Firth of Clyde FORUM

Contents

The views and opinions expressed herein are those of the authors.

Conference on the Ecology and Management of the Firth of Clyde

Papers presented to the Conference on recent research in the Clyde

Foreword

Following the success of the Conference on the Ecology and Management of the Firth of Clyde, held in Autumn 2000, I am now pleased to introduce the research papers from the Conference.

Organised by the University Marine Biological Station at Millport and by the Firth of Clyde Forum, the Conference was well attended, reaching full capacity over the 2 days, and the feedback from participants, both on the content of the papers and the networking opportunity offered, has been very positive. The authors have given freely of their time, and I would like to extend our thanks for the contribution they made to the success of the event. Thanks also go to the staff at the Marine Station, Millport for their professional organisation and the warm welcome they extended to all attending, and to the Crown Estate and Scottish Enterprise Ayrshire for their sponsorship.

I hope you will find these papers stimulating, they provide a flavour of the marine research and environmental management currently being undertaken in and around the Clyde. Importantly, whilst many of the papers presented here focus on specific problems for sustainable management, they also send out a strong message that there is much about the Clyde of which we should be proud, and the challenge to us all is ensuring that this continues.

Isabel Glasgow
Chair, Firth of Clyde Forum

February 2001

Introduction

Clare Aspinall, Project Officer, Firth of Clyde Forum

With the gathering of delegates at the Millport Conference in August 2000, the Firth of Clyde Forum successfully completed the first project from our Integrated Management Strategy and Action Plan for the Firth of Clyde. The Strategy was published in July 2000 and officially launched in Greenock by Jackie Baillie MSP, then Deputy Communities Minister. The Strategy was based on a wide-ranging consultation exercise and represents broad consensus around the Clyde on the issues for integrated coastal management.

The Firth of Clyde Forum was set up in the early 1990s to promote and help deliver integrated management of the Firth of Clyde and its coast. This was in recognition of the increasing pressures on the Clyde from a variety of activities, and the need for new types of management to accommodate these without undermining the Clyde's important environmental resources. This was within the context of the UK national Biodiversity Action Plan which resulted from agreement at the Earth Summit in 1992 and which sought to have management plans in place for the major estuaries.

The Forum has four main objectives of harnessing the economic and social advantages of the Clyde, regenerating it as a focus of activity, managing these changes on sustainable principles, and thereby balancing economic, environmental and community interests. The Forum is a voluntary partnership, it progresses towards its goals by co-operation and agreement wherever possible.

Four key themes are identified in the Management Strategy: economic enterprise; management of environmental resources; renewal of the infrastructure; and engaging the community. Under each of these themes, a number of issues, 15 in total, have emerged, and for each of these a management principle, and a number of proposals have been agreed. There are in total 64 proposals in the Management Strategy, this provides a framework for much activity around the Clyde.

But the Strategy is not intended as purely a reference document. Arguably its most important role is in promoting action and achieving results on the ground. The Forum will take forward the Strategy in a phased Action Plan, the first phase which will be implemented from 2000 to 2002 is presented in the Strategy. Whilst this is non-binding, many organisations have agreed to work together to achieve these actions. The Millport Conference was the first to be completed, involving many organisations and individuals in preparation, contributions and sponsorship. It is hoped that over the coming years many more projects will be underway. The success of this depends very much on the enthusiasm and commitment of the Forum membership and we continue to ask for ideas and participation to make this work.

One of the main obstacles to more integrated management on the Clyde is the lack of common information available in an accessible form. The Forum has therefore set itself the task of improving access to this information. Publishing these papers from the Conference is the first step. We also plan to use the Forum website and newsletter to improve the Forum's network of information, and eventually to establish a metadatabase where Clyde information will be catalogued. By widening access to information and raising awareness of work currently being done around the Clyde, we aim to provide an important tool needed in planning for the long term, healthy future of the Firth of Clyde.

Printed February 2001
ISBN 1 85397 262 2

Nature Conservation and the River Clyde

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Conference on the Ecology and Management of the Firth of Clyde
Papers
February 2001

Introduction

Striking a balance between economic development and conservation of the environment is a difficult task. Competition for space and natural resources can be particularly intense in coastal and estuarine areas. The importance of such areas for industry, recreation and amenity has meant that estuarine environments also attract large domestic settlements. The River Clyde and its estuary has an extensive and well documented history of industrialisation and aquatic pollution. While excessive pollution has led to the loss of some species, it has also led to significant population increases in others.

Davison & Baxter (1997) estimate that 36,207-43,605 species of flora and fauna co-exist in the coastal waters of Scotland. Although the potential number of freshwater species is considerably less than those found in marine or brackish water habitats, the potential number of aquatic and marine species within a catchment of the River Clyde is considerable. SNH is the statutory body responsible for the protection of the flora and fauna of the River Clyde. This paper describes the role and function of SNH. The paper also provides a brief overview of the natural heritage interests of the River Clyde, its estuary and marine environments and their protection.

Who are Scottish Natural Heritage

Scottish Natural Heritage (SNH) was established by statute in 1992 through the Natural Heritage (Scotland) Act 1991 and represents a merger between the Nature Conservancy Council for Scotland (NCCS) and the Countryside Commission for Scotland (CCS). SNH is a Non-Departmental Government Agency, answerable to the Scottish Parliament through the Scottish Executive. It is responsible for delivering the Government's programmes for the natural heritage, and delivers independent advice to Government.

The Structure and Function of SNH

SNH comprises over 530 full-time specialist staff. It operates in a devolved manner and staff work from 40 offices in 11 Areas around Scotland. SNH's mission is to *"Work with Scotland's people to care for our natural heritage"*. Its aims are to promote its care and improvement, its responsible enjoyment, its greater understanding and appreciation, and its sustainable use now and for future generations. To achieve these aims SNH works in partnership, by co-operation, negotiation and consensus, where possible, with all relevant interests in Scotland: public, private and voluntary organisations, and individuals.

SNH is responsible for the designation and management of National Nature Reserves (NNRs) and Sites of Special Scientific Interest (SSSIs) and for licensing activities otherwise unlawful under the laws protecting individual species. Both the Scottish Ministers and SNH have a specific duty to exercise their powers so as to ensure compliance with the European Habitats and Species Directives. Table 1 details the main statutory instruments used by SNH to exercise its nature conservation duties.

Table 1. The primary statutory instruments used by Scottish Natural Heritage to protect sites of conservation interest.

Statute	Purpose
National Parks and Access to the Countryside Act 1949	Allows SNH to declare areas of national or international importance for nature conservation as National Nature Reserves. NNRs contain some of the most important natural and semi-natural habitats in Great Britain and are protected for the purpose of study, research and the preservation of flora, fauna, geological and zoological interests.
Wildlife and Countryside Act 1981 (amended 1985)	Sites of Special Scientific Interest are the key areas of marine conservation and wildlife importance. They are special for the nature conservation value of the plants, animals, habitat or geological interest. SSSIs can also include rivers or inter-tidal areas as far as the low water mark. SSSI status does not change the use of the land but local authorities, owners and occupiers must consult with SNH on any activities which may affect the site. There are currently 1,448 SSSI's in Scotland, covering a total area of 919,597 hectares or 11.7% of the surface area of the Scottish land area. NNR's and Marine Nature Reserves (NMR) can also be declared by SNH under Section 35 of the Wildlife and Countryside Act 1981 (amended 1985). There are currently no MNR's in Scotland.
Conservation (Natural Habitats &c.) Regulations 1994	The Conservation (Natural Habitats &c.) Regulations 1994 implement the EC Directive on the Conservation of Wild Birds 1979 and EC Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora 1992 into Scottish and UK law. A total of 113 sites have been classified as Special Protection Areas (SPA's) under the EC Directive on the Conservation of Wild Birds. SPA's cover 391,234 hectares of land within Scotland. SPA's are created to safeguard the habitats of migratory and certain particularly threatened species of birds. A total of 134 candidate Special Conservation Areas (cSAC's), covering an area of 717,862 have been submitted to the European Commission under the EC Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora. SAC's are afforded absolute protection subject to 'imperative reasons of overriding public interest, including those of a social or economic nature'. The Directive is a response to a recognised need within the EC to protect all forms of wildlife and their habitats.
Convention on Wetlands of International Importance 1971	The Convention on Wetlands of International Importance was adopted in Ramsar, Iran in 1971 and ratified by the UK Government in 1976. The purpose of this designation is to 'stem the progressive encroachment on and loss of wetlands now and in the future'. The Ramsar Convention intends to promote the conservation and management of migratory stocks of wildfowl and wetland habitats (marsh, fen, peatland, standing waters, flowing waters (fresh or brackish) and areas of marine interest. There are 48 designated Ramsar sites in Scotland, covering a total area of 240,487 hectares.
Natural Heritage (Scotland) Act 1991	Allows SNH to designate Natural Heritage Areas (NHA's). These sites are intended to be areas of outstanding natural heritage value which contain a wide range of nature conservation and landscape interests where integrated management will be encouraged taking account of recreational use and wider socio-economic activities. There are no designated Natural Heritage Areas in Scotland.

