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FULL PAPERS

Clyde re-built: when will river invertebrate communities return to a pre-industrial condition?

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ABSTRACT

The River Clyde has been described in the past as one of the worst polluted rivers in Britain. Since then, considerable improvements in water quality have been made, which contributed to the return of Atlantic salmon to the river system in the early 1980s. Using long-term river invertebrate data collected over a 32 year period (1975 - 2006) by the Scottish Environment Protection Agency and computer generated predictions (River Invertebrate Classification Tool) of river invertebrate communities, we examined the historic and current biological status of the River Clyde and make predictions about the future condition of the river system. We found that river invertebrate community richness had significantly increased over the study period and that the River Clyde has the potential to reach a pre-industrial condition by the year 2020. Our results also highlight the importance of considering long-term change when investigating biological recovery.

INTRODUCTION

It is now 140 years since a Royal Commission Report highlighted the River Clyde as one of the most heavily polluted rivers in Britain (Hammerton, 1986). This report was the catalyst (albeit low energy) that drove national, regional and local government to pass legislation to help improve the condition of surface waters in Britain. Legislation and local efforts to enforce this legislation led to improvements in the water quality within the River Clyde catchment (Table 1), contributing to the return of Atlantic salmon (*Salmo salar*) to the river in the early 1980s (Hammerton, 1986). Thirty years have passed since this iconic moment, but has the river continued to improve and to what extent has the River Clyde recovered?

Measuring biological recovery is a complex process. The endpoint at which system recovery is deemed to have been achieved is highly dependent on the parameters used to assess system change. For example, measurement of the abiotic conditions may indicate that a disturbed system has returned to a pre-disturbed condition in terms of the physical environment (e.g., availability of habitat, water chemistry) but there is invariably a lag in the re-establishment of the biological community (e.g., Ormerod & Durance, 2009). The choice of a biological parameter used to assess recovery is also dependent on the choice of organism, or group of organisms, as organism behaviour can also influence the interpretation of results. In river systems for example, fish are highly mobile and can move from areas they perceive as poor quality. Their presence in a river might therefore be only representative of the conditions at that instant. Freshwater macroinvertebrates (invertebrates that can be seen with the unaided eye), have been used as indicators of river health for a long time (Hynes, 1966). This group of animals show a wide range of tolerances to various polluting influences (Armitage *et al*., 1983) and are relatively sedentary (*c.f.* fish). As such, macroinvertebrates provide a good indication of the prevailing abiotic (and biotic) conditions at a site.

To determine whether a system has recovered fully, an endpoint or benchmark must be selected against which to measure system change and a progression towards a pre-disturbed condition. A common approach is to make comparisons between sites that have, and have not been disturbed. This approach is of course dependent on the availability of comparable sites that have not been influenced by the disturbance being investigated. An alternative is to use a modelling approach, where the environmental characteristics of a system are used to make predictions about the community expected to be found at a site in the absence of disturbance. This approach has been used to predict for example, the composition of bird communities (Feria & Paterson, 2002), the likelihood of the establishment of invasive species (Gallardo *et al*., 2011) and the composition of macroinvertebrate communities in running water sites (e.g., Wright *et al*., 1984); it is this modelling approach we use here.

Using biological information collected from across a river catchment previously impacted by industry over a 32 year period (1975-2006) and information generated from computer simulations, we examine the degree to which the River Clyde has recovered by investigating temporal changes to the macroinvertebrate community and make predictions about the time frame for biological recovery of the River Clyde.

METHODS

The River Clyde is located in west-central Scotland (between Lat: 56° N & 55° 30' N and Long: 004° 73' W & 003° 55' W). The catchment covers an area of 3125 km^2 with a total river length of 4165 km and 26 km^2 of freshwater lochs and reservoirs. Land use in the catchment is dominated by agriculture (45%) and natural and semi-natural habitats (37%) with urban land use comprising 18%, the remaining 1% being lochs and reservoirs (Fig. 1). Although urban land use does not dominate, in 2006 31% (1.6M) of the total population of Scotland lived within the catchment (General Register Office for Scotland Report, 2007).

