Final Report **Project WFD119**

Enhancement of the River Invertebrate Classification Tool

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SNIFFER
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EXECUTIVE SUMMARY

WFD119: Enhancement of the River Invertebrate Classification Tool

Project funders/partners:
Environment Agency, Northern Ireland Environment Agency, Scotland & Northern Ireland Forum for Environmental Research, Scottish Environment Protection Agency

Background to research

The Regulatory Agencies in the UK (the Environment Agency; Scottish Environment Protection Agency; and the Northern Ireland Environment Agency) now use the River Invertebrate Classification Tool (RICT) to classify the ecological quality of rivers for Water Framework Directive compliance monitoring. RICT incorporates RIVPACS IV predictive models and is a highly capable tool written in a modern software programming language.

While RICT classifies waters for general degradation and organic pollution stress, producing assessments of status class and uncertainty, WFD compliance monitoring also requires the UK Agencies to assess the impacts of a wide range of pressures including hydromorphological and acidification stresses. Some of these pressures alter the predictor variables that current RIVPACS models use to derive predicted biotic indices. This project has sought to broaden the scope of RICT by developing one or more RIVPACS model(s) that do not use predictor variables that are affected by these stressors, but instead use alternative GIS based variables that are wholly independent of these pressures.

This project has also included a review of the wide range of biotic indices now available in RICT, identifying published sources, examining index performance, and where necessary making recommendations on further needs for index testing and development.

Objectives of research

- To remove and derive alternative predictive variables that are not affected by stressors, with particular emphasis on hydrological/acidification metric predictors.
- To construct one or more new RIVPACS model(s) using stressor independent variables.
- Review WFD reporting indices notably AWIC(species), LIFE (species), PSI & WHPT.

Key findings and recommendations

Predictor variables and intellectual property rights

An extensive suite of new variables have been derived by GIS for the RIVPACS reference sites that have been shown to act as stressor-independent predictor variables. These include measures of stream order, solid and drift geology, and a range of upstream catchment characteristics (e.g. catchment area, mean altitude of upstream catchment, and catchment aspect).

It is recommended that decisions are reached on which of the newly derived model(s) are implemented in RICT so that IPR issues for the relevant datasets can be quickly resolved and the datasets licensed. It is also recommended that licensing is sought for a point and click system (where the dataset cannot be reverse engineered) that is capable of calculating any of the time-invariant RIVPACS environmental predictor variables used by any of the newly derived (and existing) RIVPACS models, and for any potential users.

New stressor-independent RIVPACS models

Using the existing predictor variables, together with new ones derived for their properties of stressor-independence, initial step-wise forward selection discriminant models suggested a range of 36 possible models that merited further testing. Following further testing, the following models are recommended for assessing watercourses affected by flow/hydromorphological and/or acidity stress:

- For flow/hydromorphological stressors that may have modified width, depth and/or substrate in GB, it is suggested that a new **'RIVPACS IV – Hydromorphology Independent'** model (Model 24) is used (this does not use the predictor variables width, depth and substratum, but includes a suite of new stressor-independent variables).
- For acidity related stressors in GB, it is suggested that a new **'RIVPACS IV – Alkalinity Independent'** model (Model 35) is used (this does not use the predictor variable alkalinity, but includes new stressor-independent variables).
- For flow/hydromorphological stressors *and* acidity related stressors in GB, it is suggested that a new **'RIVPACS IV – Hydromorphology & Alkalinity Independent'** model (Model 13) is used (this does not use the predictor variables width, depth, substratum and alkalinity, but includes a suite of new stressor-independent variables).
- Reduced availability of appropriate GIS tools at this time has meant that no new models have been developed for Northern Ireland.

Discriminant functions and end group means have now been calculated to enable any of these models to be easily implemented in the RICT software.

Biotic indices

The RIVPACS models in RICT can now produce expected values for a wide range of biotic indices addressing a variety of stressors. These indices will support the use of RICT as a primary tool for WFD classification and reporting of the quality of UK streams and rivers. There are however a number of outstanding issues with indices that need to be addressed:

- There is a need to develop a biotic index for assessing metal pollution.
- WFD EQR banding schemes are required for many of the indices to report what is considered an acceptable degree of stress (High-Good) and what is not (Moderate, Poor or Bad).
- A comprehensive objective testing process needs to be undertaken on the indices in RICT using UK-wide, large-scale, independent test datasets to quantify their index-stressor relationships and their associated uncertainty, for example following the approach to acidity index testing in Murphy *et al*., (in review) or organic/general degradation indices in Banks & McFarland (2010).
- Following objective testing, the UK Agencies should make efforts to address any index under-performance issues that have been identified, and where necessary new work should be commissioned to modify existing indices, or develop new ones where required so that indices for all stress types meet certain minimum performance criteria.
- Testing needs to be done to examine index-stressor relationships with both observed index scores and RIVPACS observed/expected ratios. Work should also be done to compare the existing RIVPACS IV and the new stressor-independent models (developed in this project) as alternative sources of the expected index values for these tests.
- Consideration should be given to assessing the extent to which chemical and biological monitoring points co-occur. Site-matched (rather than reach-matched) chemical and biological monitoring points would i) generate the substantial training datasets needed to refine or develop new indices and ii) generate the independent datasets for testing.

Key words: RIVPACS IV, River Invertebrate Classification Tool, Water Framework Directive

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1. INTRODUCTION

As part of the continued drive to further develop and widen the scope of the River Invertebrate Classification Tool (RICT) this project has sought to address one of the more challenging aspects of RIVPACS predictive modelling, namely the problems arising when the physical variables that are used to derive predictions are themselves affected by stressors that might need to be assessed.

RIVPACS models use a set of predictive variables to predict reference values for biotic indices and predicted faunal lists at test sites. These predictor variables can be divided into two groups: time variant (different on each sampling occasion) and time-invariant predictors (relatively unchanging though time). For example:

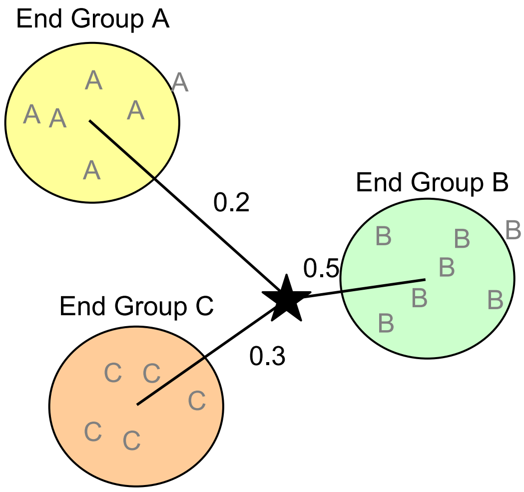
Time Invariant	Time variant
Alkalinity*	Substrate composition
Altitude	Width
Slope	Depth
Discharge category	
Distance from source	
Latitude	
Longitude	
Air Temperature	

* while alkalinity fluctuates through time, it's variability is low in relation to the other variables and it is therefore regarded as time-invariant.

Time invariant predictors are generally derived from maps or GIS layers, and represent gradients such as altitude, distance from source, or mean air temperature. These can be regarded as not being affected by any of the stressors that need to be assessed. Time variant predictors are recorded at the time a test site is sampled (width, depth, and substrate composition), or, in the case of alkalinity, over a recent period of time. Time variant variables are more prone to being altered by stressors. For example, sedimentation, abstraction, hydromorphological alteration and acidification can all affect one or more of the time variant variables. This can have consequences for predictions, because predictions may be drawn for an altered subset of reference site end groups within the model. This problem is illustrated in the example in Figure 1.

Figure 1 (A) shows a predicted NTAXA for a test site. This is calculated as the weighted average of 3 end groups (A, B and C in this example). The probability that the test site belongs to each end group, is multiplied by the average NTAXA of the reference sites within each end group, to obtain the contribution each end group makes to the NTAXA (which is then the sum of those contributions). Figure 1 (B) shows the same site, but this time subjected to a hydromorphological degradation causing alteration to the width and/or depth. The modified physical properties of the test site now alter the probabilities of it belonging to the various end groups. In this example, the test site is now more likely to belong to end groups B, C and D, and as a result, the predicted NTAXA has changed. Given that RIVPACS should be predicting the *reference* values of biotic indices at test sites, stressors that alter predictor variables, have the potential to distort predictions by falsely associating stressed sites with the wrong RIVPACS end groups (i.e. ones that naturally have physical properties that are more similar to the stressed test site).

Similar examples can be imagined for fine sediment stress affecting substrate composition, and thereby causing predictions of biotic index reference values to be distorted towards end groups that naturally have finer substrata. Similarly, acidification stress may cause biotic index predictions to be distorted towards end groups that have naturally lower alkalinities.

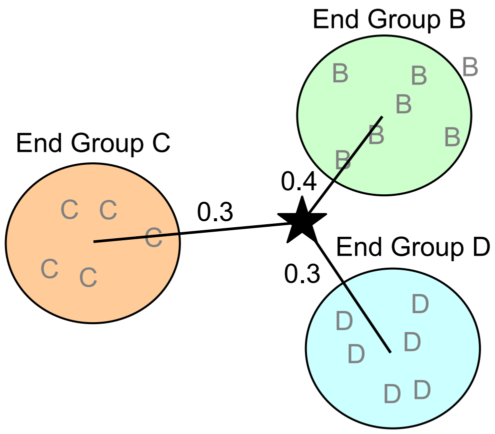


(A) Unmodified test site

Predicted NTAXA is a weighted average of probabilities of the test belonging to end groups A, B or C).

End Group	Probability site belongs to group	Mean NTAXA of group	Contribution of group to NTAXA
A	0.2	25	5.0
B	0.5	30	15.0
C	0.3	22	6.6
D	0	13	0

Predicted NTAXA = **26.6**



(B) Same site affected by hydromorphological stress

The test site has modified physical properties. The predicted NTAXA is now the weighted average of probabilities of the test belonging to end groups B, C or D).

End Group	Probability site belongs to group	Mean NTAXA of group	Contribution of group to NTAXA
A	0	25	0
B	0.4	30	12.0
C	0.3	22	6.6
D	0.3	13	3.9

Predicted NTAXA = **22.5**

Figure 1. (A) Predicted NTAXA for an unmodified test site, and (B) the same site affected by hydromorphological stress. Coloured discs represent RIVPACS end groups (A-D), the star (★) indicates a test site, and the connecting lines indicate the probabilities of the test site belonging to each of the end groups in discriminant space.

The problem of stressors affecting RIVPACS variables has been less of an issue in the past, when most water pollution problems arose from organic pollution (since this stressor does not affect any predictor variables). However, as more and more stress types now need to be assessed, and some of these are physical in nature (or alkalinity related), there has been a growing need to examine the issue of stressors affecting the RIVPACS predictor variables.

To get round this problem alternative variables are needed that are not affected by stress*. For the RIVPACS variables this means removing the time variant variables: substrate, width and depth, all of which are affected by physical modifications to test sites. It may also be necessary to remove alkalinity as a predictor variable because its measured values at test sites may be modified by acidification (and potentially sewage and industrial discharges that can add excess base thereby increasing alkalinity. The other variables are regarded as being robust with respect to stressors.

*NB - Some stresses are biological (e.g. invasive species). This is an area that has not been considered in RIVPACS to date, but may need to be investigated in the future.

2. NEW STRESSOR INDEPENDENT PREDICTOR VARIABLES

In SNIFFER project WFD100 (Davy-Bowker *et al.,* 2010) some initial work was done to attempt to identify a wish list of new predictive variables that would give greater independence from the stressors being measured. This project also investigated ways to improve the predictive capability of RICT in general by attempting to find new variables that increased overall predictive power whilst similarly not being affected by any stressors that might need to be assessed.

In order to assess the effect on overall model performance of removal of the variables affected by stressors it was first necessary to examine the relative explanatory power of the variables used in UK RIVPACS models. In Davy-Bowker *et al.* (2010) two existing analyses of explanatory power were reviewed (described again here for completeness).

Firstly, an analysis of the explanatory power of predictor variables carried out in Davy-Bowker *et al*. (2006) was reviewed. This analysis used canonical correspondence analysis (CCA) to compare the predictive power of variables in the now superseded (although still relevant) GB RIVPACS III+ model with WFD System-A variables. Table 1 below, reproduced from Davy-Bowker *et al*. (2006), shows the results of this analysis.

Table 1. Percentage variation explained by RIVPACS III+ and WFD System-A variables when each variable is the only explanatory variable in an analysis of 614 RIVPACS III+ sites across Great Britain (reproduced from Davy-Bowker *et al*., 2006).

Variable	% Variation explained
Alkalinity	7.0
Mean substrate composition	6.4
Log_{10} alkalinity	5.9
Log_{10} slope	5.9
Longitude	5.4
Log_{10} distance from source	4.3
Log_{10} altitude	3.7
Log_{10} water depth	3.7
Latitude	3.7
Log_{10} water width	3.2
River discharge (flow) category	3.2
Mean air temperature	3.2
WFD catchment size category	2.7
WFD geology – calcareous category	2.7
WFD geology – siliceous category	2.1
WFD altitude category	1.6
WFD geology – organic category	0.5

Alkalinity ranked first as the most powerful single descriptor of variation across the GB RIVPACS dataset. Substrate composition was the second most powerful variable and water depth and width ranked 8th and 10th. Alkalinity and substrate (both potentially affected by stressors) were therefore very strong predictors of macroinvertebrate community composition.

The second study reviewed was a large-scale analysis of the relative explanatory power of predictor variables in a combined analysis of clean and polluted streams and rivers from the 1995 General Quality Assessment survey of England and Wales (Murphy & Davy-Bowker, 2005). In this analysis the relative explanatory power (marginal effects in a

CCA) of predictor variables together with variables representing stressors and a range of new spatial variables was examined. The results are reproduced in Table 2 below.

Table 2. Individual explanatory power of a range of variables in an analysis of 5752 clean and polluted streams and rivers from the 1995 GQA survey of England and Wales.

Variable	Marginal effects
Substrate	0.12
Alkalinity	0.11
X (Easting)	0.10
Depth	0.06
Altitude	0.05
Slope	0.05
XY^2	0.05
Organic inputs	0.04
Distance from source	0.03
Urban run-off	0.03
Discharge category	0.02
Y (Northing)	0.02
Width	0.02
XY	0.02
Y^2	0.02
Acidification	0.02
Canalisation	0.02
X^2	0.01
X^2Y	0.01
Agri-chemical inputs	0.01
Industrial discharge and run off	0.01
Excessive plant growth	0.01
Reduced discharge	<0.01

This analysis again shows that substrate and alkalinity (variables potentially affected by stressors) are the two strongest predictors of macroinvertebrate community composition. In this analysis the predictor variables depth and width rank 4th and 13th respectively.

Thirdly, further information on explanatory power comes from work done by the Artificial Intelligence team at Staffordshire University. Alkalinity has been identified by the AI team as the chemical with the closest relationship to invertebrates. For example, it was listed as one of the most powerful predictors of ASPT, along with altitude and percentage silt, in Walley *et al*. (1998), and was also identified as the environmental variable that the invertebrate data was best able to predict in Table 3 of Walley *et. al*. (2002).

These analyses, while based on different datasets (one using RIVPACS reference sites, and the others using GQA monitoring sites) both show that alkalinity and substrate are very strong predictors of macroinvertebrate community composition and are therefore going to be hard to replace in any attempt to build RIVPACS models that are truly stressor independent.

2.1 CANDIDATE PREDICTOR VARIABLES

In discussing candidate predictor variables that might enable RIVPACS models to be built that are not affected by stressors, it is worth summarising the criteria that any new variables should ideally satisfy:

- Stressor independent (not affected by any stressors routinely encountered)

- Easily derivable (both for reference sites and test sites by Agency staff and others)

- Not dependent on external GIS layers or datasets (which might both prove impractical for some users and have IPR restrictions)

A potential list of new candidate variables has been assembled (Davy-Bowker *et al*., 2010) and is reproduced below. However the predictive power of many of these variables would overlap if they were used together, and is it highly unlikely that they would all make independent contributions to improving model performance

Group 1 – Further Map Based Variables (or from GIS)

Variable	Notes
Catchment area	Hard to calculate manually Another measure of river size - may not explain much more than distance from source. Already have this variable for all RIVPACS sites.
Stream order	Must define method and map/GIS resolution e.g. Strahler from 1 to 50:000 OS Land Ranger. Many tributaries indicate hard geology. Very few tributaries indicate a groundwater fed river.
Altitude of source	Relatively easy to derive. Provides more information on the river leading into the site in question. Should help distinguish if the river has an upland fauna upstream.
Slope - source to site	Relatively easy to derive (assuming source is clear). Provides information on the river leading into the site in question. Should correlate strongly with the number of riffles and therefore typical undisturbed substrate composition of the river upstream.
Stream power	A measure of the energy within a river system. Calculation requires slope at site and discharge (see Ferguson, 1981).
Geology	Site and upstream catchment geology (both solid and drift geology)

Group 2 – Spatial Variables

Following work done in Murphy & Davy-Bowker (2005), a set of alternative spatial variables that appear to have some degree of explanatory power is listed below. It is proposed that the same set of spatial variables as used in Murphy & Davy-Bowker (2005) are examined, perhaps together with some additional variants:

X (Easting, East-West spatial patterns)
Y (Northing, North-South spatial patterns)
XY
X^2
Y^2
XY^2
X^3
Y^3

A wish list of potential new predictor variables and three criteria that these variables need to satisfy has been identified. These include a group of new map/GIS based variables and a group of new spatial variables, both of which are wholly independent of hydromorphological and acidification stress. These variables may give additional information on the river type that could help to offset the removal of alkalinity, substrate, width and depth, and there is some evidence that at least some of these may work as predictor variables in any new RIVPACS models that are built for inclusion in RICT.

2.2 DERIVATION OF NEW VARIABLES FOR EXISTING RIVPACS SITES

The following sections describe how various groups of the candidate predictor variables above (section 2.1) have been derived for the RIVPACS reference sites. It should be noted that variable derivation by GIS has been the principle approach, and that not all of variable types above have been pursued in this project. Specifically, additional map based (group 1) variables have been derived but the square and cubic forms of the spatial (group 2) variables have not been pursued. This was because it was felt that it was easier to understand how the map based variables might provide additional discriminatory power, as opposed to variables such as X^2Y or Y^3 (which can only be correlates of unknown and un-measured variables).

Variable derivation was a two-stage process involving i) derivation of new GIS catchments (drainage basins) for each RIVPACS reference site, and ii) derivation of new predictor variables using these catchments in conjunction with various GIS data layers.

2.2.1 Derivation of GIS catchments

The derivation of catchment boundaries and outlet coordinates for the RIVPACS reference sites relied upon the CEH Wallingford's Integrated Hydrological Digital Terrain Model (IHDTM; Morris and Flavin, 1990), which has been designed to be consistent with the UK drainage basin network and allows the boundaries of around four million catchments to be derived (this discrete number of catchments is a construct due the resolution of the IHDTM; along a drainage path, catchment outlets are 50 m apart). The latest version of the IHDTM was used (referred to as 'DTMGEN'); this version improves on previous versions by having been made consistent with the OS 1:50,000 river network.

First, using the recorded coordinates of the RIVPACS reference sites, the sites were 'snapped' onto the DTMGEN. This automatically linked each site to its nearest point on the DTMGEN drainage network. Catchment boundaries (CBs) were then derived ('DTMGEN CBs'). These boundaries were compared with an earlier set of boundaries ('WFD46 CBs') produced as part of the SNIFFER project WFD46 'RIVPACS Pressure Data Analysis' (Davy-Bowker *et al.*, 2007). The WFD46 boundaries were created from the IHDTM, but from an alternate flow path grid derived using ArcGIS hydrology tools.

The WFD46 and DTMGEN CBs were then visually cross-checked. For both sets of CBs to be considered as a match, there was an allowance for small differences inherent to the use of different DTMs. When mismatches were found, high resolution OS maps and additional information were used to identify where the outlet should be and sites were snapped manually onto DTMGEN accordingly. The following rules were applied:

a) Where the WFD46 and DTMGEN gave an equally plausible CB: the site was snapped manually onto DTMGEN so the resulting CB matched the original WFD46 CB.
b) Where the DTMGEN CB improved on the original WFD46 CB: the DTMGEN CB was used.

Out of the entire UK RIVPACS reference site dataset (835 sites), only three sites were not modelled properly in the DTMGEN (sites 5852, 6242, 6844; one is a spring, and the others were too small). Catchments for these three sites were not therefore derived although they were included in the outputs with dummy coordinates (-999).

2.2.2 Flood Estimation Handbook variables

The Flood Estimation Handbook (FEH, UK industry standard for flood regionalisation studies) includes 19 basin descriptors (Bayliss, 1999). Using the IHDTM these descriptors had already been pre-calculated for all catchments with areas exceeding 0.5 km^2. The FEH basin descriptors were retrieved for the RIVPACS reference sites using the drainage basin outlet coordinates derived in section 2.2.1 above.

Although flow statistics such as mean flow, Q95 and QMED were not explicitly derived for testing in the revised models, the underlying catchment characteristics which are used to model these statistics using industry standard software tools (Low Flows Enterprise and FEH) were included.

2.2.3 The CEH Intelligent River Network

The CEH Intelligent River Network (IRN) does not cover Northern Ireland so only the 725 GB sites were processed. The IRN is based on a former version of the IHDTM (referred to as 'IRN DTM'; that differs slightly from DTMGEN especially in flat lowland areas). It was therefore necessary to perform the site snapping and quality control exercise again in order to derive the IRN variables. IRN variables include point variables, which require only correctly IRN DTM-snapped catchment outlet coordinates, and catchment variables, which require CBs. The GB sites were automatically snapped on the IRN DTM and their CBs derived. CBs were cross-checked against the WFD46/DTMGEN CBs. Approximately 670 of the 725 sites were properly snapped, or could be easily corrected manually, in order to get consistent CBs.

About 30 sites exhibited moderate discrepancies between WFD46/DTMGEN CBs and IRN CBs with their catchment areas differing by no more than 10%. These discrepancies are inherent to the use of different DTMs and modelled drainage networks, and not considered significant; the IRN CBs were therefore used without further processing. Another 30 sites produced erroneous CBs because of abnormal results in the IRN delineation procedure (e.g. CBs cutting across the drainage network). For these, although the CBs were wrong, the outlet coordinates were still correctly located on the drainage network so IRN derived point variables were accurately derived. To derive catchment variables, the WFD46/DTMGEN CBs were used and the IRN catchment variables (e.g. LCM 2000 and geology breakdowns) were derived from the IRN datasets but outside the IRN program. Any discrepancies arising from doing so were limited. Careful consideration will need to be given to how problems of this kind are dealt with when deriving variables for test sites in the future.

The three sites that could not be snapped onto the DTMGEN (5852, 6242, 6844) also failed to be processed within the IRN. Consequently, IRN variables were obtained for a total of 722 of the 725 Great Britain RIVPACS reference sites.

2.3 DRIFT AND SOLID GEOLOGY SUPER CLASSES

The British Geological Survey (BGS) geological classifications of GB comprise 116 classes of solid geology and 14 classes of drift geology, available in GIS format as the dominant solid and drift geology class in each 1km square referenced to the National Grid. These very detailed classes provide too much detail and too many variables to be used

Table 3. Amalgamation of BGS Solid Geology classes (0-115) into RHS super-classes (0-8)

BGS Code	BGS description	RHS Code	RHS description
0	No solid geology	0	No solid geology
1	Undifferentiated gneiss	8	Hard Rocks
2	Metasediments	8	Hard Rocks
3	Marble	8	Hard Rocks
4	Anorthosite	8	Hard Rocks
5	Ultrabasic rock	8	Hard Rocks
6	Intermediate and basic rock	8	Hard Rocks
7	Gneissose granite, granite and pegmatite	8	Hard Rocks
8	Undifferentiated Moine	8	Hard Rocks
9	Quartzite	8	Hard Rocks
10	Quartz-feldspar-granulite	8	Hard Rocks
11	Mica-schist, semi-pelitic schist and mixed schists	8	Hard Rocks
12	Granitic gneiss	8	Hard Rocks
13	Undifferentiated schist and gneiss of Shetland and Central Tyrone	8	Hard Rocks
14	Epidote-chlorite-schist, commonly hornblendic-Green Beds	8	Hard Rocks
15	Epidote-chlorite-schist, commonly hornblendic-Green Beds (Upper Dalradian)	8	Hard Rocks
16	Boulder bed and conglomerate	8	Hard Rocks
17	Quartzite grit, interstratified quartzose-mica-schist	8	Hard Rocks
18	Quartzose-mica-schist	8	Hard Rocks
19	Quartmica-schist, grit, slate and phyllite (Upper Dalradian)	8	Hard Rocks
20	Slate, phyllite and mica-schist	8	Hard Rocks
21	Slate, phyllite and mica-schist (Upper Dalradian)	8	Hard Rocks
22	Black shale with chert (Upper Dalradian)	8	Hard Rocks
23	Graphitic schist and slate	8	Hard Rocks
24	Limestone	8	Hard Rocks
25	Limestone (Upper Dalradian)	8	Hard Rocks
26	Serpentine	8	Hard Rocks
27	Epidiorite, hornblende-schist and allied types	8	Hard Rocks
28	Foliate granite, syenite and allied types	8	Hard Rocks
29	Hornblende schists	8	Hard Rocks
30	Gneiss, mica schists	8	Hard Rocks
31	Ultrabasic rock	8	Hard Rocks
32	Gabbro and allied types	8	Hard Rocks
33	Diorite and allied intermediate types	8	Hard Rocks
34	Granite, syenite, granophyre and allied types	8	Hard Rocks
35	Basalt dolerite, camptonite and allied types	8	Hard Rocks
36	Porphyrite, lamprophyre and allied types	8	Hard Rocks
37	Rhyolite, trachyte, felsite, elvans and allied types	8	Hard Rocks
38	Agglomerate in neck	8	Hard Rocks
39	Andesitic lava and tuff	8	Hard Rocks
40	Basalt, spilite and related tuff	8	Hard Rocks
41	Rhyolitic and trachytic lava and tuff undifferentiated	8	Hard Rocks
42	Basalt, spilite, hyaloclastic and related tuffs	8	Hard Rocks
43	Basaltic tuff	8	Hard Rocks
44	Andesitic lava and tuff, undifferentiated	8	Hard Rocks