In addition to the National Parks and Access to the Countryside Act 1949, Wildlife & Countryside Act 1981 and the Natural Heritage (Scotland) Act 1991, SNH has additional responsibilities and powers under three other Acts of Parliament (Countryside (Scotland) Act 1967, Countryside Act 1968, and the Environmental Protection Act (1990).

The Natural Heritage Interests of the River Clyde

Both the physical and biological characteristics of a river can differ dramatically within relatively short distances. As the physical characteristics change, the biota which utilise each available microhabitat may also vary. Despite this variation, it is clear that rivers must be viewed as a single ecological unit if proper management of the resource is to be achieved. For example, it is clear that the biological productivity of the estuarine reaches of many river systems is largely dependant on anthropogenic nutrient inputs from the upper and middle reaches of the catchment.The idea that river systems must be managed in a holistic manner has long been recognised and the new EU Water Framework Directive dictates that management of river systems must now be based on entire river basins.The River Clyde shows remarkable variation in character and conservation interest throughout its length.A brief description of this variation is provided below.

The Upper Reaches

The River Clyde is one of the largest rivers in Scotland and extends approximately 105 miles from source to outer reaches.The river has its origins in the North Lowther Uplands at Clydes Law. Here, the rainwater percolates through the acidic peatland habitats to form a small first order stream, the Clydes Burn.At this point the Clydes Burn is oligotrophic (nutrient poor) and biologically unproductive. As it converges with the Daer Water and it transforms into a larger third order waterway and the catchment of the upper reaches of the River Clyde becomes increasingly large.As the river bisects agricultural land and human settlements, both direct and diffuse nutrients enter the system and water quality moves from an oligotrophic to mesotrophic status. Here, the river hosts a wider variety of and biomass of macroinvertebrates and fish. Brown trout (*Salmo trutta*) are relatively common and dominate the fish community. North American signal crayfish (*Pacifasticus leniusculus*) have recently been discovered in the upper catchment of the River Clyde at Elvanfoot.This species is known to displace native European crayfish (*Astacus astacus*) by acting as a vector for *Aphanomyces astaci,* the 'crayfish plague'.The impact that this recent introduction may have on salmonid populations is unknown. As the River Clyde continues towards the City of Glasgow, it becomes considerably larger, absorbing the cumulative drainage of the Duneaton, North and South Medwin, Douglas, Nethan and Mouse Waters.

The Middle Reaches

The middle reaches of the River Clyde host, or offer supporting habitat to, a range of terrestrial and aquatic flora and fauna. Species of national conservation importance such as otter (*Lutra lutra*) and water vole (*Arvicola terrestris*) forage within the river itself and its littoral margins. Riparian habitats, particularly deep-sided gorge areas, provide a suitable environment for internationally important Tilio-Acerion woodland and also provides nesting areas for rare bird species such as the peregrine falcon (*Falco peregrinus*). The woodland also supports spectacular displays of bluebells (*Hyacinthoides non-scripta*), celandines (*Ranunculus ficaria*), wood anemone (*Anemone nemorosa*) and violets (*Viola riviniana*). Roe deer (*Capreolus capreolus*), badger (*Meles meles*) and red squirrel (*Sciurus vulgaris*) are also present. Ornithological interests in this area comprise over 100 species, ranging from kingfisher (*Alcedo atthis*), sand martin (*Riparia riparia*), dipper (*Cinclus cinclus*), grey heron (*Ardea cinerea*), buzzard (*Buteo buteo*), sparrowhawk (*Accipiter nisus*) and kestrel (*Falco tinnunculus*). Winter visitors include whooper swan (*Cygnus cygnus*), greylag geese (*Anser anser*), goosanders (*Mergus merganser*) and cormorant (*Phalocrocorax carbo*). Bats also utilise the river valleys for foraging and a thriving colony of Natterer's bat (*Myotis nattereri*) is well established at new Lanark. Special training is required to handle and research bats. SNH are responsible for the provision of such licences and co-ordinate the work of local bat monitoring groups.

The geomorphology of the Clyde catchment is complex and in certain areas the hydrology is such that the water has eroded the upper layers of glacial deposits and less resistant carboniferous sandstones to form some of the best waterfalls in Scotland.The Falls of Clyde at Bonnington Linn and Corra Linn are spectacular and, along with the Island of Staffa, was one of the most popular tourist attractions of the early nineteenth century (MacLeod & Gilroy 1991). The potential for hydroelectric power generation was identified during the 1920's and small-scale hydro-power stations were constructed at Bonnington and Stonebyres.The use of water from the River Clyde to power hydroelectric turbines has meant that the volume of water which is allowed to descend the falls is heavily controlled. However, during the winter months and during 'open' days, water is allowed to flow freely and the passage of water through the Falls of Clyde is impressive. The conservation value of these areas has been recognised by SNH and both the Falls of Clyde and the Clyde Valley Woodlands enjoy SSSI status. The Clyde Valley Woodlands are also designated as a National Nature Reserve.

As the River Clyde moves beyond Lanark, its volume is increased by the addition of water discharge from the Rivers Avon, North and South Calder and Rotten Calder. Although Atlantic salmon (*Salmo salar*) have been recorded in the Rivers Avon and Rotten Calder in recent years, none have yet been recorded in the North and South Calder. Between the Garrion and Bothwell Bridges, the hydrology of the River Clyde can be described as typical for the middle reaches of a, by now, major river. Examples of riffle, pool and glide sequences are rare and the river meanders slowly towards Glasgow. At this point, the natural heritage interests of the River Clyde, lie not within the river itself, but with the orchards and park areas which lie within its floodplain. Chatelherault Country Park was developed by the Hamilton family in the late fourteenth and early fifteenth century.This area now hosts the famous Cadzow oaks, some of which are estimated to be over 400 years old.

The Lower Reaches

As the River Clyde flows by the Blantyre Mills and industrialised areas of Rutherglen and Parkhead the riparian habitats change markedly.As the river enters Glasgow, bank stabilisation becomes a dominant feature and the path of the river is carefully controlled. Both the risk of flooding in Glasgow's city centre and the need for commercial cargo vessels to be able to penetrate into the heart of Glasgow during the nineteenth century meant that bank stabilisation and dredging was necessary. The progression of saline waters into the middle reaches of the River Clyde is prevented by the presence of a tidal weir, situated slightly upstream of the Albert Bridge. The two kilometre long area between the Broomielaw and the tidal weir can be reliably regarded as the tidal freshwater section of the Clyde estuary (McLusky, 1994). Water quality within this area has been the cause of serious concern since the elimination of fish from this area during the mid-nineteenth century. Improving trends in dissolved oxygen levels have meant that fish have returned to this section of the Clyde and otters have been seen within the River Clyde at Glasgow city centre. The Clyde is unique in Scotland in having a physical barrier to prevent saline intrusion into its middle reaches.

As the tidal freshwater section of the River Clyde moves west, it is further diluted by discharges from the Rivers Kelvin, Black Cart and Leven. The River Kelvin has been heavily restocked with brown trout, sea trout and Atlantic salmon. Widely regarded as the most polluted river within the Clyde catchment, the River Kelvin now supports a thriving sport fishery for these species. SNH has helped with this process by providing grant support for fish pass construction and continues to support rational fisheries management by providing grant aid when appropriate. The Black Cart has recently been designated as a Site of Special Scientific Interest and Special Protection Area for its internationally important population of wintering whooper swans. The River Leven is the only efferent river from Loch Lomond. All of the fish which enter the Loch Lomond catchment from marine habitats must do so through the River Leven. As well as facilitating the passage of Atlantic salmon and sea trout to Loch Lomond, the river also hosts ammocoetes of internationally important sea lamprey (*Petromyzon marinus*).

