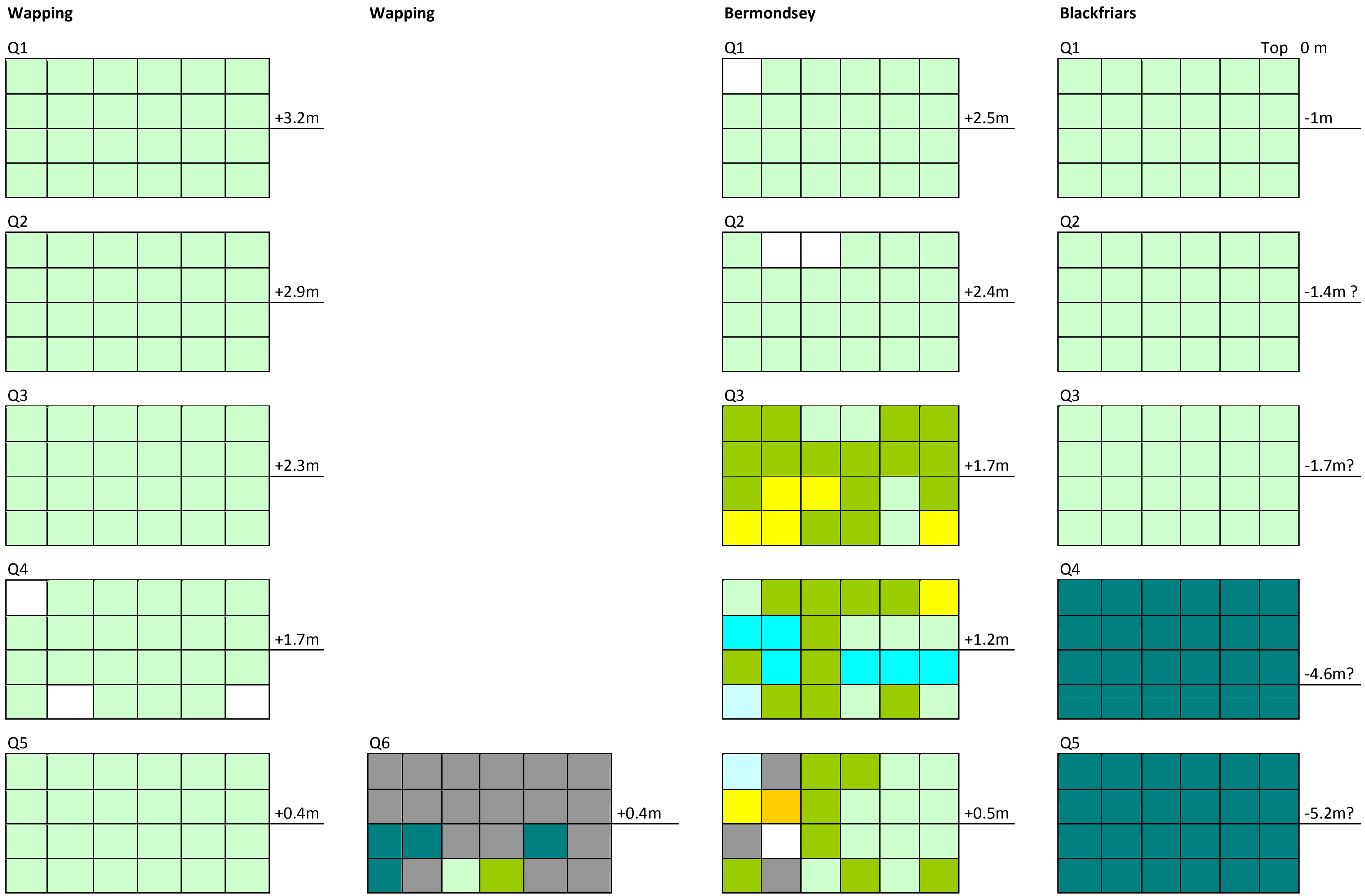
C.1.266 Riparian algal vegetation was recorded at all sites investigated. The algal cover extended vertically from high tide level to lower levels, in many cases the foot of the wall. The algal vegetation was mostly Chlorophyta (green algae) that showed as a distinct green band. The predominant species in the river from Wapping to Chelsea were *Blidingia marginata* and *B. minima*, thus characterising a distinct community. Altogether 13 species of Chlorophyta, Xanthophyceae and Rhodophyta were identified. In addition to macroalgae, micro algae - diatoms were commonly present either as epiphytes, or silt-binding on the walls, sometimes as a zone at lower levels. One species, the non-native *Hydrosera triquetra*, grew among green algae but at Westminster formed a distinct zone at low levels on the wall and steps. Cyanobacteria (formerly blue-green algae) were also commonly occurring among macroalgae or silt-binding on river walls.

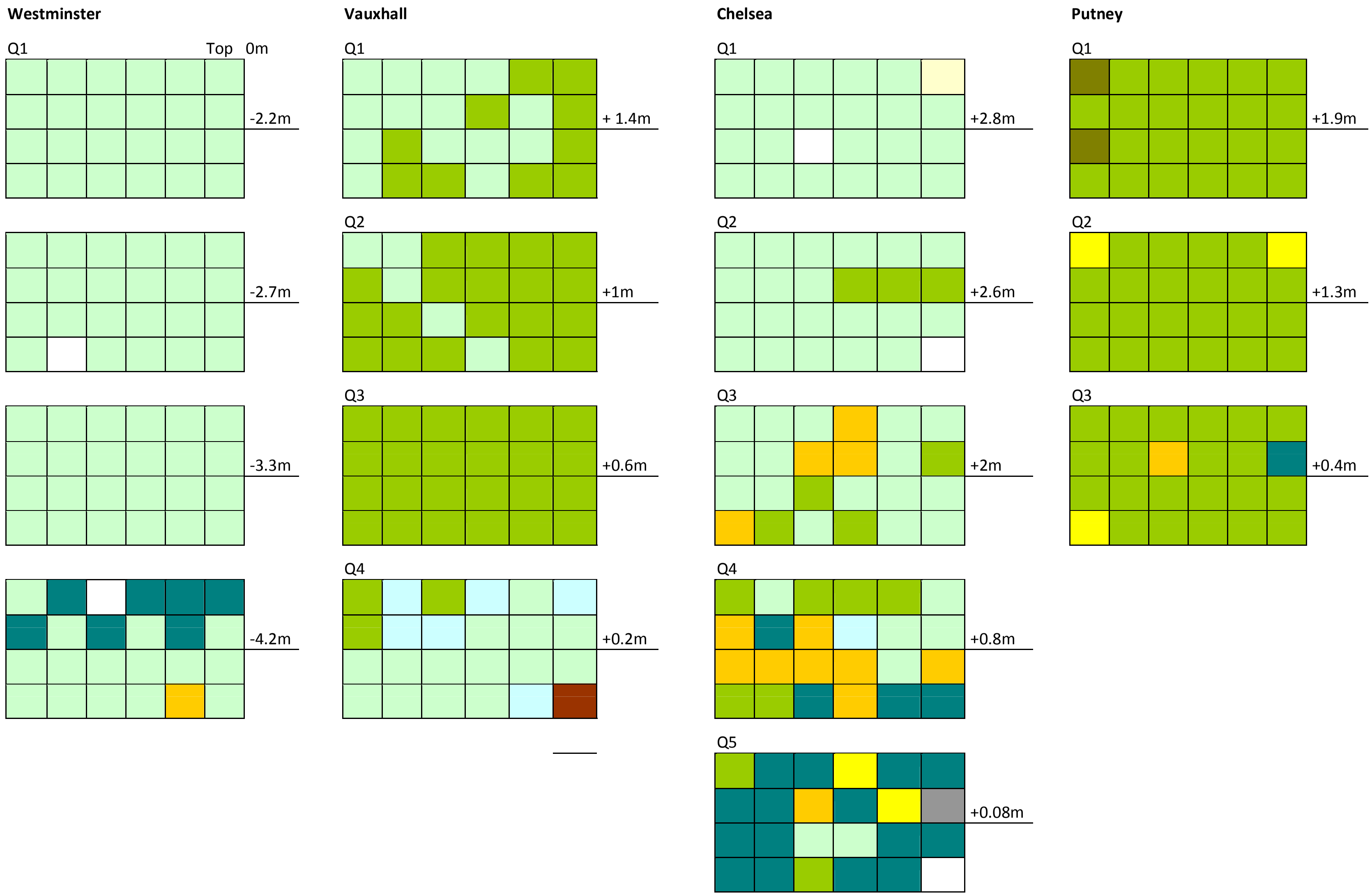
C.1.267 Vol 3 Table C.20 lists species recorded at the eight sites studied. Vol 3 Plate C.33 illustrates the distribution of algal within the site surveyed.

Vol 3 Table C.20 Algae recorded during surveys in 2012

Species/Site	Wapping	Bermondsey	Blackfriars	Westminster	Vauxhall	Battersea	Chelsea	Putney	2012 survey 8 sites
Chlorophyta									
Blidingia marginata	x	x	x	x	x		x		6 of 8
Blidingia minima	x	x	x	x	x	x	x	x	8 of 8
Cladophora glomerata	x		x	x	x	x	x	x	7 of 8
Rhizoclonium riparium	x	x	x	x	x	x	x	x	8 of 8
Ulothrix flacca							x		1 of 8
Ulva compressa	x	x							2 of 8
Ulva prolifera		x		x	x	x	x	x	6 of 8
Urospora penicilliformis					x				1 of 8
Xanthophyceae									
Vaucheria sp.	x	x	x	x	x	x	x	x	8 of 8
Rhodophyta									
Bangia atropurpurea				x	x	x			3 of 8
Polysiphonia stricta		x							1 of 8
Rhodochorton purpureum		x							1 of 8
Total species	**6**	**9**	**5**	**7**	**8**	**6**	**7**	**5**	

Vol 3 Plate C.33 Algal distribution on river walls surveyed




Westminster
Q1
Top 0m
-2.2m
-2.7m
-3.3m
-4.2m
Vauxhall
Q1
+ 1.4m
Q2
+1m
Q3
+0.6m
Q4
+0.2m
Chelsea
Q1
+2.8m
Q2
+2.6m
Q3
+2m
Q4
+0.8m
Q5
+0.08m
Putney
Q1
+1.9m
Q2
+1.3m
Q3
+0.4m

Bangia atropurpurea	Blidingia minima	Blidingia marginata
Cladophora glomerata	Cyanobacteria	Diatom mud
Rhizoclonium riparium	Moss	*Ulothrix flacca*
Ulva (*Enteromorpha*) *prolifera*	*Ulva* (*Enteromorpha*) *compressa*	*Vaucheria* sp.

Site descriptions

Wapping

C.1.268 The green algal cover on the brick wall at Wapping was almost entirely *Blidingia minima* and which extended to 3.5 – 3.7 m above beach level; occasionally small amounts of *B. marginata* and *Rhizoclonium riparium* were recorded among the *B. minima.* This was observed more in quadrat 5 near the base of the wall where the two previously mentioned species were more commonly present together with the filamentous green alga *Cladophora glomerata*. At the extreme base of the wall was a narrow mucilaginous brown zone of diatoms. An adjacent area at the same level as quadrat 5 was within a blackish red zone of filiform Cyanobacteria; *Cladophora glomerata*, *Blidingia minima* and *Rhizoclonium riparium* were occasionally dominant but commonly present as subordinate species among the Cyanobacteria, as were *Blidingia marginata, Vaucheria* sp. and the non-native colonial diatom *Hydrosera triquetra*.

Bermondsey

C.1.269 The algal cover on the wall at Wapping extended to approximately 3 m above beach level. Two main zones of algal vegetation were identified; an upper zone of mostly *Blidingia minima* (*B. marginata* occasionally present and *Rhizoclonium riparium* secondarily present in samples). At about 2 m above beach level a second zone was characterised by *Rhizoclonium riparium* and occasional patches of *Vaucheria* sp.; *Blidingia* spp. were occasionally or secondarily present. At lower levels (around 1.2 m above beach level) the vegetation was more mixed but with *R. riparium* the most common species with *Ulva* (*Enteromorpha*) spp., *Blidingia* spp. and *Vaucheria* sp. also present. A similar mix of species was recorded in the quadrat at the foot of the wall.

C.1.270 A general qualitative collection from the area adjacent to the transect revealed the red alga *Polysiphonia stricta*, the non-native diatom *Hydrosera triquetra*, and in shaded situations the red alga *Rhodochorton purpureum*.

Blackfriars

C.1.271 The Embankment wall and steps at Blackfriars bore two main zones of macroalgae; an upper zone of *Blidingia* spp., with *B. minima* most abundant and dominant at higher levels and *B. marginata* secondarily present in samples and a more prevalent feature in the lowest quadrat on the vertical wall. A much lower, dark-green zone comprised the filamentous *Cladophora glomerata*; this was present on steps and a still lower sloping face. Diatom growth formed an orange – brown zone on the lowest steps and levels on the Embankment wall.

C.1.272 Qualitative sampling in the general area revealed additionally *Rhizoclonium riparium*, *Vaucheria* sp., and the diatom *Hydrosera triquetra.*

Westminster

C.1.273 The macroalgal vegetation seen as a distinct green band on the Embankment wall and steps at Westminster was similar to that at Blackfriars except that *Blidingia marginata* was the dominant species with *B. minima* mostly secondarily present in the samples. In the lowest quadrat sampled, on a horizontal step, *Cladophora glomerata* was noticeably present as the dominant species in a sample or secondarily present where *Blidingia marginata* was the dominant species. The colonial diatom *Hydrosera triquetra* formed an orange-brown zone at the base of the wall.

C.1.274 Qualitative sampling in the general area revealed additionally *Ulva* (*Enteromorpha*) *prolifera*, *Rhizoclonium riparium*, and *Vaucheria* sp.

Vauxhall

C.1.275 The green algal mat on the north facing brick wall at upper levels (just below high water level) formed a zone comprising a mix of *Blidingia minima* and *Rhizoclonium riparium* with occasional *B. marginata*. At lower levels *R. riparium* characterised a wide zone almost to the foot of the wall (*Blidingia* spp. was present secondarily in the samples). At the foot of the wall was an approximately 0.5 m wide zone comprising a mix of species including *Ulva prolifera* and the red alga *Bangia atropurpurea*. *Cladophora glomerata* was recorded secondarily in the samples as were Cyanobacteria. To either side of the transect line *Bangia atropurpurea* was present as a narrow (2-3 cm wide) zone near the foot of the wall.

C.1.276 Qualitative sampling on the foreshore revealed a suite of species comprising *Blidingia minima*, *Cladophora glomerata*, Cyanobacteria, *Ulva prolifera* and *Vaucheria* sp.

Battersea

C.1.277 The north facing brick wall carried a dense mat of macroalgae with two zones seen by eye, probably an upper zone of *Blidingia minima*, and a lower zone of *Rhizoclonium riparium*, *Cladophora glomerata* with *Bangia atropurpurea* as a very narrow zone near the foot of the wall. Patches of *Vaucheria* sp. and Cyanobacteria were also present and small amounts *Ulva prolifera* grew among the other green algae. These species were all present in a qualitative sample. The algal zonation on an adjacent concrete wall looked quite different with two distinct zones present, an upper green zone (probably *B. minima*) and a wider lower blackish zone of Cyanobacteria.

Chelsea

C.1.278 On the brick wall was an extensive mat of macroalgae to 3 m above beach level. At upper levels (2 – 3 m above the beach) the mat comprised principally *Blidingia minima* but with secondarily *B. marginata*, *Rhizoclonium riparium* and *Ulothrix flacca.* At lower levels (around 0.8 m above beach level) there was a zone of a mix of Diatom bound mud, *Blidingia minima*, *Cladophora glomerata*, *Rhizoclonium riparium* and *Ulva prolifera*. Secondarily present in the samples were *Cyanobacteria*, *Hydrosera triquetra* and *Vaucheria* spp. The quadrat at the foot of the wall also revealed a mix of species but with *Cladophora glomerata* most abundantly present.

C.1.279 A qualitative sample from the foreshore contained *Blidingia minima*, *Hydrosera triquetra*, *Rhizoclonium riparium* and *Vaucheria* sp.

Putney

C.1.280 The north facing brick wall was almost entirely clothed from high tide level to the base by a mat of *Rhizoclonium riparium* with occasional moss, *Vaucheria* sp., and *Cladophora glomerata*. Secondarily present in the samples were *Blidingia minima* and *Ulva prolifera*.

C.1.281 Qualitative sampling on an adjacent granite wall revealed *Blidingia minima* to be the dominant species (*Cladophora glomerata* and *Rhizoclonium riparium* were present in small amounts) while on the foreshore revealed *Cladophora glomerata* to be the dominant species; also present were *Blidingia minima*, Cyanobacteria, *Rhizoclonium riparium* and *Ulothrix implexa*.

Discussion of communities and species present

C.1.282 From the distribution of benthic marine macroalgae flora in the tidal Thames four floristic sections can be recognised: (i) an outer, species rich, section to Gravesend and Tilbury; (ii) a lower reach, brackish, section to Woolwich/ Greenwich where the large brown algae occur but species-richness is lower; (iii) an inner, London reach, very low salinity section to Putney where green macroalgae are the characterising feature and where species richness is very low; (iv) an innermost, tidal freshwater section, from Putney to Teddington where a few euryhaline species (those capable of adapting to a range of salinities) persist but the flora is otherwise of freshwater species.

C.1.283 The present survey from Wapping to Putney, is in floristic section iii, and demonstrated clearly the predominance of green algae particularly *Blidingia* spp., that formed and extensive community or biotope as recognised by the *Marine Habitat Classification for Britain and Ireland*[1]. *Blidingia minima* was recorded at all eight sites studied (Vol 3 Table C.20) while *B. marginata* was found at six (Vol 3 Table C.20). Both *Blidingia* species occur widely in Britain at upper littoral and supralittoral levels, and also just above the waterline on floating structures; they are common fouling species. In this section of the tidal river, both species occur more widely in the upper littoral, i.e. from midlittoral to supralittoral fringe levels. *Blidingia minima* occur more commonly than *B. marginata* and were more abundant in insolated situations than in shade. Both are often the only species on harder, drier concrete, and elsewhere on also sheet metal piling; *Blidingia* spp. are thus likely to colonise temporary structures built into the river. *Blidingia* species are small tubular algae that superficially resemble *Ulva* (*Enteromorpha*) spp. but with smaller cells and without the basal rhizoidal cells typical of *Ulva* spp.

C.1.284 *Rhizoclonium riparium* (uniseriate filaments with rhizoidal outgrowths) occurred widely and commonly on river walls studied; it was present at the eight sites studied (Vol 3 Table C.20) but at three, all north-facing and less insolated and of brick, formed distinct communities (no biotope classification for these) and zones. The zones were more extensive at Vauxhall and Putney where the river's salinity was lower. On south-facing walls *Rhizoclonium* occurred among the mat of *Blidingia* spp. and was more noticeably present at Chelsea. *Rhizoclonium riparium* is a widely occurring species in Britain at upper littoral levels, in Kent it is common in saltmarshes and on open and shaded chalk cliff faces. It is also known from freshwater habitats.

C.1.285 The dark-green branched (often unbranched in the Thames) filamentous *Cladophora glomerata* was recorded at the eight sites studied (Vol 3 Table C.20), and at two (Blackfriars, Chelsea) formed at zone at the foot of the wall; at other sites (Wapping, Westminster) it was patchily present and at the remaining sites occurred among the macroalgal turf on the lower parts of walls. *Cladophora glomerata* is a widely occurring freshwater species that also occurs in low salinity brackish habitats as in the present study area.

C.1.286 Despite a long history of being recorded in the tidal Thames the tubular *Ulva* (*Enteromorpha*) spp. were only scantly found in the present survey although noted for seven out of the eight sites studied (Vol 3 Table C.20). Two species were identified, *U. compressa*, *U. prolifera*, which grew among the mat of macroalgae on the river walls. These former *Enteromorpha* occur widely in Britain in saltmarshes and estuaries as well as on open shores, and particularly commonly in eutrophicated situations.

C.1.287 Other green algae recorded were *Ulothrix flacca* and *Urospora penicillifomis* both not uncommon in saltmarshes and estuaries; both were only scantly recorded in this section of the tidal Thames.

C.1.288 The yellow-green alga (Ochrophyta, Xanthophyceae) *Vaucheria* (probably *compacta*) sp. was recorded at the eight sites studied. It was more noticeably present on the north facing brick walls at Bermondsey and Putney where it formed dark green thick, silt-binding, velvety patches. The species has been long-known in the tidal Thames; some *Vaucheria* spp. occurs abundantly in saltmarshes and estuaries.

C.1.289 Red algae occur rarely in low salinity estuaries being largely restricted to marine outer estuarine reaches and sea-shores; three species were recorded in the present survey (Vol 3 Table C.20).

Bangia atropurpurea, a filamentous form but which can form multicellular-wide ribbons, occurred at three sites and at two (north-facing brick walls) formed putative narrow bands (not picked out by the quadrat sampling) near the foot of the wall at approximately mid tide level. Unusually for red algae, *Bangia atropurpurea* is a species that occurs in fresh, brackish and marine conditions. On open-sea coasts in Kent it occurs on sea-walls (concrete and brick) in late winter often as a zone near high tide level (Thanet, Tittley, 2012; personal observations at Dover); this contrasts with its occurrence in early summer at midlittoral levels in the inner tidal Thames. The filamentous *Rhodochorton purpureum* was recorded as velvety red growth in shaded situations at high tide level on brick very close to the to be demolished jetty at Chambers Wharf. *Rhodochorton purpureum* occurs commonly in caves on open sea shores and is not uncommon in low salinity situations. The filamentous *Polysiphonia stricta* was found, rarely occurring among macroalgae on the brick wall at Chambers Wharf, Bermondsey. Some forms of this species have been found in low salinity environments elsewhere (Tittley, 2001, 2009). All other representatives of this genus are fully marine species. The discovery of *P. stricta* and *R. purpureum* represents an extension in their distributional range in the tidal river and their currently known maximum upriver penetrations.

Survey Photographs

Vol 3 Plate C.34 Preparing Seine net for sampling

Vol 3 Plate C.35 Setting the Seine net

Vol 3 Plate C.36 Collecting the Seine net

Vol 3 Plate C.37 Seine net repair

Vol 3 Plate C.38 Preparation for trawl

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Vol 3 Plate C.40 Oxygenation of buckets containing fish

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Vol 3 Plate C.42 Airlift sampler (main unit)

Vol 3 Plate C.43 Airlift sampler submerged into subtidal zone of the Thames

Vol 3 Plate C.44 Airlift Sampler Control Unit

Vol 3 Plate C.45 Successful airlift sample

Vol 3 Plate C.46 Airlift sample bags

Vol 3 Plate C.47 Kick sampling in intertidal zone

Vol 3 Plate C.48 Hammersmith Pumping Station sample site

Vol 3 Plate C.49 Barn Elms sample site

Vol 3 Plate C.50 Putney Bridge sample site

Vol 3 Plate C.51 Dormay Street sample site (on Bell Lane Creek)

Vol 3 Plate C.52 Jew's Row sample site

Vol 3 Plate C.53 Cremorne Wharf Depot sample site

Vol 3 Plate C.54 Chelsea Embankment sample site

Vol 3 Plate C.55 Western Pumping Station sample site

Vol 3 Plate C.56 Tideway Walk sample site

Vol 3 Plate C.57 Albert Embankment sample site

Vol 3 Plate C.58 Victoria Embankment (looking upstream)

Vol 3 Plate C.59 Victoria Embankment River Wall

Vol 3 Plate C.60 Blackfriars sample site

Vol 3 Plate C.61 King's Stairs Gardens sample site

Vol 3 Plate C.62 King Edward Memorial Park sample site

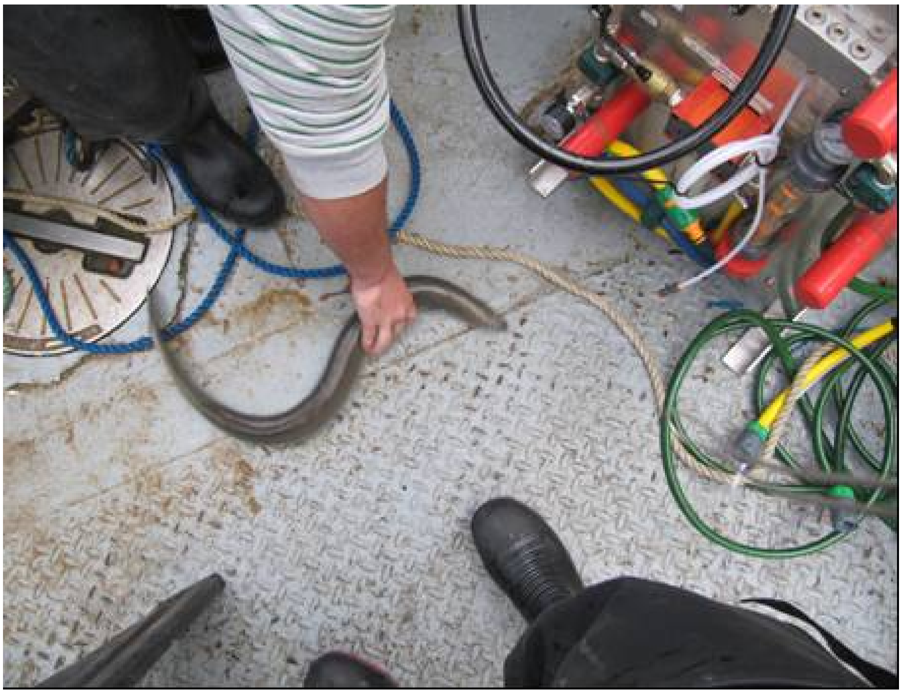
Vol 3 Plate C.63 Deptford Church Street sample site

Vol 3 Plate C.64 Common bream

Vol 3 Plate C.65 European perch

Vol 3 Plate C.66 Flounder

Vol 3 Plate C.67 European eel



Vol 3 Plate C.68 Sea bass

Vol 3 Plate C.69 Asiatic clam (right) and Radix balthica (left)

Vol 3 Plate C.70 Zebra mussel

Vol 3 Plate C.71 Chinese mitten crab

Vol 3 Plate C.72 Brown shrimp

Vol 3 Plate C.73 *Gammarus zaddachi* amphipod shrimps

Vol 3 Plate C.74 Algal surveys: Wapping brick wall

Vol 3 Plate C.75 Algal surveys: Bermondsey brick wall

Vol 3 Plate C.76 Algal surveys: Blackfriars granite embankment wall

Vol 3 Plate C.77 Algal surveys: Westminster steps

Vol 3 Plate C.78 Algal surveys: Vauxhall brick wall

Vol 3 Plate C.79 Algal surveys: Battersea brick wall

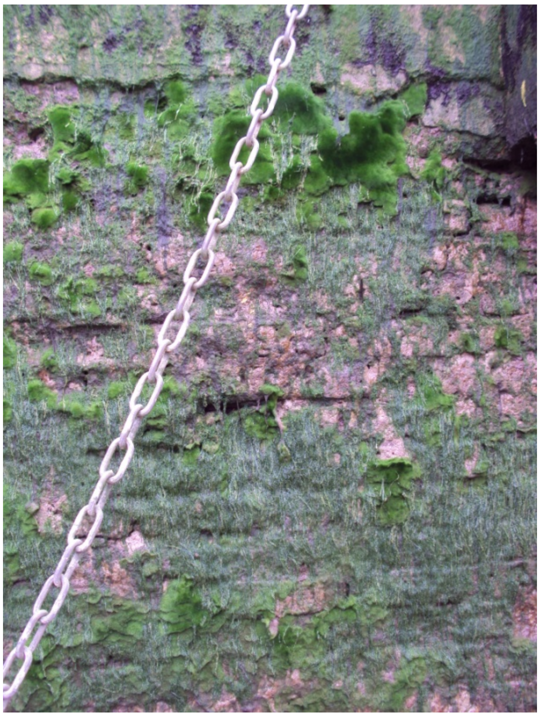
Vol 3 Plate C.80 Algal surveys: Chelsea brick wall

Vol 3 Plate C.81 Algal surveys: Putney brick wall

Vol 3 Plate C.82 Algal surveys: *Blidingia minima* mat on brick wall at Wapping

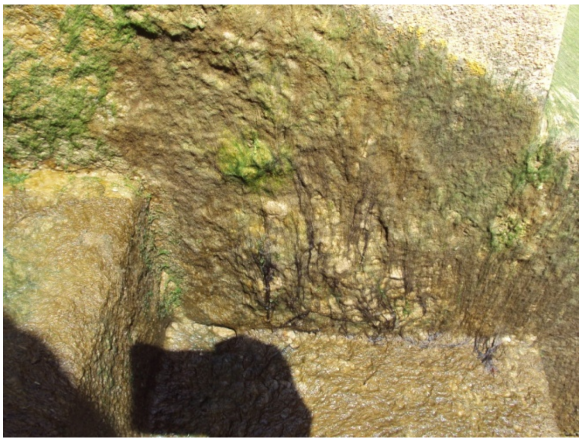
Vol 3 Plate C.83 Algal surveys: Cyanobacterial filaments at Wapping

Vol 3 Plate C.84 Algal surveys: Vaucheria mat at Bermondsey



Vol 3 Plate C.85 Algal surveys: *Blidingia minima* zone at Westminster

Vol 3 Plate C.86 Algal surveys: *Hydrosera triquetra* at Westminster



Vol 3 Plate C.87 Algal surveys: *Bangia atropurpurea* zone at base of wall at Vauxhall

References

[1] Connor *et al*. *Marine Habitat Classification for Britain and Ireland.* p. 112: 'LR.FLR.Lic.Bli, Blidingia spp. on vertical littoral fringe soft rock' (2004).

Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix C.2: Juvenile fish migration modelling report

APFP Regulations 2009: Regulation **5(2)(a)**

Hard copy available in

Box **17.2** Folder **B**
January 2013

Thames Tideway Tunnel
Creating a cleaner, healthier River Thames

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C.2 Juvenile fish migration modelling report

C.2.1 The following report has its own table of contents.

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Thames Tideway Tunnel

Environmental Statement

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Appendix C: Ecology – aquatic

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C.2 Juvenile fish migration modelling report

Introduction

C.2.1 The Thames Tunnel *Scoping Report* identified a number of potential impacts on fisheries associated with project construction and operation. These are associated with the need for both temporary (construction phase) and permanent (operational phase) structures to be built alongside, and in some cases encroaching into the river channel at the sites. Of the 24 Thames Tideway Tunnel sites, just over half encroach onto the intertidal foreshore, either in the form of temporary (construction-phase) or permanent works; the remainder are either in land, or adjacent to the Thames Tideway or its tributaries, but include no encroachment into the channel.

C.2.2 The Environment Agency's (EA) *National Encroachment Policy for Tidal Rivers and Estuaries* (Environment Agency, 2005)[1] presumes against developments riverward of existing flood defences where these would, individually or cumulatively, change flows so that fisheries were affected or cause loss or damage to habitat. This report demonstrates that the temporary and permanent works would not interfere with fish migration.

C.2.3 The background to the project-wide assessment of juvenile fish migration impacts was presented in an earlier report (see Vol 2 Appendix C.4), which provided a literature review of relevant aspects of estuarine fish biology and considered the various modelling approaches that might be applied. This report presents the findings of the modelling study; including the detailed methodologies used to set up and run the models and the outputs from them. A summary of the modelling techniques, and the process involved in setting up and running the model is provided in this section and Vol 3 Plate C.1.

Modelling techniques

Individual based model

C.2.4 The modelling method which has been used is a technique known as 'individual-based modelling' (IBM), which models individual fish as non-inert particles within a base hydraulic model. In the case of the Thames, this makes use of HR Wallingford's (HRW) existing water model for the tidal Thames, which incorporates model variants for the project baseline river condition (pre-development) as well as with temporary (construction-phase) and permanent project infrastructure in place. Typically the temporary works, including cofferdams, jetties and campsheds, are more extensive than the permanent works and would be in place for up to seven years. The HRW model has been run for a variety of flow scenarios, and the most relevant scenarios have been selected for use within the IBM fish model.

C.2.5 The literature review (see Vol 2 Appendix C.4) identified a variety of species whose early life stages require uninterrupted migration routes through much or all of the tidal Thames, but for the purpose of the assessment these were narrowed down to three species that could act as surrogates for the different behavioural strategies:

a. Eel (*Anguilla anguilla*) – juvenile ‘glass’ eel and later pigmented elver stages (anguilliform type); these stages move from the sea into the estuary and towards freshwater during the first year or so of life. Eel are a thigmophilic species, i.e. they spend much of their life in close contact with the bed and banks.

b. Flounder (*Platichthys flesus*) -0-group post-larvae to juveniles (flatfish type); flounder are spawned in the outer estuary but quickly move up through the estuary during their first weeks. Flounder are also thigmophilic and make use of the bed to shelter from strong flows.

c. Bass (*Dicentrarchus labrax*) – 0-group post-larvae to juveniles (roundfish type); juvenile bass are spawned in the open sea but move into the upper reaches of estuaries during the early lifestages. Bass are a roundfish and remain in the water column, away from the bed and banks during migrations.

C.2.6 One other species considered to represent roundfish was dace (*Leuciscus cephalus*), as this freshwater species is considered by the EA to be at risk of hydraulic displacement, or being ‘washed out’ into saline water as a result of increased water velocities caused by channel constriction. However, bass was considered likely to be a more appropriate proxy for the migratory round fish species found within the Thames Tideway.

C.2.7 In order to produce realistic fish behaviours within the model, the ‘virtual fish’ are ascribed rules which determine how they will react to changing physical cues such as channel edges, water depth tides and local hydraulic conditions. A critical element in the success of such models is in representing adequately, via a (preferably) small number of attributes, behaviours that would be recognisable by fish experts observing the model results. These would typically include directional preferences (upstream or downstream), swimming speeds, depth preferences and reactions to hydraulic gradients (rheotactic behaviour). Much of this information was obtained by literature review (see Vol 2 Appendix C.4) and additional material referenced in the present document, but observational information was also obtained from Tideway fish experts from the EA and elsewhere.

C.2.8 A series of monthly juvenile fish surveys was conducted from May to October 2011 at five sites on the Tideway, covering the project-affected reaches. These differed from prior EA surveys in focusing on juvenile habitats and sampling techniques and in providing more detailed coverage over the critical summer months. Data from these surveys give more precise information on times of arrival of species/lifestages in the Thames Tideway, changes in size distributions of fish present and dispersion through the Tideway. They therefore contribute to providing ‘ground truth’ for the IBM. The results of these surveys are reported in Vol 2 Section 5 and the methodologies are described in Vol 2 Appendix C.2.

C.2.9 In addition, flume studies of fish behaviour were carried out. The flume trials investigated specific aspects of behaviour that could not be ascertained from published literature or from field observation. These included details such as turning rates and preferred swimming depth or height above substrate in relation to the velocity of water flow.

C.2.10 The IBM modelling approach is relatively novel and had not previously been used in an environmental impact assessment (EIA) context. It has several features that make it suitable for this purpose, especially in applications where the required base hydraulic model has already been developed. Benefits of this approach include:

d. By simulating the progress of individual fish past all the project sites, any potential in-combination effects of all sites on juvenile fish migration through the Tideway can be investigated.

e. Ready comparison of the effect of hydraulic and bathymetric changes from temporary and permanent works relative to the base case.

f. Ability to model consequential biological effects, such as altered risk of predation when fish are forced to move into deeper or shallower water.

g. Flexibility in sampling the model to generate different forms of output, including lay-friendly cinematic animations of fish movement suitable for public presentation as well as static graphics and tabular formats.

Output types

C.2.11 The modelling approach used generates large data files containing all the attributes and positions of the model fish at all time-steps in the model, along with the associated hydraulic data and real times. Model outputs are post-processed from this information and this allows huge versatility in output type. Several types of output have been generated to inform the EIA:

a. Conventional chart outputs showing fish progress and survivals along the Tideway as a function of time relative to starting time.

b. Cinematic outputs (2D model animations) showing progress of groups of individual model fish in accelerated time against plan view of the Tideway channel.

c. Tabulated data showing eg, Markov coefficients (see para. C.2.13) for fish movements into and out of sequential 3 km reaches of the Tideway. This format can be used in spreadsheet form to link analyses with other modelling approaches e.g. the Tideway Fish Risk Model which is used for water quality assessment based on the same 3 km reaches.

C.2.12 Each type of output is repeated for each of the three fish species: flounder, eel and bass. In most cases it is possible to overlay findings for the base case and temporary and permanent works cases, providing for immediate comparison.

Markov chain model

C.2.13 A second method sometimes used to analyse fish movements through river, coastal and transitional waters is the Markov chain model (see Vol 2

Appendix C.4). Markov models are more typically used to process data obtained by fish telemetry studies in which the movements of fish can be determined from sequential positioning by radio- or acoustic-tagging techniques (not practicable for very small fish). The habitat is divided into a series of sections and the transitional probabilities of movement from one section to another are estimated. This has certain parallels with the Tideway Fish Risk Model (TFRM), which is being used to assess the effects on fish sustainability of water quality for pre- project and with-project conditions (see Vol 3 Appendix C.3).

C.2.14 The TFRM divides the Tideway into discrete, sequential 3 km sections based on the EA's Automated Quality Monitoring Stations (AQMS). The TFRM assesses the sustainability of fish populations, based on dissolved oxygen concentrations, within each of the 3km reaches. A further benefit of the IBM is that, in the post-processing phase, the Tideway can be divided into matching 3 km reaches, and the probability of a fish passing from one to the next can be tested using the Markov model. Positive effects of the project on water quality can then be balanced against any negative effects of the foreshore structures.

Assessment of effects

C.2.15 The project-wide effects on juvenile fish migration could be expected to manifest themselves in two particular ways that can be estimated from the IBM. An obvious effect is that more challenging hydraulic conditions could delay the progress of smaller, weakly swimming life stages through the Tideway, such that they do not become optimally distributed across all the available habitat, or that they might for example fail to reach a target habitat by a critical date/time. Temporal mismatches of this kind are known as 'phenological' changes. This can be measured in the model by estimating the mean time to cross a notional finishing line (eg, head of tide).

C.2.16 A second and more subtle effect might be that fish are forced either by the Thames Tideway Tunnel structures, or by associated flow changes, into less favourable water depths where predation risk might be increased. By assigning differential mortality rates to different water depths, the effect on mortality can be estimated. In this case, the endpoint is estimated as the proportion of the total numbers remaining after a fixed model run time. It is not necessary for the purposes of EIA to estimate these in absolute terms, only to compare the temporary and permanent works cases with the base case.

C.2.17 The modelling study therefore aims to answer the following two questions:

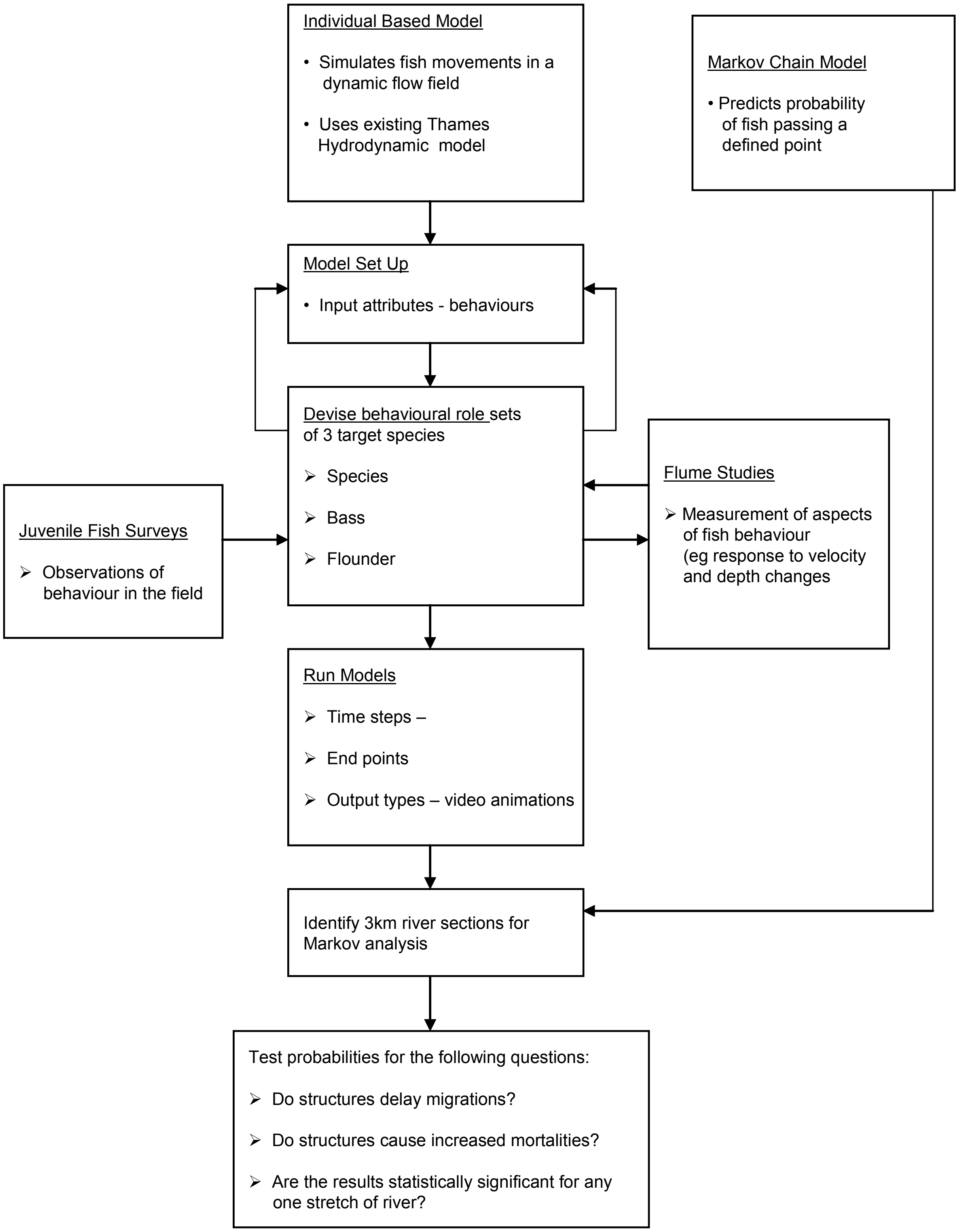
a. Whether the Thames Tideway Tunnel project structures (permanent or temporary) delay juvenile fish migrations through the estuary, for one or more species; and

b. Whether the structures result in increased mortality rates for these individuals.

C.2.18 Vol 3 Plate C.1 describes the process of setting up, ground truthing and running the model in order to answer these questions. The process of setting up and programming the IBM is described in paras. C.2.19 to

C.2.48, including the range of behavioural attributes ascribed to the fish ‘objects’. The hydrodynamic model on which the IBM is based is described in Annex C to this appendix. The juvenile fish surveys, and the laboratory flume studies which provided empirical data to inform the behavioural attributes, or behavioural ‘rule sets’ are described in paras. C.2.49 to C.2.81. The behavioural rule sets are presented in paras. C.2.82 to C.2.90. The way in which the model is set up and run to simulate realistic ‘natural’ conditions is described in paras. C.2.91 to C.2.117. Outputs from the model, including project wide results for each of the three species and Markov probabilities for each of the AQMS zones are presented in paras. C.2.118 to C.2.137. Site-specific observations at each of the Thames Tideway Tunnel sites are presented in paras C.2.138 to C.2.164.

Vol 3 Plate C.1 Modelling summary

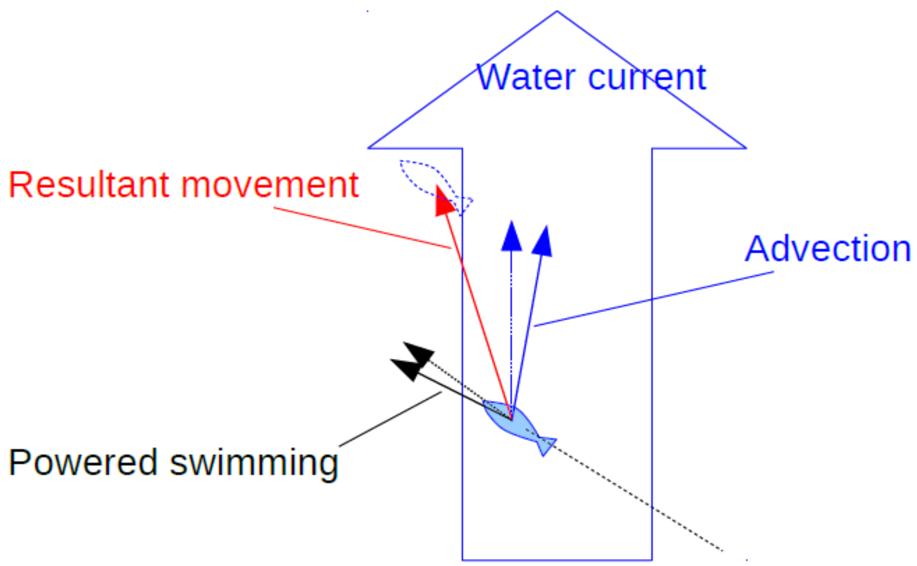


Explanation of the individual based model

Basic definition and movement of fish objects

C.2.19 In programming language all objects in a program have attributes and methods. Attributes are information stored by the object that indicate its state as the program progresses and methods define all the things that can happen to an object (which change its state). No other information is needed to define an object. The fish model is based on a (Lagrangian) drifting particle in a (Eulerian) hydrodynamic model, which has added movement based on powered swimming. So the fish object is pushed around by the water currents just like a neutrally buoyant particle of sediment with the addition of a vector for powered swimming (Vol 3 Plate C.2).