BGS Code	BGS description	RHS Code	RHS description
45	Andesitic tuff	8	Hard Rocks
46	Rhyolitic lava	8	Hard Rocks
47	Ryolitic tuff, including ignimbrite	8	Hard Rocks
48	Tuff, undifferentiated, mainly andesitic	8	Hard Rocks
49	Basalt and spilite	8	Hard Rocks
50	Andesitic and basaltic lavas and tuffs, undifferentiated	8	Hard Rocks
51	Rhyolite, trachyte and allied types	8	Hard Rocks
52	Tuff (including ignimitbrite)	8	Hard Rocks
53	Basalt and spilite	8	Hard Rocks
54	Rhyolite, trachyte and allied types	8	Hard Rocks
55	Tuff, undifferentiated, mainly basaltic	8	Hard Rocks
56	Basalt	8	Hard Rocks
57	Basalt and spilite	8	Hard Rocks
58	Rhyolite, trachyte and allied types	8	Hard Rocks
59	Tuff, undifferentiated	8	Hard Rocks
60	Rocks of Anglesey, Lleyn Peninsular, Charnwood, Longmynd, etc	8	Hard Rocks
61	Sandstone and grit	5	Sandstone
62	Pipe-Rock and Basal Quartzite	8	Hard Rocks
63	Serpulite Grit and Fucoid Beds	8	Hard Rocks
64	Lower Cambrian	8	Hard Rocks
65	Middle Cambrian	8	Hard Rocks
66	Upper Cambrian, including Tremadoc	8	Hard Rocks
67	Durness Limestone (partly Cambrian)	7	Limestone
68	Llanvirn and Arenig	8	Hard Rocks
69	Llandeilo	8	Hard Rocks
70	Caradoc	8	Hard Rocks
71	Ashgill	8	Hard Rocks
72	Llandovery	8	Hard Rocks
73	Wenlock	7	Limestone
74	Ludlow	7	Limestone
75	Lower Old Red Sandstone, including Downtonian	5	Sandstone
76	Lower Devonian (England and Wales only)	5	Sandstone
77	Middle Old Red Sandstone (Scotland) Middle Devonian (England)	5	Sandstone
78	Upper Old Red Sandstone (Scotland) Upper Old Red Sandstone and Upper Devonian (England)	5	Sandstone
79	Basal Conglomerate (including possible Devonian)	5	Sandstone
80	Tournaisian and Visean (Carboniferous Limestone Series)	6	Chalk
81	Namurian (Millstone Grit Series)	5	Sandstone
82	Lower Westphalian (mainly Productive Coal Measures)	7	Limestone
83	Upper Westphalian (including Pennant Measures)	7	Limestone
84	Westphalian and ?Stephanian, undivided, of Barren Red lithology	7	Limestone
85	Permian basal breccias, Sandstones and mudstones	5	Sandstone
86	Magnesian Limestone (Permian)	7	Limestone
87	Permian mudstones (including Middle and Upper Marls, Eden ans St Bees shales)	4	Shale
88	Budleigh Salterton Pebble Beds	5	Sandstone
89	Permian and Triassic Sandstones, undifferentiated, including Bunter and Keuper	5	Sandstone
90	Triassic mudstones including Keuper Marl, Dolomitic Conglomerate and Rhaetic)	4	Shale

BGS Code	BGS description	RHS Code	RHS description
91	Lower Lias	3	Clay
92	Middle Lias	3	Clay
93	Upper Lias	3	Clay
94	Inferior Oolite	6	Chalk
95	Great Oolite	6	Chalk
96	Cornbrash	6	Chalk
97	Oxford Clay and Kellaways Beds	3	Clay
98	Corallia	3	Clay
99	Kimmeridge Clay and Ampthill Clay	3	Clay
100	Portland Beds	6	Chalk
101	Purbeck Beds	6	Chalk
102	Hastings Beds	3	Clay
103	Weald Clay	5	Sandstone
104	Lower Greensand	5	Sandstone
105	Upper Greensand and Gault (England) & Greensand (Scotland)	5	Sandstone
106	Upper Chalk (Scotland) Chalk including Red Chalk (England)	6	Chalk
107	Inter-lava beds (Scotland) Oldhaven, Blackheath, Woolwich, & Reading & Thane	3	Clay
108	Inter-lava beds (Scotland) London Clay (England)	3	Clay
109	Inter-lava beds (Scotland) Barton, Bracklesham and Bagshot Beds (England)	5	Sandstone
110	Lough Neagh Clays (Scotland) Bovey Formation, St Angus Sands, etc (England)	3	Clay
111	Hampstead Beds and Bembridge Marls	NIL	---
112	Gravel (Scotland) Lenham Beds (England)	3	Clay
113	Gravel (Scotland) Coralline Crag (England)	3	Clay
114	Gravel (Scotland) St Erth Beds Cornwall)	3	Clay
115	Norwich Crag, Red Crag and Chillesford Clay	3	Clay

Table 4. Amalgamation of BGS Drift Geology classes (0-13) into RHS super-classes (0-5)

BGS code	BGS description	RHS Code	RHS description
0	No Drift Geology	0	No drift geology
1	Landslip	5	Sandstone
2	Blown Sand	5	Sandstone
3	Peat	1	Peat
4	Lacustrine Clays, Silts and Sands	3	Clay
5	Alluvium	2	Alluvium
6	River Terrace deposits (mainly sand and gravel)	5	Sandstone
7	Raised Beach and Marine deposits	5	Sandstone
8	Glacial Sand and Gravel	5	Sandstone
9	Boulder Clay and Morainic drift	3	Clay
10	Sand and Gravel of uncertain age or origin	5	Sandstone
11	Clay with flints	3	Clay
12	Brickearth, mainly loess	3	Clay
13	Crag	3	Clay

directly within the RIVPACS multivariate discrimination. However, following its initial trial for the River Habitat Survey (RHS), Hornby *et al*., 2002 used a super-classification of these BGS classes into major geological types leading to a much simplified geological system of seven River Habitat Survey (RHS) classes for solid geology and five RHS classes for drift geology and this super-classification has been adopted here (Table 3 and Table 4). The RHS numeric codes and order for the classes used for both solid and drift geology correspond very roughly to increasing hardness of the geology.

2.4 ESTIMATING MISSING VALUES FOR TRIAL LIST OF PREDICTOR VARIABLES

The final list of variables on which the investigative discrimination models were based is given in Table 5. The original RIVPACS IV and variables of mean and range of air temperature are only available for the 725 GB reference sites, but not for the 110 Northern Ireland (NI) reference sites. The IRN-derived variables of Strahler stream order and all of the solid and drift geology variables were not available for the NI sites (because the IRN does not cover NI – see section 2.2.3). Development of discrimination models has therefore been focused on improving the GB predictive model.

For a few GB reference sites, values for some of the new variables could not be derived from the IRN or FEH, mostly because of problems in determining the upstream catchment area and network path. There were 26 cases with no upstream catchment area value, which were all given the upstream catchment area derived for the RIVPACS reference sites from a previous version of the CEH-IRN in 2002 (Hornby *et al*., 2002). Four reference sites had no derived Strahler stream order value from the IRN; all were less than 1.8km from source and therefore were all given a Strahler value of 1. There were 17 sites with no upstream percentage cover of solid and drift geology classes and 7 sites with no values for Altitude to source and Slope to source; these were each assigned values derived manually for these sites using an earlier version of the CEH-IRN (Hornby *et al*., 2002). Two or three sites had no values for the BFI and the FEH variables listed in Table 5. For each of these sites and variables, the missing values were estimated as the mean recorded value of the variable for the other GB reference sites in the same TWINSPAN biological end-group(s), leading to missing value estimates for these sites of 0.75 for BFI, 0.50 for PROPWET, 115 for ALTBAR, 118 for ASPBAR, 8.3 for DPLBAR, 9.6 for DPSBAR and 15.2 for LDP.

Table 5. List of all environmental predictor variables to be tested in the statistical discrimination analyses and for which data is available for the GB RIVPACS references sites.

Variable name	Variable description		Derived from	Not for NI
LAT	Latitude		RIVPACS	
LONG	Longitude		RIVPACS	
ATEMPMEAN	Mean Air Temp		RIVPACS	X
ATEMPRANGE	Air Temp Range		RIVPACS	X
DISCHARGE	Discharge Category		RIVPACS	
ALK	Alkalinity		RIVPACS	
MSUBST	Mean Substratum (phi units)		RIVPACS	
LOGALT	Log$_{10}$ Altitude		RIVPACS	
LOGDFS	Log$_{10}$ Distance From Source		RIVPACS	
LOGWIDTH	Log$_{10}$ Water Width		RIVPACS	
LOGDEPTH	Log$_{10}$ Water Depth		RIVPACS	
LOGALK	Log$_{10}$ Alkalinity		RIVPACS	
LOGSLOPE	Log$_{10}$ Slope (at site)		RIVPACS	
STRAHLER	Strahler stream order		IRN	X
%DRIFT0-NONE	%Drift Geology Class 0 - None	in upstream catchment *	IRN+BGS	X

%DRIFT1-PEAT	%Drift Geology Class 1 – Peat	IRN+BGS	X
%DRIFT2-ALLUVIUM	%Drift Geology Class 2 – Alluvium	IRN+BGS	X
%DRIFT3-CLAY	%Drift Geology Class 3 - Clay	IRN+BGS	X
%DRIFT5-SANDSTONE	%Drift Geology Class 5 – Sandstone	IRN+BGS	X
%SOLID0-NONE	%Solid Geology Class 0 - None in upstream catchment *	IRN+BGS	X
%SOLID3-CLAY	%Solid Geology Class 3 - Clay	IRN+BGS	X
%SOLID4-SHALE	%Solid Geology Class 4 - Shale	IRN+BGS	X
%SOLID5-SANDSTONE	%Solid Geology Class 5 - Sandstone	IRN+BGS	X
%SOLID6-CHALK	%Solid Geology Class 6 - Chalk	IRN+BGS	X
%SOLID7-LIMESTONE	%Solid Geology Class 7 - Limestone	IRN+BGS	X
%SOLID8-HARDROCKS	%Solid Geology Class 8 - Hard Rocks	IRN+BGS	X
BFI	Base Flow Index (BFI from HOST classification)	HOST	
PROPWET	Proportion of time upstream catchment soils are wet	FEH	
LOGAREA	Log$_{10}$ Upstream catchment Area (from DTMGEN)	DTMGEN	
LOGSLOPESOURCE	Log$_{10}$(SLOPESOURCE) where SLOPESOURCE = Average slope from Source to site defined from the IRN by: (Altitude at source minus altitude at site) divided by (distance from source)	IRN	
LOGALTBAR	Log$_{10}$(ALTBAR) Mean altitude of upstream catchment	FEH	
ASPECT-SOUTH	Deviation of mean upstream catchment aspect (ASPBAR) from South (East=West=90), where ASPBAR = mean aspect (North=0, East=90) of inter-nodal slopes in upstream catchment	FEH	
LOGDPLBAR	Log$_{10}$(DPLBAR) where DPLBAR = Mean drainage path length (km) between each upstream node (on regular 50m grid) and the site; characterises upstream catchment size and configuration	FEH	
LOGDPSBAR	Log$_{10}$(DPSBAR) where DPSBAR = Mean drainage path slope (m/km) of all inter-nodal slopes for the upstream catchment; characterises overall steepness (from FEH)	FEH	
LOGLDP	Log$_{10}$(LDP) where LDP = Longest drainage path (km) from an upstream catchment node to the site; characterises size principally and also configuration (from FEH)	FEH	

3. INTELLECTUAL PROPERTY RIGHTS

The new predictor variables for each RIVPACS reference site were derived using two separate procedures and datasets: the CEH Flood Estimation Handbook (FEH) and the CEH Intelligent River Network (IRN). Virtually all of the new variables derived were characteristics of the drainage basin (catchment upstream) of a point on the river network (see section 2.2 for further details). In turn, the FEH and IRN are underlain by data from several sources, including terrain data developed by Ordnance Survey, Hydrology of Soil Types (HOST) data, with underlying data owned by several organisations, and geological data originated from BGS.

As the underlying datasets used to calculate the new variables are owned by several different organisations, all with different policies regarding their intellectual property, it is important to summarise potential IPR issues that may arise when these models are implemented in RICT.

Furthermore, as the new RIVPACS models developed in this project have made use of these variables (sections 4 and 5), inclusion of these models in RICT would mean that end-users of RICT would also need to be able to derive the same variables for test sites at any location on the river network. RICT will therefore need to provide a means of deriving these new variables.

The remainder of this section is based on discussions with the CEH data licensing team and summarises the intellectual property rights with regard to the various underlying datasets.

The first stage in the derivation of new predictor variables was the derivation of catchment boundaries using the CEH IHDTM (DTMGEN) (section 2.2.1). The CEH IHDTM (DTMGEN) was based on underlying Ordnance Survey Land-Form PANORAMA® contour data which has been processed to form a 50m elevation grid, and then processed again to form a 50m drainage path grid. Finally this drainage path grid has been adjusted so that paths converge on the actual OS 1:50,000 river network. These adjustments were particularly important in flat areas of the landscape. It is this adjusted drainage path grid which is used to define a catchment boundary for a point on the river network.

The current opinion of the CEH data licensing team is that since the underlying OS data are covered by the OS Open Data arrangements, the licensing of the CEH IHDTM data does not require recourse to OS.

Some characteristics, particularly Baseflow Index (BFI) from HOST (Hydrology of Soil Types) are derived from the HOST dataset. The IPR for HOST is complex, and CEH, Macaulay Institute and the Soil Survey & Land Research Centre are all involved. As a resolution of IPR issues with BFI from HOST would probably take considerable time, it was agreed that within the scope of this project, BFI should not be included as a predictive variable. However, it was felt that, having derived values of BFI for each reference site in the early part of this project, it made sense to assess the extent to which BFI could improve discrimination for the new stressor-independent predictive models, in order to assess whether it was worth trying to negotiate a licence to use BFI in the future.

The geological data used in the CEH IRN are owned by BGS. The data have been made freely available by BGS under a simple license, so it is not anticipated that there would be many problems using the geological data.

The FEH catchment descriptor PROPWET represents the proportion of the time catchment soils are wet. It is based on statistics calculated from MORECS, the Meteorological Office Rainfall and Evaporation Calculation System (Thompson *et al.* 1981) Soil Moisture Deficit (SMD) monthly data. SMD data were first averaged at catchment scale and then interpolated at the daily time step. The CEH data licensing team is currently examining the IPR issues related to the underlying MORECS data (note: this is not the newer MORECS Version 2.0).

All of the above datasets are, where licensing is necessary, already licensed by the national Environment Agencies (EA, SEPA and NIEA). Hence most IPR issues are likely to relate to the use of RICT by users outside these three Agencies (e.g. University researchers, Rivers Trusts, Fishing Clubs etc). To this end, any discussions on the licensing of the above datasets need firstly to consider two points.

1. Exactly which variables are required for a new version of RICT. Given this issue, it makes sense to delay final resolution of IPR issues until the final decisions are made on which model(s) will be added to RICT (and hence the variables used). This will avoid unnecessary effort resolving IPR issues for variables that are not subsequently used.

2. How the data would be used in any future version of the tool. To this end, in terms of cost and complexity of licensing, there is a distinction between a) licensing an entire dataset to be used as someone sees fit, and b) the licensing needed for a point and click system for calculating characteristics for individual sites (where the dataset cannot be reverse engineered). This relates to the value of the underlying datasets: as a whole they are valuable because of the wide range of uses to which they could be put, but focused in on a very specific system (e.g. one to calculate exactly what is required for RICT) their value is much reduced. Hence, if the end-product was a web-based system for calculating the suite of environmental variables required for the new models, this product could be owned by and use datasets licensed to SNIFFER. Users would, when accessing the software, click to accept any license restrictions that cascaded down to them. Such a system could be used to derive any of the time-invariant RIVPACS environmental predictor variables, not simply the additional variables produced and tested in this project.

In conclusion the following recommendations on Intellectual Property Rights are made:

1) Decisions are reached on which of the newly derived model(s) are implemented in RICT so that IPR issues for the relevant datasets can be quickly resolved and the datasets can be licensed.

2) licensing is sought for a point and click system (whereby a user cannot reverse engineer the entire national dataset) that is capable of calculating any of the time-invariant RIVPACS environmental predictor variables used by any of the newly derived (and existing) RIVPACS models, and for any potential users.

4. MODEL SELECTION AND TESTING

The RIVPACS bioassessment system is based on comparing the ratio (O/E) of the observed (O) values of biotic indices to the site- and season-specific expected (E) values of the indices. The expected values are based on a statistical predictive model of the relationship between the macroinvertebrate sample composition of a set of reference sites and their environmental characteristics. Separate models are needed for GB and Northern Ireland (NI).

RIVPACS model development involves three main stages:

(i) Biological classification of the reference sites using TWINSPAN into end-groups based on their (three-season combined) sample macroinvertebrate composition
(ii) Multivariate discrimination of the end-groups based on a suite of environmental predictor variables
(iii) Deriving site-specific expected (E) values of biotic indices from end-group means of observed values of indices for the reference sites, weighting end-groups by discriminant-based probabilities of the site belonging to each end-group
(iv) Assessing model effectiveness by comparing the strength of the relationship between O and E values amongst the reference sites.

An initial discrimination analysis based on optimal step-wise forward selection of environmental variables from the suite of old and new variables listed in Table 5 was used to assess the step-wise order of inclusion of variables in terms of maximising improvement in end-group discrimination (based on the standard Wilk's Lambda multivariate analysis of variance statistic, SPSS version 16, statistics package). This was done for each of four initial suites of variables (i) by considering all variables in Table 5, (ii) all except the flow-related variables (width, depth and mean substratum), (iii) all except the alkalinity variables (Alk and LogAlk), (iv) all except the flow and alkalinity variables. Table 6 gives the order of stepwise selection of the first 20 variables for each case.

New GIS variable Log upstream catchment area (LOGAREA) was selected second in all four scenarios and the current RIVPACS variable Log distance from source (LOGDFS) was then selected much later. LOGAREA is probably only a marginally better predictor, but because the two variables are very highly correlated (*r* = 0.94, Figure 2(a)), and their influence on end-group discrimination is mostly shared, LOGDFS is now only selected much later.

In all of the four step-wise scenarios (Table 6), the new GIS variable representing ($\log_{10}$) mean altitude in the upstream catchment (LOGALTBAR) appears to be an improved discriminatory variable over the existing simpler variable ($\log_{10}$) altitude at site (LOGALT); their correlation is moderate at 0.58 (Figure 2).

Both LOGAREA and LOGALTBAR initially looked promising and were therefore considered in more detail in later trial predictive models.

The new upstream catchment geology variables, and in particular the percentage covers of drift peat, solid clay, chalk, limestone and hard rocks, were selected at later stages of the step-wise forward selection of predictor variables, which suggests geological cover variables may be useful.

Base Flow Index (BFI) appeared to give some improvement to end-group discrimination, and was selected sixth in the two scenarios which excluded the use of alkalinity variables (Table 6). Although there are know IPR issues with using this variable, its potential to improve RIVPACS model predictions of expected biotic index values and O/E was investigated further.

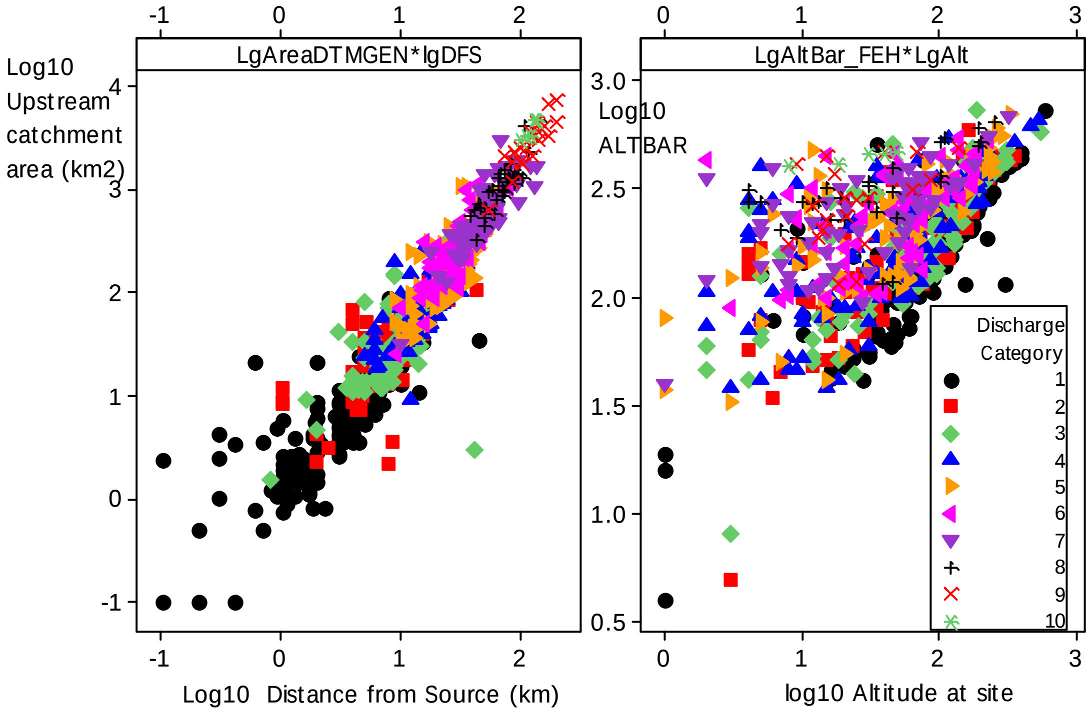


Figure 2. Relationship between (a) $\log_{10}$ upstream catchment area (from DTMGEN) and $\log_{10}$ distance from source, and (b) $\log_{10}$ mean upstream catchment altitude and $\log_{10}$ altitude at site, for the GB reference sites, grouped by variable 'historical average Discharge category'

These initial analyses were only on the variables' ability to discriminate the biological end-groups of reference sites. In the more detailed analyses the potential of the newly measured variables to improve the predictions of expected biotic index values and index O/E values is assessed.

Table 6. Order of step-wise discrimination forward selection of environmental variables based on their improvement in the overall multivariate discriminatory power (based on Wilk's Lambda between-group discrimination statistic) in cases allowing selection of (i) all variables, (ii) no flow-related variables (width, depth and mean substratum), (iii) no alkalinity (ALK and LOGALK) variables, (iv) no flow or alkalinity variables

		Order of selection of Environmental variables			
	Variable name	(i) All	(ii) -Flow vars	(iii) -Alk vars	(iv) -Flow and Alk vars
Existing RIVPACS IV variables	LAT	3	3	1	1
	LONG	10	7	7	5
	ATEMPMEAN		18	17	15
	ATEMPRANGE	7	6	4	4
	DISCHARGE	11	9	8	8
	ALK	1	1	X	X
	MSUBST	6	X	10	X
	LOGALT	14	12	15	14
	LOGDFS	19	16	16	11
	LOGWIDTH		X		X
	LOGDEPTH	8	X	5	X
	LOGALK	5	5	X	X
	LOGSLOPE	15	14	12	13
Variables newly derived in this project	STRAHLER				
	%DRIFT0-NONE				
	%DRIFT1-PEAT	13	13	20	18
	%DRIFT2-ALLUVIUM				
	%DRIFT3-CLAY			11	12
	%DRIFT5-SANDSTONE				
	%SOLID0-NONE				
	%SOLID3-CLAY	16	10	13	9
	%SOLID4-SHALE				19
	%SOLID5-SANDSTONE	20			
	%SOLID6-CHALK		17	14	10
	%SOLID7-LIMESTONE	18	19	19	17
	%SOLID8-HARDROCKS	12	11	9	7
	BFI	9	8	6	6
	PROPWET	17	15	18	16
	LOGAREA	2	2	2	2
	LOGALTSOURCE				
	LOGSLOPESOURCE				
	LOGALTBAR	4	4	3	3
	ASPECT-SOUTH				
	LOGDPLBAR				
	LOGDPSBAR		20		20
	LOGLDP				

4.1 BIOTIC INDICES USED FOR MODEL ASSESSMENT

As part of the recent SNIFFER project WFD100 (Davy-Bowker *et al.*, 2010), a new dataset was derived with observed or estimated species and family level abundance values for all of the individual seasons (Spring, Summer, Autumn) and all two- and three-season combined RIVPACS samples for each of the RIVPACS IV 725 GB reference sites and 110 NI reference sites. Davy-Bowker *et al*. (2010) then calculated the values for a wide range of macroinvertebrate indices based on data transformed to one of five taxonomic levels. It was agreed with the WFD119 project board that the indices listed in Table 7 would be tested.

Table 7. List of biotic indices to be used for model assessment, together with taxonomic level, and intended stress indicator.

Biotic Index	Taxonomic Level (TL)	Intended Stress indicator
TL1 NTAXA	1. BMWP Families	General
TL1 ASPT	1. BMWP Families	Organic
TL2 WHPT NTAXA (AbW,DistFam)	2. Revised BMWP (WHPT) families	General
TL2 WHPT ASPT (AbW,DistFam)	2. Revised BMWP (WHPT) families	Organic
TL4 WFD AWIC (Sp) McFarland	4. RIVPACS species	Acidity
TL2 LIFE (Fam) (DistFam)	2. Revised BMWP (WHPT) families	Flow*
TL4 LIFE (Sp)	4. RIVPACS species	Flow*
TL3 PSI (Fam)	3. All families	Siltation
TL4 PSI (Sp)	4. RIVPACS species	Siltation
TL2 SPEAR (Fam) %	2. Revised BMWP (WHPT) families	Pesticides
TL4 SPEAR (Sp) %	4. RIVPACS species	Pesticides
TL4 CCI	4. RIVPACS species	Rare species richness

*LIFE also responds strongly to hydromorphological degradation

4.2 METHODS TO COMPARE EFFECTIVENESS OF PREDICTIVE MODELS

4.2.1 Model effectiveness measures

The most common method of measuring statistical discrimination success as a whole is to calculate the percentage of sites discriminated to their correct group, here their TWINSPAN end-group. This can be calculated using either (i) the re-substitution method (ReSub) whereby all sites are used to fit the model and test it or (ii) the cross-validation or leave-one-out method (XVal) for which the fit to each site in turn is based on the model fitted to all other sites. The percentage correct ReSUB and XVal statistics have been used to select environmental predictor variables in all previous developments of RIVPACS (Moss *et al*., 1999, Clarke *et al*., 2003) Their advantage is that they generate overall measures of fit which are independent of any biological index. However, the RIVPACS predictive models do not allocate sites to the most probable group but calculate expected index values using the probabilities of a site belonging to each end-group. The ultimate aim is to assess site ecological status using O/E ratios. Therefore the SD(O/E) and R^2_{OE} statistics are the better measures of model effectiveness.

The strength of the relationship between the observed (O) and expected (E) values for a biotic index for the reference sites can be measured by the correlation (R_{OE}) between O and E values; obviously the higher the correlation the better.

It is more usual to quote 100 times the square of the correlation, denoted R^2_{OE}, which measures the percentage of the total variation in the observed (O) values of an index amongst the reference sites that is explained by the model predicted E values.

Figure 3 shows the relationship between observed (O) and expected (E) values for each of the 12 biotic indices being assessed; the illustration is based on the O/E values for the current RIVPACS IV predictive model and using the spring-autumn combined sample values for the 685 GB reference sites used in that model.

The aim of the modelling is for the O/E values amongst the reference sites for any particular index to vary as little as possible about the overall average value of approximately one. There should then be more opportunity and statistical power to detect departures from reference condition with low O/E values resulting from the impact of anthropogenic and other stresses.

Figure 4 shows the wide range of differences between the biotic indices in their inherent variation and frequency distribution in O/E values. The illustration is based on the O/E values for the current RIVPACS IV predictive model and using the spring-autumn combined sample values for the 685 GB references sites.

Figures 5-8 show the distribution of O/E values based on the current RIVPACS IV predictive model for the GB references sites classified by end-group (1-43) for each of the 12 indices, based on the spring-autumn combined sample O/E values. This shows the variation in O/E for the reference sites in each RIVPACS end-group; ideally the O/E should be centred roughly around one for each group.

In the world-wide RIVPACS reference condition modelling literature (reviewed in Hawkins *et al.*, 2010), this variability in O/E values amongst reference sites is usually summarised by their standard deviation (SD), denoted SD(O/E); obviously the smaller the SD the better for any particular index.

The statistic R^2_{OE} (measuring the strength of relationship between O and E) and the SD(O/E) are generally very highly (negatively) correlated, as R_{OE} increases so SD(O/E) tends to decrease, which means that both measures of model effectiveness will usually (but not always) lead to the same conclusions about which are the best models. Based on the set of trial models, the rank correlations between statistic R^2_{OE} and SD(O/E) were generally over 0.9 and over 0.95 for the ASPT, WHPT ASPT and LIFE indices. However, these rank correlations were often much lower for the PSI and CCI indices, for reasons discussed below. Overall, this suggests that comparisons of trial models and selecting the best model(s) based on SD(O/E) will usually but not always give the same results as comparisons based on R^2_{OE}.

