FISH COMMUNITIES AND FISHERIES IN WALES'S NATIONAL NATURE RESERVES: A REVIEW

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Introduction

Throughout Europe, freshwater fish faunas are under threat. A cocktail of factors such as dam construction, introduced species, overfishing and poor water quality have caused large declines and local extinctions of many species around Europe (see Kirchofer & Hefti 1996; Collares-Pereira et al. 2002 for reviews). In spite of these threats, protected areas for fish in Europe are relatively scarce (Crivelli 2002) and not always effective (Cowx 2002).

Wales is important for fish conservation in Britain. In much of Wales, catchments are small (median catchment size = 121 km^2) and frequently separated by areas of upland (> 600 m altitude), creating a highly fragmented habitat for freshwater fish. Consequently, fish communities consist mainly of diadromous species such as trout, eel and sticklebacks that were able to recolonise freshwaters via the sea following the retreat of the ice sheets ca. 10 000 years BP (Wheeler 1977, 2001; Maitland & Campbell 1992).

The fish fauna of Wales is therefore significantly less diverse than that of England (Maitland & Campbell 1992; Maitland 2004) but contains many fish populations of national and international importance, reflecting a generally lower level of human impact. Wales includes three out of four major spawning populations of UK twaite shad *Alosa fallax* (Aprahamian et al. 1999), the three southernmost populations of Arctic charr *Salvelinus alpinus* in Britain (Child 1977; Gray & Mee 2002), a unique race (and possibly species) of whitefish (*Coregonus*), the gwyniad (Beaumont et al. 1995; Kottelat 1997), three out of the top five sea trout *Salmo trutta trutta* rivers in Britain (Gray & Mee 2002), and significant populations of sea and river lampreys (*Petromyzon marinus* and *Lampetra fluviatilis* respectively) and Atlantic salmon. Most of these populations are protected by Sites of Special Scientific Interest (SSSI) under the Wildlife and Countryside Act 1981 (as amended) and / or Special Areas of Conservation (SAC) under the EC Habitats and Species Directive 1992.

In Britain, National Nature Reserves (NNRs) are flagship conservation sites (Countryside Council for Wales 1996). The NNR designation is the oldest conservation designation in Britain, having been established by

the 1949 Wildlife Act (Nature Conservancy Council 1990). The Welsh NNR series consists of 66 sites that are widely distributed around Wales, but with a concentration in the north-west (Fig. 1). These have been selected primarily with the protection of outstanding examples of specific habitat types in mind, especially broadleaved woodland, fens and sand dunes. Descriptions of many are provided in Countryside Council for Wales (1996). NNRs were seen as providing an element of security and long term stability to allow land management specifically for conservation needs, development of expertise in conservation resource management, provision for short and long term research, and provision of advice and dissemination of knowledge about nature conservation (Nature Conservancy Council 1990). However, freshwater habitats are poorly represented in the NNR series. Although various water bodies are included within the boundaries of most NNRs, they are rarely the primary reason for designating the site.

The majority of conservation sites in Wales are managed privately by the owner, using a system of management agreements designed to maintain the nature conservation interest of the site. In contrast, most NNRs are directly owned and managed by the Countryside Council for Wales (CCW) on behalf of the nation (a few are owned or managed by non-governmental bodies such as the National Trust or the Wildlife Trusts). This means that NNRs can be managed specifically according to the needs of wildlife conservation (Nature Conservancy Council 1990). Designation of the most outstanding semi-natural water bodies in Wales as NNRs is therefore likely to be an effective and powerful means of conserving their fish fauna.

Lyle & Maitland (1991) previously surveyed the fish communities of NNRs in Britain using a combination of questionnaires and field survey, with the aim of providing baseline data on fish species within NNRs. However, they did not differentiate between different water bodies within NNRs. They concluded that NNRs did not provide a particularly effective series for fish conservation, and that in particular those species most in need of conservation were least well represented in the NNR series.

This review aims to (i) update the work of Lyle and Maitland, taking into account new NNRs and additional data collected since 1991; (ii) assess the different fish communities represented on Welsh NNRs with respect to their naturalness; (iii) examine the use of NNRs for angling; (iv) evaluate opportunities for expanding the NNR series to conserve fish populations of conservation importance.

The survey

Questionnaires were sent out to NNR wardens in March 2003. Wardens were asked to enter details of each water body within the NNR, known fish species present, whether a fishery was present, which species were targeted