Vol 3 Plate C.2 Vector addition to calculate position of fish after one 15 second time step



C.2.20 The velocity of the water current (blue arrows) is added to the fish swimming velocity (black arrows). Both have random normally distributed error added (shown by alteration to the 'pure' directions shown by dotted arrows). The error in current is added to indicate turbulence below the spatial resolution of the water model (coefficient of dispersion) and the error in swimming to indicate steadfastness (aka. determination or ability to stay on existing direction).

C.2.21 In order to move, at each time step, the fish object needs to know the water current at its location, which includes the magnitude of the current and the direction – these are measured as u and v values (ms^{-1}) interpolated in space and time from the hydrodynamic model. The fish object also needs to know its swimming speed and swimming direction and how much error needs to be added – its steadfastness.
In summary these are all the pieces of information stored with a fish that relate to its movement:

a. swimming speed, (ms^{-1})

b. swimming direction, (radians)

c. steadfastness. (error term – standard deviation in radians- see C.2.20).

C.2.22 No other information exists in the model that results in the movement of a fish in the normal circumstances of it swimming in water (ie, when it jumps into an illegal position such as a dry area; however, some other movements are incorporated to put it back into a legal position – para. C.2.38 explains how the program deals with this). The fish object stores its position n x, y coordinates, and that, in combination with the above, is all the basic information that is stored with the fish object. That is, a fish is defined by these parameters, in programming language these are all its attributes.

Fish object behaviour

C.2.23 The only way to make the fish behave in response to external or internal stimuli in the model is to change one or more of the pieces of information, summarised above, that relate to its movement (speed, direction, steadfastness). There are broadly two types of behaviour in the model, intermittent behaviour and continuous behaviour. Intermittent behaviour is applied only at certain time steps (determined by some external event, or by something the fish senses in its present position) whereas continuous behaviour is applied to the fish at every time step, usually related to what it senses at its present location. Before explaining these types of behaviour in detail it is worth summarising what information can possibly be determined from the water model and thus what can possibly be a stimulus for the fish in either modes of behaviour (continuous or intermittent).

Potential stimuli for fish behaviours

C.2.24 The water model contains depth and velocity over a large number of tidal cycles. So at any point and at any time, the depth (z) and velocity (u and v) can be determined by interpolation. If the model is 'frozen' during full ebb tide and the velocity is stored, the water will be flowing seawards at any point in the model, and this is used to define ‘downstream’. The tidal cycle causes the water depth to go up and down rhythmically, so at any point the 'tidal state' can be defined by whether the water is getting deeper or shallower, defining ‘flood’ and ‘ebb’ respectively. The tide forms a wave up the river so often the tide is going out at one place while coming in at another, and vice versa, so tide state is a local variable rather than a single global variable. Thus the potential stimuli, which can be determined at any point in space and time, are:

a. water velocity

b. water depth

c. downstream direction

d. tidal state.

C.2.25 In addition, time is a known variable in the model and this can be used to determine all manner of other external or internal stimuli, eg, daylight/darkness.

Derived stimuli – pressure and acceleration

C.2.26 Pressure and acceleration can be derived from velocity if measured at two points in space or time. Bernoulli's equation for hydrodynamic pressure can be used to calculate the pressure differential between two points travelling at different velocities, even if the absolute pressure or stagnant point pressure is unknown. Acceleration can be calculated for a moving point (such as a model fish) as the difference in velocity between two subsequent time steps – this could trigger behaviour but in a 15 s time step is more useful as an output variable to contrast the impacts of different scenarios on the model fish.

Intermittent behaviour – navigation

C.2.27 Navigation in the model relates to where the fish is programmed to go. For instance, biological data indicate that for juvenile bass the model fish need to navigate upstream as quickly as they can. At a predetermined average interval, which is calculated as a randomly chosen step in an average of say eight steps, the fish is given perfect navigational information (if it is available – there is a sensitivity threshold and in some places the stimulus is not strong enough to register). Then the fish changes its present direction to the perfectly navigated direction and continues in this direction with its usual steadfastness until at some later step it is provided with navigational information again. Therefore adjustment of this average interval between navigations is critical because it can lead to either a very well informed fish or a poorly informed fish.

C.2.28 The navigation behaviour of model fish can be summarised by listing the attributes that are affected if the state is changed through this method, and the environmental cues. In this case these are outlined in Vol 3 Table C.1.

C.2.29 The navigation behaviour is triggered on a randomly selected time step with an average interval, it impacts the model fish's direction attribute and is determined by the downstream direction variable – in fact for say juvenile bass the direction will be selected as 'upstream' at all times. The sensitivity column shows how the availability of the cue is moderated by the available environmental data.

Continuous behaviour – velocity-, depth- or pressure- mediated movement

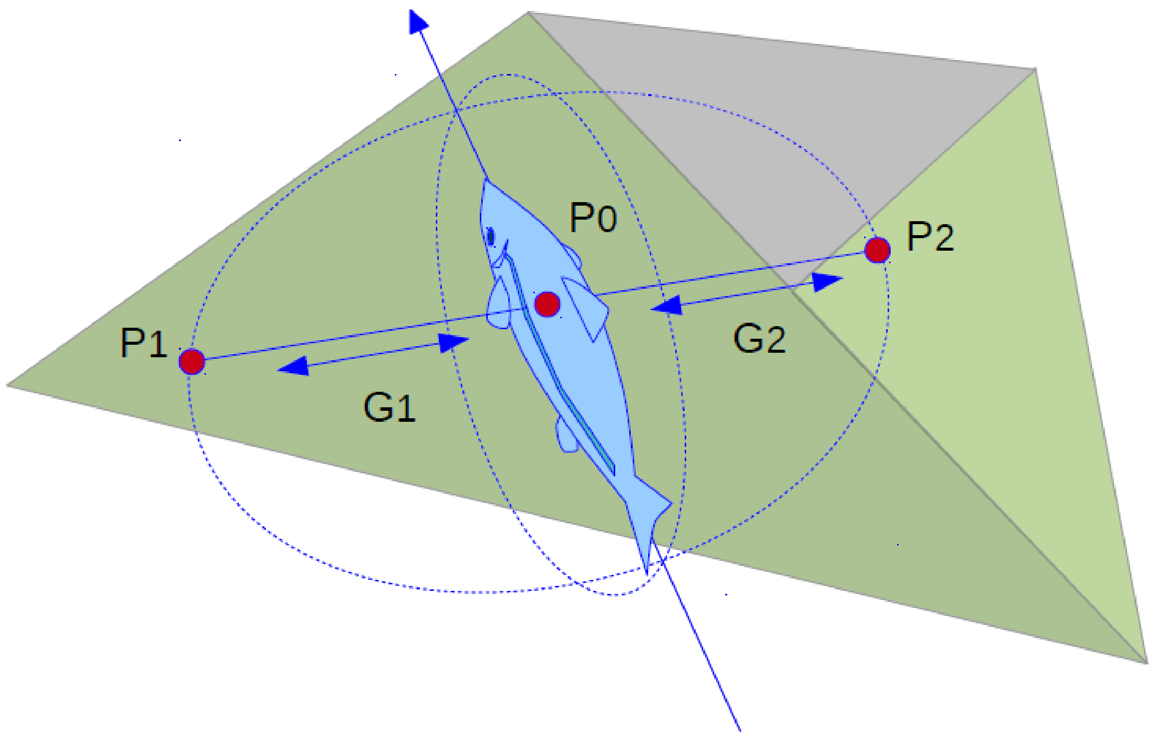
C.2.30 Continuous behaviour is applied at each step in the model and it is used for fish activity that is assumed to have a natural occurrence more frequent than the time step. For example, real fish appear to continually adjust their heading in response to changing currents (rheotaxis). There must be some minimum reaction rate but it is likely to be around 200 milliseconds or shorter for an average small vertebrate. So we can assume that a real fish may change its heading in response to certain local environment cues several times a second and therefore many times within a 15 second time step, furthermore most fish can turn round through

180 degrees within a second and so there is no physiological limit on the extent to which it can change its heading within a time step of 15 seconds.

C.2.31 In the model the fish samples the environment around its location and makes a minor heading adjustment to veer toward the more suitable condition. The rate at which it turns is a variable parameter, so for instance it may turn sharply toward some environmental cue or alternatively make many small heading changes or multiple steps. The model fish may also alter its speed in response to these environmental variations, slowing down or speeding up as appropriate.

C.2.32 Speed changes in response to local environmental cues is called klinokinesis in real animals, whereas changes to steadfastness is called orthokinesis and orientation responses in response to currents is called rheotaxis. The fish may derive an absolute value for any of the stimulus cues outlined above (velocity, depth, tidal state, and downstream direction) at its present. However, in order to change direction toward a target, the fish must know the value at its present location and secondly know which relative direction is closer to the target, thus the model fish must have an area of knowledge defined around its position, which is also called a sensory envelope (Vol 3 Plate C.3).

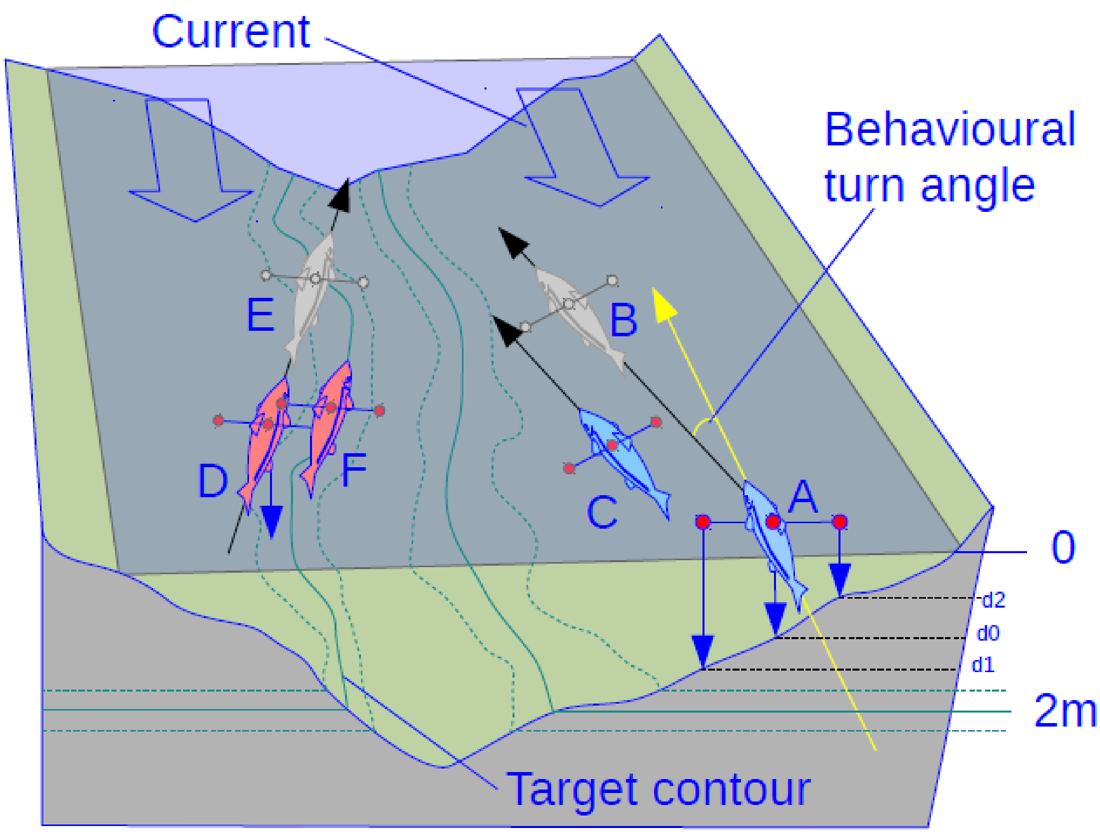
Vol 3 Plate C.3 Sensory envelope of model fish



C.2.33 The environmental information is interpolated at three points, P0 is the fish location, and P1 and P2 are laterally left and right of the present location perpendicular to the present heading. G1 and G2 are the gradients derived from these points to the left and right. It is important that the three points are all legal in the model and that P1 and P2 can be reached through legal routes: the model ensures that illegal routes do not occur. In the diagram the large triangular shapes represent the spatial elements of the hydrodynamic model, in the case where the path from the fish (P0) to the envelope (P2) crosses land or a dry element the information would be unavailable. The size of the envelope is thus dependent on the assumed sensory capabilities of the fish as well as the spatial resolution of the model – for instance if it were much larger than the average resolution of the water model the gradient information might be complicated and misleading (G1 or G2) and more samples would be beneficial.

C.2.34 A model fish uses the information derived from the sensory envelope to change its direction attribute, before using that to define the next position (Vol 3 Plate C.3). The target for the behaviour could be a particular value of an environmental variable or could be related to moving up or down a gradient. For example, in the case of a depth mediated behaviour this could mean that fish targets the deepest part of the river (swims down the gradient) or targets a particular depth, say 2m and then moves toward this target by biasing its present direction toward this value (Vol 3 Plate C.4).

Vol 3 Plate C.4 Heading adjustments made to target an absolute value of an environmental variable, in this case the 2m depth contour



C.2.35 The blue fish (A) is outside the target zone (d0 < 2m). The target zone is defined as a target value (solid contour - 2m) and an acceptable range (within dashed contours). The blue fish thus changes its heading due to depth mediated behaviour (A) and moves along this direction at its swimming speed (B) but it is also subject to advection and ends up in a new position (retaining the new heading)(C). The fish (A) samples the depth either side of itself (d1, d2) in order to calculate which way to turn to move toward the target – since it is less deep than the target it needs to move toward the deeper of d1 and d2 (or d1 and d0 if d2 is unavailable and so on). The red fish (D) is within the target zone and thus its heading is unchanged (D) and it swims along this heading (E) and is advected retaining its existing direction (F).

Thresholds and sensitivity

C.2.36 Each of the continuous behaviours requires observations to be made across the sensory envelope. The fish compares the target value of a stimulus with the value at its present position to decide if it needs to change direction or speed. It then uses the difference between the points across the envelope to decide which way to go. The values for the stimuli in the model can be calculated to 16 decimal places, far in excess of what we assume an animal can detect. So, it is necessary to set the threshold for detecting stimuli to a level which is likely to be found in a 'real' fish. In addition, as mentioned above, there are cue sensitivities that can be set for a cue such as tidal state to reflect the required sensitivity in relation to the magnitude of change expected.

Hierarchy and conflicting rules

C.2.37 The continuous rules are applied to all fish at each time step, whilst the intermittent rules are applied to those fish for which they are applicable. Therefore it is often the case that multiple rules will be applied to a fish at each time step. There is a hierarchy of rules in the intermittent behaviour that is designed to reflect the hierarchy of needs that apply to a real fish. For instance, if a fish is navigating on a migration that is part of its life history, then this may take many days or weeks. If during this migration the fish comes across dry land, a predator risk (associated in this model with deeper water), or prey, it may wish to suspend its migration to deal with the more immediate opportunity or threat for a relatively short time of a few hours. The model assumes that the fish in these cases is only doing one thing at a time, that there is a hierarchy of behaviour and only one is active at any one time (during any one time step (15 s)).

C.2.38 In this model the key intermittent behaviours are land avoidance and navigation, which are linked by the correlated random walk as mentioned in C.2.27 above. Land avoidance is the first in the hierarchy, and navigation second, all other behaviours are secondary to these. The continuous behaviours are applied to fish by small biases on its present direction or speed. If these are added in the same step, they either have an enhanced effect or cancel each other out to a certain extent. In either case the effect is logical, but in general, multiple continuous rules are to be avoided without good theoretical rationale as they lead to complex interpretation of the results. So it is more usual to model, depth-mediated behaviour during flood tide, and velocity or acceleration mediated during ebb (so that a fish migrating upstream can shelter during ebb and make headway during flood).

Swimming height and advection

C.2.39 There is a well-known relationship between the depth averaged current speed and the speed at a certain specific depth for shallow channels (0-30 m depth), which is an exponential function and often called the ‘law of the wall’. This function simply models the fact that the water is usually stationary very close to the bed or banks of a river and increases smoothly through the water column to reach a maximum near the surface. Applying this function allows a 2D hydrodynamic model to be converted into a quasi-3D model, where velocity at depth is specified at any location in the model using this relationship, the mid-water (also called depth-averaged) velocity, and the depth of the water at that location. The depth-averaged velocity is the output of 2D hydrodynamic models and is the velocity at about 60% of the water depth and is very close to the maximum velocity in the water column. The rate at which the speed increases from the bed to mid water is determined by the roughness of the bed. In an idealised channel with completely smoothed sides and bed, the speed would increase very quickly from the bed to the mid water position, whereas in a real river it tends to follow this general pattern but increases slightly less quickly.

C.2.40 The typical vertical profile is found using Soulsby's (1997)[2] empirical formula for a smooth bed:

$U(z) = U_{bar}$ (z / 0.32h) 1/7 for $0 < z < 0.5$ h

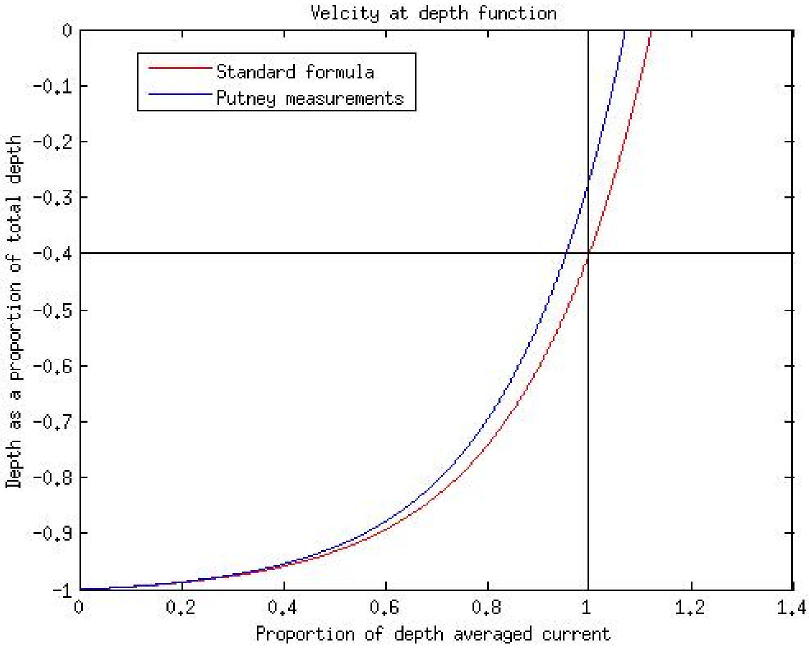
and

$U(z) = 1.07\ U_{bar}$ for $0.5h < z < h$,

where $U(z)$ is speed at height z above bed, h is water depth and U_{bar} is depth-averaged velocity.

C.2.41 Actual measurements made at Putney Bridge foreshore in July 2011 (Vol 3 Plate C.5) are represented by the blue line, which show the increased friction caused by the coarse shingle bed (Vol 3 Plate C.6), which is typical of much of the intertidal foreshore in the upper Tideway.

Vol 3 Plate C.5 Vertical velocity profile



C.2.42 As modelled by Soulsby's formula for a smooth bed (red) and based on actual measurements made on the shingle foreshore of the Tideway at Putney (July 2011).

Vol 3 Plate C.6 Intertidal substratum at Putney

Photograph of right bank, July 2011

C.2.43 Thus, in addition to being able to select its preferred velocity at a position across the river channel, a fish can chose to be in higher or lower velocities by moving up or down the vertical velocity profile.

C.2.44 In the model, the real measurements made at Putney were used to specify the parameters of the function shown in Vol 3 Plate C.4. This function allows the model to be used to determine the advection of a particle (or fish) at any point in the vertical water column and is especially important when modelling fish, such as flounder or elver, that are known to either move very close to the bed or banks, or fish which are known to use the boundary layer to fine tune their exposure to currents.

C.2.45 The flume experiments (see below) suggest that all species targeted in this model were capable of using the boundary layer (the boundary layer is a convenient conversational term which approximates as 'slow near bed' = boundary layer, as opposed to, 'fast away from bed' = mid-water). Thus, for each fish in the model the height of swimming above the bed was specified for each time step (either as a result of some behaviour or as a pre-set parameter of the fish at initialisation). It was assumed that since water depths are no more than a few metres at all sites a fish could change vertical position from and to any position in the water column in a 15 s time step and therefore did not model vertical swimming capabilities. We also used this function to moderate swimming speed related to depth, on the assumption that fish which are close to the bed or banks may be impeded relative to their mid water swimming speed. This was confirmed by our flume experiments, qualitatively, where the fish did not generally make large movements while remaining in the boundary layer.

Species-specific behaviours

C.2.46 Two additional behaviours included for flounder or eel are 'peel off' and day/night response. 'Peel off' works by specifying a threshold mid-water velocity – if this is exceeded at the fish position, the fish is moved up to a pre-set height above the bed. This means that a flounder or eel could be positioned close to the bed (and thus experience a fraction of the mid-water current) but when the current threshold is exceeded, it is moved up and carried in the main flow. At each subsequent step it attempts to reattach to the bed, and to swim toward its pre-set target mid-water current velocity, but as long as the current remains above the threshold at its position, it continues to be moved to the 'peel off' height above the bed. When it reaches a position at which the mid-water current is below the threshold the fish resumes its pre-set height above the bed.

C.2.47 The peel-off behaviour is applied to flounder and eel. Eels are also known to prefer to stay away from mid-water until night time. Therefore the day/night behaviour causes the eel swimming height to be lower (closer to the bed) during the hours of daylight. The models of each species start at a specific real time and date, and therefore night and day times are available to the model and can be accessed at each time step.

C.2.48 Vol 3 Table C.1 outlines some of key rules that can be applied in the fish model, the order in the table indicates their position in the hierarchy, near the top indicates the priority. Those highlighted in orange were not required in the final models but were used in development. The actual rules applied to individual species modelled and the reasons for their selection are detailed later.

Vol 3 Table C.1 Candidate rules for a fish individual-based model

Behaviour	Trigger	Cues required from the environment	Attributes changed for individual fish	Sensitivity
Land Avoidance	Intermittent, (detect zero depth or illegal element)	Depth	Direction (turn through 90 degrees randomly chosen left or right)	On or off
Navigation	Intermittent, (average number of steps)	Downstream direction	Direction	Based on downstream direction cue threshold
Emergency deep	Continuous	Depth	Direction – speed (move to burst speed, and sharp directional change)	Depth gradient sensitivity
Emergency shallow	Continuous	Depth	Direction – move to downstream direction	Downstream sensitivity
Velocity target	Intermittent – based on tidal state	Velocity tidal state	Direction	Velocity gradient sensitivity
Depth target	Intermittent – based on tidal state	Depth tidal state	Direction	Depth gradient sensitivity
Pressure gradient	Intermittent – based on tidal state	Velocity tidal state	Direction – move toward peak in pressure gradient	Velocity gradient sensitivity
Peel off	Intermittent – velocity threshold	Velocity	Swimming height	On or off
Day \ Night	Intermittent – based on time	None - External clock	Swimming height	On or off

Laboratory and field based studies of fish behaviour

C.2.49 This section describes the empirical studies undertaken based on ‘actual’ fish used to inform and refine the behavioural attributes used in the IBM. They include observation and measurement of aspects of fish behaviour within the controlled environment of a flume; and sampling of fish within the Thames Tideway using quantitative sampling techniques.

Laboratory flume studies

Objectives of flume studies

C.2.50 As the previous section indicated, certain aspects of the IBM are strongly influenced by assumptions of how fish behave. Critical unknowns concerned how quickly fish react to velocity gradients, and whether they exhibit preferences for the vertical position at which they swim in the water column per se or whether they are just reacting to vertical variations in velocity. No relevant published information on these aspects was identified during the literature review. To improve the veracity of the IBM, both aspects were therefore examined under controlled conditions in laboratory flume studies and used to inform the model set-up.

Reaction to velocity gradients

C.2.51 How a fish will react to a water current depends upon the tide, i.e. whether the fish is in a resting phase or moving with the tide in the direction of its intended migration. In the first case it is advantageous to select areas of low velocity to minimise energetic cost, while an actively migrating fish will be better served by entering fast currents. Midwater fish constantly move around to sample velocity gradients for this purpose. Bottom fish such as eels and flatfish can usually find refuge in the boundary layer and will remain there until the current changes direction or else they rise into the water column to feed. A critical parameter represented in the IBM is the rate at which they move across the water to sample velocity gradients relative to the time-steps of the model. Within the model this can have a significant effect on the rate of progress upstream. It was therefore considered necessary to measure this parameter directly by observing fish closely under controlled laboratory conditions.

Vertical velocity profile

C.2.52 Again, flume studies provided the opportunity study the reactions of fish to vertical current profiles in detail. By providing a substrate of coarse shingle comparable with that on the Thames foreshore (Vol 3 Plate C.1) on the floor of the flumes, a realistic vertical current profile could be replicated experimentally.

Description of flumes

ICER flume

C.2.53 Two separate flumes were used to study these aspects fish behaviour. The first stages of the work were carried out in the Southampton University International Centre for Ecohydraulics Research (ICER) indoor flume at Chilworth. This is a large flume with high flow capacity (12 m long, 1.4 m wide, 0.6 m deep, maximum flow rate 0.47 $m3s^{-1}$). This flume was suitable for work on the larger fish but was too large to allow detailed scrutiny of glass-stage elvers, which are transparent and proved difficult to spot on closed-circuit television (CCTV) footage.

Vol 3 Plate C.7 Indoor ICER flume, Chilworth

Ashurst flume

C.2.54 A second small flume was purpose-built at THA's laboratory site in Ashurst (Vol 3 Plate C.8). The test viewing section dimensions of this flume were 0.2 m wide x 0.35 m maximum water depth x 1.0 m long, with a maximum flow velocities in the test section of approxiamtely100 cms^{-1}.

C.2.55 Both flumes allowed overhead and side-viewing of fish behaviour.

Vol 3 Plate C.8 Small THA flume used for fine observation studies

CCTV observation and recording

C.2.56 For both flumes, observation of fish behaviour used CCTV cameras, fixed overhead to see the test section in plan view and to the side of the flume to give a view through the transparent side-wall. In the Ashurst flume, three overhead cameras were deployed along the length of the test section to maximise visible detail. The cameras fed into the same digital video recorder (DVR) with a common timer, allowing vertical and horizontal views to be synchronised. Thus, with parallax correction the x-y (horizontal) and z (vertical) coordinates of a fish could be determined at any point during an experiment. Recordings were made at a rate of 25 frames per second.

Water velocity measurements

C.2.57 Water velocities in the ICER flume were measured with a Nortek Doppler flow meter and in the Ashurst flume with a Nixon Streamflo miniature (10 mm dia.) propeller flow meter. Nominal test velocities reported for the experiments were made with the sensor located in mid-test section at a water depth of 60%. Velocity profiles were made at points indicated for each test series. Point velocities were averaged over a minimum of 10s for each reading.

Experimental set-Up and trial procedure

C.2.58 A number of arrangements were tested to evaluate different aspects of behaviour. These could be set up in either of the flumes.

Sloping bed

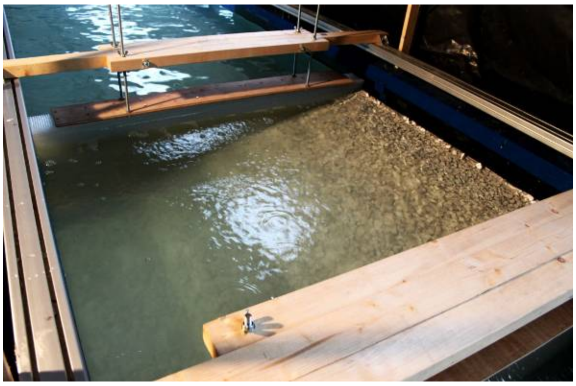
C.2.59 Natural conditions at the channel edge of the Upper Tideway are typified by the sloping shingle foreshore seen at Putney (Vol 3 Plate C.9). In flume studies this was represented by installing a false sloping floor coated with coarse gravel, attached using epoxy adhesive. The surface was then lightly spray-painted to improve visibility of fish against the background (Vol 3 Plate C.10).

C.2.60 The sloping-bed experiments were designed to offer the fish independent choice of water depth and proximity to the bed. This was to distinguish whether fish were showing a preference for one or the other factor. At the bottom of the slope in the flume set-up, the bed levelled out to provide a horizontal strip in front of the glass viewing panel. Bed slope was 58 degrees and in the ICER flume the flat bottom strip was 27 cm wide. This arrangement was replicated at a smaller scale in the Ashurst flume, but without a bottom strip.

C.2.61 At the start of the experiment, a single fish was introduced and allowed to acclimate for 5-10 min in slow flowing water (approximately 5 cms^{-1}). The CCTV recording was then turned on and the water velocity increased in three 10 min stages to Low, Medium and High settings. The High setting was designed to give mid-depth water velocities close to the maximum sustainable swimming speed for a fish of the size and species being tested so that its behaviour could be observed under a state of physiologically challenge. The Low and Medium settings were approximately half and three-quarters of this value respectively. The behaviour and positions of the fish were filmed throughout this period.

Vol 3 Plate C.9 Sloping shingle foreshore at Putney

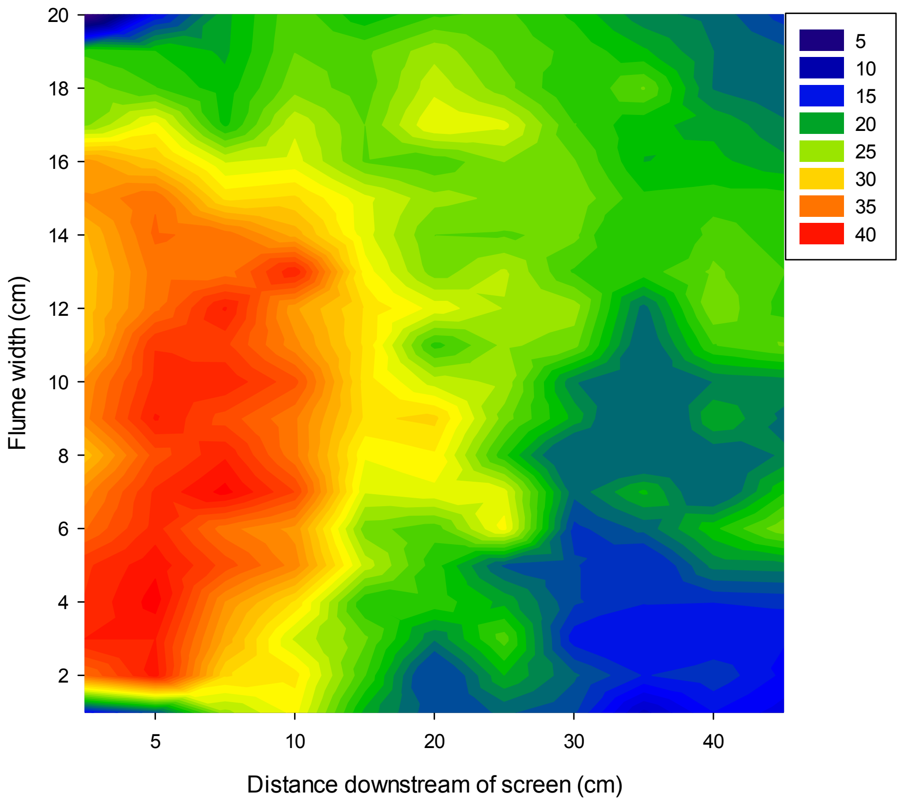
Vol 3 Plate C.10 Representation of the sloping bed in the Chilworth flume



Flat bed

C.2.62 Further experiments carried out over a flat flume bed in the smaller Ashurst flume were designed to investigate fish turning behaviour and horizontal velocity sampling. The close-up viewing allowed by use of the smaller-dimensioned flume facilitated more-detailed geometric analysis. For these experiments a single fish was introduced and left to settle for 5-10 min before starting the cameras. The water velocity was then increased to a value close to the expected maximum sustainable swimming speed and the fish was then filmed for 5 min at a steady flow. As the velocity profile across the flume was very uniform owing to the smooth walls, after 5 min the fish was then challenged by introducing a plywood baffle to cover part of the upstream screen, thereby creating a horizontal velocity gradient, allowing fish to choose preferred velocities (Vol 3 Plate C.6). Filming was continued for a further 5 min to complete the experiment.

Vol 3 Plate C.11 Horizontal velocity gradient



Example of horizontal velocity gradient downstream of screen created by blocking part of the screen (shown by black rectangle) at the upstream end of the flume test section

Sourcing and husbandry of fish

C.2.63 Owing to the (autumn) timing the flume work, sourcing of test fish of suitable size/lifestage from the Tideway was not feasible and other sources had to be found. 0-group bass were collected by shoreline seine-netting from the Eling Creek at the head of Southampton Water, Hampshire. Elvers (as glass eels) were obtained in November 2011 from a supplier in northern France, where elvers enter coastal waters earlier than in Britain. These had advanced to the fully pigmented stage by the time they were tested in January 2012. Flounder proved more problematical. After mounting several dedicated seine-netting and trawling surveys in Southampton Water and the Solent, small numbers of flounder were obtained from the cooling water screens of Tilbury Power Station on the Thames Estuary. These were supplemented by a number of the closely related Pleuronectid species, plaice (*Pleuronectes platessa*).

C.2.64 After collection, generally from mid-to high salinities, all fish were acclimated over a number of days to salinities of less than 10. Prior to and after testing, fish were held in recirculating tanks held at low salinity at either the Chilworth or Ashurst site. As all the species are euryhaline (tolerant of wide salinity variation) it was possible to maintain freshwater in the flumes, returning the test fish to the higher salinity of the holding facility after testing. Testing in the flumes was for short periods only (<1 h total exposure).

Analysis of video images

C.2.65 Analysis of data from VCR footage was carried out using Logger Pro 3™ (Vernier Software), a program which allows co-ordinate information to be extracted from still-frame 2D video picture. This is a time-consuming manual ‘mouse-and-cursor’ process, in which for each frame inspected, an operator has to track the position of a fixed point on the fish (e.g. an eye) in the horizontal view and register the x-z co-ordinates. The procedure is then repeated for corresponding frames in the overhead view to give a complete x-y-z co-ordinate. An algorithm then adjusts the position to remove parallax error caused by camera viewing perspectives.

Sloping bed experiment

C.2.66 For this trial series, the position of the fish was represented in two measurements:

C.2.67 The percentage depth of water column: The water column at its greatest depth was divided into zones of 10%. Using the observed depth measurements, histograms were produced for each fish and a composite one for all fish.

C.2.68 Distance above the bed: The formula for the gravel slope was calculated. For the flume width points exceeding the start of the slope, the flat surface width was subtracted and then multiplied by the slope constant to get the height of the slope at each individual position. The slope height was then subtracted from the observed depths to get the distance from the substrate for each fish. These were then grouped into 20mm wide bands and histograms produced for individual fish and a composite graph for all fish.

Flat bed fish turning trial analysis

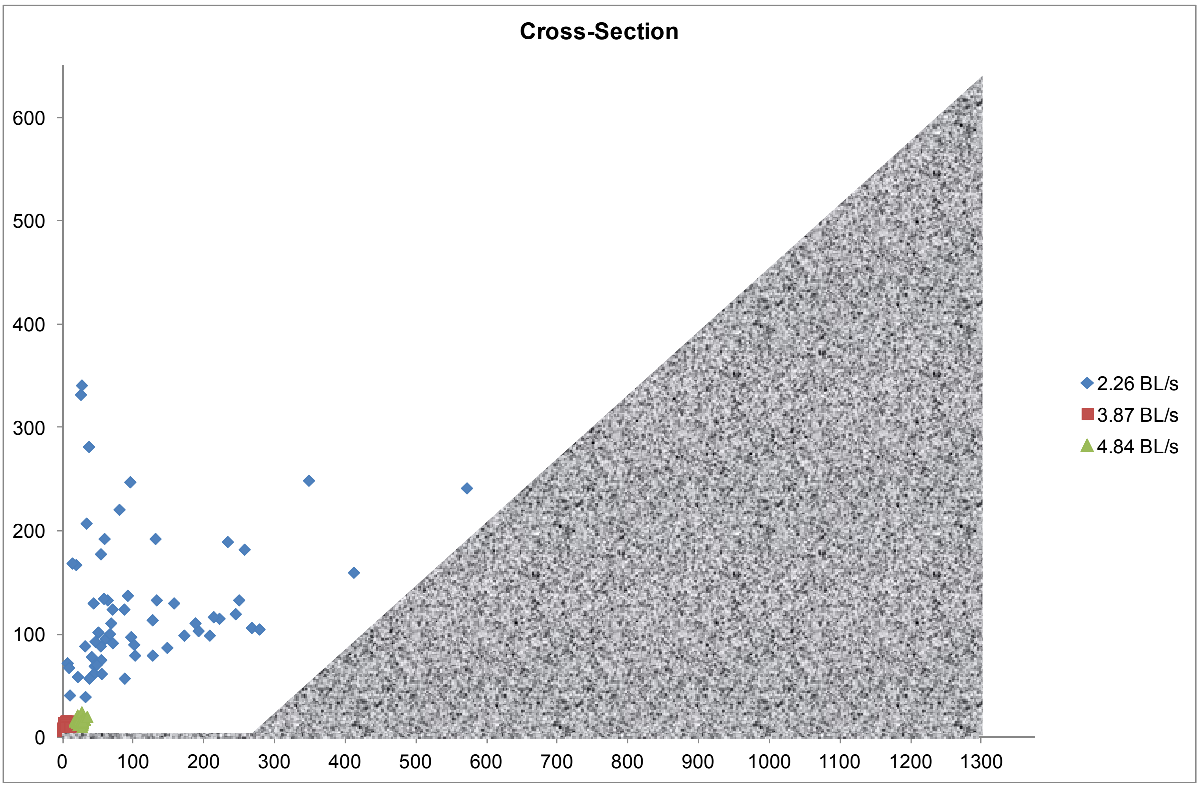
C.2.69 Analysis of turning behaviour was made for selected sequences of video based on Ashurst flume observations only. In order to select useable sequences for detailed analysis, the whole film was first reviewed to identify times when fish were demonstrating velocity sampling behaviour, i.e. swimming laterally across the test channel in response to an uneven velocity gradient. The side view camera was then consulted to ascertain which of the top cameras the fish held position over the trial. The relevant top camera video sequence was then loaded into Logger Pro 3™ and settings changed to allow multiple points to be recorded per frame. A sequence was identified as a lateral movement across the channel either a one-way or a return sweep as long as the fish remained orientated upstream. Every 0.2s interval over the duration of the turning sequence the position of the snout, point of inflection and tip of the tail fin of the fish was recorded. The points were transferred to an Excel spreadsheet, each sequence separated and just the head and tail points were isolated. For each sequence a separate line graph was produced, showing alignments at successive 0.2s intervals, from which turning rates (radians per second) were estimated.

Flume trial results summary

C.2.70 Results presented here are illustrative.

C.2.71 Vol 3 Plate C.12and Vol 3 Plate C.13 show results for 0-group bass obtained in sloping bed trials in the Chilworth flume. Vol 3 Plate C.12 shows an example of data from a single fish experiment for the three velocity settings. It is seen that at the Low speed setting the fish moved around in the water column. At the Medium and High speed settings the fish locked down onto the shingle boundary and moved little.

Vol 3 Plate C.12 Fish position co-ordinates



**Example of fish position co-ordinates from a single 0 group bass experiement with sloping floor flume arrangement*

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C.2.72 The upper edge of the grey shaded area represents the surface of the gravel slope. Blue, brown and green points represent observations made at Low, Medium and High velocity settings respectively. The left-hand axis represents the glass wall of the flume. The x- and y-scales are dimensions in millimetres.

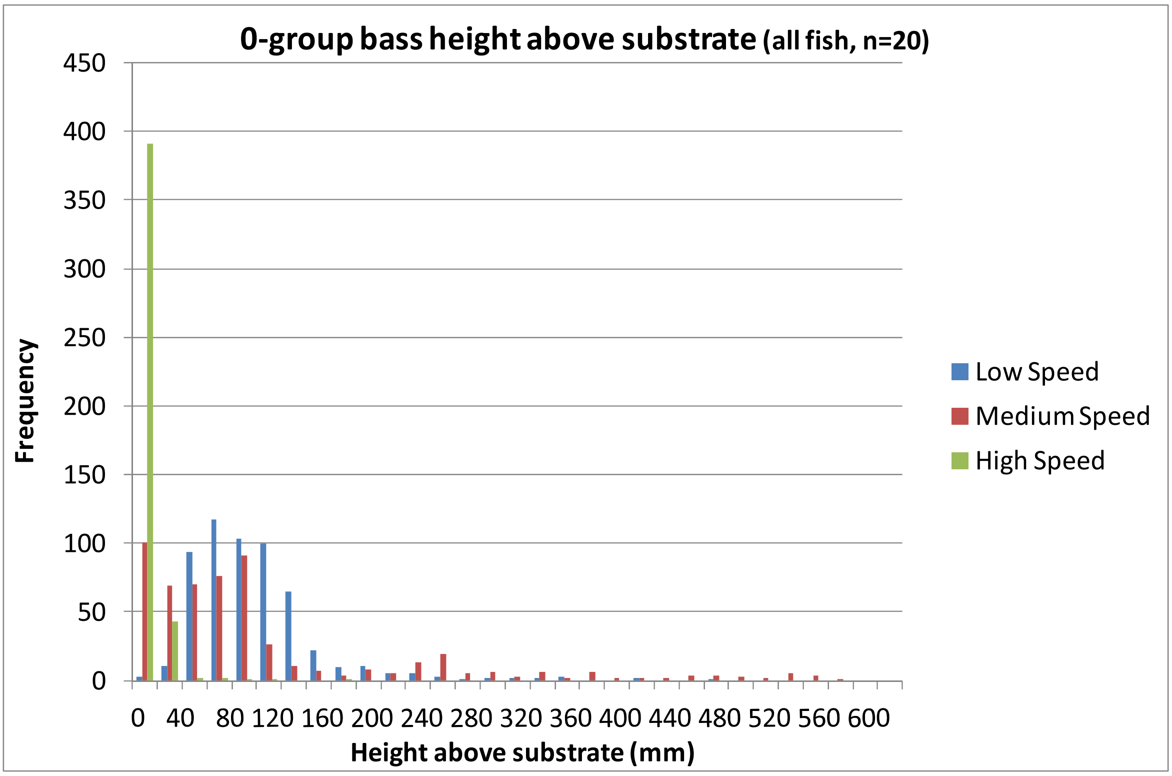
C.2.73 Vol 3 Plate C.13 and Vol 3 Plate C.14 present the combined data for all 0-group bass from the same experimental series. Vol 3 Plate C.13 shows fish height above the substrate and Vol 3 Plate C.14 shows percentage height in the water column. Vol 3 Table C.2 gives mean values. It is seen that at High speed (i.e. close to the fish's maximum sustainable swimming speed, the fish sit close to the bed (13 mm mean, i.e. about one body depth from the substrate) and about 5% of the water column depth above the bed. Vol 3 Plate C.4, the latter would expose the fish to a maximum of about 40% of the depth-averaged current speed, rising to about 70% for the Low and Medium speed cases. The experiment is equivalent to the ebb tide case, in which the fish has a preferred direction of movement towards the head of tide and stems the tide when it is flowing in the reverse direction. In doing so, adjustment of its height above the substrate allows it to maintain a physiological swimming optimum without contacting the substrate itself.

C.2.74 Similar sloping-bed experiments conducted for both flounder and elver showed that these species remained on the bed throughout the exposure period, avoiding the need to make vertical adjustments to maintain station. Such species are known as 'thigmophilic' (touch-loving) and their robust skin and mucous coating protects them from abrasion damage, unlike the more sensitive mid-water 'thigmophobic' species. The wider ecological implications of these strategies are not relevant here but remaining in the water column, though energetically more costly, does for example allow midwater fish to continue feeding.

