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Opinion Paper

Atlantic Island freshwater ecosystems: challenges and considerations following the EU Water Framework Directive

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Abstract

The Water Framework Directive or WFD constitutes a major step forward in the protection of the aquatic environment and associated habitats, since it legislates for the characterization of surface water bodies across defined ecoregions and the development of ecological monitoring systems based upon elements of the aquatic biota. The Macaronesian archipelagos include the Azores, Madeira and the Canary Islands. The peripheral situation of the Macaronesian islands has set them apart from many European initiatives concerning the implementation of the WFD, which is biased towards better known continental systems. As a result, they have been included in the same ecoregion as the Iberian Peninsula and the Balearic Islands for management purposes. However, because of their oceanic situation and volcanic origin, the freshwater systems of the Macaronesian islands differ strongly from continental systems in watershed morphology and the composition of the biotic assemblages, which merits separate identification rather than inclusion within the larger Iberic-Macaronesian ecoregion and special attention concerning regional implementation of programmes of measures under the Directive.

Introduction

The Water Framework Directive is an ambitious and challenging piece of European legislation that came into force in December 2000. The WFD implements wide-ranging measures for sustainable water management at catchment level across defined aquatic ecoregions and is particularly innovative since it legislates that EU member states must prevent the further deterioration of aquatic ecosystems by setting ecological targets and determining ecological status of surface waters with respect to reference conditions (Logan & Furse, 2002). All member states must develop and implement ecological monitoring systems based upon elements of aquatic flora and fauna (macrophytes, phytobenthos, fish fauna, macroinvertebrates) and all surface waters must attain “good” ecological status or ecological potential by 2015.

The far-reaching implications and the stringent timing concerning the phased implementation of the WFD have led to the establishment of working groups to develop guidance and methods and to collaborative research projects to identify reference conditions, key biological elements of the aquatic biota, hydromorphology and chemistry, and to develop compatible, cross-calibrated assessment methods that reliably express ecological quality across taxonomic groups and aquatic ecoregions. Major projects include, for instance, AQEM “The Development and Testing of an integrated Assessment of the Ecological Quality of Streams and Rivers throughout Europe using Benthic Invertebrates" (Hering et al., 2004) and STAR "Standardisation of river classifications: Framework method for calibrating different biological survey results against ecological quality classifications to be developed for the Water Framework Directive".

These large scale projects have focused on continental or UK surface waters although there are also separate initiatives for Ireland and the Mediterranean islands (MEDIS project). The smaller Macaronesian islands comprising the Azores, Madeira and the Canary Islands (Figure 1) have not been integrated into any of these projects and are presently included together with the Iberian Peninsula and the Balearic Islands in a single ecoregion for management purposes. The former archipelagos together with Cape Verde form the Palaearctic sub region of Macaronesia but we define Macaronesia in the context of this paper as the former three archipelagos only since Cape Verde is not contemplated by the WFD. However, due to a complex interplay of biogeographical, environmental, physical and anthropogenic factors directly related to insularity, the lotic systems of the Macaronesian islands differ markedly from the continental systems from which criteria for reference conditions and monitoring methods have been derived.

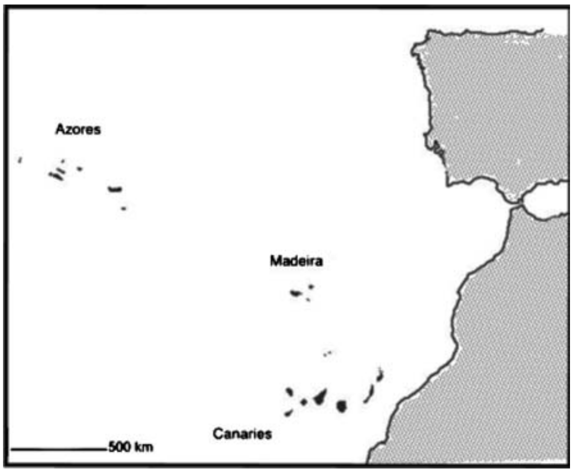

Figure 1. The geographical location of the Macaronesian archipelagos (except the Cape Verde Islands) in the Atlantic off the Iberian and NW African coasts.

Here we briefly outline the physical character of Atlantic Island lotic ecosystems and their distinct, highly valuable biota. We show that together these factors justify careful consideration at regional level when implementing the phased measures of the WFD and also the establishment of a separate Atlantic Island ecoregion, discrete from continental systems and more suited to island ecosystems. The latter argument is given weight by Moog et al. (2004), who proposed that the present European ecoregion classification based on ecological data based on studies in central Europe is too unwieldy to reliably underpin the regional management of surface waters.