The statistic SD(O/E) has been used in this study to measure and compare the effectiveness of the various trial discrimination models and recommend the best to carry forward. However, the various trial models are also summarised and compared by their R_{OE} values as a check.

4.2.2 Comparison with Null Model SD(O/E)

If there was no predictive model for the expected values, or none of the trial models had any real discriminatory power, there would be no reliable information to set different “target” expected E values for an index for the different types of site. In such cases it would only be possible to use the average of the observed values of an index across all reference sites as the single ‘target’ expected E value for all sites. This is termed a ‘Null Model’ because there are no predictor variables involved. It is akin to a regression model with no explanatory X variables and just an intercept term (which is then estimated as the overall average of the dependent Y variable).

The SD(O/E) for the Null Model, termed SD_0(O/E), is simply the SD of the O values for all of the reference sites divided by their mean value (which is equivalent to the coefficient of variation (CV =SD/Mean) of the observed index values for the reference sites (Van Sickle *et al*., 2005). The effectiveness of any predictive model for any one index can be compared both to other models and to the Null Model by comparing their SD(O/E) for the same index. The lower the value, the better the model is at predicting observed values for the reference sites, and thus the site-specific 'target' expected (E) for other sites.

Table 8 gives the Null Model SD(O/E), denoted SD_0(O/E), amongst the 685 GB reference sites for each biotic index based all single and combined season samples.

Table 8. Null Model SD_0(O/E) for each biotic index for the 685 RIVPACS IV GB reference sites for each RIVPACS season (Spr, Sum Aut) and combined-season samples and average across the single seasons

Biotic Index	Spr	Sum	Aut	Average Single Season	Spr+Sum	Spr+Aut	Sum+Aut	All 3 seasons
TL1 NTAXA	0.266	0.274	0.264	0.268	0.227	0.226	0.223	0.209
TL1 ASPT	0.119	0.116	0.126	0.120	0.104	0.105	0.104	0.097
TL2 WHPT NTAXA	0.281	0.284	0.277	0.281	0.241	0.244	0.238	0.226
TL2 WHPT ASPT)	0.158	0.149	0.171	0.159	0.148	0.154	0.152	0.147
TL4 WFD AWIC (Sp)	0.129	0.102	0.136	0.122	0.110	0.122	0.118	0.114
TL2 LIFE (Fam)	0.081	0.089	0.085	0.085	0.083	0.081	0.084	0.082
TL4 LIFE (Sp)	0.096	0.099	0.102	0.099	0.099	0.100	0.102	0.102
TL3 PSI (Fam)	0.286	0.306	0.317	0.303	0.275	0.279	0.283	0.267
TL4 PSI (Sp)	0.331	0.344	0.363	0.346	0.330	0.340	0.341	0.333
TL2 SPEAR (Fam) %	0.316	0.320	0.388	0.341	0.278	0.303	0.300	0.274
TL4 SPEAR (Sp) %	0.334	0.313	0.397	0.348	0.285	0.318	0.310	0.288
TL4 CCI	0.459	0.476	0.449	0.461	0.396	0.387	0.403	0.369

It is important to understand that some biotic indices are inherently more variable in orders of magnitude than others. This is represented by their CV amongst reference sites which, as mentioned above, is equal to the SD(O/E) for a Null Model. Therefore although the observed (O) values of each biotic index are 'standardised' by dividing by the site-specific expected E values to give O/E with an average value across all reference sites of around one, in practice, the O/E values are inherently more variable for some indices than others. For example, the Null Model SD_0(O/E) for BMWP number of families (TL1 NTAXA) is more than double that for BMWP ASPT (TL1 ASPT) for every possible choice of season(s) involved. The average SD_0(O/E) for single season samples is 0.268 for BMWP NTAXA but only 0.120 for BMWP ASPT (Table 8). However, as mentioned above, for a given index, any reduction in SD(O/E) obtained by using a different discrimination model indicates an improvement in overall predictive ability for that index.

Incidentally, the relatively untested family and species level PSI and the CCI indices can give low values for some types of reference sites, which makes some expected values relatively low and some O/E values very high (some over 3 for PSI species and CCI) which have undue influence on the SD(O/E) measure. Notice the bi-modal distribution of O/E values for the CCI index (Figure 4), which also suggests some unusual and undesirable feature of the variation in O and E values for different types of reference site; maybe the use of O/E ratios to compare O and E CCI values is not ideal for all types of site. Further investigation of the statistical relationship of O and E values and the potential use and frequency distribution of O/E for these new indices merits further careful investigation before they are used operationally, but this is beyond the scope of this project.

Notice how the variation in O/E amongst the reference sites differs enormously between indices, even for best-fitting models (Figure 4). This is mainly because of index differences in (i) their inherent orders of magnitude of variability (i.e. coefficient of variation (CV)) in their observed values (as discussed above), but also differences in their predictability from the RIVPACS predictive model, and often a combination of both.

In comparing the effectiveness of different trial models, the main emphasis should be on comparing the SD(O/E) values and R^2_{OE} values separately within indices. In particular, it is useful to compare the SD(O/E) with the Null Model SD_0(O/E) and also the R^2_{OE} with a Null Model R^2 value of zero.

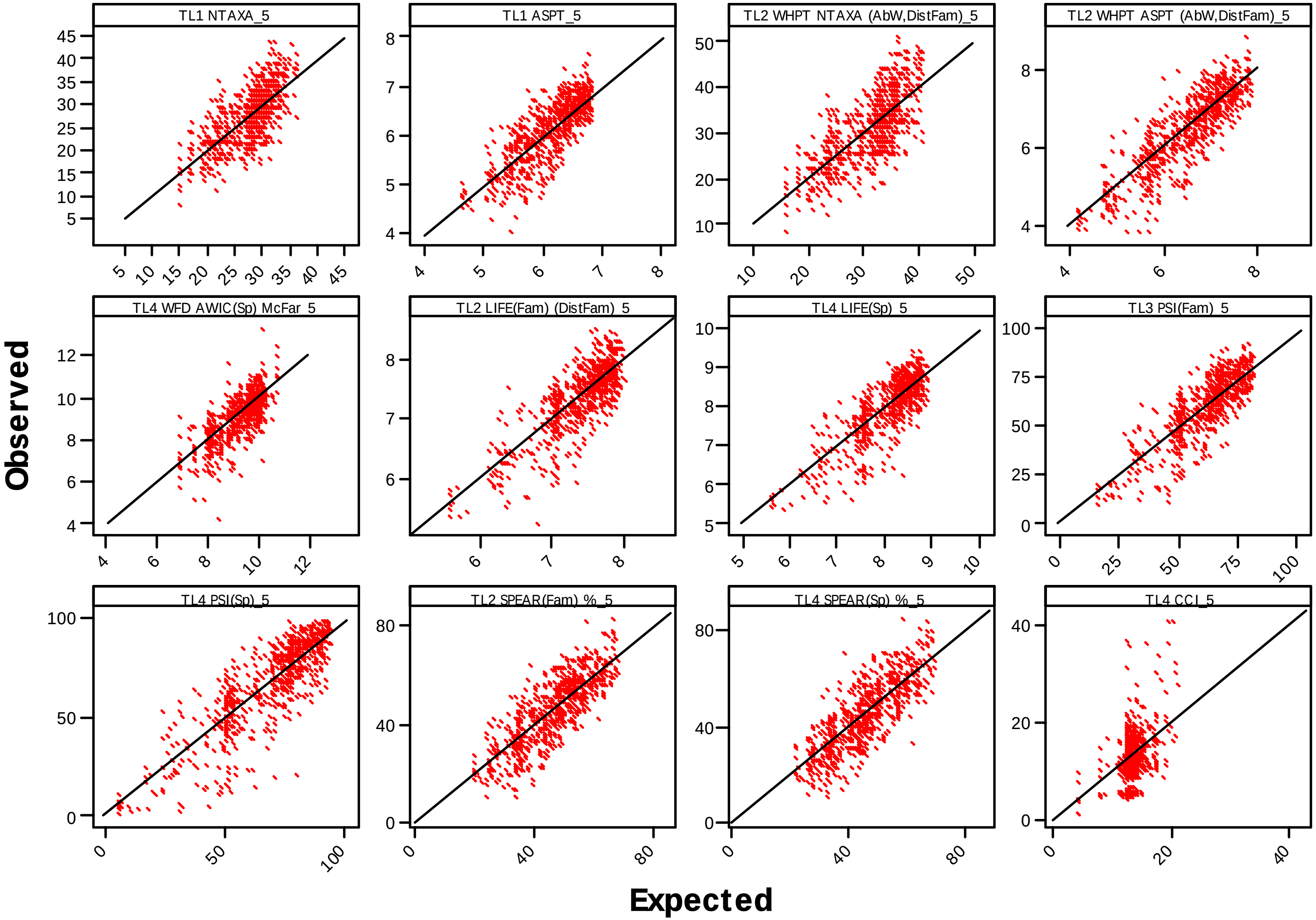


Figure 3. Plot of observed (O) against expected (E) values with 1:1 line for each of the 12 biotic indices under assessment (based on the current RIVPACS IV predictive model and using spring-autumn combined sample values).

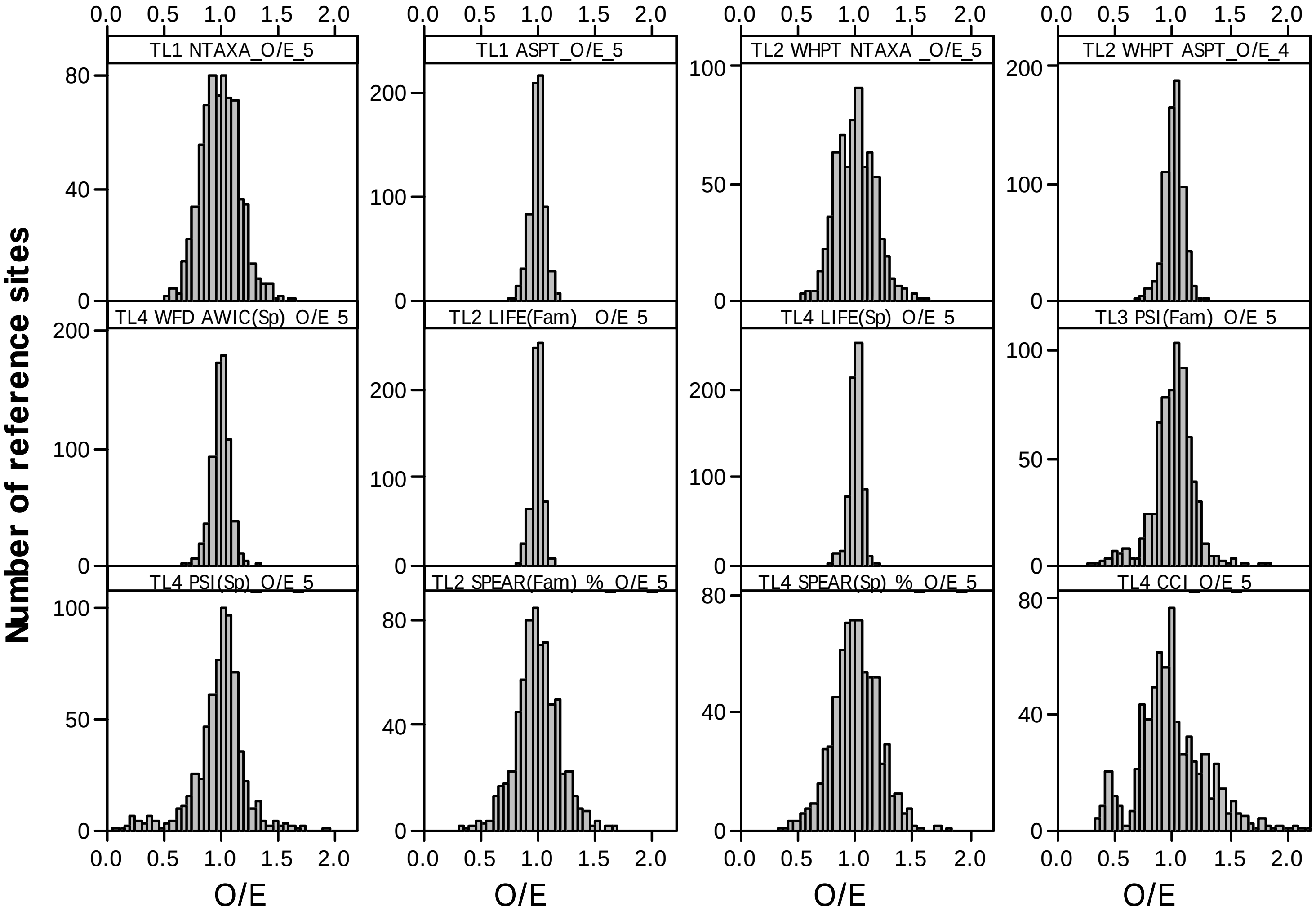


Figure 4. Frequency histograms of the distribution of O/E values for each of the 12 biotic indices under assessment (based on the current RIVPACS IV predictive model and using spring-autumn combined sample values); O/E values truncated at 2.2 for the PSI and CCI indices.

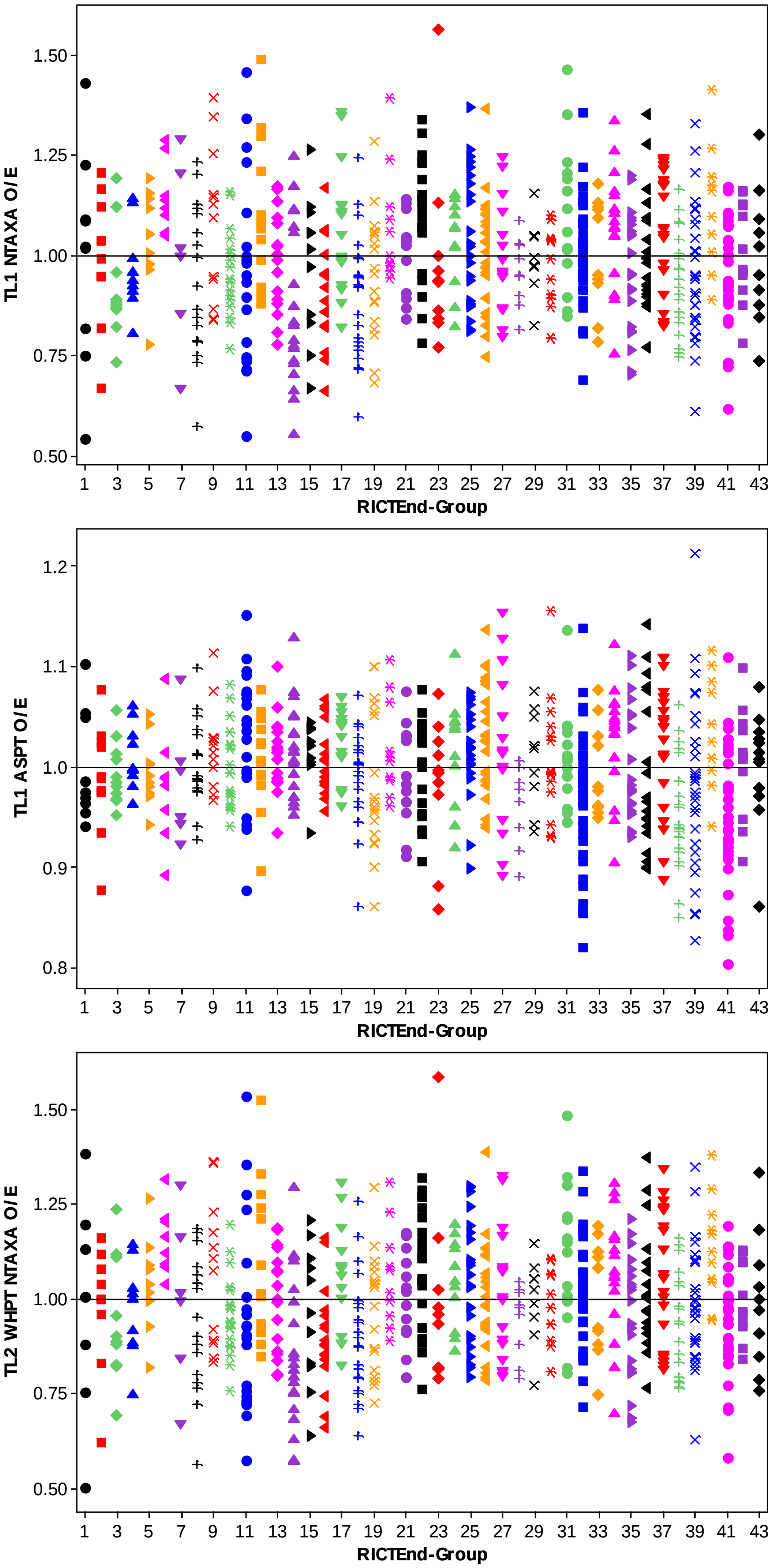


Figure 5. Plot of individual reference site O/E values by end-group (spring-autumn combined season samples) for (a) TL1 NTAXA (b) TL1 ASPT, (c) TL2 WHPT NTAXA using predictions based on the current RIVPACS IV model (model 1 in this report).

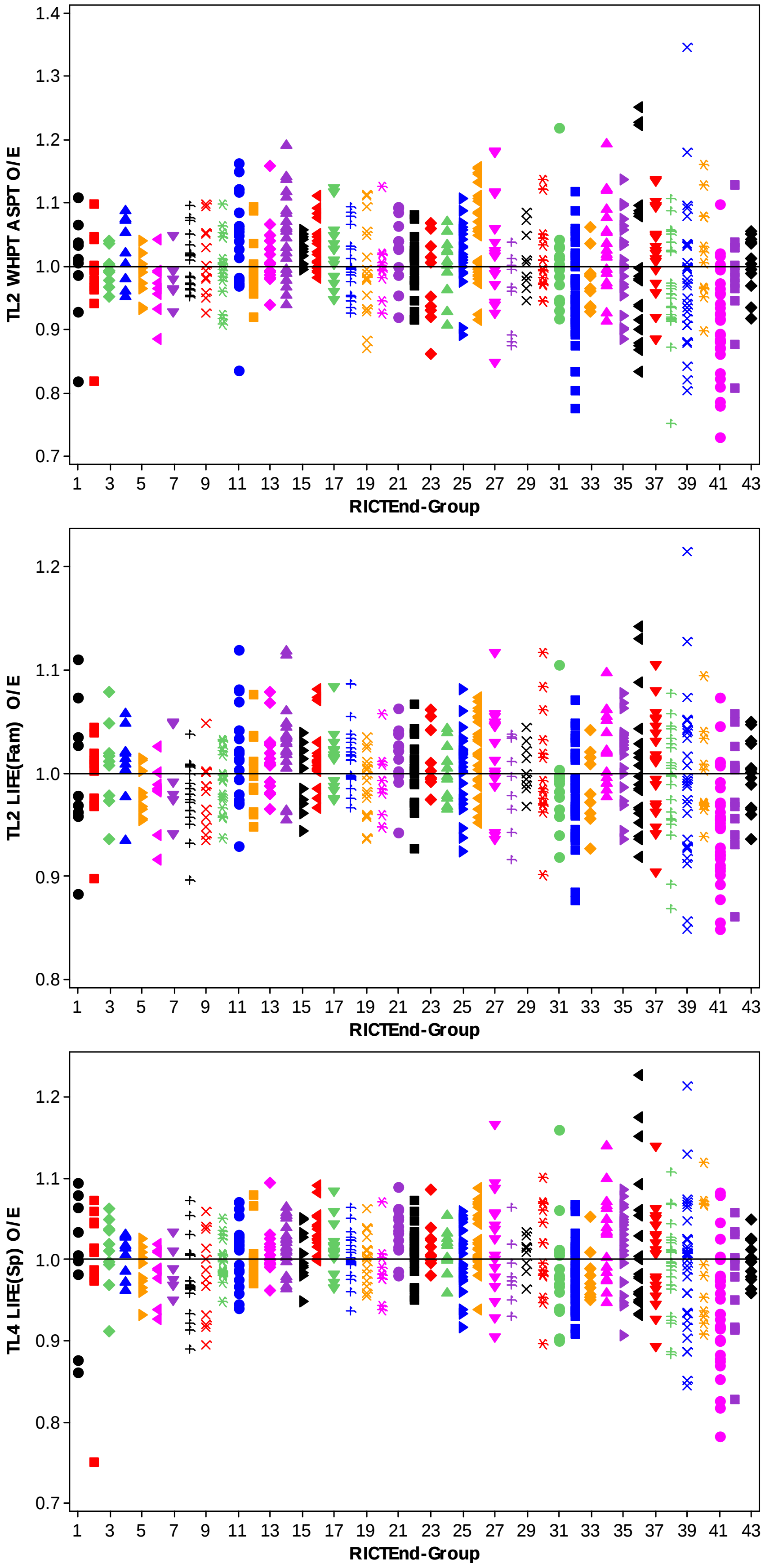


Figure 6. Plot of individual reference site O/E values by end-group (spring-autumn combined season samples) for (a) TL2 WHPT ASPT (b) TL2 LIFE (Fam), (c) TL4 LIFE (Sp) using predictions based on the current RIVPACS IV model (model 1 in this report).

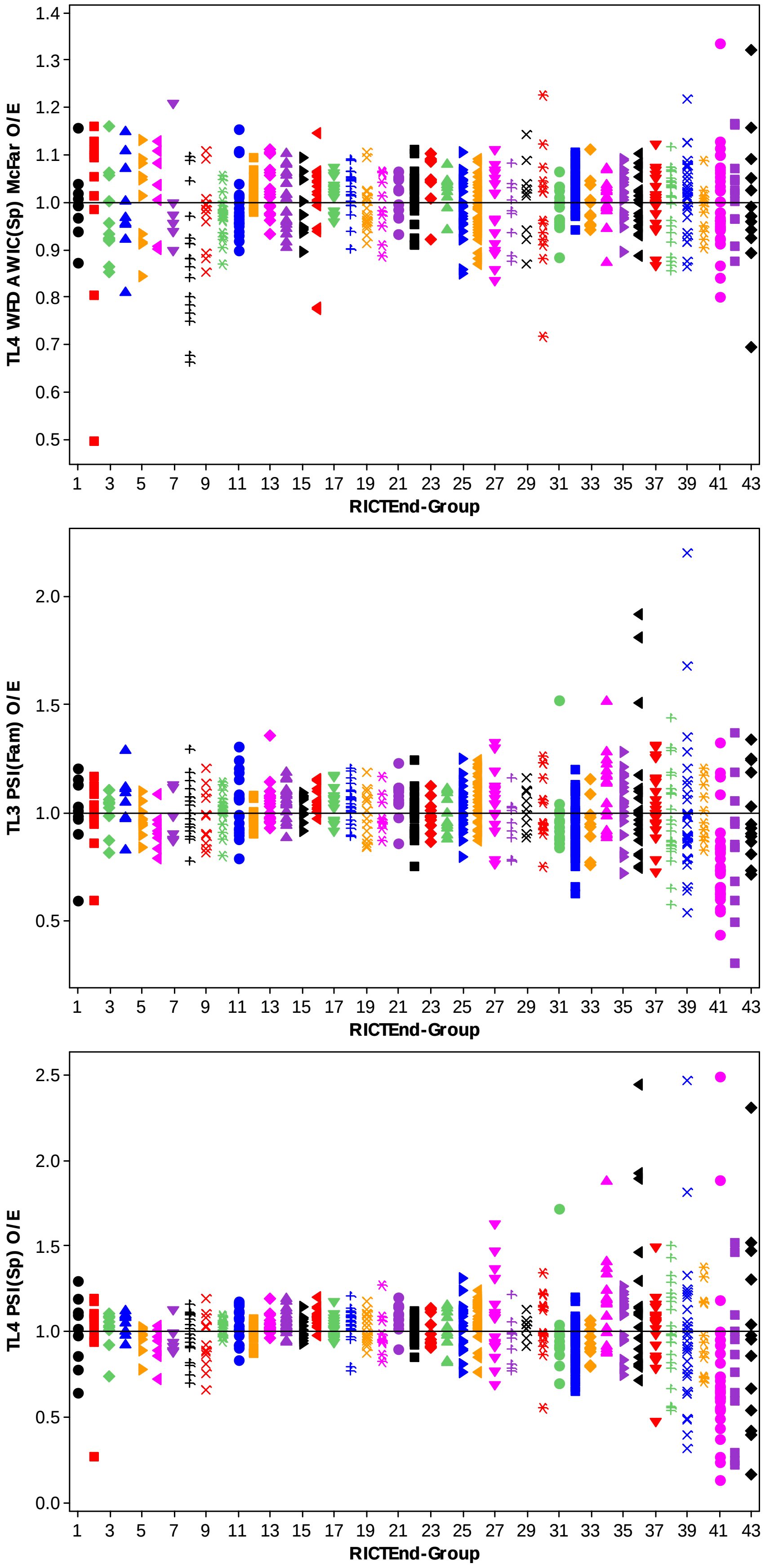


Figure 7. Plot of individual reference site O/E values by end-group (spring-autumn combined season samples) for (a) TL4 WFD AWIC (b) TL3 PSI (Fam), (c) TL4 PSI (Sp) using predictions based on the current RIVPACS IV model (model 1 in this report).

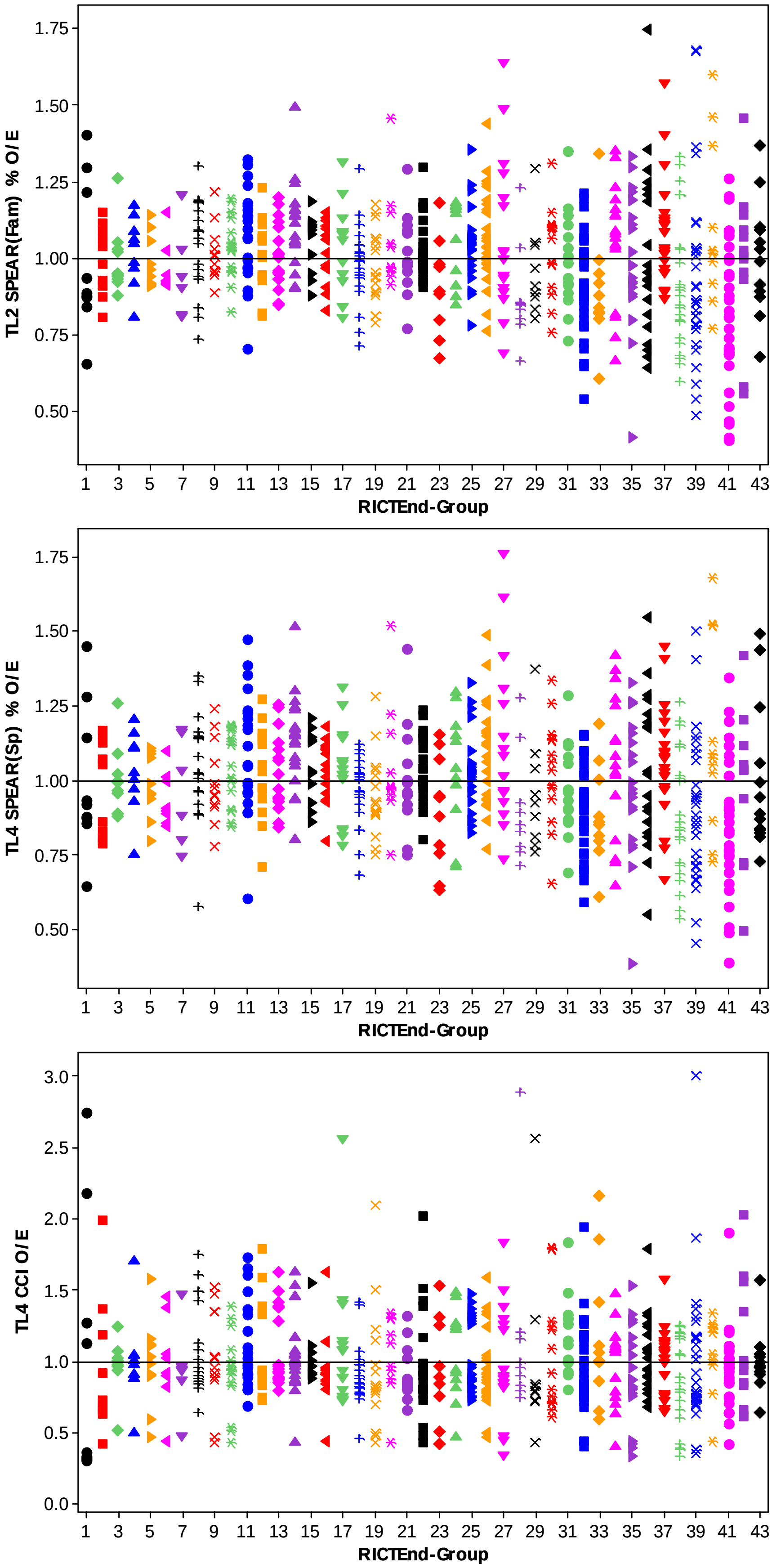


Figure 8. Plot of individual reference site O/E values by end-group (spring-autumn combined season samples) for (a) TL2 SPEAR (Fam) (b) TL4 SPEAR (Sp), (c) TL4 CCI using predictions based on the current RIVPACS IV model (model 1 in this report).