Macroinvertebrate data have been collected from the River Clyde by the Scottish Environment Protection Agency (SEPA) and its previous incarnations since 1975, to monitor the water quality of the watercourse. The same standard three minute kick sample using a standard (1 mm mesh size) pond net has been used to collect biological samples since 1975 with the addition of a one minute hand search from 1990 (Doughty, R. *pers. comm.*). Collected material was preserved and later identified in the laboratory to the taxonomic level of family (see examples Plate 1). This information was then used to assess the biological condition of the river water at a site using the Biological Monitoring Working Party (BMWP) system (see Armitage *et al.*, 1983). We use these data to assess the biological recovery of the River Clyde.

Community richness was determined from the list of 82 macroinvertebrate families (but excluding the families Aphelocheridae, Brachycentridae, Goeridae, Lepidostomatidae, Odontoceridae, Psychmyiidae and Valvatidae because of taxonomic and recording issues at the start of the study period) that are recorded as part of the BMWP system (Armitage *et al.*, 1983). Community richness measured at the taxonomic resolution of family from the constrained BMWP list of scoring families has been shown to be a highly significant (R = 0.854, P < 0.0001) representation of species richness found at running water sites in Great Britain (Wright *et al.*, 1998).

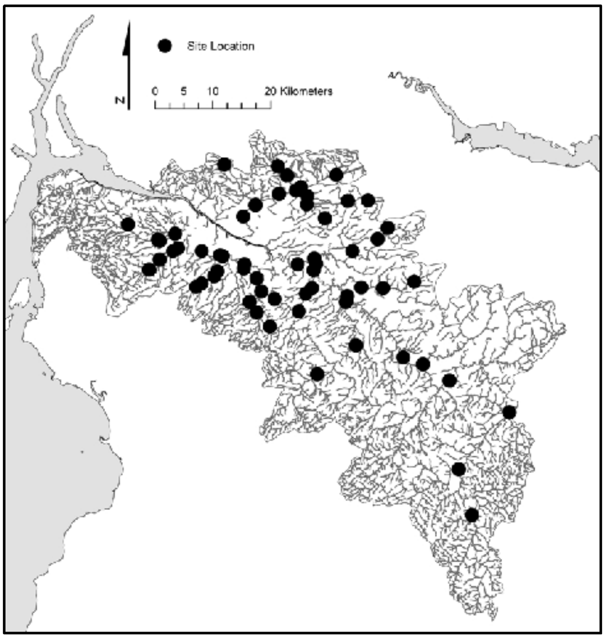

Fig. 1. Location of the 62 sites in the River Clyde at which invertebrate data were collected (2618 samples) over the 32 year (1975 - 2006) study period.

Table 1. Chronology of the River Clyde pollution abatement efforts (adapted from Hammerton, 1986).

Year	Event
1872	Royal Commission Report highlighted the River Clyde as one of the most heavily polluted rivers in Britain.
1876	Rivers Pollution Act enacted.
1895	Within the Clyde catchment Lanark County Council established as a pollution control authority to enforce the provisions of the Rivers Pollution Act, 1876.
1903 1909 1924	Lanark County Council pollution reports highlight improvements in domestic waste treatment, the 1924 report highlighted the shortcomings of the current legislation in allowing the county council to set effluents standards and take speedy legal action against polluters.
1927	Scottish Board of Health survey of river pollution highlighted the River Clyde as the worst affected with 235 'pollutions' of the 880 total in Scotland (the River Fourth was next with 107 'pollutions'.
1927	Secretary of State for Scotland appointed an Advisory Committee on Rivers Pollution Prevention.
1936	Special report produced by the Advisory Committee on River Pollution Prevention stated *"we cannot over emphasise the serious situation that exists in many parts of the country on account of the gross pollution of river and have come to the conclusion that a satisfactory solution of the problems of rivers pollution is not possible under the present administrative arrangements".*