Ecological monitoring – a historical perspective

In its present form the WFD reflects strongly the history behind current European freshwater ecological monitoring methods. Dating back to the late nineteenth century, major European countries such as Germany, France, Belgium and Great Britain underwent considerable periods of industrialisation and development, concomitant with substantial environmental degradation, particularly regarding surface water quality and associated habitats. Further, major trans-national European rivers such as the Rhine carry wastes of these activities across political boundaries, forcing neighbouring countries to collaborate or at least work in parallel in implementing monitoring programmes and remedial measures.

As a result of these events, most freshwater biologists today are familiar with the evolution of surface water ecological monitoring methods (many of them are based on macroinvertebrate assemblages) starting with the saprobien based systems (Kolkowitz & Marsson, 1902; Liebmann, 1962; Sladacek, 1965), various biotic indices such as Trent Biotic Index (Woodiwiss, 1964) the Extended Biotic Index (Verneaux & Tuffery, 1967) and the Belgian Biotic Index (De Pauw & Vanhooren, 1983), the Chandler Score (Chandler, 1970), the BMWP, (National Water Council, 1981; Alba Tercedor & Sánchez Ortega, 1988) and finally the more sophisticated multimetric or multivariate predictive methods such as RIVPACS (Wright et al., 2000).

The evolution of ecological monitoring methods shows how they have been adapted according to national policy and to best express ecological quality across Europe. Thus, many continental EU member states have a long history of monitoring surface water quality and have generated impressive long-term data sets, which are essential for defining the character of freshwater communities and distinguishing the effects of environmental disturbance from natural events (WFD, annex V).

The Macaronesian Islands are far less economically developed than mainland member states of the EU as a direct result of their geographic isolation and insular nature. Consequently they have been largely excluded from the WFD related initiatives outlined above. However, although comparatively far smaller and generally less developed than mainland catchments, Atlantic Islands surface water ecosystems are just as, if not more, susceptible to anthropogenic impacts (Malmqvist & Rundle, 2002) that result in habitat degradation, alterations in water chemistry and biodiversity loss. Impacts of special concern to the freshwaters of the Canary Islands and Madeira have been detailed by Malmqvist et al. (1995) and Hughes (1995a, 2003) and include increasing pressures from a growing human population, increasing tourism, urban development, agriculture and water extraction.

Long term data sets are relatively rare on the Atlantic Islands. Often considered as "living laboratories" for the study of evolutionary processes, these islands have tended to be the focus of intensive collecting trips of short duration carried out by foreign scientists. Other scientific contributions came in the late 19th Century from convalescing naturalists such as Thomas Vernon Wollaston (1854, 1857, 1858, 1878), since the Canary Islands and Madeira were well known sanatoria for tuberculosis sufferers. In the case of insular freshwater systems, scientific focus has tended to concentrate on areas traditionally associated with island-based studies such as biogeography (Stauder, 1991; Hughes et al., 1998), taxonomy, systematics, phylogeny, gene flow and rates of speciation of endemic species while in recent years emphasis has shifted from ecological to molecular studies (Kelly et al., 2001; Kelly et al., 2002; Ribera et al., 2003; Drotz, 2003). The findings of such studies clearly indicate high levels of endemism in the Macaronesian macroinvertebrate fauna, conferring considerable conservation value to the regions' freshwater habitats (Table 1).

While these studies emphasise the conservation value of the habitats on the Macaronesian islands, they provide little information on long term temporal and spatial community patterns. Although works exist on the lotic macroinvertebrate communities of Tenerife, Gran Canaria (Malmqvist et al. 1993, 1995, 1997; Nilsson et al., 1998; Kelly, 2001) and Madeira (Malmqvist, 1988; Hughes, 1995a, 2003; Stauder, 1995; Hughes and Furse, 2001) the scarcity of long-term studies has prevented the identification of reference levels of ecological status required by the WFD (but see Gonçalves & Rodrigues, 1999 and Green, 1992 for detailed studies on phytoplankton and zooplankton communities, respectively, on the Azores).

Macaronesian island typology: a case apart?

