WCMC Biodiversity Series No. 8

Freshwater Biodiversity: a preliminary global assessment

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5. DIVERSITY, RISK AND PRIORITIES: A FRAMEWORK FOR ANALYSIS OF RIVER BASINS

This chapter develops a global analysis of fish diversity at catchment level as the main element in an outline assessment of pressures and the relative global importance of river basins. An overall measure of relative wilderness value is used to estimate the magnitude of high-level regional and landscape scale effects on the current condition of catchment basins. Estimates of future pressures on water resources at national level are then used to indicate possible trends in catchment condition. These two factors are then evaluated together with fish diversity data in order to suggest levels of priority at global scale.

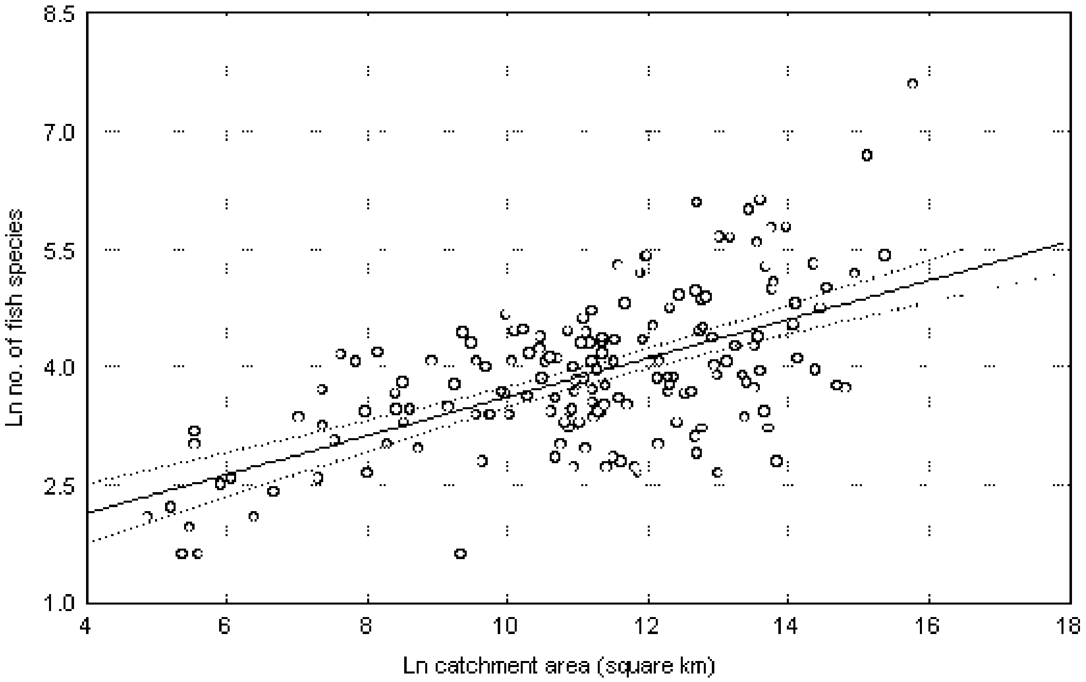
Freshwater fishes: analysis of global diversity

A first step in planning for improved biodiversity management is to assess the biological resources present, and at local or national level it is important to consider this information in a continental or global context. With this in mind, we have assembled a database of estimates of the number of fish species in a large number of river basins.

The data have been gathered from a wide range of sources, including published literature and unpublished data supplied by colleagues (please refer to Acknowledgements, above). Figures are available for 166 basins, of which 107 are amongst the 151 mapped in the present analysis (Map 1, and Annex 1). Fish species included are those that spend a significant part of their life within river systems (including anadromous and catadromous species, that is those that migrate up or down rivers to breed); introduced species and marine species that enter estuarine waters only have been excluded where possible.