4.3 Effectiveness of Predictive Models

From our initial explorations and results from the stepwise forward selection discrimination models, a wide range of trial Models (1-36) was assessed:

Model 1 = Current RIVPACS IV model based on:
Latitude (LAT) and Longitude (LONG),
mean (ATEMPMEAN and range (ATEMPRANG) of air temperature,
(historical) discharge category (DISCHARGE)
Mean substratum composition (in phi units) (MSUBST)
Alkalinity (ALK) and Log_{10} Alkalinity (LOGALK)
and the logarithmic form of
distance from source (LOGDFS),
altitude (LOGALT) and slope (LOGSLOPE) at site
stream width (LOGWIDTH) and depth (LOGDEPTH)

Model 2 = Model 1 without flow-related variables (MSUBST, LOGWIDTH & LOGDEPTH)

Model 3 = Model 1 without alkalinity variables (ALK & LOGALK)

Model 4 = Model 1 without flow-related or alkalinity variables

Models 5-10 try to improve on Model 4 involving the BFI HOST and other new variables, by successively adding BFI (Model 5), key geology variables (Model 6), LOGAREA (Model 7), LOGALTBAR (Model 8), PROPWET (Model 9) and finally removing the geology variables (Model 10).

Models 11-14 try to improve on Model 4 by successively adding LOGAREA and LOGALTBAR (Model 11), PROPWET (Model 12), key geology variables (Model 13) and then finally remove the old RIVPACS variables of LOGDFS and LOGALT whose ‘influence’ may have been replaced by the new upstream catchment LOGAREA and LOGALTBAR variables.

Models 15-25 assess trial models which do not involve any of the flow-related variables (MSUBST, LOGWIDTH & LOGDEPTH).
Model 15 = Model 2
Models 16-25 are equivalent to Models 5-14, but without the flow-related variables only

Models 26-36 assess trial models which do not involve any of the alkalinity variables
Model 26 = Model 3
Models 27-36 are equivalent to Models 5-14, but without the alkalinity variables only

For every model, for each index the SD(O/E) and R^2_{OE} values were calculated. This was done separately for the sample data from each separate single season, and each combination of two and three seasons combined samples and these are all provided in Appendix 1. However it was not obvious which season combinations were best to use for comparisons of trial model relative effectiveness. As a compromise, the SD(O/E)s for each single season have been averaged to provide the average single season sample SD(O/E) amongst the reference sites. Similarly for R^2_{OE} values for the reference sites based on each of the three single seasons data have been averaged to provide the average single season sample R^2_{OE} amongst the reference sites

For every model, the percentage of sites discriminated to their correct TWINSPAN end-group by both the re-substitution method (ReSub) and the cross-validation method (XVal) was also calculated.

The effectiveness of the predictive models for each index, as represented by their SD(O/E) and R^2_{OE} (and % correctly discriminated) are summarised in Table 9 (Models 1-4), Table 10 (Models 5-14), Table 11 (Models 15-25) and Table 12 (Models 26-36).

4.3.1 Impact of leaving out flow-related and/or alkalinity variables

The size of the effect of not involving either the flow-related variables or the alkalinity variables on discriminant model success is on average similar in terms of the reduction in %correct allocated to correct group). The effect of leaving out the flow variables on increasing SD(O/E) and reducing R^2_{OE} is marginally greater for the two LIFE indices, as might be expected, whereas the effect of not involving alkalinity is slightly greater for most other indices.

Table 9. Average single season R^2_{OE} and SD(O/E) of Models 1-4; together with %reduction from Null Model SD_0(O/E) and % correctly discriminated to biological end-group (ReSub and XVal); bold highlights which of Models 2-3 has greatest loss of predictive power.

	Model					Model			
	Null	1	2	3	4	1	2	3	4
Variables excluded	All	None	-Flow	-Alk	-Both	None	-Flow	-Alk	-Both
MSUBST	1		1		1				
LOGWIDTH	1		1		1				
LOGDEPTH	1		1		1				
ALK	1			1	1				
LOGALK	1			1	1				
%Correct (Resub)		51.7	**47.3**	47.4	40.1				
%Correct (XVal)		38.7	36.4	**35.5**	33.4				
			SD(O/E)			% reduction from SD_0(O/E)			
TL1 NTAXA	0.268	0.200	0.203	**0.204**	0.207	25	24	**24**	23
TL1 ASPT	0.120	0.076	0.079	**0.082**	0.086	37	34	**32**	28
TL2 WHPT NTAXA	0.281	0.206	0.208	**0.210**	0.212	27	26	**25**	25
TL2 WHPT ASPT	0.159	0.088	0.092	**0.093**	0.099	45	42	42	38
TL4 WFD AWIC (Sp)	0.122	0.091	0.090	**0.095**	0.095	25	26	**22**	22
TL2 LIFE (Fam)	0.085	0.053	**0.055**	0.054	0.057	38	**35**	36	33
TL4 LIFE (Sp)	0.099	0.057	**0.061**	0.059	0.063	42	**38**	40	36
TL3 PSI (Fam)	0.303	0.213	0.209	**0.218**	0.223	30	31	**28**	26
TL4 PSI (Sp)	0.346	0.271	0.256	**0.281**	0.279	22	26	**19**	19
TL2 SPEAR (Fam) %	0.341	0.228	0.233	**0.241**	0.252	33	32	**29**	26
TL4 SPEAR (Sp) %	0.348	0.241	0.246	**0.252**	0.260	31	29	**28**	25
TL4 CCI	0.461	0.428	**0.429**	0.426	0.427	7	**7**	8	7
			R^2_{OE}						
TL1 NTAXA	0.0	44.3	43.1	43.4	41.9				
TL1 ASPT	0.0	61.8	58.8	**56.2**	52.2				
TL2 WHPT NTAXA	0.0	45.7	**44.7**	45.0	43.9				
TL2 WHPT ASPT	0.0	71.8	68.7	**68.2**	64.0				
TL4 WFD AWIC (Sp)	0.0	43.9	44.6	**39.4**	39.4				
TL2 LIFE (Fam)	0.0	63.1	**58.9**	61.8	56.1				
TL4 LIFE (Sp)	0.0	68.8	**65.0**	67.5	62.4				
TL3 PSI (Fam)	0.0	70.1	**66.3**	68.2	63.4				
TL4 PSI (Sp)	0.0	74.8	**70.7**	72.7	67.4				
TL2 SPEAR (Fam) %	0.0	64.5	61.9	**60.8**	57.7				
TL4 SPEAR (Sp) %	0.0	58.2	55.9	**54.9**	52.6				
TL4 CCI	0.0	17.6	17.2	**16.9**	16.7				

The percentage reduction in the SD(O/E) of a Null Model (i.e. SD_0(O/E)) obtained using the current RIVPACS IV model varies considerably between indices from 37-45% for the BMWP APST, WHPT ASPT and two LIFE indices, to 31-33% for the SPEAR indices, 25-27% for the NTAXA indices down to only 7% for the new CCI index. The SD(O/E) of all indices increased when either flow-related or alkalinity variables were not used in the predictions (Models 2 or 3) and increased further when both flow-related and alkalinity variables were excluded from the predictions (Table 9). However, even with both of these potentially stress-related types of variable excluded, the predictive model (4) was still a major improvement over no (i.e. Null) model (except for CCI), with reductions in SD(O/E) of between 19% (PSI (Sp)) and 38% (WHPT ASPT). The reduction in the percentage (R^2_{OE}) of variation in O index values explained by the predictive model E values because of using restricted Model 4 compared to full RIVPACS IV Model 1 was never more than 10% (max 9.2% for BMWP ASPT).

Together this indicates, that even without the flow-related and alkalinity predictor variables, the restricted model is still a considerable improvement over no model. However, in the next sub-sections attempts to develop better stressor-independent predictor models using the best of the new GIS variables are described.

4.3.2 Best new models not involving the flow-related or alkalinity variables

An assessment was made of which new variables might help improve the effectiveness of models which did not involve any of the flow-related or alkalinity variables in the current RIVPACS IV model (Table 10). Some minor improvements were made.

If the BFI is available, then the best model (Model 10 in Table 10) involves BFI, the upstream catchment area (LOGAREA) and average altitude (LOGALTBAR) and the FEH estimated proportion of time the upstream catchment soils are wet (PROPWET). A similar model (Model 9) which additionally involves the percentage upstream catchment cover of key geological types (% drift cover as peat, % solid geology as each of clay, chalk, limestone and hard rocks) was about as good or even slightly better for some indices.

However, if the BFI values for each site are not available, an equally good model (Model 13) is available. Model 13 is equivalent to Model 9 without BFI, so involves LOGAREA, LOGALTBAR, PROPWET and the same geology variables (Table 10). In this case including the geological variables adds some small improvement (compared to Model 12 without geology variables).

On leaving out the old variables of distance from source and altitude at site (Model 14), on the assumption they are not needed when upstream area and average altitude are included, performance is worse overall and for all indices. Therefore it is best to retain those variables in the predictive model.

4.3.3 Best new models not involving the flow-related variables

Next it was important to assess which new variables might help improve the effectiveness of models which did not involve any of the RIVPACS flow-related variables (MSUBST, WIDTH and DEPTH), but still include the alkalinity variables. Only very minor improvements were possible (Table 11).

If BFI is available, then the best model is Model 21 involving additional new variables BFI, LOGAREA, LOGALTBAR and PROPWET; however, the improvement over Model 15 is minor.

The equivalent to Model 21 without BFI, namely Model 24, is very similar, but overall offers negligible improvement over the base Model 15 which is the RIVPACS IV model without the flow related variables (Table 11).

No new model appears to be able to increase the predictive model SD(O/E) and R^2_{OE} values back to the levels in the RIVPACS IV model (namely Model 1). But of course, the current RIVPACS IV model may be giving inappropriate predictions for some non-reference sites whose current water width and depth and substratum composition have already been altered beyond normally expected amounts by the flow-related stresses whose biological impacts are those that need to be assessed.

In statistical terms, this means that the new best model (Model 24) may give less precise predictions of the reference site values (which do actually partly depend on width, depth and substratum composition), but may give unbiased and hence more appropriate estimates of the expected (E) values of indices for non-reference sites.

4.3.4 Best new models not involving the alkalinity variables

Finally it was important to assess which new variables might help improve the effectiveness of models which did not involve the alkalinity variables (ALK and LOGALK) but still include the RIVPACS flow-related variables (MSUBST, WIDTH and DEPTH). Such models are intended for assessing the condition of sites subject to acidity stress and/or modified (non-reference) alkalinity levels. The target expected (E) values for the AWIC index (or any other indices) should not be biased by using inappropriate, non-reference condition, values of alkalinity.

The best model (Model 35) does not require BFI values, but involves values for upstream catchment area (LOGAREA), average upstream altitude (LOGALTBAR) and FEH estimated proportion of time upstream catchment soils are wet (PROPWET).

Table 10. Average single season (a) % correct discrimination, (b) SD(O/E) and (c) R^2_{OE} for current RIVPACS IV model (1) and trial models 4-14 (without flow or alkalinity variables); all models include LAT,LONG, Air temperature mean and range, discharge category and log slope at site; best models improving on model 4 in bold.

Variable name	1	4	5	6	7	8	9	10	11	12	13	14
ALK	1	0	0	0	0	0	0	0	0	0	0	0
MSUBST	1	0	0	0	0	0	0	0	0	0	0	0
LOGALT	1	1	1	1	1	1	1	1	1	1	1	0
LOGDFS	1	1	1	1	1	1	1	1	1	1	1	0
LOGWIDTH	1	0	0	0	0	0	0	0	0	0	0	0
LOGDEPTH	1	0	0	0	0	0	0	0	0	0	0	0
LOGALK	1	0	0	0	0	0	0	0	0	0	0	0
%DRIFT1-PEAT	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID3-CLAY	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID6-CHALK	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID7-LIMESTONE	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID8-HARDROCK	0	0	0	1	1	1	1	0	0	0	1	1
BFI	0	0	1	1	1	1	1	1	0	0	0	0
PROPWET	0	0	0	0	0	0	1	1	0	1	1	1
LOGAREA	0	0	0	0	1	1	1	1	1	1	1	1
LOGALTBAR	0	0	0	0	0	1	1	1	1	1	1	1
(a) %Correct	51.7	40.1	41.5	44.5	45.0	46.4	**48.0**	46.7	41.9	45.4	**47.0**	45.7
%Correct (XVal)	38.7	33.4	34.3	34.0	33.7	35.0	36.2	**36.5**	33.0	35.9	**36.2**	32.8
(b) SD(O/E)												
TL1 NTAXA	0.200	0.207	0.205	0.207	0.205	0.204	0.204	**0.202**	**0.203**	**0.203**	**0.203**	0.204
TL1 ASPT	0.076	0.086	0.086	0.085	0.085	**0.084**	**0.084**	**0.084**	0.084	0.084	**0.082**	0.083
TL2 WHPT NTAXA	0.206	0.212	0.211	0.213	0.212	0.211	0.210	**0.208**	**0.209**	**0.209**	**0.209**	0.210
TL2 WHPT ASPT	0.088	0.099	0.100	0.099	0.099	**0.097**	**0.097**	**0.097**	0.097	0.097	**0.096**	0.097
TL4 WFD AWIC (Sp)	0.091	0.095	0.094	0.094	0.094	0.094	0.094	0.094	0.095	0.095	0.095	0.095
TL2 LIFE (Fam)	0.053	0.057	0.058	0.057	0.057	0.056	0.056	0.057	0.057	0.056	0.055	0.056
TL4 LIFE (Sp)	0.057	0.063	0.063	0.063	0.063	0.062	0.062	0.062	0.062	0.062	**0.061**	0.062
TL3 PSI (Fam)	0.213	0.223	0.223	**0.218**	**0.218**	**0.218**	**0.218**	**0.218**	0.221	0.218	0.214	0.216
TL4 PSI (Sp)	0.271	0.279	0.280	0.267	**0.263**	**0.263**	**0.264**	0.280	0.300	0.281	**0.258**	0.260
TL2 SPEAR (Fam) %	0.228	0.252	0.249	0.248	0.248	0.245	0.245	**0.242**	0.243	0.242	**0.240**	0.242
TL4 SPEAR (Sp) %	0.241	0.260	0.258	0.259	0.258	0.255	0.255	**0.252**	0.253	0.253	**0.252**	0.253
TL4 CCI	0.428	0.427	**0.425**	0.431	0.431	0.430	0.430	0.433	0.427	0.435	0.430	0.432
(c) R^2_{OE}												
TL1 NTAXA	44.3	41.9	42.9	42.5	43.2	44.0	44.2	**44.9**	43.7	44.1	**44.4**	44.1
TL1 ASPT	61.8	52.2	51.8	52.9	53.0	54.3	**54.3**	53.2	53.8	53.7	**55.4**	54.6
TL2 WHPT NTAXA	45.7	43.9	44.6	44.3	44.8	45.6	45.9	**46.4**	45.4	45.8	**46.2**	46.0
TL2 WHPT ASPT	71.8	64.0	63.4	63.6	63.7	65.1	**65.3**	65.0	65.6	65.6	**66.0**	65.2
TL4 WFD AWIC (Sp)	43.9	39.4	40.6	40.9	41.3	40.9	41.3	**41.5**	39.4	40.0	**40.1**	**40.1**
TL2 LIFE (Fam)	63.1	56.1	55.6	57.0	56.9	57.5	**57.9**	57.0	57.1	57.4	**58.7**	57.7
TL4 LIFE (Sp)	68.8	62.4	61.9	62.4	62.4	63.5	**63.8**	63.5	63.5	63.9	**64.2**	63.0
TL3 PSI (Fam)	70.1	63.4	62.9	63.4	63.2	63.9	64.2	**64.4**	64.5	64.8	**64.9**	64.0
TL4 PSI (Sp)	74.8	67.4	66.9	67.7	67.6	68.5	**68.8**	68.4	68.5	68.8	**69.3**	68.0
TL2 SPEAR (Fam) %	64.5	57.7	57.9	57.9	58.1	59.8	59.7	**60.2**	60.2	60.3	**60.5**	59.8
TL4 SPEAR (Sp) %	58.2	52.6	52.8	52.2	52.3	54.0	53.8	**54.9**	54.9	**55.0**	54.6	53.8
TL4 CCI	17.6	16.7	17.2	17.4	17.5	**17.7**	17.5	17.5	17.5	17.1	**17.9**	16.6

Table 11. Average single season (a) % correct discrimination, (b) SD(O/E) and (c) R^2_{OE} for current RIVPACS IV model (1) and trial models15-25 (without flow-related variables); all models include LAT,LONG, Air temperature mean and range, discharge category and log slope at site; best models improving on model 15 (which is the same as model 2) in bold.

Variable name	**1**	**15(2)**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
ALK	1	1	1	1	1	1	1	1	1	1	1	1
MSUBST	1	0	0	0	0	0	0	0	0	0	0	0
LOGALT	1	1	1	1	1	1	1	1	1	1	1	0
LOGDFS	1	1	1	1	1	1	1	1	1	1	1	0
LOGWIDTH	1	0	0	0	0	0	0	0	0	0	0	0
LOGDEPTH	1	0	0	0	0	0	0	0	0	0	0	0
LOGALK	1	1	1	1	1	1	1	1	1	1	1	1
%DRIFT1-PEAT	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID3-CLAY	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID6-CHALK	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID7-LIMESTONE	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID8-HARDROCK	0	0	0	1	1	1	1	0	0	0	1	1
BFI	0	0	1	1	1	1	1	1	0	0	0	0
PROPWET	0	0	0	0	0	0	1	1	0	1	1	1
LOGAREA	0	0	0	0	1	1	1	1	1	1	1	1
LOGALTBAR	0	0	0	0	0	1	1	1	1	1	1	1
(a) %Correct	51.7	47.3	48.9	48.9	50.8	50.8	**51.5**	**51.5**	48.8	50.1	**51.2**	48.3
%Correct (XVal)	38.7	36.4	38.1	37.8	37.1	37.5	38.5	**39.9**	36.9	38.2	**38.4**	36.9
(b) SD(O/E)												
TL1 NTAXA	0.200	0.203	0.201	0.200	0.200	0.198	**0.197**	**0.197**	0.199	0.198	**0.197**	0.198
TL1 ASPT	0.076	0.079	0.078	0.079	0.079	0.079	0.079	0.078	0.079	0.079	0.079	0.079
TL2 WHPT NTAXA	0.206	0.208	0.207	0.206	0.206	0.204	**0.203**	**0.203**	0.205	0.204	**0.202**	0.205
TL2 WHPT ASPT	0.088	0.092	0.091	0.092	0.092	0.092	0.092	0.091	0.092	0.092	0.092	0.092
TL4 WFD AWIC (Sp)	0.091	0.090	0.090	0.091	0.091	0.091	0.091	0.090	0.090	0.090	0.091	0.091
TL2 LIFE (Fam)	0.053	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
TL4 LIFE (Sp)	0.057	0.061	0.060	0.060	0.061	0.061	0.060	0.060	0.061	0.061	0.061	0.061
TL3 PSI (Fam)	0.213	0.209	0.209	0.210	0.216	0.216	0.215	0.223	0.221	0.221	0.212	0.209
TL4 PSI (Sp)	0.271	0.256	0.261	0.257	0.284	0.285	0.278	0.412	0.395	0.390	0.280	**0.252**
TL2 SPEAR (Fam) %	0.228	0.233	**0.229**	0.231	0.231	0.231	0.230	**0.229**	0.230	0.230	**0.229**	**0.229**
TL4 SPEAR (Sp) %	0.241	0.246	0.243	0.246	0.246	0.245	0.244	**0.241**	**0.242**	**0.242**	0.243	0.244
TL4 CCI	0.428	0.429	0.428	0.434	0.433	0.434	0.434	0.429	0.428	0.430	0.433	0.433
(c) R^2_{OE}												
TL1 NTAXA	44.3	43.1	44.0	44.7	45.2	46.1	**46.2**	46.0	44.5	44.9	**46.5**	46.1
TL1 ASPT	61.8	58.8	59.5	58.8	58.9	59.0	59.1	**59.3**	59.2	59.2	59.3	59.2
TL2 WHPT NTAXA	45.7	44.7	45.3	46.3	46.6	47.5	47.7	47.1	45.9	46.2	**48.0**	47.6
TL2 WHPT ASPT	71.8	68.7	69.1	68.3	68.2	68.5	68.7	69.0	68.9	69.1	68.7	68.5
TL4 WFD AWIC (Sp)	43.9	44.6	44.5	44.0	44.0	44.2	44.5	**45.1**	44.5	44.7	43.9	44.0
TL2 LIFE (Fam)	63.1	58.9	59.6	59.9	59.4	59.7	**60.2**	59.5	59.0	59.2	60.2	59.6
TL4 LIFE (Sp)	68.8	65.0	66.0	65.4	64.8	65.3	65.7	**65.9**	65.0	65.2	65.2	64.8
TL3 PSI (Fam)	70.1	66.3	67.1	66.6	66.3	66.4	66.8	66.9	66.3	66.6	66.7	66.3
TL4 PSI (Sp)	74.8	70.7	71.5	71.2	70.7	71.0	71.4	71.5	70.7	71.0	71.1	70.3
TL2 SPEAR (Fam) %	64.5	61.9	62.6	61.8	62.0	62.4	62.6	63.5	63.3	63.4	**63.0**	62.6
TL4 SPEAR (Sp) %	58.2	55.9	56.5	55.5	55.6	56.2	56.4	**57.7**	57.5	57.7	56.8	56.2
TL4 CCI	17.6	17.2	17.3	17.0	17.1	17.1	17.2	17.9	**18.0**	17.7	17.5	16.8

Table 12. Average single season (a) % correct discrimination, (b) SD(O/E) and (c) R^2_{OE} for current RIVPACS IV model (1) and trial models 26-36 (without alkalinity variables); all models include LAT,LONG, air temperature mean and range, discharge category and log slope at site; best models improving on Model 26 (which is the same as model 3) in bold.

Variable name	**1**	**26(3)**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
ALK	1	0	0	0	0	0	0	0	0	0	0	0
MSUBST	1	1	1	1	1	1	1	1	1	1	1	1
LOGALT	1	1	1	1	1	1	1	1	1	1	1	0
LOGDFS	1	1	1	1	1	1	1	1	1	1	1	0
LOGWIDTH	1	1	1	1	1	1	1	1	1	1	1	1
LOGDEPTH	1	1	1	1	1	1	1	1	1	1	1	1
LOGALK	1	0	0	0	0	0	0	0	0	0	0	0
%DRIFT1-PEAT	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID3-CLAY	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID6-CHALK	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID7-LIMESTONE	0	0	0	1	1	1	1	0	0	0	1	1
%SOLID8-HARDROCK	0	0	0	1	1	1	1	0	0	0	1	1
BFI	0	0	1	1	1	1	1	1	0	0	0	0
PROPWET	0	0	0	0	0	0	1	1	0	1	1	1
LOGAREA	0	0	0	0	1	1	1	1	1	1	1	1
LOGALTBAR	0	0	0	0	0	1	1	1	1	1	1	1
(a) %Correct	51.7	47.4	48.6	49.2	50.5	50.1	**52.3**	50.7	48.5	49.3	**52.6**	49.9
%Correct (XVal)	38.7	35.5	36.8	36.5	35.6	36.8	37.5	**38.7**	36.6	**38.0**	36.9	34.3
(b) SD(O/E)												
TL1 NTAXA	0.200	0.204	0.203	0.204	0.204	0.203	0.203	**0.202**	**0.202**	0.203	**0.202**	0.203
TL1 ASPT	0.076	0.082	0.082	0.081	0.081	0.080	0.080	0.081	0.080	0.081	**0.079**	**0.079**
TL2 WHPT NTAXA	0.206	0.210	0.209	0.210	0.210	0.209	0.209	**0.208**	**0.208**	0.209	**0.208**	0.209
TL2 WHPT ASPT	0.088	0.093	0.093	0.093	0.093	0.091	0.091	0.092	0.091	0.092	0.090	0.091
TL4 WFD AWIC (Sp)	0.091	0.095	0.094	0.094	0.094	0.094	0.094	0.094	0.095	0.095	0.095	0.095
TL2 LIFE (Fam)	0.053	0.054	0.053	0.053	0.053	**0.052**	**0.052**	0.053	0.053	0.053	**0.052**	0.053
TL4 LIFE (Sp)	0.057	0.059	0.058	0.058	0.058	**0.057**	**0.057**	**0.057**	0.058	**0.057**	**0.057**	0.058
TL3 PSI (Fam)	0.213	0.218	0.216	0.218	0.217	0.212	**0.210**	0.213	0.215	0.214	**0.211**	0.216
TL4 PSI (Sp)	0.271	0.281	0.278	0.296	0.292	0.284	0.282	**0.276**	0.276	**0.275**	0.281	0.295
TL2 SPEAR (Fam) %	0.228	0.241	0.240	0.238	0.237	**0.236**	**0.236**	**0.236**	0.236	0.236	**0.234**	0.235
TL4 SPEAR (Sp) %	0.241	0.252	0.251	0.251	0.251	0.249	0.249	**0.247**	**0.247**	0.248	0.248	0.249
TL4 CCI	0.428	0.426	**0.424**	0.427	0.426	0.426	0.427	0.434	0.428	0.438	0.428	0.428
(c) R^2_{OE}												
TL1 NTAXA	44.3	43.4	43.8	43.5	43.8	44.7	44.8	**44.9**	44.4	44.6	**45.1**	44.8
TL1 ASPT	61.8	56.2	56.1	57.2	57.3	58.0	**58.1**	57.0	57.5	57.3	**58.7**	58.3
TL2 WHPT NTAXA	45.7	45.0	45.4	45.4	45.6	46.5	**46.6**	**46.6**	46.1	46.3	**46.9**	46.6
TL2 WHPT ASPT	71.8	68.2	67.8	68.1	68.3	69.1	69.3	68.8	69.3	69.1	**69.6**	69.2
TL4 WFD AWIC (Sp)	43.9	39.4	40.3	40.4	40.6	40.6	**41.0**	40.8	39.3	**39.8**	39.7	39.7
TL2 LIFE (Fam)	63.1	61.8	61.9	62.7	62.8	63.4	**63.7**	62.6	62.3	62.4	**63.6**	63.0
TL4 LIFE (Sp)	68.8	67.5	67.7	68.0	68.2	69.3	**69.4**	68.9	68.6	68.7	**69.1**	68.1
TL3 PSI (Fam)	70.1	68.2	68.4	69.0	69.0	69.8	**70.1**	69.5	69.1	69.2	**69.9**	69.5
TL4 PSI (Sp)	74.8	72.7	72.9	73.5	73.6	74.5	**74.6**	74.1	73.7	73.9	**74.4**	73.6
TL2 SPEAR (Fam) %	64.5	60.8	61.0	61.5	61.5	**62.6**	62.5	62.5	**62.7**	62.6	62.6	62.2
TL4 SPEAR (Sp) %	58.2	54.9	55.0	54.8	54.9	56.0	55.8	**56.5**	**56.8**	56.6	55.9	55.5
TL4 CCI	17.6	16.9	17.5	17.9	17.9	18.2	**18.1**	17.8	17.7	17.2	**17.8**	17.3

4.4 SUMMARY OF REDUCED AND BEST ADDITIONAL VARIABLE MODELS

The effectiveness of predictions for reference site expected (E) index values (in terms of SD(O/E) and R^2_{OE}) decreased when the models no longer involved the use of flow-related variables measured at the time of sampling (namely water width, depth and mean substratum composition). The same occurs if the alkalinity variables are removed, and effectiveness is reduced further if both the flow and alkalinity variables are removed from the predictive model.