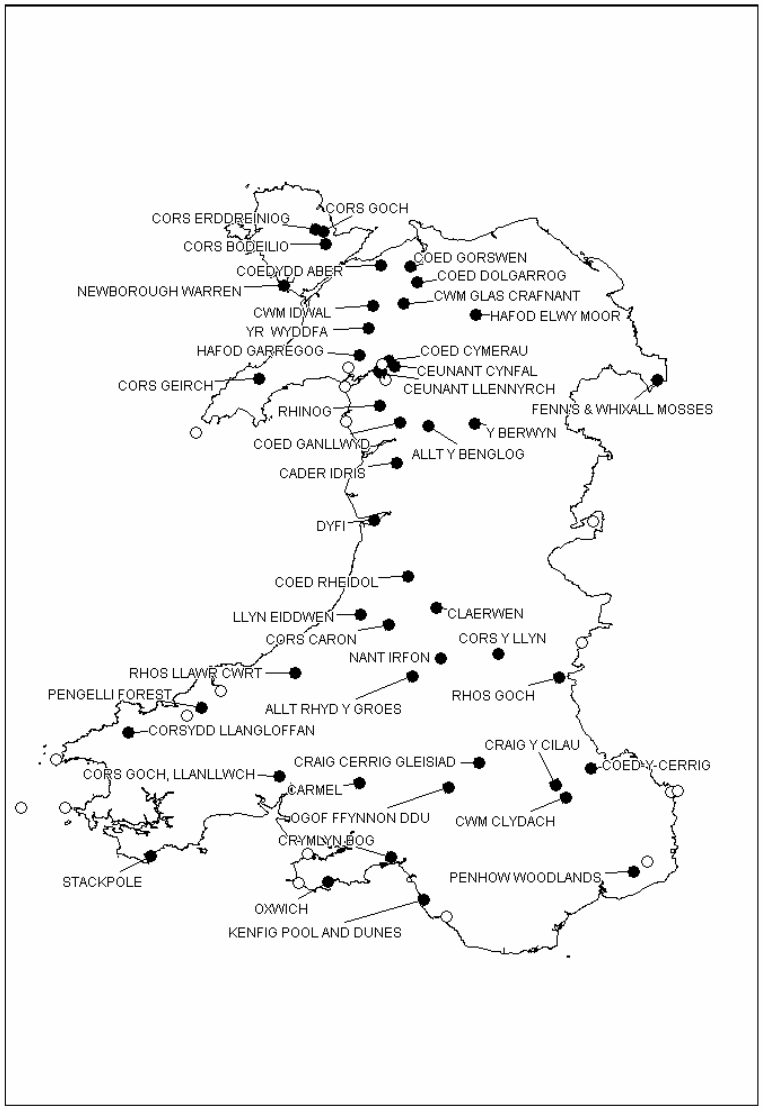

FIG. 1. Distribution of NNRs in Wales. Dark circles (labelled with site name) are sites containing water bodies. Open circles (unlabelled) were reported as lacking water bodies. Points indicate the approximate centre of the reserve.

by anglers and various details of the fishery such as stocking, fishing intensity, fishing restrictions, impacts etc. Habitats were divided into 5 category types; 'streams' (running waters < 5 m in width), 'rivers' (running waters > 5 m in width), 'ponds' (standing waters < 1 ha in area), 'lakes' (standing waters > 1 ha in area) and 'ditches' (man-made drainage channels). A separate form was filled in for each water body on the NNR, to allow differences in fish community among water bodies to be identified. Information on fish occurrence was also collected from fisheries reports, salmon action plans, other published accounts (Ward 1931; Condry 1966, 1990; Roberts 1995; Davidson & Appleby 2003) and unpublished CCW and Environment Agency data.

Seventy-one per cent of Welsh NNRs contain at least one water body, and some larger sites such as Yr Wyddfa (Snowdon) include a number of standing and running waters. Fish communities for these are summarised in Table 1a. Five water bodies are fishless (Table 1b), and 18 NNRs lack water bodies (Table 1c). Seventeen out of 76 water bodies (mostly small streams and ponds) lack fish data (Table 1d). At least some of these are likely to be fishless.

Fish species and communities

Recorded species diversity is generally low, with a mean species diversity of 4.2 per NNR for sites where fish were recorded as present and reliable data were available. This is somewhat higher than that recorded by Lyle & Maitland (1991), who recorded a mean of 3.5 species at the same sites. However, more sites were data deficient in the current survey. A more ecologically meaningful measure is the mean number of species per water body, since many sites have more than one water body corresponding to very different habitats (e.g. standing and running water). Individual water bodies have a mean of 2.9 fish species.

The most commonly occurring fish were salmonids (Table 2), representing 33 % of all records. Trout (*Salmo trutta*) dominated many communities; many were brown trout but a significant number of sea trout records were provided, reflecting their relative importance in Wales (Gray & Mee 2002). For sites recorded as having 'trout' or brown trout only, sea trout accessibility was checked against Gray & Mee (2002). This indicated that most water bodies assessed as having brown trout only were inaccessible to sea trout. Many water bodies within NNRs are not easily accessible to migratory fish, since they tend to be near headwaters, reflecting the distribution of semi-natural terrestrial habitat. Lowland NNRs are often dunes, fens or mires, where water bodies may be inaccessible for other reasons, such as the presence of sluices to control water level. Such sites may also lack suitable habitat for most species.

Table 1a *(part 1 of 3)*. Freshwater fish occurrence by water body. Order of sites as for Fig. 3. + indicates presence; ++ indicates abundant or dominant, where known. Solid vertical lines indicate groups of sites with similar faunas as defined by cluster analysis. Dashed line indicates division between trout only sites and a group of mainly trout dominated sites.

Cluster analysis group	1		2													
NNR	Stackpole	Kenfig Pool & Dunes	Dyfi	Cors Erddreiniog	Cors Erddreiniog	Cors Caron	Coed Rheidol	Corsydd Llangloffan	Oxwich	Cors Caron	Kenfig Pool & Dunes	Cors Geirch	Cors Bodeilio	Cors Gyfelog	Coedydd Aber	Coed Ganllwyd
Water body	Bosherston Lakes	Kenfig Pool	Dyfi Estuary	Afon Erddreiniog	Llyn yr Wyth Eidion	Afon Teifi	Afon Rheidol	Western Cleddau	Oxwich Ditch system	Maesllyn Lake	River Kenfig	Afon Geirch	Afon Nodwydd	Afon Dwyfach / Desach	Afon Rhaeadr Fawr	Afon Gamlan
Salmo trutta fario				+	+	+	+	+		+	+	+	+	+	+	+
Salmo trutta trutta			++	+		+	+	+	+		+	+		+	+	+
Salmo salar			++			+	+								+	+
*Oncorhynchus mykiss***							+			+						
Anguilla anguilla	+	++	+	+	+	+	+	+	+		+	+	+	+	+	
Lampetra fluviatilis						+	+	+				+				
Lampetra planeri						+	+	+								
Perca fluviatilis	+	++				+	+			+						
Gasterosteus aculeatus	+		+	++	++	+			+			+	+	+		
Pungitius pungitius		+		++	++	+			+				+			
Barbatula barbatula						+		+								
Cottus gobio	+					+		+								
Esox lucius	++	++				+										
Platichthys flesus	+		+						+		+	+				
Chelon labrosus			+						+		+					
Liza ramada			+													
Liza aurata			+													
*Cyprinus carpio***	+	+														
*Scardinius erythrophthalmus**	+	+														
*Rutilus rutilus**	++								+							
Phoxinus phoxinus						+	+	+								
*Tinca tinca**	+	+								+						
Total fish species	10	7	8	5	4	12	8	8	7	4	4	6	4	4	4	3

Table 1a *(part 2 of 3)*.