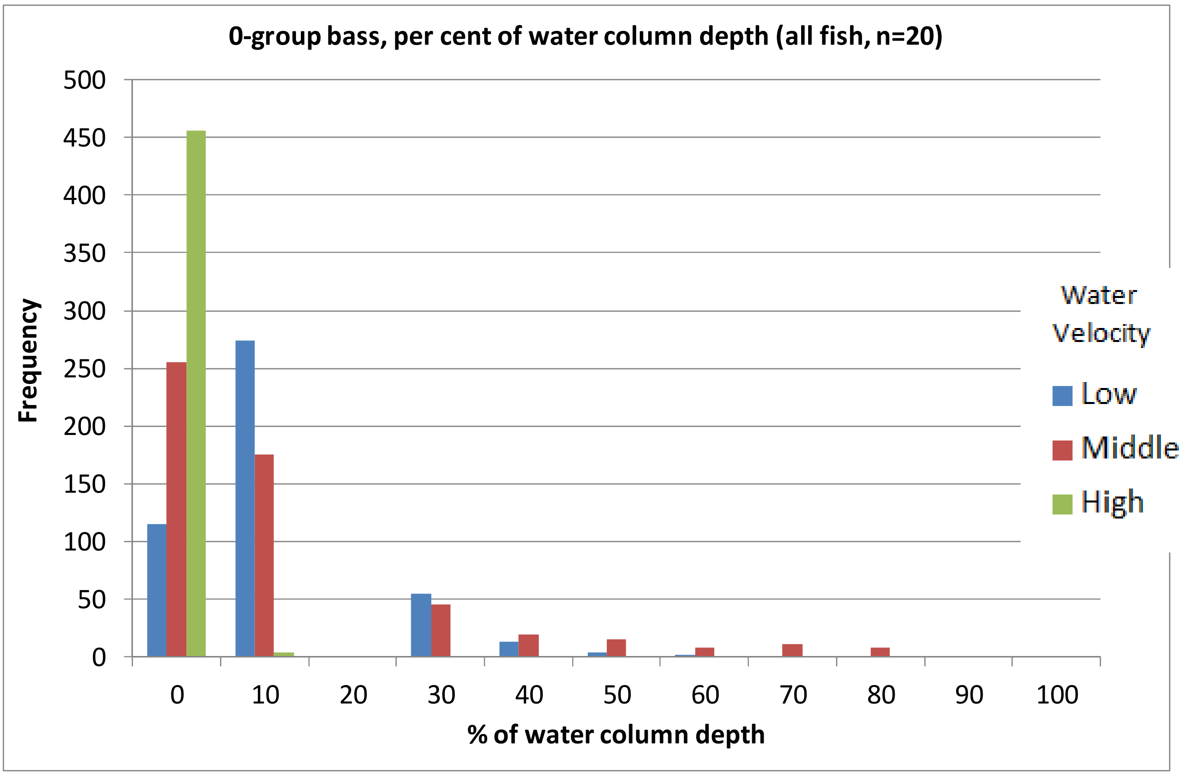
Vol 3 Table C.2 Mean values of height above substrate and percentage height in the water column for 0-group bass

Parameter	Low Speed	Medium Speed	High Speed
Height above substrate (mm)	100	107	13
% height in water column	16.4	17.2	5.1

Vol 3 Plate C.13 Experimental observations of 0-group bass preferred height above the substrate



Vol 3 Plate C.14 Preferred vertical position in the water column



Field survey data

C.2.75 A series of approximately monthly juvenile fish surveys was carried out at five sites on the Tideway over the months May to October, 2011. The purpose of these surveys was to gain more detailed information on juvenile fish distribution, growth and seasonality than had previously been available from EA survey datasets, in order to 'ground- truth' rule sets developed from literature review. The surveys are reported in full in Vol 3 Appendix C.1.

C.2.76 The five juvenile fish survey sites are listed in Vol 3 Table C.3. The sites were chosen to include the Tideway section common to all proposed Tunnel routes. Three sampling methods were adopted to maximise information, these being micromesh beach seine netting, Riley push-netting and kick-sampling. The three methods sampled water depths from zero to approximately 1.5 m. Riley push-netting was routinely carried out at two water depths, 30 cm and 60 cm (nominal) allowing small-scale depth-related variations in distribution to be evaluated. As sampling was carried out near to low water on the tidal cycle, this included the subtidal and intertidal.

Vol 3 Table C.3 Juvenile fish survey sites

Juvenile fish survey sites on the Tideway*	
Survey Site	**National Grid Reference**
Kew	TQ19097787
Putney Bridge	TQ23947582
Chelsea	TQ28277781
Blackfriars Bridge (Southbank)	TQ31248051
Bermondsey Wall East (London Bridge)	TQ3457379757

**Sampled May – October 2011*

C.2.77 The juvenile surveys provide the following key data:

a. Times of first entry of 0-group individuals into the Tideway reaches that would be affected by the Thames Tideway Tunnel;

b. Fish length distributions at time of first arrival, and changes in length distribution over the rest of the summer/early autumn (indicative of growth and new waves of fish entering the Tideway section);

c. Relative abundance (catch-per-unit-effort: CPUE) of fish at each of the survey sites through the summer/early autumn period.

C.2.78 The distributions of different species within the Tideway shifted during the course of the seasons, indicating the highly mobile nature of these juveniles as they match environmental requirements to the needs of the lifestage. The initial incursions of species such as flounder and bass that are spawned in the outer estuary or at sea were rapid and they were found throughout the Tideway soon after their first appearance. 0-group bass built up in densities in the upper Tideway as the season progressed, while

0-group flounder penetrated upstream reaches early in the season and became more uniformly distributed along the Tideway as the seasons progressed; by September, there was a major shift in their distribution back towards downstream areas.

C.2.79 The survey work confirmed the importance of the shallow, sloping marginal intertidal areas of the upper Tideway for juveniles of many species, including flounder, dace, bass, perch, gobies. It is predominantly these areas that would be affected by temporary and permanent project structures. Although juvenile fish were found predominantly in the shallow margins, comparative fishing across the 30 to 60 cm depth range showed that flounder and bass were uniformly distributed across these depths. Although seine-netting reached to depths of 1.5 m, it was not feasible to distinguish at what particular depth fish were caught at depths >60 cm.

C.2.80 During the study, glass eels, elvers and eels were caught only occasionally throughout the sampling programme, underlining the current general low abundance of the species in the upper Tideway. The drastic decline of the European eel in freshwaters over the past twenty years is well documented and recent catches from the Thames system have been very low (Gollock et al. 2011). Recruitment of glass eels has declined and since 2000 and is at an historical low at just 1-5% of the pre-1980 levels (Freyhof & Kottelat, 2008). 0-group smelt, although appearing in samples early in the year (June), disappeared following a serious combined sewer overflow (CSO) pollution event in the upper Tideway later in that month.

C.2.81 While for the purposes of the IBM, data for only the species used in the model (flounder, eel, bass) were of interest, the substantial dataset for other species has provided additional baseline data for the Tunnel Project.

Fish behaviour rule sets

Introduction to fish rules

C.2.82 The information regarding fish behaviour derived from background literature and supplemented with the laboratory flume studies and field surveys was used to create a ‘rule set’ for each of the three target fish species. The general principles of fish rule sets were introduced in the first section of this report. The addition of fish behaviour rules to the model differentiates the IBM from a simple hydraulic model in which particles move passively with the flow. Running the IBM with appropriate rules in place needs to create fish behaviours that reflect reality and that would be recognised by the expert observer.

C.2.83 It is neither necessary nor practicable to emulate every aspect of fish behaviour, only those which concern the question(s) being asked. In developing an IBM, therefore, it is good to take a reductionist approach to rule selection. In this approach, after taking and applying a group of candidate rules, the effect of removing one or more rules on the modelled behaviour is tested until a rational behaviour is achieved using the least number of rules. Running the model then demonstrates to the observer the implications of the rules selected.

Candidate rules

C.2.84 Vol 3 Table C.4 illustrates the candidate rule set used for flounder, as an example. Expanded tables for flounder, elver and bass are to be found in Annex A, where supporting evidence for the rules extracted from the literature is provided. The final rule sets shown in Annex B incorporate evidence from the juvenile fish field surveys and flume studies discussed below.

Vol 3 Table C.4 Candidate rule set for flounder

Behavioural Attribute	Rule Description
Predominant Direction of Migration	Juvenile flounder progress upstream towards head of tide in April May at lengths 12-25 mm. From July they begin to disperse back downstream at a modal length of ~40 mm.
Responses to Tides	April- July, length <40 mm, apply selective tidal stream transport, biased to move on flood tide. Stay on bed on ebb, following tide down. Also, see Response to Velocity Gradients below: assume displaced if >45 cm/s velocity. August-October, length >40mm, disperse downstream to maximise habitat use.
Preferred Water Depths	Target water depth <1m up to a length of 40mm, April-July. Target water depth 1-2 m July to September, length>40 mm. Target deepest water mid-channel from October.
Vertical Position in Water Column	Remain on bed on ebb tide. Enter water column on flood.
Fish Size and Swimming speeds Volitional, MSSS, Burst	Apply MSSS from table as follows: April: assume length 12 mm; May: assume length 20 mm; June: assume length 32 m; July: assume length 44 m; August: assume length 58 m; September: assume length 68 mm; use 1 bl/s for volitional swimming.
Predator Evasion	Apply “danger” rule for fish of <30 mm if they stray into depth . 1m.
Response to Velocity Gradients (shear)	Fish sample vertical velocity profile, selecting low velocities in resting phase and high velocities during active migration.
Diurnal Changes in Behaviour	Do not apply day-night rule on Tideway.
Salinity Lethal levels Avoidance levels	Do not apply salinity rule to flounder.

Depth-dependent mortality rule

C.2.85 Some further explanation is required for the depth-mortality rule.

C.2.86 The principle behind this rule is that juvenile fish prefer to remain in shallow water, as moving into deeper water may expose them to a greater predation risk from piscivorous (fish-eating) fish. Yearling-to-adult bass, eel, pike, salmonids and other predatory species are examples of piscivorous fish species. However, this risk must be balanced by predation risk at the water margins from shallow-water crustaceans such as shrimps, prawns and crabs and from piscivorous wading birds. Applying the rule for base, temporary works and permanent works cases provides a formal basis for assessing the cumulative effect over the whole Tideway passage of any increased mortality caused by fish being pushed into deeper water as a result of the Project structures.

C.2.87 Review of the literature (Vol 2 Appendix C.2) indicates the existence of these threats but presently data are insufficient to form scientifically defensible equations relating mortality risk to water depth. The approach taken has therefore been to include a depth-dependent mortality rule within the IBM and to apply realistic natural mortality rates (M) from the literature to demonstrate sensitivity to this rule.

C.2.88 Within the IBM, the rule ascribes one instantaneous mortality rate ($M_{shallow}$) to fish swimming in shallow water and another to fish swimming in deep water (M_{deep}). Mortality is accumulated through each time step of the model at the appropriate rate, so that its risk is changed more as the fish spends longer in deep water. Whilst the presumption based on the literature review is that mortality rate increases as a fish moves into deeper water, the model will reflect whatever values are ascribed to $M_{shallow}$ and $M_{deep.}$

C.2.89 In selecting reasonable values for $M_{shallow}$ and $M_{deep,}$ published values for each species (or closely related species) were collated to generate a range of observed natural mortality rate values for relevant life stages. The upper and lower bounds of these values were used to constrain the values used for sensitivity analysis. For consistency with the above hypothesis of increasing mortality risk with depth, $M_{shallow}$ was set at the low-end value of M, while M_{deep} was set at the maximum observed value as shown in Vol 3 Table C.5. These have been drawn from a collation of published mortality values given in Annex A. For the purposes of the model, the change in mortality rate is shifted between $M_{shallow}$ and M_{deep} as the fish cross the 1m depth contour.

Vol 3 Table C.5 Assumed shallow and deep-water mortality rates used in sensitivity analysis

Species	Lifestage/ Size	Instantaneous Daily Mortality Rate (proportion per day)	
		Depth ≤1 m $M_{shallow}$	Depth >1 m M_{deep}
Bass/striped bass	30-70 mm	0.0014	0.008
Flounder/plaice/sole/dab	10-75 mm	0.006	0.017
Eel, European/American	Glass eel Elver	0.010	0.067

Expert consultation and final rule sets

C.2.90 To ensure alignment with expert views, these candidate rule sets were circulated for comment and peer review to the EA and to Mr Steve Colclough (independent transitional water fish specialist). The process proved helpful and informative and led to a number of improvements in the rule sets based on observational experience on the Tideway. Responses are included in Annex B.

Initial model runs and refinements

C.2.91 The following section describes the way in which the model is set up to simulate the migration of a shoal of fish through the Tideway under the three development scenarios (i.e. base case, temporary works and permanent works). It includes the rationale for the:

a. Number of model fish per run;

b. Geographic start and end points for the model;

c. Assumed tidal conditions under which the model is initiated;

d. Anomalous conditions caused by assumptions regarding water movement at the boundaries of the hydrodynamic model

C.2.92 Paras. C.2.105 to C.2.112 describe the way in which the sensitivity of the model was tested for variations in any single parameter. This is important since excessive or insufficient sensitivity to changes in a parameter such as fish swimming speed may result in model outputs which do not accurately reflect real conditions.

C.2.93 The way in which the Markov chain model is incorporated into the IBM is described in paras. C.2.113 to C.2.117. By dividing the river into zones, and calculating the probability of fish passing through each zone, the Markov model provides outputs which can be used in the ecological impact assessment. Paras. C.2.115 to C.2.117 describe the data required from the IBM, and the steps used to generate the Markov probabilities. Further details of the Markov model are presented in para. C.2.13.

C.2.94 In all cases where screenshots are presented, they are interpreted as follows:

a. Arrows represent direction of flow

b. Background colours show relative water velocities (cold colours slow, warm colours faster)

c. White structures, temporary works; white dots, model fish positions for temporary works

d. Red structures, permanent works; red dots, model fish positions for permanent works

e. Black dots, model fish positions for base case.

Number of model fish per run

C.2.95 Each IBM model run was seeded with 2,500 fish particles to provide 25 sets of results which could be used in a simple Student's t-test to differentiate between treatments (base case, permanent and temporary works) to test for statistical significance of difference between results for treatments in a robust manner.

Geographic start and end points

C.2.96 Geographic start points were randomly distributed within two 50 m square areas approximately 1.5 km west of the Thames Barrier on either side of the river, in water about 5m deep. The release areas were chosen to allow the model fish enough time before reaching the first works site to ensure that their pattern of dispersion was entirely due to their behaviour and the water currents rather than the distribution of their release points. This provided a long run-in period of more than a day and several entire tidal cycles. The sensitivity testing demonstrated that this release zone was more cautionary than required.

C.2.97 The model was run for five days for each of the scenarios. This period of time is adequate to ensure that all species had interacted with all of the works areas. The geographic finishing lines varied among species but were between Putney Bridge and Kew Bridge. Again, the models were tested in preliminary runs and found to operate as expected, right up close to the boundary of the hydrodynamic model - although it would not be good practice to report results from areas close to the boundaries of the model where hydraulic anomalies are more likely to occur. The hydraulic conditions for all treatments are exactly the same upriver of Putney and so little benefit was to be derived in comparative tests between the treatments past this point, but model runs were still valuable in checking calibration of the base case to ensure that the fish acted as expected in all areas of the river that could be evaluated.

Initialization

C.2.98 Particles are originally deposited in the model at beginning of ebb tide in two zones which are defined in the input data structure. They are released randomly over a period of 4 hours and this release period can be set to any time. They are released in water that is over their emergency depth and therefore their immediate behaviour on release is to swim to shallower depths. ‘Emergency depth’ is a term used in the model to describe very shallow depths where there is a risk of fish going onto dry land. It was set to 20 cm. These initialisation zones were placed well upriver of the first works to give the model fish time to reach a stable distribution determined by their behaviour.

C.2.99 The chosen start date was different for each species to comply with observations on first appearance of the 0-group fish of each species observed in the juvenile fish field sampling programme undertaken in 2011 (see below). The start time was determined from the Port of London Authority tide tables for that date in 2011 to match the tidal state of the model with a particular time of day. These were as follows:

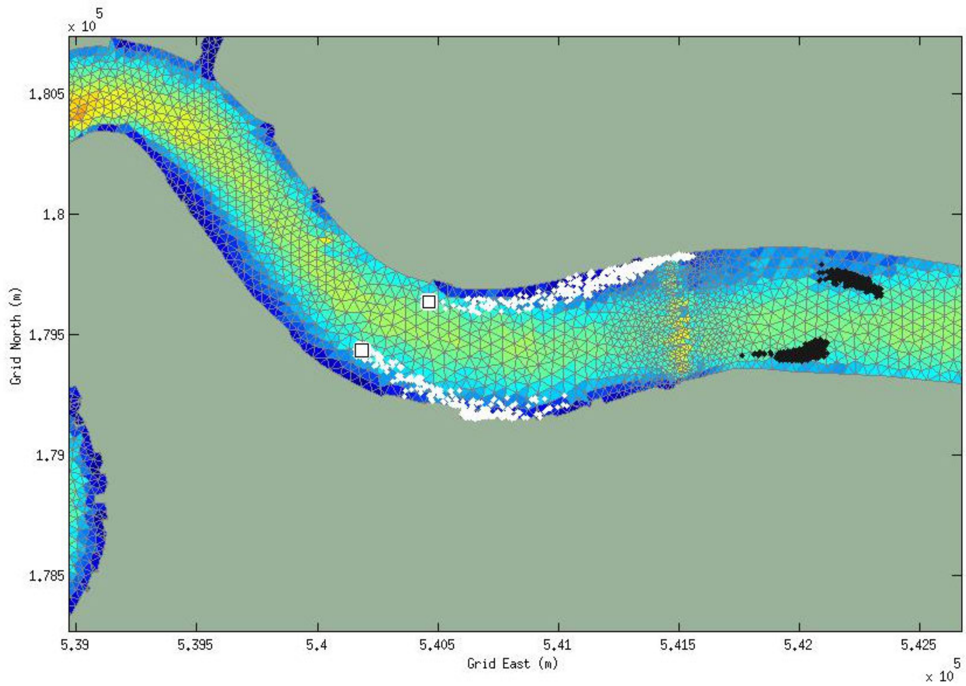
a. Bass 30-Jun-2011 00:33:00

b. Flounder 01-May-2011 00:23:00

c. Eel 01-Jun-2011 00:58:00.

C.2.100 From these start times, the 2,500 fish were randomly staggered in starting time over a four hour period to spread them out over the tidal cycle. The sensitivity tests indicated that the model is insensitive to the time of release through the tidal cycle, so this staggering of release proved unnecessary but that was unknown earlier in the modelling.

Vol 3 Plate C.15 Release of particles from initialisation zones at the beginning of the model



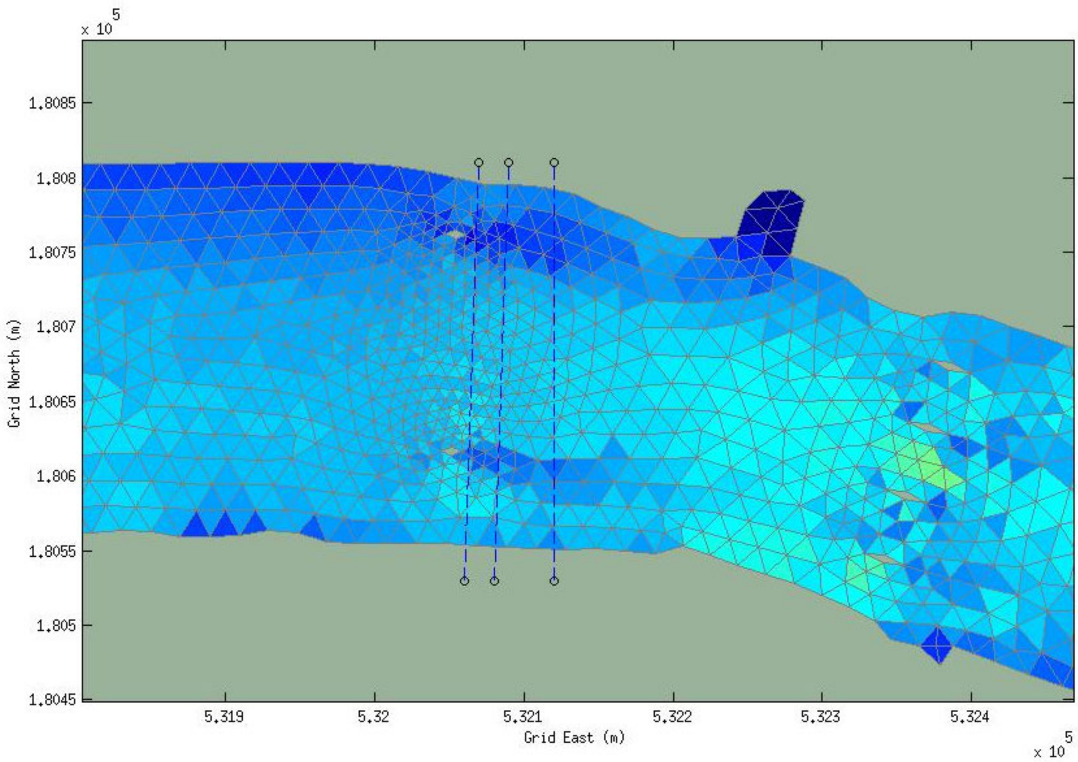
C.2.101 The coloured triangles in Vol 3 Plate C.15 represent the grid of the hydrodynamic model. They are colour-scaled by water speed, with smaller triangles representing high-resolution of the model.

Dealing with boundaries, drying and artefacts

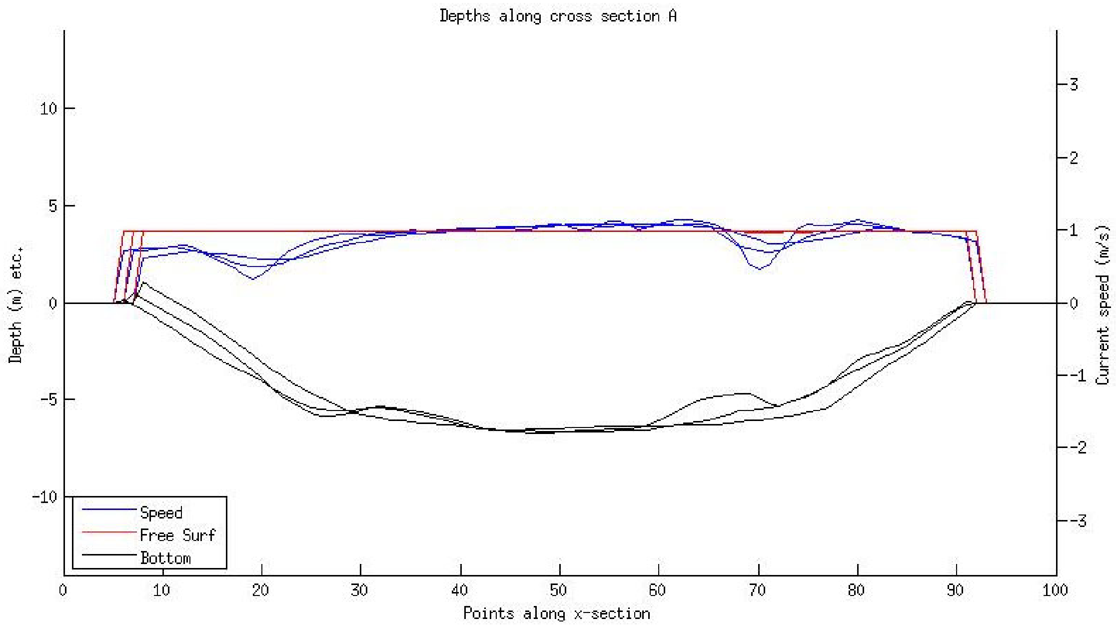
C.2.102 The water models were also checked carefully for anomalous flow conditions around boundaries and structures. The water model balances the water momentum at the boundaries to ensure no water leaves or enters the model during a run. This can lead to currents directed outward through a dry boundary or inward from one. While this is not a problem for the water model, it can be a problem in the fish model, because fish or passive particles represented in the model can become trapped against a dry boundary.

C.2.103 Examination of the water model allowed any anomalous behaviour in the water model to be filtered out when applied to the fish model. In particular, the models were checked In the vicinity of structures to ensure logical water conditions were represented, since these might strongly influence some of the fish behaviours (where they have been seen to shelter in these zones) (Vol 3 Plate C.15 and Vol 3 Plate C.16). Video clips may be generated to view the movements of these types of graphs through a tidal cycle.

Vol 3 Plate C.16 Transects across the modelled Thames (near Millennium Bridge) used to assess the water conditions downstream of bridge piers

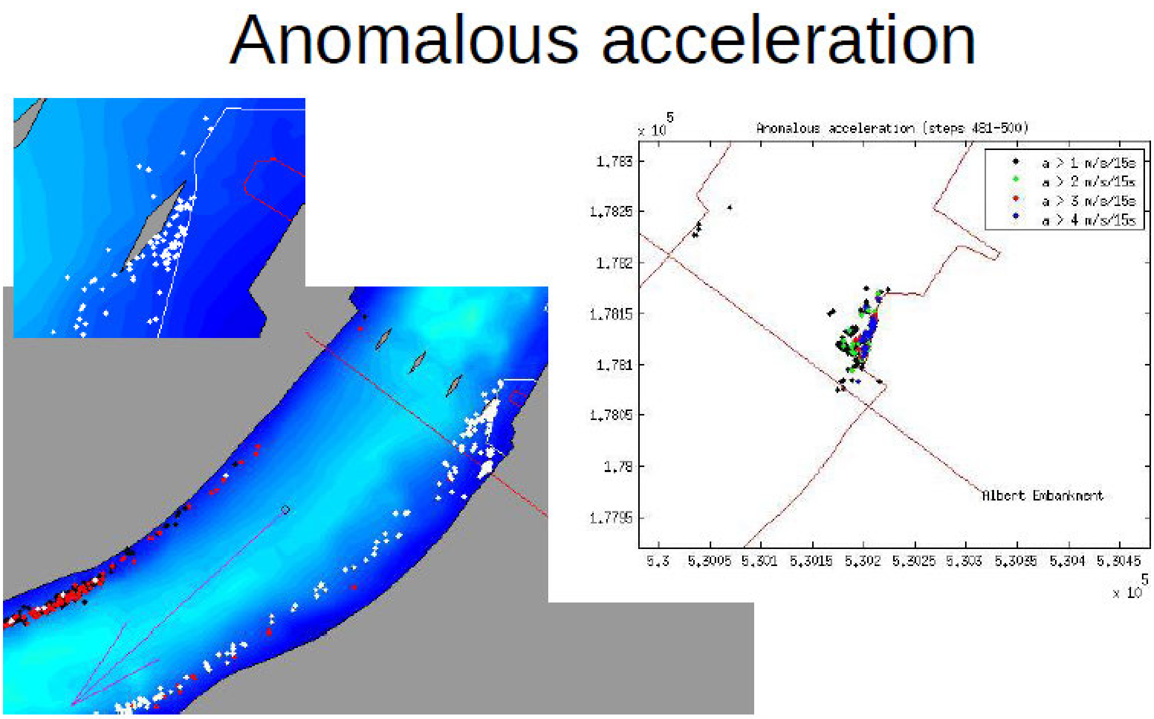


Vol 3 Plate C.17 Speeds, depths and free surface across transects in Vol 3 Plate C.14



C.2.104 Vol 3 Plate C.17 shows how the current speed drops close to the bridge piers.

Vol 3 Plate C.18 Examples from IBM model run in the vicinity of Albert Embankment



The customised graph on right highlights the position of any anomalously high situations of acceleration between steps 481-500 (~3 hours). The viewer sections on left show typical views of a single step during this time (white being temporary works fish and developments in this case) – some of which get caught between bridge pier and proposed works.

Sensitivity analysis

Purpose and principle

C.2.105 Sensitivity tests were conducted to assess whether the results of the modelling were heavily dependent on relatively small variation in any of the parameters. High sensitivity of the overall result to small variations in input parameters is a not a concern if those differences can be shown to be realistic. For instance, a fish movement behaviour model should be sensitive to swimming speed of fish, and results across a broad range of fish capabilities should be represented. On the other hand, very low sensitivity to variation of certain input parameters suggests that those parameters are not required in the model and may serve to confuse the meaning or to give a false impression of realism without adding any value. So lack of sensitivity should also be identified through sensitivity testing. The model is also built on a number of sub-models and it is possible that parameters are not independently sensitive. This was tested for by running the model across a wide range of input parameter sets.

C.2.106 The model developed here provides an analysis of how fish that use selective tidal stream transport would be impacted by changes to the hydrodynamics of the river in three potential development scenarios ('base', 'temporary' and 'permanent'). Thus the results of the model are reported by comparing the three treatments. The model is calibrated against expert opinion and scientific data on fish life history. The model is therefore designed to interpret the implications of expert opinion, while the statistical results of the scenario comparisons can be reported by simple but robust comparative statistics between the treatments, there is no requirement for formal analysis of uncertainty in the absolute truth of the model.

C.2.107 Sensitivity testing has been used to highlight any sensitivities in the result (of a difference between treatments) to relatively small parameter variation. For testing purpose, small, medium and large variations have been defined as 1%, 10% and 50% respectively, and the logical consequences of parameter variations are 'dispersive' (where variation serves to increase model-induced variation in the results and can obscure the signal which is used to identify a result), 'anti-dispersant' (the opposite) and 'systemic logical' (where variation pushes the results in a logical way (i.e. increased swimming speed leads to faster movement up river) or 'systemic illogical' (the opposite and a potential cause for concern, or an interesting counter-intuitive result).

Sensitivity testing results

C.2.108 Sensitivity of parameters is outlined in Vol 3 Table C.6, which uses a colour coding to denote parameter sensitivities. The red colour denotes a high dependency of the model results on the value of this parameter, the orange denotes moderate sensitivity to this parameter and the green denotes low sensitivity. Where red and orange codings are shown, additional refinement of the model was needed to produce stable results.

C.2.109 The model was run >200 times, across the full range of the river and species variations. Each run consisted of 2,500 similar model instantiations of a single model fish. The time step for the model is shown as red, or high dependency, and after a number of sensitivity runs was set at a conservatively low value of 15 s, although only when it exceeded 60 s did it make any significant difference to the results. Each run consisted of around 30,000 fish object updates and behavioural steps (75 million per run).

C.2.110 The key test during development and calibration was to ensure that the model fish moved up the river in the time expected using selective tidal stream transport and were not indefinitely trapped by any structure, current or beach. For example, in the case of swimming objects in hydrodynamic models, without additional behaviour, it is very common for a fish object to be trapped on a gently graded beach as it moves to a position that dries before the next step. It is for this reason that the short time step of 15 s was chosen, and specific land avoidance behaviour modelled. The number of hold-ups was measured and shown to be consistently less than 1% of fish at any step (these stipulations were relaxed slightly (~5% max hold up) for eel and flounder which interact strongly with shallow water and can spend a low-tide period in ephemeral ponds which form on wide beaches).

C.2.111 Vol 3 Table C.6 identifies all the key variables in the model and, where appropriate, the values assigned to them on the basis of the literature review and field and laboratory studies. The role of these variables is in most cases discussed in earlier sections of this report.

Vol 3 Table C.6 Results of sensitivity testing

Variable Type	Sensitivity Class	Values Used		
		Eel	Flounder	Bass
Size of start zone		50	50	50
Model time step (seconds)		15	15	15
Diffusion coefficient- horizontal		0.02	0.02	0.02
Diffusion coefficient- vertical		1.0e-03	1.0e-03	1.0e-03
Arbitrary fish start direction		3.6128	3.6128	3.6128
Ave no. of steps between perfect navigational data		5	5	5
Fish burst swimming speed (ms^{-1})		0.5	0.3	0.3
Length of burst (seconds)		20	20	20
Length of relax time after burst (seconds)		60	60	60
Cruising speed (ms^{-1})		0.08	0.03	0.11
Most efficient speed (ms^{-1})		0.05	0.02	0.05
Velocity target flood (ms^{-1})		0.6	0.3	0.5
Velocity target ebb (ms^{-1})		0.2	0.2	0.05
Velocity target range (ms^{-1})		0.02	0.05	0.05
Turning angle / rad.(rad)		0.0982	0.0982	0.0982
Emergency turning angle / (rad.)		0.3927	0.3927	0.3927
Sensitivity to velocity (rad)		0.005	0.005	0.005
Peel off velocity (ms^{-1})		0.45	0.45	n/a
Peel off height (m)		0.1	0.1	n/a
Flood tide swimming height off bed (m)		0.5	0.5	0.5
Ebb tide swimming height off bed (m)		0.01	0.01	0.01
Velocity at depth function (ms^{-1})		5e-04 to 0.05	5e-04 to 0.05	5e-04 to 0.05
Sensitivity to navigational cue (ms^{-1})		0.05	0.05	0.05

**The colours indicate the level of concern about the sensitivity of a particular parameter*

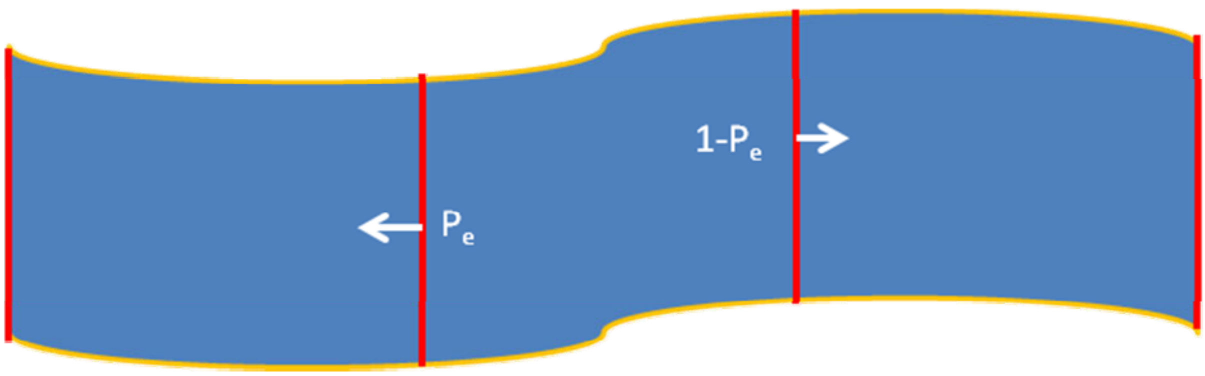
Sensitivity Levels		
No concern	Potential concern	Further analysis

C.2.112 It is expected that parameters that form the basis of the model results should be 'no concern' (green), i.e. that they are not excessively dependent on the accuracy of the values given and that we can expect to specify them with sufficient accuracy. Parameters where this is a potential concern (orange) need more attention and so, e.g. the velocity at depth function was measured for typical Tideway intertidal habitat (Vol 3 Plate C.5). No parameters were super-sensitive to the 1% level which would be a major concern, and only one was illogical in its sensitivity (time step). The time step in the model is a key parameter on which all the others depend, including in terms of sensitivity and so is shown in red, requiring further analysis. The low value was chosen to be as conservative as possible, ensuring that detail was not missed.

Markov chain method

C.2.113 Markov-chain models are commonly used in ecology to analyse animal movements along one or more pathways (Southwood and Henderson, 2000[3]). The Thames Tideway can be viewed as a linear series (1-D) of connecting boxes, each box representing a section of river. Fish in one 'box' can either remain there or move upstream or downstream to the next 'box', with probabilities of p or (1-p) respectively (Vol 3 Plate C.19). In Markov terminology, the 'box' is referred to as a 'Markov state', and the probabilities of a fish moving from one state to another as a 'transition probability'. The mathematics of Markov chains can be found in text books such as Kemeny and Snell (1960).

Vol 3 Plate C.19 Illustration of Markov chain applied to movement of fish between adjacent river reaches



C.2.114 The Markov analysis divided the Tideway into the AQMS zones used by the EA for reporting water quality data provide suitable 'boxes' for the Markov analysis (see para. C.2.14). Vol 3 Table C.7 shows their positions relative to London Bridge, and into which zones individual project sites fall. Project sites in every case occupy only a fraction of the 3 km zone.

Vol 3 Table C.7 Environment Agency AQMS zones

Location	EA AWMS Zone No.	Distance Downstream from London Bridge (km)	Thames Tideway Tunnel Foreshore Construction Sites which fall within Zone
Upper Tideway	2	-27	(Teddington)
	3	-22	
	4	-19	
	5	-16	
	6	-13	Putney Embankment Foreshore (12.0km)
	7	-9	Chelsea Embankment Foreshore (6.6km)
	8	-6	Heathwall Pumping Station (5.4km) Albert Embankment Foreshore (4.6km)
	9	-3	Victoria Embankment Foreshore (2.6km) Blackfriars Bridge Foreshore (1.4km)
	10	0	(LONDON BRIDGE)
	11	3	Chambers Wharf (1.7km)
Lower Tideway	12	6	King Edward Memorial Park Foreshore (3.2km)
	13	9	
	14	13	
	15	16	(Thames Barrier)
	16	19	
	17	22	
	18	27	
	19	31	
	20	36	
	21	41	

Note: Locations of numbered Environment Agency AQMS zones as river kilometres upstream and downstream of London Bridge, and zones in which the project foreshore sites fall. Bracketed locations are defined as spatial reference points, but are not Thames Tideway Tunnel sites.

C.2.115 All of the data used to generate Markov statistics can be extracted from the individual-based model during post-processing. The following key elements are used:

a. Matrix of positions of all fish at each time step

a. Matrix of depth of water at each fish position at each time step

b. Position of start of each Markov section every 3 km up and down stream of London Bridge.

C.2.116 The following analytical steps are then performed:

a. Convert daily death rates into survival probabilities (1-survival=mortality)

a. Convert daily survival rates into per time step survival rates

b. Use matrix of depths at all output positions to define which survival probability to use

c. Generate random number matrix of the same size as output depths matrix

d. Calculate elements where a death occurs using (c) and (d) above

e. Calculate the nearest way mark to the position of first death for each fish that dies

f. Repeat (d) to (f) 30 times

g. Use Markov positions to identify the Markov zone for each way mark

h. Convert way mark death positions to Markov zone positions

i. Convert all positions to Markov zones

j. Use (i) and (j) to produce a death rate/time in zone statistic

k. Output other statistics as a table for cross check.

C.2.117 The raising of small numbers to power of 1/144, and the binary nature of death, has the effect of introducing rounding errors and so cross checking was used to ensure the per-zone death rates per time in zone were similar to the input values. The difference between zones was the key result from these tests.

Model output results

Project-wide effects on upstream fish migration

Basis of Assessment

C.2.118 The individual-based model was run under the Case (e) 'Aquatic Ecology' flow scenario for the outputs presented below (see Fluvial Flow Cases in Annex A). Model runs were started on the following dates and times, based on the predicted tides for those dates:

a. Bass 30-Jun-2011 00:33:00

b. Flounder 01-May-2011 00:23:00

c. Eel 01-Jun-2011 00:58:00.

C.2.119 The starting point in each case was 1.5 km west of the Thames Barrier. Run time was generally in the order of five days for the majority of the 2,500 model fish to reach the endpoint in the Upper Tideway.

C.2.120 The key questions being asked of the IBM, for each of the three species, are:

a. Whether permanent or temporary structures delay migration of juvenile fish through the Tideway

a. Whether the structures result in increased mortality of individuals

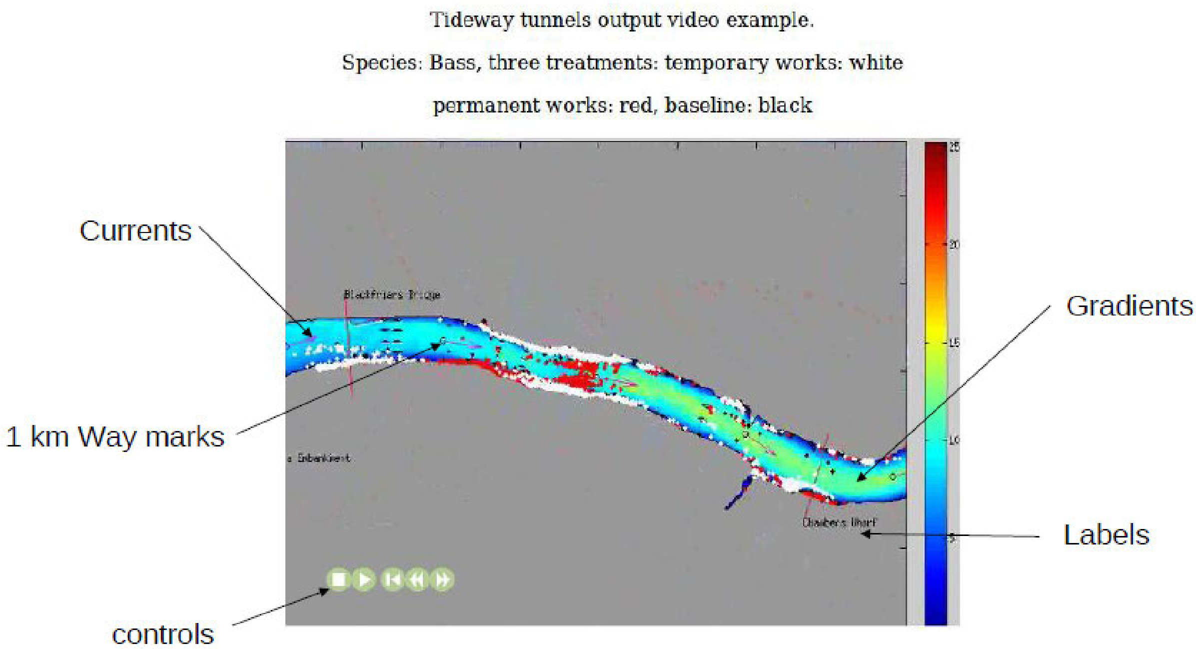
C.2.121 The aim of the modelling carried out here was not to obtain absolute estimates of the time an average model fish will take to pass the 'obstacle course' of new structures, or to estimate the absolute mortality rates associated with each configuration, but to compare findings for the permanent and temporary project cases against the base case with otherwise identical model conditions.

C.2.122 Also, the objective of every fish to ascend the whole length of the Tideway is a convenience within the modelling to provide a uniform basis for statistical comparisons, rather than a realistic ecological expectation. In reality, individuals of all three species will hold fast at intermediate points along the Tideway to maximise use of free habitat and only some will find the need to penetrate the entire channel length. The model endpoint therefore represents the ecologically most demanding, or 'worst' case.

Progress of fish along the tideway

C.2.123 The model findings can be represented in several different ways. The graphical outputs are shown in this report, while video formats or interactive computing versions can also be generated as shown in Vol 3 Plate C.20. The latter have the advantage of allowing the viewer to focus in on particular areas or features of interest.

Vol 3 Plate C.20 Screen shot from live model run

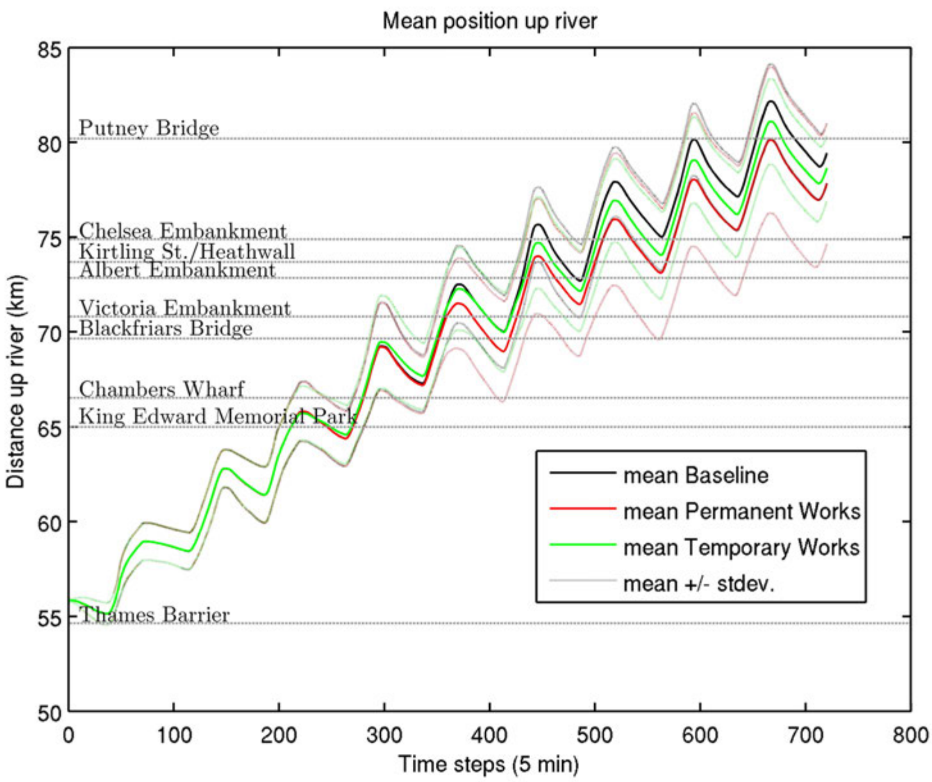


Staircase plots

C.2.124 The 'staircase' plots shown in Vol 3 Plate C.21 to Vol 3 Plate C.23 for all three species demonstrate progress of the group upstream versus model time-steps. The time-steps here are 5 min each and are display intervals rather than computational intervals. The general pattern reflects the selective tidal stream transport mechanism, whereby fish advance upstream carried by a combination of volitional forward swimming and water movement (advection), then attempting to hold station on the ebb tide. In the case of flounder and elver, these species benefit from low boundary layer velocities by hugging the bed during the ebb tide phase, while bass must find low-velocity refuges by moving closer to the bed or into quiet shallows. In the staircase plots, the ascending sections of the plot represent the flood phase and descending sections, the ebb phase (see inset of Vol 3 Plate C.23). In all cases, the mechanism acts as an imperfect ratchet: in the perfect case the ebb phase line would remain horizontal. Crossing lines for each of the foreshore construction sites are shown.