Table 13 provide an overall summary of the effect of removing flow and/or alkalinity predictor variables and of the best replacement time-invariant GIS-based upstream catchment variables (without using BFI).

It has not been possible to find any new time-invariant GIS-based environmental predictor variables which completely replace the predictive power of either of these two groups of potentially stressor-dependent field-based variables. In many respects this is not surprising as the macroinvertebrate community present at a site is dependent on the current and recent actual environmental conditions at the sampling site. It is likely that map-based time-invariant surrogate variables will not be as effective as they are, in a sense, trying to predict these environmental conditions at the sampling site in order to predict the expected community for a site in reference quality.

However, when these flow and/or alkalinity variables are excluded, minor improvements can be made by using augmented models (24, 35 or 13) involving new upstream catchment variables of area (LOGAREA), mean altitude (LOGALTBAR), FEH estimated proportion of time soils are wet (PROPWET) and upstream catchment cover of key geological types (% drift cover as peat, % solid geology as each of clay, chalk, limestone and hard rocks) (Table 13).

As an illustration of the effectiveness of new Model 13 (which excludes both the flow-related and alkalinity variables but includes the new GIS variables), Figures 9-12 show the distribution of O/E values from this model for the GB references sites classified by end-group (1-43) for each of the 12 indices, based on the spring-autumn combined sample O/E values.

4.5 SUGGESTED NEW STRESSOR INDEPENDENT GB MODELS WITHIN RICT

(1) It is suggested that for indices and sites where flow-related stress may be present and may have influenced the current values of stream width, depth and substratum composition, but where there is no obvious acidity-related stress, then Model 24 should be used. This has the current RIVPACS IV model variables except stream width, depth and substratum composition and includes the new key variables listed at (4) below.

Model 24 is named ‘**RIVPACS IV – Hydromorphology Independent**’ model.

(2) It is suggested that for indices and sites where alkalinity-modifying stress may be present, but where there is no obvious flow-related stress, then Model 35 should be used. This is the current RIIVPACS IV model except for the alkalinity variables and includes the new key variables listed at (4) below.

Model 35 is herby named the ‘**RIVPACS IV – Alkalinity Independent**’ model.

(3) It is suggested that for indices and sites where both flow and acidity related stress may be present, then Model 13 should be used. This has the current RIVPACS IV model

variables except for the stream width, depth and substratum composition and alkalinity variables and includes the new key variables listed at (4) below.

Model 13 is named '**RIVPACS IV – Hydromorphology & Alkalinity Independent**' model.

(4) The 3 new GB models in (1), (2) and (3) above include new upstream catchment variables of area (LOGAREA), mean altitude (LOGALTBAR), FEH estimated proportion of the time soils are wet (PROPWET) and upstream catchment cover of key geological types (% drift cover as peat, % solid geology as each of clay, chalk, limestone and hard rocks), but do not include BFI.

(5) Models 2-4 may be useful stress-independent predictor models for situations where values for the new GIS variables needed for Models 24, 35 or 13 respectively are not yet available for the river sites to be assessed for ecological status.

Table 13. Summary of Models 1-4 and the best replacement Models 24, 35 and 13 involving upstream catchment LOGAREA, LOGALTBAR, PROPWET and key GIS-based geological cover variables; based on average single season SD(O/E) and R^2_{OE} , together with the discrimination % correctly allocated (ReSub and XVal) to biological end-group.

	Model				Model		
	1	2	3	4	24	35	13
RIVPACS IV minus -->	None	-Flow	-Alk	-Both	-Flow	-Alk	-Both
+ new GIS variables -->					Y	Y	Y
%Correct (ReSub)	51.7	47.3	47.4	40.1	51.2	52.6	47.0
%Correct (XVal)	38.7	36.4	35.5	33.4	38.4	36.9	36.2
SD(O/E) (lower is better)							
TL1 NTAXA	0.200	0.203	0.204	0.207	0.197	0.202	0.203
TL1 ASPT	0.076	0.079	0.082	0.086	0.079	0.079	0.082
TL2 WHPT NTAXA	0.206	0.208	0.210	0.212	0.202	0.208	0.209
TL2 WHPT ASPT	0.088	0.092	0.093	0.099	0.092	0.090	0.096
TL4 WFD AWIC (Sp)	0.091	0.090	0.095	0.095	0.091	0.095	0.095
TL2 LIFE (Fam)	0.053	0.055	0.054	0.057	0.055	0.052	0.055
TL4 LIFE (Sp)	0.057	0.061	0.059	0.063	0.061	0.057	0.061
TL3 PSI (Fam)	0.213	0.209	0.218	0.223	0.212	0.211	0.214
TL4 PSI (Sp)	0.271	0.256	0.281	0.279	0.280	0.281	0.258
TL2 SPEAR (Fam) %	0.228	0.233	0.241	0.252	0.229	0.234	0.240
TL4 SPEAR (Sp) %	0.241	0.246	0.252	0.260	0.243	0.248	0.252
TL4 CCI	0.428	0.429	0.426	0.427	0.433	0.428	0.430
R^2_{OE} (higher is better)							
TL1 NTAXA	44.3	43.1	43.4	41.9	46.5	45.1	44.4
TL1 ASPT	61.8	58.8	56.2	52.2	59.3	58.7	55.4
TL2 WHPT NTAXA	45.7	44.7	45.0	43.9	48.0	46.9	46.2
TL2 WHPT ASPT	71.8	68.7	68.2	64.0	68.7	69.6	66.0
TL4 WFD AWIC (Sp)	43.9	44.6	39.4	39.4	43.9	39.7	40.1
TL2 LIFE (Fam)	63.1	58.9	61.8	56.1	60.2	63.6	58.7
TL4 LIFE (Sp)	68.8	65.0	67.5	62.4	65.2	69.1	64.2
TL3 PSI (Fam)	70.1	66.3	68.2	63.4	66.7	69.9	64.9
TL4 PSI (Sp)	74.8	70.7	72.7	67.4	71.1	74.4	69.3
TL2 SPEAR (Fam) %	64.5	61.9	60.8	57.7	63.0	62.6	60.5
TL4 SPEAR (Sp) %	58.2	55.9	54.9	52.6	56.8	55.9	54.6
TL4 CCI	17.6	17.2	16.9	16.7	17.5	17.8	17.9

4.6 NEW STRESSOR INDEPENDENT MODELS FOR NORTHERN IRELAND

Acidification stress is not a significant issue within Northern Ireland and there was therefore no requirement for a separate model that excluded alkalinity as a predictor variable (pers. comm. Imelda O'Neill in minutes of project meeting of 15th December 2010).

In the GB models which exclude the flow-related predictor variables, most of the new variables in the new models which provide some improvement were derived from the CEH Intelligent River Network (IRN), the BGS geology and the Digital Terrain Model (DTMGEN) which are not all readily available for Northern Ireland and the NI reference sites.

Equivalent new models could not therefore be developed for use at any hydromorphologically stressed sites in Northern Ireland. At present, the existing RIVPACS IV model should still be used.

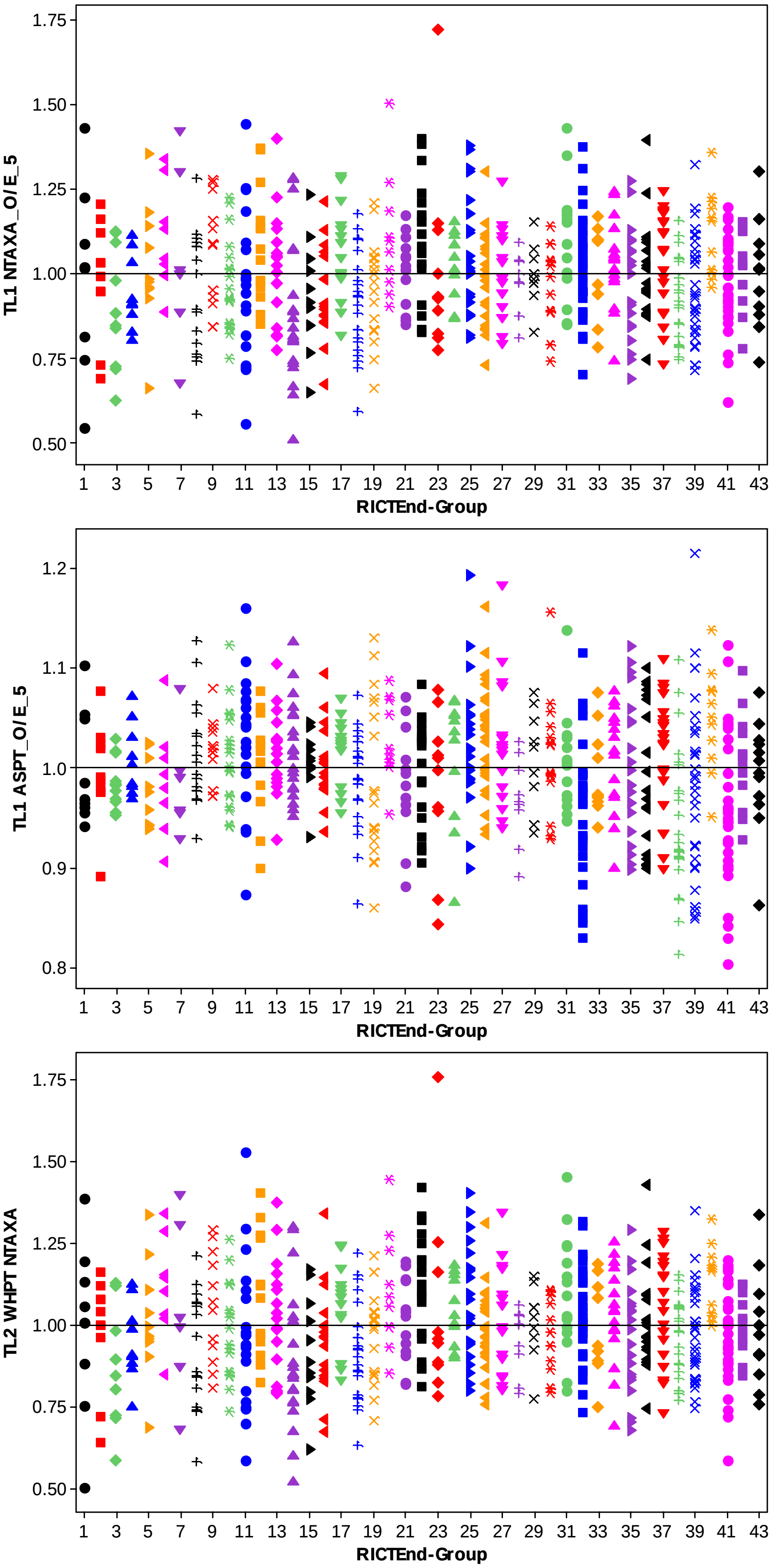


Figure 9. Plot of individual reference site O/E values by end-group (spring-autumn combined season samples) for (a) TL1 NTAXA (b) TL1 ASPT, (c) TL2 WHPT NTAXA using predictions based on Model 13, which excludes flow-related and alkalinity variables but includes GIS predictor variables.

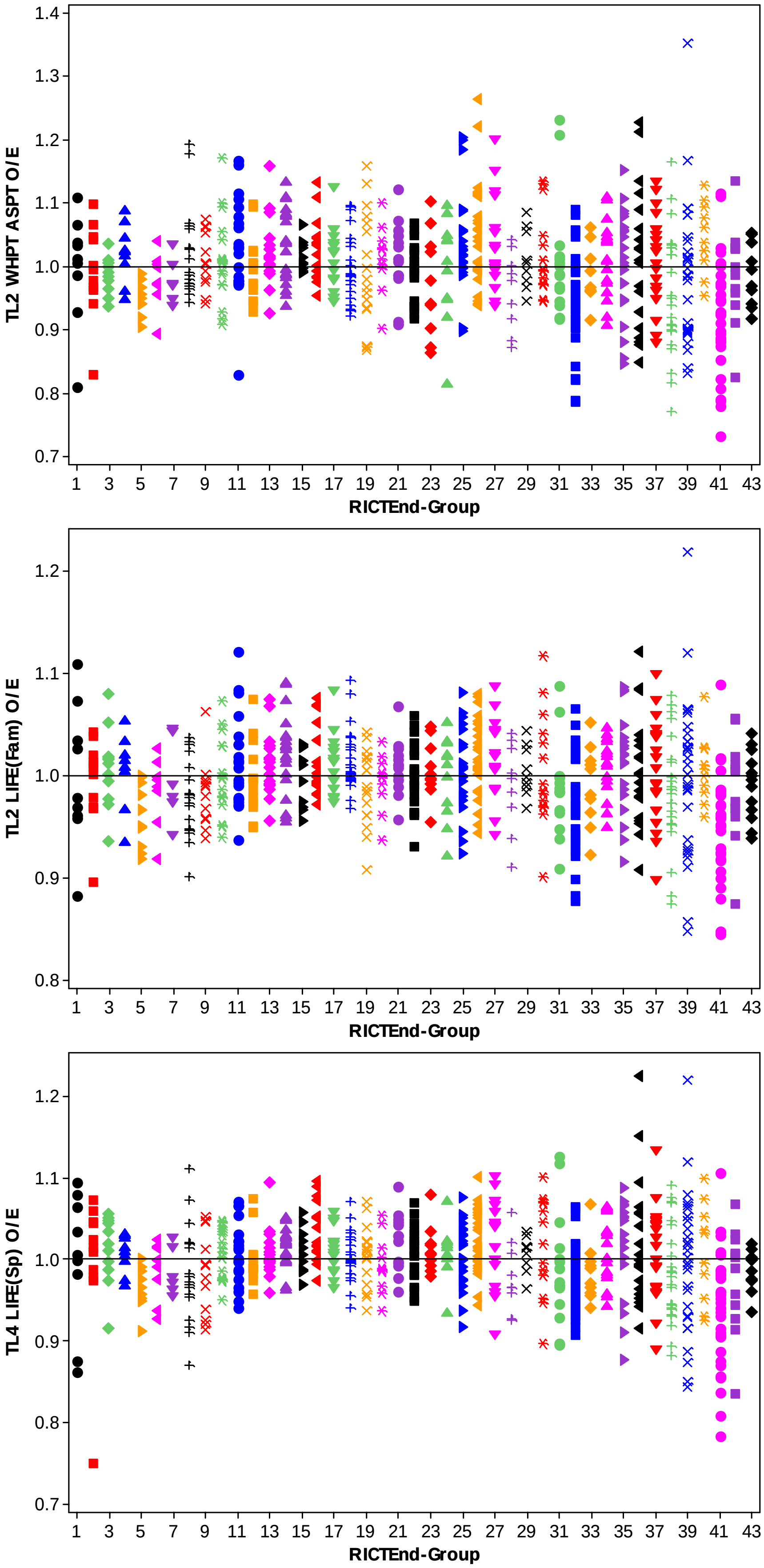


Figure 10. Plot of individual reference site O/E values by end-group (spring-autumn combined season samples) for (a) TL2 WHPT ASPT (b) TL2 LIFE (Fam), (c) TL4 LIFE (Sp) using predictions based on Model 13, which excludes flow-related and alkalinity variables but includes GIS predictor variables.

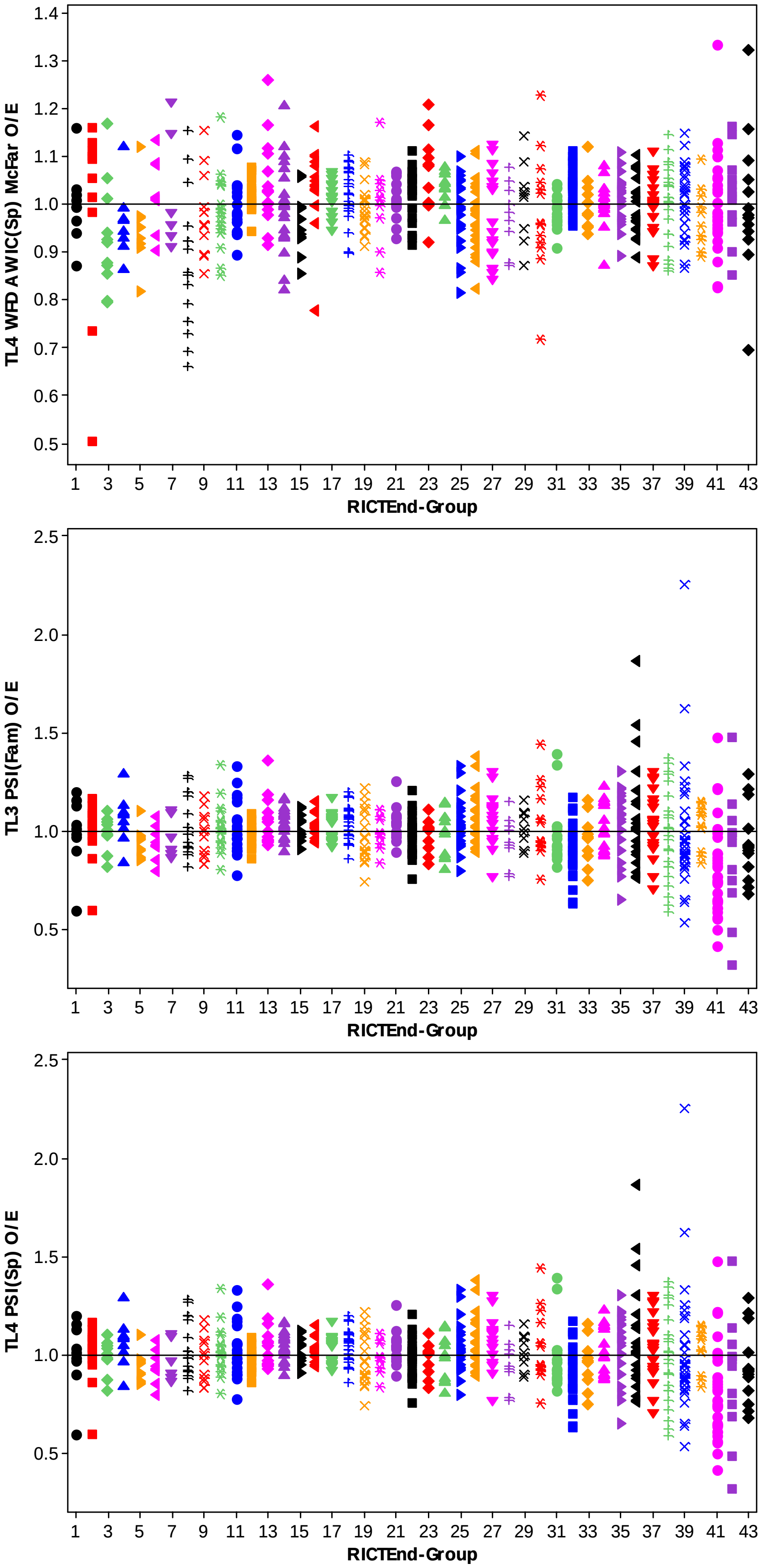


Figure 11. Plot of individual reference site O/E values by end-group (spring-autumn combined season samples) for (a) TL4 WFD AWIC (b) TL3 PSI (Fam), (c) TL4 PSI (Sp) using predictions based on Model 13, which excludes flow-related and alkalinity variables but includes GIS predictor variables.

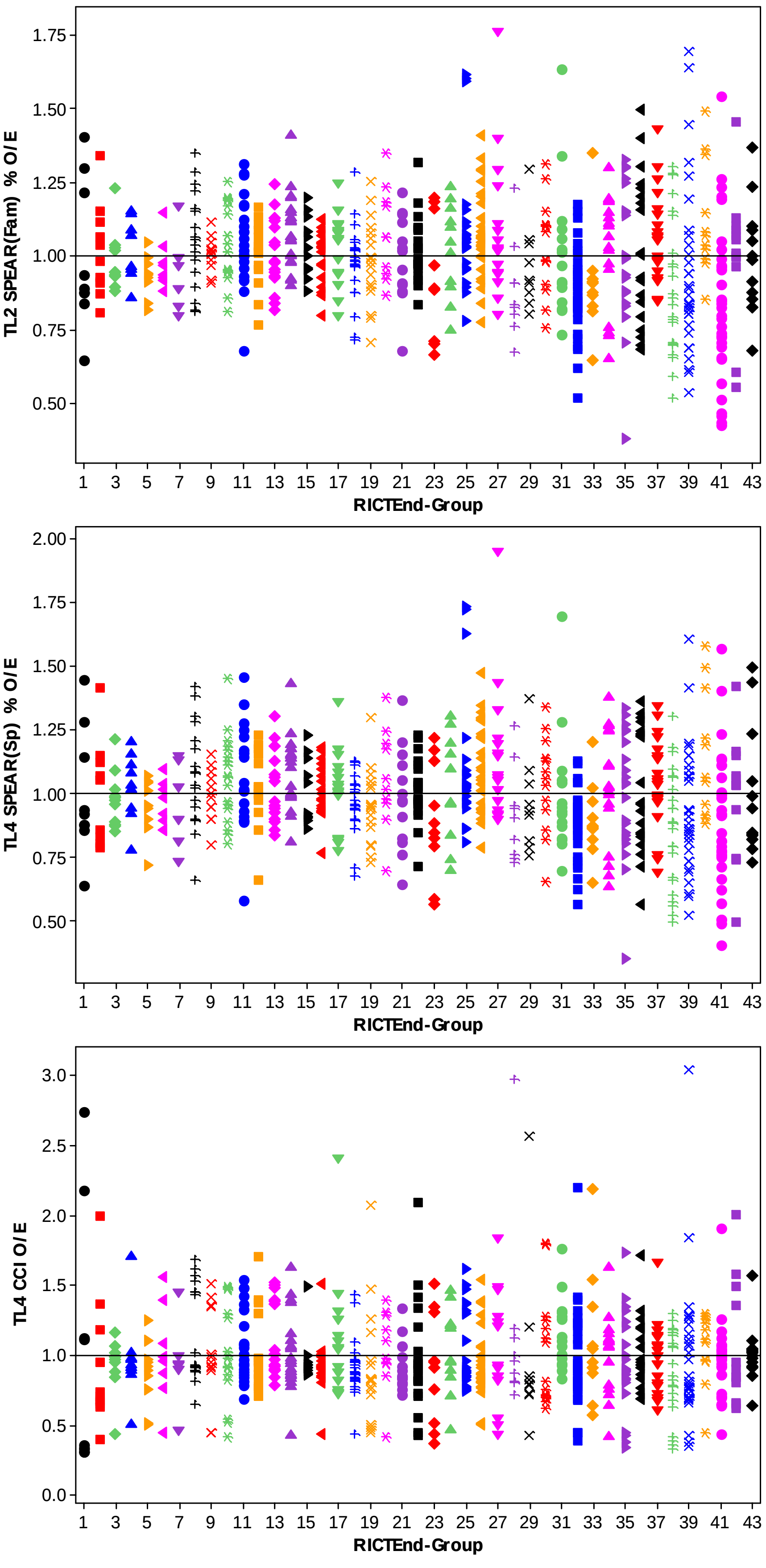


Figure 12. Plot of individual reference site O/E values by end-group (spring-autumn combined season samples) for (a) TL2 SPEAR (Fam) (b) TL4 SPEAR (Sp), (c) TL4 CCI using predictions based on Model 13, which excludes flow-related and alkalinity variables but includes GIS predictor variables.

5. CONSTRUCTION OF NEW STRESSOR INDEPENDENT PREDICTOR MODELS

To construct any one of the suggested new stressor independent predictor models for GB (Models 13, 24 and 35 or Models 2-4), the only new information that is needed is:

(i) the coefficients (DFCOEFF) for each of the new discriminant functions in the model
(ii) the end-group mean reference site scores (DFMEAN) for each discriminant function

Each discriminant function (DF) has a discriminant coefficient for each predictor variable involved in the model. In our GB RIVPACS models with more end-groups than predictor variables, the number of discriminant functions is equal to the number of predictor variables involved in that model.

Together, the DF coefficients and end-group mean DF scores are used to calculate the probabilities of any particular site belonging to each of the 43 TWINSPAN end-groups in the current RIVPACS IV GB model.

The discriminant function coefficients (DFCOEFF) and end-group mean DF scores (DFMEAN) for each of the suggested new models (2-4, 13, 24 and 35) are all provided in the following EXCEL file, which accompanies this report:

“WFD119 Discriminant functions coefficients (DFCOEFF) and End-group mean (DFMEAN) for new RICT models.xls”

This EXCEL file contains a separate worksheet for each new model. They hold both the DF coefficients and the end-group means in the same layout as in RICT so they can be used to make new predictive GB models in a future enhanced version of the RICT software.

The detailed algorithms for using the set of model discriminant functions to calculate probabilities of a site belonging to each end-group are given in the original RICT project WFD72C Final Report (Davy-Bowker *et al*., June 2008), in particular in the algorithm section WE1.3 pages 34-40, to which any interested reader and any future RICT programmer should refer.

This is all the information that is needed to set up any of the new models within an enhanced RICT software system.

6. REVIEW OF BIOTIC INDEX PERFORMANCE

6.1 INTRODUCTION

The RIVPACS models within RICT can now produce expected values for a wide variety of biotic indices (Davy-Bowker *et al.,* 2010). Some of these are well known and widely used (e.g. NTAXA and ASPT) while others are new (e.g. PSI and SPEAR). Some report on the familiar organic/general degradation stress while many others have been included to address one or more specific stress types e.g. acidity, sedimentation, morphological degradation or low flow stress. It is fundamentally important that any biotic index can inform the user of something useful about the community upon which it has been calculated. To that end, while the list of indices in RIVPACS has broadened to address a wider range of stress types, it has also been restricted to those that were thought to be both useful and reliable.

The indices in RIVPACS have been developed independently by a wide range of UK and international researchers and together represent what are thought to be the best indices available at this time. However, it is important to realise that none of the indices used by the RIVPACS models in RICT have been developed as part of the RIVPACS development process. Furthermore, while many of these indices have been presented in the scientific literature, some have been obtained from internal reports of the UK Agencies, or from personal communications with the groups that developed them.