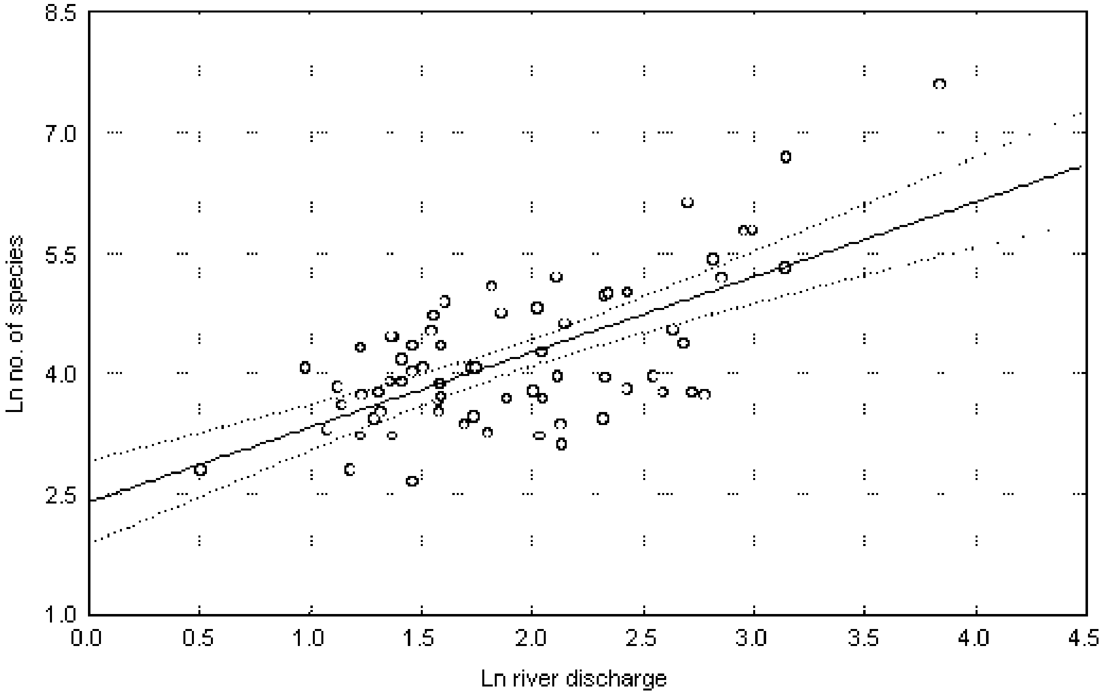
For most catchment basins actual counts of species are included; however in the case of a small number of very large tropical catchments (the Amazon, Mekong and Congo/Zaire) where it is known that species counts are very incomplete, expert assessments of likely overall numbers are included. The figures for the Mekong and Zaire are believed to be fairly reliable; for the Amazon the figure used (2,500) is certainly a very rough estimate. A number of rivers, particularly larger tropical ones, are incompletely known and the totals given are likely to under-represent the true figure somewhat. The number of native fish species per catchment ranges from 5 to an estimate of 2,500 for the Amazon system.

Figure 7. Relationship between species number and basin area



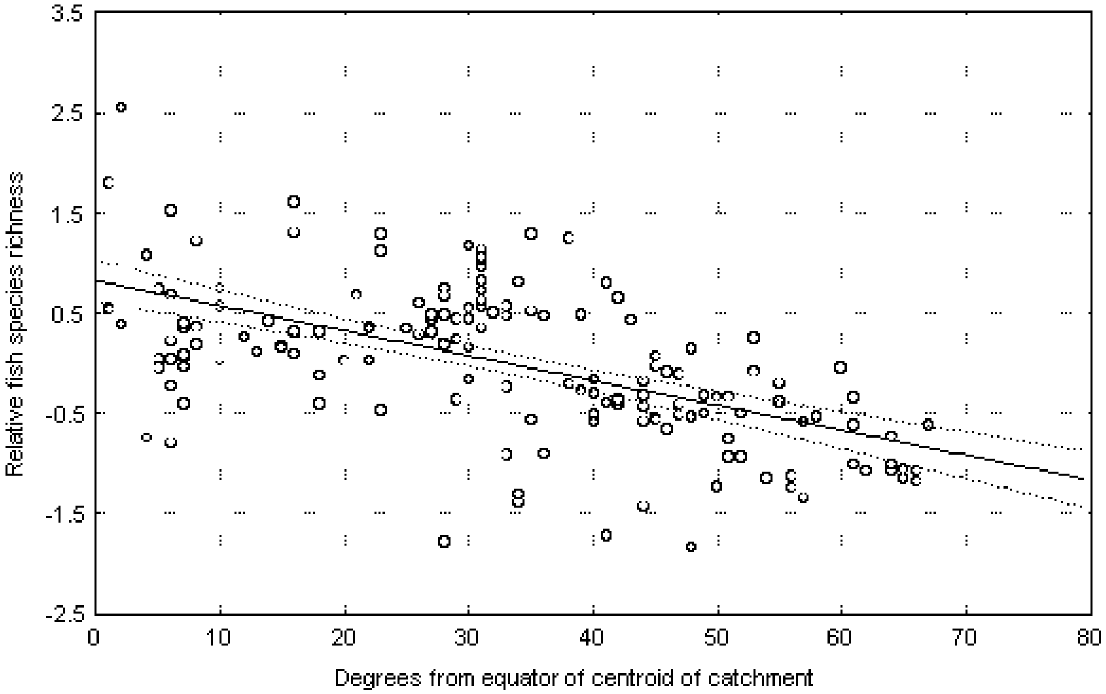
Notes: log-log plot, see Annex 2, dashed lines indicate 90% confidence limits.