1946	Secretary of State for Scotland appointed the Sub-committee of the Scottish Water Advisory Committee to recommend how to amend the law on river pollution.
1950	Sub-committee of the Scottish Water Advisory Committee report produced.
1951	Rivers (Pollution Prevention) (Scotland) Act enacted, which involved the setup of independent river purification boards.
1956	Clyde River Purification Board established.
1958	Chemist appointed to Clyde River Purification Board.
1960	First water chemistry samples recorded.
1965	Rivers (Pollution Prevention) (Scotland) Act revised.
1972	Clyde River Purification Board Act enacted, a local act was passed to control the discharge of pollutants underground and the extraction of minerals such as sand and gravel directly from the river bed.
1975	First biological water samples recorded.
1983	First run of Atlantic salmon in the River Clyde for over 120 years.
2000	Water Framework Directive, European Legislation requires EU states to achieve “good ecological and chemical status” in all waterbodies by 2015.

Macroinvertebrate information was available from 62 sites across the River Clyde catchment (Fig. 1). Generally, each site was sampled in spring (March to May) and autumn (September to November) each year for the study period, although there were some minor deviations from this pattern and data from 1991 to 1994 were lost in storage and not available for analysis.

River Clyde macroinvertebrate community richness change

To determine if there had been a significant change in the richness of the River Clyde macroinvertebrate communities, we used a mixed effects linear model to examine the relationship between community richness and year, including 'site' as a random factor (to account for pseudo-replication as sites were sampled multiple times over the study period).

Modelled community richness

To investigate the community richness for the River Clyde we would expect in the absence of human influence, we used a predictive model, the River Invertebrate Classification Tool (RICT; SEPA, 2012). RICT is a web-based application that can provide predictions (based on a few environmental characteristics) of the number and type of macroinvertebrate families found in a section of a river in the absence of human influence (Table 2). Originally developed under the acronym RIVPACS (River Invertebrate Prediction and Classification System), this predictive approach to water quality assessment was pioneered in the U.K. (Wright *et al.*, 1984) and has been accepted as a standard method in the European Union as part of Water Framework Directive (WFD; European Commission, 2000) monitoring (Logan & Furse, 2002) and has been developed for use in other countries worldwide [e.g. AUSRIVAS (Australia), Davies, 2000; $\text{SEPAC}_{\text{SRI}}$ (Sweden), Davy-Bowker *et al.*, 2006; PERLA (Czech Republic), Kokeš *et al.*, 2006)].

In brief, the model uses community composition data collected from reference sites (i.e., river sites deemed to be of "very high" ecological quality, with minimal impact from human activity). Reference sites are grouped according to the similarities in the relationship between the environmental characteristics and the invertebrate community composition, and it is these reference groups that form the basis of the predictive model. Variables measured (Table 2) at a site are then used to predict which families are likely to present at that site given the local environmental conditions (see Wright *et al.*, 2000 and CEH, 2012).

For each of the sites, environmental characteristics required for RICT were derived from Ordinance Survey (OS) maps, field sheets and alkalinity data were provided by the chemistry department in SEPA. As sampling sites were chosen to represent the best available natural conditions (Doughty, R., *pers. comm.*) within river sections, site substrate (one of the environmental variables used in the model) was in relatively good condition and, the measured alkalinity (another model variable) in 2006 was unremarkable (87.3 mg L^{-1} ± 9.5, 2 standard errors = 95% confidence interval) given the underlying geology (carboniferous rocks and coal measures; BGS, 1985). The remaining environmental variables derived from OS maps remain constant for millennia. We therefore defined model predictions based on the 2006 environmental variables as a benchmark against which to assess River Clyde community richness.

Table 2. Environmental variables used to determine community composition using the RICT system.