The Clyde Estuary

Although most of Scotland's coastal habitat is relatively inaccessible and undeveloped, riparian and coastal development is widespread in areas adjacent to the central belt. In these areas, anthropogenic influences include housing, industry, harbours and tourist facilities. The historical decline in water quality within the Clyde estuary was coincident with the development of Glasgow as an industrial centre. Rapid population growth and the expansion of heavy industry within the area during the eighteenth and nineteenth centuries led to a massive increases in nutrient loading and sedimentation. Although Atlantic salmon, a species which was once plentiful within the river (Mackay & Doughty 1986), disappeared the nutrient input led to eutrophication (nutrient enrichment) of the estuarine environment with a coincident increase in biological productivity. The increased production of benthic macroinvertebrates, particularly the polychaete *Corophium volutator*, led to a rise in the number of wading birds observed there during the winter months (Furness *et al.* 1986). This increase in benthic prey availability also supported a diverse estuarine fish population (Henderson & Hamilton 1986) and it is likely that this led to a subsequent increase in the number of piscivorous birds.

After 1945, domestic legislative procedures were introduced to control both domestic and trade effluent into rivers and tidal environments. The Clyde River Purification Board (now the Scottish Environmental Protection Agency) were given the responsibility to monitor the water quality status of the River Clyde and effect remedial action. The success of the legislative procedures adopted by the CRPB can be measured by the return of Atlantic salmon to the River Clyde in the 1970's after an absence of almost 100 years. The transposition of more stringent European pollution legislation and the EU Water Framework Directive into Scottish and UK law means that the River Clyde may yet return to its post-industrialised status. Although a reduction in nutrient loading and resultant improvement in water quality may appear to represent the most desirable environmental strategy, it is perhaps ironic this may lead to an overall decline in the numbers of wading birds and their prey.

The Clyde Estuary also hosts two nuclear power stations at Hunterston and an oil fuelled station at Inverkip. Container vessels still utilise the Clyde for the commercial transport of sugar and timber to Greenock. Oil and petroleum are also transported to storage facilities at Finnart and Bowling. The port facilities for the entire Clyde estuary are controlled by Clydeport Plc., a private company which was formerly known as the Clyde Port Authority. Oil spills are a constant threat within the Inner and Outer Clyde, where the threat of collision between the large volume of coastal passenger traffic and commercial freight vessels is a very real possibility. All harbour authorities are required to construct Oil Spill Contingency Plans. Scottish Natural Heritage play an statutory role within these and offer specialist advice when required.

Despite its obvious recreational value, few statistics are available to testify to the importance of the River Clyde as a tourism or sporting venue. National Watersports centres are sited at Cumbrae and Largs, and these are supported by outdoor centres at Ardentinny, Benmore, Blairvaddich, Castle Toward, Garelochhead, Greenock, Rhu and Inverkip (Kerr, 1986). Angling and bird-watching are other popular forms of recreation within the River Clyde and its catchment. Angling for salmonids is largely controlled by the United Clyde Fisheries Trust and the Loch Lomond Angling Improvement Association. Sea angling is not controlled and is commonly practised throughout the Clyde Estuary and Outer Firth. Ornithologists tend to concentrate their efforts in areas around Ailsa Craig, Ardmore Point, Ballantrae, Shingle Beach, Bogside Flats, Dumbuck Foreshore-Pillar Bank and Erskine-Langbank. The Royal Society for the Protection of Birds (RSPB) owns reserves at Dumbuck, Bishopton/Longhaugh and Finlaystone.

The Outer Clyde and its Sealochs

Beyond the Clyde estuary, a number of fjordic sealochs contribute to the rich biodiversity of the Clyde Sea area. The innermost lochs of the Clyde, situated in close proximity to the Clyde estuary are subject to the greatest environmental pressure (Hiscock, 1998). These lochs receive pollutants from the Clyde estuary, support large numbers of pleasure craft, host a number of large naval installations (Faslane, Coulport, Loch Goil and the Holy Loch (until 1992)). Loch Fyne, with a linear length of 70 km and depths of up to 200m, is the longest and deepest of all of the Scottish sealochs. The fjordic structure of Loch Fyne lends itself well to marine aquaculture and it hosts a large number of commercial aquaculture units. A combination of high nutrient loading and poor water exchange has led to the occasional development of toxic algal blooms. In extreme cases, this has resulted in high mortalities within commercial salmon cages. The impact on natural fish and mammal populations has not yet been assessed.

The Outer Clyde supports well established pelagic (Bailey *et al.* 1986), demersal (Hislop 1986), *Nephrops* (Bailey *et al.* 1986) and shellfish (Mason & Fraser 1986) fisheries, although productivity has shown a gradual decline in recent years.

Grey seals (*Halichoerus grypus*) are the dominant pinnipeds within the Inner and Outer Clyde. Common seals (*Phoca vitulina*), despite their name, are relatively rare within this area. Sightings of common dolphin (*Delphinus delphis*), have increased markedly over the last forty years (Gibson 1986). Despite its relatively restricted area, the Outer Clyde is visited by a range of species which can be considered uncommon or rare within Scottish marine environments. Example of exotic migrants include walrus (*Odobenus rosmarus*), killer whale (*Orcinus orca*) and leatherback turtle (*Dermochelys coriacea*).

Protected Areas within the Clyde

The Scottish coastline is internationally renowned for its aesthetic qualities and is commonly associated with pristine beaches and dramatic, rugged, landscapes. Such is the uniqueness of Scotland's range of coastal habitats within the UK, that approximately 400 coastal sites have been designated as Sites of Special Scientific Interest (Brampton *et al.* 1999). An inventory of protected sites was compiled by Kerr (1986). However, the enactment of EU conservation directives into domestic legislation has led to development of a new suite of international designations, some of which must be underpinned by SSSI designation.

Sites of Special Scientific Interest

The biodiversity and geological complexity of the Inner and Outer Clyde is reflected in the wide range of notified (nationally important) interests. A map showing the location of SSSI's within the Inner and Outer Clyde is shown in Figure 1. A description of the notified interests of each SSSI is provided in Table 2.

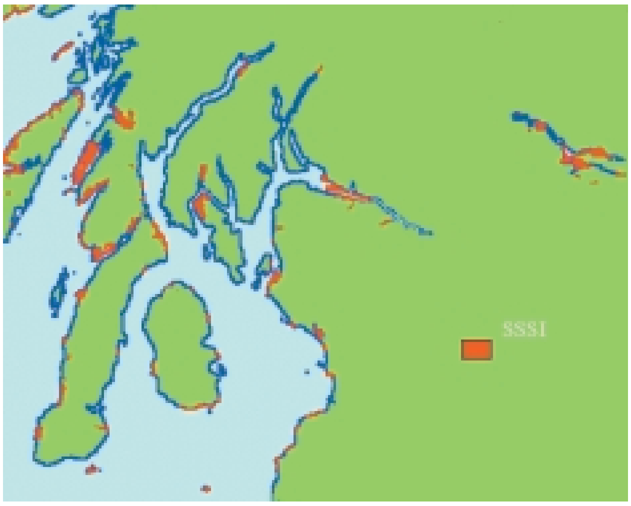

Figure 1. The distribution of Sites of Special Scientific Interest within the Inner and Outer Clyde.

Table 2. Description of Sites of Special Scientific Interest within the Inner and Outer Clyde.

Site Name	Features of Interest
1. Dumbarton Rock	Volcanic plug of the lower Carboniferous age composed of Hawaiitic basalt. Exhibits a well developed columnar which forms a pattern which indicates that the plug occupies a cone shaped pipe that narrows downwards.
2. Inner Clyde	Mudflat feeding ranges and restricted saltmarshes are particularly important for a range of wildfowl and wintering waders.The Area supports internationally important numbers of wintering redshank and is of national importance for its populations of oystercatcher, goldeneye and eider.The area also supports regionally important populations of mallard, shelduck, dunlin, greenshank, lapwing and black-headed gull. Supersedes the Erskine to Langbank, Dumbuck Foreshore-Pillar Bank and Ardmore Point SSSIs.
3. Rhu Point	Contains a sequence of glacial and marine deposits which provide valuable lithostratigraphic evidence for the interpretation of Devensian late-glacial events in Western Scotland.
4. Ruel Estuary	Silt and sand flats support dwarf eel grass and saltmarsh areas.The area represents one of the best examples of transition from estuarine to terrestrial habitat.
5. Claonaig Wood	Representative relic of native oakwood which shows transition from woodland to raised beach marshes.
6. Mealdarroch	A National Nature Reserve which contains Atlantic bryophytes and ferns, as well as gorge woodland.
7. Strone Point	Contains Ardrishaig phyllites.
8. North Largs Coast	Braided stream deposits.
9. Ballochmartin Bay	Site of importance for research and teaching of marine biology.
10. Kames Bay	Classic Scottish site for the study of intertidal marine biology.
11. Portencross Coast	A nationally important site for wildfowl and waders.The site also contains exposures of Upper Old Red Sandstone with outcrops of igneous intrusions and rucked sediments.
12. Ardrossan–Saltcoats Coast	Contains exposed teschenite and picrite sills.
13. Bogside Flats	The only extensive area of merse and mudflat between the Solway firth and the River Clyde. It contains the best example of saltmarsh in Ayrshire and supports large wintering flocks of redshank and golden plover. Large numbers of lapwing, dunlin, oystercatcher, shelduck and widgeon are also present.
14. Western Gailes	The Western Gailes foreshore is backed by dunes which support a rich invertebrate fauna.
15. Girvan-Ballantrae	The Ballantrae Complex, of Ordovician age, consists of three belts of pillow lavas and associated sediments, separated from each other by ultramafic intrusive rocks. The Complex shows many of the features of an obducted ophiolite although geochemical studies indicate that the various igneous rocks were generated in a variety of tectonic settings and have since been tectonically juxtaposed.