Figure 8. Relationship between species number and basin discharge volume



Notes: log-log plot, see Annex 2, dashed lines indicate 90% confidence limits.

Figure 9. Species richness against basin latitude



Notes: this graph plots species richness relative to number of species expected on basis of basin size against latitude of centroid of basin (dashed lines indicate 90% confidence limits).

The readily available estimates of fish richness have resulted from studies made at various times and reflect different approaches to fish taxonomy, so the dataset is uneven in quality. However, both the low intensity of field survey work and the slow rate at which the few experienced systematists can deal with available specimens imply that the available global dataset is unlikely to be greatly improved in the near future.

The number of fish species in the 151 basins included in this analysis is shown in simplified form in Map 6, and fish species richness (in terms of actual number *versu*s number expected on basis of basin area) in Map 7.

As might be expected from the classic species-area relationship (ie. that other things being equal, the number of species present increases with increasing area), there is overall a strong correlation between the size of a river and the number of fish species present (Figure 7). The 'size' of a river can be represented by the area of the basin, or by the volume of water flowing through the river system in any given period; the latter is a better predictor of fish species richness than is basin area (Figure 8). See Annex 3 for a note on methodology. Similar observations were reported in more detail by Oberdorff *et al.* (1995) and Guégan *et al*. (1998), including discussion of the rôle of energy availability.

By fitting a regression line through a log-transformed plot of species number against catchment area and measuring the distance from this line of each point (ie. the residual of each point), we estimate whether any given river is richer or poorer in species than would be expected on the basis of its size alone. A plot of these residuals (a measure of fish-species richness) against latitude (taken as the latitude of the centroid of each catchment) demonstrates overall a strong inverse correlation between latitude and species richness (Figure 9), so that in general the lower the latitude of the river, the richer in species it is. This is a clear manifestation of the most well known global diversity gradient, namely that species diversity increases with decreasing latitude. Analysis by Guégan *et al*. (1998) appears to indicate that latitude may be a surrogate measure for productivity within the basin.

Fish family diversity

In general, at any site there are certain to be far fewer families (or other higher taxa) present than individual species, and so it is usually quicker and easier during field collection at new sites, and subsequent museum study of samples, to determine how many families are present than how many different and perhaps undescribed species. So the question whether higher taxon richness is a valid surrogate of species richness is an important one in the context of biodiversity assessment. With this, and the incomplete and uneven nature of the fish diversity dataset in mind, we have examined family richness in fishes.

Distribution maps from Berra (1981) for the 142 fish families recognised by him with representatives in freshwater have been digitised. Although there have been some changes to the names and content of families mapped by Berra, and the maps themselves are coarse in scale, we have taken this source to represent a reasonable consensus view of fish families.

We have included all primary freshwater families and the inland areas of all those peripheral and secondary division families that extend significantly beyond estuarine waters into inland systems (primary families are strictly freshwater, secondary families are mainly freshwater but have some salt tolerance, peripheral groups occur mainly or partly in freshwater but are clearly derived from marine ancestors). From the digitised maps, a global density surface of numbers of freshwater fish families has been prepared (Map 8). By overlaying the outlines of the river catchments mapped in this analysis, the number of fish families in each of these basins has been estimated (Map 9).

The number of families per basin ranges from two in the Dra river in southern Morocco to 49 in the Amazon as a whole. This range is clearly far smaller than the range in fish species diversity (a 25-fold increase from least to most diverse, compared with a 250-fold for species). As with fish species, there is a clear, but less strong, relationship between the number of fish families in a catchment and the size of catchment. Again, as with fish species, the relationship with discharge is clearly better than that with catchment area. However, as data for discharge are incomplete, we have used catchment area in this analysis.