Watersheds and watercourses

The Macaronesian archipelagos are scattered across the North Atlantic from the Mid Atlantic Ridge to the North African coast (Table 2). Formed by accumulative volcanic eruptions on the ocean floor that eventually emerged above sea level, the islands are mostly steep sided with jagged peaks and troughs formed by differential erosion by water of mainly effusive deposits. A similar origin has also been described for neotropical (Smith et al., 2003) and Pacific (Craig, 2003)

Table 1. Macaronesian endemicity (%) of some important freshwater insect orders. Data from Gran Canaria (Nilsson et al., 1998), Tenerife (Malmqvist et al., 1995) and Madeira (Hughes et al., 1998; Hughes, 2003)

Taxonomic group	Gran Canaria	Tenerife	Madeira
Ephemeroptera	40	33	
Odonata	10	10	
Hemiptera	13	17	
Coleoptera	32	32	48
Trichoptera	30	64	67
Diptera	29	49	
Study total	28	39	

Table 2. Geographical position, area, age and elevation of the Macaronesian archipelagoes. (from Mitchell Thomé, 1989; Galopim de Carvalho and Brandão, 1991; Martins, 1993; Nunes, 1999; P. Oromí personal communication)

Archipelago	Island	Area (km^2)	Maximum estimated geological age (Ma)	Maximum altitude (m)	Distance from continent (km)
Azores	Santa Maria	97	6	587	1343
36° 45′–39° 43′ N	São Miguel	750	4.01	1103	1358
24° 45′–31° 17′ W	Terceira	400	3.52	1020	1552
	Graçiosa	62	2.5	398	1625
	São Jorge	246	0.55	1067	1614
	Pico	436	0.25	2351	1640
	Faial	173	0.73	1043	1688
	Flores	143	0.71	913	1898
	Corvo	17	0.7	718	1890
Madeira	Madeira	742	5.2	1862	640
32° 30′–33° 00′ N	Porto Santo	43	14	517	630
	Salvage Islands	3	11	154	270
Canary Islands	Lanzarote	796	15.5	671	131
27° 37′–29° 25′ N	Fuerteventura	1725	21	807	94
13° 20′–18° 10′ W	Gran Canaria	1532	14	1950	188
	Tenerife	2058	11.6	3718	263
	La Gomera	378	12	1482	313
	La Palma	729	2	2426	375
	El Hierro	278	0.8	1501	344

islands. The Atlantic islands are geologically young and truly oceanic, with no physical connection to continental landmass at any time. They also differ from higher latitude Atlantic islands, such as the Shetlands, Faroe Islands, Iceland and Greenland, which have undergone repeated glaciations with resulting *tabula rasa* made evident by their low biodiversity and general lack of endemism (Coope, 1986).

Insular watersheds formed by volcanism are characteristically small, short and very steep with near vertical valley walls (Hughes, 2003; Smith et al., 2003). Streams drop dramatically in altitude over a very short distance and are somewhat similar to continental headwater streams, being narrow, straight and shallow with a turbulent, torrential, and often seasonal flow. Substrates are coarse, comprising bedrock, boulders, cobbles, gravel and sand. Gradients in older deeper catchments where incision is considerable and in areas near the coast are somewhat reduced. Based upon the River Continuum Concept of Vannote et al. (1980) the headwater channels of the Macaronesian islands should be detritus-based systems dominated by shredder and collector feeding guilds while in the middle sections increased light and nutrients should result in greater algal production and higher biomass of scrapers and grazers. Lower floodplains are absent from the Atlantic islands, although there may be some small "floodplains", constrained by valley walls in older, wider catchments such as Machico, on Madeira. The low spatial heterogeneity and habitat diversity of these systems compared with larger continental systems will limit the pool of invertebrates able to colonize and inhabit them (Malmqvist, 2002).

Madicolous habitats, found on vertical walls where groundwater seepages or surface water films permanently irrigate the rock surface, are common on the Macaronesian islands. Many Macaronesian madicolous macoinvertebrate groups exhibit high levels of endemicity but have not yet been systematically investigated. The WFD does not appear to include madicolous habitats among the surface water types listed, although they are contemplated in the AQEM methodology (Hering et al., 2004) and should be considered "water dependent habitats", linked to the WFD via the Habitats Directive.

Available data show that the physical dimensions and character of Macaronesian lotic systems clearly differ from their mainland counterparts, including those in the same ecoregion, based on the somewhat rough delimitations in *Limnofauna Europaea* (Illies, 1978). This presents problems concerning the establishment of type-specific reference conditions according to the WFD's surface water typologies which must be considered by regional entities responsible for implementation. For example, category A lotic typology concerning catchments area (most Macaronesian catchments fall below the 10 km^2 lower limit) and geology (the stipulated calcareous, siliceous, and organic categories do not include basaltic basic geology of the islands) is clearly unsuitable. Regional characterisation of type-specific reference conditions must therefore based on a selection of reliable system B descriptors and a possible surrogate of catchment geology to make typology based decisions.