With the increased choice and diverse origins of biotic indices now available to the RIVPACS models within RICT (Table 14) it is now important to bring together a review of all of these indices. It is hoped that users of the RICT software will find this review useful when wishing to understand more about the performance or meaning of the biotic index values they are using, or as a resource from which to base wider research into the origins of the indices available in RICT.

For the taxon scores used to calculate each index below, see Appendix XI of Davy-Bowker *et al.* (2010).

Table 14. List of biotic indices for which reference values have now been calculated and added to the RIVPACS database (and supplied as end group means for RICT).

Index (and variants)	Season combination(s) calculated*
TL1 BMWP	1-7
TL1 NTAXA	1-7
TL1 ASPT	1-7
TL2 WHPT Score (Non Abundance Weighted, Distinct Families)	1-7
TL2 WHPT NTAXA (Non Abundance Weighted, Distinct Families)	1-7
TL2 WHPT ASPT (Non Abundance Weighted, Distinct Families)	1-7
TL2 WHPT Score (Non Abundance Weighted, Composite Families)	1-7
TL2 WHPT NTAXA (Non Abundance Weighted, Composite Families)	1-7
TL2 WHPT ASPT (Non Abundance Weighted, Composite Families)	1-7
TL2 WHPT Score (Abundance Weighted, Distinct Families)	1-7
TL2 WHPT NTAXA (Abundance Weighted, Distinct Families)	1-7
TL2 WHPT ASPT (Abundance Weighted, Distinct Families)	1-7
TL2 WHPT Score (Abundance Weighted, Composite Families)	1-7
TL2 WHPT NTAXA (Abundance Weighted, Composite Families)	1-7
TL2 WHPT ASPT (Abundance Weighted, Composite Families)	1-7
TL1 AWIC (Fam)	1-7

TL4 AWIC (Sp) Murphy	1-7
TL5 AWIC (Sp) Murphy	1-7
TL4 WFD AWIC (Sp) McFarland	1-7
TL5 WFD AWIC (Sp) McFarland	1-7
TL4 Raddum	1-7
TL5 Raddum	1-7
TL4 SEPA % Acid Sensitive Taxa	1-7
TL5 SEPA % Acid Sensitive Taxa	1-7
TL2 LIFE (Fam) (Distinct Families)	1-7
TL1/2 LIFE (Fam) (Composite Families)	1-7
TL4 LIFE (Sp)	1-7
TL5 LIFE (Sp)	1-7
TL3 PSI (Fam)	1-7
TL4 PSI (Sp)	1-7
TL5 PSI (Sp)	1-7
TL4 German Stream Fauna Index GSFI FI05	1-7
TL5 German Stream Fauna Index GSFI FI05	1-7
TL4 German Stream Fauna Index GSFI FI09	1-7
TL5 German Stream Fauna Index GSFI FI09	1-7
TL4 German Stream Fauna Index GSFI FI091	1-7
TL5 German Stream Fauna Index GSFI FI091	1-7
TL4 German Stream Fauna Index GSFI FI091_K	1-7
TL5 German Stream Fauna Index GSFI FI091_K	1-7
TL4 German Stream Fauna Index GSFI FI092	1-7
TL5 German Stream Fauna Index GSFI FI092	1-7
TL4 German Stream Fauna Index GSFI FI11_12	1-7
TL5 German Stream Fauna Index GSFI FI11_12	1-7
TL4 German Stream Fauna Index GSFI FI14_16	1-7
TL5 German Stream Fauna Index GSFI FI14_16	1-7
TL4 German Stream Fauna Index GSFI FI15_17	1-7
TL5 German Stream Fauna Index GSFI FI15_17	1-7
TL4 German Stream Fauna Index GSFI FI152	1-7
TL5 German Stream Fauna Index GSFI FI152	1-7
TL2 SPEAR (Fam) %	1-7
TL4 SPEAR (Sp) %	1-7
TL5 SPEAR (Sp) %	1-7
TL4 Community Conservation Index	1-7
TL5 Community Conservation Index	1-7
TL3/TL1 ICM ASPT-2	5
TL3/TL1 ICM EPT	5
TL3/TL1 ICM N Fam	5
TL3/TL1 ICM Portuguese Gold	5
TL3/TL1 ICM Sel EPTD	5
TL3/TL1 Shannon-Weiner	5
TL1 ICM ASPT-2	5
TL1 ICM EPT	5
TL1 ICM N Fam	5
TL1 ICM Portuguese Gold	5
TL1 ICM Sel EPTD	5
TL1 ICM Shannon-Weiner	5

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*Season combination(s): 1 = spring; 2 = summer; 3 = autumn; 4 = spring & summer combined; 5 = spring & autumn combined; 6 = summer & autumn combined; and 7 = spring, summer & autumn combined.

6.1.1 Biological Monitoring Working Party (BMWP, NTAXA, ASPT)

The Biological Monitoring Working Party scoring system was originally developed for the 1980 National River Quality Survey (Biological Monitoring Working Party, 1978) and was designed primarily to summarise the effects of organic pollution on freshwater macroinvertebrate communities in the form a single index that could be used easily by water quality managers. The original BMWP-score has been modified on several occasions by removal of semi-aquatic/terrestrial families (e.g. Chrysomelidae and Curculionidae) and merger of several families to form artificial taxon groups (e.g. Rhyacophilidae including Glossosomatidae), see Murray-Bligh *et al*. (1997) and Hawkes (1997) for reviews.

In its current form, as used by the UK Agencies, BMWP comprises 82 scoring taxa (including 8 artificial taxon groups) as given in Appendix II of Davy-Bowker *et al*. (2008). Furthermore, the UK Agencies no longer use BMWP-score per se, but instead use the number of BMWP scoring taxa (NTAXA) and the Average Score Per Taxon (ASPT). These two indices are now used to describe both organic pollution stress and also double as indices of general degradation in the Agencies WFD classification schemes. The two indices are intergrated to determine the overall status class of a test site based on the O/E (EQI) value of each index independently and then applying a pre-set rule for deriving the overall status class based on the classes for the individual metrics. The current WFD biological classification system rule (MINTA, or the “worst case” rule) therefore takes the worst of the two classes determined by EQI for NTAXA and EQI for ASPT, where the metric class limits are determined by the UK Agencies (Davy-Bowker *et al*., 2008).

The performance of the BMWP-score and ASPT indices was examined over a range of unpolluted river sites by Armitage *et al*. (1983). ASPT in particular performed well, with low variability in ASPT scores between seasons, only minor ASPT taxon accretion effects because of replicate sampling, and a high proportion of variance explained when equations were used to predict ASPT. In a more recent comparative analysis of the ASPT and WHPT indices, Banks & McFarland (2010) examined the performance of ASPT in terms of their linear regression relationships with common water quality variables of organic pollution stress. The study sites were carefully selected to give a good gradient from organically stressed to clean sites. ASPT performed well, having strongly significant correlations with all of the examined organic pollution variables: Ammonia ($mg.l^{-1}$); dissolved Oxygen ($mg.l^{-1}$); dissolved Oxygen (% saturation); and Biochemical Oxygen Demand ($mg.l^{-1}$) underlining its usefulness as a descriptor of organic pollution stress.

ASPT is now widely used in a number of international bioassessment systems and it is also the predominant (most highly-weighted) biotic index of the 6 Intercalibration Common Metrics (ICMs) used in the European Intercalibration Common Metric index (ICMi) (van de Bund, 2009), see also section (6.13).

6.1.2 Walley Hawkes Paisley Trigg (WHPT, NTAXA, ASPT)

A new organic pollution/general degradation index called Walley Hawkes Paisley Trigg (WHPT) has recently been developed. This is based on the well-established BMWP system. However, unlike the BMWP scoring system (where taxon scores were defined by expert judgment), in the WHPT index taxon scores were defined by making use of a large scale Environment Agency dataset to better-define the organic pollution tolerances of each scoring family. Further refinements have included a revision of the taxonomy of the scoring taxa, inclusion of more families, and the additional of a $\log_{10}$ abundance weighting scheme (Walley & Hawkes, 1996; Walley & Hawkes, 1997; Paisley & Trigg, 2007).

The new WHPT score, and its associated ASPT index, have been comprehensively tested by Banks and McFarland (2010). After first assembling an extensive site-matched macroinvertebrate (spring and autumn only) and chemical (36 months prior to biological sampling) sample dataset from across the UK, Banks and McFarland selected groups of sites that corresponded to the WFD System-A physical typology (CEC, 2000). Five river types had sufficient numbers of sites to permit analysis. Despite a bias in the dataset towards sites in England, the five stream types selected probably represented the commonest System-A stream types found in Great Britain. Within each stream type, sites were further divided into five pressure groups (High, Good, Moderate, Poor and Bad) as separately defined by Ammonia ($mg.l^{-1}$), dissolved Oxygen ($mg.l^{-1}$), Oxygen saturation (% saturation), and Biochemical Oxygen Demand ($mg.l^{-1}$) so that as far as possible a balanced number of sites existed across each pressure gradient within each stream type. It was not possible to obtain sufficient data for some pressure gradients for some stream types, for example because some upland stream types did not contain enough sites with strong organic pollution pressure. These river types were excluded from the analysis because the pressure gradient spanned was not sufficiently great.

Relationships between the biotic indices and organic pollution gradients were tested by linear regression. WHPT score (and associated ASPT) were examined, together with the original BMWP-score and ASPT indices (section 6.1.1). Pressure gradients for Ammonia and BOD were log transformed prior to analysis. Regressions were calculated separately by river type and pressure. Data were tested for normality (Anderson-Darling test) and transformed where necessary (Johnson transformations). Bonferroni corrections were applied to *p*-values to compensate for multiple testing.

All the indices tested: original BMWP-score; ASPT; WHPT score; and WHPT ASPT, had strongly significant correlations ($p < 0.0001$) with all of the organic pollution variables: Ammonia ($mg.l^{-1}$); dissolved Oxygen ($mg.l^{-1}$); dissolved Oxygen (% saturation); and Biochemical Oxygen Demand ($mg.l^{-1}$). The original BMWP-score marginally outperformed WHPT-score in terms of ability to predict Ammonia concentration. For both dissolved Oxygen and Oxygen % saturation, WHPT-score was more highly correlated than BMWP-score. For one common river type (lowland, small, calcareous, representing 25.9% of the entire GB river network), WHPT-score was 16% better at predicting Oxygen ($mg.l^{-1}$). The authors concluded that using WHPT-score may result in a considerable improvement in monitoring in this widespread river type. For BOD, BMWP and WHPT scores gave broadly similar results (both indices were weakest on this pressure). A possible explanation for this may be that BOD data was selected on the basis of 'risk' rather than empirical data making pressure gradients less reliable.

Overall, while the differences in BMWP and WHPT score relationships with pressure gradients were generally quite small, WHPT was marginally better. While Banks and McFarland concentrate their discussion on BMWP and WHPT scores, the same conclusions can probably be drawn for BMWP and WHPT ASPTs. This improvement is probably due in large part to the inclusion of abundance weighting in the WHPT indices.

6.1.3 AWIC – Family Level (AWIC Fam)

The Acid Water Indicator Community family level index, AWIC (fam) was designed to assess the impact of acidity on macroinvertebrate communities (Davy-Bowker *et al*., 2005). AWIC (fam) was developed using a training dataset of 1042 macroinvertebrate samples from a wide variety of stream types and locations across England and Wales. Only samples collected in the spring were included as this is the time of year during which the macroinvertebrate community has been shown to respond most markedly to stream pH (Hämäläinen & Huttunen, 1996). The site-matched physical variables altitude and distance from source were also obtained along with pH data from the Environment Agency.

AWIC (fam) was developed using an approach that sought to factor out the influence of physical variables that might otherwise confound the relationship between macroinvertebrate community composition and pH. To achieve this, partial canonical correspondence analysis (pCCA) was used with physical variables other than pH as co-variables, and mean pH as the explanatory variable. This produced a ranking of macroinvertebrate families along the first axis of the pCCA (that was strongly correlated with mean pH). This therefore provided the basis for the assignment of index scores. Taxa ranked as acid sensitive (e.g. Ephemeridae and Physidae) were given scores of 6, while taxa ranked as acid tolerant (e.g. Chloroperlidae and Nemouridae) were given scores of 1. AWIC (fam) scores were then calculated as the average score per taxon of all scoring taxa.

AWIC (fam) was tested on the training dataset of 1042 samples and also on an independent dataset of 2710 Environment Agency, 1995 General Quality Assessment (GQA) samples from England and Wales (Davy-Bowker *et al*., 2005). The AWIC index and mean pH were significantly correlated in the training dataset ($r_s = 0.814$, $P < 0.001$) and tests for significant differences between 0.5 unit AWIC classes showed that with the exception of the two highest AWIC classes (both circum-neutral), all classes of AWIC scores were significantly different from each other in terms of their median observed pH. AWIC index and mean pH were also significantly correlated in the testing dataset ($r_s = 0.490$, $P < 0.001$) and again all classes of AWIC scores were significantly different from each other. Furthermore, plotting AWIC (fam) scores for the entire 6016 site Environment Agency 1995 GQA survey dataset showed that the AWIC family level index was effective in identifying streams in acid sensitive areas of the north of England, Wales and southwest England. The number of false positives was also low compared to another acidity index that was plotted on the same dataset.

Davy-Bowker *et al*. (2005) concluded that, at family level, macroinvertebrate communities are not characterized by a specific obligate acid-waters assemblage. While most acid sites support families that are acid tolerant, these families are also commonly found in circum-neutral waters. AWIC (fam) therefore works by distinguishing sites on the basis of the absence of any of a large number of acid sensitive families, the presence of any of which can shift the overall AWIC index towards one indicative of higher mean pH.

Following the original publication of the AWIC index, Ormerod *et al*. (2006) examined the performance of the AWIC (fam) index using a dataset of 132 acid sensitive streams in Wales and Scotland. AWIC index values correlated significantly with a number of acid-base variables including pH, calcium concentration, alkalinity and dissolved aluminium. Measured base-flow pH was within 0.5 pH units of values expected from invertebrates at over 50-70% of test sites, and within 1 pH unit at 87-100% of sites. These AWIC (fam) results were considered to be comparable to direct measurement of pH itself, where fortnightly-monthly samples are typically required to confidently estimate mean pH to within 0.7 – 1.2 pH units.

Ormerod *et al*. (2006) also made recommendations about how the AWIC index might be further refined. These recommendations included using more species-level taxa and a more targeted (pH balanced) calibration dataset to i) improve discrimination of sensitive streams of differing acidity; ii) increase the accuracy of pH determination based on index scores, iii) avoid apparent over-estimation of pH in lower AWIC classes, and iv) clearly differentiate between acid-sensitive and acidified streams. These recommendations to further refine AWIC have been applied to the next two species-level AWIC index versions that are reviewed below.

Overall, AWIC (fam) index has been developed using a rigorous statistical process and despite working at a fairly coarse (family) level of taxonomic level of resolution, clearly has merit in discriminating sites with differing acidity using their macroinvertebrate communities.

6.1.4 AWIC – Species Level (AWIC Sp)

Following the development of the AWIC family level index (section 6.1.3) a new AWIC index was developed using similar statistical techniques, but this time using species-level data and a training dataset that while smaller, was more carefully balanced in terms of the numbers of acid and circum-neutral sites (Murphy *et al*., in review).

The training dataset for AWIC (sp) comprised 197 sites drawn from seven datasets representing streams in England, Scotland and Wales. Only samples from spring were included and any sites with forms of anthropogenic stress other than acidification were dropped from the analysis. These biological data were then matched to pH data and associated physical variables (altitude, distance from source, slope and stream order).

AWIC (sp) was tested using an independent test dataset of 76 sites from streams in northwest and southwest Scotland and north and central Wales. The performance of AWIC (sp) was compared to four other acidity indices (AWIC fam; Wade *et al*.,1989; Henrikson and Medin, 1986; and Fjellheim & Raddum, 1990).

AWIC (sp) outperformed the family-level AWIC (fam) index in its relationships with base-flow and storm-flow pH and with base-flow and storm-flow ANC. In comparison with the other species-level indices (Wade *et al*.,1989; Henrikson and Medin, 1986; and Fjellheim & Raddum, 1990), AWIC (sp) was also consistently the species-level index that best accounted for variation in base-flow and storm-flow pH and ANC in the test dataset.

Overall, AWIC (sp) is a powerful species-level index, effectively discriminating sites with low pH.

6.1.5 Abundance-Weighted AWIC - Species Level (WFD AWIC Sp)

In the final index in the AWIC series that is currently included in RIVPACS, further work has been done on AWIC (sp) to add a $\log_{10}$ abundance weighting to the taxon scores in the index (McFarland, 2010). This work has made the AWIC (sp) index more compliant with the Water Framework Directive requirement to assess the abundances of biological quality elements (hence the name 'WFD AWIC sp').

Whilst retaining the original pCCA species ranking of the AWIC (sp) index, the abundance weightings in WFD AWIC (sp) are structured in such as way as to allocate higher scores to sensitive taxa when they are found in greater numbers. Conversely, when tolerant taxa are found in high numbers, low scores are assigned.

Subsequent testing of AWIC (fam), AWIC (sp) and WFD AWIC (sp) on an independent 49-site dataset (pH range 4.24-6.80) showed that the two species level indices outperform AWIC (fam), and that WFD AWIC (sp) had marginally better relationships with pH and ANC than the original AWIC (sp).

6.1.6 Raddum

The Raddum index (Fjellheim & Raddum, 1990) was developed using monitoring data from five catchments in Norway in the early 1980s. Commonly occurring invertebrates were divided into four categories (a-d) based on their perceived sensitivity (tolerance) to acidification. These categories were then allocated scores between 0 (most tolerant to low pH) and 1.0 (least tolerant to low pH). Test sites are then given Raddum index scores based on the presence of species in these groups. A score of 1 is given where any of the acid sensitive species in category (a) are present. Scores of 0.5 and 0.25 indicate increasing acidity. A score of 0 (indicating a highly acidified site) is given when only those species in category (d) are present.

The Raddum index suffers from a number of problems when applied in the UK. Firstly, being developed in Norway, there are many invertebrate species that were allocated acidification index tolerance limits that don't actually occur in the UK. Similarly, many of the species that are found in the UK are not given scores. Secondly, being a categorical index, when applied to a single site or sample, there are only 4 possible outcomes from applying the Raddum index (0, 0.25, 0.5 or 1.0) making the index discontinuous unlike many later indices. Thirdly, being a tolerance limit based index, the presence of even a single individual of an acid sensitive category alters the overall index value.

Whilst useful, in the UK the Raddum index is now probably out performed by other more recently developed species-level indices such as AWIC (sp) (Murphy *et al*., in review) and WFD abundance-weighted AWIC (sp) (Mcfarland, 2010).

6.1.7 SEPA % Acid Sensitive Taxa

The Scottish Environment Protection Agency % Acid Sensitive Taxa index (David Rendall, SEPA, pers. comm., 20th January 2010) is an index developed from the Clyde River Purification Board Index. SEPA % Acid Sensitive Taxa is calculated as a ratio of the number of acid sensitive taxa (List A) to numbers of all taxa (List A plus List B), all multiplied by 100.

There do not appear to be any publications relating to the development or performance of the SEPA % Acid Sensitive Taxa index. The capacity to obtain predictions of expected values from RIVPACS is included at the request of users in SEPA to enable the calculation of observed/expected ratios for this index.

6.1.8 Lotic-Invertebrate Index for Flow Evaluation (LIFE)

The Lotic-invertebrate Index for Flow Evaluation (LIFE) was developed by scientists in the Environment Agency, Anglian Region (Extence *et al*., 1999). LIFE was designed to assess the effects of flow stress in streams and rivers (e.g. low flows, over-abstraction, and flow augmentation) and also as a basis for setting benchmark flows suitable for protecting and maintaining good ecological integrity.

LIFE was based on recognised flow associations that exist for different macroinvertebrate taxa, both at family-level and species-level. The index was developed by placing these taxa into one of six flow groups to represent their primary ecological affiliation with respect to flow. Groups 1 to 5 represent a gradient from rapid flow to standing waters, while group 6 represents drying or drought impacted sites. The taxa were allocated to these groups by the authors using information on flow associations from a wide range of published literature sources.

Both family and species level LIFE indices are abundance-weighted (Log_{10} abundance), and scores are calculated by first passing each family in a test sample through a flow group-abundance category matrix to obtain a flow score (*fs*). The abundance weighting gives the highest *fs* scores to taxa that are both associated with high flows and abundant. The overall LIFE index is calculated as the sum of *fs* scores divided by the number of scoring taxa (high LIFE scores indicating high flows).

Extence *et al*. (1999) went on to test which flow statistics best relate to LIFE scores (e.g. mean flow, percentile, running summer mean) in five geographically and geologically distinct rivers in England. Summer flows were highlighted as being most influential in predicting LIFE score in most chalk and limestone streams, while short-term hydrological events were found to be more important in rivers draining impermeable catchments.

Overall, the performance of the LIFE indices were impressive, successfully relating various flow variables to changes in LIFE family and species-level index values in a range of different stream types and geologies.

More recently, Monk *et al.* (2006) has shown that LIFE scores correlate strongly with descriptors of riverine flow, and that species level LIFE scores perform particularly well (Monk *et al*., 2011). Furthermore, LIFE score also appears to have a potential role in discriminating hydromorphological stress. Dunbar *et al*. (2010a) found that the LIFE index responded to both antecedent flow and habitat modification in two separate datasets from lowland wadeable streams, and Dunbar *et al*. (2010b) has shown that bed and bank re-sectioning can reduce overall LIFE scores and increase the steepness of the LIFE response to low (Q95) flow. These findings are particularly interesting given the shortage of effective biotic indices for describing hydromorphological stress, and point to a potential for the LIFE index to fulfil this role.

6.1.9 Proportion of Sediment-Sensitive Invertebrates (PSI)

The Proportion of Sediment-sensitive Invertebrates (PSI) are a pair of new family and species-level indices designed to relate macroinvertebrate communities to fine sedimentation stress. PSI (fam) and PSI (sp) have been developed by (Extence *et al*., accepted) using a similar approach to that used in the development of the LIFE indices, but in this case assigning one of four Sediment Sensitivity Rating (SSR) taxon scores to British benthic macroinvertebrates using a major literature review of over 100 literature sources. This review considered traits enabling exploitation of fine sediment as a habitat, including anatomical traits (e.g. gill covers in caenid mayfly nymphs), physiological adaptations to sedimented environments (e.g. in the oligochaete worms), and behavioural traits associated with either predation (e.g. camouflage for the predatory *Cordulegaster boltonii*) or predator-avoidance (e.g. certain limnephilid caddis larvae). Traits preventing colonisation of sedimented habitats were also considered (e.g. the highly sensitive respiratory apparatus of perlodid stonefly nymphs, loss of algae as a food resource to scrapers such as heptagenid mayfly nymphs, and blockage of collecting nets or filtering apparatus for hydropsychid caddis and simulid larvae respectively).

Various taxa were not given SSR scores; for example, if they were indifferent to sediment composition, had strong associations with aquatic macrophytes, or where allocation of SSR scores was only possible at species-level due to the very wide range of sediment preferences within a family.

PSI scores are calculated by first assigning each taxon its Sediment Sensitivity rating (SSR) and then combining this with its $\log_{10}$ abundance to derive a Sediment Score for each taxon. PSI is then determined by calculating the ratio of sediment-sensitive taxa (expressed as summed sensitive - SSR scores) in the whole sample (expressed as total - SSR scores) and multiplying by 100.

PSI scores range from 0 (entirely silted) to 100 (entirely silt free) and Extence *et al*. (accepted) have suggested a provisional banding for PSI scores as well as an observed/expected ratio EQR banding scheme.

As noted in Extence *et al*. (accepted) the PSI family and species indices probably require further testing in terms of their ability to assess sites in terms of fine sedimentation stress. One point of interest that has emerged has been the high correlations observed between LIFE and PSI. This is perhaps not surprising given that lower current velocities often give rise to sedimentation. Nonetheless, the various case studies described in Extence *et al*. (accepted) indicate that the PSI indices tracked observed changes in sediment composition in the rivers studied and could distinguish sedimented sites successfully. Additionally, diagnostic capability is greatly improved by examining the response of PSI alongside other key macroinvertebrate metrics, such as ASPT, NTAXA and LIFE.

6.1.10 German Stream Fauna Index (GSFI)

The German Stream Fauna Indices (GSFI) were developed in mainland Europe for assessing the impact of hydromorphological degradation on the macroinvertebrate fauna of German streams (Lorenz *et al.,* 2004). The latest versions of the GSFI indices as given in RIVPACS were provided by Daniel Hering of the University of Essen (pers. comm. 17th March 2009). Separate GSFI indices were developed for various German stream types, and as such have not been specifically designed for or tested on streams in the UK.

The original GSFI indices were developed by firstly collecting invertebrate samples from between 12 and 20 sites in each stream type, ranging from lowland streams in Northern Germany to sites in the lower mountainous areas of western Germany (Lorenz *et al.,* 2004). Sites were selected to cover a gradient from near-natural to heavily degraded within each stream type. The degradation was due largely to hydromorphological alterations, and sites with excessive organic pollution were excluded. Sampling and laboratory processing methods differed from those routinely used for routine bioassessment in the UK. The 'AQEM' multi-habitat sampling technique was used (Hering *et al.,* 2003) and invertebrate identification was carried out to species-level (with the exception of certain *Dipteran families*). Alongside the invertebrate sampling, approximately 200 parameters were recorded from each site describing morphology, chemistry, hydrology and catchment characteristics. These data were used to derive hydromorphological 'Structure Indices' for each stream type ranging from 0 (degraded) to 100 (natural).

The German Stream Fauna Indices were then developed by compiling a stream-type specific list of indicator taxa using the following criteria: i) occurrence and/or abundance of an indicator taxon correlated with the Structure Index; ii) the taxon showed a preference for a certain habitat type; iii) historical records of the indicator taxon in a given stream type; and iv) under near-natural conditions, the indicator taxon shows a clear preference for that stream type. Using these criteria, one of four scores was assigned to each indicator taxon (-2, -1, +1, +2), where -2 is indicative of species capable of tolerating degraded morphology, and +2 is assocaited with species requiring a near natural morphology. The German Stream Fauna indices also incorporate abundance-weighting into the calculation of index scores (grouped into the following eight categories: 0 individuals, 1-3, 4-10, 11-30, 31-100, 101-300, 301-1000 and >1000 individuals).

In general the GSFI indices described in Lorenz *et al.* (2004) appeared to have strong linear relationships with hydromorphological degradation. However, these indices have not been tested on independent datasets from the UK so it is less clear how well they will work beyond the German stream-types for which they were developed. Nonetheless, with the exception of the LIFE index (section 6.1.8), the GSFI indices are probably the only biotic indices available at this time that relate hydromorphological stress to macroinvertebrate communities.

6.1.11 SPEAR %

The SPEAR indices, SPEAR % (family-level) and SPEAR % (species-level) are designed to indicate the level of pesticide contamination in running waters (Beketov *et al.,* 2008).

SPEAR was originally developed in mainland Europe as a database of ecological traits (Liess *et al*., 2008). This database contained information on taxon-specific sensitivity to organic toxicants (termed $S_{organic}$), generation time, presence of aquatic stages at times of maximum pesticide usage, and migration abilities. Species were defined as “at risk” if they had (i) a $S_{organic}$ value above –0.36; (ii) a generation time equal to or greater than one year; (iii) aquatic stages during May-June; and (iv) low migration abilities.