Map 10 shows the relative richness in families of the 151 river catchments mapped. The most obvious observation is that the richest rivers are all found in the tropics, most notably in northern and central south America. There are lesser centres of fish family diversity in western Africa and southeast Asia. This well reflects the density/contour map of fish family diversity. Of further note, by far the most diverse area outside the tropics or subtropics is eastern North America, where family richness calculated in this way is comparable to that in much of Africa and in the Indian sub-continent. This is reflected also in the species-richness of river catchments in this area (Map 7). It is likely that this effect is at least in part because catchment area has been used to calculate relative richness rather than discharge or runoff: rivers in much of Africa in particular have far lower runoff that would be expected from the size of their catchments, and therefore would be expected to have fewer fish species and families in them than predicted from the size of the catchment and its latitude.

Because of the relatively coarse level of resolution of the source data for fish family distribution, it is likely that the number of families in some smaller rivers, particularly in the tropics, has been overestimated. That is, it has not been confirmed that every catchment within the delimited range of a given family contains representatives of that family. Clearly this may alter results to some extent but is unlikely to have significantly distorted the overall picture.

How well does fish family richness indicate fish species richness?

A simple plot of number of fish species in a river catchment against estimated number of fish families demonstrates a correlation between the two (Figure 10). With the exception of a small number of catchments with a very large number of species (the Amazon, Congo/Zaire, Mekong and Yangtze, each with over 300 species), the relationship between fish species and fish numbers is a close one. At first inspection it appears to be roughly linear, with around five fish species for each family represented. In the four very species-rich rivers, there are over twice this number of fish species per family.

Figure 10. Relationship between number of fish species and fish families in catchment basins

Notes: species richness estimates derived from literature and personal communications; number of fish families per basin calculated from GIS overlay of fish family ranges on our sample catchment outlines. The outlying point is the Amazon basin.

Fitting a series of curves to the plot indicates that, in fact, the relationship between fish species and fish family richness is probably not strictly a linear one. The best fit

of an exponential or power series curve is derived from a power series in which number of species is related to number of families to the power of 1.5 (Figure 10). Using this relationship, family number can explain over 80% of the variation in species number between river catchments. However, even then three of the most species rich rivers (in this case the Amazon, Zaire and Yangtze) deviate considerably from the relationship, with between from nearly three to nearly seven times the number of species predicted by family number (although the highest anomaly is for the Amazon, where the species estimate is very approximate). There is however,apparently no significant relationship between latitude and number of species per family, indicating that speciation at this level is similar in the tropics and in temperate regions.

There is still overall considerable variation in the relationship between number of species and number of families in different catchments. Because of uncertainties in some of the underlying data, it is difficult to tell how much of this is an artefact and how much reflects real differences. Of some note are the two catchments in New Guinea mapped in this study, the Fly and the Sepik. Both these are depauperate in fish families, as may be expected from the geographical position and geological history of the island, which is isolated from major continental centres of freshwater fish diversity. They are also apparently depauperate in number of species, compared with that to be expected of rivers of that size and at that latitude. However, both have considerably more numbers of species per family than predicted from the overall relationship set out above (130% and 80% more respectively), indicating that those families that have colonised these catchments have undergone a higher degree of speciation than normal.

It seems likely that as the data are refined, through more accurate counts of fish species and fish families and use of discharge rather than catchment area, the fit will improve somewhat and more interesting individual patterns will emerge.

Overall, however, it is clear that even with the variable quality of the existing data, at a global level fish family diversity is a good surrogate for fish species diversity, in that the general patterns in one are well reflected in the other.

indicators of habitat condition in river catchments.

Wilderness

A measure of wilderness in each of the catchments analysed has been derived, based on the Wilderness Index developed by the Australian Heritage Commission (R. Lesslie, *in litt*., 30 May 1998). The wilderness value of any given point is essentially a measure of remoteness from human influence and is assessed on the basis of: remoteness from settlement (settled land or points of permanent occupation), from access (constructed vehicle access routes), and apparent naturalness (remoteness from permanent manmade structures) (Lesslie and Maslen, 1995). The analysis is carried out on a grid, using data from the Digital Chart of the World (DCW), and remoteness is measured as a distance from each grid point to the nearest feature of each class within a given radius (generally 30 km). Wilderness value is the sum of standardised values for each indicator class. The value used here is the mean wilderness value for all points within the catchment; this dataset is represented in simplified form in Map 11.