Indigenous biodiversity

Macaronesian islands are distinct because of their indigenous vegetation, the laurisilva, a Tertiary relict humid cloud zone community. Widespread Holocene (Quaternary) glaciations wiped out widespread Southern European and the Mediterranean laurisilva stands (Costa Neves et al., 1996). However, laurisilva persisted on the Macaronesian islands where the climate remained more amenable. Historical records indicate that the islands were entirely forested prior to human colonisation. Subsequent large-scale clearance for timber and land has reduced the amount of indigenous forest cover, especially in the coastal areas, where development is most pronounced. With an estimated area of 15,954 hectares (20% of the island's total area) occurring between 300 and 1300 m altitude, Madeira houses the largest remaining area of laurisilva worldwide, which has UNESCO world heritage status and is protected by the Parque Natural da Madeira. In Tenerife and Gran Canaria the extent of the laurisilva is now only 10% and 1%, respectively, of its extent 500 years ago (Bramwell, 1990). Data gleaned from Borges et al. (2000) indicate that laurisilva covers less than 4% of the archipelago of the Azores. Limited to areas with increased cloud cover, high humidity and elevated levels of precipitation, the laurisilva plays a vital role in the insular hydrological cycle by recharging surface water and groundwater reservoirs via occult and contact precipitation and infiltration.

Over 208 Natura 2000 sites with an area of 3,487 square kilometres of land (representing 34% of the total land area of the islands) are listed for Macaronesia. The laurisilva is protected and recognised as a Site of Community Importance (SCI). The unique and threatened nature of this water dependent ecosystem, with high levels of endemism within the flora and the entomofauna, is a strong motive for establishing a separate Macaronesian ecoregion under the WFD. Regional implementation of the WFD will further emphasise the value of the laurisilva, given its key role in the maintenance or improvement of water status and the high levels of endemism occurring in associated flora and fauna (Annex VI of the WFD). Examples of highly endemic fauna include terrestrial molluscs and isopods, Diplopoda, Dermaptera, Neuroptera, Psocoptera, Trichoptera, Hemiptera Homoptera, Coleoptera and several Dipteran families with aquatic larval stages (Baez, 1993; Juan et al. 2000). The laurisilva represents the natural, undisturbed reference conditions of Macaronesian lotic systems central to determining "high ecological status" for Macaronesian surface water bodies as well as Ecological Quality Ratios stipulated by the Directive. However, defining reference conditions in coastal areas where habitat destruction has been extensive as a result of human intervention (habitation, development and agriculture) will be particularly difficult and will possibly have to rely on expert opinion or modelling.

Biogeography of the freshwater biota

Oceanic islands are isolated from continents by varying distances. For freshwater organisms these distances can be overcome by natural dispersal processes or with help from man. Rainbow and brown trout in Madeiran streams and guppies and mosquito fish in Canarian ponds and reservoirs are some prime examples of introductions of exotic species in order to provide fisheries and to control mosquitos, respectively. Many invertebrates are, however, likely to have dispersed to the islands naturally as a consequence of low-rate jump events (cf. Malmqvist et al., 1997; Ribera et al., 2003), possibly in connection with easterly gales – even the remote Azores archipelago is dominated by species of European origin (Crosskey, 1986). Smaller organisms may be transported as aerial plankton, but rafting on driftwood or attached to animals (e.g. amongst feathers or on muddy feet of birds) are other examples of passive dispersal mechanisms. Active dispersal may take place in strong-flying species, which may explain the relatively high diversity of dragonflies in the Canaries. Other taxa, e.g. stoneflies, are notoriously poor fliers and have probably never reached even the closest islands. Thus, taxa differ considerably in dispersal capacity. A sizeable proportion of species that have established themselves in Macaronesia now occur on several islands indicating repeated dispersal events over time, either from nearby continental landmasses or in successive steps between islands.

Reaching an island is of course not sufficient for a successful colonisation. Not only must there be a possibility of reproduction, i.e. at least one male and one female, or a gravid or parthenogenetic female, but arriving species must also find suitable habitats where they are able to survive. Probably only a minor fraction of all colonisers are able to establish themselves. The dispersal barriers of marine waters and more local abiotic and physical factors affecting the success of the establishment act as environmental filters (Poff, 1997; Malmqvist, 2002). For example, immigrant species must be able to cope with the highly seasonal flow regime that is so characteristic for Canary Island streams. For this particular condition, life history adaptations are required that typically involve rapid development and drought-resistant stages (Poff & Ward, 1989).

Successful establishment on islands leads to speciation and radiation facilitated by geographical isolation. In the Macaronesian archipelagos these processes have resulted in a biota characterised by high diversity and distinctiveness.