Group	3									4						
NNR	Newborough Warren	Oxwich	Fenn's, Whixhall and Bettisfield Mosses	Dyfi	Craig y Cilau	Coed Lletywalter	Fenn's, Whixhall and Bettisfield Mosses	Rhos Llawr Cwrt	Rhos Llawr Cwrt	Cwm Cadlan	Llyn Eiddwen	Cors Goch	Rhos Goch	Cors Goch	Cader Idris	Cwm Idwal	Rhinog
Water body	Llyn Rhosddu	Serpentine Lake	Unnamed Pond	Cors Fochno Ditches	Nant Onneu	Llyn Lletywalter	Unnamed ditch	Afon Bwdram	Afon Clettwr	Nant Cadlan	Llyn Eiddwen	Llyn Cadarn	Bachwy / Arrow headwaters	Unnamed Pond	Nant Cadair	Llyn Idwal	Llyn Du
Salmo trutta fario					+					+	+	+			+	+	+
Salmo trutta trutta																	
Salmo salar															+		
*Oncorhynchus mykiss***																	
Anguilla anguilla	+	+		+	+	+	+	+	+	+							
Lampetra fluviatilis																	
Lampetra planeri																	
Perca fluviatilis																	
Gasterosteus aculeatus	+	+									+	+	+	+			
Pungitius pungitius			+	+													
Barbatula barbatula																	
Cottus gobio										+							
Esox lucius																	+
Platichthys flesus																	
Chelon labrosus																	
Liza ramada																	
Liza aurata																	
*Cyprinus carpio***																	
*Scardinius erythrophthalmus**		+															
*Rutilus rutilus**											+						
Phoxinus phoxinus																+	
*Tinca tinca**																	
Total fish species	2	3	1	2	2	1	1	1	1	3	3	2	1	1	2	2	2

Table 1a *(part 3 of 3)*.

Group	(4)																	
NNR	Cader Idris	Ogof Ffynnon Ddu	Yr Wyddfa	Yr Wyddfa	Yr Wyddfa	Yr Wyddfa	Yr Wyddfa	Yr Wyddfa	Yr Wyddfa	Nant Irfon	Allt Rhyd y Groes	Claerwen	Claerwen	Claerwen	Cwm Idwal	Cwm Idwal	Cwm Glas Crafnant
Water body	Llyn Cau	Underground streams	Llyn Teyrn	Llyn Nadroedd	Llyn Du'r Arddu	Llyn Ffynnon y Gwas	Llyn Coch	Llyn Glas (1)	Llyn Glas (2)	Irfon	Pysgotwr & Doethie	Llyn Cerrigllwydion Uchaf	Claerwen Reservoir	Afon Claerwen	Llyn Clyd	Llyn y Cwn	Unnamed stream
Salmo trutta fario	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Salmo trutta trutta																	
Salmo salar																	
*Oncorhynchus mykiss***																	
Anguilla anguilla																	
Lampetra fluviatilis																	
Lampetra planeri																	
Perca fluviatilis																	
Gasterosteus aculeatus																	
Pungitius pungitius																	
Barbatula barbatula																	
Cottus gobio																	
Esox lucius																	
Platichthys flesus																	
Chelon labrosus																	
Liza ramada																	
Liza aurata																	
*Cyprinus carpio***																	
*Scardinius erythrophthalmus**																	
*Rutilus rutilus**																	
Phoxinus phoxinus																	
*Tinca tinca**																	
Total fish species	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 1b. Known fishless sites.

NNR	Water Body	Reason
Cernydd Carmel	Pant-y-Llyn	Temporary water body - naturally fishless
Craig Cerrig-gleisiad	Mountain streams	Inaccessible to fish
Yr Wyddfa	Llyn Llydaw	Historic copper mine pollution (Roberts 1995)
Yr Wyddfa	Glaslyn	Historic copper mine pollution (Roberts 1995)
Yr Wyddfa	Llyn Bach	Small high altitude lake, perhaps naturally fishless?

Table 1c. List of NNRs without water bodies. *Occasionally flooded by high water levels from the artificial lake, Llyn Trawsfynydd.

Coed Camlyn	Fiddler's Elbow	Morfa Harlech
Coed Tremadog	Gower Coast	Penhow
Coed y Rhygen*	Grassholm Island	Ramsey Island
Coedmor	Lady Park Wood	Roundton Hill
Coedydd Maentwrog	Merthyr Mawr Warren	Skomer Island
Coombe Valley Woods	Morfa Dyffryn	Stanner Rocks

Table 1d. Sites with water bodies, but where no data was available.