Variable	Unit of Measurement	Data Source
Location	National Grid Reference	OS maps
Altitude	m	OS maps
Distance from river source	m	OS maps
Slope	m km^{-1}	OS maps
Discharge category (9 categories)	m^3s^{-1} 1 (< 0.31 m^3s^{-1}) 2 (0.31 – 0.62 m^3s^{-1}) 3 (0.62 – 1.25 m^3s^{-1})	SEPA Hydrology Unit

	4 (1.25 – 2.5 m^{3}s^{-1}) 5 (2.5 – 5.0 m^{3}s^{-1}) 6 (5 – 10 m^{3}s^{-1}) 7 (10 – 20 m^{3}s^{-1}) 8 (20 – 40 m^{3}s^{-1}) 9 (40 – 80 m^{3}s^{-1})	
Substratum characteristics (5 categories, summing to 100%)	% cover boulder/cobble (> 64mm); pebble/gravel (2-64 mm); sand (0.06 – 2 mm); silt/clay (< 0.06 mm)	SEPA field sheets
Stream width	m	SEPA field sheets
Stream depth	cm	SEPA field sheets
Sample season (3 categories)	Spring (*March – May, incl. February*) Summer (*June – August*) Autumn (*September – November, incl. January & December*)	
Alkalinity	mgL^{-1}	SEPA chemistry unit

River Clyde recovery

We investigated the time frame in which the River Clyde has the potential to attain a community richness expected in the absence of human impact using short- and long-term measurements of contemporary community richness.

As a short-term assessment of the invertebrate communities of the River Clyde, we compared measured (sampled) community richness in 2006 with RICT modelled predictions of site community richness *i.e.*, the probable community richness of an un-impacted site (based on the environmental variables measured in 2006) for each of the 62 sites in a paired t-test.

To account for long-term change we extrapolated the results of the linear mixed model. The intersection of the regression line (± 2 standard errors) and mean modelled community richness (± 2 standard errors) (2006 RICT predictions) provides an indication of the period over which the River Clyde is likely to achieve a biological level akin to that expected in the absence of human mediated stress. All statistical analyses were performed in R version 2.13.1 (R Development Core Team, 2010)

RESULTS

Over the period from 1975 to 2006, 2618 samples were collected from 62 sites in the River Clyde catchment. The mean number of families in a collected sample was 15.6 ± 0.2 (2 standard errors) (range 0 - 34 families) over the 32 year period.

River Clyde macroinvertebrate community richness change

Macroinvertebrate community richness increased significantly over the 32 year study period ($t_{(2618,62)} = 30.355$, $P < 0.001$; Fig. 2) and the regression equation took the form:

Community Richness = 0.214 * Year – 410.713

This approximates to a mean increase of one macroinvertebrate family every five years, within the River Clyde catchment over the study period.

Modelled community richness

The predicted, un-impacted, community richness supported at each of the 62 sites (determined using RICT) ranged from 19.1 to 27.9 families [mean 22.2 ± 0.3 (2 standard errors)]. Actual community richness measured from samples collected from the 62 sites in 2006 ranged from 9 to 31 families [mean 21.2 ± 0.8 (2 standard errors)]. The mean of the RICT modelled community richness and the mean of the measured (actual) community richness in 2006 were close to being statistically significantly different (paired t-test, $t_{(124)} = 1.805$, $P = 0.07$; Fig. 3).

River Clyde recovery

The intersection between modelled community richness and the extrapolation of the linear regression of macroinvertebrate community richness on year occurred at 2019.8 (range 2018.6 – 2021.2; Fig 2)

DISCUSSION

Since the Royal Commission Report, in 1872, there have been significant changes to legislation controlling the effects of human impact on U.K. river systems (Hammerton, 1986; European Commission, 2000). The results from this study have provided an insight into the long-term change of the biological state of a river recovering from industrial activity, as a result of the implementation of this legislation, and have highlighted the importance of accounting for historic change in assessing the recovery of a biological system.