The SPEAR database was then adapted for use in England and Wales. Alterations included the addition of 38 new taxa, creation of 125 UK-specific taxa entries (e.g. for UK-specific generation or emergence times), and amendment of information on Europe-wide ecological traits based on additional information that was discovered during this process. In addition to the species-level SPEAR database, a new family-level database was developed for the UK using the predominant risk status of the species comprising each family.

The effectiveness of the SPEAR % (family and species) indices was examined in Beketov *et al.* (2008) using a test dataset of sites from Germany, France and Finland. All correlations between the SPEAR family and species indices and water toxicity were statistically significant. Comparison of the effectiveness of the family versus species SPEAR indices suggested that the family-level version was only slightly less effective in detecting pesticide contamination. Beketov *et al.* (2008) conclude that given the time-consuming and expensive nature of species-level identification, the family-level index is probably the most promising and cost-effective biomonitoring tool for detecting pesticide contamination in streams.

6.1.12 Community Conservation Index (CCI)

Developed by the same group that developed the LIFE index above, the Community Composition Index (CCI) is a comparatively recent index designed to provide an empirical basis for conservation initiatives by summarising the richness and rarity of the species present in a macroinvertebrate sample (Chadd & Extence, 2004). CCI was developed by assigning a conservation score (CS) to a list of those species of British macroinvertebrate that could be identified relatively easily and for which sufficient knowledge on conservation status was available. Conservation scores were then assigned with reference to an authoritative body of supporting scientific literature. CS values ranged from 1 (very common), to 10 (RDB1 – Endangered) and incorporated both the Red Data Book and nationally/regionally notable systems within this scale.

To calculate a CCI score for a test site, the sample is first identified to species level and then CS values are assigned to all appropriate species. The sum of CS scores is then divided by the number of CS scoring species. To prevent information about a particularly rare species being lost among a wider assemblage of very common taxa, this average is then multiplied by a community score derived from a second table of Community Score (CoS) categories, the highest of these corresponding to the maximum CS score of any species found in the sample. A second approach is also given in the paper by Chadd &

Extence (2004) whereby CoS categories can be derived from BMWP scores, however the former approach of using the maximum CS score is the one that has been used to calculate expected values for CCI and it is therefore this one that should be used to calculate observed CCI scores for O/E ratios in RIVPACS.

CCI scores typically range from 0 to >40 and were categorised by Chadd & Extence (2004) into a series of bands in 5 unit intervals (e.g. >15.0 to 20.0 – which was described as 'sites supporting several uncommon species, at least one of which may be nationally rare and/or a community of high taxon richness'). Sites with CCI scores >20.0 were identified as potentially meriting statutory protection.

Chadd & Extence (2004) tested the performance of the CCI index in a number of case studies of river reaches. CCI was successful in highlighting rare species in these test sites and also proved to be very useful in summarising complex conservation information into a single user-friendly index value. Given that CCI is probably the first and only biotic index in existence to date that integrates the conservation status of the full range of macroinvertebrate species found in streams and rivers, and that CCI is specifically designed with conservation weightings for Great Britain, the CCI index therefore appears to be a valuable additional tool for the evaluation and protection of the aquatic environment.

CCI is unusual in that it picks out sites with exceptional rarities, so can occasionally have very high observed values. Conversely, expected values tend to be more conservative as these are weighted across end groups . The apparent weakness of CCI in Table 9, where SD (O/E) is high (0.429) is therefore not a huge concern. It is probably a feature of the fact that this index does not behave like a more familiar index such as ASPT (which can be banded and used to reflect stress). A low CCI score does not necessarily imply damage while the occasional high scores is of note as it is associated with the presence of rare species. This behaviour is also apparent in the plots of individual reference site O/E values (Figures 8c and 12c).

6.1.13 Intercalibration Common Metric Index (ICMi)

The final biotic index that has been calculated for the RIVPACS reference sites is the Intercalibration Common Metric Index (ICMi). The ICMi is not used routinely in water quality classification or reporting and so it has not been made available in RIVPACS as a index for which expected values can be obtained. However, the ICMi has an important role in the process of international boundary setting (intercalibration) across the EU and so it has been included in the RIVPACS database and is therefore reviewed here.

A key action identified by the EU Water Framework Directive has been to carry out a Europe-wide intercalibration exercise to ensure that the ecological quality bands used in individual Member States are both consistent with the Directive's generic description and, importantly, are comparable across the European Union. The intercalibration process has been managed by the Common Implementation Strategy Working Group A - Ecological Status (ECOSTAT) and all 27 Member States have been involved, plus Norway on a voluntary basis (ECOSTAT, 2003 & 2005; Van de Bund, 2009).

Expert groups have been established for lakes, rivers and coastal/transitional waters, each subdivided into Geographical Intercalibration Groups, within which water body types were considered to be broadly similar and therefore suitable for intercalibration.

For rivers, five Geographical Intercalibration Groups (GIGs) were established across the EU (each further sub-divided into stream types). National class boundaries were initially set separately by each Member State using their own bioassessment system and metrics. This was then followed by calibration against an Intercalibration Common Metric used across each GIG. A process of harmonisation of class boundaries was then carried out to fine-tune national class boundaries to correspond to this GIG-wide definition of quality classes. Particular attention has been paid to the boundary between the two upper quality classes (High and Good) and the lower three classes (Moderate, Poor and Bad), since all Member States are required to ensure that all their water bodies reach Good ecological status by 2015.

For rivers, the United Kingdom has been involved in two GIGs (Northern GIG and Central/Baltic GIG – the UK leads the Central/Baltic GIG). The same Intercalibration Common Metric index (ICMi) has been used as the common metric across both of these GIGs. The ICMi is a multi-metric consisting of six Intercalibration Common Metrics (ICMs). The overall ICMi is then calculated as a weighted average of these indices (Van de Bund, 2009):

Average Score Per Taxon (ASPT)
Log10(sel_EPTD+1)
1-GOLD
total number of taxa (families)
number of EPT (Ephemeroptera, Plecoptera and Trichoptera) taxa (families)
Shannon-Wiener diversity index

The RIVPACS database contains these six ICMs. These were calculated by John Murray-Bligh (Environment Agency) using spring and autumn combined RIVPACS reference samples for the 614 RIVPACS III+ GB and 110 Northern Ireland sites.

These metrics were calculated in a manner consistent with the European WFD intercalibration process (using the ASTERICS software) and remain unchanged since their original addition to the RIVPACS database as part of SNIFFER project WFD72C in June 2008. Step-by-step instructions detailing how these indices were calculated exist in the file 'Instruction_text_ASTERICS.doc' which can be obtained from John Murray-Bligh on request (Murray-Bligh *et al*., 2006).

6.2 DISCUSSION AND RECOMMENDATIONS

As a result of the work done in SNIFFER project WFD100 (Davy-Bowker *et al*., 2010) the RIVPACS IV models designed for RICT can now produce expected values for a wide range of biotic indices addressing a variety of stressor gradients. These indices will support the use of RICT as a primary tool for water quality managers performing WFD classification and reporting of the quality of streams and rivers in the UK. The wide sweep of stress types that can now be assessed using RICT will also make this tool more generally useful in water quality management.

There are however a number of issues with the available biotic indices that need to be addressed. Firstly, while the indices that have been brought together in RICT represent what are thought to be the best available at this time, some will be better than others at describing stress gradients, and for some stress types, there are no indices available at all. This is particularly the case with metals (although some recent work by Stockdale *et al*., 2010 has indicated that EPT could be useful). It is therefore important that further work to refine and develop biotic indices should continue. Whilst organic pollution stress is quantified very effectively by the NTAXA and ASPT indices (and even more so by the WHPT and WHPT ASPT indices), other stress types have proved more difficult to assess using macroinvertebrates. Important progress has been made in the last 10 years with new indices for acidity, flow, sediments, and conservation value. All of these look set to become established as the best currently available tools for biomonitoring. However, not all of these have received the same level of testing. Indices for other stress types, such as hydromorphology and pesticides have been more challenging to develop. In these cases, indices have been sought from outside the UK and modified to better suit the UK macroinvertebrate fauna. The index-stressor relationships of these indices are perhaps the least well understood and certainly need to be studied in more detail.

A more comprehensive testing process therefore needs to be undertaken on the indices in RICT using UK-wide, large-scale, independent test datasets to quantify their index-stressor relationships and their assocaited uncertainty. These tests need to examine both index and O/E index-stressor relationships and to also include comparative testing of the existing RIVPACS IV and the new stressor-independent models developed in this project as sources of expected index values.

In order to refine, develop and test new indices, some consideration should be given to how monitoring data is gathered by the UK Agencies for WFD classification. Currently, chemical and biological sampling programmes tend to operate somewhat independently and don’t necessarily share the same sampling locations. If opportunities could be taken to bring these two sampling programmes closer together, this would enable the clearest possible data on biological communities and physicochemical variables to be gathered. The resultant increase in the quality and quantity of site-matched chemical and biological data would provide a considerable resource for the biotic index development and testing suggested above.

The following general recommendations are made in relation to biotic indices:

1. There is a need to develop a biotic index for assessing metal pollution.

2. WFD EQR banding schemes are required for many of the indices to report what is considered an acceptable degree of stress (High-Good) and what is not (Moderate, Poor or Bad).

3. A comprehensive objective testing process needs to be undertaken on the indices in RICT using UK-wide, large-scale, independent test datasets to quantify their index-stressor relationships and their associated uncertainty, for example following the approach to acidity index testing in Murphy *et al*., (in review) or organic/general degradation indices in Banks & McFarland (2010).

4. Following objective testing, the UK Agencies should make efforts to address any index under-performance issues identified, and where necessary new work should be commissioned to modify existing indices, or develop new ones where required so that indices for all stress types meet certain minimum performance criteria.

5. Testing needs to be done to examine index-stressor relationships with both observed index scores and RIVPACS observed/expected ratios. Work should also be done to compare the existing RIVPACS IV and the new stressor-independent models (developed in this project) as alternative sources of the expected index values for these tests.

6. Consideration should be given to assessing the extent to which chemical and biological monitoring points co-occur. Site-matched (rather than reach-matched) chemical and biological monitoring points would i) generate the substantial training datasets needed to refine or develop new indices and ii) generate the independent datasets for testing.

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9. GLOSSARY

ALK	Alkalinity
ALTBAR	ALTBAR Mean altitude of upstream catchment
ANC	Acid Neutralising Capacity
ASPBAR	Mean aspect (North=0, East=90) of inter-nodal slopes in upstream catchment
ArcGIS	Geographical information system software produced by ArcGIS
ASPECT-SOUTH	Deviation of mean upstream catchment aspect (ASPBAR) from South (East=West=90), where ASPBAR = mean aspect (North=0, East=90) of inter-nodal slopes in upstream catchment
ASPT	BMWP / NTAXA
ASTERICS	A software package for calculating biotic indices developed in the EU funded AQEM and STAR projects
ATEMPMEAN	Mean Air Temp
ATEMPRANGE	Air Temp Range
AWIC	Acid Water Community Index
BFI	Base Flow Index (BFI from HOST classification)
BGS	British Geological Survey
BMWP	Biological Monitoring Working Party
BOD	Biochemical Oxygen Demand
CB	Catchment Boundary
CCA	Canonical Correspondence Analysis
CCI	Community Conservation Index
CEH	Centre for Ecology & Hydrology
CEH-IRN	A former version of CEH Wallingford’s Intelligent River Network
CoS	CCI index Community Score Categories
CS	CCI index Conservation Score
CV	Coefficient of Variation
DF	Discriminant Function
DFCOEFF	Discriminant Function COEFFicient
DFMEAN	Discriminant Function end-group MEAN
DISCHARGE	Discharge Category
DPLBAR	Mean drainage path length (km) between each upstream node (on regular 50m grid) and the site; characterises upstream catchment size and configuration

DPSBAR	Mean drainage path slope (m/km) of all inter-nodal slopes for the upstream catchment; characterises overall steepness (from FEH)
DTM	Digital Terrain Model
DTMGEN	The latest version of CEH Wallingford's Integrated Hydrological Digital Terrain Model
E	Expected value
EA	Environment Agency
ECOSTAT	Common Implementation Strategy Working Group A – Ecological Status
EPT	Number of Ephemeroptera, Plecoptera and Trichoptera families
EPTD	Number of Ephemeroptera, Plecoptera, Trichoptera and Diptera families
EQI	Environmental Quality Index
EQR	Ecological Quality Ratio
FEH	Flood Estimation Handbook
fs	LIFE index Flow Score
GIG	Geographical Intercalibration Group
GIS	Geographical Information System
GOLD	Number of Gastropoda, Oligochaeta and Diptera families
GQA	General Quality Assessment
GSFI	German Stream Fauna Index
HOST	Hydrology of Soil Types
ICM	Intercalibration Common Metric
ICMi	Intercalibration Common Metric Index
IHDTM	CEH Wallingford's Integrated Hydrological Digital Terrain Model
IPR	Intellectual Property Rights
IRN	CEH Wallingford's Intelligent River Network
IRN DTM	A former version of CEH Wallingford's Integrated Hydrological Digital Terrain Model
LAT	Latitude
LCM 2000	Land Cover Map 2000
LDP	Longest drainage path (km) from an upstream catchment node to the site; characterises size principally and also configuration (from FEH)
LIFE	Lotic-invertebrate Index for Flow Evaluation
LOGALK	Log Alkalinity
LOGALT	Log Altitude
LOGALTBAR	Log(ALTBAR) Mean altitude of upstream catchment

LOGAREA	Log Upstream catchment Area (from DTMGEN)
LOGDEPTH	Log Water Depth
LOGDFS	Log Distance From Source
LOGDPLBAR	Log(DPLBAR) where DPLBAR = Mean drainage path length (km) between each upstream node (on regular 50m grid) and the site; characterises upstream catchment size and configuration
LOGDPSBAR	LOG(DPSBAR) where DPSBAR = Mean drainage path slope (m/km) of all inter-nodal slopes for the upstream catchment; characterises overall steepness (from FEH)
LOGLDP	LOG(LDP) where LDP = Longest drainage path (km) from an upstream catchment node to the site; characterises size principally and also configuration (from FEH)
LOGSLOPE	Log Slope (at site)
LOGSLOPESOURCE	Log Average Slope from Source to site
LOGWIDTH	Log Water Width
LONG	Longitude
MORECS	Meteorological Office Rainfall and Evaporation Calculation System
MSUBST	Mean Substratum (phi units)
NIEA	Northern Ireland Environment Agency
NTAXA	Number of BMWP scoring taxa
O	Observed value
O/E	Observed / Expected ratio
OS	Ordnance Survey
PANORAMA®	Ordnance Survey Land-Form contour data
pCCA	Partial Canonical Correspondence Analysis
PROPWET	Proportion of time upstream catchment soils are wet
PSI	Proportion of Sediment sensitive Invertebrates
Q95	Flow rate exceeded 95% of the time
RICT	River Invertebrate Classification Tool
SD(O/E)	Standard deviation of observed / expected ratios
SD_0(O/E)	Standard deviation of observed / expected ratios for a Null Model
SEPA	Scottish Environment Protection Agency
SNIFFER	Scotland & Northern Ireland Forum for Environmental Research
SPEAR	A biotic index of pesticide sensitivity
TL1, TL2 … TL5	Taxonomic Level. RIVPACS IV predicts taxa lists and biotic index values at these 5 possible taxonomic levels.

R^2	Proportion of variability that is accounted for by a model
R^2_{OE}	The percentage of the total variation in the observed (O) values of an index amongst the reference sites which is explained by the model predicted (E) values.
RDB1	Red Data Book 1 - Endangered
ReSub	Re-substitution (a model testing method)
RHS	River Habitat Survey
RIVPACS	River InVertebrate Prediction and Classification System (I, II, III, III+ & IV are different versions)
SMD	Soil Moisture Deficit (a statistic derived from MORECS)
$S_{organic}$	SPEAR index rating of sensitivity to organic toxicants
SPSS	Statistical Package for Social Sciences
SSR	PSI index Sediment Sensitivity Rating
STRAHLER	Strahler stream order
TWINSPAN	Two-Way INdicator SPecies ANalysis
WHPT	Walley, Hawkes, Paisley Trigg
WFD	Water Framework Directive
WFD46 WFD72B WFD72C WFD100 WFD119	SNIFFER project codes for various recent RIVPACS/RICT research and development projects
Xval	Cross-validation or leave-one-out (a model testing method)
%DRIFT0-NONE	%Drift Geology Class 0 - None in upstream catchment
%DRIFT1-PEAT	%Drift Geology Class 1 – Peat in upstream catchment
%DRIFT2-ALLUVIUM	%Drift Geology Class 2 – Alluvium in upstream catchment
%DRIFT3-CLAY	%Drift Geology Class 3 - Clay in upstream catchment
%DRIFT5-SANDSTONE	%Drift Geology Class 5 – Sandstone in upstream catchment
%SOLID0-NONE	%Solid Geology Class 0 - None in upstream catchment
%SOLID3-CLAY	%Solid Geology Class 3 - Clay in upstream catchment
%SOLID4-SHALE	%Solid Geology Class 4 - Shale in upstream catchment
%SOLID5-SANDSTONE	%Solid Geology Class 5 - Sandstone in upstream catchment
%SOLID6-CHALK	%Solid Geology Class 6 - Chalk in upstream catchment
%SOLID7-LIMESTONE	%Solid Geology Class 7 - Limestone in upstream catchment
%SOLID8-HARDROCKS	%Solid Geology Class 8 - Hard Rocks in upstream catchment

10. APPENDICES

Appendix I: Summary of all trial Models 1-36 in terms of average single season SD(O/E) and R^2_{OE} and discrimination % correctly allocated (ReSub and XVal) to biological end-group. Results for all indices for all possible RIVPACS single or combined season samples for the 685 RIVPACS IV GB reference sites.

Appendix I

Summary of all trial Models 1-36 in terms of % correctly discriminated to biological end-group (ReSub and XVal), and the SD(O/E) for all indices for all possible RIVPACS single or combined season samples for the 685 RIVPACS IV GB reference sites.

Variable name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	**15**	**16**	**17**	**18**
ALK	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
MSUBST	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LOGALT	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
LOGDFS	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
LOGWIDTH	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LOGDEPTH	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LOGALK	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
%DRIFT1-PEAT	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	0	1	1
%SOLID3-CLAY	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	0	1	1
%SOLID6-CHALK	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	0	1	1
%SOLID7-LIMESTONE	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	0	1	1
%SOLID8-HARDROCK	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	0	1	1
BFI	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	1	1	1
PROPWET	0	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	0
LOGAREA	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	1
LOGALTBAR	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
(a) %Correct	51.7	**47.3**	47.4	40.1	41.5	44.5	45.0	46.4	**48.0**	46.7	41.9	45.4	**47.0**	45.7	47.3	48.9	48.9	50.8
%Correct (XVal)	38.7	36.4	**35.5**	33.4	34.3	34.0	33.7	35.0	36.2	**36.5**	33.0	35.9	**36.2**	32.8	36.4	38.1	37.8	37.1

Variable name	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
ALK	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
MSUBST	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
LOGALT	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0
LOGDFS	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0
LOGWIDTH	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
LOGDEPTH	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
LOGALK	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
%DRIFT1-PEAT	1	1	0	0	0	1	1	0	0	1	1	1	1	0	0	0	1	1
%SOLID3-CLAY	1	1	0	0	0	1	1	0	0	1	1	1	1	0	0	0	1	1
%SOLID6-CHALK	1	1	0	0	0	1	1	0	0	1	1	1	1	0	0	0	1	1
%SOLID7-LIMESTONE	1	1	0	0	0	1	1	0	0	1	1	1	1	0	0	0	1	1
%SOLID8-HARDROCK	1	1	0	0	0	1	1	0	0	1	1	1	1	0	0	0	1	1
BFI	1	1	1	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0
PROPWET	0	1	1	0	1	1	1	0	0	0	0	0	1	1	0	1	1	1
LOGAREA	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1
LOGALTBAR	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1
(a) %Correct	50.8	**51.5**	**51.5**	48.8	50.1	**51.2**	48.3	47.4	48.6	49.2	50.5	50.1	**52.3**	50.7	48.5	49.3	**52.6**	49.9
%Correct (XVal)	37.5	38.5	**39.9**	36.9	38.2	**38.4**	36.9	35.5	36.8	36.5	35.6	36.8	37.5	**38.7**	36.6	**38.0**	36.9	34.3

Spring SD(O/E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	**15**	**16**	**17**	**18**
TL1 NTAXA	0.204	0.205	0.208	0.209	0.207	0.209	0.209	0.207	0.207	0.204	0.205	0.206	0.207	0.208	0.205	0.203	0.204	0.204
TL1 ASPT	0.071	0.074	0.077	0.081	0.082	0.081	0.080	0.080	0.080	0.081	0.080	0.080	0.078	0.079	0.074	0.074	0.074	0.074
TL2 WHPT NTAXA	0.209	0.210	0.213	0.213	0.212	0.214	0.213	0.211	0.211	0.208	0.210	0.210	0.211	0.212	0.210	0.208	0.208	0.208
TL2 WHPT ASPT	0.078	0.082	0.085	0.092	0.092	0.092	0.092	0.089	0.089	0.090	0.089	0.089	0.087	0.088	0.082	0.082	0.084	0.084
TL4 WFD AWIC (Sp)	0.090	0.089	0.093	0.093	0.093	0.092	0.092	0.093	0.092	0.092	0.094	0.093	0.094	0.094	0.089	0.089	0.090	0.090
TL2 LIFE (Fam)	0.047	0.050	0.048	0.052	0.053	0.052	0.052	0.051	0.051	0.052	0.052	0.051	0.050	0.051	0.050	0.050	0.050	0.050
TL4 LIFE (Sp)	0.052	0.055	0.053	0.058	0.058	0.058	0.058	0.057	0.057	0.057	0.057	0.057	0.056	0.057	0.055	0.055	0.056	0.057
TL3 PSI (Fam)	0.192	0.192	0.199	0.208	0.209	0.202	0.202	0.202	0.202	0.202	0.204	0.201	0.196	0.196	0.192	0.194	0.194	0.202
TL4 PSI (Sp)	0.235	0.244	0.242	0.272	0.273	0.250	0.248	0.245	0.244	0.268	0.303	0.272	0.239	0.239	0.244	0.249	0.237	0.285
TL2 SPEAR (Fam) %	0.205	0.210	0.216	0.229	0.228	0.227	0.226	0.222	0.222	0.221	0.220	0.219	0.217	0.218	0.210	0.209	0.213	0.212
TL4 SPEAR (Sp) %	0.231	0.236	0.240	0.250	0.249	0.252	0.251	0.247	0.247	0.243	0.243	0.242	0.242	0.244	0.236	0.236	0.240	0.239
TL4 CCI	0.204	0.205	0.208	0.209	0.207	0.209	0.209	0.207	0.207	0.204	0.205	0.206	0.207	0.208	0.205	0.203	0.204	0.204

Spring SD(O/E)	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
TL1 NTAXA	0.201	0.201	0.199	0.202	0.202	0.202	0.203	0.208	0.206	0.207	0.207	0.205	0.205	0.204	0.205	0.206	0.206	0.207
TL1 ASPT	0.074	0.074	0.075	0.074	0.074	0.074	0.074	0.077	0.077	0.076	0.076	0.075	0.075	0.077	0.076	0.076	0.074	0.074
TL2 WHPT NTAXA	0.205	0.205	0.204	0.207	0.206	0.205	0.208	0.213	0.210	0.212	0.212	0.210	0.210	0.208	0.210	0.211	0.210	0.211
TL2 WHPT ASPT	0.084	0.083	0.083	0.083	0.083	0.083	0.083	0.085	0.085	0.085	0.084	0.083	0.083	0.084	0.083	0.083	0.081	0.082
TL4 WFD AWIC (Sp)	0.090	0.090	0.089	0.089	0.089	0.090	0.091	0.093	0.092	0.092	0.092	0.092	0.092	0.092	0.094	0.093	0.093	0.093
TL2 LIFE (Fam)	0.050	0.049	0.050	0.050	0.050	0.049	0.049	0.048	0.048	0.047	0.047	0.047	0.047	0.048	0.048	0.048	0.047	0.047
TL4 LIFE (Sp)	0.056	0.056	0.055	0.056	0.056	0.056	0.056	0.053	0.053	0.053	0.052	0.051	0.051	0.051	0.052	0.052	0.051	0.052
TL3 PSI (Fam)	0.201	0.200	0.210	0.206	0.206	0.196	0.190	0.199	0.199	0.197	0.196	0.191	0.189	0.194	0.195	0.194	0.188	0.190
TL4 PSI (Sp)	0.284	0.273	0.466	0.447	0.440	0.283	0.233	0.242	0.244	0.239	0.234	0.230	0.227	0.238	0.238	0.236	0.227	0.238
TL2 SPEAR (Fam) %	0.211	0.210	0.208	0.207	0.207	0.208	0.208	0.216	0.216	0.215	0.214	0.212	0.212	0.212	0.211	0.211	0.210	0.211
TL4 SPEAR (Sp) %	0.237	0.237	0.233	0.232	0.232	0.235	0.236	0.240	0.240	0.242	0.241	0.239	0.240	0.236	0.236	0.236	0.237	0.237
TL4 CCI	0.427	0.427	0.421	0.421	0.421	0.426	0.425	0.421	0.420	0.424	0.423	0.422	0.423	0.429	0.423	0.432	0.422	0.421

Summer SD(O/E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	**15**	**16**	**17**	**18**
TL1 NTAXA	0.190	0.194	0.196	0.200	0.199	0.200	0.198	0.197	0.196	0.196	0.196	0.196	0.195	0.196	0.194	0.193	0.190	0.189
TL1 ASPT	0.076	0.079	0.081	0.086	0.086	0.085	0.084	0.083	0.083	0.085	0.084	0.085	0.082	0.083	0.079	0.078	0.079	0.079
TL2 WHPT NTAXA	0.197	0.199	0.203	0.205	0.205	0.207	0.205	0.205	0.204	0.202	0.203	0.203	0.202	0.203	0.199	0.199	0.196	0.196
TL2 WHPT ASPT	0.088	0.092	0.093	0.099	0.099	0.098	0.098	0.096	0.096	0.097	0.096	0.097	0.095	0.096	0.092	0.091	0.092	0.092
TL4 WFD AWIC (Sp)	0.088	0.087	0.091	0.090	0.090	0.090	0.089	0.089	0.089	0.089	0.090	0.090	0.090	0.090	0.087	0.087	0.087	0.087
TL2 LIFE (Fam)	0.058	0.060	0.058	0.062	0.062	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.060	0.061	0.060	0.059	0.059	0.059
TL4 LIFE (Sp)	0.061	0.063	0.062	0.065	0.065	0.065	0.065	0.064	0.064	0.064	0.065	0.064	0.064	0.065	0.063	0.062	0.062	0.063
TL3 PSI (Fam)	0.227	0.217	0.232	0.229	0.229	0.224	0.223	0.224	0.224	0.226	0.229	0.226	0.220	0.224	0.217	0.218	0.219	0.223
TL4 PSI (Sp)	0.282	0.250	0.295	0.272	0.273	0.261	0.259	0.260	0.261	0.271	0.285	0.270	0.254	0.261	0.250	0.258	0.258	0.275
TL2 SPEAR (Fam) %	0.226	0.230	0.236	0.245	0.242	0.238	0.238	0.236	0.236	0.237	0.238	0.239	0.234	0.235	0.230	0.225	0.224	0.225
TL4 SPEAR (Sp) %	0.232	0.235	0.240	0.246	0.243	0.242	0.241	0.240	0.241	0.240	0.241	0.242	0.239	0.241	0.235	0.232	0.231	0.232
TL4 CCI	0.452	0.455	0.449	0.451	0.445	0.459	0.459	0.459	0.459	0.454	0.453	0.458	0.460	0.460	0.455	0.452	0.463	0.462