NNR Name	Water Body	Comments / Lyle & Maitland (1991) record
Allt y Benglog	Afon Eiddon	
Ceunant Cynfal	Afon Cynfal	
Ceunant Llennyrch	Afon Prysor	Trout and eel
Coed Cymerau	Afon Goedol	Trout, salmon and eel
Coed Dolgarrog	Afon Porth Llwyd	Trout and eel
Coed Dolgarrog	Afon Ddu	Trout and eel
Coed Gorswen	Afon Gorswen	Trout and eel
Coed y Cerrig	Grwyne Fawr feeder stream	
Cors Goch, Llanllwch	Un-named ditch	
Cors y Llyn	Un-named pond	Thought to be fishless
Cors y Llyn	Wye feeder stream	Thought to be fishless
Crymlyn Bog and Pant y Sais	Afon Crymlyn	Pike, chub, roach, tench, eel, 3sp stickleback
Hafod Elwy Moor	Streams	
Hafod Garregog	Afon Nanmor	Trout, salmon and eel
Pengelli Forest	Nant Hafren	
Pengelli Forest	Un-named pond	
Pengelli Forest	Un-named pond	
Rhinog	Nant Llyn Du	Possibly fishless due to acidification
Tanygader	Un-named ditch	
Tanygader	Un-named stream	
Ty Canol	Ty Canol streams	Brown trout, eel, bullhead

Table 2. Fish species in Welsh NNRs, listed by habitat and family.
* = British species not native to Wales. ** = fish species non-native to Britain.

Scientific Name	Common Name	Ditch	Lake	Pond	River	Stream	Total
Petromyzontidae							
Lampetra fluviatilis	River lamprey					2	2
Lampetra planeri	Brook lamprey				2	1	3
Salmonidae							
Salmo trutta fario	Brown trout		14	4	5	13	36
Salmo trutta trutta	Sea trout	1			5	5	11
Salmo salar	Atlantic salmon				5	1	6
Oncorhynchus mykiss **	Rainbow trout		1		1		2
Anguillidae							
Anguilla anguilla	European eel	3	5	1	4	10	23
Gasterosteidae							
Gasterosteus aculeatus	Three-spined stickleback	1	5		2	5	13
Pungitius pungitius	9-spined stickleback	2	2	1	1	2	8
Percidae							
Perca fluviatilis	Perch		3		2		5
Mugilidae							
Chelon / *Liza* spp.	Mullets	1			3	1	5
Cottidae							
Cottus gobio	Bullhead		1		1	2	4
Pleuronectidae							
Platichthys flesus	Flounder		1		1	2	4
Esocidae							
Esox lucius	Pike		2		1		3
Cyprinidae							
Phoxinus phoxinus	Minnow				2	1	3
Rutilus rutilus *	Roach	1	2				3
*Scardinius erythrophthalmus**	Rudd		3				3
Tinca tinca *	Tench		3				3
Cyprinus carpio **	Common carp		2				2
Cobitidae							
Barbatula barbatula	Stone loach				1	1	2
	Total	14	46	10	42	54	166

Species recorded from Wales but not in NNRs: Common bream *Abramis brama**, bleak *Alburnus alburnus**, allis shad *Alosa alosa*, twaite shad *Alosa fallax*, barbel *Barbus barbus**, white bream *Blicca bjoerkna**, goldfish *Carassius auratus***, crucian carp *Carassius carassius**, gwyniad *Coregonus lavaretus*, grass carp *Ctenopharyngodon idella***, gudgeon *Gobio gobio**, chub *Leuciscus cephalus**, dace *Leuciscus leuciscus*, smelt *Osmerus eperlanus*, sea lamprey *Petromyzon marinus*, Arctic charr *Salvelinus alpinus*, brook charr *Salvelinus fontinalis***, wels *Siluris glanis***, grayling *Thymallus thymallus*.

Apart from salmonids, the principal fish groups were cyprinids, eels and sticklebacks (Table 2). Five different cyprinid species were found in approximately equal proportions, but only minnows were recorded in running water. Sticklebacks, especially *Gasterosteus aculeatus*, were commonly recorded. However, of greater conservation interest is the distribution of nine-spined stickleback *Pungitius pungitius*. This species occurs only locally in Wales, mainly at lowland sites close to the sea. Comparison with recently published atlas data (Davies et al. 2004) suggests that perhaps as many as half of all Welsh occurrences of this little fish may be within NNRs. A record of 'seven-spined stickleback' at Fenns, Whixhall and Bettisfield Mosses NNR is presumed to be this species and is included with it in Table 2. If so, it appears to be a new record for the Shropshire / Wrexham area.

A cluster analysis of the sites using the Complete Linkage Agglomerative Clustering method in the Community Analysis Package (Henderson & Seaby 2002) found four different groups of sites broadly corresponding to habitat requirements (Fig. 2; Table 1a). These are coarse fish sites (Bosherston Lake and Kenfig Pool), mixed diadromous fish sites (e.g. Dyfi Estuary, Afon Teifi, Afon Geirch), eel-dominated communities (e.g. Cors Fochno ditches, Serpentine Lake, Llyn Lletywalter) and brown trout sites (e.g. Llyn Cau, Llyn Teyrn).

The fish community at both the coarse fish sites (Group 1) consists of eel, perch, pike, common carp, rudd and tench, plus some additional species (e.g. roach at Bosherston). This community is artificial, the result of stocking both past and present. Indeed, Bosherston Lake itself is artificial, created as an ornamental lily pond by impounding a small calcareous stream. The native fish community of Kenfig Pool is unclear and the site appears to have a long history of stocking, perhaps stretching back to the Middle Ages (see Giles 2003 for a discussion).

Diadromous fish sites (Group 2) are mainly running waters accessible to migratory fish. They contain a varied fauna including various combinations of mostly diadromous species such as *Salmo trutta trutta*, *S.t. fario*, *Salmo salar*, *Gasterosteus aculeatus*, *Pungitius pungitius*, *Lampetra* spp., *Platichthys flesus* and *Cottus gobio.* A wide range of river types seems to be represented in this group. Rainbow trout *Oncorhynchus mykiss* are stocked on the Rheidol and at Maesllyn Lake but generally the fish communities seem relatively natural, with little evidence of introductions.