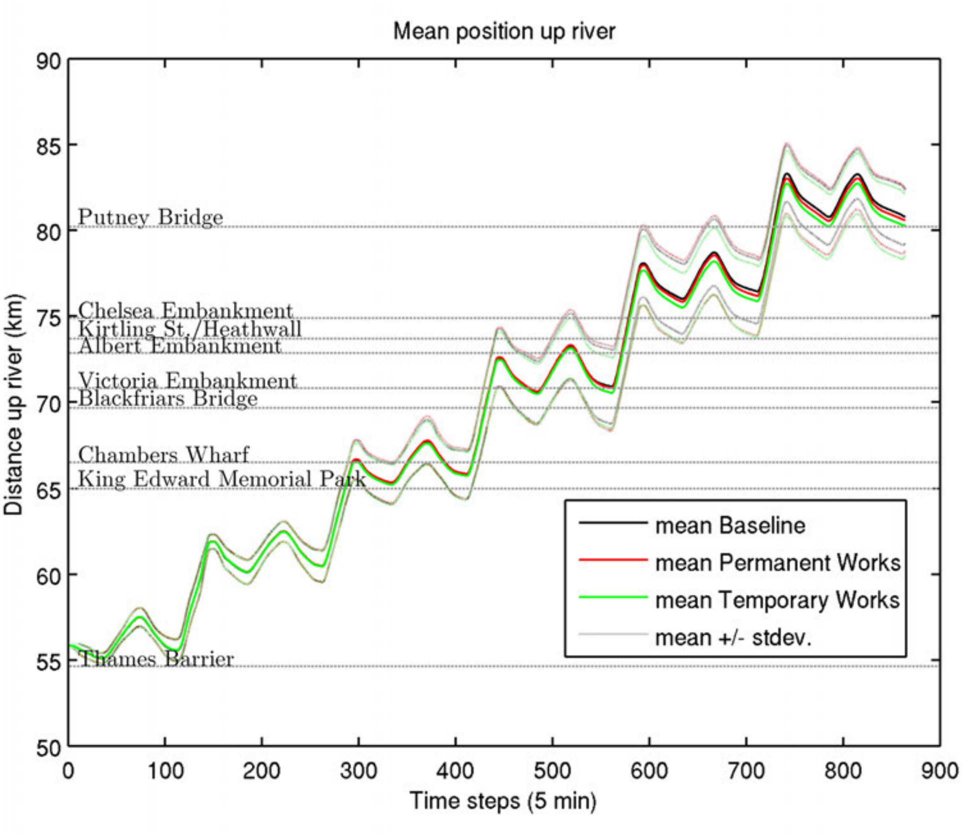
C.2.125 Considering first the base cases (black lines), flounder passed Putney Bridge first (590 time steps), whereas elver was next (720 time steps), with bass lagging behind (800 time steps). The differences reflect a combination of forward swimming ability and ability to hold station on the ebb: although bass are better swimmers, their less effective use of the bed and boundary layer puts them at a migratory disadvantage against the other species. Other differences in the form of the staircase curves reflect more subtle interactions with local hydraulic conditions in different reaches of the Tideway. Where these arise in proximity to proposed temporary or permanent structures they are discussed in the context of individual sites in paras. C.2.138 to C.2.164. The bracketing dotted lines on these plots represent the standard deviation of the distribution, i.e. the spread of response among the 2,500 fish released into the model. Essentially this represents the spread of transit speed caused by individuals each following a slightly different course upriver. Hence the degree of dispersion increases with time from start.

Vol 3 Plate C.21 Staircase plot for (a) 0-group flounder

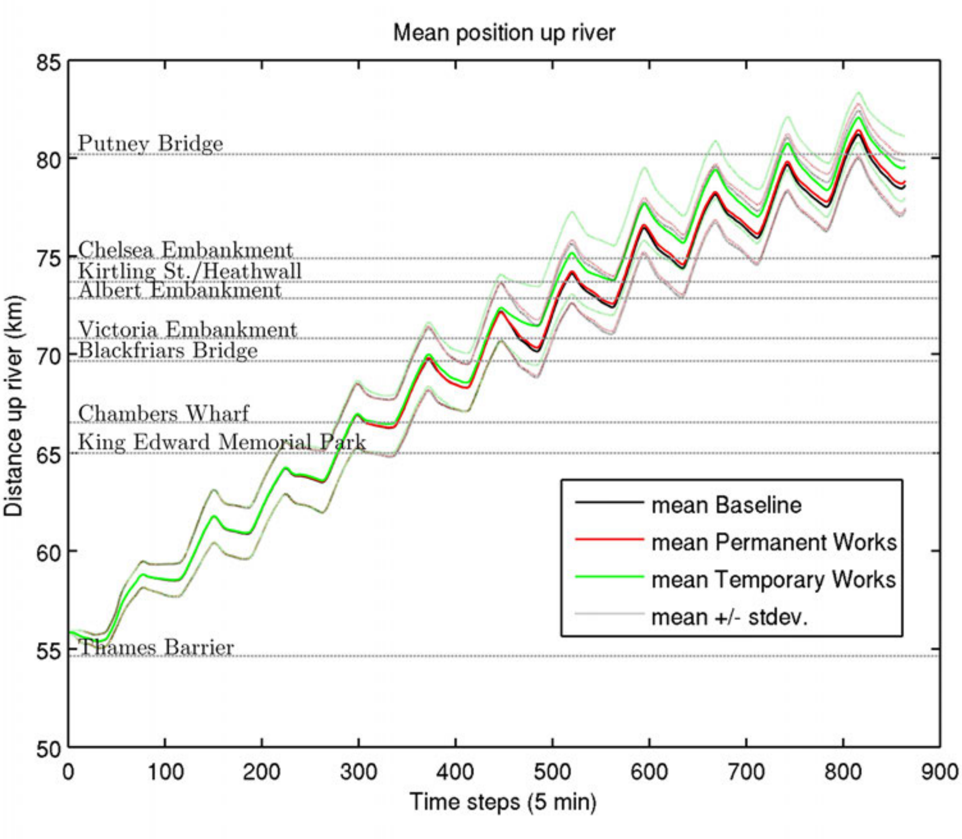


Note: The origin is (57 km upriver) is 1.5 km west of the Thames Barrier. Base case (black), temporary (green) and permanent works (red) lines show the mean upstream progress of the model fish group from the point of release

Vol 3 Plate C.22 Staircase plot for elver



Vol 3 Plate C.23 Staircase plot for 0 group bass



C.2.126 Vol 3 Table C.8 to 0 below provides a statistical analysis for significant difference in rate of upriver migration. To facilitate statistical analysis, rather than comparing time to cross a notional finishing line, results here are presented in terms of distance covered in a fixed runtime adequate to reach the head of the river (5 or 6 days, depending on species); by this method, the number of time steps is kept constant. Some cases show small but statistically significant differences between treatments. These very small statistically significant differences are detectable owing to the large sample sizes (N=2500) but in none of the cases would they be construed as ecologically significant.

Vol 3 Table C.8 Statistical analysis comparing migration rates for base, temporary and permanent works - Flounder

(a) Flounder: Run length: 5 days, N=2500, (significance test p<0.001, N=25 sub-groups of 100)						
Treatment	**Migration (km) mean**	**Migration dispersion (km) 1 SD**	**Standard Deviation of means of 25 sub-groups**	**Significant Difference Base x Permanent**	**Significant Difference Base x Temporary**	**Significant Difference Permanent x Temporary**
Base	23.43	1.592	0.1656	**1**	**1**	**0**
Permanent	21.81 (-6.9%)	3.176	0.1647			
Temporary	22.64 (-3.3%)	1.727	0.1788			

Note: Figures in brackets alongside migration mean distance s are percentage difference from base values (shown only where differences are significant).

Vol 3 Table C.9 Statistical analysis comparing migration rates for base, temporary and permanent works - Elver

(b) Elver: Run length: 6 days, N=2500, (significance test p<0.001, N=25 sub-groups of 100)						
Treatment	**Migration (km) mean**	**Migration dispersion (km) 1 SD**	**Standard Deviation of means of 25 sub-groups**	**Significant Difference Base x Permanent**	**Significant Difference Base x Temporary**	**Significant Difference Permanent x Temporary**
Base	**24.80**	1.544	0.1771	**0**	**1**	**0**
Permanent	24.62 (-0.7%)	1.797	0.3846			
Temporary	24.32 (-1.7%)	1.762	0.2052			

Vol 3 Table C.10 Statistical analysis comparing migration rates for base, temporary and permanent works - Bass

(c) Bass: Run length: 6 days, N=2500, (significance test p<0.001, N=25 sub-groups of 100)						
Treatment	**Migration (km) mean**	**Migration dispersion (km) 1 SD**	**Standard Deviation of means of 25 sub-groups**	**Significant Difference Base x Permanent**	**Significant Difference Base x Temporary**	**Significant Difference Permanent x Temporary**
Base	22.62	1.285	0.1488	**1**	**1**	**1**
Permanent	22.84 (+0.1%)	1.387	0.2151			
Temporary	23.57 (+4.2%)	1.574	0.1514			

Flounder (see Vol 3 Plate C.21)

C.2.127 The three cases for 0-group flounder present indistinguishable rates of progress as far upstream as Blackfriars Bridge, after which both the temporary and permanent works make slightly slower progress. Interestingly, the permanent works appear to have more effect than the temporary works, although creating smaller footprints on the foreshore. This result arises from the greater hydraulic heterogeneity of the temporary works, offering more habitat diversity (in terms of sheltered areas for holding) than the permanent works case. The net predicted result is for flounder arrival at Putney Bridge to be delayed by a single tide; hence no ecological significance can be attached to this.

C.2.128 It is concluded from this that the temporary and permanent works would have no ecologically significant effect on the migration of 0-group flounder through the Tideway on a project-wide basis.

Elver (see Vol 3 Plate C.22)

C.2.129 Both temporary and permanent works cases are practically indistinguishable from each other and the base case over the whole course of the river. The small differences (-0.7%) between base and temporary works cases is statistically, but not ecologically, significant (see Vol 3 Table C.9) (less than 1 tide difference in upstream arrival time). Statistical significance is achieved because the large number of fish in the model allows very small changes to be resolved, whereas such a small change would never be detectable in a real population, given the wide natural variability inherent in ecological processes.

C.2.130 It is concluded that the temporary and permanent works would have no ecologically significant effect on the migration of elvers through the Tideway on a project-wide basis.

Bass (see Vol 3 Plate C.23)

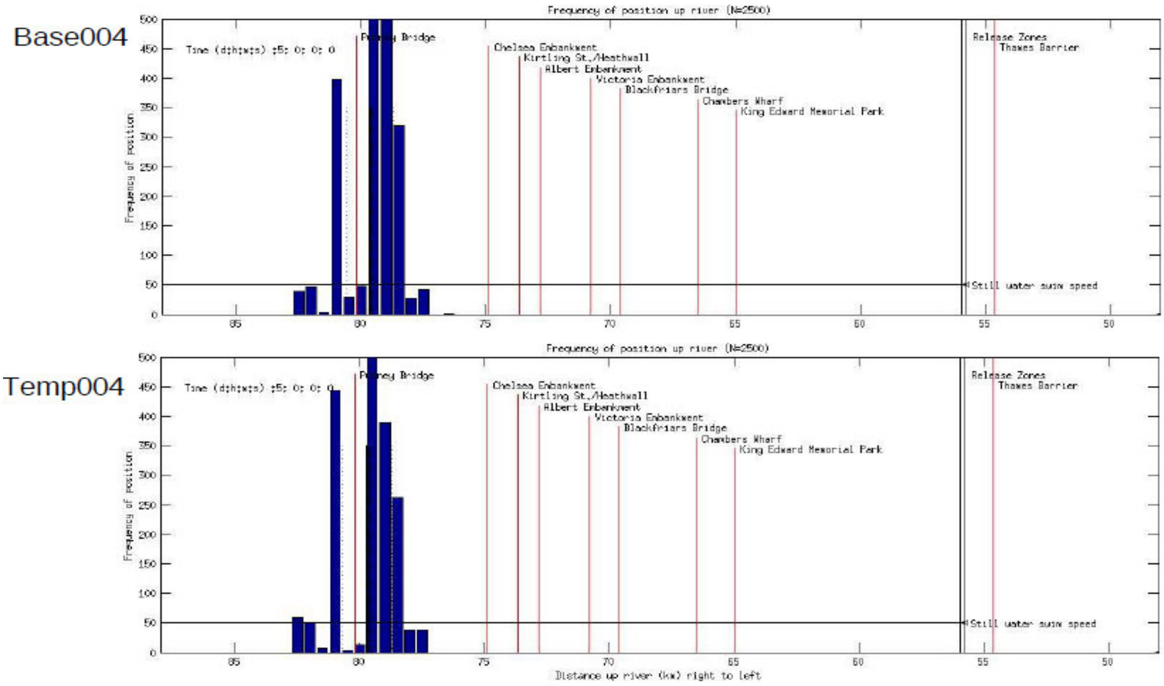
C.2.131 The effect of temporary and permanent works differs slightly from that on the other species. Both cases appear to be advantageous to bass migration, with the temporary works being notably better. Again, based on the IBM, this results from the hydraulic conditions created around the structures and the extra shelter thereby created. However, while the differences between cases are statistically significant they are of no ecological consequence (less than 1 tide difference in upstream arrival time).

C.2.132 It is concluded that the temporary and permanent works would have no ecologically significant effect on the migration of elvers through the Tideway on a project-wide basis, though possibly a small positive effect.

Upstream progression histograms

C.2.133 A different type of output is shown in Vol 3 Plate C.24. Upstream progression histograms provide a snapshot in time, and can be drawn to represent any time after the release of the fish into the model. The examples in Vol 3 Plate C.24 are taken at 5 days from the start of a model run and show the degree of dispersion at this stage.

Vol 3 Plate C.24 Upstream progression histogram - bass



Note: Example of an upstream progression histogram, comparing progress and dispersion of bass after 5 day model run for base and temporary works cases

Effect on fish mortality risk of temporary and permanent works

C.2.134 The principle underlying this rule is that, by forcing juvenile fish into deeper water, they may be exposed to increased predation risk. While there is some evidence for this in the literature, owing to the lack of any formally demonstrated relationship between depth and predation, the outcomes from applying the depth-mortality rule are presented here as a form of sensitivity analysis. By testing the effect of applying reported upper and lower extremes of natural mortality rate in 0-group populations of the species in question, a demonstration of no significant difference between treatments would indicate no sensitivity to this effect and therefore it could be ignored. On the other hand demonstration of significant differences between treatments might indicate the need for further investigation.

C.2.135 The cumulative mortality plots in Vol 3 Plate C.25 to Vol 3 Plate C.27 show the effect of applying the depth-mortality rule for the base, temporary and permanent works treatments, along with standard deviations of the mean values. Natural mortality rates through predation, starvation and environmental factors are very high in the early lifestages (see Vol 3 Table C.6 above- mortality rates) and this is reflected in losses of between <1% to>5% per day in the 5-day plots shown for the base case. Modelled mortality rates for the temporary and permanent works treatments vary little from the base case and statistical analysis (Vol 3 Table C.11 to Vol 3 Table C.13) confirms that any small differences seen are non-significant.

C.2.136 The explanation for this is that, while structures may have the effect of forcing some fish into deeper water as they pass the structure, their instinctive and continuous searching for preferred lower velocity conditions rapidly brings them back into shallow water as and when it becomes available. Thus they would only spend a small proportion of their time in deeper water and even where the mortality risk is increased several-fold, the exposure time is too small to make any significant difference.

C.2.137 It is concluded that any effect on mortality risk of fish being forced by new shoreline structures into deeper water would not statistically or ecologically significant.

Vol 3 Table C.11 Statistical analysis of mortality rate differences after five days after applying the depth-mortality rule - bass

Bass: Run length: 6 days, N=2500, (significance test p<0.001, N=25 sub-groups of 100)					
Treatment	**Mortality mean**	**Standard Deviation of mortality**	**Significant Difference Baseline x Permanent**	**Significant Difference Baseline x Temporary**	**Significant Difference Permanent x Temporary**
Baseline	90.13	11.13	**0**	**0**	**0**
Permanent	86.90 (-3.6%)	7.73			
Temporary	89.37 (-0.1%)	7.59			

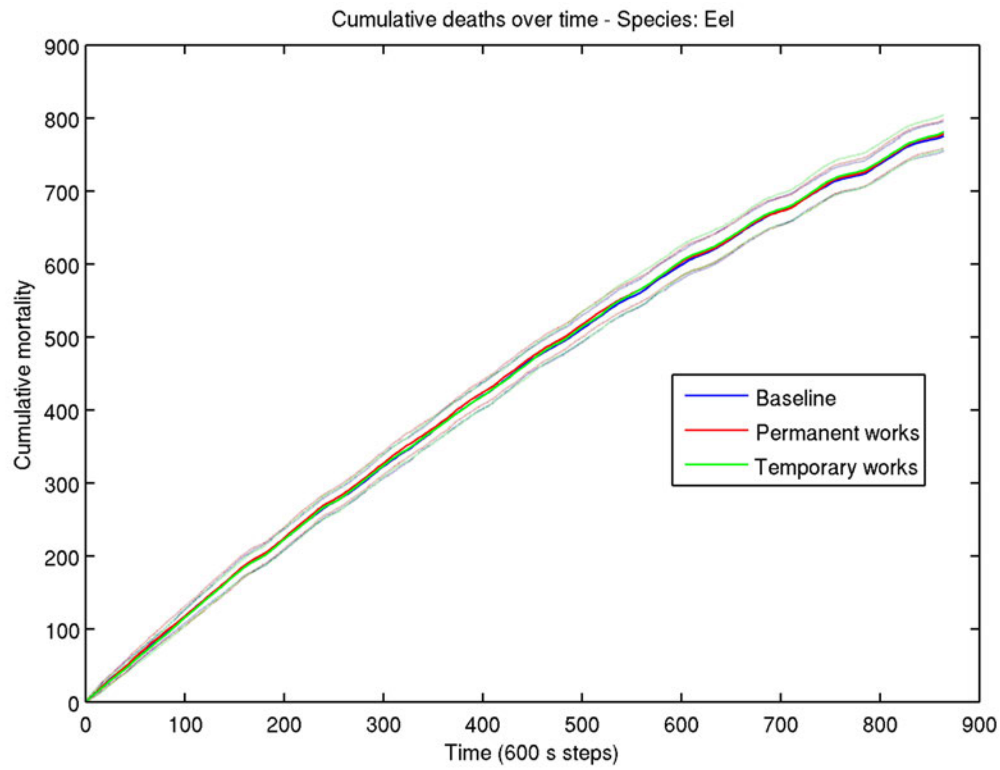
Vol 3 Table C.12 Statistical analysis of mortality rate differences after five days after applying the depth-mortality rule – 0 group flounder

0-group flounder: Run length: 5 days, N=2500, (significance test p<0.001, N=25 sub-groups of 100)					
Treatment	**Mortality mean**	**Standard Deviation of mortality**	**Significant Difference Baseline x Permanent**	**Significant Difference Baseline x Temporary**	**Significant Difference Permanent x Temporary**
Baseline	192.73	13.39	**0**	**0**	**0**
Permanent	194.16 (-0.7%)	12.70			
Temporary	190 (-1.4%)	10.76			

Vol 3 Table C.13 Statistical analysis of mortality rate differences after five days after applying the depth-mortality rule – elver

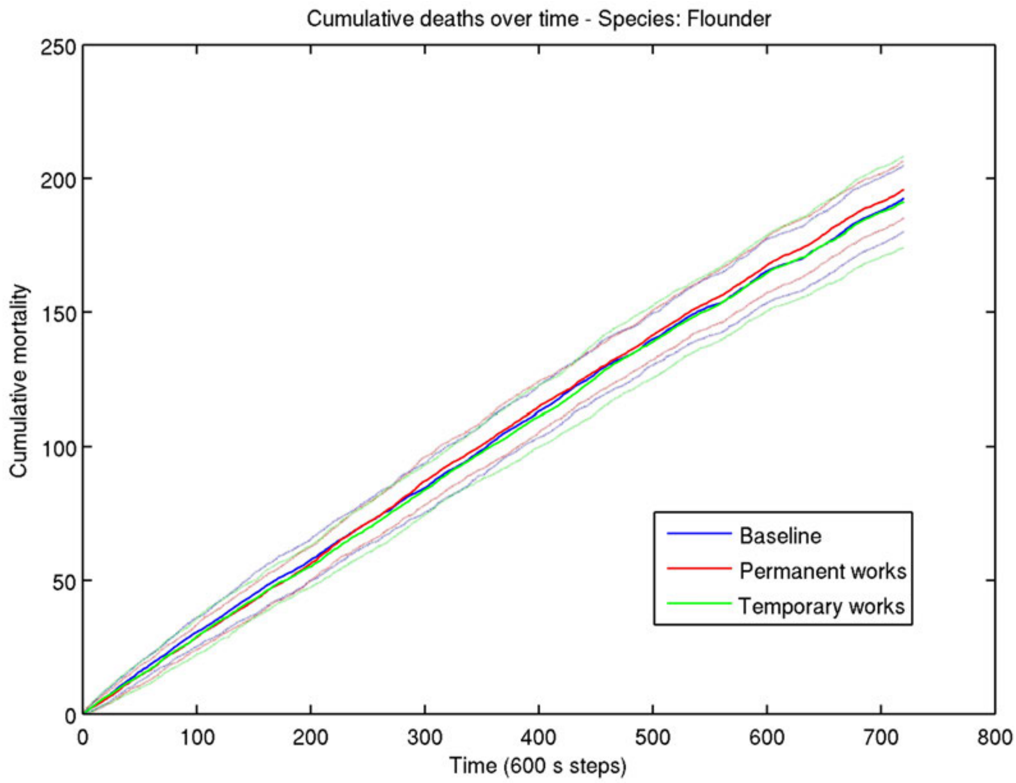
Elver: Run length: 6 days, N=2500, (significance test p<0.001, N=25 sub-groups of 100)					
Treatment	**Mortality mean**	**Standard Deviation of mortality**	**Significant Difference Baseline x Permanent**	**Significant Difference Baseline x Temporary**	**Significant Difference Permanent x Temporary**
Baseline	774.86	23.04	**0**	**0**	**0**
Permanent	778 (-0.4%)	21.89			
Temporary	774.80 (0.0%)	22.54			

Vol 3 Plate C.25 Modelled cumulative mortalities of elver when the depth-mortality rule is applied

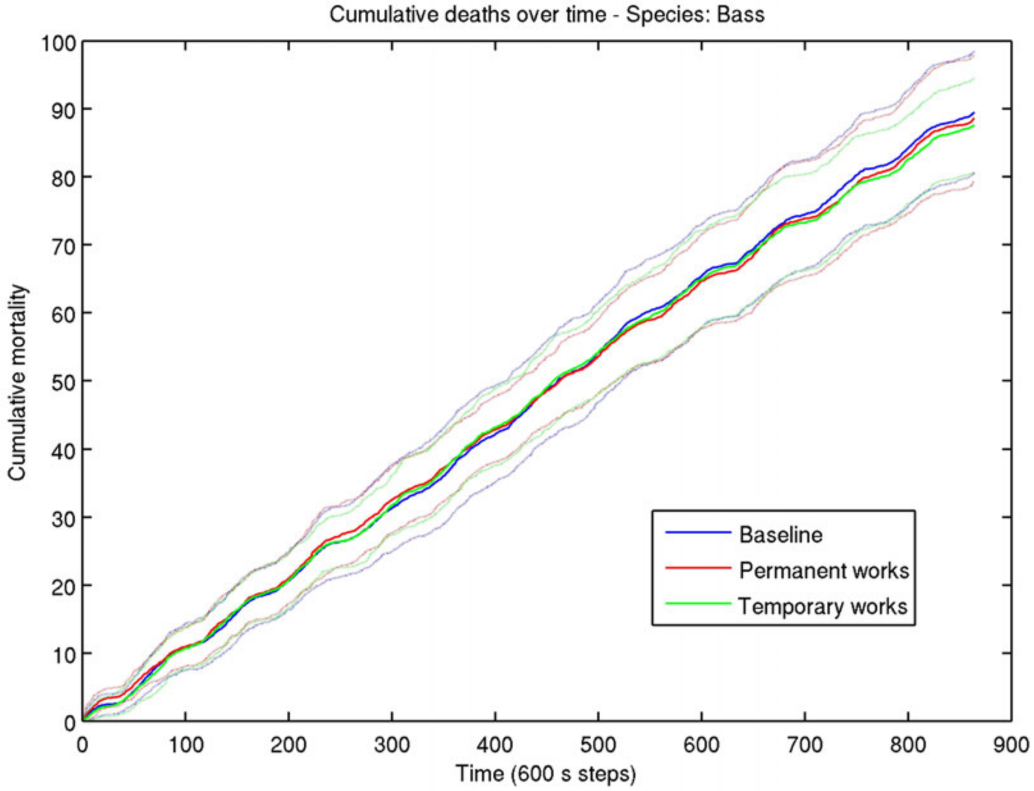


Note: Dotted lines are standard deviations

Vol 3 Plate C.26 Modelled cumulative mortalities of flounder when the depth mortality rule is applied



Vol 3 Plate C.27 Modelled cumulative mortalities of bass when the depth-mortality rule is applied



Site and reach-based assessment

C.2.138 While the focus of this study is the project-wide assessment of potential impacts on juvenile fish migration, the IBM and Markov chain methods provide the opportunity to examine effects at individual project foreshore sites or in specific reaches of the Tideway. Having demonstrated with the IBM that no statistically significant impacts on juvenile fish migration are expected to arise from the effects associated with passing all of the project sites, it is axiomatic that there would be no significant impact from any individual site. Nonetheless, modelled fish behaviour around individual sites has been undertaken, and is described in the next sections below.

Markov chain analysis

C.2.139 Markov chain modelling statistics for elver, and 0-group flounder and bass are presented in Vol 3 Table C.14, Vol 3 Table C.15 and Vol 3 Table C.16 below. These show the average number of 600 s (5 min) time steps that the 2,500 model fish spent within each AQMS zone, the mean number of deaths occurring in each zone when the depth-mortality rule is applied and equivalent mean daily mortality rates, along with standard deviations of these values. Vol 3 Table C.17 shows Student's t-test values for comparison of temporary and permanent works treatments against base case values for each species.

Time in zone

C.2.140 The time-in-zone comparisons tested in Vol 3 Table C.17 show, as would be expected, no significant differences between treatments in Zones 14 to 12 (where no works exist) and none in Zone 11, which includes Chambers Wharf and King Edward Memorial Park. For eel (elver), no differences are detected until Zone 8 (Chelsea Embankment, Heathwall, Albert Embankment). Upstream from Zone 8, there are statistically significant differences for all species in most reaches. The comments above regarding the unlikely ecological significance of these differences should again be noted, as well as the fact that some of the differences are positive, i.e. the fish are predicted to move upstream faster as a result of treatments.

Daily mortality rate

C.2.141 Comparisons of daily mortality rates between treatments by zone are shown in Vol 3 Table C.18. In only one case (bass, permanent versus base in Zone 5) does a significant difference appear, and this is not a zone containing project works, so can be dismissed. Where a large number of statistics are calculated, the odd one may show up as significant just by chance.

C.2.142 The conclusion of 'no significant effect' reached for the project-wide assessment is therefore also supported by the individual zone Markov assessments.

Vol 3 Table C.14 Markov analysis of model fish migration and mortality through 3 km AQMS zones: Elver

(a) Base case

Site name	Mean number of deaths in zone (30 trials)	Standard Deviation of deaths in zone	Average time in zone per fish (600 s time steps)	Mean of daily mortality rate	Standard Deviation of daily mortality rate	EA AQMS Zone
	82	7.52	249.44	0.0191	0.0215	14
	72	6.34	215.91	0.0193	0.0205	13
	113	9.96	400.82	0.0172	0.0176	12
Chambers Wharf, King Edward Memorial Park	59	8.61	203.93	0.0189	0.0191	11
Blackfriars Bridge	110	9.89	387.84	0.0189	0.0180	10
Victoria Embankment	64	8.08	242.00	0.0176	0.0165	9
Chelsea Embankment, Heathwall, Albert Embankment	73	7.55	287.20	0.0180	0.0164	8
	61	8.32	264.79	0.0164	0.0141	7
Putney Bridge	43	7.77	210.83	0.0160	0.0137	6
	9	3.75	37.23	0.0190	0.0188	5

(b) Temporary works

Site name	Mean number of deaths in zone (30 trials)	Standard Deviation of deaths in zone	Average time in zone per fish (600 s time steps)	Mean of daily mortality rate	Standard Deviation of daily mortality rate	EA AQMS Zone
	82	8.76	250.10	0.0187	0.0213	14
	73	6.65	216.15	0.0192	0.0210	13
	116	6.04	405.49	0.0179	0.0182	12

Chambers Wharf, King Edward Memorial Park	60	8.55	205.76	0.0182	0.0185	11
Blackfriars Bridge	117	10.32	396.38	0.0195	0.0188	10
Victoria Embankment	61	7.17	233.96	0.0180	0.0167	9
Chelsea Embankment, Heathwall, Albert Embankment	82	8.43	330.36	0.0171	0.0152	8
	53	9.04	245.22	0.0170	0.0150	7
Putney Bridge	41	4.78	199.81	0.0166	0.0145	6
	4	1.88	16.74	0.0198	0.0213	5
(c) Permanent works						
Site name	**Mean number of deaths in zone (30 trials)**	**Standard Deviation of deaths in zone**	**Average time in zone per fish (600 s time steps)**	**Mean of daily mortality rate**	**Standard Deviation of daily mortality rate**	**EA AQMS Zone**
	80	9.53	249.59	0.0192	0.0217	14
	72	8.56	215.07	0.0199	0.0214	13
	114	9.32	400.90	0.0176	0.0182	12
Chambers Wharf, King Edward Memorial Park	61	9.68	201.68	0.0195	0.0193	11
Blackfriars Bridge	116	10.19	399.13	0.0191	0.0180	10
Victoria Embankment	63	7.46	244.80	0.0183	0.0166	9
Chelsea Embankment, Heathwall, Albert Embankment	74	8.41	305.44	0.0189	0.0171	8
	54	7.66	238.98	0.0175	0.0152	7
Putney Bridge	42	6.53	205.44	0.0156	0.0134	6
	10	3.34	38.97	0.0184	0.0170	5

Vol 3 Table C.15 Markov analysis of model fish migration and mortality through 3 km AQMS zones: Flounder

(a) Base case						
Site name	**Mean number of deaths in zone (30 trials)**	**Standard Deviation of deaths in zone**	**Average time in zone per fish (600 s time steps)**	**Mean of daily mortality rate**	**Standard Deviation of daily mortality rate**	**EA AQMS Zone**
	13	3.60	157.94	0.0046	0.0059	14
	16	3.68	193.24	0.0048	0.0058	13
	17	4.39	211.83	0.0047	0.0059	12
Chambers Wharf, King Edward Memorial Park	21	4.40	279.69	0.0045	0.0053	11
Blackfriars Bridge	22	4.31	279.99	0.0047	0.0055	10
Victoria Embankment	17	3.39	228.69	0.0044	0.0051	9
Chelsea Embankment, Heathwall, Albert Embankment	22	4.06	280.44	0.0047	0.0053	8
	22	3.98	336.57	0.0039	0.0044	7
Putney Bridge	24	4.05	361.33	0.0041	0.0045	6
	11	2.50	153.16	0.0042	0.0049	5
	2	1.06	17.13	0.0060	0.0091	4
(b) Temporary works						
Site name	**Mean number of deaths in zone (30 trials)**	**Standard Deviation of deaths in zone**	**Average time in zone per fish (600 s time steps)**	**Mean of daily mortality rate**	**Standard Deviation of daily mortality rate**	**EA AQMS Zone**
	13	3.87	157.74	0.0046	0.0060	14
	15	3.91	188.00	0.0046	0.0058	13
	19	3.46	213.49	0.0052	0.0060	12

Chambers Wharf, King Edward Memorial Park	22	5.87	280.11	0.0046	0.0058	11
Blackfriars Bridge	24	4.77	277.07	0.0052	0.0060	10
Victoria Embankment	22	3.49	278.85	0.0047	0.0052	9
Chelsea Embankment, Heathwall, Albert Embankment	24	5.51	330.44	0.0044	0.0052	8
	24	4.11	348.73	0.0041	0.0046	7
Putney Bridge	20	4.28	311.04	0.0040	0.0045	6
	6	1.82	100.07	0.0036	0.0044	5
	1	1.08	14.38	0.0046	0.0086	4
(c) Permanent works						
Site name	**Mean number of deaths in zone (30 trials)**	**Standard Deviation of deaths in zone**	**Average time in zone per fish (600 s time steps)**	**Mean of daily mortality rate**	**Standard Deviation of daily mortality rate**	**EA AQMS Zone**
	13	3.03	157.87	0.0048	0.0059	14
	16	3.59	188.67	0.0048	0.0058	13
	17	3.85	213.79	0.0047	0.0057	12
Chambers Wharf, King Edward Memorial Park	21	5.17	283.95	0.0044	0.0054	11
Blackfriars Bridge	30	5.64	364.76	0.0049	0.0056	10
Victoria Embankment	27	5.79	341.63	0.0047	0.0055	9
Chelsea Embankment, Heathwall, Albert Embankment	20	4.33	272.95	0.0046	0.0052	8
	20	3.34	283.22	0.0043	0.0048	7
Putney Bridge	20	5.10	284.63	0.0042	0.0050	6
	7	2.92	93.54	0.0047	0.0062	5
	1	0.87	14.96	0.0039	0.0069	4

Vol 3 Table C.16 Markov analysis of model fish migration and mortality through 3 km AQMS zones: Bass.

(a) Base case						
Site name	**Mean number of deaths in zone (30 trials)**	**Standard Deviation of deaths in zone**	**Average time in zone per fish (600 s time steps)**	**Mean of daily mortality rate**	**Standard Deviation of daily mortality rate**	**EA AQMS Zone**
	3	2.01	159.12	0.0012	0.0018	14
	7	3.17	235.69	0.0020	0.0028	13
	8	2.43	266.04	0.0016	0.0021	12
Chambers Wharf, KEMP	10	3.50	303.08	0.0016	0.0022	11
Blackfriars Bridge	10	3.04	321.35	0.0018	0.0025	10
Victoria Embankment	12	2.97	366.58	0.0020	0.0025	9
Chelsea Embankment, Heathwall, Albert Embankment	10	3.61	343.11	0.0016	0.0022	8
	10	2.61	371.76	0.0017	0.0022	7
Putney Bridge	3	1.74	129.72	0.0019	0.0028	6
	0	0.31	3.56	0.0038	0.0107	5
(b) Temporary works						
Site name	**Mean number of deaths in zone (30 trials)**	**Standard Deviation of deaths in zone**	**Average time in zone per fish (600 s time steps)**	**Mean of daily mortality rate**	**Standard Deviation of daily mortality rate**	**EA AQMS Zone**
	4	2.43	159.30	0.0014	0.0024	14
	8	2.15	234.06	0.0018	0.0025	13
	8	2.61	262.75	0.0017	0.0023	12
Chambers Wharf, King Edward Memorial Park	9	3.09	301.93	0.0015	0.0020	11

(a) Base case						
Site name	**Mean number of deaths in zone (30 trials)**	**Standard Deviation of deaths in zone**	**Average time in zone per fish (600 s time steps)**	**Mean of daily mortality rate**	**Standard Deviation of daily mortality rate**	**EA AQMS Zone**
Blackfriars Bridge	10	2.74	299.55	0.0019	0.0025	10
Victoria Embankment	11	2.92	332.20	0.0019	0.0025	9
Chelsea Embankment, Heathwall, Albert Embankment	7	2.38	224.22	0.0020	0.0027	8
	11	3.21	393.44	0.0015	0.0019	7
Putney Bridge	8	2.41	271.80	0.0017	0.0023	6
	1	0.75	20.75	0.0023	0.0045	5
(c) Permanent works						
Site name	**Mean number of deaths in zone (30 trials)**	**Standard Deviation of deaths in zone**	**Average time in zone per fish (600 s time steps)**	**Mean of daily mortality rate**	**Standard Deviation of daily mortality rate**	**EA AQMS Zone**
	5	2.44	159.28	0.0015	0.0022	14
	8	2.18	237.01	0.0017	0.0022	13
	7	2.74	262.52	0.0018	0.0024	12
Chambers Wharf, KEMP	9	2.83	301.87	0.0018	0.0022	11
Blackfriars Bridge	10	3.51	329.02	0.0017	0.0022	10
Victoria Embankment	12	3.64	352.94	0.0019	0.0025	9
Chelsea Embankment, Heathwall, Albert Embankment	10	3.46	327.35	0.0018	0.0024	8
	10	3.04	372.73	0.0016	0.0020	7
Putney Bridge	4	1.94	154.04	0.0015	0.0022	6
	0	0.35	3.25	0.0006	0.0038	5

Vol 3 Table C.17 Student's t-values comparing permanent and temporary simulations with base case figures for time in zone per fish for three fish species

Time in zone			Time in zone per fish (600 s time steps)					
			Eel		Flounder		Bass	
Site code	AQMS Zone	Value	Perm	Temp	Perm	Temp	Perm	Temp
	14	p	0.0834	0.0289	0.8247	0.5515	0.9352	0.4003
		t	-1.7320	-2.1865	-0.2215	-0.5956	0.0813	-0.8412
	13	p	0.0318	0.0237	0.2963	0.2288	0.9986	0.8112
		t	2.1479	2.2633	-1.0447	-1.2036	-0.0018	-0.2389
	12	p	0.1243	0.6804	0.5025	0.5680	0.9336	0.7648
		t	-1.5376	0.4119	0.6706	0.5711	-0.0833	-0.2993
Chambers Wharf, King Edward Memorial Park	11	p	0.4559	0.2626	0.0519	0.8468	0.1022	0.0977
		t	-0.7458	1.1205	1.9449	0.1932	-1.6348	-1.6568
Blackfriars Bridge	10	p	0.0051	0.0077	0.0000	0.0851	0.0000	0.0000
		t	2.8061	2.6685	28.0258	-1.7225	5.1080	-12.5802
Victoria Embankment	9	p	0.8893	0.0565	0.0000	0.0000	0.0000	0.0000
		t	-0.1392	-1.9080	27.0426	15.9671	-5.1842	-12.2814
Chelsea Embankment, Heathwall, Albert Embankment	8	p	0.0000	0.0000	0.0052	0.0000	0.0000	0.0000
		t	7.3062	13.7202	-2.7971	15.6823	-8.2967	-41.5120
	7	p	0.0000	0.0116	0.0000	0.0000	0.0000	0.0000
		t	-4.7963	-2.5272	-19.5174	5.3879	-4.4991	-12.6904

Time in zone			Time in zone per fish (600 s time steps)					
			Eel		Flounder		Bass	
Site code	AQMS Zone	Value	Perm	Temp	Perm	Temp	Perm	Temp
Putney Bridge	6	p	0.0000	0.0000	0.0000	0.0000	0.0396	0.0000
		t	5.7125	9.2108	-18.0764	-13.5851	2.0590	23.5678
	5	p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		t	-7.4773	-11.0899	-20.1610	-17.6055	7.1042	29.8771
	4	p	0.5166	0.0000	0.0458	0.0165	0.0001	0.0000
		t	0.6487	-8.1240	-1.9982	-2.4000	3.9982	10.0708

Vol 3 Table C.18 Student's t-values comparing permanent and temporary simulations with base case figures for daily mortality rate, for three fish species

Daily mortality rate			Daily mortality rate					
			Eel		Flounder		Bass	
Site code	Zone	Value	Perm	Temp	Perm	Temp	Perm	Temp
	14	p	0.9079	0.6350	0.1686	0.0212	0.2642	0.2153
		t	0.1167	0.4798	1.4121	2.4368	-1.1386	-1.2668
	13	p	0.9667	0.9280	0.6379	0.7704	0.9993	0.2299
		t	-0.0422	-0.0912	-0.4756	-0.2946	-0.0009	-1.2263
	12	p	0.6941	0.8577	0.3176	0.8622	0.2035	0.9403
		t	-0.3972	-0.1810	-1.0169	0.1751	1.3010	-0.0756

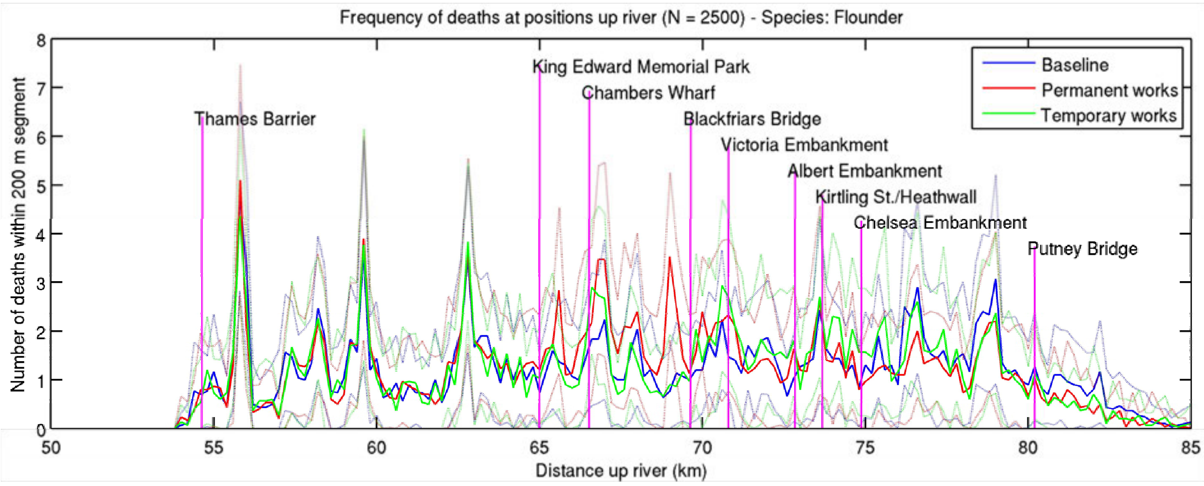
Daily mortality rate			Daily mortality rate					
			Eel		Flounder		Bass	
Site code	**Zone**	**Value**	**Perm**	**Temp**	**Perm**	**Temp**	**Perm**	**Temp**
Chambers Wharf,	11	p	0.6670	0.5810	0.8024	0.0946	0.5195	0.0958
King Edward Memorial Park		t	-0.4347	-0.5582	0.2526	-1.7280	-0.6521	-1.7214
Blackfriars Bridge	10	p	0.5536	0.9798	0.8783	0.7318	0.2443	0.4545
		t	-0.5994	-0.0255	0.1545	0.3460	1.1884	0.7582
Victoria Embankment	9	p	0.8682	0.6919	0.4149	0.8714	0.3702	0.0813
		t	-0.1675	-0.4002	-0.8271	0.1633	-0.9102	-1.8059
Chelsea Embankment, Heathwall,	8	p	0.7192	0.9202	0.5791	0.1425	0.6967	0.4243
Albert Embankment		t	0.3631	0.1010	-0.5610	-1.5076	-0.3937	0.8104
	7	p	0.7211	0.7685	0.4021	0.3527	0.4872	0.6058
		t	0.3605	-0.2971	0.8504	0.9444	0.7037	-0.5217
Putney Bridge	6	p	0.5165	0.5356	0.3071	0.1940	0.8884	0.4812
		t	0.6568	0.6269	1.0397	1.3296	-0.1416	-0.7135
	5	p	0.6519	0.7430	0.6260	0.2609	0.0000	0.2096
		t	-0.4558	0.3311	-0.4926	1.1466	-5.9240	-1.2830

Note: Cells are coloured pink where values are significant at $p<0.001$.