Table 2. contd. Description of Sites of Special Scientific Interest within the Inner and Outer Clyde.

Site Name	Features of Interest
16. Maidens-Doonfoot	The foreshore between Bracken Bay and Longhill point shows an unusual Visean aged (Lower Carboniferous) development of Cementstone facies. These are unconformably overlain by Passage Group sediments and lavas. The Cementstones here are the lateral time equivalents of both the Clyde Plateau Lavas, and of deltaic sediments in Fife.
17. Troon Golf Links and Foreshore	The fixed sand dunes and the dune grassland and scrub of the adjacent golf course are botanically rich and diverse, and are the best example of this habitat type in the country. The sandy beach and rocky outcrops, some of which form islands at high tide, are of significance for the numbers of passage\wintering wildfowl and waders, particularly curlew. Meikle Craigs is an important gull roost and moulting area for eider.
18. Turnberry Dunes	The site contains an extensive, unbroken sandy beach backed by a large foredune ridge which becomes narrower and higher towards the north and rises to over 14 m in places. Its importance for insect conservation is related to the quality of the beach and dune habitats and the occurrence of rare and uncommon beetles (Coleoptera), including a number of species for which the site is the most northerly known station in Britain.
19. Ailsa Craig	Ailsa Craig is internationally important for its rocky shore and cliff habitats with their associated large concentrations of breeding seabirds. The gannetry is ancient and is the fourth largest in Britain. Razorbill, guillemot, Kittiwake and herring gull are each numbered in thousands of pairs. Other breeding species include fulmar, black guillemot, peregrine, raven and twite. There is a subsidiary geological interest in the rock type, a distinctive Tertiary riebeckite microgranite which has been important in tracing the directions of iceflow during the last glaciation. The site is also notable for beetles (Coleoptera) and flies (Diptera).
20. Laggan	A fossil site, particularly noted for the presence of Carboniferous lycopods.
21. Corrie Foreshore	An outstanding site for lithological and facies studies in the Lower Carboniferous.
22. North Newton Shore	An unconformity used by James Hutton to demonstrate geological movements.

In addition to SSSI's the Outer Clyde hosts two Areas of Special Protection (AoSP), Horse Isle and Lady Isle. An AoSP is a designation which replaced Bird Sanctuary Orders (Protection of Birds Act 1967). AoSP's are created under the Wildlife & Countryside Act 1981 with the aim of preventing disturbance or destruction of birds.

The Clyde and its sealochs is an area of national and international importance for its complex geomorphology. The area hosts 17 sites identified by SNH and its predecessor as being of sufficient quality for inclusion within the Geological Conservation Review (GCR). Many of these sites have achieved SSSI status, and one (Mealdarroch) has been designated as an NNR, however, some have yet to be awarded protection under the Wildlife and Countryside Act. These areas include Geilston, Baron's Point, Glen Dhault, Portincaple and Toward Quay. Full descriptions of the geomorphology of the Clyde area are provided by Jardine (1986) and McAdam & Robertson (1997).

Natura 2000

The strongest legal protection is offered to sites designated under the Habitats and Species Directive, as implemented by the 1994 Regulations. These sites, which together form the Natura 2000 network of protected sites across the European Community, are sites of Community importance. The Natura 2000 network includes two types of area. A Special Area of Conservation (SAC) may be designated where the site supports certain rare, endangered or vulnerable species of plants or animals (other than birds) or if the area supports outstanding examples of habitats characteristic to the region. If an area supports significant numbers of wild birds and their associated habitat, it may be designated as a Special Protection Area (SPA). In some cases, sites may be designated as both SAC and SPA and it is worth noting that the European Court of Justice has emphasised that if the ecological criteria for designation of these sites are met, then an area should be designated regardless of any competing economic or social interests. There are three Special protection Areas associated with the Inner and Outer Clyde. In 1999-2000 the Inner Clyde SSSI was classified as a Special Protection Area and Ramsar site, reflecting its international importance for wintering redshank

(*Tringa totanus*) and ornithological interests. The Black Cart flows into the River Clyde at Renfrew and was recently classified as a Special protection area for wintering whooper swans (*Cygnus cygnus*). Ailsa Craig is internationally important for its rocky shore and cliff habitats with their associated large concentrations of breeding seabirds (Monaghan & Zonfrillo 1986). The gannetry is ancient and is the fourth largest in Britain. A map showing the position of Special Protection Areas within the Clyde are is provided in Figure 2.

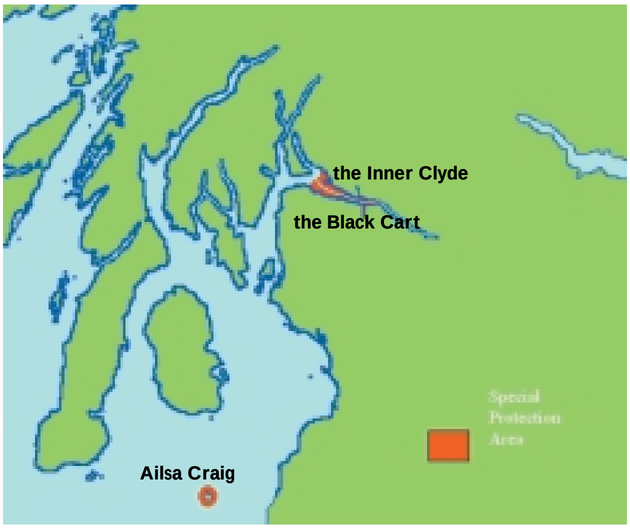

Figure 2. The location of classified Special Protection Areas within the Inner and Outer Clyde.

Ramsar Sites

The UK Government is also party to the Convention on Wetlands of International Importance (the Ramsar Convention). The Ramsar Convention was signed in 1971 and affords special protection to wetlands of international importance in terms of their ecology, botany, zoology, limnology, hydrology and ornithological interests. Wetlands protected through the Ramsar Convention are designated by the Secretary of State for inclusion in the List of Wetlands of International Importance maintained under the Convention. In common with sites protected under Natura 2000 legislation, Scottish Ramsar sites should already be protected as SSSIs. The Inner Clyde was put forward for Ramsar status in 1999.

Other Designations

Not all of the areas valued by Scottish Natural Heritage are protected for their biological or geological attributes. National Scenic Areas (NSA's) for example, represent nationally important areas of outstanding natural beauty and some of Scotland's finest landscapes. They were identified by the Countryside commission for Scotland in their report *'Scotland's Scenic Heritage'* (1978) and confirmed by the UK Government through the issue of Circular 20/1980. National planning policy for NSA's is set out in the National Planning Policy Guidelines for the Natural Heritage (NPPG 14). SNH is required to be consulted on specific categories of development within these areas. There are currently 40 NSA's in Scotland, covering an area of approximately one million hectares. Two NSA's (Kyles of Bute and North Arran) are located within the Clyde area. The position of these areas are shown in Figure 3.

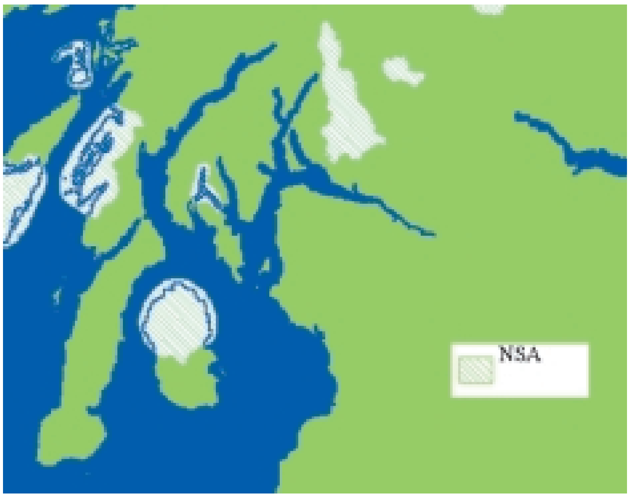

Figure 3. The location of National Scenic Areas within the Clyde area.