Eel dominated sites (Group 3) are mainly lowland, species-poor ditches, ponds and pools inaccessible to or unsuitable for most fish. Eels and sticklebacks (usually *G. aculeatus*) are the only fish species commonly found. However, most of these sites have not been adequately surveyed.

Brown trout sites (Group 4) were relatively numerous and were characteristically small, oligotrophic lakes in upland sites inaccessible to

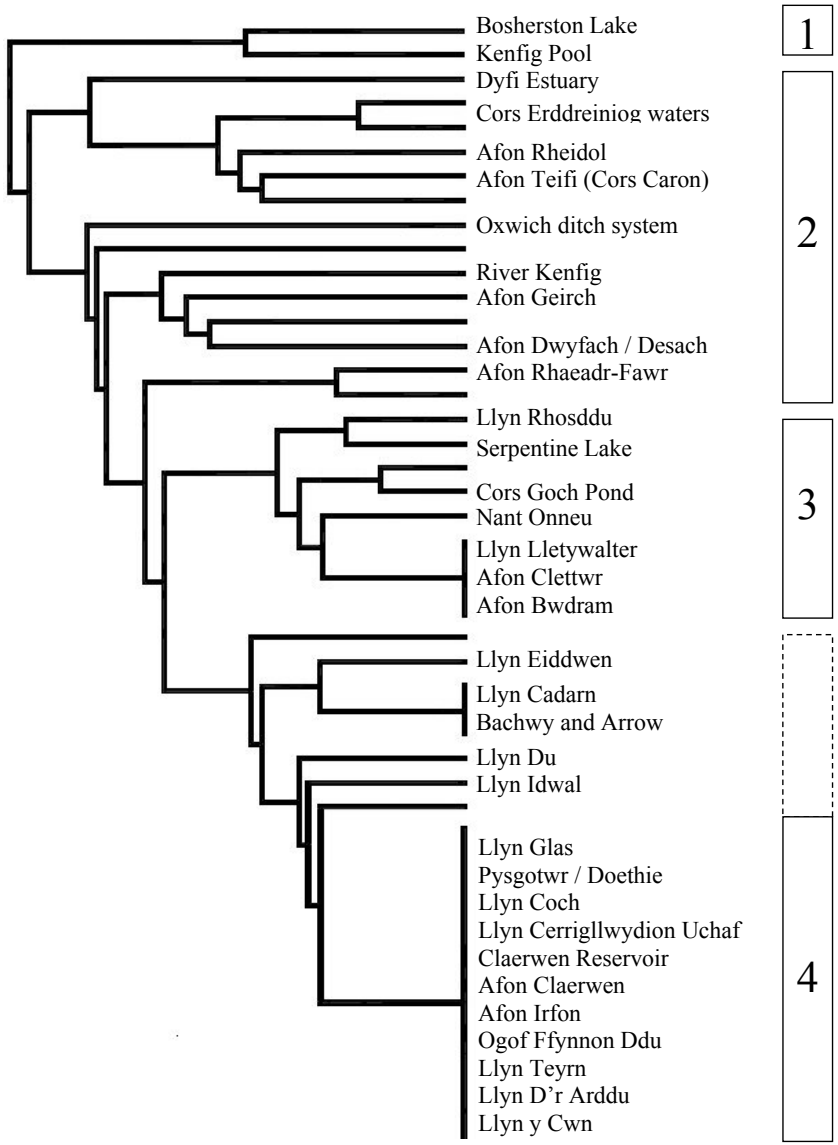

FIG. 2. Dendrogram showing relationships among water bodies. Numbers on right hand side indicate the occurrence of principal fish communities. Dashed line indicates sites with trout plus one other species, most conveniently assigned to Group 4. For reasons of space not all water body names are shown. See text for further details.

migratory fish. A good example is Llyn Du'r Arddu, close to Snowdon and part of Yr Wyddfa NNR. An 1854 account describes this water as a '…black lake where the fishes have monstrous heads and little bodies' (Roberts 1995). Some of these may also contain low densities of other species, especially eel; however, these may be hard to detect even with a specialist survey programme. A series of other sites had brown trout and another species, usually stickleback or eel. In many cases such associations are apparently natural. Others have had additional species introduced either accidentally or intentionally. For example, Llyn Idwal now contains a population of minnows, most likely introduced by anglers using them as live bait. Minnow introduction is a widespread problem in trout-dominated Scandinavian lakes (Lien 1981; Museth et al. 2002; Tammi et al. 2003) because minnows compete with juvenile trout for food in lake environments, and adult trout do not seem to be effective predators of minnows (Lien 1981; Museth et al. 2002).

Changes in fish community

There was little clear evidence for significant changes in fish communities since the previous survey of Lyle & Maitland (1991) (see Table 3). Pairwise comparison of each site at the two different dates gave a mean Jaccard's coefficient of 0.70, a high degree of correspondence among responses considering the species-poor nature of most communities. When differences were examined more closely or other supporting data were available, however, they were best attributed to errors or omissions in returns rather than introductions or loss of species. These problems reflect the limitations of questionnaire data. While questionnaires are an effective method for providing initial data on fish composition on a wide scale, they do not seem to be sufficiently reliable for detailed faunal comparisons at individual sites. A programme of field surveys would be required to document any changes with certainty. However, questionnaires can be used as an inexpensive initial screen to target field survey.

One potential change of significance is roach in Kenfig Pool. Lyle and Maitland (1991) recorded this species at Kenfig, but roach were not mentioned in the current questionnaire and Giles (2003) recorded it last at this site prior to 1936. However, Kenfig Pool has a long history of fish stocking and extinctions (see Giles 2003 for details), so loss of roach cannot be entirely ruled out.