Mortality risk in relation to project sites

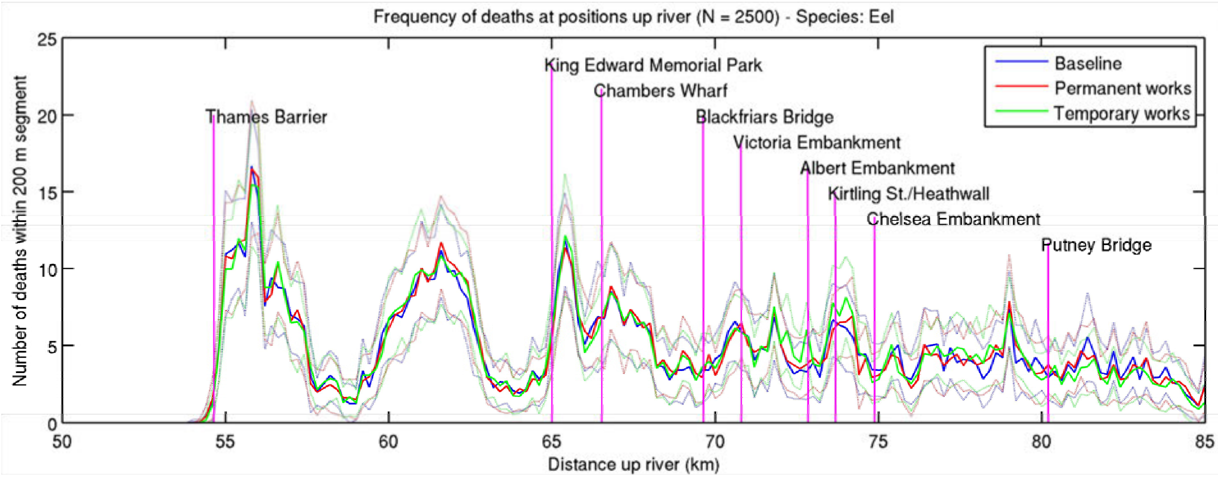
C.2.143 Vol 3 Plate C.28 shows modelled mortality as a function of progress upriver (number of deaths within 200 m segment). This form of plot identifies in which river sections fish are forced more into deeper water and therefore may be at higher mortality risk. The outcomes (under each treatment: base case, temporary and permanent works) are expected to be similar in the stretch of the Tideway to the east of the first Thames Tideway Tunnel site (King Edward Memorial Park) as the fish move from left to right through the model, and there is somewhat more variation in outcomes as the fish move past the works and into the Upper Tideway. The differences between the works are only noticeable in the case of flounder and in the area immediately downstream of Blackfriars Bridge where the permanent works (red) outcome is higher than the other two in several peaks. It is likely that this is related to a flood tide gyre that forms which can trap the fish (in relative slow moving but deep water). Overall however, mortality risk was not significantly higher over the whole Tideway.

Vol 3 Plate C.28 Effect of applying the depth-mortality rule to (a) 0-group bass for base, temporary and permanent works cases

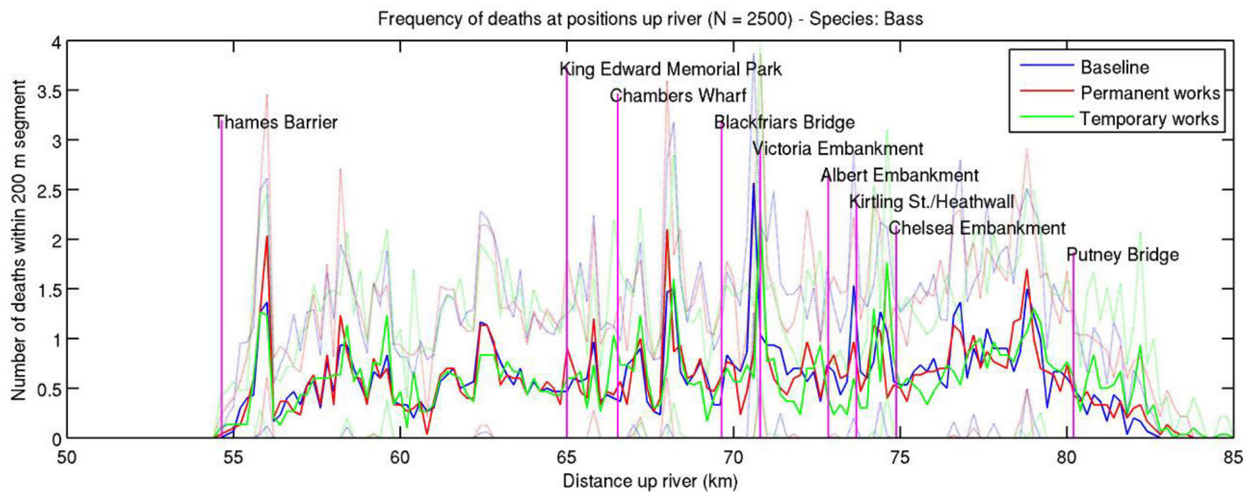


Note: Shown here relative to distance moved upstream from start point and in relation to project site locations. Dotted lines again show standard deviations of the means

Vol 3 Plate C.29 Vol 3 Plate C.29 Effect of applying the depth-mortality rule to elver for base, temporary and permanent works cases



Vol 3 Plate C.30 Effect of applying the depth-mortality rule to 0-group flounder for base, temporary and permanent works cases



Commentary from IBM on individual sites

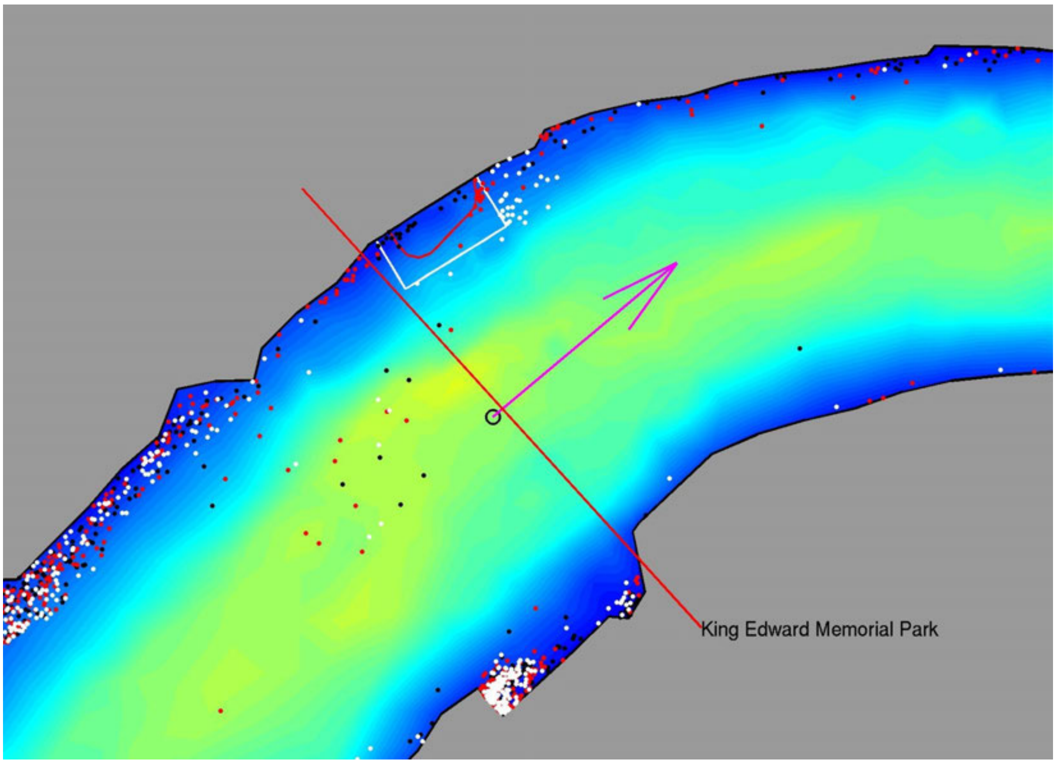
C.2.144 The following section includes screenshot examples from the IBM showing the passage of fish past individual sites. They help to identify mechanisms of fish holding and effects of different designs. See section 1 of the Figures volume within each ES site volume for the site works parameter plans which show the 'zone within which all permanent site structures would be located' and the 'maximum extent of temporary works platform'. In all cases, screenshots show all three cases (base case, temporary and permanent works). Other characteristics are as described in para. C.2.94.

King Edward Memorial Park

C.2.145 The works are seen here on the north bank of the river (top of picture). The model demonstrates how the square sides of the temporary structure outline provides more shelter for fish in its wake (white dots) than the more compact and smoothly rounded permanent works (red dots). Note how other features of bankform on both banks provide refuges for fish.

C.2.146 Vol 3 Plate C.31 shows no notable effect of the depth-mortality rule at this site, with the exception of a minor red spike for bass indicating that the permanent structure may force bass briefly into deeper water.

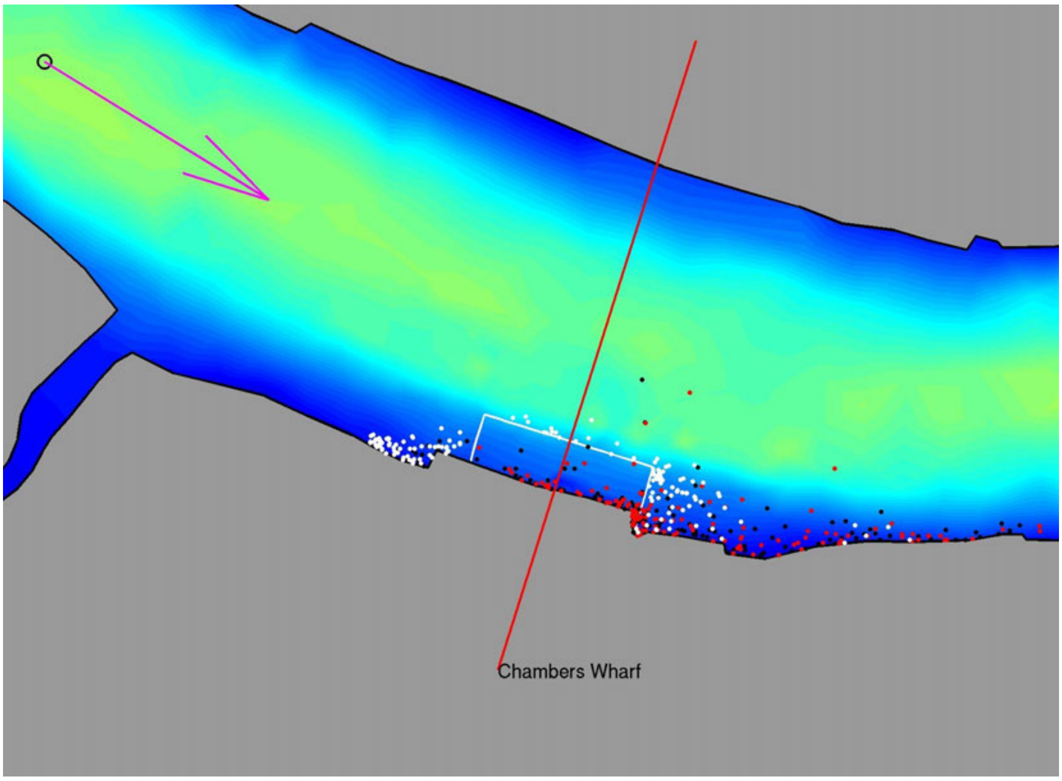
Vol 3 Plate C.31 Screen shot of King Edward Memorial Park showing features of fish behaviour.



Chambers Wharf

C.2.147 The screenshot for Chamber's Wharf shows again how fish benefit from the square edges of a temporary structure. Vol 3 Plate C.32 shows minimal effect of the depth mortality rules, except in this case for flounder in the permanent works case.

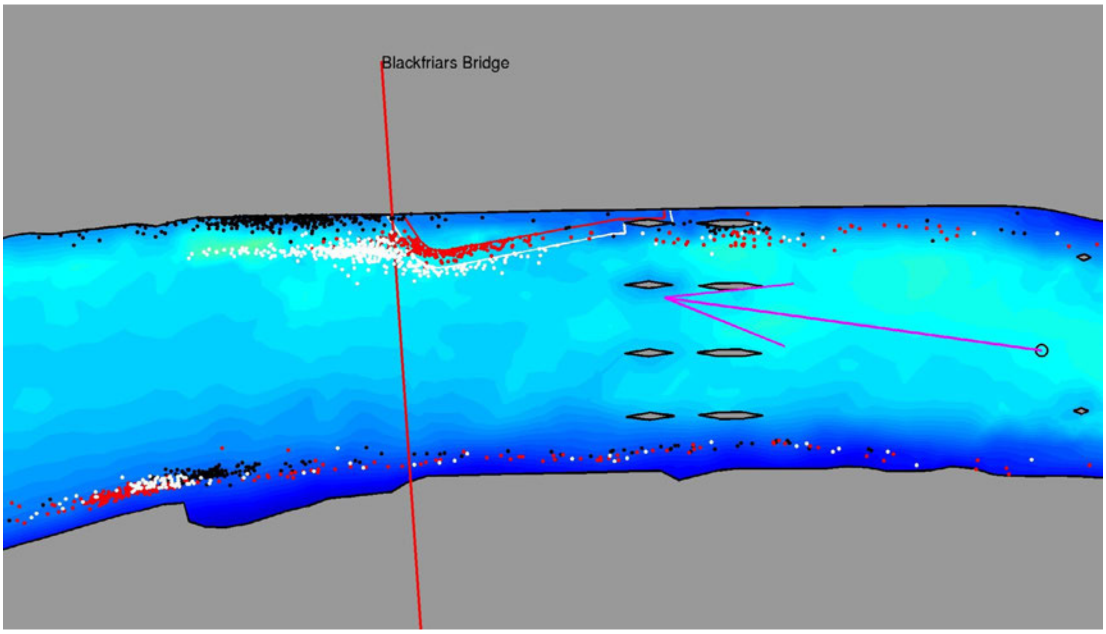
Vol 3 Plate C.32 Screen shots of Chambers Wharf showing features of fish behaviour



Blackfriars Bridge Foreshore

C.2.148 Permanent group fares worse around Blackfriars Bridge Foreshore, Vol 3 Plate C.33 shows a large gyre that forms on the flood tide between Blackfriars and Millennium Bridge. Flounder very low swim speed does not allow them to swim out of it – unlike the other species.

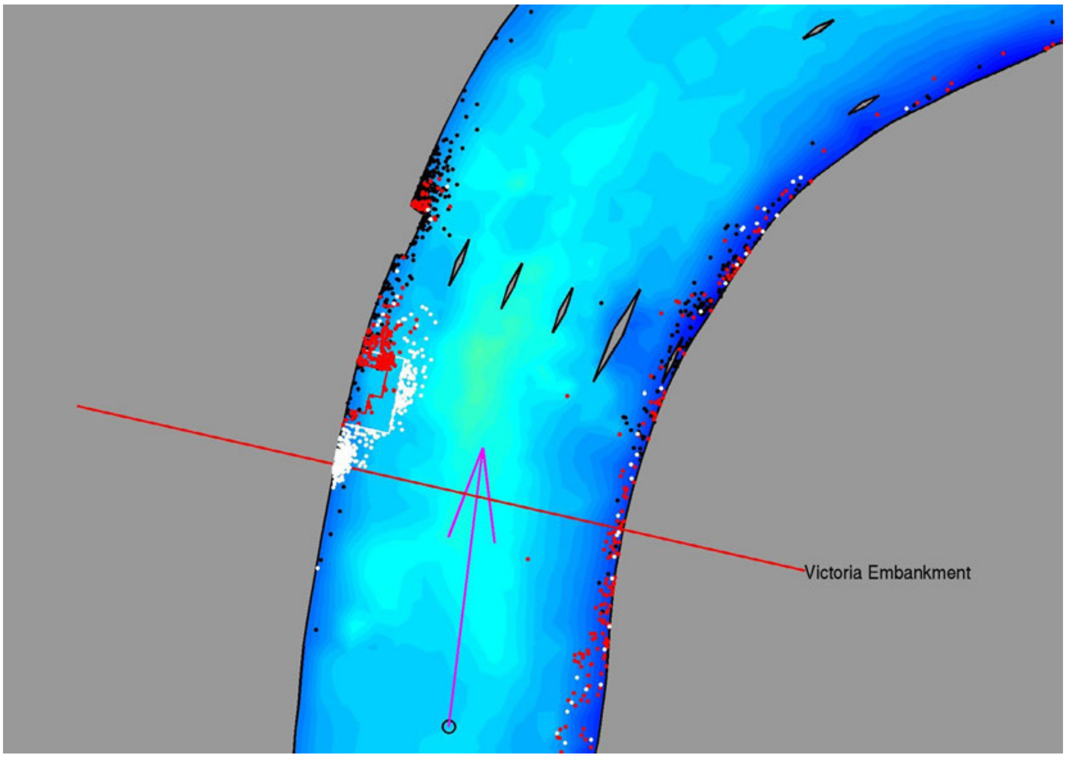
Vol 3 Plate C.33 Screen shots of Blackfriars Bridge showing features of fish behaviour



Victoria Embankment Foreshore

C.2.149 Vol 3 Plate C.34 shows how fish shelter in front of sharp-cornered works as well as behind and on the outward face of the works, and how a sharp-edged permanent structure provides good shelter in a channelised section where otherwise fish would be pushed back to a single, rare point of refuge.

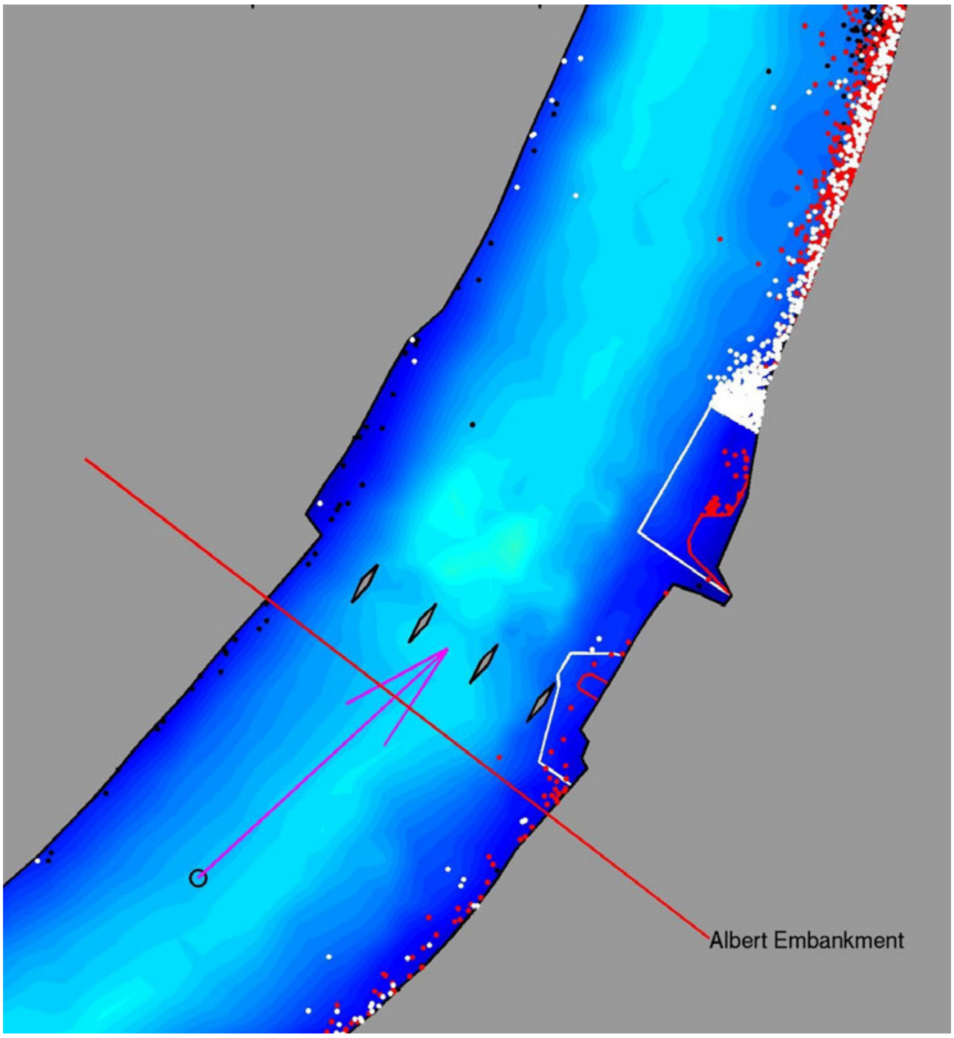
Vol 3 Plate C.34 Screen shots of Victoria Embankment Foreshore showing features of fish behaviour



Albert Embankment Foreshore

C.2.150 As shown in Vol 3 Plate C.35, the square-edged structure provides an attractive refuge and hence potentially beneficial effect for fish during the temporary works (white). The effect is seen to be much reduced for the permanent works (red). Overall, however, this had no significant effect on Tideway passage.

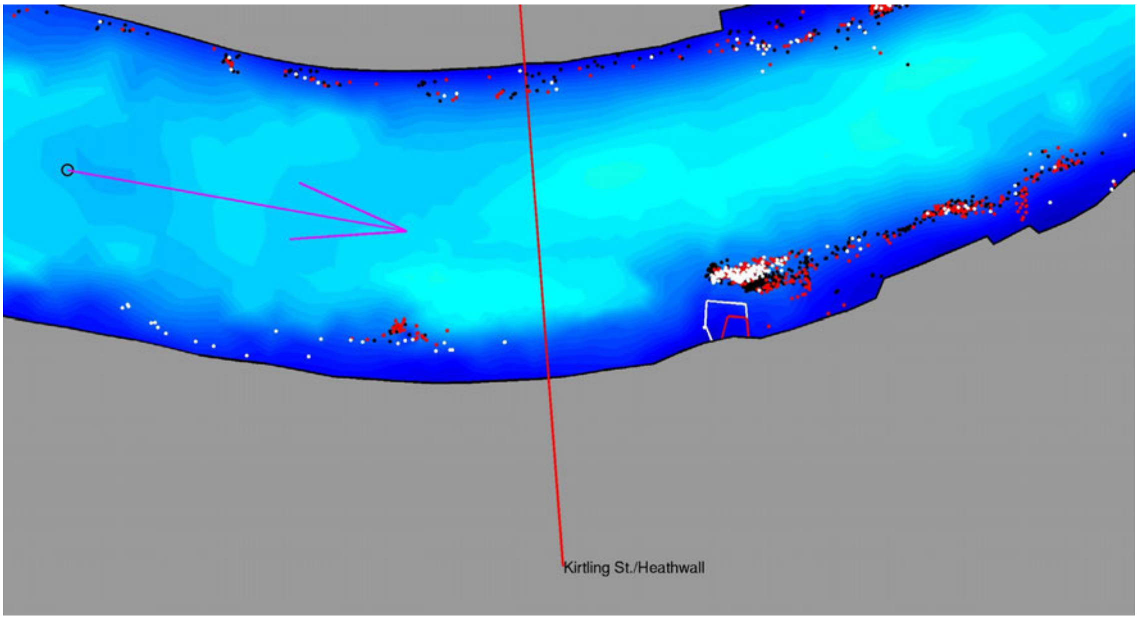
Vol 3 Plate C.35 Screen shots of Albert Embankment showing features of fish behaviour



Kirtling Street/ Heathwall Pumping Station

C.2.151 The temporary and permanent works are seen to have minimal effect at this site as shown in Vol 3 Plate C.36.

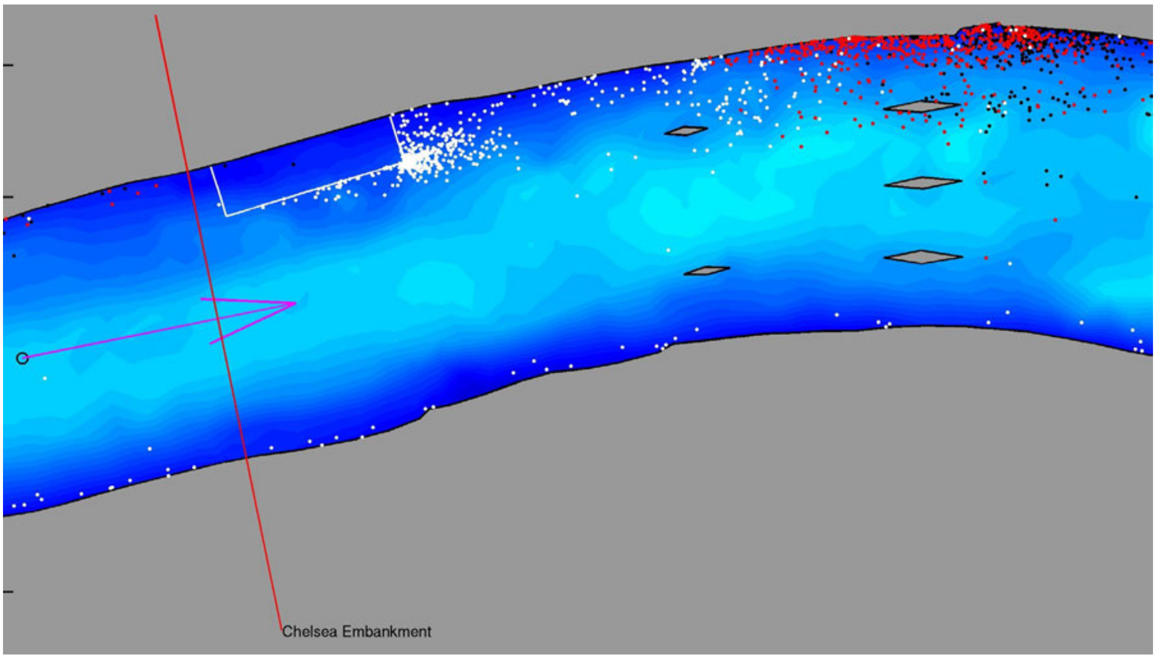
Vol 3 Plate C.36 Screen shots of Kirtling Street/ Heathwall Pumping Station showing features of fish behaviour



Chelsea Embankment

C.2.152 The rectangular temporary structure in Vol 3 Plate C.37 shows another example of the works providing shelter in its lee.

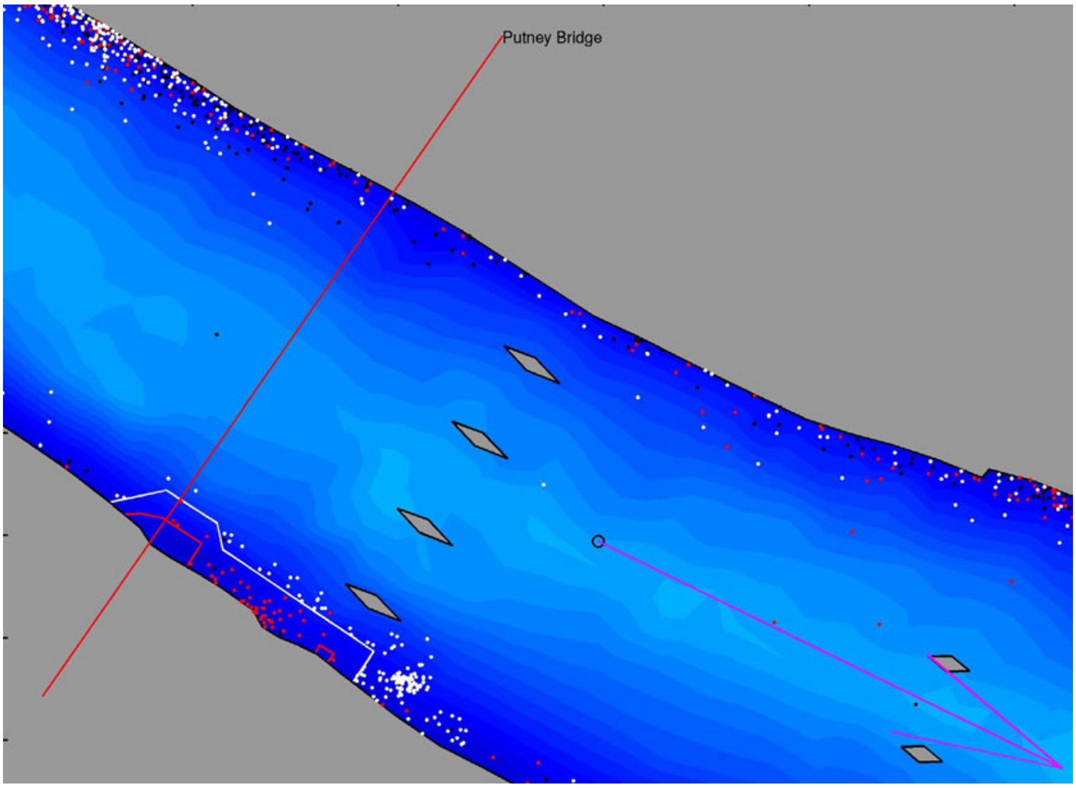
Vol 3 Plate C.37 Screen shots of Chelsea Embankment Foreshore showing features of fish behaviour



Putney Bridge

C.2.153 Both sets of works at Putney Embankment Foreshore provide flow refuges for fish, as shown in Vol 3 Plate C.38.

Vol 3 Plate C.38 Screen shots of Putney Embankment Foreshore showing features of fish behaviour



Features of Fish Behaviour Shown By Model

Importance of velocity profile

C.2.154 The most important finding from the IBM is the role of water velocity in determining fish migration behaviour. While factors such as selection of preferred depth were at the outset considered likely to influence migration behaviour, the model demonstrated that knowledge of velocity and tidal direction is all that is required by fish to navigate the river using selective stream transport. The depth at which the fish swims is shown to be a consequence of velocity selection, and no further effect is achieved by adding in a depth preference rule.

C.2.155 This was further corroborated by the flume studies, where fish chose a velocity cue over a depth cue when presented with counter example of both. The importance of velocity cues has previously been suggested in the literature and is in accordance with knowledge of fish physiology (Metcalf *et al*, 2006). The modelling demonstrated that adding in depth-mediated behaviour made migration up river more complicated and more prone to illogical behaviour.

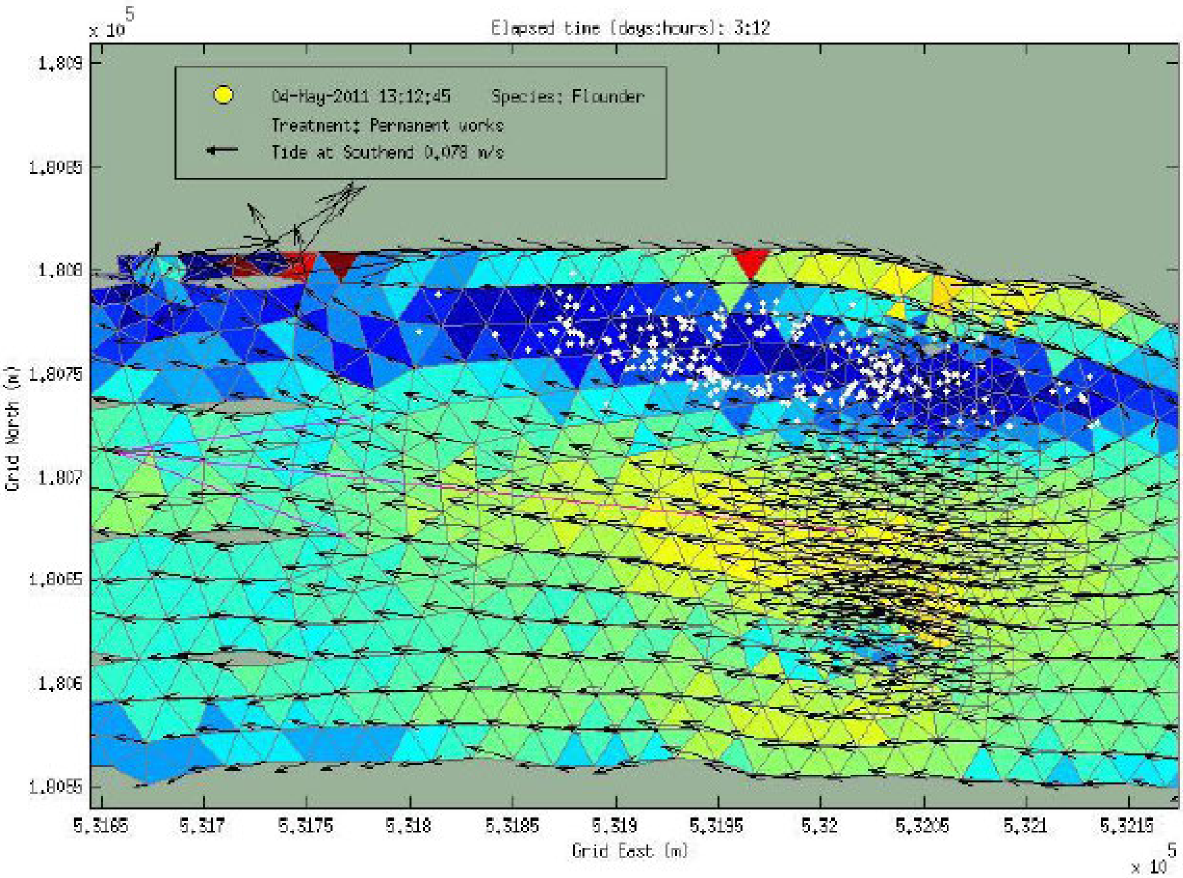
Effect of foreshore structures on fish migration

C.2.156 Compared with the base case, there is no evidence that the proposed temporary and permanent works would act as barriers to upriver movement of juvenile fish. Modelling demonstrates that the works should benefit upstream migration by presenting more opportunities for fish to shelter from disadvantageous currents. Furthermore, modelling shows that fish of the sizes tested would be unable to swim directly against the currents in the centre of the river in any case, therefore, any increase in current speed in the centre of the river caused by the works would have no impact.

C.2.157 The IBM demonstrates an interesting feature of fish sheltering in front of, as well as behind structures as a result of the local hydraulic changes. In this respect, structures with sharp corners were shown to be more effective fish than streamlined structures.

C.2.158 Large ephemeral eddies caused the model fish to slow down and hold in deeper water than they would otherwise select. It is unknown whether fish have a mechanism to avoid becoming trapped in recirculating eddies, and expert opinion indicated that young fish are commonly observed in such locations on the Tideway (Steve Colclough, pers. comm). No specific behaviour rule for escaping eddies was included within the IBM and it is assumed that they would escape either by random behaviour or at the point in the tidal cycle when the eddy disappears.

Vol 3 Plate C.39 Model fish (flounder: white dots) accumulate in gyre in the vicinity of Blackfriars Bridge



Fidelity to channel side

C.2.159 Owing to the tendency of young fish to stay within lower velocities near the margin, there is a tendency of model fish to remain near to the bank of the river they first find, with relatively little crossover. Viewing video files reveals certain sets of conditions where mixing across the river occurs in some species and this can be promoted by the presence of the proposed structures.

C.2.160 The most marked bank fidelity effect is evident in the transit progress histograms (Vol 3 Plate C.39) for elver, in which the differential progress of cohorts on opposite banks led to a bimodal progress distribution by the time they reached the top of the river. Some exchange across the channel is thought to be advantageous to migration, as it allows fish that may be inhibited by structures – more likely lack of structures – on one bank some chance of continuing migration via the other bank. Thus the introduction of new structures may both help fish to mix across the river and to provide more shelters.

C.2.161 Mortality risk associated with brief exposure to deeper water was found to be minimal and therefore mixing across the river would have no impact in this respect.

River regime

Effects of existing structures on fish passage

C.2.162 The presence of the proposed temporary and permanent structures reported above do not present features that are new to the Thames Tideway, similar effects being repeated at the numerous existing jetties, wharfs, revetments, embayments and other natural and artificial structures.

C.2.163 The general principle demonstrated by the IBM is that complexity in bathymetry (bed profile) and bank structure creates velocity gradients across the river channel. Provided that there is sufficient habitat complexity, fish have access to a choice of velocities and are very effective in moving into favourable holding conditions.

C.2.164 For juvenile fish, this is corroborated by the modelling, by flume trials, by field survey data and by the observation of experts on the Thames Tideway.

Assessment and conclusions

C.2.165 The following section presents an assessment of the effects of the temporary and permanent structures on fish migration in the context of the significance criteria used in the EIA. It also considers the outputs of the model in the context of the questions posed of the model:

a. Whether the Thames Tideway Tunnel structures (temporary or permanent) delay juvenile fish migrations through the estuary, for one or more species; and

b. Whether the structures result in increased mortality rates for these individuals.

C.2.166 The potential impacts of delayed migration and increased mortality are assessed against an objective scale ranging from high negative to negligible (presented in Vol. 2 Section 5). When combined with the value of the receptor High (Regional) any impacts of greater than low negative magnitude are likely to give rise to moderate, and therefore significant effects.

Effects of temporary structures

C.2.167 The study found that there were small, statistically significant differences in the rate of upriver migration between the baseline and the temporary works scenarios. For example, for flounder there was a 3.3% difference in the mean (average) time taken for the population to undertake an upstream migration upstream between the baseline and temporary case. However, in real terms this represents a delay of a single tidal cycle, over a 5 day period, and is considered to arise as a result of the large size of the population sampled (2500 individuals) and therefore the inherent variation between individuals. Effects are thus considered to be negligible for flounder.

C.2.168 The effects of the temporary works on bass are advantageous, with the mean distance migrated over a 6 day period 4.4% greater than for the base case. This is likely to be due to the hydraulic conditions created around the structures giving rise to extra shelter from the tidal currents. However, the advantage is considered to be only slight and therefore overall effects on bass are negligible.

C.2.169 No difference between the temporary and baseline situations were recorded for eel and therefore effects are also negligible.

C.2.170 In terms of differences in mortality rate as a result of fish being forced into deeper water as they pass the structures, modelled mortality rates for the temporary and permanent works treatments vary little from the base case and statistical analysis confirms that any small differences seen are non-significant.

C.2.171 The explanation for this is that, while structures may have the effect of forcing some fish into deeper water as they pass the structure, their instinctive and continuous searching for preferred lower velocity conditions rapidly brings them back into shallow water as and when it becomes available. Thus they would only spend a small proportion of their time in deeper water and even where the mortality risk is increased several-fold, the exposure time is too small to make any significant difference.

C.2.172 Effects are thus also considered to be negligible for all three species.

C.2.173 Overall, the study shows that effects on the three fish species of changes in flow velocity associated with the temporary structures are negligible.

Effects from permanent structures

C.2.174 As for the temporary structures the assessment was considered in the context of whether the structures may delay juvenile fish migrations, or result in a higher mortality rate due to juvenile fish being forced into deeper water where predation rates are greater.

C.2.175 The modelling shows that there would be no significant differences in the rate at which fish migrate through the estuary between the baseline and the permanent case. The differences were greatest for flounder (rate of progress is 6.9% slower for the permanent works compared with the baseline). However, this is considered to be as a result of the large number of individuals within the modelled population.

C.2.176 For elver the rate of progress is practically indistinguishable for the permanent case compared with the base case. For bass, the permanent case is slightly more favourable than the base case, which is likely to reflect their use of the structures to shelter from the current. Interestingly, the rate of progress for the permanent case was slightly less favourable than the temporary case. This is considered to be because the more angular temporary structures are considered to offer more effective shelter than the streamlined permanent structures.

C.2.177 Similarly, there are only small difference in the mortality rate for any of the three species between the baseline and the permanent case. The differences between the works are only noticeable in the case of flounder and in the area immediately downstream of Blackfriars Bridge where the permanent works is higher than the base case. It is likely that this is related to a flood tide gyre that forms which can trap the fish (in relatively slow moving but deep water).

C.2.178 Overall however, mortality risk was not significantly higher over the whole Tideway. This is because although fish are forced into deeper water by the structures, their instinctive search for lower velocity conditions brings them back into shallow water when it becomes available. They thus spend only a small proportion of time in deeper water where mortality rates are higher.

C.2.179 Overall, the effects on migration rates and mortality of the temporary structures on all three species are considered to be negligible.

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Annex A Expanded candidate rule set

Flounder

Vol 3 Table C.19 Species:0-group Flounder (*Platichthys flesus*)

Behavioural attribute	Synopsis of known biology	Rule description
Predominant Direction of Migration	Flounder spawn in the outer estuary and make their way upstream to the head of tide, into brackish or freshwater, typically in April to early May (Skerrit, 2010)[4]. At the size of a postage stamp, young flounder are very abundant in the upper tidal reaches (Maitland and Herdson, 2009)[5]. The 2011 Tunnel Project surveys found (post-larvae/metamorphosed) juvenile most abundant in upstream sampling sites during May and June, with modal lengths increasing from 12 mm in early May, 18 mm in late May to 32 mm in June (in support of Colclough *et al*. (2002)[6] results). From July, flounders were larger, much less abundant and spread back down the Tideway. Although in some rivers they will penetrate many miles above the head of tide, Teddington Weir creates an upstream limit in the Thames. Flounder are a true estuarine resident species and their strategy during the first year of life is to maximise use of feeding habitat and to minimise predation risk. Movement to deeper brackish water and return lower estuary/seaward migration occurs during November and February1.	Juvenile flounder progress upstream towards head of tide in April May at lengths 12-25 mm. From July they begin to disperse back downstream at a modal length of ~40 mm.
Responses to Tides	Selective tidal stream transport (Gibson, 2005)[7]. During this behaviour, fish swim off the bottom both day and night, and synchronise ascents and descents with tidal and diel cycles (Able *et al*, 2005)[8]. Juvenile flounder migrate far upstream in tidal rivers by moving only on the flood tide, anchoring themselves to the bed on the ebb (Wheeler, 1988[9]; Moller and Dieckwisch, 1991[10]). (Velocity high on flood and low on ebb tides in the Tideway). Juveniles feed intensively in intertidal/marginal area on flood tides and recede with the tide on ebb.	April- July, length <40 mm, apply selective tidal stream transport, biased to move on flood tide. Stay on bed on ebb, following tide down. Also, see Response to Velocity Gradients

Behavioural attribute	Synopsis of known biology	Rule description
		below: assume displaced if >45 cm/s velocity. August-October, length >40mm, disperse downstream to maximise habitat use.
Preferred Water Depths	Use estuarine margins during early life stages but move further into the deeper estuarine channel as the summer/autumn progresses and temperatures decline .	Target water depth <1m up to a length of 40mm, April-July. Target water depth 1-2 m July to September, length>40 mm. Target deepest water mid-channel from October.
Vertical Position in Water Column	Larval stages are pelagic. Metamorphosed flatfishes are epibenthic. And negatively buoyant, spending the majority of their time on the sediment, which lowers the energetic costs of swimming. However, they are also capable pelagic swimmers using a swim and glide motion allowing travel in straight lines. Cues for timing movement can be both biotic and abiotic into the water column include hunger, pressure, currents, and turbulence (Gibson, 2005)[11]. Flounder larvae found near surface on flood tides and low in the water column (or on the surface) during ebb tides, re-dispersing by turbulent mixing when velocities increase again (Jager, 1999)[12].	Remain on bed on ebb tide. Enter water column on flood.
Fish Size and Swimming speeds	Swimming speeds of flatfishes have rarely been measured but maximum sustainable swimming speeds (MSSS) in the range of 1–6 body lengths s–1 have been recorded in the laboratory for four	Apply MSSS from table as follows: April: assume

<table>
<tr><th>Behavioural attribute</th><th>Synopsis of known biology</th><th>Rule description</th></tr>
<tr><td>Volitional, MSSS, Burst</td><td>North Atlantic species (Blaxter and Dickson, 1959)[13]. Table below is for flatfish, calculated from EA Screening guide, Table 5.2 (Turnpenny and O'Keeffe, 2005)[14]

<table>
<tr><td></td><td></td><td colspan="2">MSSS, cm/s</td></tr>
<tr><td>Length, mm</td><td>Temp</td><td>Median</td><td>90%ile</td></tr>
<tr><td>12</td><td>15</td><td>5.4</td><td>3.6</td></tr>
<tr><td>20</td><td>18</td><td>8.4</td><td>5.5</td></tr>
<tr><td>32</td><td>18</td><td>11.1</td><td>7.3</td></tr>
<tr><td>44</td><td>20</td><td>14.5</td><td>9.6</td></tr>
<tr><td>58</td><td>21</td><td>17.8</td><td>11.7</td></tr>
<tr><td>68</td><td>21</td><td>19.6</td><td>12.9</td></tr>
</table></td><td>length 12 mm May: assume length 20 mm June: assume length 32 mm July: assume length 44 mm August: assume length 58 mm September: assume length 68 mm Use 1 bl/s for volitional swimming.</td></tr>
<tr><td>Predator Evasion</td><td>Growth reduces the number and range of predators to which a fish is vulnerable, thus early stages suffer greatest predation mortality. Juvenile flatfish are prey for many different invertebrates and fishes. Depth distribution of flounder is influenced by the presence of crustaceans such as brown shrimp (Crangon crangon) (Modin and Pihl, 1996)[15] and occupying shallow marginal zone is safer for early stages. Sizes greater than 30mm are thought "safe" from shrimp predation (Skerrit, 2010)[16].</td><td>Apply "danger" rule for fish of <30 mm if they stray into depth . 1m.</td></tr>
<tr><td>Response to Velocity Gradients (shear)</td><td>Flatfish, when in resting phase, seek low velocities near bed, and anchor onto bed by negative hydraulic lift. In sediment, flatfish can bury themselves, reducing the risk of displacement and allowing them to hold station using minimal energy but suitable sediment may be eroded (Gibson, 2005)[17] at higher current speeds. Flatfish may detect bed by sampling vertical velocity gradient or by pressure, though lack of a functional swimbladder makes the former more likely.