In addition to NSA's the Clyde hosts areas which are listed as Regional Landscape Designations (RLD's). RLD's provide a mechanism whereby local planning authorities can identify sites where there should be a presumption against development. Examples of RLD's include Loch Long, Loch Goil and East & West Loch Fyne. Developmental controls are also placed on Preferred Conservation Zones (PCZ's). These are coastal areas of particular scenic or environmental interest in which some types of development, such as oil or gas installations, may be inappropriate. Examples of PCZ's within the Clyde area include Loch Goil, Loch Long, Arran, Bute and the Cumbraes.

Marine Consultation Area status is a non-statutory designation which identifies areas considered by SNH to deserve particular attention with regard to the quality and vulnerability of the marine environment. Examples of MCA's within the Clyde area include Upper Loch Fyne and the Cumbraes.

Research and Awareness

Atkins (1999), Baxter & Davison (1999) and Sankey (1999) describe the increasing importance of local community and individual involvement to coastal conservation. The range of membership interests encapsulated within the Clyde Forum testify that the coastal environment and inherent biodiversity are considered to be important by local communities, industry, tourists and recreational users. SNH has contributed to the public understanding of marine and coastal natural heritage issues through the establishment of the Firths Initiative in 1993 and its involvement and promotion of the Cromarty Firth Liaison Group, Forth Estuary Forum, Minch Project, Solway Partnership, Minch Forum, Clyde Estuary Forum, Moray Firth Partnership, Tay Forum and the Scottish Coastal Forum.

In addition to its practical and financial contribution to coastal initiatives, partnerships and fora, SNH raise awareness of coastal conservation issues by producing a wide range of popular and specialist scientific literature. Freshwater and marine consultation documents are produced by both SNH and the Joint Nature Conservation Committee (a Government Agency financially supported SNH, English Nature and the Countryside Council for Wales, it provides strategic and policy guidance for UK-wide conservation issues).

Summary

The River Clyde and its estuarine and marine environment hosts or provides essential habitat for a diverse range of plant and animal species, some of which are present in nationally or internationally important numbers. The Clyde catchment is also of notable interest for its complex geology and geomorphology. Scottish Natural Heritage is the statutory agency responsible for the protection of the natural heritage of the Clyde catchment and plays an important role in the maintenance of its scenic heritage. Protection can take the form of site-designation using a range of statutory instruments and by providing specialist advice to other relevant Government Agencies (e.g. SEPA, Maritime Coastguard Agency) and local authorities. SNH also contributes to site protection by raising awareness of natural heritage issues and promoting best practice.

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The RSPB and its perspective on the Management of the Firth of Clyde

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Introduction

The aim of this paper is to explain RSPBís work on estuary management and to examine the past and future management issues relevant to the exploitation and conservation of the Firth of Clyde.

The RSPB: Its Aims and Operations

The RSPB is Europe's largest voluntary wildlife conservation organisation, with a current UK membership of over one million people. The organisation focuses on the protection of wild birds, and where appropriate, works to conserve wider biodiversity, tackle broader environmental issues and take an active role in promoting more sustainable forms of development.

In order to cover this remit, the RSPB is active across a wide geographical area, working to influence government policy at the Scottish Executive level, Whitehall, Brussels and through a variety of international fora. Locally, staff are in more or less continuous liaison with councils and statutory environmental agencies, to provide comments on land use plans, initiatives and individual development proposals. The organisation operates the largest youth environment club in the world and RSPB members run a network of local groups that fundraise, help prevent damaging developments and host a variety of meetings and talks.

In addition to advocacy, education and policy work, the RSPB owns or leases areas of special importance for birds. In Scotland, there are now a total of 65 reserves, many at coastal locations. This reserve network brings with it many benefits not just for birds but for wider biodiversity. It also brings support to people in surrounding areas, through recreation and economic spin-offs. Finally, a significant part of RSPB's resources go into research, the results of which help to inform our policy and reserve management work.

The History of RSPB's Work on Coastal Issues

Having outlined its work, this section gives the reasons why the RSPB is involved with coastal issues, in the face of so many other demands on its resources.

The first part of the answer is that the UK's inshore and marine habitats are extremely important for birds.

By virtue of its geographical position under the East Atlantic Flyway and its daily exposure to a substantial tide, Britain's shoreline harbours a vast inter-tidal larder that is vital for millions of waders and wildfowl migrating between their breeding and wintering grounds. Mudflats in particular, on account of their high biological productivity, provide essential estuarine life support stop-overs and enable these birds to survive migration. Their presence, plus the populations of resident waders and wildfowl, accounts for RSPB's heavy involvement in the protection of these critical habitats.

In addition to estuaries, Britain's abundant cliffs, islands and productive seas host major concentrations of breeding seabirds. Scotland is especially significant in this respect, with several nesting colonies of international importance. Given the threat from pollution and the birds' reliance on healthy fish stocks, the RSPB has also had to become involved in marine habitat protection.

The second factor driving RSPB's work on coastal issues is more to do with economics and politics than ecology. Over the 1970s and 80s, it became evident from casework and research by other conservation bodies that estuaries and their wildlife were at risk. Land claim was booming and new types of threat emerged, from recreation, climate change and sea level rise. When trying to resolve conflicts, the RSPB and other environmental bodies were confronted by legislation and planning frameworks unable to address these pressures. Repeatedly, controversial developments exposed conflicting policies and practices between different sectors and across local authority boundaries, and such circumstances conspired to obstruct wise use of estuaries. With no obvious end to these trends and with coastal habitats disappearing, increment by increment, it was evidently necessary to do more to protect our coast.

Working Towards Solutions

In response to such trends, the RSPB began to acquire important coastal areas, a strategy which was designed to gain a stake in discussions about the future of these habitats. As a result, there are reserves on many of Scotland's major estuaries, including the Firth of Clyde, Forth and Solway. This approach has proved highly successful, and has enabled the RSPB to engage as a full stakeholder in consultations about developments, as a policy advocate and as a landowner.

The 1990s saw a broadening of this approach, and the RSPB launched its first major estuaries campaign, 'Turning the Tide'. Specifically designed to raise the profile of estuarine issues, it aimed to highlight threats to shorebirds and to promote more sustainable estuary use. The 1993 campaign, 'A Shore Future', took this work forward, presenting new findings on coastal development pressures and responding to the emerging political and policy debate on coastal zone management. To build on this momentum, the Marine Life campaign was launched in 1994, to raise awareness of problems facing the environment further out to sea, from pollution and over-fishing in particular.

Through these initiatives, and alongside other conservation bodies, the RSPB worked to collate information, table proposals for new legislation, build partnerships and lobby for comprehensive European, national and local planning structures to protect our coasts from damaging development. As a practical framework to deliver better protection, estuary fora were proposed, with the capacity and power to produce statutory, binding and integrated estuary management plans. This approach was designed to prevent damage to coastal habitats, direct development towards more sustainable goals and foster cross-sector co-ordination.

Whilst this work was going on, there were, of course, external changes taking place that had significant implications for coastal environments. Of special relevance for this region was the restructuring of local government, which in the Clyde's case, removed Strathclyde Regional Council, the one agency with a Firth-wide perspective and powers to match. The decline of traditional industries continued, raising the political imperative of job creation and bringing into being regeneration QUANGOS who operated largely outside the planning framework. Local authority funding suffered repeated cuts and the budgets of many statutory agencies underwent similar reductions.

On the plus side, new statutory agencies emerged, along with a host of new legislation to improve environmental protection. Partial devolution occurred and with it, a much greater emphasis on open government and involvement of communities in the decision-making process.

Is There Better Protection and Management of Our Coasts?

In order to answer this question, the campaign documents, casework correspondence and news items from the 1980s and 1990s provide a useful reference.

At the macro scale, there is not the European or national coastal zone legislation called for by many environmental bodies, including the RSPB. There is, however, stronger national planning guidance on coastal development, in the form of NPPG 13. The Scottish Coastal Forum is also up and running, fulfilling an advisory role to the Scottish Executive. In the planning and commercial realms, there has also been an increasing (albeit, sometimes reluctant) acceptance of conservation as a legitimate interest and sustainable development as a valuable goal.