Summer SD(O/E)	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
TL1 NTAXA	0.187	0.187	0.189	0.189	0.189	0.185	0.187	0.196	0.195	0.198	0.197	0.196	0.196	0.196	0.196	0.197	0.195	0.195
TL1 ASPT	0.079	0.079	0.079	0.079	0.079	0.078	0.078	0.081	0.081	0.081	0.080	0.080	0.080	0.081	0.080	0.081	0.079	0.079
TL2 WHPT NTAXA	0.194	0.193	0.195	0.196	0.195	0.192	0.194	0.203	0.202	0.204	0.204	0.203	0.203	0.203	0.203	0.203	0.202	0.201
TL2 WHPT ASPT	0.092	0.091	0.092	0.092	0.092	0.092	0.091	0.093	0.093	0.093	0.092	0.091	0.091	0.092	0.091	0.092	0.091	0.091
TL4 WFD AWIC (Sp)	0.087	0.087	0.086	0.087	0.087	0.087	0.087	0.091	0.091	0.091	0.090	0.090	0.090	0.090	0.091	0.091	0.091	0.091
TL2 LIFE (Fam)	0.059	0.059	0.060	0.060	0.060	0.059	0.060	0.058	0.058	0.058	0.058	0.058	0.057	0.058	0.058	0.058	0.057	0.058
TL4 LIFE (Sp)	0.062	0.062	0.063	0.063	0.063	0.063	0.063	0.062	0.061	0.061	0.061	0.060	0.060	0.060	0.061	0.061	0.060	0.062
TL3 PSI (Fam)	0.223	0.222	0.233	0.230	0.230	0.219	0.217	0.232	0.230	0.234	0.233	0.227	0.226	0.227	0.228	0.227	0.225	0.234
TL4 PSI (Sp)	0.276	0.272	0.374	0.356	0.352	0.268	0.253	0.295	0.292	0.329	0.324	0.313	0.311	0.289	0.287	0.287	0.308	0.330
TL2 SPEAR (Fam) %	0.226	0.225	0.227	0.229	0.229	0.225	0.225	0.236	0.234	0.231	0.230	0.229	0.228	0.232	0.231	0.233	0.229	0.230
TL4 SPEAR (Sp) %	0.232	0.232	0.232	0.233	0.233	0.232	0.232	0.240	0.239	0.239	0.238	0.237	0.236	0.236	0.236	0.237	0.237	0.240
TL4 CCI	0.464	0.463	0.456	0.457	0.458	0.464	0.463	0.449	0.445	0.451	0.450	0.452	0.451	0.452	0.449	0.457	0.455	0.454

Autuumn SD(O/E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	**15**	**16**	**17**	**18**
TL1 NTAXA	0.205	0.209	0.207	0.211	0.210	0.211	0.210	0.209	0.209	0.206	0.208	0.207	0.207	0.209	0.209	0.208	0.207	0.207
TL1 ASPT	0.081	0.084	0.087	0.090	0.090	0.089	0.089	0.088	0.088	0.087	0.088	0.088	0.087	0.088	0.084	0.082	0.083	0.083
TL2 WHPT NTAXA	0.212	0.215	0.214	0.217	0.217	0.217	0.217	0.216	0.216	0.213	0.214	0.214	0.214	0.216	0.215	0.215	0.214	0.214
TL2 WHPT ASPT	0.096	0.101	0.102	0.108	0.108	0.108	0.108	0.106	0.106	0.105	0.105	0.105	0.105	0.106	0.101	0.099	0.101	0.101
TL4 WFD AWIC (Sp)	0.095	0.095	0.100	0.101	0.100	0.100	0.100	0.101	0.100	0.100	0.101	0.101	0.101	0.101	0.095	0.095	0.096	0.096
TL2 LIFE (Fam)	0.053	0.056	0.054	0.058	0.058	0.057	0.057	0.057	0.056	0.057	0.057	0.057	0.056	0.057	0.056	0.055	0.055	0.056
TL4 LIFE (Sp)	0.060	0.063	0.061	0.066	0.066	0.065	0.065	0.065	0.064	0.065	0.065	0.064	0.064	0.065	0.063	0.062	0.063	0.063
TL3 PSI (Fam)	0.218	0.219	0.224	0.230	0.230	0.228	0.228	0.229	0.229	0.226	0.229	0.227	0.225	0.228	0.219	0.215	0.218	0.222
TL4 PSI (Sp)	0.295	0.275	0.305	0.293	0.294	0.289	0.284	0.285	0.286	0.300	0.312	0.300	0.280	0.280	0.275	0.275	0.276	0.293
TL2 SPEAR (Fam) %	0.252	0.258	0.271	0.281	0.278	0.279	0.279	0.277	0.276	0.268	0.270	0.269	0.270	0.271	0.258	0.252	0.257	0.257
TL4 SPEAR (Sp) %	0.259	0.266	0.275	0.285	0.282	0.282	0.282	0.279	0.279	0.273	0.275	0.274	0.273	0.275	0.266	0.262	0.266	0.266
TL4 CCI	0.408	0.409	0.409	0.410	0.410	0.411	0.410	0.409	0.410	0.423	0.411	0.424	0.410	0.412	0.409	0.407	0.412	0.411

Autumn SD(O/E)	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
TL1 NTAXA	0.205	0.204	0.203	0.205	0.204	0.203	0.205	0.207	0.207	0.209	0.208	0.207	0.207	0.205	0.205	0.205	0.206	0.207
TL1 ASPT	0.083	0.083	0.082	0.083	0.082	0.083	0.084	0.087	0.087	0.086	0.086	0.085	0.085	0.085	0.085	0.085	0.084	0.085
TL2 WHPT NTAXA	0.212	0.212	0.210	0.212	0.211	0.210	0.212	0.214	0.214	0.215	0.215	0.214	0.214	0.213	0.212	0.212	0.213	0.214
TL2 WHPT ASPT	0.101	0.100	0.099	0.100	0.100	0.101	0.101	0.102	0.102	0.101	0.101	0.100	0.100	0.100	0.100	0.100	0.099	0.100
TL4 WFD AWIC (Sp)	0.096	0.096	0.095	0.095	0.095	0.095	0.096	0.100	0.099	0.100	0.100	0.100	0.100	0.100	0.101	0.101	0.101	0.101
TL2 LIFE (Fam)	0.056	0.055	0.055	0.056	0.056	0.055	0.056	0.054	0.053	0.053	0.053	0.052	0.052	0.053	0.053	0.053	0.052	0.053
TL4 LIFE (Sp)	0.063	0.063	0.063	0.064	0.063	0.063	0.063	0.061	0.061	0.060	0.060	0.059	0.059	0.060	0.060	0.060	0.059	0.060
TL3 PSI (Fam)	0.223	0.223	0.226	0.226	0.226	0.221	0.219	0.224	0.220	0.223	0.224	0.218	0.216	0.217	0.222	0.222	0.220	0.225
TL4 PSI (Sp)	0.294	0.290	0.396	0.382	0.379	0.290	0.270	0.305	0.300	0.319	0.316	0.308	0.307	0.300	0.303	0.302	0.307	0.317
TL2 SPEAR (Fam) %	0.256	0.256	0.250	0.253	0.253	0.255	0.255	0.271	0.270	0.268	0.268	0.267	0.267	0.263	0.265	0.264	0.263	0.264
TL4 SPEAR (Sp) %	0.265	0.264	0.259	0.260	0.261	0.262	0.263	0.275	0.275	0.274	0.273	0.272	0.272	0.268	0.270	0.270	0.270	0.269
TL4 CCI	0.410	0.411	0.409	0.407	0.411	0.411	0.412	0.409	0.407	0.406	0.405	0.405	0.406	0.423	0.411	0.425	0.408	0.407

Spring+Summer SD(O/E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	**15**	**16**	**17**	**18**
TL1 NTAXA	0.156	0.158	0.162	0.164	0.163	0.164	0.163	0.162	0.162	0.159	0.161	0.161	0.161	0.162	0.158	0.157	0.156	0.155
TL1 ASPT	0.059	0.061	0.064	0.068	0.068	0.067	0.067	0.066	0.066	0.067	0.067	0.067	0.064	0.065	0.061	0.060	0.061	0.061
TL2 WHPT NTAXA	0.161	0.162	0.167	0.168	0.167	0.168	0.167	0.166	0.166	0.164	0.165	0.165	0.165	0.166	0.162	0.162	0.159	0.159
TL2 WHPT ASPT	0.073	0.076	0.080	0.085	0.085	0.085	0.084	0.082	0.082	0.083	0.082	0.082	0.081	0.082	0.076	0.075	0.076	0.077
TL4 WFD AWIC (Sp)	0.076	0.076	0.081	0.082	0.081	0.081	0.081	0.081	0.080	0.080	0.082	0.081	0.082	0.081	0.076	0.076	0.077	0.077
TL2 LIFE (Fam)	0.048	0.050	0.049	0.052	0.052	0.051	0.051	0.051	0.051	0.052	0.052	0.052	0.050	0.051	0.050	0.049	0.049	0.049
TL4 LIFE (Sp)	0.053	0.055	0.054	0.059	0.059	0.058	0.058	0.057	0.057	0.057	0.058	0.057	0.056	0.058	0.055	0.054	0.055	0.056
TL3 PSI (Fam)	0.175	0.174	0.181	0.188	0.188	0.182	0.182	0.182	0.182	0.185	0.188	0.185	0.178	0.180	0.174	0.173	0.174	0.180
TL4 PSI (Sp)	0.231	0.220	0.241	0.244	0.244	0.232	0.229	0.228	0.228	0.241	0.259	0.242	0.222	0.226	0.220	0.225	0.223	0.246
TL2 SPEAR (Fam) %	0.171	0.176	0.182	0.194	0.192	0.190	0.190	0.186	0.186	0.187	0.187	0.187	0.183	0.184	0.176	0.173	0.174	0.175
TL4 SPEAR (Sp) %	0.183	0.188	0.195	0.203	0.202	0.202	0.201	0.198	0.198	0.197	0.197	0.197	0.196	0.197	0.188	0.185	0.188	0.188
TL4 CCI	0.352	0.355	0.350	0.349	0.350	0.361	0.361	0.361	0.362	0.358	0.352	0.360	0.361	0.362	0.355	0.356	0.365	0.365
Spring+Summer SD(O/E)	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
TL1 NTAXA	0.153	0.153	0.153	0.155	0.155	0.153	0.155	0.162	0.161	0.162	0.162	0.161	0.161	0.160	0.161	0.161	0.161	0.161
TL1 ASPT	0.061	0.061	0.061	0.061	0.061	0.060	0.061	0.064	0.064	0.063	0.063	0.062	0.062	0.064	0.063	0.063	0.061	0.062
TL2 WHPT NTAXA	0.157	0.157	0.158	0.159	0.159	0.156	0.158	0.167	0.165	0.167	0.166	0.165	0.165	0.164	0.166	0.166	0.165	0.164
TL2 WHPT ASPT	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.080	0.080	0.079	0.079	0.077	0.077	0.078	0.077	0.078	0.076	0.077
TL4 WFD AWIC(Sp)	0.077	0.077	0.076	0.076	0.076	0.077	0.077	0.081	0.081	0.081	0.081	0.081	0.080	0.080	0.082	0.081	0.081	0.081
TL2 LIFE (Fam)	0.049	0.049	0.050	0.050	0.050	0.049	0.049	0.049	0.048	0.048	0.048	0.047	0.047	0.048	0.048	0.048	0.047	0.048
TL4 LIFE (Sp)	0.055	0.055	0.055	0.056	0.056	0.056	0.056	0.054	0.053	0.054	0.053	0.052	0.052	0.052	0.053	0.053	0.052	0.054
TL3 PSI (Fam)	0.180	0.179	0.190	0.188	0.188	0.177	0.174	0.181	0.179	0.180	0.179	0.175	0.174	0.176	0.178	0.178	0.173	0.178
TL4 PSI (Sp)	0.245	0.240	0.344	0.331	0.326	0.241	0.218	0.241	0.239	0.261	0.256	0.248	0.246	0.236	0.236	0.235	0.244	0.260
TL2 SPEAR (Fam) %	0.175	0.174	0.174	0.176	0.176	0.174	0.174	0.182	0.182	0.179	0.178	0.176	0.176	0.178	0.178	0.178	0.175	0.176
TL4 SPEAR (Sp) %	0.187	0.187	0.185	0.186	0.187	0.187	0.187	0.195	0.194	0.193	0.192	0.190	0.191	0.191	0.190	0.192	0.190	0.191
TL4 CCI	0.366	0.366	0.357	0.356	0.357	0.365	0.363	0.350	0.349	0.358	0.358	0.358	0.358	0.359	0.353	0.362	0.358	0.358

Spring+Autumn SD(O/E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	**15**	**16**	**17**	**18**
TL1 NTAXA	0.160	0.162	0.163	0.165	0.165	0.166	0.165	0.164	0.164	0.161	0.162	0.162	0.163	0.165	0.162	0.161	0.160	0.160
TL1 ASPT	0.059	0.062	0.065	0.069	0.069	0.068	0.068	0.067	0.067	0.067	0.067	0.067	0.066	0.067	0.062	0.061	0.062	0.062
TL2 WHPT NTAXA	0.166	0.167	0.169	0.170	0.170	0.170	0.170	0.169	0.169	0.166	0.167	0.167	0.168	0.169	0.167	0.166	0.165	0.165
TL2 WHPT ASPT	0.074	0.078	0.081	0.088	0.088	0.087	0.087	0.085	0.085	0.085	0.084	0.084	0.084	0.085	0.078	0.077	0.079	0.079
TL4 WFD AWIC(Sp)	0.078	0.078	0.083	0.084	0.083	0.083	0.083	0.084	0.083	0.083	0.084	0.084	0.084	0.084	0.078	0.078	0.079	0.079
TL2 LIFE (Fam)	0.045	0.048	0.047	0.051	0.051	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.049	0.050	0.048	0.048	0.048	0.048
TL4 LIFE (Sp)	0.053	0.057	0.054	0.059	0.060	0.059	0.059	0.058	0.058	0.058	0.058	0.058	0.057	0.058	0.057	0.055	0.056	0.057
TL3 PSI (Fam)	0.167	0.173	0.174	0.187	0.187	0.184	0.183	0.183	0.183	0.182	0.183	0.181	0.179	0.181	0.173	0.171	0.173	0.176
TL4 PSI (Sp)	0.234	0.235	0.244	0.259	0.259	0.245	0.241	0.238	0.238	0.256	0.277	0.258	0.234	0.234	0.235	0.236	0.231	0.256
TL2 SPEAR (Fam) %	0.182	0.188	0.196	0.208	0.207	0.206	0.205	0.202	0.201	0.199	0.199	0.199	0.197	0.199	0.188	0.185	0.189	0.188
TL4 SPEAR (Sp) %	0.194	0.201	0.209	0.220	0.219	0.219	0.218	0.214	0.214	0.210	0.211	0.211	0.210	0.212	0.201	0.199	0.202	0.202
TL4 CCI	0.345	0.345	0.345	0.344	0.342	0.346	0.346	0.345	0.346	0.351	0.344	0.353	0.345	0.349	0.345	0.345	0.347	0.347
Spring+Autumn SD(O/E)	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
TL1 NTAXA	0.158	0.158	0.157	0.158	0.158	0.157	0.159	0.163	0.163	0.165	0.164	0.163	0.163	0.161	0.161	0.162	0.163	0.163
TL1 ASPT	0.062	0.062	0.062	0.061	0.061	0.062	0.062	0.065	0.065	0.064	0.064	0.063	0.063	0.064	0.063	0.064	0.062	0.063
TL2 WHPT NTAXA	0.163	0.163	0.162	0.164	0.163	0.162	0.164	0.169	0.168	0.169	0.169	0.168	0.168	0.167	0.167	0.167	0.167	0.168
TL2 WHPT ASPT	0.079	0.079	0.078	0.078	0.078	0.079	0.079	0.081	0.081	0.081	0.080	0.079	0.079	0.079	0.079	0.079	0.077	0.078
TL4 WFD AWIC (Sp)	0.078	0.078	0.078	0.078	0.078	0.079	0.079	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.084	0.084	0.084	0.084
TL2 LIFE (Fam)	0.048	0.048	0.048	0.049	0.048	0.048	0.048	0.047	0.046	0.046	0.046	0.045	0.045	0.046	0.046	0.046	0.045	0.045
TL4 LIFE (Sp)	0.057	0.056	0.056	0.057	0.057	0.057	0.057	0.054	0.054	0.053	0.053	0.052	0.052	0.052	0.053	0.053	0.052	0.053
TL3 PSI (Fam)	0.176	0.175	0.179	0.179	0.179	0.174	0.172	0.174	0.172	0.170	0.170	0.168	0.167	0.170	0.173	0.172	0.167	0.169
TL4 PSI (Sp)	0.256	0.249	0.374	0.362	0.357	0.254	0.225	0.244	0.241	0.254	0.250	0.246	0.245	0.241	0.244	0.242	0.244	0.251
TL2 SPEAR (Fam) %	0.187	0.187	0.184	0.185	0.185	0.186	0.187	0.196	0.196	0.193	0.193	0.191	0.191	0.191	0.191	0.191	0.188	0.189
TL4 SPEAR (Sp) %	0.200	0.200	0.196	0.198	0.198	0.199	0.200	0.209	0.209	0.208	0.207	0.205	0.205	0.204	0.204	0.204	0.203	0.203
TL4 CCI	0.347	0.348	0.345	0.343	0.346	0.347	0.348	0.345	0.344	0.345	0.344	0.343	0.344	0.356	0.347	0.358	0.344	0.345

Summer+Autumn SD(O/E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	**15**	**16**	**17**	**18**
TL1 NTAXA	0.155	0.159	0.160	0.163	0.162	0.163	0.161	0.161	0.160	0.159	0.160	0.159	0.159	0.160	0.159	0.158	0.156	0.155
TL1 ASPT	0.062	0.065	0.068	0.071	0.070	0.070	0.070	0.068	0.068	0.069	0.069	0.069	0.067	0.069	0.065	0.063	0.064	0.064
TL2 WHPT NTAXA	0.162	0.165	0.167	0.170	0.170	0.170	0.169	0.169	0.168	0.167	0.167	0.167	0.166	0.167	0.165	0.165	0.162	0.161
TL2 WHPT ASPT	0.081	0.085	0.087	0.092	0.092	0.092	0.092	0.090	0.089	0.089	0.090	0.089	0.089	0.090	0.085	0.083	0.084	0.085
TL4 WFD AWIC (Sp)	0.081	0.081	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.088	0.087	0.087	0.087	0.081	0.082	0.082	0.082
TL2 LIFE (Fam)	0.050	0.053	0.051	0.055	0.055	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.053	0.054	0.053	0.052	0.052	0.052
TL4 LIFE (Sp)	0.057	0.060	0.059	0.063	0.063	0.062	0.062	0.061	0.061	0.061	0.062	0.062	0.061	0.062	0.060	0.059	0.059	0.060
TL3 PSI (Fam)	0.182	0.185	0.187	0.196	0.195	0.193	0.193	0.194	0.194	0.194	0.197	0.195	0.191	0.194	0.185	0.182	0.186	0.190
TL4 PSI (Sp)	0.247	0.233	0.260	0.255	0.254	0.245	0.242	0.243	0.243	0.253	0.266	0.254	0.238	0.242	0.233	0.234	0.234	0.249
TL2 SPEAR (Fam) %	0.189	0.195	0.204	0.214	0.211	0.210	0.209	0.207	0.207	0.204	0.206	0.205	0.203	0.204	0.195	0.189	0.191	0.191
TL4 SPEAR (Sp) %	0.192	0.200	0.207	0.218	0.215	0.214	0.214	0.212	0.212	0.209	0.211	0.210	0.209	0.210	0.200	0.196	0.197	0.198
TL4 CCI	0.370	0.373	0.367	0.370	0.369	0.381	0.381	0.380	0.382	0.376	0.371	0.377	0.381	0.382	0.373	0.372	0.383	0.382

Summer+Autumn SD(O/E)	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
TL1 NTAXA	0.154	0.153	0.154	0.155	0.154	0.151	0.152	0.160	0.159	0.160	0.160	0.159	0.159	0.159	0.158	0.159	0.158	0.157
TL1 ASPT	0.064	0.064	0.063	0.064	0.064	0.064	0.065	0.068	0.067	0.066	0.066	0.065	0.065	0.066	0.066	0.066	0.065	0.065
TL2 WHPT NTAXA	0.160	0.160	0.162	0.162	0.161	0.158	0.159	0.167	0.167	0.167	0.167	0.166	0.166	0.166	0.166	0.166	0.165	0.164
TL2 WHPT ASPT	0.084	0.084	0.084	0.084	0.084	0.084	0.085	0.087	0.087	0.086	0.086	0.085	0.084	0.085	0.085	0.085	0.084	0.085
TL4 WFD AWIC (Sp)	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.087	0.086	0.087	0.087	0.088	0.087	0.086	0.087	0.087	0.088	0.087
TL2 LIFE (Fam)	0.052	0.052	0.052	0.053	0.053	0.052	0.052	0.051	0.051	0.050	0.050	0.050	0.050	0.050	0.051	0.051	0.050	0.050
TL4 LIFE (Sp)	0.060	0.059	0.060	0.061	0.060	0.060	0.060	0.059	0.058	0.058	0.058	0.056	0.056	0.057	0.058	0.058	0.057	0.058
TL3 PSI (Fam)	0.191	0.189	0.196	0.195	0.195	0.188	0.186	0.187	0.184	0.186	0.186	0.182	0.182	0.182	0.185	0.185	0.183	0.187
TL4 PSI (Sp)	0.251	0.246	0.337	0.325	0.322	0.246	0.232	0.260	0.255	0.280	0.277	0.272	0.271	0.257	0.258	0.258	0.268	0.282
TL2 SPEAR (Fam) %	0.191	0.191	0.190	0.192	0.193	0.191	0.191	0.204	0.202	0.199	0.199	0.198	0.197	0.198	0.199	0.199	0.196	0.197
TL4 SPEAR (Sp) %	0.198	0.198	0.196	0.197	0.198	0.197	0.198	0.207	0.207	0.205	0.205	0.204	0.204	0.202	0.203	0.203	0.203	0.204
TL4 CCI	0.383	0.384	0.375	0.373	0.376	0.384	0.383	0.367	0.363	0.370	0.369	0.370	0.371	0.368	0.366	0.373	0.375	0.375

All 3 seasons SD(O/E)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	**15**	**16**	**17**	**18**
TL1 NTAXA	0.138	0.138	0.138	0.139	0.139	0.137	0.138	0.145	0.145	0.146	0.146	0.145	0.145	0.144	0.144	0.144	0.144	0.144
TL1 ASPT	0.055	0.055	0.055	0.055	0.055	0.055	0.056	0.059	0.059	0.058	0.058	0.057	0.057	0.057	0.057	0.057	0.055	0.056
TL2 WHPT NTAXA	0.143	0.143	0.144	0.145	0.145	0.142	0.143	0.152	0.151	0.152	0.151	0.151	0.151	0.150	0.150	0.150	0.150	0.149
TL2 WHPT ASPT	0.075	0.074	0.074	0.075	0.074	0.075	0.075	0.078	0.078	0.078	0.078	0.076	0.075	0.076	0.076	0.076	0.074	0.075
TL4 WFD AWIC (Sp)	0.074	0.074	0.073	0.074	0.073	0.074	0.074	0.079	0.078	0.079	0.079	0.079	0.079	0.078	0.080	0.079	0.079	0.079
TL2 LIFE (Fam)	0.048	0.048	0.048	0.049	0.049	0.048	0.048	0.047	0.047	0.046	0.046	0.046	0.046	0.046	0.047	0.047	0.046	0.046
TL4 LIFE (Sp)	0.056	0.056	0.056	0.057	0.057	0.056	0.057	0.055	0.054	0.054	0.054	0.052	0.052	0.053	0.054	0.054	0.053	0.054
TL3 PSI (Fam)	0.166	0.165	0.170	0.171	0.170	0.164	0.162	0.164	0.161	0.161	0.161	0.158	0.157	0.159	0.162	0.161	0.157	0.160
TL4 PSI (Sp)	0.233	0.228	0.314	0.305	0.302	0.230	0.212	0.231	0.227	0.243	0.240	0.234	0.232	0.226	0.228	0.227	0.231	0.243
TL2 SPEAR (Fam) %	0.165	0.165	0.164	0.166	0.166	0.165	0.165	0.175	0.174	0.171	0.171	0.169	0.169	0.170	0.171	0.171	0.167	0.168
TL4 SPEAR (Sp) %	0.176	0.175	0.173	0.175	0.175	0.175	0.176	0.186	0.185	0.183	0.183	0.181	0.181	0.180	0.181	0.181	0.179	0.180
TL4 CCI	0.340	0.341	0.332	0.331	0.333	0.340	0.340	0.325	0.324	0.331	0.331	0.331	0.332	0.331	0.326	0.334	0.333	0.334

All 3 seasons SD(O/E)	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
TL1 NTAXA	0.138	0.138	0.138	0.139	0.139	0.137	0.138	0.145	0.145	0.146	0.146	0.145	0.145	0.144	0.144	0.144	0.144	0.144
TL1 ASPT	0.055	0.055	0.055	0.055	0.055	0.055	0.056	0.059	0.059	0.058	0.058	0.057	0.057	0.057	0.057	0.057	0.055	0.056
TL2 WHPT NTAXA	0.143	0.143	0.144	0.145	0.145	0.142	0.143	0.152	0.151	0.152	0.151	0.151	0.151	0.150	0.150	0.150	0.150	0.149
TL2 WHPT ASPT	0.075	0.074	0.074	0.075	0.074	0.075	0.075	0.078	0.078	0.078	0.078	0.076	0.075	0.076	0.076	0.076	0.074	0.075
TL4 WFD AWIC (Sp)	0.074	0.074	0.073	0.074	0.073	0.074	0.074	0.079	0.078	0.079	0.079	0.079	0.079	0.078	0.080	0.079	0.079	0.079
TL2 LIFE (Fam)	0.048	0.048	0.048	0.049	0.049	0.048	0.048	0.047	0.047	0.046	0.046	0.046	0.046	0.046	0.047	0.047	0.046	0.046
TL4 LIFE (Sp)	0.056	0.056	0.056	0.057	0.057	0.056	0.057	0.055	0.054	0.054	0.054	0.052	0.052	0.053	0.054	0.054	0.053	0.054
TL3 PSI (Fam)	0.166	0.165	0.170	0.171	0.170	0.164	0.162	0.164	0.161	0.161	0.161	0.158	0.157	0.159	0.162	0.161	0.157	0.160
TL4 PSI (Sp)	0.233	0.228	0.314	0.305	0.302	0.230	0.212	0.231	0.227	0.243	0.240	0.234	0.232	0.226	0.228	0.227	0.231	0.243
TL2 SPEAR (Fam) %	0.165	0.165	0.164	0.166	0.166	0.165	0.165	0.175	0.174	0.171	0.171	0.169	0.169	0.170	0.171	0.171	0.167	0.168
TL4 SPEAR (Sp) %	0.176	0.175	0.173	0.175	0.175	0.175	0.176	0.186	0.185	0.183	0.183	0.181	0.181	0.180	0.181	0.181	0.179	0.180
TL4 CCI	0.340	0.341	0.332	0.331	0.333	0.340	0.340	0.325	0.324	0.331	0.331	0.331	0.332	0.331	0.326	0.334	0.333	0.334