The behavioural responses of 0-group plaice (Pleuronectes platessa) have been recorded on a smooth Perspex bottom (Arnold, 1969)[18]:
Stage 1. Still-low currents (approx 0-8cm/sec): No response and random orientation
Stage 2. 8 -30cm/sec: Positive rheotaxis- turn to head upstream without leaving the bottom.
Stage 3. Approx 25-40 cm/sec : Slipping and swimming, slight displacement downstream- slips</td><td>Fish sample vertical velocity profile, selecting low velocities in resting phase and high velocities during active migration.</td></tr>
</table>

Behavioural attribute	Synopsis of known biology	Rule description
	of as much as 5 cm were then counteracted by moving upstream and burying or clamping to surface. As downstream displacement was more frequent the fish responded with bursts of swimming, clearing the bed, and moving 10-20 cm upstream. If the fish touched the weir at the end of the flume it was capable of swimming against the current, upstream for 1-2m and of strong bursts of swimming. When on the bed, the posterior fin seen to be beating and arched back to counteract lifting force on body. Stage 4. Displacement (Approx 45-47 cm/sec).	
Diurnal Changes in Behaviour	Without the influence of tides, flatfish move inshore during the evening and return to deeper waters at dawn (Able *et al*, 2005)[19].	Do not apply day-night rule on Tideway.
Salinity Lethal levels Avoidance levels	Flounder in the River Itchen were found to remain in very low salinities (<2o/oo), where the freshwater layer was in contact with the substrate, moving up the shore with the advancing tide. Fish avoided contact with saline water (20 o/oo) brought in on the flood tide but it was noted that despite the behavioural preference, fish would swim readily into higher salinity water if disturbed. Post-larvae and juveniles collected from the Itchen were found to be fully euryhaline in laboratory studies- smaller fish prefer less saline water and found at higher densities in these areas (Hutchinson and Hawkins, 1993)[20]. *P. flesus* has been known to survive in freshwater ponds and extend to far reaches in estuaries beyond the tidal influence- saline water dense so can form bottom wedge, may be able to utilise due to position in water column (Skerrit, 2010)[21]. Juvenile *P. flesus* can experience reduced growth at lower salinities and reduced recruitment to estuaries.	Do not apply salinity rule to flounder.

Elver

Vol 3 Table C.20 Species: 0-group Elver (*Anguilla anguilla*)

Behavioural attribute	Synopsis of known biology	Rule description
Predominant Direction of Migration	Juvenile European eels (*Anguilla anguilla*) are believed to cross the Atlantic from spawning grounds in the Sargasso Sea as leptocephalus larvae, using ocean currents to reach European coastal areas where they metamorphose into glass eels. Glass eels enter European estuaries	Glass eels/elvers head upstream towards head of tide.

Behavioural attribute	Synopsis of known biology	Rule description
	from autumn through to spring (Bureau du Colombier *et al*, 2007)[22]. This entry into the estuary is not continuous, it occurs in waves, perhaps cued by smell, electric fields, biological clock or salinity variation (Creutzberg, 1961[23];Prouzet *et al*, 2009)[24]. In the Thames, the upstream migration of glass eels predominantly occurs over an approximated 47 day period from May-June (Naismith and Knights, 1988)[25]. They then penetrate to the head of the estuary and into freshwater; to complete their catadromous lifestyle and maximise use of available habitat until sexually mature, when they return to sea as 'silver' eels. Most unpigmented eels spend at least a year in the Thames, and the migrants leaving the estuary into freshwater reaches are mostly between 1-3 years old, pigmented juveniles (elvers). River colonisation does not start before May-June for most individuals. It is known that some eels can spend their whole continental-shelf life in estuaries and coastal waters: the decision to remain in the tideway rather than migrate to freshwater is governed not only by ability to move between habitats, but also food availability, competition and predation risk (Railsback *et al*, 1999)[26]. The 2011 survey results show elver sizes ranging from 50mm to 120 mm in the early surveys (May and June), with a mode length of approximately 70 mm in June, and a range from 50 mm to 180 mm in later surveys (but insufficient numbers to determine a clear mode in most survey weeks).	
Responses to Tides	Glass eels migrate upstream using selective tidal stream transport (STST), enabling minimal energy expenditure (Bureau Du Colombier *et al*, 2007)[27]. STST has been shown to increase the mean migration rate for juvenile eels for example from 0.64 ± 0.6 km day-1 in the non-tidal sections of the Rivers Severn and Avon (White and Knights, 1997)[28] to 3.5 km per day- in the Gironde estuary (Beaulaton and Castelnaud, 2005)[29] . Bolliet *et al*. (2007)[30] proposed that glass eels exhibit rhythmic patterns of swimming activity closely matched to the tidal cycle, i.e. individuals were not passively drifting with the current during the flood; instead they actively swam with the current, before alternating and swimming against the current. Flume experiments conducted by	Apply selective tidal stream transport, biased to move on flood tide. Stay on bed on ebb, following tide down.

Behavioural attribute	Synopsis of known biology	Rule description
	Bureau Du Colombier *et al*. (2009)[31] showed that active eels showed strong negative rheotaxis whilst the other sedentary eels (that demonstrate burying activities) showed strong positive rheotaxis; only 5% of eels were hyperactive swimming both with and against the tide with no rest period. There is evidence that glass eels do not use every tide to migrate, and some individuals may not complete migration to freshwater, instead completing their lifecycle in coastal/estuarine waters. Gascuel (1986)[32] observed only 10% of glass eels use flood tides optimally, while Beaulaton and Castelnaud (2005)[33] observed 20% and partial utility of the tides by some eels, missing tides or using an ebb tide. Eels are able to stop estuarine migration at least temporarily (Bureau Du Colombier *et al*, 2007)[34]. During the glass eel phase, active migration is very directional, but once pigmented, yellow eels show more random dispersion behaviour (Ibbotson *et al*, 2002)[35].	
Preferred Water Depths	In the River Fremur, northern Brittany, eels <150mm and eels between 150-300mm appeared to have similar habitat requirements. Small eels preferred shallow habitats (less than 6m) with flow velocity >0.1m/sec, substrate composed of gravel, pebbles and/or boulders, medium and high aquatic vegetation density and low riparian vegetation cover (Laffaille *et al*, 2003)[36].	Target water depth <1m
Vertical Position in Water Column	When migrating, glass eels shelter on bottom in lower velocities during the ebb tide and then move up into the water column to be carried in or swim with the flood time.	Remain on bed on ebb tide. Enter water column on flood.
Swimming speeds Volitional, MSSS, Burst	Glass eels have a weak swimming ability. McCleave (1980)[37] investigated swimming endurance times of elvers with an average length of 72mm, and found that endurance time decreased logarithmically with increased swimming speed from 3.0 minutes at 25 cm/sec to 0.7 minutes at 36 cm/sec. Elvers could swim at burst speeds for 45m at 25 cm/sec, 15m at 36 cm/sec and less than 10 m (very poor progress) at 54 cm/sec. It was hypothesised that at slower swimming speeds, longer distances could be	Use maximum sustainable swimming speed of 8.3 (90%ile 7.9) cm/s for an 8 cm glass eel/elver and burst speed of 50 (90%ile

Behavioural attribute	Synopsis of known biology	Rule description
	achievable. While an 80 mm elver can maintain position within a current of 30 cm s-1 for a "few minutes" as observed by Sörenson (1951), or even as much as 50 cm s-1 for a period of 20 seconds (at spring temperatures, estimated from computer program SWIMIT v3.3: EA, 2005). The EA SWIMIIT programme gives maximum sustainable swimming speed of 8.3 (90th percentile 7.9) cm/sec for an 8 cm glass eel/elver and burst speed of 50 (90th percentile 25) cm/sec.	25) cm/s. Use 1 bl/s for volitional swimming.
Predator Evasion	It can be inferred that activity during the dark provides cover from visual predators.	
Response to Velocity Gradients (shear)	Specific behaviour is associated with ebb current velocities. Glass eels have been found in the water column when the downstream current had a speed lower than 30 cm/sec (Prouzet *et al*, 2009)[38]. Creutzberg (1961)[39] demonstrated in the laboratory that glass eels expressed a positive rheotaxis for ebb currents of 0.2 m/sec, and a negative one for ebb currents higher than 0.36 m/sec. For ebb currents higher than 0.36 ms-1 glass eels swim close to the sediment surface of bury themselves if sand substrates are available. Prouzet *et al* (2009)[40] concluded that migration speed may be equal to the displacement of the tide (approximately 0.4 m/sec) in the Ardour Estuary, France.	Elvers sample vertical velocity profile, selecting low velocities in resting phase and high velocities during active migration.
Diurnal Changes in Behaviour	Anguilla glass eels move up estuaries mainly at night when temperatures exceed 6oC, when predator efficiency is lowest, using selective tidal stream transport. Bureau du Colombier *et al* (2009)[41] found two types of photo-related activity: some responded to a decrease of light intensity by moving with the flow whilst others remained buried in the gravel.	Do not apply day-night rule on Tideway.
Salinity Lethal levels Avoidance levels	Glass eels always survive sudden shifts between freshwater and saline water (Wilson *et al*, 2004)[42], but glass eels arriving from the sea appear to require a delay period before voluntarily entering into freshwater (Bult and Dekker, 2007)[43]. When glass eels collect in the estuaries, there is a developmental change in salinity preference: glass eels prefer 100% sea water, semipigmented elvers show no clear preference and fully pigmented elvers prefer freshwater (May and Marshall, 2008)[44]. A study by Crean *et a*l. (2005)[45] showed that both glass eels and elvers	Do not apply salinity rule on Tideway.

Behavioural attribute	Synopsis of known biology	Rule description
	are strong osmoregulators, there were no mortalities recorded within three weeks of rapid transfer between widely differing salinities. However, fully-pigmented eels had a lower tolerance of full-strength seawater, with mortalities occurring within 24h; this was attributed to their physiological adaption to low salinity in preparation for their freshwater life during their approximately four month migration period through the estuary (White and Knights, 1997)[46]. Conversely, glass eels, when given a choice between freshwater and full-strength seawater, preferred the seawater compartment.	

Bass

Vol 3 Table C.21 Species: 0-group Bass (*Dicentrarchus labrax*)

Behavioural attribute	Synopsis of known biology	Rule description
Predominant Purpose and Direction of Migration	Bass spawn offshore and enter estuaries in their first year as postlarvae. They typically enter the estuary in June and progress upstream to the head of tide (Kelley, 1988)[47]. Dando and Demir (1985)[48] recorded 10- to 15-mm larvae gathering near the salt/freshwater interface in Plymouth. The 2011 juvenile surveys first recorded bass in the upper Tideway (at Putney) at a modal length of 16 mm in late June. In July, bass modal length increased to 21mm, in August to 37mm and September to 41mm, and was most abundant at Kew. Subsequently, bass disperse back downstream to utilise productive intertidal feeding areas along the estuarine margins and tidal creeks. By late autumn bass return to deeper water and back to the lower estuary (Colclough *et al*, 2002)[49]. In Southampton Water, bass are found concentrated near the head of tide in poor recruitment years but in strong recruitment years they spread seawards into tidal creeks and sub-estuaries (Kelley, 1986)[50], indicating that there is a fitness advantage in occupying the upper limits of the estuary; this would imply an advantage to getting there first. Various fish species penetrate to the tidal limit	0-group bass aim for head of tide over June-September. From October they head downstream for deeper water.

Behavioural attribute	Synopsis of known biology	Rule description
	during their early life history and this is believed have benefits in terms of feeding and predator avoidance. In autumn, 0-group bass leave marginal estuarine habitat for deeper, warmer water, often being seen on power station screens at this time (Pickett and Pawson, 1994)[51].	
Responses to Tides	Jennings and Pawson (1992)[52] comment that the larval transport mechanism into estuaries is initially passive, becoming active through selective behavioural strategies such as selective tidal stream transport.	Apply selective tidal stream transport, biased to move on flood tide. Search for low velocity refuges on ebb.
Preferred Water Depths	In their first summer, bass in UK waters favour shallow creeks, channels, marsh pools and tributary streams, moving into the deeper parts of the estuary in about October (Kelley, 1988)[53].	Target water depth <1m up to a length of 50mm, June-September.
Vertical Position in Water Column	Bass are a pelagic species. Based on the selective tidal stream transport behaviour it can be hypothesised that juvenile bass attempt to hold station in channel margins and in the lee of piers, jetties and other structures on the ebb tide.	Midwater, avoiding contact with the bed.
Swimming speeds Volitional, MSSS, Burst	Volitional = 1-2 bl/s (assumed) Swimming performance of bass measured by Turnpenny (1981)[54] MSSS=9.15 /7.2 bl/s @ 12°C (median/90%ile) Burst= 12 bl/s	Apply values shown to left.
Predator Evasion	Juvenile bass are predated on by larger fish, including gadoids and bass (Henderson and Corps, 1997)[55]. Individuals mobile at night but otherwise travel in groups during daylight (Anras *et al*, 1997)[56].	Apply “danger” rule for fish of <30 mm if they stray into depth > 1m.
Response to Velocity Gradients (shear)	Probably varies with tidal state, seeking low velocity refuges on the ebb tide and high velocities on the flood.	Fish sample horizontal and vertical velocity profile, selecting low

Behavioural attribute	Synopsis of known biology	Rule description
		velocities in resting phase and high velocities during active migration.
Diurnal Changes in Behaviour	Juvenile bass are visual predators, and have been reported to feed both by day and night. Furthermore, juvenile bass are group hunters, preferring to forage in groups by day and scatter at night, at which time individuals remain immobile in sight of the bottom. In a tracking exercise by Anras *et al*. (1997)[57] on the French coast, juvenile bass appeared to switch from being nocturnal to diurnal in response to social interactions, potentially due to the adaptive advantages of shoaling. Nocturnal behaviour by solitary fish may be explained by the avoidance of avian predators, adopting crypsis or refuging in deeper areas during daylight when they are more vulnerable to predation and more timid than those who are part of a shoal.	School by day, disaggregate at night.
Salinity Lethal levels Avoidance levels	Bass (of all ages) are euryhaline; they can tolerate freshwater and will freely move to it. Some mortality has been recorded in juvenile stages when exposed to low salinity water (Giffard *et al*, 2008)[58]. Osmoregulatory capacity is size- and age- dependent and reached its maximum for fish 17-26mm long, 63-86 days after hatching. This early development of osmoregulatory ability, and thus salinity tolerance, in sea bass, may provide an advantageous flexibility for the timing of migration towards low salinity habitats (Varsamos *et al*, 2001)[59]. Therefore, this species migrates between different habitats during its lifecycle, and its different developmental stages are exposed to various salinity regimes. Although postlarvae gather near the salt/freshwater interface in estuaries, it is questioned whether bass are attracted to lower salinities or if the influence of temperature or the availability of food is a greater draw (Dando and Demir, 1985)[60]. Under experimental conditions, sea bass juveniles are able to live in different salinities ranging from freshwater to 60o/oo salinity (Jensen *et al*, 1998)[61]. Chervinski	Do not apply salinity rule.

Behavioural attribute	Synopsis of known biology	Rule description
	(1974)[62], working in Israel, reported that 0-group bass (20-34 mm in length), which have been transferred from high-salinity lagoons to low-salinity ponds, survived and grew. Direct transfer from seawater to tap water (salinity 0.5%) at around 18oC resulted in total mortality, but all fish survived direct transfer to dilute seawater with a salinity of 3.9%. A gradual salinity reduction from 10 to 0.5 o/oo over a 24 hour period resulted in 100% survival of the juvenile bass. Freshwater adaptation is therefore quite possible under cultivation conditions. In river systems, abrupt changes in salinity are unlikely, and mortality of bass attributed to freshwater incursion has not been observed, implying a strong ability to osmoregulate (Pickett and Pawson, 1994)[63]. Kelley (1986)[64] found that, in some creeks in West Wales, 0-group bass moved towards freshwater in times of drought and flood following high rainfall inland.	

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Annex B Candidate rule set consultation responses

Environment Agency

Vol 3 Table C.22 Fish rules memo: Environment Agency comments December 2011

Comment	Response
The list of the behavioural responses to be used in the model, research methods are very good. However, this is all behavioural response, and does not address the effects on fish survival. For example, fish pushed into un-preferred deeper water will seek shallower water, but if they cannot find this shallower water what happens then? Presumably they either fail to get around the obstruction and stay downstream, or will be eaten. Have fish deaths related to changes in behaviour been taken into account? Are we correct in thinking that the model will contain the same number of fish at the beginning and the end of the model run? We anticipate that the potential increase in predation could be significant? Is there any way of accounting for this impact?	The model can kill off fish if they go into deeper water, e.g. using some probability of lethality if they cross a certain depth boundary. Endpoints are then time to cross finishing line and proportion finishing.
How is tidal speed being modelled, is it an average speed or is the increased velocity associated with a big spring and fluvial flow being considered?	Specific illustrative tidal conditions are being run rather average.
Is the bed type in the various locations being considered? This will effect foraging and will also affect roughness, which in turn will affect the ability of fish to hold station in the current. Increased bed roughness could help fish pass the major foreshore obstructions, areas of cobble etc may better support behaviours such as holding station and migrating than mud. For example, elvers and small eels, will happily spend the low tide under large cobbles and small boulders on the exposed foreshore, so they are not limited to the wetted channel.	Bed type per se is not incorporated into the model, though the boundary layer effect is. We are have also obtained more detailed information from our supporting flume studies, in which we have represented a shingle bed. Interesting observation about elvers holding station in the 'dry'. The proportion that do this is unknown therefore it has not been possible to incorporate it into this model.
One other aspect that we would like the model to pick up is the variation in river morphology over the tidal cycle, this can be dramatic. Fish will actively	The model picks up these features on the basis of the velocity and depth rules

Comment	Response
seek the backwaters and vegetated margins at the top of the tide. At low tide, refuge areas are far more limited.	proposed. Initial runs indicated that velocity only would cause this behaviour.
Flounder - as the juveniles get larger over summer they tend to move into deeper water. Possibly to avoid avian predation.	As shown also by our field studies on the Tideway in summer 2011. Effectively this means that at a certain size they will pass out of the 'range of interest' of the model.
The Known Biology sections states "that Teddington lock forms the upstream limit for Flounder". This is not true, we find Flounder on the Molesey to Teddington reach boom boat surveys every summer. It's more likely that Molesey is the limit however we've also found Flounder more than 2 miles up tributaries in totally fresh water.	Noted. Our model runs to Teddington so this has been taken as the upstream limit.
Bass - in a normal year the 'Head of tide' (the limit of saline intrusion) tends to be in the Cadagon area. Bass are often found upstream of here and Kew is quite a distance upriver. It may be worth checking where the 'Head of tide' is in a typical year and checking if bass are regularly found further upriver than this point? The model may need to allow for bass penetration further that the Head of tide.	We may have used 'head of tide' in a different sense. We were referring to limit of tidal height influence. We found significant numbers of bass juveniles in 2011 above Richmond ½ tide weir and will take Teddington Weir as our limit.
The document states that Bass enter the estuary in June. Please note that we find Bass in small numbers in our up river spring surveys in May suggesting that either they never entirely left or migrated upriver significantly earlier than June	Our smallest bass (12-14 mm) occurred in June. Anything larger than 30-40mm occurring before this are probably previous year's brood, though some year-to-year variation can be expected. Our June starting point is probably a good average.
Eel - see earlier comment on substrate type and low tide.	See response above.

Independent fish specialist: Mr Steve Colclough

Vol 3 Table C.23 Fish rules: Independent review comments by Mr Steve Colclough

Comment
Elver: Naismith & Knights 1993 cite 65mm as the minimum elver size. The Water Framework Directive Thames data set from 1992 onwards agrees. You have them as small as 50mm. Is this a real change or a reflection of the sampling window? You cite that unpigmented eels are present in the Thames for up to a year. I have not seen this quotation, is it from Naismith and Knights? Naismith and Knights postulated that recolonisation of a system was density dependant, with some of each new wave of elvers settling out when they first came to an area of very low density. Elver runs in the Thames are extremely low compared to historic records pre-pollution. If Naismith and Knights are right, this would be manifested in very slow rates of recolonisation of the freshwater catchments. This is supported by evidence from the long term freshwater fish survey programmes in the Thames tributaries. Bolliett 2007. I have noted a similar active movement up into the water column and out into the faster current streams in both flounder post-larvae (sites such as Putney) and sole post-larvae (sites such as Greenhithe). I wondered why you are not applying the day night rule on the estuary. There is good evidence of this diurnal activity elsewhere.
Flounder: Our work consistently showed flounder post-larvae as small at 8mm penetrate as least as far as Putney, as early as early May. Some of these have not yet fully transformed. These swim at 45 degrees and the eye has yet to complete its migration. These are nearly transparent, with very little pigmentation yet. Further upstream, the smallest we have seen are at 10mm, fully transformed, at sites such as Chiswick Ait and further upstream, again by mid May. We had thought that this was one modal group. A useful MSc study by Belinda Bush in 1998 demonstrated that further groups of 8mm post-larvae continue to arrive until late June. Belinda sampled with a standard kick net in the margins at low water from March until July. As with many other estuarine species, yoy flounder are known to move downstream as freshwater flows increase and temperature drops in the late Autumn. They disappear from the intertidal margins by early November in most years. In one investigative study completed before the WFD formal sampling programme began, we located the yoy flounder in late November and early December (2002 and 2003) in a restricted band in the deepest part of the main channel, at a number of sites above Vauxhall. I have observed STST closely at sites like Putney with flounder post-larvae in May over a number of years. As soon as the tide begins to flood, very high

Comment
densities of 8-12mm individuals, lift off from a narrow subtidal band about 1-2m in width in the extreme margins. They move to the surface layer and spread out actively into the faster currents. Within 30 mins of the flood commencing, there is a broad track up to 5m wide from the margins out. Standing in the water column next to the fish does not seem to deter them. I have personally tracked individual fish at 10mm or so moving on the surface like this for 10's of metres and even in one case for over 100m. My own interpretation of this behaviour is that the very small fish can stay in the surface film easily and could drift for most of the tidal excursion if they chose. As they grow, body mass and gravity dictate that they become progressively less efficient at this process. The speed with which large densities of 8mm post-larvae arrive in early May each year does suggest very rapid movement. I would like to get Cefas to age some of these post-larvae to see how far and fast they have travelled. We did the same for bass -see later. You cite elvers using STST to move up to 3.5km a day. I would suggest that flounder, particularly the smallest size groups, are much more efficient than this. You cite the use of sediment by resting flounder on the ebbing tide. In practice, the vast majority of the bed used by the earliest life stages in the upper estuary from May onwards is gravel. One of our routine sampling methodologies is to sample these subtidal gravel beds with a kick net just before the tide starts to flood. Very large numbers of juveniles can be taken from May until early July when they become too active.
Bass: The smallest we have come across is 12mm at Vauxhall in mid June. These are still transparent with black edging on the dorsal and ventral surfaces. A purplish sheen is laid down before the scales become apparent. We did think that such small fish suggested a local spawning site had become established. Graham Pickett aged our early samples to 45 days. This fits in with established spawning patterns further afield and did not clearly show the development of a new local spawning site. However, this study was in the mid 90's. Bass are now known to be reacting to climate change quite actively, and the situation may now be different. We have noted multiple modal groups of yoy bass in the estuary. The first wave of 12mm + fish arrive in mid/late June. There are later waves in July, August and in some years, even early September. This was reported by another of our MSc students (Caetano, 2002). These multiple waves of fry have been reported elsewhere and are thought to reflect spatial and temporal differences in spawning in contributory groups. On your salinity rule, I would just add that to my knowledge, no bass over 30cm have ever been reported from the estuary above Woolwich. In one interesting case, together with Cefas, we investigated a long running mortality event occurring in the Royal Docks, exclusively involving large bass (45-60cm). At this point in the estuary, salinity varies significantly over the annual cycle. Bass fry move into the docks over the spring and summer. Some probably leave in the autumn, but some remain through the winter months. In most winters, the

Comment
freshwater flows here are such that low salinity is maintained in the docks. Over the annual cycle then, the salinity range can be tolerated by bass as they mature. However, over a very wet period of 18 months in the late 1990's, salinity remained very low in the docks throughout. Cefas later determined that the bass mortalities were associated with long term osmotic stress.
Dace: We have found dace spawning on subtidal gravels in the margins at the same time and place as smelt, in mid April in 1986 & again in 1987, near Putney Bridge. We consistently see two modal groups in the dace fry. The first appears by mid/late May, the second 3/4 weeks later. We had thought that this may reflect contributions from spawning populations in at least two tributary streams, Mann reported two dace spawning annually, 3/4 weeks apart, in his classic studies on southern chalkstreams. This is more likely to be the explanation in the Thames estuary too. Another of our students (Geogeghan, 1995) found some interesting data with the dace fry. Knowing the spawning time and location, he began to find 7mm plus larvae down through the city reaches as far downstream as Greenwich in June. If we assume passive movement of the fry over say the first 14 days of life and a typical net tidal excursion downstream movement of 1- 2 km per day at this time of year, I think that puts most of the dace fry down in the wide bend at Greenwich in slacker flows, in most years, before they can begin to use STST. The narrow funnelling effect between Vauxhall and Wapping may tend to hasten this downstream movement. The dace fry at Greenwich are often found together with the smelt post-larvae, who may well have undergone the same journey at the same time. By early July, large numbers of dace fry at 20mm plus can be found in back eddies in the margins on the ebb tide. The densities are particularly large in the very narrow reaches just upstream of London Bridge. This is the observation that prompted me to press for SWIMIT to include dace fry. HR can demonstrate that the minimum velocity on the ebb in the margins in this reach is now 0.7m/sec. This is well in excess of the MSSS. Given that round fish fry have to find refuge on the ebb in the margins, and that this habitat is extremely limited in these narrow reaches, in my view this reach has become critically narrow for the dace. In a dialogue with HR some years ago, they became very interested in this aspect as a continuity issue, to extend the existing Encroachment Policy, which is largely site specific. If the conditions seen at say London Bridge were to be extended over a full tidal excursion, and no marginal habitat were available, this would see the dace yoy move down below the city but unable to reascend. This threat may also apply to other roundfish, but with more ability than the dace to tolerate rising salinities. Potentially, this could see a progressive reduction in the numbers of dace fry which are able to penetrate back up through the narrow reaches to the freshwater estuary upsteam. In dry years, these fry may be lost to rising salinity somewhere below Tower Bridge. Today, we could use our knowledge of STST to suggest that the aggregate impacts of encroachment might jeopardize GES under WFD, if the fry migrations are hindered or cease.

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Annex C The hydrodynamic model

Type of model

C.2.180 The Thames Base model was set up by HR Wallingford in 2004 on behalf of the Port of London Authority and EA, to provide a model of known provenance to aid the two organisations in their regulatory responsibilities. The modelling tool used for the Thames Base model is TELEMAC2D. TELEMAC2D, developed by EDF-LNHE. It solves the depth-averaged shallow water equations using a finite element triangular grid. This triangular grid allows the model mesh resolution to continually vary in space resulting in accurate representation of features such as the various bridge piers and the river wall. The model mesh can be made more detailed on a particular area of interest to resolve structures in the flow such as the proposed permanent and temporary works.

C.2.181 The mesh used by the Thames Base model in the study area was refined in the vicinity of the Thames Tideway Tunnel project sites in order to fit around the proposed temporary and permanent structures.

Fluvial flow cases

C.2.182 Any investigation of peak water levels in the Thames Tideway has to take account of the operation of the Thames Barrier which was designed to prevent large storm surges with the potential to exceed the flood defences propagating into the Thames Estuary upstream of the barrier. To minimise flood risk the Thames Barrier is operated to a closure rule based upon the exceedence of combinations of predicted high water level at Southend and river flows measured at Kingston.

C.2.183 Following discussions with the EA a set of scenarios of tide level / fluvial combinations was chosen to show the effect of the works on water levels at the limiting conditions for closure of the Thames Barrier. These were considered to be the most extreme cases, likely to demonstrate the largest effect of the works.

C.2.184 The chosen tide /fluvial flow cases were as follows:

a. HW Southend 3.85 OD(N) + mean daily flow at Teddington (65 cumecs)

b. HW Southend 3.85 OD(N) + zero flow at Teddington

c. HW Southend 2.75 OD(N) + 1:100 year flow (800 cumecs).

d. HW Southend 2.75 OD(N) + zero flow at Teddington

e. Mean tide (HW at Southend 2.4 m OD(N))+ daily flow at Teddington (65 cumecs)

f. Mean spring tide (HW at Southend 2.9 m OD(N) + largest flow for Barrier open for this tide (~ 736 cumecs)

g. Most extreme fluvial flow for Barrier open (1051 cumecs + HW Southend 2.35 OD(N).

C.2.185 The reasoning for the choices is as follows:

C.2.186 Cases (a) and (c) examine effect on water levels for the low fluvial flows and high tides, and high fluvial flows and low tides, respectively; extreme ends of the current Thames Barrier Operating rules. Cases (b) and (d) are included to provide an understanding of the impact fluvial flows have on levels. Case (e) is included to provide average flow conditions so that the impact on aquatic life can be better understood.

C.2.187 For the purposes of the IBM case (e) was therefore used. The other cases were checked and several high resolution versions near works were considered but it was concluded that case e was most suitable for fish modelling purposes. Fish get strongly washed out of the river by other cases.

Representation of base case, temporary and permanent works in model

C.2.188 Temporary and permanent works are represented in the flow model by replacing base case channel boundaries with those associated with the temporary and permanent structures. Temporary works, including temporary jetties and cofferdams, would be in place for up to seven years during construction. Permanent works, remaining once construction has been completed, would occupy a smaller footprint at each site. In both cases, intrusion onto the foreshore would affect hydraulic conditions across the river channel and for some distance upstream and downstream, these varying according to tides and fluvial flows. In particular, they would affect the amount of intertidal habitat in the immediate vicinity of the site; the velocity profiles across the river channel; and they may lead to temporary gyre formation around areas of sharply changing velocities.

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Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix C.3: Tideway fish risk model methodology

APFP Regulations 2009: Regulation **5(2)(a)**

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C.3 Tideway fish risk model (TFRM): methodology

C.3.1 The following report has its own table of contents.

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C.3 Tideway Fish Risk Model (TFRM) Methodology

Introduction

C.3.1 The Tideway Fish Risk Model (TFRM) has been used within the Thames Tideway Tunnel project-wide environmental assessment to evaluate the effects of predicted water quality improvements arising from implementing the tunnel solution (known as Option 1d) on sustainability of fish populations.

C.3.2 The TFRM was initially developed to evaluate proposed dissolved oxygen (DO) standards for the Thames Tideway (Turnpenny *et al*., 2004)[1] as part of the *Thames Tideway Strategic Study (TTSS).* The model assimilates data on the seasonal distribution of fish, seasonality and spatial distribution of hypoxic risk and on the lethal sensitivity of different fish species and lifestages to hypoxia. As an output it provides a systematic score representing the predicted sustainability of fish populations with respect to hypoxic effects based on suite of indicator fish species. Water quality data are input as processed outputs from the Environment Agency (EA)'s QUESTS model, which, for a set of DO regulatory standards, can generate the frequency at which a given DO standard is breached over each month of the year and in each of 17 Tideway AQMS (Automated Quality Monitoring System) 3 km zones extending from 25 km above, to 30 km below, London Bridge. Vol 3 Table C.1 details the current Tideway DO standards, developed under the *TTSS*. Compliance with all four standards, which have different allowable return frequencies, is required.

Vol 3 Table C.1 *TTSS* Surface Water Quality Standards for Dissolved Oxygen in the Thames Tideway

Standard No.	Dissolved Oxygen (mgL-1)	Return Period (years)	Duration (no. of 6 h tides)
1	4	1	29
2	3	3	3
3	2	5	1
4	1.5	10	1

C.3.3 The TFRM was peer-reviewed by Prof. Mike Elliott of Hull University (appendix in Turnpenny *et al*., 2004)[2]. A detailed review of the TFRM demonstrating its fitness for purpose for the Thames Tideway Tunnel project was subsequently undertaken (Thames Water, 2010)[3]. This also showed that there is a close correspondence between DO status achieved with the *TTSS* standards and those subsequently developed nationally under WFD, although the *TTSS* standards were considered more appropriate for the Thames Tideway Tunnel project in particular. While complying with the standards should ensure fish sustainability, the TFRM provides a more detailed evaluation for different fish species and lifestages.

Model description

C.3.4 The TFRM is based on the premise that risk of hypoxic conditions within the Tideway is not randomly distributed with respect to either time or position along the Tideway. Hypoxia is predominantly a summer phenomenon, building up over the spring months and dying away in autumn. Although the model accepts data for all months of the year, in practice the incidence of hypoxic months is only significant between the months April and October and months outside of this period are given zero values for incidence DO standards failures. Differences in hypoxic risk along the length of the Tideway relate to the positions of the major STW and CSO inputs and Tideway hydraulics. Overlaid upon the temporal and spatial patterns of hypoxia are variations in the temporal and spatial distributions of fish lifestages. For example, some potentially sensitive fry stages might only be present in spring, before the risk of hypoxia occurs, or may be in a low-risk area of the river. Risk of fish exposure to hypoxia is calculated within the model by juxtaposing these spatial and temporal probability distributions to calculate the overall probability that fish of any given species and lifestage will experience exposure. For the different water quality scenarios, the risk of fish mortalities by lifestage and AQMS zone is calculated for the whole 55 km length of the Tideway, allowing prediction of the total annual mortality associated with hypoxia (low DO) from the scenario being evaluated.

C.3.5 Of the 125 fish species that have been recorded in the tidal Thames, hypoxia tolerances of most are unknown and therefore a subset of seven indicator species was selected for the *TTSS* work, for which hypoxia tolerances were measured in the laboratory (Turnpenny *et al*., 2004)[4]. These were:

a. Brown trout (*Salmo trutta*) – as a surrogate for Atlantic salmon (*S. salar*)

b. Smelt (*Osmerus eperlanus*)

c. Sand smelt (*Atherina presbyter*)

d. Flounder (*Platichthys flesus*)

e. Common goby (*Pomatoschistus microps*)

f. Dace (*Leuciscus leuciscus*)

g. Bass (*Dicentrarchus labrax*)

C.3.6 These species are among the most common in EA records for the Tideway and represent a cross-section of fish biology in the Tideway. Apart from the salmon and bass, all of these species are known to spawn within the tidal Thames. Bass spawn offshore but are present in large concentrations in the Tideway as juveniles (0-group especially) during the summer months. It is important to note that in the development of the DO standards, the fish selected have been adopted not only as surrogates for all fish species in the Tideway but for the aquatic ecology as a whole.

C.3.7 Within the TFRM, the effect of hypoxia on each species is considered to be sustainable if annual mortality across its whole Tideway population is <10%, or in the case of some more resilient longer-lived species such as flounder or salmon, up to 30% (Vol 3 Table C.2). This recognises that some exploited commercial fisheries are considered sustainable at fishing mortality rates in excess of 50%). The TFRM scores the effect of the water quality scenario being examined in terms of the number of unsustainable species/ lifestage cases, the ideal being zero.

Vol 3 Table C.2 Reproductive Years Classes of Species Used in the TFRM, and Percentage Values Assumed to be Sustainable

Species	No. of Reproductive Year Classes	Sustainable Annual Mortality %
Salmon	3	30
Bass	10	30
Sand smelt	2	10
Dace	4	20
Smelt	4	10
Flounder	7	30
Common Goby	2	10

Methods

C.3.8 For the purposes of the TFRM, it is assumed that to meet any of the four *TTSS* Standards (Vol 3 Table C.1), the criteria associated with each standard must be met at the worst time and worst position along the Tideway: consequently, the risk to fish will be lower at any other position and time. For all positions and all times of the year, the risk $\boldsymbol{R_{tot}}$ relative to that pertaining to the position/time at which the Standard is just met (taken as unity), is given by:

$$\boldsymbol{R_{tot} = \{R_{breach}\} * \{R_{fish}\}} \qquad \text{….. (1)}$$

where $\boldsymbol{\{R_{breach}\}}$ is a matrix containing standards breach frequencies as a function of time (month of the year) and position along the Tideway (zone) and $\boldsymbol{\{R_{fish}\}}$ represents the distribution of fish, also as a function of time and Tideway zone (Vol 3 Plate C.1). $\boldsymbol{R_{tot}}$ represents the proportion of the population of a given species/lifestage that will be at risk from a CSO event taking account of the coincidence of the DO sag and the fish stock in time and space. The value $\boldsymbol{R_{tot}}$ is then multiplied by the predicted mortality rate ***(M)*** given in Vol 3 Table C.2 to give the Population Level Effect ***(PLE)***:

$$\boldsymbol{PLE = R_{tot} \times M} \qquad \text{…………………………………….. (2).}$$

C.3.9 ***PLE*** is calculated as a percentage value and represents the predicted annual loss to the Tideway population of a species/lifestage as a result of the Tideway water quality regime to any specified standard. Thus the effects of different standards can be compared.

Vol 3 Plate C.1 Example of matrix {Rfish} and {Rbreach}*

Proportion of stock in each river zone by month

River Zone	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00
2	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.00
3	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.00
4	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.00
5	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.00
6	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.00
7	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.00

X

Probability of Standard Breach

River Zone	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.0000	0.0000	0.0000	0.0006	0.0062	0.0073	0.0090	0.0101	0.0073	0.0039	0.0006	0.0006
2	0.0000	0.0000	0.0000	0.0011	0.0123	0.0146	0.0180	0.0202	0.0146	0.0079	0.0011	0.0011
3	0.0000	0.0000	0.0000	0.0011	0.0123	0.0146	0.0180	0.0202	0.0146	0.0079	0.0011	0.0011
4	0.0000	0.0000	0.0000	0.0011	0.0123	0.0146	0.0180	0.0202	0.0146	0.0079	0.0011	0.0011
5	0.0000	0.0000	0.0000	0.0025	0.0278	0.0328	0.0404	0.0455	0.0328	0.0177	0.0025	0.0025
6	0.0055	0.0018	0.0165	0.0275	0.0330	0.0385	0.0440	0.0367	0.0367	0.0294	0.0220	0.0037
7	0.0089	0.0030	0.0267	0.0445	0.0534	0.0623	0.0711	0.0593	0.0593	0.0474	0.0356	0.0059

{Rtot}

=

Risk Factor

River Zone	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.001	0.001	0.001	0.001	0.000
7	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.002	0.002	0.002	0.001	0.000
Rtot	**0.031**											

** {Rbreach} represents the relative probabilities of a standard breach for different river zones and months, while {Rfish} represents the proportionate distribution of the fish stock along the Tideway zones in different months. The corresponding cells are multiplied together to generate the Risk Matrix {Rtot}.The cells of this matrix are added together to give the risk factor Rtot*

Scenarios

C.3.10 For the Thames Tideway Tunnel project, the TFRM has been applied to three water quality scenarios modelled by QUESTS to evaluate:

a. Scenario 1, Baseline Case 2006: Baseline conditions using a year 2006 London population, i.e. representing the current condition.

b. Scenario 2, Baseline Case 2020: Effects of proposed interim infrastructure projects, including the ongoing AMP4 sewage treatment works (STW) upgrades at Mogden, Beckton and Crossness due for completion in 2013, combined with operation of the Lee Tunnel project. This scenario assumes a London population for the year 2020, and can be regarded as the pre-tunnel project baseline, as the tunnel would not be completed until after 2020.

c. Scenario 3, Full tunnel solution: Option 1d, which includes AMP4 STW upgrades and Lee Tunnel in operation and assumes a London population for the year 2020.

Data inputs

Water quality data

C.3.11 The QUESTS results are based on WRc's Compliance Test Procedure (CTP), which looks at 242 rainfall events from 1970 to 2010 that were selected as those most likely to cause combined sewer overflows (CSOs) to operate and therefore potentially cause the DO levels in the estuary to fall under summer temperature and flow conditions.

C.3.12 The QUESTS Estuary Model (2-km grid size; as used in recent work for London Thames Tunnels) was set up with loads from the sewer system based on 2006 populations and STW operations model inputs updated with historic temperature records and a 'with abstractions' flow series that represents the LTOA operating over the 1970 to 2010 period.

C.3.13 The QUESTS time-series results were processed to half-tide format to determine DO values at 1km intervals along the estuary (relative to London Bridge) and to identify how many of the 242 events caused an exceedence of each threshold. This is broken down by month (April to October) in the databases.

Fish population data

C.3.14 Data on seasonal distribution of different fish species and lifestages within the Tideway are based on EA monitoring and ad hoc surveys from 1992 to 2011, published data as described in *Turnpenny et al*. (2004)[5] and fish surveys carried out for the Thames Tideway Tunnel project (Vol 2 Appendix C.2) and represent the most up-to-date and comprehensive dataset available.

TFRM results

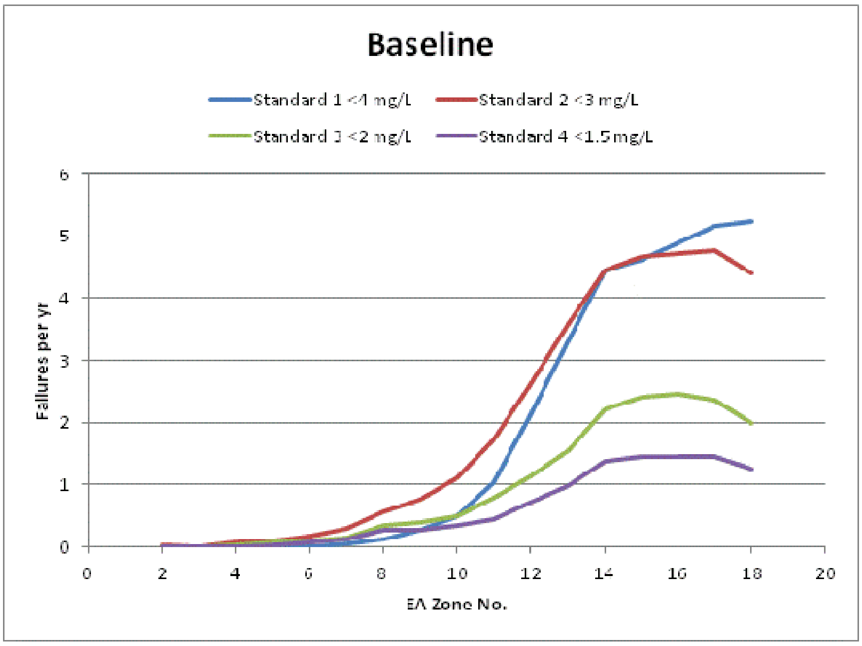
C.3.15 The QUESTS data used for input to the TFRM for each of the three scenarios are listed in full in Annex A of this document. These are shown for the 3 km AQMS zones as computed within the TFRM in Vol 3 Table C.3 to Vol 3 Table C.5 and Vol 3 Plate C.2 to Vol 3 Plate C.4 below. The data shows progressive reductions in the frequencies of standards failures moving from the 2006 Baseline case, through 2020 AMP4 /Lee Tunnel Baseline, with very low failure frequencies throughout the Tideway for the tunnel, Option 1d case.

C.3.16 In the 2006 Baseline case, the frequency of standards failures is seen to be relatively low in the upper Tideway down to AQMS zone 8, increasing towards the lower Tideway. As would be expected, the higher-DO value Standards 1 and 2 are breached most frequently.

C.3.17 For the 2020 AMP4 STW/Lee Tunnel Baseline scenario, the more severe cases (Standards 3 and 4) are greatly reduced throughout the Tideway, but Standards 1 and 2 failures remain high. For the full tunnel Option 1d case, failures of all four standards are reduced to a very low level.