Over the 32 year study period community richness in the River Clyde increased on average by one family every five years and represents an average addition to the River Clyde macroinvertebrate community by just over six families over the study period.

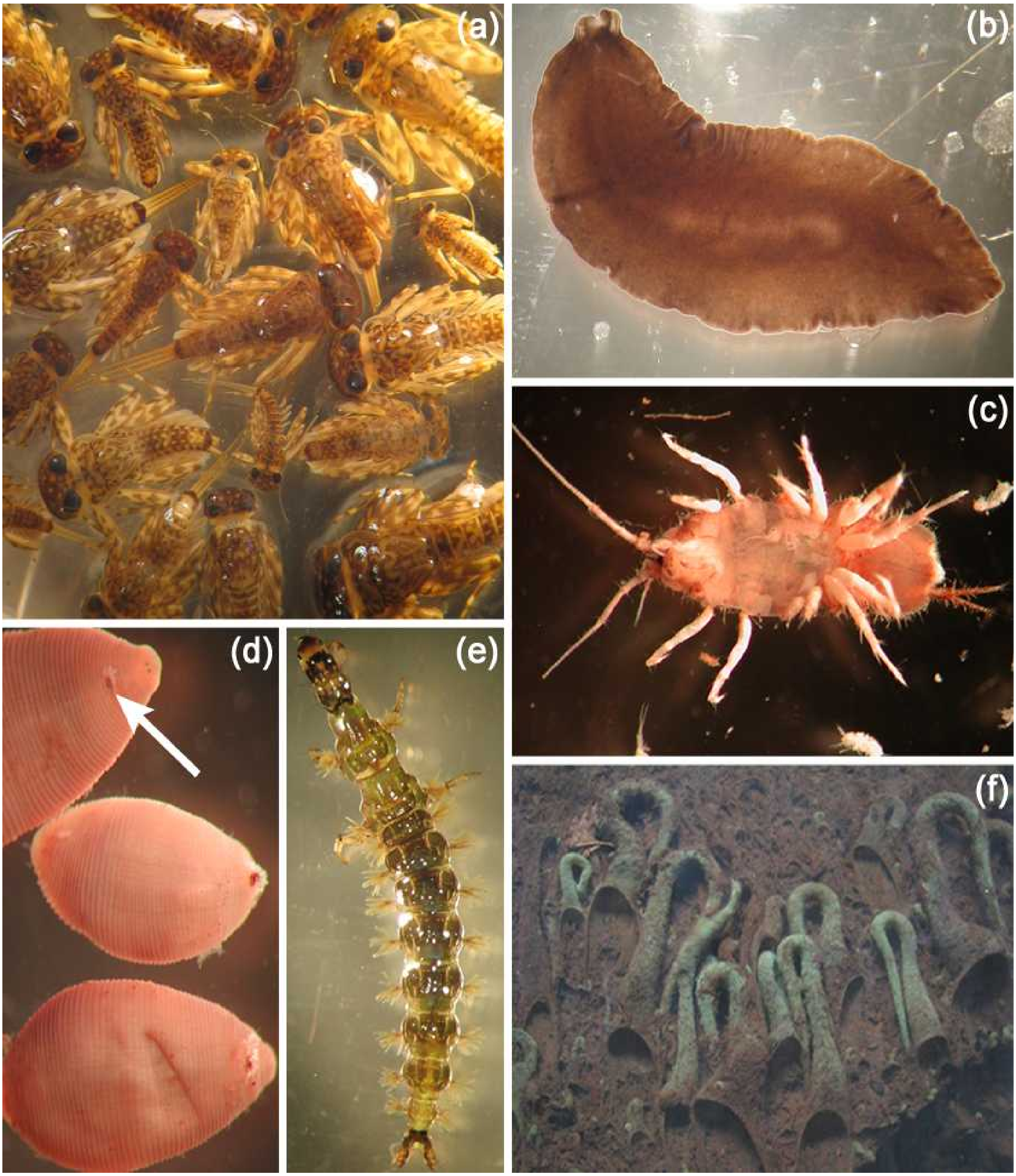

Plate 1. Some macroinvertebrates of the River Clyde. (a) Ephemeroptera belonging to the taxonomic family, Heptageniidae (genus *Ecdyonurus* pictured). Frequently found in rivers of good to high water quality, this family feeds in fast flowing river sections by scraping algae from the substrate surface. Species in this family are dorso-ventrally flattened to allow them to feed in the boundary layer. (b) *Bdellocephala punctata* a member of the family Dendrocoelidae (Tricladida). This family is indicative of good to moderate water quality has been described from a wide variety of habitats from still water to fast flowing river sections. This particular species is nationally uncommon, but is found in the River Clyde. (c) *Asellus aquaticus* (Asellidae) is an aquatic analogue of the terrestrial woodlouse (multiple genera). Asellidae are generalist detrivores and can tolerate very poor water quality. Pictured here is a ventral view of