Fisheries

Twenty-three water bodies in 11 NNRs had active fisheries. A further two sites were considered likely to develop fisheries in the future. Fisheries were most often present in standing waters (Fig. 3), with 70 % of standing

Table 3. Differences in fish community between Lyle and Maitland (1991) and present. Current = present species diversity; 1990 = Lyle and Maitland 1991 species diversity; C_J = Jaccard similarity coefficient between dates; changes = new record since Lyle and Maitland (indicated by a +) or no longer recorded (indicated by a -). NNRs newly designated since 1990 or deemed fishless are not shown.

NNR Name	Current	1990	C_J	Changes
Allt Rhyd y Groes	1	3	0.33	Salmon (-), Eel (-)
Cadair Idris	2	1	0.50	Salmon (+)
Coed Ganllwyd	2	4	0.50	Eel (-), Minnow (-)
Coed Rheidol	6	6	0.50	3sp stickleback (-), Rainbow Trout (+), Bullhead (-), Perch (+)
Coedydd Aber	3	2	0.67	Eel (+)
Cors Bodeilio	4	4	1.00	
Cors Caron	13	10	0.77	9sp stickleback (+), Rainbow Trout (+), Tench (+)
Cors Erddreiniog	4	4	1.00	
Cors Geirch	5	4	0.80	Flounder (+)
Craig y Cilau	2	2	1.00	
Cwm Clydach	3	4	0.40	Salmon (-), Eel (-), Brook Lamprey (+)
Cwm Idwal	2	3	0.67	Minnow (-)
Dyfi	3	2	0.66	3sp stickleback (+)
Fenn's, Whixall and Bettisfield Mosses	2	2	1.00	
Kenfig Pool and Dunes	9	8	0.55	Brown trout (+), Rainbow trout (-), Roach (-), Flounder (+), Grey Mullet (+)
Nant Irfon	1	1	1.00	
Newborough Warren and Ynys Llandwyn	2	2	1.00	
Oxwich	6	7	0.86	Flounder (-)
Rhinog	2	2	0.33	Eel (-), Pike (?+)
Rhos Goch	1	1	1.00	
Rhos Llawr Cwrt	1	1	0	Brown trout (-), Eel (+)
Stackpole	10	9	0.73	Minnow (-), Rudd (+), Flounder (+)
Ynys Enlli	1	1	1.00	
Yr Wyddfa	1	1	1.00	

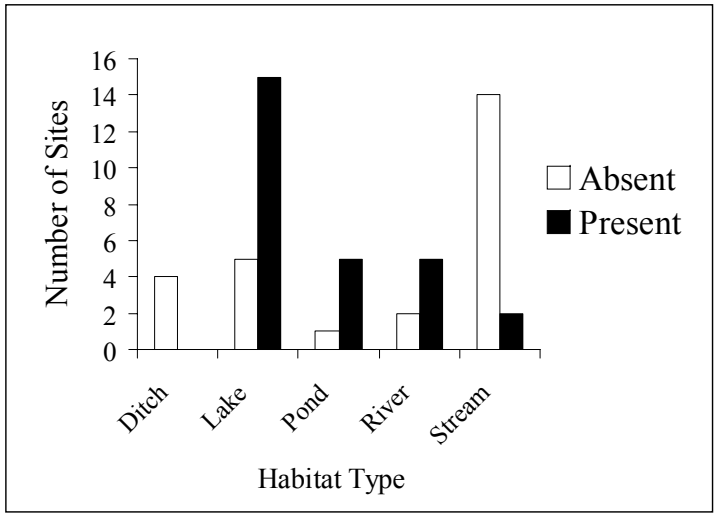

FIG. 3. Fishery presence by habitat.

waters having fisheries. In contrast, running waters often lacked fisheries; however, the majority of running waters were small streams < 5 m wide and thus unlikely to be able to support a fishery. Five out of seven river sites were fished. Of four ditch systems within NNRs, none had a fishery. Thus, at most sites where fishery development was feasible, a fishery was already present.

Fishermen targeted a wide range of species. With the exception of smaller species such as sticklebacks and minnows that are not normally exploited in the UK, most species considered desirable as a fishery species (e.g. trout, roach, perch, tench) were exploited to some extent, though often at very low intensity. The principal exception to this was eel, which was usually unexploited even where other species were present. Sixty per cent of all fisheries were for trout, with the majority of these being brown trout.

The overwhelming majority of fisheries in NNRs were rod fisheries. Only two other methods were used – a seine net licence for salmon and sea trout was active on Dyfi NNR, and fyke netting for eels in Kenfig Pool.

Very few sites had a restriction on the number of rods permitted. However, most rod fishing along NNRs was described as 'very low intensity', often less than one angler per week. Rights were usually held by landowners or angling clubs. At four sites with well-established fisheries, more stringent fishing restrictions such as gear restrictions, bag limits and bans on live baiting were in force.

Stocking and introductions

Stocking was generally thought to be patchy and low intensity. Fisheries were usually described as 'wild' (i.e. no known stocking) or 'historical' (past stocking known to have taken place but not practised recently). Some key exceptions are listed below:

- Afon Rheidol – supported brown trout fishery
- Cors Caron – occasional EA stocking of salmon and trout in the Afon Teifi; Maesllyn lake stocked with Rainbow trout
- Kenfig Pool – eel fishery supported with occasional stocking of elvers. Put and take brown trout fishery
- Bosherston Lake – historical stocking of coarse fish (common carp, tench, roach, rudd, perch, pike).

Although apparently not widely practiced at present, the legacy of historical stockings is evident. Seven water bodies contained populations of one or more non-native species (asterisked species in Table 2). For example, early in the 20th century, Kenfig Pool had pike, gudgeon, 9-spined stickleback and eel (Salmon 1918, in Giles 2003). Some 80 years later, the fish fauna has been profoundly altered by introduction of carp, tench and rudd, augmented by occasional stocking of brown and rainbow trout. Similarly, angling clubs and the Environment Agency have stocked various river systems adjacent to NNRs for fisheries reasons.