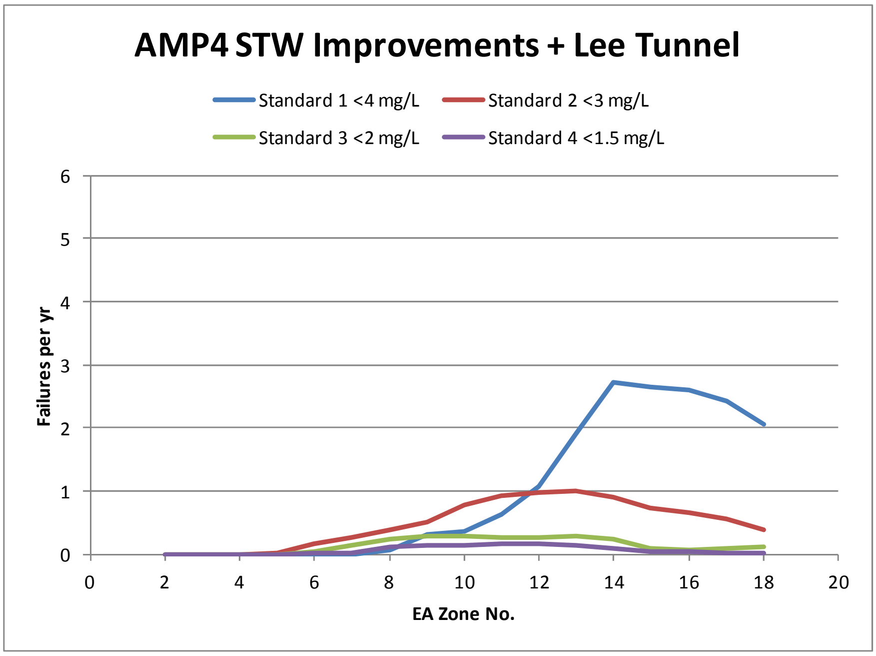
Vol 3 Plate C.2 Baseline Case: Average annual frequency of standards failures over 41 years for Tideway AQMS Zones

	Baseline			
EA Zone	Standard 1 <4 mg/L	Standard 2 <3 mg/L	Standard 3 <2 mg/L	Standard 4 <1.5 mg/L
2	0.000	0.024	0.000	0.000
3	0.000	0.000	0.000	0.000
4	0.000	0.073	0.024	0.000
5	0.000	0.098	0.073	0.024
6	0.000	0.171	0.098	0.073
7	0.049	0.293	0.146	0.122
8	0.122	0.561	0.341	0.268
9	0.268	0.756	0.390	0.268
10	0.488	1.122	0.488	0.341
11	1.024	1.732	0.780	0.439
12	2.122	2.610	1.146	0.707
13	3.317	3.585	1.561	0.976
14	4.463	4.463	2.220	1.390
15	4.634	4.683	2.415	1.463
16	4.902	4.732	2.463	1.463
17	5.171	4.780	2.366	1.463
18	5.244	4.415	2.000	1.268
Total	**31.80**	**34.10**	**16.51**	**10.27**



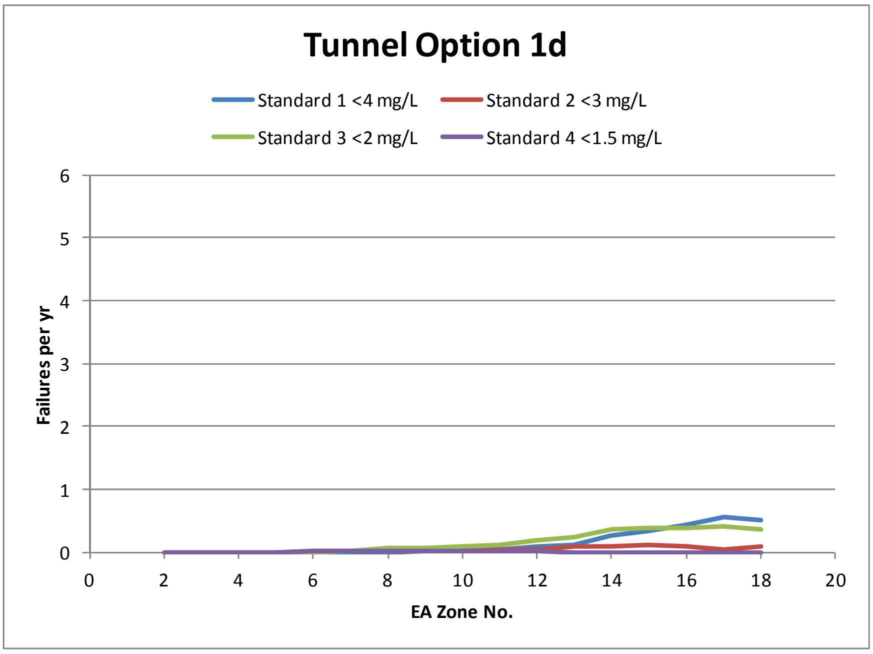
Vol 3 Plate C.3 AMP4 STW improvements + Lee Tunnel Case: Average annual frequency of standards failures over 41 years for Tideway AQMS Zones

	AMP4 STW Improvements + Lee Tunnel			
EA Zone	Standard 1 <4 mg/L	Standard 2 <3 mg/L	Standard 3 <2 mg/L	Standard 4 <1.5 mg/L
2	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000
5	0.000	0.024	0.000	0.000
6	0.000	0.171	0.049	0.024
7	0.000	0.268	0.146	0.024
8	0.073	0.390	0.244	0.122
9	0.317	0.512	0.293	0.146
10	0.366	0.780	0.293	0.146
11	0.634	0.927	0.268	0.171
12	1.073	0.976	0.268	0.171
13	1.902	1.000	0.293	0.146
14	2.732	0.902	0.244	0.098
15	2.659	0.732	0.098	0.049
16	2.610	0.659	0.073	0.049
17	2.439	0.561	0.098	0.024
18	2.073	0.390	0.122	0.024
Total	**16.88**	**8.29**	**2.49**	**1.20**



Vol 3 Plate C.4 Full Tunnel Option 1d Case: Average annual frequency of standards failures over 41 years for Tideway AQMS Zones

	Tunnel Option 1d			
EA Zone	Standard 1 <4 mg/L	Standard 2 <3 mg/L	Standard 3 <2 mg/L	Standard 4 <1.5 mg/L
2	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000
6	0.000	0.024	0.000	0.024
7	0.000	0.024	0.024	0.024
8	0.000	0.024	0.073	0.024
9	0.024	0.024	0.073	0.024
10	0.049	0.024	0.098	0.024
11	0.049	0.049	0.122	0.024
12	0.098	0.049	0.195	0.024
13	0.122	0.098	0.244	0.000
14	0.268	0.098	0.366	0.000
15	0.341	0.122	0.390	0.000
16	0.439	0.098	0.390	0.000
17	0.561	0.049	0.415	0.000
18	0.512	0.098	0.366	0.000
Total	**2.46**	**0.78**	**2.76**	**0.17**



C.3.18 Vol 3 Table C.3 to Vol 3 Table C.5 provide standard TFRM output tables which show the predicted effects on the seven 'indicator' species for the three scenarios selected. The tables bring together information on the expected mortality rates of the species/life stage, when the standards are breached and the proportion of the population affected. The mortality rate is estimated from the laboratory data of Turnpenny *et al*. (2004)[6]. The risk factor is the proportion of the Tideway population affected, as set out in

Vol 3 Plate C.1 above, which depends on the Tideway reaches affected by the hypoxic event and the distribution of fish within the Tideway during the affected month. The product of these factors generates the Population Level Effect (PLE). Within these tables, PLE values considered sustainable are shown in black, with unsustainable values shown in red. Values shown in blue type are considered likely to be sustainable owing to the more robust life-history strategy of the species.

C.3.19 Of greatest interest from Vol 3 Table C.3 (Baseline Case, 2006) are the predicted unsustainable effects on salmon and dace associated with breaches of Standards 2 to 4, indicating that up to 100% mortality could arise for adult salmon and species of similar sensitivity, such as sea trout, and 58% of dace. In the case of adult salmon, the figure should be regarded as a worst-case scenario, as the model assumes salmon to be at risk throughout the summer. This assumption is made owing to the extended migration period (at least July –November for salmon), the peak of which coincides with a high-risk period for standard breaches. Also, although salmon may not be migrating through the estuary during all this period, there is evidence that returning adults will hold up in the outer Tideway, where they may be at risk (Turnpenny et al., 2004)[7].

C.3.20 In Vol 3 Table C.4 (Baseline Case, 2020), the overall sustainability of fish populations is improved but salmonids are predicted to remain unsustainable, with 50% predicted annual mortality.

C.3.21 With the full tunnel Option 1d in operation (see Vol 3 Table C.5), predicted mortalities of all species are reduced to sustainable levels.

Conclusions

C.3.22 When considering these findings, it should be noted that they are relevant to the whole Tideway fish community of up to 125 species, not just the subset of seven indicator species. Thus any indication of non-sustainability for a single species would be expected to apply to multiple species within the community in practice. Achieving a healthy fish community therefore requires sustainability across all the indicator species. Of the scenarios examined, only the full tunnel solution (Option 1d) attains this target.

Vol 3 Table C.3 Baseline Case, 2006

Baseline, 2006 Population																
Species	Lifestage	Standard 4 1.5 mg L^{-1} (6h in 10y)			Standard 3 2.0 mg L^{-1} (6h in 5y)			Standard 2 3.0 mg L^{-1} (18h in 3y)			Standard 1 4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.5mgL^{-1}	No. of Reproductive Age classes	Sustainable Mortality %**
		Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**			
Salmon	Smolt	100%	0.04	**<10%**	100.0%	0.08	**<10%**	<10%	0.11	**<10%**	<10%	0.11	**<10%**	3	3	30
	Adult	100%	0.95	**94.7%**	100.0%	1.00	**100.0%**	90.0%	1.00	**90.0%**	<10%	1.00	**<10%**			
Bass	Young Fry	10%	0.69	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	0	10	30
	Juvenile	10%	0.84	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Sand smelt	Egg/fry	*	0.06	**<10%**		0.09			0.18			1.00		0	2	10
	Juvenile	10%	0.95	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	10%	0.95	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Dace	Egg/fry	100%	0.44	**44.0%**	85.0%	0.68	**57.7%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	3	4	20
	Juvenile	30%	0.35	**10.6%**	<10%	0.56	**<10%**	<10%	1.00	**<10%**	<10%	0.87	**<10%**			
	Adult	10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Smelt	Egg/fry	*	0.60	**<10%**		0.93			1.00			1.00		0	4	10
	Juvenile	10%	0.99	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Flounder	Egg/fry	*	0.00	**<10%**		0.00			0.00			0.00		2	7	30
	Juvenile	10%	0.95	**<10%**	15.0%	1.00	**15.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	10%	1.00	**<10%**	15.0%	1.00	**15.0%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
Common goby	Egg/fry	0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	0	2	10
	Juvenile	10%	0.95	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
	Adult	10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**	<10%	1.00	**<10%**			
											Total PL Effects occurrences >10%			**8**		
	* Note:no ecotox data for early life stages										Total PL Effects 'not sustainable'			**5**		

Expected fish mortalities for TTSS Standards 1 to 4 based on TFRM, Year 2006 population, with no improvements. Note: Blue figures indicate >10% annual mortality due to hypoxia and possible marginal sustainability. Black figures indicate likely sustainability; red figures: not sustainable. PL Effect-=Population Level Effect

Vol 3 Table C.4 Baseline Case, 2020

Species	Lifestage	Standard 4 1.5 mg L^{-1} (6h in 10y)			Standard 3 2.0 mg L^{-1} (6h in 5y)			Standard 2 3.0 mg L^{-1} (18h in 3y)			Standard 1 4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.5mgL^{-1}
		Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	
Salmon	Smolt	100%	0.00	**<10%**	100.0%	0.00	**<10%**	<10%	0.09	**<10%**	<10%	0.10	**<10%**	2
	Adult	100%	0.09	**<10%**	100.0%	0.15	**15.5%**	90.0%	0.56	**50.0%**	<10%	1.00	**<10%**	
Bass	Young Fry	10%	0.02	**<10%**	<10%	0.03	**<10%**	<10%	0.11	**<10%**	<10%	0.12	**<10%**	0
	Juvenile	10%	0.08	**<10%**	<10%	0.15	**<10%**	<10%	0.55	**<10%**	<10%	1.00	**<10%**	
Sand smelt	Egg/fry	*	0.02	**<10%**		0.02			0.16			0.10		0
	Juvenile	10%	0.09	**<10%**	<10%	0.15	**<10%**	<10%	0.59	**<10%**	<10%	1.00	**<10%**	
	Adult	10%	0.09	**<10%**	<10%	0.15	**<10%**	<10%	0.59	**<10%**	<10%	1.00	**<10%**	
Dace	Egg/fry	100%	0.00	**<10%**	85.0%	0.02	**<10%**	<10%	0.08	**<10%**	<10%	0.05	**<10%**	0
	Juvenile	30%	0.13	**<10%**	<10%	0.19	**<10%**	<10%	0.51	**<10%**	<10%	0.23	**<10%**	
	Adult	10%	0.12	**<10%**	<10%	0.18	**<10%**	<10%	0.51	**<10%**	<10%	0.22	**<10%**	
Smelt	Egg/fry	*	0.03	**<10%**		0.03			0.11			0.10		0
	Juvenile	10%	0.09	**<10%**	<10%	0.16	**<10%**	<10%	0.60	**<10%**	<10%	1.00	**<10%**	
	Adult	10%	0.05	**<10%**	<10%	0.12	**<10%**	<10%	0.60	**<10%**	<10%	1.00	**<10%**	
Flounder	Egg/fry	*	0.00	**<10%**		0.00			0.00			0.00		0
	Juvenile	10%	0.09	**<10%**	15.0%	0.15	**<10%**	<10%	0.59	**<10%**	<10%	1.00	**<10%**	
	Adult	10%	0.06	**<10%**	15.0%	0.14	**<10%**	<10%	0.64	**<10%**	<10%	1.00	**<10%**	
Common goby	Egg/fry	0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	0
	Juvenile	10%	0.09	**<10%**	<10%	0.15	**<10%**	<10%	0.59	**<10%**	<10%	1.00	**<10%**	
	Adult	10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	
											Total PL Effects occurrences >10%			**2**
	* Note:no ecotox data for early life stages										Total PL Effects 'not sustainable'			**1**
	** Note: maximumum sustainable annual mortality is an 'expert' judgement based on no. of reproductive age-classes.													

AMP4 STW Improvements + Lee Tunnel: Expected fish mortalities for TTSS Standards 1 to 4 based on TFRM, Year 2020 population, with no improvements. Note: Blue figures indicate >10% annual mortality due to hypoxia and possible marginal sustainability. Black figures indicate likely sustainability; red figures: not sustainable. PL Effect-=Population Level Effect.

Vol 3 Table C.5 Full Tunnel. Option 1 d

Solution 1d- Abbey Mills Route, 2020														
Species	Lifestage	Standard 4 1.5 mg L^{-1} (6h in 10y)			Standard 3 2.0 mg L^{-1} (6h in 5y)			Standard 2 3.0 mg L^{-1} (18h in 3y)			Standard 1 4.0 mg L^{-1} (1 wk per y)			No. of >10% PL Effect @1.5mgL^{-1}
		Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	Mortality Rate	Risk Factor	**Population Level Effect**	
Salmon	Smolt	100%	0.00	**<10%**	100.0%	0.00	**<10%**	<10%	0.01	**<10%**	<10%	0.02	**<10%**	1
	Adult	100%	0.01	**<10%**	100.0%	0.26	**26.0%**	90.0%	0.07	**<10%**	<10%	0.26	**<10%**	
Bass	Young Fry	10%	0.00	**<10%**	<10%	0.25	**<10%**	<10%	0.00	**<10%**	<10%	0.04	**<10%**	0
	Juvenile	10%	0.01	**<10%**	<10%	0.26	**<10%**	<10%	0.06	**<10%**	<10%	0.26	**<10%**	
Sand smelt	Egg/fry	*	0.00	**<10%**		0.00			0.00			0.03		0
	Juvenile	10%	0.01	**<10%**	<10%	0.26	**<10%**	<10%	0.07	**<10%**	<10%	0.28	**<10%**	
	Adult	10%	0.01	**<10%**	<10%	0.26	**<10%**	<10%	0.07	**<10%**	<10%	0.45	**<10%**	
Dace	Egg/fry	100%	0.00	**<10%**	85.0%	0.14	**12.1%**	<10%	0.00	**<10%**	<10%	0.02	**<10%**	1
	Juvenile	30%	0.02	**<10%**	<10%	0.10	**<10%**	<10%	0.03	**<10%**	<10%	0.03	**<10%**	
	Adult	10%	0.02	**<10%**	<10%	0.08	**<10%**	<10%	0.03	**<10%**	<10%	0.03	**<10%**	
Smelt	Egg/fry	*	0.00	**<10%**		0.20			0.01			0.03		0
	Juvenile	10%	0.01	**<10%**	<10%	0.26	**<10%**	<10%	0.07	**<10%**	<10%	0.28	**<10%**	
	Adult	10%	0.00	**<10%**	<10%	0.38	**<10%**	<10%	0.09	**<10%**	<10%	0.45	**<10%**	
Flounder	Egg/fry	*	0.00	**<10%**		0.00			0.00			0.00		0
	Juvenile	10%	0.01	**<10%**	15.0%	0.26	**<10%**	<10%	0.07	**<10%**	<10%	0.27	**<10%**	
	Adult	10%	0.00	**<10%**	15.0%	0.35	**<10%**	<10%	0.09	**<10%**	<10%	0.41	**<10%**	
Common goby	Egg/fry	0%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	0
	Juvenile	10%	0.01	**<10%**	<10%	0.26	**<10%**	<10%	0.07	**<10%**	<10%	0.27	**<10%**	
	Adult	10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	<10%	0.00	**<10%**	
											Total PL Effects occurrences >10%			**2**
	* Note:no ecotox data for early life stages										Total PL Effects 'not sustainable'			**0**
	** Note: maximumum sustainable annual mortality is an 'expert' judgement based on no. of reproductive age-classes.													

**Expected fish mortalities for TTSS Standards 1 to 4 based on TFRM, Year 2020 population, with full Tunnel Option 1 d solution. Note: Blue figures indicate >10% annual mortality due to hypoxia and possible marginal sustainability. Black figures indicate likely sustainability; red figures: not sustainable. PL Effect- =Population Level Effect*

Annex A Quest input data used in the TFRM analyses

Vol 3 Plate C.5 Baseline case

Standard 1: 4mg/l for 29 tides								
Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Number**
CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
-25	0	0	0	0	0	0	0	0
-24	0	0	0	0	0	0	0	0
-23	0	0	0	0	0	0	0	0
-22	0	0	0	0	0	0	0	0
-21	0	0	0	0	0	0	0	0
-20	0	0	0	0	0	0	0	0
-19	0	0	0	0	0	0	0	0
-18	0	0	0	0	0	0	0	0
-17	0	0	0	0	0	0	0	0
-16	0	0	0	0	0	0	0	0
-15	0	0	0	0	0	0	0	0
-14	0	0	0	0	0	0	0	0
-13	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0
-11	0	0	0	0	0	0	0	0
-10	0	0	0	0	0	0	0	0
-9	0	0	0	0	0	0	0	0
-8	0	0	0	1	1	0	0	2
-7	0	0	0	1	1	0	0	2
-6	0	0	0	1	2	0	0	3
-5	0	0	0	1	4	0	0	5
-4	0	0	0	1	2	0	0	3
-3	0	0	0	1	5	0	0	6
-2	0	0	2	1	8	0	0	11
-1	0	0	1	2	11	1	0	15
0	0	0	1	1	9	0	0	11
1	0	0	4	3	12	1	0	20
2	0	0	4	6	18	1	0	29
3	0	0	5	7	19	2	1	34
4	0	0	6	8	25	2	1	42
5	0	1	6	12	29	3	2	53
6	0	1	6	15	33	4	3	62
7	0	2	7	19	46	10	3	87
8	0	2	7	22	52	11	3	97
9	0	2	7	28	64	16	3	120
10	0	3	8	31	74	17	3	136
11	0	3	8	34	85	20	3	153
12	0	3	8	37	84	25	3	160
13	0	3	9	38	90	29	4	173
14	0	6	9	39	92	32	5	183
15	0	5	9	40	94	34	6	188
16	0	5	9	40	94	34	5	187
17	0	5	10	40	95	34	6	190
18	0	6	9	40	96	36	7	194
19	0	6	11	40	99	36	6	198
20	0	6	11	40	100	37	6	200
21	0	6	12	40	99	36	8	201
22	0	6	12	40	100	39	9	206
23	0	6	12	39	102	39	8	206
24	1	7	14	39	101	38	9	209
25	1	8	14	39	101	38	10	211
26	1	8	14	39	101	39	9	211
27	1	9	14	39	100	37	9	209
28	1	8	14	39	98	37	9	206
29	1	8	15	38	98	34	11	205
30	1	9	15	37	97	30	11	200

Standard 2: 3mg/l for 3 tides							
Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Number**
CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
-25	0	1	0	0	0	0	0	0
-24	0	0	0	0	0	0	0	0
-23	0	0	0	0	0	0	0	0
-22	0	0	0	0	0	0	0	0
-21	0	0	0	0	0	0	0	0
-20	0	0	0	0	0	0	0	0
-19	0	0	0	0	0	0	0	0
-18	0	0	0	1	2	0	0	3
-17	0	0	0	0	2	1	0	3
-16	0	0	0	1	2	1	0	4
-15	0	0	0	1	2	1	0	4
-14	0	0	0	1	2	1	0	4
-13	0	0	0	1	3	1	0	5
-12	0	0	0	1	4	2	0	7
-11	0	0	0	1	4	2	0	7
-10	0	0	0	1	6	2	0	9
-9	0	0	0	1	6	3	0	10
-8	0	0	0	1	8	2	0	11
-7	0	0	1	1	10	4	0	16
-6	0	0	1	1	12	4	0	18
-5	0	0	3	1	13	5	1	23
-4	0	0	2	1	11	4	1	19
-3	0	0	2	1	13	4	1	21
-2	0	0	4	2	18	6	1	31
-1	0	1	4	5	21	8	1	40
0	0	1	4	2	17	8	1	33
1	0	1	4	5	25	9	2	46
2	0	1	5	8	32	9	2	57
3	0	1	6	10	36	12	1	66
4	0	2	6	10	39	12	2	71
5	0	2	6	12	42	14	3	79
6	0	2	7	14	46	17	3	89
7	0	3	7	19	55	20	3	107
8	0	3	7	21	59	21	3	114
9	1	3	9	24	72	22	4	135
10	1	3	9	28	74	28	4	147
11	1	4	10	33	81	29	5	163
12	1	5	10	35	82	28	7	168
13	1	5	11	34	86	31	8	176
14	1	5	11	35	90	32	9	183
15	1	6	11	35	93	32	9	187
16	1	6	11	35	90	33	9	185
17	1	6	12	36	91	34	10	190
18	1	6	12	37	90	34	11	191
19	1	6	12	37	90	35	11	192
20	1	6	14	37	90	33	10	191
21	1	6	14	37	90	33	12	193
22	1	6	16	37	90	32	11	193
23	1	6	13	36	88	29	13	186
24	1	6	14	36	85	26	13	181
25	1	6	13	36	85	25	13	179
26	1	6	13	35	75	26	13	169
27	1	6	13	34	72	22	13	161
28	1	7	12	32	67	21	11	151
29	1	7	12	29	65	20	12	146
30	1	7	10	24	52	19	10	123

	Standard 3: 2mg/l for 1 tide								
	Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Number**
	CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
	-25	0	0	0	0	0	0	0	0
	-24	0	0	0	0	0	0	0	0
	-23	0	0	0	0	0	0	0	0
	-22	0	0	0	0	0	0	0	0
	-21	0	0	0	0	0	0	0	0
	-20	0	0	0	0	0	0	0	0
	-19	0	0	0	0	1	0	0	1
	-18	0	0	0	0	1	0	0	1
	-17	0	0	0	0	2	0	0	2
	-16	0	0	0	1	2	0	0	3
	-15	0	0	0	0	2	0	0	2
	-14	0	0	0	1	2	0	0	3
	-13	0	0	0	1	2	0	0	3
	-12	0	0	0	1	2	0	0	3
	-11	0	0	0	1	3	0	0	4
	-10	0	0	0	1	3	0	0	4
	-9	0	0	0	1	4	0	0	5
	-8	0	0	0	1	5	0	0	6
	-7	0	0	0	1	9	0	0	10
	-6	0	0	0	1	11	0	0	12
	-5	0	0	0	1	11	2	0	14
[redacted]	-4	0	0	0	1	10	2	1	14
	-3	0	0	0	1	10	2	0	13
	-2	0	0	0	1	12	2	1	16
	-1	0	0	1	1	13	3	1	19
	0	0	0	1	1	11	3	1	17
	1	0	0	2	1	12	3	1	19
	2	0	0	2	1	15	4	1	23
	3	0	2	3	4	17	3	1	30
	4	0	0	3	2	18	4	1	28
	5	0	1	3	3	20	5	1	33
	6	0	2	4	7	22	6	2	43
	7	0	2	4	7	25	7	2	47
	8	0	2	4	8	28	9	2	53
	9	0	2	4	11	32	9	3	61
	10	0	3	4	11	33	8	4	63
	11	0	3	5	14	36	9	4	71
	12	0	4	5	15	40	12	4	80
	13	1	4	5	16	45	12	4	87
	14	1	4	5	17	46	14	4	91
	15	1	4	5	20	48	15	4	97
	16	0	4	5	20	47	14	4	94
	17	1	4	5	20	49	15	5	99
	18	1	4	6	21	47	15	5	99
	19	1	5	6	21	46	15	5	99
	20	1	4	7	20	45	14	5	96
	21	1	5	6	17	45	15	5	94
	22	1	5	7	17	41	15	6	92
	23	1	5	6	17	38	15	6	88
	24	1	5	7	15	36	16	6	86
	25	1	4	7	15	34	14	7	82
	26	1	4	6	15	28	12	7	73
	27	1	4	6	12	26	11	7	67
	28	1	3	6	11	26	11	7	65
	29	1	4	6	13	22	9	6	61
	30	1	2	5	9	19	9	6	51

Standard 4: 1.5mg/l for 1 tide

Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Number**
CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
-25	0	0	0	0	0	0	0	0
-24	0	0	0	0	0	0	0	0
-23	0	0	0	0	0	0	0	0
-22	0	0	0	0	0	0	0	0
-21	0	0	0	0	0	0	0	0
-20	0	0	0	0	0	0	0	0
-19	0	0	0	0	0	0	0	0
-18	0	0	0	0	1	0	0	1
-17	0	0	0	0	1	0	0	1
-16	0	0	0	0	1	0	0	1
-15	0	0	0	0	2	0	0	2
-14	0	0	0	1	3	0	0	4
-13	0	0	0	1	3	0	0	4
-12	0	0	0	1	3	0	0	4
-11	0	0	0	1	4	0	0	5
-10	0	0	0	1	4	0	0	5
-9	0	0	0	1	4	0	0	5
-8	0	0	0	1	5	0	0	6
-7	0	0	0	1	6	1	0	8
-6	0	0	0	1	8	1	0	10
-5	0	0	0	1	8	2	0	11
-4	0	0	0	1	8	2	1	12
-3	0	0	0	1	9	2	1	13
-2	0	0	0	1	11	2	1	15
-1	0	0	0	1	12	3	1	17
0	0	0	0	1	12	3	1	17
1	0	0	0	1	12	3	1	17
2	0	0	1	1	12	3	1	18
3	0	0	1	1	12	3	1	18
4	0	0	1	2	14	4	1	22
5	0	1	1	4	17	4	1	28
6	0	1	3	4	19	5	2	34
7	0	1	4	4	20	5	2	36
8	0	1	4	6	20	5	2	38
9	0	1	4	6	21	6	3	41
10	0	1	4	6	23	6	4	44
11	0	1	4	8	25	6	4	48
12	0	1	4	8	27	6	4	50
13	0	2	5	9	29	7	4	56
14	0	2	2	10	29	8	4	55
15	0	3	4	10	29	8	4	58
16	0	3	4	11	31	8	4	61
17	0	3	4	11	32	8	4	62
18	0	3	4	12	34	8	4	65
19	0	3	4	12	30	8	4	61
20	1	3	5	12	30	8	4	63
21	0	3	6	12	28	9	5	63
22	1	3	6	13	27	9	5	64
23	0	3	6	13	25	10	5	62
24	0	3	6	11	25	9	5	59
25	0	3	6	9	22	10	6	56
26	0	2	6	8	18	9	4	47
27	0	1	6	7	17	8	3	42
28	0	1	6	7	16	9	4	43
29	0	1	5	5	15	7	3	36
30	0	1	5	5	12	7	2	32

Vol 3 Plate C.6 AMP4 STW Upgrades + Lee Tunnel in Operation

Standard 1: 4mg/l for 29 tides								
Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Number Events Simulated**
CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
-25	0	0	0	0	0	0	0	0
-24	0	0	0	0	0	0	0	0
-23	0	0	0	0	0	0	0	0
-22	0	0	0	0	0	0	0	0
-21	0	0	0	0	0	0	0	0
-20	0	0	0	0	0	0	0	0
-19	0	0	0	0	0	0	0	0
-18	0	0	0	0	0	0	0	0
-17	0	0	0	0	0	0	0	0
-16	0	0	0	0	0	0	0	0
-15	0	0	0	0	0	0	0	0
-14	0	0	0	0	0	0	0	0
-13	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0
-11	0	0	0	0	0	0	0	0
-10	0	0	0	0	0	0	0	0
-9	0	0	0	0	0	0	0	0
-8	0	0	0	0	0	0	0	0
-7	0	0	0	1	1	0	0	2
-6	0	0	0	1	1	0	0	2
-5	0	0	0	1	1	0	0	2
-4	0	0	0	0	1	0	0	1
-3	0	0	0	1	4	0	0	5
-2	0	0	0	1	6	0	0	7
-1	0	0	0	1	7	0	0	8
0	0	0	0	1	6	0	0	7
1	0	0	0	1	7	0	0	8
2	0	0	0	1	9	0	0	10
3	0	0	1	4	8	0	0	13
4	0	0	2	4	10	0	0	16
5	0	0	3	5	10	0	0	18
6	0	0	4	7	14	1	0	26
7	0	0	4	8	16	1	0	29
8	0	0	5	10	19	1	0	35
9	0	0	5	14	20	1	0	40
10	0	2	6	14	28	3	0	53
11	0	1	6	18	29	3	0	57
12	0	2	5	20	31	4	0	62
13	0	2	4	22	35	4	0	67
14	0	2	4	24	40	4	0	74
15	0	2	5	23	39	6	0	75
16	0	1	4	23	37	6	0	71
17	0	2	4	24	39	4	0	73
18	0	1	4	24	37	5	0	71
19	0	3	4	25	37	5	0	74
20	0	2	2	26	33	4	0	67
21	0	2	2	27	34	4	0	69
22	0	2	2	26	34	6	0	70
23	0	2	2	24	34	6	0	68
24	0	1	3	21	32	5	0	62
25	0	1	3	21	30	6	0	61
26	0	1	3	18	28	5	0	55
27	0	1	2	15	25	5	0	48
28	0	1	2	12	19	4	0	38
29	0	1	2	10	16	4	0	33
30	0	1	1	10	15	3	0	30

Standard 2: 3mg/l for 3 tides

Month	4	5	6	7	8	9	10	Total Number Events Simulated
CTP Events in Month	2	13	16	40	103	48	20	242
-25	0	0	0	0	0	0	0	0
-24	0	0	0	0	0	0	0	0
-23	0	0	0	0	0	0	0	0
-22	0	0	0	0	0	0	0	0
-21	0	0	0	0	0	0	0	0
-20	0	0	0	0	0	0	0	0
-19	0	0	0	0	0	0	0	0
-18	0	0	0	0	0	0	0	0
-17	0	0	0	0	0	0	0	0
-16	0	0	0	0	1	0	0	1
-15	0	0	0	0	0	0	0	0
-14	0	0	0	0	2	0	0	2
-13	0	0	0	0	3	2	0	5
-12	0	0	0	1	4	2	0	7
-11	0	0	0	1	4	2	0	7
-10	0	0	1	1	5	2	0	9
-9	0	0	1	1	5	2	0	9
-8	0	0	1	1	7	2	0	11
-7	0	0	1	1	9	2	0	13
-6	0	0	1	1	12	2	0	16
-5	0	0	1	1	12	2	0	16
-4	0	0	1	1	12	1	0	15
-3	0	0	1	1	12	2	0	16
-2	0	0	1	2	16	2	0	21
-1	0	1	2	3	19	4	0	29
0	0	1	2	2	15	4	0	24
1	0	2	2	3	20	5	0	32
2	0	2	2	4	21	4	0	33
3	0	2	2	5	22	5	0	36
4	0	2	2	6	23	4	0	37
5	0	2	3	7	23	4	0	39
6	0	2	4	6	22	4	0	38
7	0	2	4	6	21	4	0	37
8	0	3	4	7	21	4	0	39
9	0	3	4	6	23	4	0	40
10	0	3	4	7	22	4	0	40
11	0	3	4	6	19	3	0	35
12	0	3	3	6	17	3	0	32
13	0	3	3	7	17	3	0	33
14	0	2	3	8	15	3	0	31
15	0	2	2	6	17	3	0	30
16	0	2	2	6	15	3	0	28
17	0	1	2	6	15	3	0	27
18	0	1	2	6	14	3	0	26
19	0	1	2	6	15	3	0	27
20	0	1	1	6	13	3	0	24
21	0	1	1	6	10	3	0	21
22	0	1	1	6	10	3	0	21
23	0	1	2	5	7	3	0	18
24	0	1	2	3	5	2	1	14
25	0	1	1	2	6	3	1	14
26	0	1	3	1	5	2	1	13
27	0	1	3	1	4	2	1	12
28	0	1	3	1	5	1	1	12
29	0	0	3	1	4	1	1	10
30	0	0	2	1	4	0	1	8

Standard 3: 2mg/l for 1 tide

Month	4	5	6	7	8	9	10	Total Number Events Simulated
CTP Events in Month	2	13	16	40	103	48	20	242
-25	0	0	0	0	0	0	0	0
-24	0	0	0	0	0	0	0	0
-23	0	0	0	0	0	0	0	0
-22	0	0	0	0	0	0	0	0
-21	0	0	0	0	0	0	0	0
-20	0	0	0	0	0	0	0	0
-19	0	0	0	0	0	0	0	0
-18	0	0	0	0	0	0	0	0
-17	0	0	0	0	0	0	0	0
-16	0	0	0	0	0	0	0	0
-15	0	0	0	0	0	0	0	0
-14	0	0	0	0	0	0	0	0
-13	0	0	0	0	0	0	0	0
-12	0	0	0	0	2	0	0	2
-11	0	0	0	0	2	0	0	2
-10	0	0	0	0	2	1	0	3
-9	0	0	0	1	3	1	0	5
-8	0	0	0	1	4	1	0	6
-7	0	0	0	1	6	1	0	8
-6	0	0	0	1	7	1	0	9
-5	0	0	0	1	8	1	0	10
-4	0	0	0	1	8	2	0	11
-3	0	0	0	1	9	1	0	11
-2	0	0	0	1	8	1	0	10
-1	0	0	0	1	9	2	0	12
0	0	0	0	1	9	1	0	11
1	0	0	0	1	7	1	0	9
2	0	0	0	1	7	2	0	10
3	0	0	0	1	7	2	0	10
4	0	0	0	1	8	2	0	11
5	0	0	0	1	8	2	0	11
6	0	0	0	1	8	2	0	11
7	0	0	0	1	8	2	0	11
8	0	0	0	1	8	2	0	11
9	0	0	0	1	8	2	0	11
10	0	0	0	0	9	2	0	11
11	0	0	0	0	8	2	0	10
12	0	0	0	0	7	2	0	9
13	0	0	0	0	6	2	0	8
14	0	0	0	0	5	2	0	7
15	0	0	0	0	3	1	0	4
16	0	0	0	0	3	1	0	4
17	0	0	0	0	2	1	0	3
18	0	0	0	0	2	0	0	2
19	0	0	0	0	2	1	0	3
20	0	0	0	0	2	0	0	2
21	0	0	0	0	2	1	0	3
22	0	0	0	0	2	0	0	2
23	0	0	0	0	2	0	0	2
24	0	0	0	0	3	0	0	3
25	0	0	0	0	3	0	1	4
26	0	0	0	0	3	0	1	4
27	0	0	0	0	3	0	1	4
28	0	0	0	0	3	0	1	4
29	0	0	1	0	2	0	1	4
30	0	0	0	0	1	0	1	2

Standard 4: 1.5mg/l for 1 tide

Month	4	5	6	7	8	9	10	Total Number Events Simulated
CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
-25	0	0	0	0	0	0	0	0
-24	0	0	0	0	0	0	0	0
-23	0	0	0	0	0	0	0	0
-22	0	0	0	0	0	0	0	0
-21	0	0	0	0	0	0	0	0
-20	0	0	0	0	0	0	0	0
-19	0	0	0	0	0	0	0	0
-18	0	0	0	0	0	0	0	0
-17	0	0	0	0	0	0	0	0
-16	0	0	0	0	0	0	0	0
-15	0	0	0	0	1	0	0	1
-14	0	0	0	0	1	0	0	1
-13	0	0	0	0	1	0	0	1
-12	0	0	0	0	1	0	0	1
-11	0	0	0	0	2	0	0	2
-10	0	0	0	1	1	0	0	2
-9	0	0	0	1	3	0	0	4
-8	0	0	0	1	2	0	0	3
-7	0	0	0	1	4	0	0	5
-6	0	0	0	1	3	0	0	4
-5	0	0	0	1	5	0	0	6
-4	0	0	0	1	5	1	0	7
-3	0	0	0	1	4	1	0	6
-2	0	0	0	1	5	1	0	7
-1	0	0	0	1	5	1	0	7
0	0	0	0	1	4	1	0	6
1	0	0	0	1	4	1	0	6
2	0	0	0	1	5	1	0	7
3	0	0	0	1	5	2	0	8
4	0	0	0	1	5	2	0	8
5	0	0	0	1	5	2	0	8
6	0	0	0	1	4	2	0	7
7	0	0	0	1	4	2	0	7
8	0	0	0	0	4	2	0	6
9	0	0	0	0	5	2	0	7
10	0	0	0	0	4	2	0	6
11	0	0	0	0	4	1	0	5
12	0	0	0	0	3	1	0	4
13	0	0	0	0	1	1	0	2
14	0	0	0	0	2	0	0	2
15	0	0	0	0	2	0	0	2
16	0	0	0	0	2	0	0	2
17	0	0	0	0	1	0	0	1
18	0	0	0	0	2	0	0	2
19	0	0	0	0	2	0	0	2
20	0	0	0	0	1	0	0	1
21	0	0	0	0	1	0	0	1
22	0	0	0	0	1	0	0	1
23	0	0	0	0	1	0	0	1
24	0	0	0	0	1	0	0	1
25	0	0	0	0	1	0	0	1
26	0	0	0	0	1	0	0	1
27	0	0	0	0	1	0	0	1
28	0	0	0	0	1	0	1	2
29	0	0	0	0	1	0	0	1
30	0	0	0	0	1	0	1	2

Vol 3 Plate C.7 Full Tunnel Solution (Option 1d)

Standard 1: 4mg/l for 29 tides								
Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Number**
CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
-25	0	0	0	0	0	0	0	0
-24	0	0	0	0	0	0	0	0
-23	0	0	0	0	0	0	0	0
-22	0	0	0	0	0	0	0	0
-21	0	0	0	0	0	0	0	0
-20	0	0	0	0	0	0	0	0
-19	0	0	0	0	0	0	0	0
-18	0	0	0	0	0	0	0	0
-17	0	0	0	0	0	0	0	0
-16	0	0	0	0	0	0	0	0
-15	0	0	0	0	0	0	0	0
-14	0	0	0	0	0	0	0	0
-13	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	0	0	0
-11	0	0	0	0	0	0	0	0
-10	0	0	0	0	0	0	0	0
-9	0	0	0	0	0	0	0	0
-8	0	0	0	0	1	0	0	1
-7	0	0	0	0	0	0	0	0
-6	0	0	0	0	0	0	0	0
-5	0	0	0	0	0	0	0	0
-4	0	0	0	0	1	0	0	1
-3	0	0	0	0	0	0	0	0
-2	0	0	0	0	1	0	0	1
-1	0	0	0	0	1	0	0	1
0	0	0	0	0	3	0	0	3
1	0	0	0	1	4	0	0	5
2	0	0	0	1	3	0	0	4
3	0	0	0	1	3	0	0	4
4	0	0	0	1	2	0	0	3
5	0	0	0	1	3	0	0	4
6	0	0	0	1	3	0	0	4
7	0	0	0	1	2	0	0	3
8	0	0	0	2	3	0	0	5
9	0	0	1	1	3	0	0	5
10	0	0	0	1	3	0	0	4
11	0	0	1	2	2	0	0	5
12	0	0	1	3	4	0	0	8
13	0	0	1	3	4	0	0	8
14	0	0	1	4	4	0	0	9
15	0	0	1	7	6	0	0	14
16	0	0	1	7	6	1	0	15
17	0	0	1	7	6	1	0	15
18	0	0	1	7	6	1	0	15
19	0	0	1	8	6	2	0	17
20	0	0	1	8	7	1	0	17
21	0	0	1	8	7	2	0	18
22	0	0	1	10	8	2	0	21
23	0	0	1	8	9	2	0	20
24	0	0	1	7	9	2	0	19
25	0	0	1	6	10	2	0	19
26	0	0	1	7	9	2	0	19
27	0	0	1	7	9	2	0	19
28	0	0	1	7	9	2	0	19
29	0	0	1	6	6	2	0	15
30	0	0	0	4	4	1	0	9

	Standard 2: 3mg/l for 3 tides							
	Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Number**
	CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
	-25	0	0	0	0	0	0	0	0
	-24	0	0	0	0	0	0	0	0
	-23	0	0	0	0	0	0	0	0
	-22	0	0	0	0	0	0	0	0
	-21	0	0	0	0	0	0	0	0
	-20	0	0	0	0	0	0	0	0
	-19	0	0	0	0	0	0	0	0
	-18	0	0	0	0	0	0	0	0
	-17	0	0	0	0	0	0	0	0
	-16	0	0	0	0	0	0	0	0
	-15	0	0	0	0	0	0	0	0
	-14	0	0	0	0	0	0	0	0
	-13	0	0	0	0	0	0	0	0
	-12	0	0	0	0	1	0	0	1
	-11	0	0	0	0	1	0	0	1
	-10	0	0	0	0	1	0	0	1
	-9	0	0	0	0	1	0	0	1
	-8	0	0	0	0	1	0	0	1
	-7	0	0	0	0	1	0	0	1
	-6	0	0	0	0	1	0	0	1
	-5	0	0	0	0	1	0	0	1
[redacted]	-4	0	0	0	0	1	0	0	1
	-3	0	0	0	0	1	0	0	1
	-2	0	0	0	0	1	0	0	1
	-1	0	0	0	0	1	0	0	1
	0	0	0	0	0	1	0	0	1
	1	0	0	0	0	1	0	0	1
	2	0	0	0	0	1	0	0	1
	3	0	0	0	0	2	0	0	2
	4	0	0	0	0	2	0	0	2
	5	0	0	0	0	2	0	0	2
	6	0	0	0	0	2	0	0	2
	7	0	0	0	0	2	0	0	2
	8	0	0	0	0	2	0	0	2
	9	0	0	1	0	2	0	0	3
	10	0	0	1	0	2	0	0	3
	11	0	0	1	0	2	0	0	3
	12	0	0	1	0	2	0	0	3
	13	0	0	1	0	3	0	0	4
	14	0	0	1	0	3	0	0	4
	15	0	0	1	0	3	0	0	4
	16	0	0	0	0	3	0	0	3
	17	0	0	0	0	4	0	0	4
	18	0	0	1	0	3	0	0	4
	19	0	0	0	0	2	0	0	2
	20	0	0	0	0	2	0	0	2
	21	0	0	0	0	2	0	0	2
	22	0	0	0	0	2	0	0	2
	23	0	0	0	0	2	0	0	2
	24	0	0	0	0	2	0	0	2
	25	0	0	0	0	2	0	0	2
	26	0	0	0	0	3	0	0	3
	27	0	0	0	0	3	0	0	3
	28	0	0	0	0	3	0	0	3
	29	0	0	0	0	3	0	0	3
	30	0	0	0	0	1	0	0	1

	Standard 3: 2mg/l for 1 tide								
	Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Number**
	CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
	-25	0	0	0	0	0	0	0	0
	-24	0	0	0	0	0	0	0	0
	-23	0	0	0	0	0	0	0	0
	-22	0	0	0	0	0	0	0	0
	-21	0	0	0	0	0	0	0	0
	-20	0	0	0	0	0	0	0	0
	-19	0	0	0	0	0	0	0	0
	-18	0	0	0	0	0	0	0	0
	-17	0	0	0	0	0	0	0	0
	-16	0	0	0	0	0	0	0	0
	-15	0	0	0	0	0	0	0	0
	-14	0	0	0	0	0	0	0	0
	-13	0	0	0	0	0	0	0	0
	-12	0	0	0	0	0	0	0	0
	-11	0	0	0	0	0	0	0	0
	-10	0	0	0	0	1	0	0	1
	-9	0	0	0	0	1	0	0	1
	-8	0	0	0	0	1	0	0	1
	-7	0	0	0	0	1	0	0	1
	-6	0	0	0	0	1	0	0	1
[redacted]	-5	0	0	0	0	1	0	0	1
	-4	0	0	0	0	1	0	0	1
	-3	0	0	0	0	1	0	0	1
	-2	0	0	0	0	1	0	0	1
	-1	0	0	0	0	1	0	0	1
	0	0	0	0	0	1	0	0	1
	1	0	0	0	0	1	0	0	1
	2	0	0	0	0	1	0	0	1
	3	0	0	0	0	1	0	0	1
	4	0	0	0	0	1	0	0	1
	5	0	0	0	0	1	0	0	1
	6	0	0	0	0	1	0	0	1
	7	0	0	0	0	1	0	0	1
	8	0	0	0	0	1	0	0	1
	9	0	0	0	0	1	0	0	1
	10	0	0	0	0	1	0	0	1
	11	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0
	13	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0
	17	0	0	0	0	0	0	0	0
	18	0	0	0	0	0	0	0	0
	19	0	0	0	0	1	0	0	1
	20	0	0	0	0	0	0	0	0
	21	0	0	0	0	0	0	0	0
	22	0	0	0	0	0	0	0	0
	23	0	0	0	0	0	0	0	0
	24	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0
	26	0	0	0	0	0	0	0	0
	27	0	0	0	0	0	0	0	0
	28	0	0	0	0	0	0	0	0
	29	0	0	0	0	0	0	0	0
	30	0	0	0	0	0	0	0	0

Standard 4: 1.5mg/l for 1 tide								
Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total Number**
CTP Events in Month	**2**	**13**	**16**	**40**	**103**	**48**	**20**	**242**
-25	0	0	0	0	0	0	0	0
-24	0	0	0	0	0	0	0	0
-23	0	0	0	0	0	0	0	0
-22	0	0	0	0	0	0	0	0
-21	0	0	0	0	0	0	0	0
-20	0	0	0	0	0	0	0	0
-19	0	0	0	0	0	0	0	0
-18	0	0	0	0	0	0	0	0
-17	0	0	0	0	0	0	0	0
-16	0	0	0	0	0	0	0	0
-15	0	0	0	0	0	0	0	0
-14	0	0	0	0	0	0	0	0
-13	0	0	0	0	1	0	0	1
-12	0	0	0	0	1	0	0	1
-11	0	0	0	0	1	0	0	1
-10	0	0	0	0	1	0	0	1
-9	0	0	0	0	1	0	0	1
-8	0	0	0	0	1	0	0	1
-7	0	0	0	0	1	0	0	1
-6	0	0	0	0	1	0	0	1
-5	0	0	0	0	1	0	0	1
-4	0	0	0	0	1	0	0	1
-3	0	0	0	0	1	0	0	1
-2	0	0	0	0	1	0	0	1
-1	0	0	0	0	1	0	0	1
0	0	0	0	0	1	0	0	1
1	0	0	0	0	1	0	0	1
2	0	0	0	0	1	0	0	1
3	0	0	0	0	1	0	0	1
4	0	0	0	0	1	0	0	1
5	0	0	0	0	1	0	0	1
6	0	0	0	0	1	0	0	1
7	0	0	0	0	1	0	0	1
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0

Note: Plates show predicted standards failures by month and position for months 4-10 (April-October)

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Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix C.4: Foreshore reinstatement at temporary cofferdam locations

APFP Regulations 2009: Regulation **5(2)(a)**

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C.4 Foreshore reinstatement at temporary cofferdam locations

C.4.1 The following report has its own table of contents.