Water resource vulnerability

A measure of water resource vulnerability for each catchment has been calculated following Raskin *et al.* (1997). This team compiled a novel Water Resource Vulnerability Index (WRVI) for each country on the basis of three water resource stress indices: reliability; use-to-resource; and coping capacity.

"Reliability" incorporates three separate factors: storage-to-flow (national reservoir storage capacity in relation to average annual water supply; annual coefficient of variation of precipitation (ie. long-term predictability of rainfall); and import dependence (the percentage of a national water supply that flows from external sources). "Use-to-resource ratio" is a measure of annual water withdrawals divided by annual renewable water resources. "Coping capacity" is GDP per capita and serves as a proxy for a nation's capacity to cope with water problems and uncertainties, and to deliver basic water services to its citizens.

For each measure, including the three separate factors in "reliability", four classes (from "no stress" to "high stress") have been designated in Raskin (1997). A compound WRVI (model I) for each country is derived by giving equal weightings to each of the three stress indices (Model I).

We have calculated a measure of vulnerability for each catchment by measuring that proportion of each catchment which lies within any given country and weighting this proportion by the WRVI of that country. This analysis is represented in Map 12.

Water resource vulnerability and wilderness are both high-level measures of the state of water catchments and the pressures exerted on them. The extent to which they can provide actual insight into the state of riverine ecosystems in individual catchments is a matter of great interest.

In particular, the former is a measure of the extent to which water supply is or may be expected to become a problem to the human population in a country and is therefore only indirectly a measure of vulnerability of or degree of threat to riverine ecosystems. Further, being derived from country-level indices, it may be expected to provide only a limited insight into the state of individual catchments. Indeed, Raskin (1997) notes that "Ideally, the analysis would be conducted at the river catchment level where the relationship among water resources, human requirements and ecosystems is most direct. But a comprehensive global assessment that is built from numerous river catchments would be a problematic undertaking due to the sheer scale of effort and to the lack of a comprehensive water data-base organised by catchment."

Nevertheless, inspection of the map of water resource vulnerability shows good agreement with what may intuitively be expected at a global level, namely that the most vulnerable catchments overall are in South Asia, which has very high human population density, and in the northern half of Africa where rainfall is generally low and unpredictable. In contrast, the least vulnerable catchments are in high latitude countries with predictable rainfall and low population densities (Canada and Finland). Some evident anomalies arise, of which perhaps the most noticeable are the two Alaskan catchments (the Yukon and the Kuskokwim). These may intuitively be expected to be of very low vulnerability, essentially in the same class as adjacent catchments such as the Mackenzie in Canada. However, because by this system the value for the USA as a whole has been applied, they are classified as of somewhat higher vulnerability.

The wilderness estimate is derived from data mapped by grid-squares rather than at country level, and is therefore of a much finer resolution and can be applied as a direct measure for each catchment. Again in general the map (Map 12) gives good overall agreement with what may be intuitively expected. Major apparent anomalies include the relatively low wilderness value ascribed to the Zaire catchment and the relatively high value ascribed to the Yangtze. The former is probably because the base data, taken from the Digital Chart of the World (DCW) are not completely standardised across the globe. Thus in parts of Central Africa several low-grade forms of access (tracks, trails and footpaths), and the settlements associated with them, that are not normally marked on DCW maps, are marked. This will tend to decrease the apparent wilderness value of the area compared with other regions (R. Lesslie, *in litt*., 30 May 1998). In contrast, the Yangtze catchment, despite much of it lying in one of the most densely populated parts of the world, contains significant areas of montane regions with little marked access, so that the catchment as a whole has a higher wilderness value ascribed to it than might be expected.

Further refinements of the base-line information used to generate the wilderness index should resolve many of these apparent anomalies. However, the most important caveat to use of the wilderness index in this context is that it is a measure of the amount of wilderness in the land area of the catchment as a whole and does not directly reflect the condition of riverine ecosystems. Reasonably, other things being equal, it would be expected that there would be a good correspondence between the two, in that a catchment with a high wilderness rating should be relatively undisturbed and therefore have at least a proportion of its riverine ecosystems also relatively undisturbed. However, this may be expected not strictly to hold in arid and semi-arid areas (in this case most notably in northern Africa). Here, the wilderness measure for the catchment is often high because large areas of desert or subdesert hinterland are very sparsely inhabited, but the rivers themselves may be expected to be disproportionately affected by human activity (ie. should in fact have a low wilderness measure) because this is were the bulk of the human population in the catchment is settled.