a mature female detailing a juvenile in the brood-pouch. (d) The leach *Helobdella stagnalis* is a member of the taxonomic family Glossiphoniidae and is easily identified though the presence of a chitinoid scute (indicated by the arrow). (e) A trichopteran of the family Rhyachophilidae, *Rhyacophila dorsalis* is an active foraging predator found in clean fast flowing sections of river systems. This species is widespread throughout the River Clyde. (f) Some other species of predatory Trichoptera build nets and collect drifting material that becomes entrained. In this picture the water is flowing from the bottom of the picture and the animal inhabits the u-shaped section of the net.

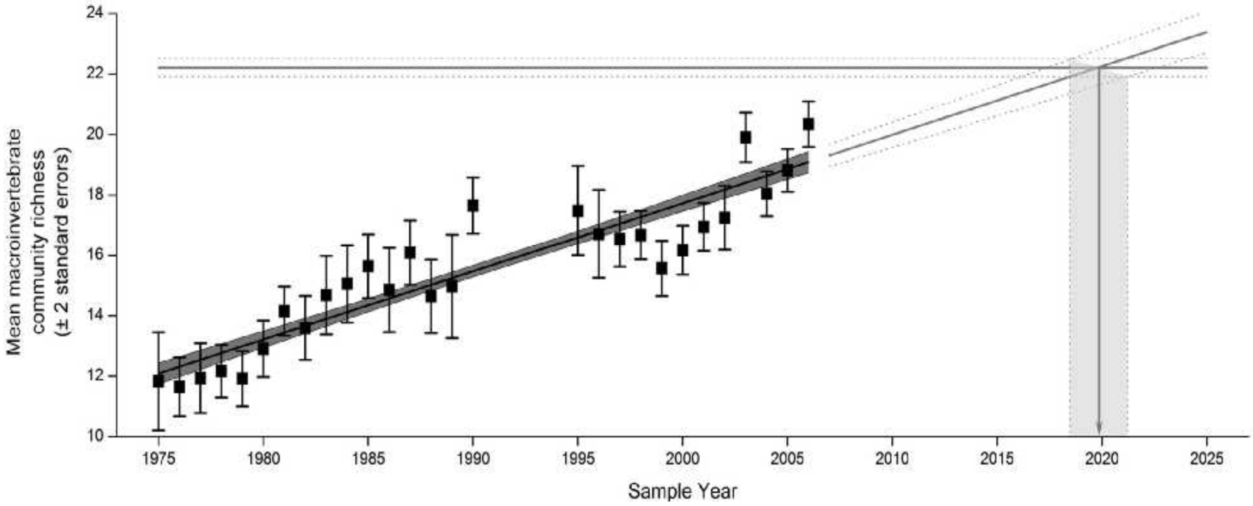

Fig. 2. Temporal change in community richness in the River Clyde over the study period. Mean collected community richness (black squares); regression line of community richness on year (black line); extrapolation of temporal change in community richness (grey line); mean modelled (RICT predictions) community richness (horizontal grey line); intersection of extrapolated mean and modelled mean community richness (grey arrow). All confidence intervals are 2 standard errors (= 95% confidence intervals).