Turning more specifically to the Firth of Clyde, how does progress compare to what the RSPB promoted in 1991 in its 'Turning the Tide in the Clyde' Leaflet?

In putting in place designations to protect wildlife, there has been very welcome progress through the recent designation of the Inner Clyde Special Protection Area. Proposals for Local Nature Reserves are also well advanced for Newshot Island and Maidens.

The RSPB had also called for a reduction in pollution and progress on this front has also been good. A major part of the Clyde is covered by Clydeport's new oil spill contingency plan, tested in a major simulated exercise in 1999. Whilst it exposed certain deficiencies, Clydeport have been positive about incorporating suggested improvements.

Threats from poorly conceived developments have decreased to some degree, due to stronger planning policies, government guidance and fuller stakeholder consultation by developers. The new Glasgow & Clyde Valley Structure Plan and South Ayrshire Council's Coastal Development Strategy are very welcome examples of new planning frameworks that actively promote wildlife conservation and sustainable development. The use of conservation-related planning conditions has enabled compromises whenever possible, for example in the case of the Big Idea at Irvine. Control of visitors to this site, will, it is hoped, ensure that birds are allowed to feed undisturbed on nearby mudflats. Then, of course, there is the Firth of Clyde Forum itself, which has identified the core issues in need of action. Several members of the Forum, including RSPB, have committed themselves to a first phase of actions and projects to address these matters. The recent decision at Bogside, in North Ayrshire, which sanctioned loss of coastal habitat for a landfill and sand quarry, does, however, show that there is still a long way to go.

The Need for Further Progress

At the macro-level, the RSPB is seeking the introduction of new approaches to environmental management, through European directives on Strategic Environmental Assessment, Coastal Zone Management and the Water Framework directive. The organisation will then lobby for full implementation through national legislation.

In terms of coastal fora, English Nature's review south of the border has proved instructive. Although it concludes they have promoted better liaison, it also raised questions about their effectiveness in making a difference on the ground. Nobody wants a forum that is just a talking shop, and it is essential that participants ensure delivery of actions that make a real difference. It is also essential that they provide a service to their members, facilitating projects and bringing benefits from greater co-operation and efficiency. Fora must pay their way and be of practical use at the same time as helping development to take place in a more sustainable way.

To get useful work done and for the Firth of Clyde Forum to earn its keep, examples of activities could include the marketing of the Clyde as a development location of high environmental quality and the development of responses to sea level rise. The RSPB would also like to see more sustainable fisheries and a Firth-wide oil spill contingency plan (rather than the somewhat fragmented approach at present). With wildlife designations in place, the organisation will help ensure they operate effectively to protect and enhance habitats. Furthermore, the RSPB believes that marine protected areas should also be established where appropriate. As seabirds spend only a quarter of their time on land, it is vital the marine habitats on which they depend are also protected. Experience from the USA, the continent and elsewhere shows that it can be done, and lessons should be learnt and applied locally.

At an institutional and political level, the RSPB also considers it essential to have full participation in the Forum from all Councils around the Clyde. In the immediate future, it is also essential that links are developed with the emerging National Park. The RSPB, along with many others, is working to ensure the philosophy of sustainable development is at the core of the Park's functions, and its role and that of the Firth of Clyde Forum should be mutually re-enforcing. The RSPB will also encourage the integration of national and local biodiversity action plans into the Forumís work.

For its part, the RSPB will continue to protect its reserve network and expand it if resources allow. It will support Scottish Natural Heritage in its work, particularly in relation to management of the Special Protection Area and in calling for more resources for it to do its job. The RSPB will aim to build public and political support for the conservation of the Clyde's birds and to get more people interested in wildlife and the environment. Council members are a particularly important target audience in this work so they cease to see conservation as a threat to development but an essential part of it. Of equal importance, the RSPB will continue to work with developers and planners to help ensure wildlife interests are protected and enhanced. The RSPB will also assist in tackling the challenges from climate change and sea level rise.

In conclusion, this paper shows progress has been made towards the more sustainable management of the Firth of Clyde. A repeat assessment in 10 years time will again provide an opportunity to assess how much further this has gone.

Changes in the Seabird Populations of the Firth of Clyde

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Introduction

The Clyde Sea Area and its islands provide an ecosystem of great diversity and complexity for both land and marine life. The action of glaciers during the Ice-Age had formed not only cliffs and headlands suitable for seabirds to nest upon, but modified the sub-sea habitat by forming deep glacial gouges that were then colonised by marine life more usually found off the continental shelf.

Twenty-one seabird species breed or have been known to breed on the Firth of Clyde, from a grand total of around twenty-five species regularly nesting within the British Isles. Roseate Tern has not bred for many years and of the remaining four species of terns, Common, Arctic, Sandwich and Little presently breed in the Clyde area in only relatively small numbers.

Since the advent of man, and particularly modern man in the past 150 years, threats to the wildlife on land and in the sea have been both real and apparent. Modern man has been the agent of change, sometimes drastic and rapid, in both narrow habitat and broad ecosystem by direct and indirect actions on both land and at sea.

Seabird colonies

Ailsa Craig, at the entrance to the Firth of Clyde, rises abruptly to almost 380 m above sea level. The weathered columnar granite ledges form ideal breeding sites for seabirds making it the most important site in the area. For a relatively small island, Ailsa Craig has a diverse flora (Zonfrillo, 1994) and an interesting fauna. Among several previously introduced mammals (including Badgers and Racoons) only Rabbits and Brown Rats persisted (Lawson, 1896). The island is privately owned by the Marquess of Ailsa. Other important Clyde seabird islands include Sanda, Inchmarnock and Little Cumbrae are also privately owned. Only Lady Isle and Horse Island, both off the Ayrshire coast are designated nature reserves.

Many old accounts of seabird populations were nothing better than rough estimates, in error by perhaps even an order of magnitude (Paton and Pike, 1929). Since the 1980's, standardised methods for estimating breeding seabirds numbers at colonies are now generally applied (see Lloyd *et al.* 1991).

Gannets were counted in 1995 by Wanless and Murray (pers. com.) and elsewhere, seabirds on the Sanda Islands were counted by I. Livingstone & R Morton (pers. com). All other sites and species apart from those on the Sanda Islands were personally counted by the author.

Results

Counts given in Table 1 represent the most recent counts available since the publication of the Seabird Colony Register (Lloyd *et al.*, 1991) and come from within the past decade.

Table 1. Recent counts and estimates, including year 2000, of seabirds breeding in the Clyde Area. Numbers of non-breeding birds are not included in the totals.

Species	**Total** (pairs)
Fulmar *Fulmarus glacialis*	1204
Manx Shearwater *Puffinus puffinus*	200
Storm Petrel *Hydrobates pelagicus*	200
Gannet *Morus bassanus*	40,000 *
Cormorant *Phalacrocorax carbo*	266
Shag *Phalacrocorax aristotelis*	736
Terns (4 species) *Sterna* -sp. **	100
Lesser Black-backed Gull *Larus fuscus*	4004
Herring Gull *Larus argentatus*	7,500
Great Black-backed Gull *Larus marinus*	310
Common Gull *Larus canus*	265
Kittiwake *Rissa tridactyla*	1800
Black-headed Gull *Larus ridibundus* ***	30
Razorbill *Alca torda*	3000
Guillemot *Uria aalge*	14,100
Puffin *Fratercula arctica*	150
Black Guillemot *Cepphus grylle*	300

* = Current (2000) total derived from known rates of increase during past 20 years
** = Grouped for convenience. *** = All major colonies are inland.

Population changes

Some seabird populations have fluctuated widely over the years within the Clyde Area. The Fulmar in the Clyde has increased from zero to well over a thousand breeding pairs since 1938 when the species first bred (Fisher, 1952 & 1966), and the number of colonies it occupies has also increased. However the breeding performance of this spectacularly successful species in the area has been poor. Between 1980 and 1990 the annual rate of increase was 14 % but numbers were fuelled by immigration and not local reproduction. Fulmar chicks and eggs at many Clyde colonies are vulnerable to alien predators such as rats and minks. In their absence they thrive.

Gannet breeding numbers on Ailsa Craig have increased gradually at a rate of almost 4% per annum since the 1970's (Nelson, 1978), with the present internationally important Ailsa population estimated at almost 40,000 breeding pairs. Ailsa presently holds all of the Clyde Gannets and 18 % of Gannets breeding in Great Britain and Ireland. Gannets are adaptable in their feeding and raise young successfully most years.