Despite these problems, the measure does seem to provide a good starting point for assessing how disturbed or impacted the world's major catchments are overall.

A good overall impression of stress to or probable impact on riverine ecosystems can be gained by combining the water resource vulnerability index with the negative of the wilderness index (i.e. a measure of the absence of wilderness in a catchment). This has been done by normalising the two, so that all values for each lie between 0 and 1, and subtracting wilderness value from the water resource vulnerability index. Both indices have essentially the same spread of values (approximately four-fold increase from the lowest value to the highest), so that each contributes equally to an overall value for threat calculated in this way.

Map 13 shows an overall vulnerability or impact value for the river catchment as calculated in this way. Interestingly, combining these two independent measures appears to have the effect of mitigating some of the more obvious anomalies found for each of the measures separately (discussed above). Overall, the pattern mapped agrees well with what might intuitively be expected, with few evident anomalies. This is particularly noteworthy because neither of the two indices used to generate this measure includes direct measures of the state of the riverine ecosystems (although the use-to-resource ratio, used as part of the Water Resources Vulnerability Index provides some insight into this in that it estimates what proportion of river water is physically removed).

Using these measures, the most stressed catchments are to be found in South Asia (the Indian subcontinent), the Middle East and western and north-central Europe. The least stressed are those in the north-western part of North America.

Clearly, this methodology represents a preliminary assessment, at a coarse level, of likely major impacts on catchments. Further refinement of the system should take into account measurable impacts on individual catchments. Two major factors that should be considered in trying to obtain more direct measures of impacts on riverine ecosystems are dams and pollution.

Dams

Dams, particularly large dams, self-evidently have a major impact on the rivers they are built on. They affect flow regimes, often dramatically, and destroy large areas of existing habitat while creating new ones (eg. Dynesius and Nilsson, 1994). They have particularly significant impacts on catadromous and anadromous fishes (those that migrate down or up river systems to breed). Dams, particularly those used for generating hydroelectric power, may be, and indeed often are, built in areas that are not heavily populated or under major water stress. It may be expected therefore that their presence will not accurately be reflected in the indicators outlined above. Preliminary analysis of data on large dams shows that these are very unevenly distributed across the world's major catchments, with an enormous concentration in North America, particularly within the contiguous states of the USA, where at least eight catchments have over one hundred large dams in each. Clearly, such information should be incorporated into any further assessment of threats to catchments.

Pollution

The degree of pollution in a basin may be expected to be reflected to some extent both in the amount of wilderness in the basin and the measure of water resource vulnerability. However the connection is likely not to be straightforward. Point sources of pollution may have major impacts on river systems that are otherwise relatively undisturbed and therefore have a high wilderness value (as reportedly with the Fly River in New Guinea, which is affected by pollution from mining within its catchment). Furthermore catchments in areas of low water vulnerability (often in developed, temperate countries), may be expected to be particularly susceptible to pollution. This, however, is likely to be reflected in a low wilderness measure.

A framework for prioritisation

Despite the various caveats, the measures for fish family richness and overall stress elaborated above do appear to be reasonable indicators respectively of biodiversity in riverine systems and the threats to it. Combining these can give some indication of global level priorities for the maintenance of riverine biodiversity. Figure 11 shows a scatter-plot of these two measures.

We suggest for this preliminary approach that highly diverse and highly stressed river systems (ie. those towards the top, right-hand part of the graph) should be accorded highest priority and systems with low diversity and low stress (ie. those towards the bottom left-hand part of the graph) should be accorded lowest priority.

There is no single *a priori* way of ranking the others, which may have high diversity and low stress, low stress and high diversity or moderate measures of both. However, simply allotting equal weight to richness and stress (i.e. normalising and averaging the two) allows a single measure to be derived for each catchment that can be used to identify three groups: high priority; intermediate priority; lower priority. The division between these three groups is arbitrary, particularly as there is very little numerical difference between many of the catchments of intermediate value.