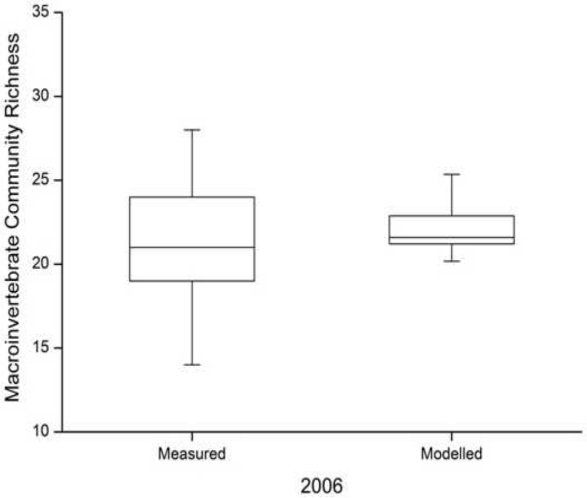

Fig. 3. Box [25, 50 (median) and 75 percentile] and whisker plot (5 and 95 percentile) of measured and modelled community richness in the River Clyde in 2006.

The increase in community richness within the River Clyde has arisen as a result of improvements to the chemical water quality (e.g., reductions in ammonia and suspended solids and increases in dissolved oxygen) and these changes have facilitated the colonisation of additional macroinvertebrate families through the opening of previously unavailable niche space.

How representative the rate of change in River Clyde community richness is in terms of ecological recovery of a river system is difficult to explain. Recovery trajectories are reliant on the ecological parameter measured and the endpoint (at which recovery is deemed to be achieved) selected. In a review assessing long-term change in river systems Jackson & Füreder (2006) highlighted a lack of studies detailing change over longer-term periods (which they defined as greater than five years). In fact of the 236 sites identified in their review the majority (63%) were of 10 years or less.

Our study also highlighted the importance of considering historical changes when assessing recovery. Sampled community richness in 2006 in the River Clyde almost met the threshold for being significantly different than that expected in the absence of human impact (RICT predicted richness), and this snapshot of condition could lead to a conclusion that the river had recovered to a healthy state at that time. The inclusion of the pattern of ecological changes prior to 2006 shifts this conclusion by over a decade, indicating a healthy river state will not be achieved until 2020. These results highlight the importance of using data collected over biologically meaningful time scales that dampen the effects of short-term fluctuations.

The results from this study are encouraging for the biological recovery of the River Clyde. The ambitious aims set by the WFD, that all water bodies (with the exception of heavily modified water bodies) need to reach ‘good ecological status’ by 2015 (with the possible extension for another 12 years; European Commission, 2000), may be achieved within the River Clyde. There is overwhelming evidence from Europe that, even within the extended time period, many regions will struggle to meet ‘good ecological status’ by 2027 (Hering, *et al.*, 2010). The extrapolation of our result indicates that the River Clyde should be achieving target community richness by 2020, seven years prior to the 2027 deadline.

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REFERENCES

Armitage, P. D., Moss, D., Wright, J. F. & Furse, M. T. (1983). The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Research* 17, 333-347.

BGS (1985). The Midland Valley of Scotland (British Regional Geology). 3rd Revised Edition. pp 180.

CEH (2012). Centre for Ecology and Hydrology web site information (URL accessed on 9 November 2012) http://www.ceh.ac.uk/products/software/RIVPACS.html.

Clarke, R. T., Furse, M. T., Davy-Bowker, J. & Gunn, I. D. M. (2005). RPBATCH: RIVPACS III+ River InVertebrate Prediction and Classification System with error assessments. Release 3.3 (January 2005). User Manual. Produced for the Environment Agency, Scottish Environment Protection Agency (SEPA) and Environment and Heritage Service Northern Ireland. pp. 64 & 14 Appendices.