Other species such as trout and minnow are likely to have been introduced intentionally or accidentally to sites outside their natural range. A number of well known trout fishing lakes are close to NNRs and these are most likely stocked on a regular basis. Even historical stockings may have a significant effect on trout genetics. Bland (2003) was able to detect the genetic signature of stocked Loch Leven trout in Llyn Idwal more than 100 years after their original introduction.

Fishery management structures and activities

These were varied and usually related to access. Paths and car parking were most commonly reported, but these were not always solely or even primarily for angling purposes (e.g. at Llyn Idwal where the footpath is primarily utilised by hillwalkers). Other more specifically angling related activities included a boat mooring in the Dyfi Estuary and placement of 50 fishing pegs at Bosherston Lakes. The fishery at Kenfig Pool had a weed cutting programme. Predatory fish (pike) removal had previously occurred at Cors Caron in an attempt to boost trout numbers. Impacts related to fisheries were recorded relatively infrequently and were mainly associated with the more heavily exploited sites. Litter (6 occurrences) and discarded tackle (3 occurrences) were most often reported.

Maitland (1992) reviewed fishery activity on freshwater Sites of Special Scientific Interest (SSSIs) in Scotland. In comparison to fishery management in Scotland, Welsh fishery management is lower intensity and far less interventionist. For example, Maitland (1992) categorised control of predatory fish, groynes and fishing jetties, casual fish introductions and stocking as 'common' or 'very common', and even documented fish removal including the use of rotenone at several sites. Rotenone is now illegal in the UK as a piscicide, but all the other impacts were documented here. As Maitland (1992) did not define terms such as 'common' it is difficult to compare results objectively. However, no impacts unambiguously caused by fisheries could be said to be 'common' in Welsh NNRs.

NNRs and fish conservation

Conservationists have previously been criticized for not taking sufficient action directed at freshwater fish conservation (e.g. Keith 2000; Cowx 2002; Crivelli 2002). Thirteen years ago, Lyle & Maitland (1991) observed that 'species most in need of [NNR] protection are inadequately represented in NNRs'. This statement remains true today. Of 17 NNRs declared since Lyle and Maitland's publication, 4 are data deficient, 4 lack water bodies and 2 are fishless. Only one new site, Llyn Eiddwen, has any significant freshwater interest and even this site contains only trout, 3-spined stickleback and introduced roach. No fish species is a qualifying feature at any of the 66 Welsh NNRs. However, although NNRs are key sites, they are not the only type of protected area in Wales. A series of SSSIs and SACs have been designated to conserve many important fish sites, such as the salmon and shad populations of the Wye and Usk, or the Arctic charr in Llyn Padarn and Llyn Cwellyn. Unlike NNRs, SSSIs and SACs are not directly managed by CCW and rely mainly on management agreements for their management. This has not always resulted in maintenance of the quality of SSSIs (Nature Conservancy Council 1990). This is likely to be especially true for aquatic systems, which are strongly influenced by human activity on the surrounding catchment as well as the water body itself. The Nature Conservancy Council (1990) considered the SSSI system 'insufficient on its own to fulfil the overall nature conservation aims of the maintenance of the current range and distribution of our wildlife resource... and its appropriate use by society'.

Even if the reserve is not managed for them, fish within water bodies on site may gain a certain amount of indirect protection. Water bodies within NNRs – and hence the fish populations in them – are often protected from many negative impacts including introduction of non-native species, eutrophication and overfishing. For example, the *Spartina* saltmarshes in Dyfi NNR are thought to be an important sea bass (*Dicentrarchus labrax*)

nursery area (M. Bailey, personal communication). Even water bodies adjacent to NNRs may benefit, for example by having reduced grazing pressure on the banks and a more natural flood cycle. However, management for another feature may also reduce habitat quality for fish. This is particularly noticeable in fen sites such as Corsydd Llangloffan, Oxwich, Cors Geirch and Cors Erddreiniog. All four contain canalised sections of river with sluices in order to maintain high water tables for appropriate management of the fen vegetation which is the primary conservation interest feature on these sites. Although they may achieve the desired result in terms of management of the site, these structures cause reduced instream physical diversity and may impede migratory fish. This kind of conflict between different habitats and species is common in nature conservation and highlights the importance of having dedicated sites designed to protect important fish communities.

Fisheries have had a profound effect on freshwater fish communities in Wales. Since at least the Middle Ages, humans have manipulated fish communities for food and sport – for example, the monks at Strata Florida Abbey 'stocked coarse fish in their waters to the east of the Cambrian mountains, and trout in their waters to the west' (Ward 1931). Although primarily historical, fish introductions have been extensive, and most sites where fish introductions have not occurred are upland sites where the oligotrophic, acidic waters naturally restrict fish diversity and fishery development. Most lowland lakes within NNRs have at least one introduced species, and in some, the fish community is significantly altered. NNR status has not always been effective in reducing stocking pressure.

Welsh NNRs are already quite widely used as recreational fisheries, with most sites that are suitable for use as a fishery having at least some visits. However, few sites are heavily exploited. On the majority of sites, fishery management seems to be sympathetic, with low angler numbers, no stocking and a fishery targeted at the natural fish species (in most cases, brown trout). These fisheries seem sustainable and compatible with the requirements of other users, including conservation.

However, at a few sites there was the potential for conflict between fishery and conservation interests. Particularly problematic are situations where historic fish introductions have resulted in a fish community that may be detrimental to the conservation management of the site. Kenfig Pool and Bosherston Lake are the two sites with the least natural fish communities. Both sites are of European importance for their aquatic plant communities, but both are considered to be ecologically impacted (CCW, unpublished data). Careful fisheries management is particularly important in shallow lake sites where introduced coarse fish can prosper and may

have a significant detrimental effect on lake ecology (Moss et al. 1996; Williams et al. 2000).