Shags showed an average 2 % per annum decline between the mid fifties and the late sixties followed by a 3 % increase up to 1980, thereafter an average 11 % increase until the present. This species has its strongest colony on the Sanda islands where it nests under boulders and on small cliffs. Ailsa Craig held only 30 pairs on high vertical cliffs until the late 1990's since when over 25 pairs (2000 count) have now started to breed under rocks below the Gannetry and may in future hold much larger numbers.

The Herring Gull, like the Fulmar, has gone through a period of increase in part of the twentieth century since formerly being scarce as a breeding species (Gray, 1871). Between 1969 and 1979 the Clyde area population increased by around 6 % per annum and in 1987 stood at almost 11,000 breeding pairs, the increase having been maintained into the following decade. Currently Little Cumbrae Island holds the largest colony (pers. obs, 1992 visit), but numbers have been culled at some islands e.g. Horse Island, R.S.P.B. Reserve, influencing overall natural fluctuations to some extent. Ailsa Craig Herring Gulls have suffered from outbreaks of botulism in recent years (1998 - 2000) killing many hundreds of adult birds. Consequently numbers appear to be in decline.

The Lesser Black-backed Gull also appears to be declining at some of its Clyde Island haunts, probably for the same reasons as Herring Gulls. However Lesser Black-backed Gulls have successfully colonised urban and city rooftops, with Glasgow alone holding more than 400 breeding pairs (inland totals are not included in this paper).

Breeding numbers of Great Black-backed Gulls within the Clyde area also fluctuate, perhaps through persecution, at and away from some colonies, as well as through causes such as botulism. The recent decline in the past decade follows a gradual 4% per annum increase over a 30 year period.

The trend for the Kittiwake breeding population on Ailsa Craig over the decades showed initially a decline but past counts (up to 1970) seem excessive and may not have been accurate. Similarly the 1981 count of 3000 pairs may have been an under-estimate due to early failed breeding attempts. Overall numbers are declining since several years of poor breeding success (up to 1998) will have reduced recruitment.

Terns (all species) have also declined in the Clyde since 1965, going from several colonies, and many hundreds of breeding pairs, to just over 30 pairs in 1990. With abundant small fish now in the upper reaches of the Clyde some new areas have been colonised within the past few years by Arctic Terns and Sandwich Terns. Expansion however seems limited and former colonies such as Lady Isle, Horse Island and Pladda will hopefully be re-occupied with local birds.

Razorbill numbers increased on Sanda Island while remaining fairly stable on Ailsa Craig, but present numbers (around 3000 breeding pairs) are still below those recorded for the Clyde in the past. Some mainland cliffs on the Ayrshire coast recently colonised (late 1980's) have not shown any significant increase.

Guillemots on Ailsa Craig and on Sanda had shown a slight long-term decline since the 1950's but stabilised by the early 1980's (Monaghan and Zonfrillo, 1986). Guillemot numbers during the late 1980's and 1990's have increased dramatically on the Sanda Islands group. Less than a hundred birds bred on the Sanda islands for much of the 1960's and 1970's (Maguire, 1981 ; Lloyd *et al*. 1991). Here numbers increased rapidly in a 4 year period to over 1500 breeding pairs in 1991, and by 2000 they reached around 5000 (I Livingstone, pers com). A slight decline at Ailsa Craig during the 1980's was countered by a massive increase in the late 1990's. In summer 2000 Ailsa and Sanda between them held over 14,000 apparently incubating Guillemots.

Puffins, on the other hand, have failed to recover on their former major stronghold of Ailsa Craig, going from many tens or perhaps even hundreds of thousands of breeding pairs in the late 19th century to a few hundreds in the 1930's with zero at present (Lawson, 1896; Gibson, 1951; Harris, 1984). The reasons for this particular decline is probably a totally land-based phenomenon through the accidental introduction of predatory Brown Rats (Campbell, 1892). Only a single Clyde outpost remains today on the Sanda Islands totalling around 150 pairs. Sanda has no rats and following their eradication from Ailsa Craig in 1991, Puffins are once again prospecting but have not yet bred.

Discussion

Reasons for population changes

Seabird populations fluctuate for several reasons. Because seabirds are long-lived, their declines tend to be slow when related to environmental factors such as over-exploitation of the sea by man. Oiling incidents are more immediate and high-profile but much fewer than in past decades. Factors that affect adult mortality, such as botulism in gulls, rather than young production will have the most rapid and marked effects.

Bird species that show a high degree of philopatry and breed in large numbers can mask declines in productivity simply by their sheer numbers and longevity, unless scientifically monitored. The Clyde Fulmars have experienced very poor breeding success resulting from predation on land by mammals for at least the past two decades and the population increase is largely explained by immigration. It is probable that the annual rate of increase of 14 % since 1980 until 1990 was due to recruitment from more northern colonies. Following rat eradication in 1991 Ailsa Craig Fulmars showed a rapid response in breeding success and the numbers there are now increasing. The largest Clyde Fulmar colony is presently on Sanda where rats are absent.

The Puffin decline on Ailsa Craig, following the accidental introduction of Brown Rats, took over thirty years of low-recruitment before a decline became obvious to those who made their living from seabird "farming" (Campbell, 1892: Lawson, 1896). Terns on the other hand can simply desert their colonies en-masse when birds in colonies fail to breed successfully through disturbance by alien mammals such as American Mink or through poor food supply (Monaghan and Zonfrillo 1986; Craik, 1995). Such desertion may only be temporary because birds may return in future years if breeding conditions improve or predators are removed. For many islands, particularly rocky ones, the status and effects of mammalian predators is unknown, particularly since rats and minks are largely nocturnal or secretive in their behaviour.

The rise or fall in some seabird numbers may indicate changing marine conditions. The fluctuations in numbers of Shags is not easily explained but may be initially due to a decline through human persecution, a stabilisation or slight increase due to less persecution followed by a substantial increase due to protection, environmental clean-up and an abundance of small fish on the upper reaches of the Clyde where this species shows the greatest increases. Ailsa Craig was historically never a large colony, and Shag chicks and eggs may have suffered from the depredations of rats. In their absence the Shag numbers breeding on Ailsa Craig have increased. Sanda Island has a large thriving colony and other colonies now exist on Little Cumbrae, Pladda and Lady Isle where Cormorants have also colonised. Shags feed mainly on sandeels and small Clupeid fish and probably indicate an abundance of such species within foraging range of the breeding sites. The new colonies now appearing on the upper small islands of the Clyde may be explained by a combination of recent modernised treatment of sewage effluent and extermination of most large predatory fish species by the fishing industry resulting in an abundance of small estuarine fish, that in turn may be attracting Shags and Guillemots to a new area of rich feeding.

It can be argued that many seabird species owe their increase to improved feeding conditions at sea, natural and man-provided, and to protection from persecution and exploitation by law, when on land.

In recent years Guillemots and Razorbills were probably not under the same threat from the oiling incidents which were commonplace on the Clyde until the late sixties (pers.obs.). Over the past fifty years, oil pollution incidents in the Clyde, although locally damaging, have proved to have little long-term effect on overall numbers of seabirds. However, incidents of oiling have been mainly in winter (in e.g. 1969, 1973 and 1981) when numbers of auks normally are lower.

Alien mammals, such as rabbits and rats in particular, were both deliberately and accidentally transported by shipping to islands where they caused added problems by direct depredation of breeding birds and by altering habitat directly and indirectly usually to the detriment of the indigenous animal and plant species. While some seabird colonies had existed for many thousands of years, rats, introduced through the agency of man, led to their extirpation in only three or four decades.

Black Guillemots have recently colonised the Ailsa Craig (Zonfrillo & Nogales, 1992), in the absence of rats, and Puffins have been seen ashore prospecting. Seabird population monitoring will in future reveal trends for numbers on Ailsa, and elsewhere on the Clyde.

Threats to seabird populations on the Clyde, and in general, also come from shooting and other forms of direct persecution by humans, e.g. egg collecting, long-line fishing, lobster traps, and oil pollution (Gibson, 1951; pers. obs). Indirectly, humans also destroy seabirds through botulism and habitat destruction. Seabirds on Ailsa Craig have suffered from all of these at one time or another in the past and also at present. During wartime the island was also used for naval target practice even during the breeding season (Gibson, 1951).