Davies, P. E. (2000). Development of a national river bioassessment system (AUSRIVS) in Australia. In: Assessing the biological quality of fresh water: RIVPACS and other techniques (eds. Wright, J. F., Sutcliffe, D. W. & Furse, M. T.). Freshwater Biological Association, Ambleside, Cumbria, UK. pp. 373 + xxiv.

Davy-Bowker, J., Clarke, R. T., Johnson, R. K., Kokes, J., Murphy, J. F. & Zahrádková, S. (2006). A comparison of the European Water Framework Directive physical topology and RIVPACS-type models as alternative methods of establishing reference conditions for benthic macroinvertebrates. *Hydrobiologia* 566, 91-105.

European Commission (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities L 327, 1-72.

Feria, A.T.P. & Paterson, A.T. (2002). Prediction of bird community composition based on point-occurrence data and inferential algorithms: a valuable tool in biodiversity assessments. *Diversity & Distributions* 8, 49-56.

Gallardo, B., Errea, M. & Aldridge, D. (2011). Application of bioclimatic models coupled with network analysis for risk assessment of the killer shrimp, *Dikerogammarus villosus*, in Great Britain. *Biological Invasions* 14, 1265-1278.

General Register for Scotland Report (2007). Scotland's Population 2007: The registrar general's annual review of demographic trends: 153rd edition. General Register Office for Scotland, Edinburgh.

Hammerton, D. (1986). Cleaning the Clyde - a Century of Progress? *Journal of the Operational Research Society* 37, 911-921.

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliot, M., Feld, C.K., Heiskanen, A-S., Johnson, R.K., Moe, J., Pont, D., Solheim, A.L. & van de Bund, W. (2010). The European Water Framework Directive at the age of 10: A critical review of the achievements with recommendations for the future. *Science of the Total Environment* 408, 4007-4019.

Hynes, H. B. N. (1966). The Biology of Polluted Waters. Liverpool University Press, pp. 202 + xiv.

Jackson, J.K. & Füreder, L. (2006). Long-term studies of freshwater macroinvertebrates: a review of the frequency, duration and ecological significance. *Freshwater Biology* 51, 591-603.

Kokeš, J., Zahrádková, D., Němejcová, J., Hodovsky, J., Jarkovsky, J. & Soldán, T. (2006). The PERLA system in the Czech Republic: a multivariate approach for assessing the ecological status of running waters. *Hydrobiologia* 566, 343-354.

Logan, P. & Furse, M.T. (2002). Preparing for the European Water Framework Directive – making the links between habitat and aquatic biota. *Aquatic Conservation: Marine and Freshwater Ecosystems* 12, 425-437.

Ormerod, S.J. & Durnace, I. (2009). Restoration and recovery from acidification in upland Welsh streams over 25 years. *Journal of Applied Ecology* 46, 164-174.

R Development Core Team (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

SEPA (2012). River Invertebrate Classification Tool (RICT) web based application available at http://www.sepa.org.uk/science_and_research/what_we_do/monitoring_and_reporting/ecology/rict.aspx. (URL accessed on 4 February 2012)

Wright, J.F., Moss, D., Armitage, P.D. & Furse, M.T. (1984). A preliminary classification of running water sites in Great Britain based on macro-invertebrate species and prediction of community types using environmental data. *Freshwater Biology* 14, 221-256.

Wright, J.F., Moss, D. & Furse, M. T. (1998). Macroinvertebrate richness at running-water sites in Great Britain: a comparison of species and family richness. *Fundamental and Applied Limnology* 26, 1174-1178.

Wright, J. F., Sutcliffe, D. W. & Furse, M. T. (eds) (2000). Assessing the biological quality of fresh water: RIVPACS and other techniques. Freshwater

Biological Association, Ambleside, Cumbria, U.K. pp. 373 + xxiv.