Maitland (1992) suggested fishery management plans as a means of controlling angling activity on SSSIs in Scotland, and provided a provisional checklist for assessing whether action is needed. However, this checklist does not consider angling intensity or conservation interest. In most Welsh NNRs low to very low intensity trout fishing is the only activity. In these cases, adequate provision is already made for managing fisheries by agreements with angling clubs, salmon action plans and other local level agreements.

Where the fishery is more substantial, fisheries management plans may be both appropriate and necessary. A fishery management plan has already been produced for Kenfig Pool (Giles 2003) and plans for other sites, especially Bosherston Lake, are under consideration.

Future role of NNRs in fish conservation

The legislative tools available for fish conservation have become more varied in recent years. As well as UK legislation, the EC Habitats and Species Directive in Wales has stimulated a marked increase in the number of protected sites, with several major river systems being designated as Special Areas of Conservation (SACs) for various freshwater fish including Atlantic salmon, bullhead, lampreys and shads. The advent of the Water Framework Directive should also see an improvement in the general quality of freshwater environments for fish. However, both mechanisms are restricted. The Habitats and Species Directive only protects certain specified habitats and species, which are not necessarily those most in need of conservation in Wales, and lacks a provision for protecting threatened fish communities. The Water Framework Directive should provide improvements in habitat and water quality, but it specifically excludes the impact of fisheries and is unlikely to provide adequate protection against the effects of stocking and translocation. NNRs can therefore still play a part in fish conservation by giving a high level of protection for the sites of greatest conservation importance to freshwater fish in Wales.

Lakes often contain rare fish species or unusual fish communities. However, they are also relatively vulnerable to outside impacts. Two NNRs are already selected for the conservation importance of their standing waters, and several others have one or more lake habitat types as interest features. The potential for using NNRs as a lake management tool seems considerable, because lakes often have a relatively small catchment that could be bought together with the water body and managed in such a way as to maintain or restore it.

The two most threatened lake fish species in Wales are Arctic charr *Salvelinus alpinus* and gwyniad *Coregonus lavaretus*. Charr occur

naturally in three lakes in Snowdonia, Llyn Cwellyn, Llyn Padarn and Llyn Bodlyn. Cwellyn and Padarn are already SSSIs for Arctic charr; both are also quite heavily managed systems for which NNR designation would be difficult. Llyn Bodlyn is not protected at present and represents the most southerly population of Arctic charr in Britain. Serious consideration should be given to the designation of it and its catchment as an NNR for this species.

Gwyniad is probably the most endangered fish in Wales. It occurs naturally only in Llyn Tegid, where the population is threatened by eutrophication (Millband et al. 2002) and egg predation from introduced ruffe *Gymnocephalus cernuus* (Winfield 1992). This highly regulated lake is already designated as a SSSI / SAC and Ramsar site, and it is doubtful whether further conservation designation is the best approach to its protection. Other conservation measures such as a catchment-wide agri-environment scheme (Millband et al. 2002) are considered more likely to be effective than designating this site as a NNR.

Some waters lack fish altogether. However, fishless waters are interesting because under these circumstances a rich invertebrate community can develop. Relatively little is known about the ecology of such sites, but they are of conservation interest in their own right. Lyle and East (1989) and Lyle & Maitland (1991) detected enormous aggregations of *Glaenocorixa propinqua* (Heteroptera: Corixidae) in fishless lakes such as Loch Grannoch, Scotland and Llyn Llydaw using echosounding. At Llyn Llydaw, heavy metal pollution from a copper mine caused the demise of the native trout population. In fishless streams in Wales, the top predator is often *Cordulegaster boltonii* (Odonata: Cordulegastridae). Woodward & Hildrew (2001, 2002) describe the ecology of a community dominated by this species in an acidic fishless stream in England.

Britain has a large number of fish communities not found on mainland Europe, due primarily to the relatively small number of fish species and the large number of small catchments inhibiting colonisation (Winfield 1992). These patterns have been greatly altered by stocking and introductions (Maitland & Campbell 1992; Wheeler 2001). For these reasons, sites with a pristine fish community should be considered to be of conservation significance. Unfortunately, the lack of reliable records and the difficulty of determining *a priori* which species are native make identification of such sites difficult.

Fish conservation is also intimately linked with conservation of the aquatic environment as a whole, especially in lakes. Fish are often keystone species in lake habitats and can have a profound effect on the entire biota (Moss et al. 1996), so that effective conservation of the lake is likely to be difficult without taking steps to conserve its fish community.

Any natural lake considered suitable for conservation should have its fish community carefully considered.

Owing to their relatively large catchments and complexity, rivers are much more difficult to protect using the NNR system. This fact is reflected in the NNR series, which has no river sites at all. However, protection of smaller river systems or sub-catchments (Crivelli 2002) using the NNR framework is likely to be more effective. This method could be used to conserve evolutionarily significant units (ESUs) of species such as trout and salmon. The ESU approach, which involves protecting morphologically or genetically discrete populations at a catchment or subcatchment level has been successfully applied to the conservation of *Oncorhychus* spp. in the United States (Waples 1991; 1998). Examples of ESUs in Wales might include unstocked trout populations that have been isolated by impassable falls since the last Ice Age, unexploited populations of salmon, or morphologically distinctive runs of sea trout. NNRs could also be used in a more strategic way in larger catchments such as the Wye and Tywi to protect and connect areas of remnant riverine habitat such as active channels, wet woodland, floodplain grassland and valley mire. These habitats are often important feeding areas, nursery areas or refugia for fish during floods, and could act as nuclei for downstream recolonisation.

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