The Macaronesian freshwater biota and biomonitoring

Macaronesia's freshwater biota, shaped by the biogeographical factors described above, present challenges concerning the development of biological monitoring systems especially since most of the biological elements described by the WFD are poorly studied.

Phytoplankton, macrophytes and phytobenthos communities are no exception (although see Gonçalves & Rodrigues, 1999; Santos et al., 1999; Sepúlveda et al., 1999). The flashy seasonal flow and extreme gradient in the Macaronesian lotic environment (harsh local environment) together with the isolated nature of the archipelagos (affecting dispersal) results in poorly developed macrophyte communities, limiting their applicability as indicators of ecological quality. Observations on Madeira and the Canary Islands show that bryophytes and the giant reed *Arundo donax* occur at many lotic sites (Hughes, 2003; Malmqvist et al., 1995); the latter is more usually associated with degraded habitats. Clearly, these communities need to be better studied and characterised in order to establish their suitability as indicators of ecological quality.

The Macaronesian indigenous "freshwater" fish fauna is extremely poor. Species occurring in freshwater include the eel *Anguilla anguilla* L., 1758 (all three archipelagos), the allis shad *Alosa alosa* (L., 1758) (Canary Islands), the rock goby *Gobius paganellus* L, 1758 (Azores, Canary Islands) and the thin lip mullet *Liza ramado* (Risso, 1810) (Madeira). These diadromous or euryhaline species spend the greater part of their life in the sea but tend to be tolerant of enriched inland waters. These factors, together with poor diversity render the Macaronesian fish fauna unsuitable for freshwater ecological quality assessment. Freshwater species introduced to the Azores include various species of trout (*Salmo* spp.), goldfish *Carassius* spp., roach (*Rutilus* spp.), common carp (*Cyprinus carpio* L, 1758), bleak (*Alburnus alburnus* (L, 1758)), perch (*Perca fluviatilis* L, 1758), largemouth bass (*Micropterus salmoides* (Lacepède, 1802)), pikeperch or Zander (*Sander lucioperca* (L, 1758)) and northern pike (*Esox lucius* L, 1758). Introduced species on Madeira include rainbow *Onchorynchus mykis*s (Walbaum, 1792) and brown trout *Salmo trutta*. The latter species is restricted to the cooler headwaters of the islands' streams, where breeding populations are said to be established. Introduced exotic species cannot be associated with near-natural reference conditions since their presence indicates an alteration of ecosystem integrity via human intervention.

The Macaronesian benthic macroinvertebrate fauna, particularly that of Madeira and some of the Canary Islands, is relatively well studied. The fauna is less diverse than continental assemblages; families contain few or single genera most of which include low numbers of or even single species. Insects predominate, being active dispersers (Bilton et al. 2001). Although the Macaronesian macroinvertebrate fauna is predominantly Western Palaearctic, the percentage of endemic species, is high, estimated e.g. in Madeira at 25.5% (72 species and sub-species) (Hughes, 2003). Some 9% of the Madeiran aquatic macroinvertebrate taxa are endemic to Macaronesia but tend to be shared with only one other constituent archipelago (5% with the Canary Islands, 2% with the Azores, 2% across all three archipelagos). In the Canaries, endemicity is likewise high; Macaronesian endemic species (most of them Canarian and in several cases endemism is restricted to one island) amounted in two studies to 28% and 39% in Gran Canaria and Tenerife, respectively. Table 1 shows how different aquatic insect taxa varied in the degree to which they were endemics. Clearly, Coleoptera and Trichoptera would be promising for searching candidate indicators. For example, the former order includes some potentially interesting and charismatic insects, such as *Meladema* and the madicolous *Hydroporus* (both in the Dytiscidae family).

Concluding remarks

Like the Galapagos Islands, the biological character of the Macaronesian islands is shaped by geographical isolation, which is part of the reason that they are so fascinating to natural scientists. However, a consequence of this isolation is the limited knowledge of the large-scale temporal and spatial dynamics of the Macaronesian freshwater systems. Insular lotic systems lack the diversity of continental systems; however, the very distinct character of the freshwater biota is due to the interplay of complex biological and geological processes (Smith et al., 2003). These problems must be properly addressed across all Atlantic Islands in order to develop reliable classification, monitoring and ecological research and may even require the development of island-specific protocols.

In this paper we claim that freshwater systems on the Macaronesian islands are unique and vulnerable. If we are to protect these streams efficiently urgent actions are necessary. Although the rapid implementation of the WFD in the European Union brings new hope that such actions will be successful, recognising their distinctiveness is an essential step towards good stewardship of Macaronesian freshwater ecosystems.

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