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Appendix C: Ecology – aquatic

C.4 Foreshore reinstatement at temporary cofferdam locations

Introduction

C.4.1 This method statement covers the approach to reinstatement of substrates following removal of temporary cofferdams at the seven Thames Tideway Tunnel project sites where a temporary cofferdam would be located in the foreshore:

a. Putney Embankment Foreshore

b. Chelsea Embankment Foreshore

c. Heathwall Pumping Station,

d. Albert Embankment Foreshore

e. Victoria Embankment Foreshore

f. Blackfriars Bridge Foreshore

g. King Edward Memorial Park

C.4.2 Sites where works within the foreshore consist of temporary campsheds (ie, Carnwath Road Riverside and Kirtling Street and reinstatement of an existing campshed at Cremorne Wharf Depot) have been excluded since no specific restoration proposals are required for these structures.

C.4.3 The method statement is intended to supplement the measures controlling the installation and removal of cofferdams described in the *Code of Construction Practice (CoCP)*[i]. The objective of this method statement is to ensure that the substrates which would lie within the temporary cofferdam are restored to the equivalent or higher ecological value as the existing foreshore.

C.4.4 A summary of the process of installing and removing the cofferdams is provided in paras. C.4.5 to C.4.10. The anticipated ground conditions (i.e. the substrates present) at each of the sites is described in paras. C.4.11 to C.4.16. Two categories of sites have been identified in terms of ground conditions and the approach to creating suitable ground conditions and the subsequent reinstatement at each is described in paras. C.4.17 to C.4.23. An assessment of the ecological effects following reinstatement and anticipated recovery is described in paras. C.4.24 to C.4.27.

Construction sequence and reinstatement

C.4.5 The stages of the construction process in terms of cofferdam installation and removal are explained in detail in Section 3 of the *Environmental Statement* site-specific volumes (Vol 4 to 27), but for completeness this is summarised below.

[i] *The Code of Construction Practice (CoCP)* is provided in Vol 1 Appendix A. It contains general requirements (Part A), and site specific requirements for this site (Part B).

C.4.6 Temporary sheet pile cofferdams would be formed in the foreshore to create a working platform. For structural reasons, soft material located adjacent to the perimeter of the temporary cofferdam and adjacent to the river wall would be removed. This is expected to comprise silt and clay alluvium and organic rich soils. Removal of this material would ensure that any settlement of the cofferdam fill material would not adversely affect the ties between the walls of the twin walled temporary cofferdam leading to structural difficulties. Permanent cofferdams would be formed to create a permanent foreshore structure to accommodate permanent infrastructure. All soft material within permanent cofferdams would be removed to ensure sound foundations for permanent infrastructure.

C.4.7 It is assumed that the majority of foreshore material within the temporary cofferdams would remain in situ. Soft material is expected to represent no more than 20% of the total volume of the substrate.

C.4.8 The excavated ‘soft’ soil would be replaced to foreshore level with an inert granular fill which is described in para C.4.21.

C.4.9 A marker geotextile membrane would be placed at foreshore level. Cofferdam fill material would then be placed onto the foreshore on top of the geotextile layer to above mean high water level to provide a stable working platform. Suitable sized plant would be utilised to reduce potential load impacts on the foreshore.

C.4.10 Upon removal of the temporary cofferdam, the fill and geotextile layer would be removed and the bed would be reinstated to match the existing river bed conditions. Material excavated would be disposed of in accordance with defined waste management procedures.

Anticipated ground conditions at the shaft locations

C.4.11 Borehole data collected at Thames Tideway Tunnel sites were used to make an assessment of likely ground conditions at each site. Habitat survey data, comprising the relative composition of the substrate was used to supplement the borehole data.

C.4.12 From the borehole records and habitat survey information the substrates found overlying the London Clay are summarised in Vol 3 Table C.1. For sites where there is more than one entry in the table (eg, Victoria Embankment Foreshore) this indicates that the site contains a mixture of substrate types. The first entry in the table for each site is considered to be the dominant soil type.

Vol 3 Table C.1 Substrate types found at each of the foreshore sites

Location	Strata Description	Strata Name	Thickness (m)
Putney Embankment Foreshore	Grey sandy GRAVEL with occasional cobbles and rare pockets of soft and firm silty clay. Gravel is subangular to rounded with flint and other lithologies. Sand is medium to	River Terrace Deposits	0.4

Location	Strata Description	Strata Name	Thickness (m)
	coarse. Cobbles are subangular to subrounded of flint.		
Chelsea Embankment Foreshore	GRAVEL with occasional cobbles. Gravel is angular to subrounded and contains flint, brick and pottery fragments.	Alluvium	0.3 - 1.5
	Slightly sandy and sandy GRAVEL with occasional cobbles. Gravel is angular to rounded, fine to coarse of flint. Sand is medium to coarse. Cobbles are angular and subrounded.	River Terrace Deposits	1.0
Heathwall Pumping Station	Gravelly SAND. Sand is medium to coarse. Gravel is subangular to subrounded, fine to medium of black and brown flint.	River Terrace Deposits	1.3
Albert Embankment Foreshore	Slightly silty sandy GRAVEL. Gravel is angular to subrounded, fine to coarse. Sand is coarse.	River Terrace Deposits	1.5
Victoria Embankment Foreshore	Very soft silty CLAY with occasional to abundant dark grey and black coal fragments.	Alluvium	1.5
	Very soft slightly sandy gravelly CLAY. Sand is fine to medium. Gravel is predominantly subangular fine and medium of dark grey very weak sandstone with black coal fragments.	Alluvium	0.5
	Multicoloured slightly silty very gravelly SAND with rare gastropod shells fragments. Sand is medium and coarse. Gravel is subangular to rounded, fine of flint.	River Terrace Deposits	1.0
	Possibly very loose, brown and black, sandy GRAVEL. Gravel is subangular and subrounded, fine and medium of flint. Sand is medium and coarse.	River Terrace Deposits	1.5

Location	Strata Description	Strata Name	Thickness (m)
	Loose to medium dense becoming medium dense, multicoloured locally slightly silty, slightly sandy becoming very sandy GRAVEL. Gravel is angular to rounded, predominantly of medium and coarse flint. Sand is coarse.	River Terrace Deposits	2.0
	Loose GRAVEL and gravelly SAND with occasional cobbles and pockets of clay.	River Terrace Deposits	8.3
Blackfriars Bridge Foreshore	Slightly silty very sandy GRAVEL. Gravel is angular to subangular, fine to coarse of flint.	River Terrace Deposits	1.1 - 1.3
King Edward Memorial Park	Slightly silty, sandy GRAVEL with occasional cobbles and occasional pockets of soft grey clay. Occasional rootlets, fibrous plant remains, bivalve shell fragments and bone fragments. Gravel is angular to rounded, fine to coarse of flint, quartzite, white chalk, clinker, brick fragments, slate, ceramic, tile, glass and rubber. Hydrocarbon/organic odour.	Alluvium	0.9
Chambers Wharf	Soft and firm gravelly CLAY with occasional cobbles. Gravel is subangular to rounded, fine to coarse of flint and occasional brick fragments.	Alluvium	1.0

C.4.13 River Terrace Deposits (RTDs) (ie, gravel and sand) were found to be the dominant substrate type at the majority of locations (Putney Embankment Foreshore, Heathwall Pumping Station, Albert Embankment Foreshore and Blackfriars). This is a stable substrate material likely to undergo relatively little consolidation beneath the cofferdam. There is likely to be minimal soft material at these sites. For the purposes of this method statement these are known as Group 1 sites.

C.4.14 Soft material (i.e. clay) was found in varying quantities at two locations, Chambers Wharf and Victoria Embankment Foreshore. This substrate would be less stable and subject to consolidation and would be removed as part of the construction process. These are referred to as Group 2 sites.

C.4.15 The presence of Alluvium (rather than RTDs) at Chelsea Embankment Foreshore and King Edward Memorial Park suggests that soft material in the form of clay may also be present at these sites. For the purposes of the method statement these sites are grouped together with the Group 2 sites.

C.4.16 The approach to cofferdam installation and subsequent reinstatement of the substrates following removal of temporary cofferdams are described for the Group 1 and Group 2 sites in the sections below.

Approach to cofferdam installation and reinstatement at Group 1 sites

C.4.17 At sites where gravel and sand were found to be the dominant substrate (i.e. Putney Embankment Foreshore, Albert Embankment Foreshore, Heathwall Pumping Station and Blackfriars) there is likely to be minimal or no removal of soft material required in order to stabilise the sheet piles during installation of the cofferdam. The geotextile membrane would be placed directly on top of the strata within the cofferdam.

C.4.18 On completion of construction the cofferdam fill and the geotextile membrane would be removed taking care to ensure that none of the cofferdam fill is allowed to spill on to the underlying foreshore. No further reinstatement would be undertaken at these sites. No plant or machinery would be permitted on the newly exposed area to avoid unnecessary damage to the underlying deposits

Approach to cofferdam installation and reinstatement at Group 2 sites

C.4.19 At four sites (Chelsea Embankment Foreshore, Victoria Embankment Foreshore, Chambers Wharf, and King Edward Memorial Park) soft material is likely to be the dominant material, or at least a component of the substrate within the cofferdam. At these sites the soft material would need to be removed and replaced with a material which provides sufficient stability for the sheet piles.

C.4.20 In order to meet these stability requirements whilst ensuring that the habitat that remains following removal of the cofferdams is appropriate to meet the ecological objectives the material would have the following properties:

a. coarse granular soil that is resistant to erosion and scour

b. similar to the coarse sediments present below the river bed ie RTDs

C.4.21 At these sites the replacement fill would be a sand and gravel mix similar in grading to the River Terrace Gravel Deposits in the area. Specifically, the fill would be a granular material comprised of natural gravel, natural sand, crushed gravel or crushed rock other than argillaceous rock or chalk. The material would be inert and durable. Leachable contaminant concentrations would be below the Environmental Quality Standards for saline waters.

C.4.22 The grading of the material would be such that it would self-compact, when placed in dry areas or and be relatively resistant to scour when submerged.

C.4.23 Removal of the cofferdam would follow the same process as described for Group 1 sites.

Assessment of effects following reinstatement

C.4.24 No consolidation of the sand and gravel underlying the cofferdam is anticipated for Group 1 sites, although there may be some consolidation in the underlying London Clay. Based on loading calculations prepared by Thames Water, the maximum load applied is considered to be approximately 200kPa (from a maxium of 10m depth of fill). This increase in load would result in settlement in the region of up to 200mm in the London Clay, which would rebound over time. No further habitat reinstatement action would be taken following removal of the sheet piles and the geotextile membrane. Recolonisation of these substrates by inverbrates is expected to occur within 6 months of cofferdam removal, and by Year 6 of operation (the operational assessment year) full recovery of these sites is expected to have occured.

C.4.25 The degree of consolidation at the Group 2 sites is anticipated to be greater since although soft material around the margins of the cofferdam would be replaced with the coarse granular soil, some soft material would remain. Water would gradually penetrate this consolidated material over a period of several years and over time it is expected to recover fully.

C.4.26 Benthic invertebrate species such as Oligochaeta and Polychaeta, which are characteristic of fine sediments, may be excluded from those areas where consolidation has occurred. In general, sedimentary habitats are the most productive within the intertidal environment since organic material adheres to the clay particles within them and provides a food source for invertebrates. Although dissolved oxygen conditions can be low within these sediments, the animals (such as Oligochaete and Polychaete worms) that can tolerate these conditions often multiply rapidly, thereby contributing disproportionately to the total biomass of the estuarine environment. Consolidation of the fine sediments within the cofferdam area would exclude these organisms. Re-colonisation is expected to occur as water penetrates the consolidated areas, and full recovery of the benthic invertebrate community is expected within three years.

C.4.27 The coarse material placed within the temporary cofferdam at the Group 2 sites is not expected to undergo consolidation, and therefore recovery of these areas would be more rapid. Although there may be a shift in the overall composition of the substrate from one dominated by soft material to a greater proportion of gravels, the invertebrate communities which typically occupy these two habitat types comprise a similar suite of species, and both communities are well represented within the Thames tideway. The impact of replacing soft material with coarse gravels at the Group 2 sites is thus considered to be negligible.

Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix C.5: Assessment of effects on draft MCZ

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C.5 Assessment of effects on draft (MCZ)

C.5.1 The following report has its own table of contents.

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C.5 Assessment of effects on draft MCZ

Introduction

Marine Conservation Zones

C.5.1 To fulfil its international obligations, the UK has embarked on a process to establish an ecologically coherent network of Marine Protected Areas (MPAs) in UK waters. The network will include existing MPAs and Marine Conservation Zones (MCZs), a new type of site created by the Marine and Coastal Access Act 2009. The purpose of MCZs is to protect the full range of nationally important biodiversity, as well as certain rare and threatened species and habitats. The identification of these sites has been done using a stakeholder engagement process through the establishment of four regional MCZ projects.

C.5.2 The grounds for designation of a MCZ are set out in section 117 of the Marine and Coastal Access Act 2009 ('the MCA 2009'). In short, it must be desirable to make such a designation for the purpose of conserving marine flora or fauna, marine habitats or types of marine habitat; or features of geological or geo-morphological interest (subsection (1)). Subsection (3) explains that the reference in subsection (1)(a) to conserving marine flora or fauna includes in particular a reference to conserving any species that is rare or threatened because of limited numbers or locations where it is present.

Thames Estuary Marine Conservation Zone

C.5.3 The Thames Estuary Marine Conservation Zone (MCZ) has not yet been designated, but has been proposed for designation. According to the Defra website[1] a decision on designation is expected in mid 2013, and thus before the decision is made on the application for development consent (the 'application'). The purpose of this appendix is to 'future proof' the project-wide assessment (Vol 3 Section 5) by determining how the designation of the MCZ anticipated for 2013 would alter the assessment contained within Section 5 of that volume (if at all).

C.5.4 Assuming the MCZ is designated, the decision-maker dealing with the application relating to the Thames Tideway Tunnel project would need to comply with the duties imposed by section 126 of the MCA 2009. This imposes certain duties on public authorities determining applications for authorising the doing of an act, if the act is capable of affecting (other than insignificantly) the protected features of a MCZ, or any ecological or geomorphological process on which the conservation of any protected feature of a MCZ is (wholly or in part) dependent.

Conservation objectives

C.5.5 The recommended conservation objectives for each feature are to be found in Appendix 1 of the Thames Estuary sMCZ No. 5 Marine Conservation Zone: Selection Assessment Document.

C.5.6 For both Smelt and the European Eel, the draft conservation objective is "MAINTAIN", and no particular activity is identified as exerting pressure. However, in the column for stakeholder comments on draft conservation objectives and potential management measures alongside the entry for Smelt, Appendix 1 states: "*In response to SNCB request for further information, the LG noted (July 2011): …*

a. Pollution (sewage) events correlate with low recruitment levels of smelt into the estuary – Tideway Tunnel is the mitigation for this and will eliminate 37 out of 50 CSOs. (but eels are more susceptible than smelt).

b. *The seven year construction period of the Tideway Tunnel may have an impact on migratory species (might lead to short term damage to smelt spawning sites), but EIAs are required and the EA are involved. EA don't think there will be any major impacts and the maritime community fully support the tunnel. …*"

Designated features

C.5.7 The Thames Estuary MCZ Selection Assessment Document (Balanced Seas, 2011)[2] describes the reasons for designation of the MCZ. The site as a whole is considered to be an important spawning and nursery ground for Smelt *Osmerus eperlanus* and European Eel *Anguilla anguilla*. Its designation is aimed at providing the protection required for their seasonal seaward migration from freshwater to sea, and subsequent recruitment into the estuary. The assessment document also explains the existence of the geographically restricted but important population of Tentacled Lagoon Worm *Alkmaria romijni* at Greenhithe and that from West Thurrock downstream to the estuary mouth the site is aimed at ensuring bank-to-bank habitat protection. The MCZ is also proposed for designation due to the presence of large currently undesignated areas of intertidal sand/muddy sand, intertidal mixed sediments, intertidal coarse sediments, subtidal sand and subtidal mud downstream of West Thurrock.

Impact assessment

Scope of assessment

C.5.8 The Thames Tideway Tunnel project lies within the western section of the MCZ (ie, the section from Richmond to West Thurrock). According to the Selection Assessment Document (Balanced Seas, 2011)[3] this section has no directly specified habitat conservation objectives, other than that specifically required for Smelt and Eel. Although the MCZ in the western section covers the entire River Thames below Mean High Water that does not imply that all habitat within the river is of national importance; it will however be important to maintain a clear migration route for the nationally important populations of smelt and eel and to preserve the key spawning grounds for smelt that are found within this western section.

C.5.9 The only features for which the MCZ would be designated that are present within the Thames Tideway Tunnel project assessment area are therefore the populations of smelt and eel, the smelt spawning habitat and the migration routes of both species. These species are currently accorded medium-high (regional) value as part of the overall fish assemblage for the tidal River Thames. Designation of the MCZ would essentially raise the value of the tidal River Thames for these two particular species to High (national).

Habitats of importance for eel and smelt

C.5.10 Movements of juvenile eel (*Anguilla anguilla*) through the Thames estuary was studied by Naismith and Knights (1988)[4]. Eel enter the Thames Estuary as juvenile unpigmented ‘glass’ eels from sea in spring; remain in estuary, or move up into freshwater over first few years of life. They utilise shallow marginal habitat to migrate through the estuary using a system known as selective tidal stream transport in which movements up the estuary are made during the flood tide. During the ebb tide individuals remain close to the bed of the river within shallow water where current velocities are lowest.

C.5.11 Smelt gather below Gravesend in February and March prior to migrating upstream to spawn in March/April. Mass spawning takes place on sub-tidal gravels just below the low tide mark, mainly at night between Battersea and Wandsworth. Most of the adult fish then descend to the lower estuary. Very early post-larvae are often detected at Millwall and Greenwich, suggesting hatching may take place just downstream of the narrow inner city reaches (Environment Agency, 2010)[5]. Post-larvae then ascend the river utilising selective tidal stream transport (Colclough *et al*, 2002)[6]. Smelt as young as 0+ fish can be taken as far upstream at Richmond by late June. Most of the juvenile fish descend to the lower estuary by the early autumn.

Key impacts

C.5.12 The effects of the project on fish, including smelt and eel, during the construction and operational stage are described in Vol 3 Sections 5.5 and 5.6. Of specific note in respect of the MCZ are impacts which may affect the spawning and nursery habitat of smelt, and the ability of either species to migrate through the estuary. The following section highlights these impacts and discusses specific effects on smelt and eel populations.

Impacts on smelt spawning habitat

C.5.13 One Thames Tideway Tunnel construction site, Carnwath Road Riverside lies within the smelt spawning zone between Battersea and Wandsworth. A second site, Putney Embankment Foreshore lies immediately upstream of the spawning zone. There would be approximately 3150m^2 of temporary landtake at Carnwath Road Riverside associated with the campshed. Depending on which in-river infrastructure option is selected at this site, this would be located either in the intertidal or in the subtidal zone. This would involve the temporary landtake of approximately 1% of the total spawning habitat available within that zone.

Impacts on fish migration

C.5.14 The individual and combined effects on fish of predicted changes in flow velocity associated with the temporary and permanent structures have been assessed using an individual based modelling (IBM) technique. The model uses three species, dace, flounder and eel, as agreed with the

Environment Agency, as proxies for the various morphologies of fish represented in the Tideway. The behaviours ascribed to the model fish are based on a set of 'rules' derived from a combination of background literature review and field and laboratory studies (see Vol 3 Appendix C.2 for details of the technique and the model outputs).

C.5.15 The study found that there were small, statistically significant reductions in the rate of upriver migration between the base case and the scenario with temporary works structures in place. For example, for flounder there was a 3.3% difference in the mean (average) time taken for the population to undertake an upstream migration upstream between the base case and the scenario with temporary works structures in place. However, statistical significance does not necessarily correlate to ecological significance. In real terms this represents a delay of a single tidal cycle, over a 5 day period, and is considered to arise as a result of the large size of the population sampled (2500 individuals) and therefore the inherent variation between individuals. No difference between the base case and scenario with temporary works structures in place were predicted for eel and therefore effects would also be negligible. In terms of differences in mortality rate as a result of fish being forced into deeper water as they pass the structures, modelled mortality rates for scenarios with the temporary and permanent structures vary little from the base case, and statistical analysis confirms that any small differences seen are non-significant.

C.5.16 The presence of temporary or permanent structures in the river can cause changes in flow velocity of relevance to smelt and eel movements; if sufficiently great, passage of both species can be disrupted. However simulated modelling has identified that the impact would be negligible for all fish species including smelt and eel.

Effects if the MCZ was designated

C.5.17 Vol 3 Table C.1 and Vol 3 Table C.2 below summarise the impacts on fish during construction and operation as identified within the project-wide assessment and the effect levels on fish communities (including smelt and eel) that have been identified for each impact. These are based on the matrix of impact magnitude against receptor value in Vol. 2 Section 5.5, refined using professional judgment. The final row of each table then uses the same matrix to set out the effect level that would apply if the MCZ was designated and the value of 'fish' as a receptor was thus elevated to 'national'. Those effect levels which would differ from the current assessment are given in bold text.

Vol 3 Table C.1 Construction impacts and effects on fish (including eel and smelt)

	Impact					
	Loss of spawning, feeding, resting and nursery habitat for fish due to temporary landtake	**Loss of feeding, resting and nursery habitat for fish due to sediment disturbance and consolidation**	**Loss of feeding, resting, spawning and nursery habitat due to scour**	**Interference with the migratory movements of fish**	**Effects of waterborne noise and vibration on fish**	**Water quality effects on fish and reduction in water column visibility due to suspended sediment**
Impact magnitude	Low negative	Low negative	Low negative	Negligible	Low negative	Negligible
Current effect level	Moderate adverse	Minor adverse	Minor adverse	Negligible	Minor adverse	Negligible
Effect level if MCZ designated (using matrix presented in Vol. 2 Section 5.5)	Moderate adverse	Minor adverse	Minor adverse	Negligible	Minor adverse	Negligible

Vol 3 Table C.2 Operational impacts and effects on fish (eel and smelt)

	Impact				
	Reduction in the occurrence of dissolved oxygen related fish mortalities (hypoxia)	**Increase in the distribution of pollution sensitive fish species**	**Permanent loss of intertidal spawning, feeding and resting habitat for fish due to landtake**	**Modification of intertidal feeding and subtidal habitat for fish**	**Interference with migratory movements of fish**
Impact magnitude	Medium positive	Medium positive	Medium negative	Low negative	Negligible
Current effect level	Moderate beneficial	Minor beneficial	Moderate adverse	Minor adverse	Negligible
Effect level if MCZ designated (using matrix presented in Vol. 2 Section 5.5)	Major/Moderate beneficial	Minor beneficial	Major/Moderate adverse	Minor adverse	Negligible

C.5.18 There would be no change in the level of effects arising from the construction stage impact if the value of the fish community was elevated to national importance (Vol 3 Table C.1). This is because the impact magnitude would not change (remaining low) and the elevated value of the fish community would be insufficient to lead to an increase in effects.

C.5.19 In respect of operational stage effects (Vol 3 Table C.2) there would be change from moderate adverse to major/moderate adverse associated with permanent landtake from intertidal and subtidal habitats. However, there would be no permanent landtake from subtidal spawning habitats, and the overall proportion of habitat loss would be less than 1% of the area of the habitat available to smelt and eel within the western section of the MCZ. Furthermore, since permanent habitat loss has already been identified as a significant adverse effect for which habitat compensation measures have been identified (Vol 3 Section 5.8) requiring compensation, the change in effect level would not trigger any requirement for mitigation/compensation that has not already been identified.

C.5.20 There would also be a positive change in the effect level associated with the reduction in hypoxia. By increasing the value of the fish receptor to national importance the effect level would increase to major/moderate beneficial. Juvenile smelt, eggs and fry in particular are known to be sensitive to hypoxia, and therefore it is reasonable to assume that populations are currently suppressed by mass mortality events. The project is likely to result in improvements in both the survival of juvenile smelt and spawning success. This is specifically referenced in the conservation objectives table for smelt in the Thames Estuary sMCZ No. 5 Marine Conservation Zone: Selection Assessment Document: *‘Pollution (sewage) events correlate with low recruitment levels of smelt into the estuary – Tideway Tunnel is the mitigation for this ...’*.

Conclusion

C.5.21 Designation of the MCZ would not result in any additional significant adverse effects, although adverse effects associated with permanent landtake would increase from moderate to major/moderate. Compensation measures are already incorporated into the project to offset the effects of landtake.

C.5.22 The importance of the project in ensuring the sustainability of the smelt populations has been recognised during consultation for the proposed MCZ. Increasing the value of the fish receptor to national would elevate the positive benefits associated with reduced hypoxia to moderate/major beneficial.

References

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[2] Balanced Seas.. *Thames Estuary sMCZ No. 5 Marine Conservation Zone: Selection Assessment Document*. September 2011. Available at http://www.balancedseas.org/page/RSG%20Resources.html. Accessed 17/12/12

[3] Balanced Seas. September 2011. See citation above.

[4] Naismith, I.A. and Knights, B. 1988. *Migration of elvers and juvenile European eels, Anguilla anguilla L., in the River Thames*. Journal of Fish Biology 33: 161-175. (1988)

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Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix C.6: Project-wide engagement with stakeholders

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C.6 Project-wide engagement with stakeholders

C.6.1 The following report has its own table of contents

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Appendix C: Ecology – aquatic

C.6 Project-wide engagement with stakeholders

Vol 3 Table C.1 Stakeholder engagement for the project-wide assessment

Organisation	Comment	Response
Scoping		
Environment Agency (EA)	Highlighting diversity of higher plants (macrophytes) on the walls and banks of the River Thames. The structure of the algal mats should be assessed.	The *Environmental Statement* includes baseline information on algae and river wall communities.
	The Tidal Thames is London's largest wildlife site, containing a diverse mosaic of habitats and species, while also providing and important corridor for both terrestrial and aquatic species. The impact of habitat connectivity both temporally and spatially needs to be assessed as part of a cumulative impact assessment.	Impacts on habitats and their continuity through the tidal Thames have been considered in the project wide assessment (Vol 3 Section 5).
	Grey seals are regularly seen upstream of QE2 Bridge and have been as far upriver as Chiswick and Richmond. They use sheltered areas of foreshore that have little disturbance to haul out and rest eg, Chiswick Eyot.	Marine mammal data analysis is considered in the site-specific and project-wide assessments (see Section 5 in Vols 3 to 27).
	Autumn fish surveys (October) can show the presence and relative abundance of the 'young of the year' juveniles. Combined spring and autumn fish surveys give the best indication of seasonal adult and juvenile fish movements.	Baseline surveys for fish and invertebrates have been undertaken in spring and autumn at a range of sites through the tidal Thames. Juvenile fish surveys have also been undertaken in order to inform predictive modelling of the hydraulic impacts of the project on fish migration. Methodologies for these surveys, and details of the sites covered are presented in Vol 2

Organisation	Comment	Response
		Section 5.
	The impact on the extent of change to river bed due to scour needs to be considered for fish and invertebrates.	Outputs from the scour model and modelling to simulate effects on fish migration have been used in the assessment, and are reported in the *Environmental Statement*.
	For mitigation options it recommends that any permanent structures within the river are designed in a manner that the scour will be minimised. If this requires that the area of land take is greater than that which is operationally needed, then terraces or shelves may be incorporated.	Scour modelling has been undertaken and measures to minimise scour designed into the project for foreshore sites.
	A balance sheet approach to mitigation and compensation should be adopted.	We consider that the balance sheet approach places a disproportionate emphasis on the losses and gains that can be expressed as an area and does not adequately reflect the benefits of the water quality improvements which are integral to the scheme. We have therefore described the losses and gains through effects, mitigation and compensation in a narrative form in Vol 3 Section 5.8 with a summary table to show clearly how the balance between loss and gain has been achieved.
	Intertidal mudflat or gravels could be partially compensated for by creating high level intertidal vegetated areas.	The approach to mitigation is outlined in Vol 3 Section 5. This approach has been considered where compensation is deemed to be necessary.

Organisation	Comment	Response
	Within the mitigation options, it is recommended that river wall designs incorporating the approaches described within the Estuary Edges Guidance is incorporated. Generally the creation of intertidal vegetated areas between MHWS and MHWN will provide foraging and refuge opportunities for both juvenile and adult fish.	The design principles for the project (see *Design Principles* report in Vol 1 Appendix B) set out a range of measures such as including horizontal or vertical timber fenders in order to promote aquatic ecology. Where possible other measures, such as an intertidal terrace at the Dormay Street site, have been embedded into the project design.
	In some areas, mitigation in the form of fish passage improvements may offset negative impacts to fish populations within the Tideway. In some circumstances, temporary impacts to fish migrations could be offset by permanent improvements to migration opportunities.	This approach has been considered within the project-wide assessment, and the approach to mitigation and compensation is outlined in Vol 3 Section 5.
	Cumulative (ie, project-wide compound) effects should be properly assessed. For fish this should include noise and vibration as well as hydrodynamics.	Modelling has been undertaken to predict the project-wide hydraulic effects on fish as described in Vol 3 Section 5.5. Site-specific and project-wide noise effects have been assessed based on professional judgement and understanding of the response of individual species to noise impacts (see Vols 3 to 27).
	There are many fish species known to spawn within the tidal Thames in discrete areas dependent upon specific habitats, fluvial qualities and optimum requirements for egg survival and growth. Salmon, sea trout and eels, are known to migrate into and out of the estuary at different life stages. Ensuring that these migrations remain unaffected is key.	The location of spawning areas for individual fish species has been investigated as part of a series of juvenile fish migration surveys. The importance of the tidal Thames as a migratory corridor for salmon, sea trout and eels is recognised (Vol 3 Section

Organisation	Comment	Response
		5.4). Effects on fish migration have been assessed through a predictive model which is described in detail in Vol 3 Appendix C.3.
	Any construction works riverward of the flood defences, particularly on the foreshore and within the watercourse, may have impacts on fish resident or migrating though the area. We would require investigation and assessment of the possible damage of this habitat during construction and more detail of the methodologies to be used, along with the timing and duration of works. We are happy to advise Thames Water further on what piling methods are most suitable and when works within the river should take place.	Effects of construction activities on aquatic ecology receptors are assessed in Vol 3 Section 5.5. The *CoCP* (see Vol 1 Appendix A) details the approach adopted to minimise impacts such as noise and vibration and seasonal working restrictions.
	Large scale abstractions or dewatering operations may also have impacts on fish. Dredging works to enable activities such as barge access may negatively impact on the habitats and species within the tidal Bow Creek and Thames, these should be investigated and assessed.	There would be no large-scale abstractions. Dewatering operations would be controlled through the *CoCP* (see Vol 1 Appendix A). The requirement for dredging is limited and described in Vol 3 Section 5.2.
Phase two consultation		
Environment Agency (phase two consultation responses)	At certain times of the year, migratory species such as salmon, sea trout and lamprey will be passing the construction and operational sites. At those times, if work has the potential to impact upon their movements then the sensitivity and value scores should reflect this.	The *CoCP* (see Vol 1 Appendix A) contains measures that would avoid certain works (eg, piling) at sensitive times of year. Juvenile fish surveys and migration modelling has been used to inform the assessment.
	Previous discussions looked at the possibility of installing a membrane or geotextile layer between the foreshore and the granular fill for the cofferdams, to allow it to be	This is addressed within the *CoCP* and Vol 3 Appendix C.4

Organisation	Comment	Response
	reinstated when the temporary cofferdams are removed. If this is not the case then the viability of reinstatement of foreshore areas needs to be carefully considered by the *Environmental Statement*. If reinstatement is not possible, then this must be recorded as permanent damage and appropriately mitigated and compensated for.	
	All dredging works need to be assessed within the *Environmental Statement*. The area that needs to be dredged for the new Blackfriars Pier will need to be considered in terms of the need for maintenance dredging. If this is required regularly then there will be a permanent degradation of those areas of subtidal habitat.	Dredging works are proposed at, Carnwath Road Riverside, Kirtling Street and Blackfriars Bridge Foreshore sites. The impacts of the dredging works are considered in Section 5 of the relevant site specific volumes (Vols 10, 14 and 18).
	The feasibility of reinstatement of habitat post-construction will need to be carefully addressed by the *Environmental Statement*.	This is addressed within the *CoCP* and Vol 3 Appendix C.4
	Tidal creeks are valuable refuge and foraging habitats for adult and juvenile fish of all species. They should be considered highly sensitive in terms of construction or permanent works within them, but also areas of high opportunity for habitat enhancement work, and /or mitigation options.	Habitat compensation measures are proposed on the tidal sections of tributary creeks where there are greater opportunities for enhancements. For example, a set back is proposed within strengthened flood defences at Dormay Street site.
	The Thames was not awarded the Theiss River Prize solely in recognition of progress made, but because there are plans in place to further improve it, including the Thames Tunnel.	Noted and incorporated into assessment.
	The tidal Thames is being considered as a candidate Marine Conservation	Effects on the MCZ designation are

Organisation	Comment	Response
	Zone (MCZ) for smelt and eel by the Balanced Seas project.	considered in Vol 3 Appendix C5.
	The short snouted sea horse (protected species) and European eel NERC S40 & 41, should be included.	These species have been included within the baseline.
	Some species are missing from a table within the baseline information ie, depressed river mussel, German hairy snail and two lipped door snail.	These species have been included within the baseline.
	You may wish to include the proposed MCZ designation.	Effects on the MCZ designation are considered in Vol 3 Appendix C5.
	The *Environmental Statement* will need to make clear the benefits of a reduced volume of storm sewage will have on the tideway.	Vol 3 Section 5.6 considers the beneficial effects of the Thames Tideway Tunnel project on fish and invertebrates.
Section 48 responses		
Environment Agency (Section 48 responses)	Further details are required on scour, specifically relating to impacts on habitats and aquatic ecology. Clarification of extent of protection, and reduction and mitigation of scour is needed.	The assessment of scour and clarification of protection measures is provided in Section 5.6 (Operational effects assessment) of each of the site-specific volumes (Vols 4 to 27) and the project-wide assessment (Vol 3).
	6ha of intertidal and subtidal habitat to be lost, 1.3ha of this permanently. An equivalent area of habitat should be provided as a minimum. Could be site-specific or off-site. Reasoning for decisions on whether mitigation is needed or not should be clear and justified for sites.	Areas affected by temporary land take would be reinstated following construction. The approach to reinstatement is detailed in Vol 3 Appendix C.4. The approach to habitat compensation is described in Section 5.8 of the site-specific assessments (Vols 4 to 27) and the project-wide assessment (Vol 3).
	Detailed fish modelling results are required.	The juvenile fish migration modelling report

Organisation	Comment	Response
		is included in Vol 3 Appendix C.2.
	Environmental Statement must demonstrate use of decision hierarchy. Decision making and methodologies must be clear throughout.	The way in which the mitigation hierarchy has been used to guide the design is described in Section 5.8 of each of the site-specific assessments (Vols 4 to 27).
	Foreshore structures should be minimised in size and only placed there if essential.	The size of the temporary and permanent structures has been minimised through the iterative design process. For example, the permanent structure at King Edward Memorial Park Foreshore site has been reduced in size. Some sites, such as Cremorne Wharf Depot have been moved onshore to limit impacts on the foreshore.
	It is not acceptable to encroach further into the foreshore for the sake of creating intertidal habitat terraces.	Intertidal habitat terraces would be created where an opportunity exists without further encroachment of the foreshore, eg, at Dormay Street.
	Site boundaries should take into account scour extents and also sites for ecological compensation.	The Site works parameter plans for each site include the area within which scour protection measures would be located (see Vols 4 to 27 separate volumes of figures).
	Reinstated flood defences should be set back, especially relevant to Dormay St and Chambers Wharf.	A tidal terrace is proposed within strengthened flood defences at Dormay Street. The flood defences at Chambers Wharf are not owned by Thames Water and

Organisation	Comment	Response
		therefore no opportunity exists to incorporate a setback.
	Existing aprons should be removed where possible and this can count as compensation.	A review of the existing aprons has been undertaken. Redundant aprons would be removed where it is technically feasible.
	Cofferdam materials should be removed and foreshore reinstated.	As per the *CoCP* (see Vol 1 Appendix A), a geotextile membrane would be laid below cofferdam fill material to prevent mixing with underlying substrate. The approach to reinstatement of temporary cofferdams is detailed in the *CoCP* and Vol 3 Appendix C.4.
	Silent piling methods should be used where possible.	The approach to piling is set out in the *CoCP (*see Vol 1 Appendix A). The assessment assumes that vibro piling would be used.
	A decrease in nutrient levels would not be of moderate beneficial effect for fish. Algal blooms do not occur.	The assessment of nutrient levels on fish has been removed. The reduction in suspended solids and Total Organic Nitrogen (TON) and the effect that this would have on tidal Thames habitats (including those used by fish) is assessed as a minor beneficial effect.
	Permanent and temporary loss of intertidal habitat should be a greater effect than minor adverse. Losses due to scour protection need to be accounted for. Compensatory schemes should be highlighted.	Permanent land take at a project-wide and site-specific levels has been assessed as a moderate adverse effect, although given the scale of the loss it is not anticipated to affect

Organisation	Comment	Response
		integrity of habitats. In general, effects are considered to be moderate adverse for construction and operation for each of the foreshore sites except where land take is minimal (eg, Kirtling Street). Effects due to scour protection measures are considered within the operational effects section for each site (Section 5.6 of Vols 3 to 27). Compensation measures are described in Vol 3 Section 5.8.
	Ship impact buffers should be used for mitigation where included.	The potential to incorporate intertidal terraces into the ship impact buffers has been considered but it has been concluded that it would be unfeasible.
	Where on-site effects cannot be made less significant, compensation should be provided as close as possible to the site.	Opportunities for compensation on the main River Thames are limited, particularly within the central section of the project. Habitat compensation measures are therefore proposed on the tidal sections of tributary creeks where there are greater opportunities for enhancements.
	Clarity is sought on which structures will be permanent and which temporary.	The *Environmental Statement* volumes make clear which aspects of design are relevant to construction (temporary) and operational (permanent) works.
Port of London Authority (PLA)	Further detail needed on hydrodynamic effects and on extents	The hydraulic effects of the permanent and

Organisation	Comment	Response
	of land take.	temporary structures on juvenile fish has been assessed using an Individual Based Modelling approach. The juvenile fish migration modelling report is appended to Vol 3 Appendix C.2
Local authorities – Royal Borough of Kensington and Chelsea	Biodiversity enhancements should be fitted to the river wall along the Chelsea Wharf (from Chelsea Creek to the Chelsea yacht and boat club), thus enhancing the flora and fauna of the intertidal habitat and providing refuge for juvenile fish.	Proposed habitat compensation measures and the approach to identifying them are detailed in Section 5.8 of Vol 3. Enhancement to Chelsea Wharf is not one of the proposed schemes on the basis that sufficient compensation has been identified through other schemes.
Local authorities – London Borough (LB) of Wandsworth	There has been a dramatic decline in elver numbers in recent years and specific works at sites such as Bell Lane Creek need to take into account the potential presence of this species.	Impacts on these species are considered in the site specific assessments (Vol 11 and Vol 12).
Local authorities – LB of Wandsworth (King George's Park)	The applicant has failed to recognise the park as a SINC (Grade 2) and that there is a borehole to fill the lake which may potentially be impacted by the works. This needs to be recognised and addressed.	Noted. This is considered in the terrestrial ecology site specific assessment (Section 6 of Vol 12).
	The council would require full justification as to why ecology aquatic has been scoped out for King George's Park (there is a pond near the site) and Jews Row (on the river).	The assessment of effects on the lake within King George's Park is covered under the terrestrial ecology assessment (Section 6 of Vol 12). Assessment of the improvements arising from interception of the CSO into the River Wandle and tidal Thames

Organisation	Comment	Response
		is covered in the operational aquatic ecology assessment (Section 5 Vol 12). Jews Row is not part of the final proposed development.
	Referred the applicants to the London Invasive Species Initiative (LISI) currently co-ordinated by the Environment Agency. This identifies invasive species of conservation concern for London, enables their specific recording via GIGL and will give guidance on best practice in prevention, control or eradication.	Noted. The control of invasive species is covered within the *CoCP*.(see Vol 1 Appendix A). Impacts on aquatic ecology have been considered in the *Environmental Statement* in the site-specific (Vols 4 to 27) and project wide assessments (Vol 3).
LB of Wandsworth	The final design of the new permanent structure on the foreshore needs to be refined to limit scouring of the riverbed and foreshore habitat which is believed to be important for fish breeding.	Scour protection has been incorporated into the design of the permanent structures. The impact of the scour protection on fish is assessed in the site volumes (Vols 4 to 27) and the project-wide assessment (Vol 3).
Local authorities – LB of Southwark	We accept that there may be some small scale disturbance to juvenile fish movements however we expect this to be minimised and mitigated as much as possible.	The *Environmental Statement* concludes that the effects on juvenile fish migrations of temporary and permanent structures would be negligible (in part due to measures embedded in the scheme design).
Local authorities – LB of Hounslow	Syon Park SSSI is in hydrological continuity with the project and Barnes Wetland Centre does have an occasional connection. We are anticipating that aquatic species would likely only benefit from the proposal.	These designated sites are included within the scope of the project-wide assessment on aquatic ecology (Section 5 in Vol 3).
City of London Corporation	Blackfriars Bridge Foreshore - every effort should be made to ensure that	During operation the permanent loss of

Organisation	Comment	Response
	the encroachment of the new structures into the river and the relocated Blackfriars Pier create minimal impacts on the environment of the river.	intertidal foreshore is considered to be a moderate adverse effect. The footprint of the permanent structure has been minimised as far as possible to accommodate the necessary works therefore further mitigation on-site is not possible. The permanent loss of habitat at the Blackfriars Bridge Foreshore site contributes to an overall loss arising from all of the foreshore sites. Compensation for this project-wide permanent loss of foreshore habitat is described in Section 5.8 of Vol 3.

Thames Tideway Tunnel
Thames Water Utilities Limited

Application for Development Consent

Application Reference Number: WWO10001

Environmental Statement

Doc Ref: **6.2.03**

Volume 3: Project-wide effects assessment appendices

Appendix D: Ecology - terrestrial

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Appendix D: Ecology – terrestrial

D.1 Introduction

D.1.1 Construction and operational project-wide effects assessments for this topic do not require the provision of any supporting information, so this appendix is intentionally empty.

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DCO-DT-000-ZZZZZ-060203