The results are shown in Map 14. For clarity we have chosen to show the top thirty as high priority and the bottom thirty as lower priority, with the remaining 91 basins as intermediate. The 30 high priority basins are represented by a black marker in Figure 11 and named in Table 18.

This preliminary analysis of diversity and risk analysis could be further developed by *inter alia* the following steps:

1. Use discharge data, as a better predictor of fish richness than catchment area.

2. Verify and expand the dataset on fish species per catchment.

3. Revise fish family taxonomy and occurrence, and seek field data on fish richness per family, particularly for smaller river basins.

4. Most importantly, include system-specific information on river condition: dams; pollution; abstraction of water for irrigation; canalisation, etc.

Figure 11. Scatter diagram of fish family richness per basin against vulnerability

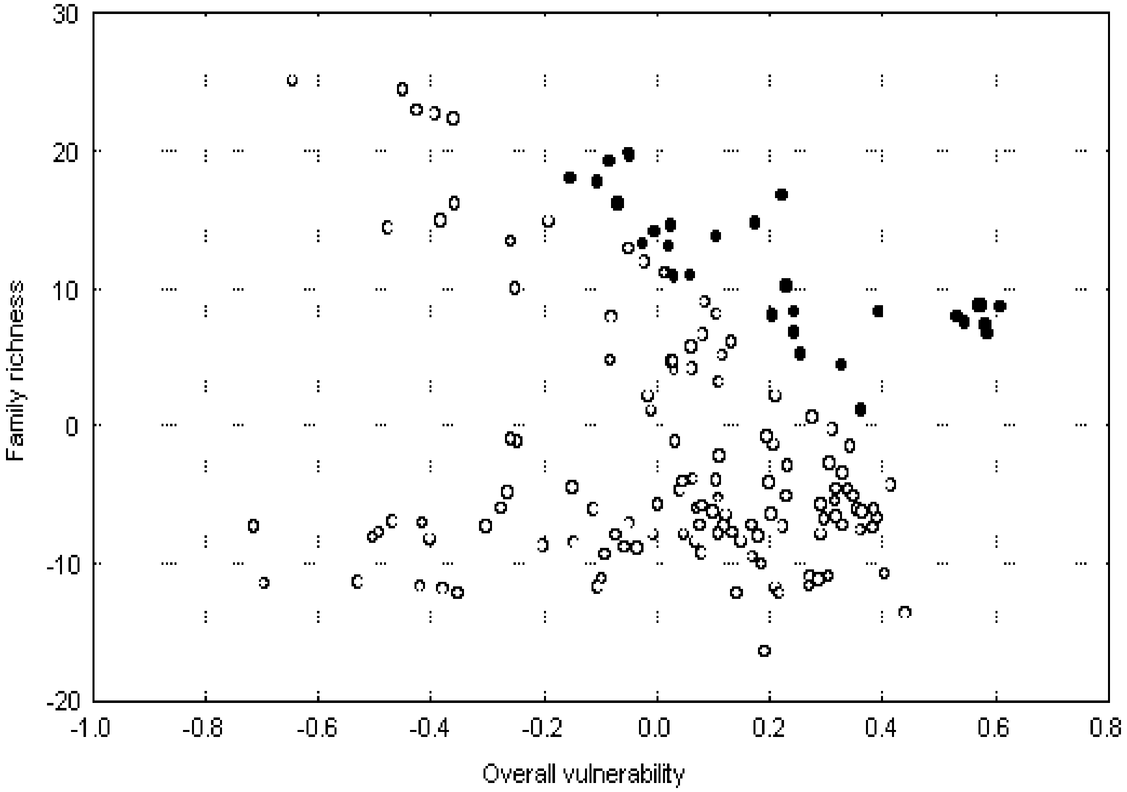


Table 18. Thirty high priority river basins

Ca	Magdalena	Perak
Cauvery	Mahanadi	Salween
Chao Phraya	Mekong	Sao Francisco
Gambia	Narmada	Senegal
Ganges-Brahmaputra	Niger	Sittang
Godavari	Nile	Song Hong (Red)
Indus	Pahang	Tapti
Irrawaddy	Parana	Tembesi-Hari
Krishna	Parnaiba	Uruguay
Ma	Penner	Volta

Notes. These are thirty river basins that support high biodiversity (assessed as fish family richness) and are most vulnerable to future pressures (have a low wilderness score, and high water resource vulnerability index). See text for further explanation. Basins are listed in alphabetical sequence.