The future

Some seabirds are presently doing well in raising young, other are experiencing problems. Both categories require systematic monitoring on a regular basis. Climatic factors apart, only the agency of man can rectify the activities of the past, both on land and at sea. The period of environmental recovery required by an island may even equal that of the deterioration, although the effort put into conservation can sometimes produce immediate results in the short term. While land-based problems may be tackled more immediately than those at sea, it is the sea-based changes that urgently require a much more enlightened approach than at present and sweeping, if not draconian, legal measures to save what little remains. Many seabird studies focus on the effects of changes in the marine ecosystem but do not examine the causes. As data are built up over long periods it may be possible to relate causes to effects observed in the fluctuating fortunes of seabirds as both individuals and colonies.

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Eider in the Firth of Clyde: a 20th Century success story

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Introduction

Weighing in at around 2 kg, the Common Eider *Somateria mollissima* is the largest seaduck in the world. It is almost entirely associated with salt water, where it eats primarily Blue Mussels *Mytilus edulis*, up to 40mm long, and from depths of up to 10m (Cramp & Simmons 1977).

The Eider is currently ubiquitous in the Firth of Clyde, but this has not always been the case. The twentieth century has seen the status of Eider in the Firth of Clyde rise from that of an occasional casual non-breeding visitor to that of a potentially internationally important population, which breeds, moults and winters within the firth. This paper outlines the spread and growth of the Eider population and its current status in the Clyde.

The Spread of Eider in the Firth of Clyde

In the second half of the nineteenth century the presence and status of Eider in the Firth of Clyde sea area is unclear. However, at the end of the nineteenth century, the Eider was, at best, a scarce non-breeding visitor to the Firth of Clyde. (Paterson 1901, Holloway 1996).

Such was the uncertainty that Harvie-Brown (1910) wrote that the first Eider in the Clyde sea area were 5 recorded by R.F Graham off Skipness Pt, in November 1909, increasing to 7 there, by April 1910. Harvie-Brown also added that he expected that breeding in the Firth of Clyde would be proved soon afterwards.

McWilliam (1924) wrote "*Mr Harvie-Brown stated that as long ago as 1908 he knew of this species nesting on Loch Fyne, though no details have been given of this occurrence*". There are no details as to location or source of this record, which if substantiated would have contradicted Harvie-Brown's 1910 report cited above. Therefore, in the absence of any recorded details, there must be considerable doubt as to the reliability of this 1908 breeding record.

As a result, the first documented breeding record for the Firth of Clyde that can be accepted is the following; *in 1921 W. Stewart saw a female with three young birds near the head of Loch Fyne* (McWilliam 1924).

The source of these Eider and their subsequent spread and colonisation of the Firth of Clyde is now summarised. Appendix 1 details Firth of Clyde records and references.

It is thought that the colonisation of the Firth of Clyde was a continuation of range expansion and population growth spreading out from Colonsay and Oronsay, from about 1870s. On these, and adjacent Inner Hebrides, Eider was long known. It has even been suggested that Eider may have been introduced from Norway to Colonsay at the end of the 9th Century by the vikings (Holloway 1996 based on Harvie-Brown & Buckley 1892). Many of these breeding populations were regularly harvested for their eggs, e.g. Gray (1871) records eggs from Islay, and to a lesser extent from Tiree and Coll, being sent to market in Glasgow. In contrast, the breeding colonies on Colonsay and Oronsay were given special protection, by Lord Colonsay. Berry (1939) comments that *there can be no question that Lord Colonsay's protection of the species played a very important part in its increase and extension of range. As already mentioned in the previous section (Clyde), it is thought that Colonsay served as a zone of dispersal for the spread to Kintyre and thence to the Firth of Clyde.*

Expanding out from Colonsay birds colonised beyond Islay and Jura, southwards to Gigha and Cara, eventually to the Mull of Kintyre, and into the Firth of Clyde. It is also thought that some birds crossed the narrow isthmus at Tarbert, into the mouth of Loch Fyne in 1909 (Harvie-Brown 1910).

By the early 1920s the Loch Fyne birds had colonised the Sgat isles at the mouth of the loch, spreading onto the west side of Bute (and/or Inchmarnock) and also reached near to the head of the Loch Fyne. The Kintyre birds slowly expanded up the eastern (Clyde) coast of Kintyre and in the 1920s had reached the vicinity of Campbeltown.

During the 1930s birds continued to expand up the Kintyre coast of the Kilbrannan Sound and the first birds reached the east coast of Arran. There was consolidation of breeding birds on the west side of Bute and Inchmarnock, and probable colonisation of the Cumbraes (broods being recorded off the Ayrshire coast from Largs to Portencross probably originating from the islands).

In the 1940s, there was little evidence of range expansion, but confirmation of nesting on west and east coasts of Bute, Great Cumbrae and Davaar, suggest some consolidation of range and probable population growth. Further expansion may well have been restricted by the extensive military use of the coastline during the war years in the first half of this decade.

The 1950s saw further expansion around Arran (first nests recorded on Holy Island and Pladda), along the Ayrshire coast to Lady Isle and Ailsa Craig, and through the Kyles of Bute.

At the time of the BTO Atlas period 1968-72 (Sharrock 1976), Eider had become firmly established as a breeding species throughout the Firth of Clyde, reaching as far as the Rosneath peninsula and upper Loch Long. Confirmed breeding was recorded from every coastal 10km square along the Kintyre, Arran, Loch Fyne, Cowal, Bute and the Cumbraes and adjacent north Ayrshire coast, Horse Isle, Lady Isle, Ailsa Craig, and adjacent south Ayrshire coasts. During the 1970s broods were widely reported along the Renfrewshire coast into the Clyde estuary as far as Longhaugh Pt, and the Dunbartonshire coast as far as Cardross.

During the 1988-91 New Atlas period (Gibbons *et al* 1993) the expansion into the Clyde estuary was demonstrated, and confirmed breeding recorded along central Ayrshire coasts.

This shows that the main range of the Eider in the Firth of Clyde was well established by about 1970, with little expansion since. These records suggest that the colonisation of the Firth of Clyde was largely complete within 50 years of the first breeding record. However, although the range has largely remained static since 1970, the population has continued to grow.

Current status and population

Monitoring of Rhu-Coulport 1985-1999

This 25km count stretch incorporates the Gare Loch, Rosneath Peninsula and the south-eastern shore of Loch Long. As part of BOEE & WeBS monitoring, the author has undertaken counts from September to March from 1985/6 until 1999/2000. Eider were the most prominent and numerous species of waterfowl. The results of these counts are presented in Figure 1. A regular annual pattern is clear. There is a distinctive autumn peak that declined throughout the winter and spring. This data also shows that the size of the autumn peak has risen dramatically over the 15 counting seasons. It was important to determine if these additional birds represented displaced individuals from elsewhere or a sizeable growth rate in the population as a whole.

Extension of September monitoring

1995

Following discussion with Iain Gibson, we undertook a count out from the estuary into the adjoining areas of Cowal and North Ayrshire in 1995. 2 counters covered the Clyde estuary out to Toward Point and Largs. A total of over 7000 birds were found.

1996

Following the 1995 counts, discussions were also held with Brian Orr, WeBS co-ordinator for Ayrshire, and Ian Hopkins on Bute to extend the co-ordinated counts. 6 counters took part. The results of this count were 15,702

1997

For 1997 it was felt that if a co-ordinated count of the whole of the Firth of Clyde could be achieved, it was likely that the Eider population could approach 20,000. Support from the Argyll Bird Club and the Arran Naturalists enabled a serious attempt to add the Argyll and Arran coasts to our co-ordinated coverage. This took place over the 13/14 September weekend, with up to a week either side allowed. Coverage was good and 35 counters took part. A total of 19,450 birds were counted.

1998

The complete Firth was counted again in mid September 1998 (19/20 target weekend to coincide with WeBS). 41 counters took part. Coverage was good, similar to 1997. 14,539 birds were counted.

Despite excellent counting conditions over the target weekend, there were few birds along the south Ayrshire coastline, almost 5000 fewer than 1997. These birds largely account for the difference between 1997 and 1998. The whereabouts of these missing birds is unknown.

The 1998 count was co-ordinated with a count from Kintyre to Ardnamurchan, including the Argyll islands (Furness & Waltho 1999).

1999

Again the complete Firth was counted in mid September (11-19 target period). 36 counters took part. Coverage was again good. 16,546 birds were counted. The increase of 2000 birds from 1998 total can largely be accounted for by a similar increase of birds being recorded from the Ayrshire coast.

These counts (Table 1, Figure 2) demonstrate that the annual variation in birds counted in the Firth of Clyde as a whole can largely be accounted for by the variations recorded along the Ayrshire coast. The cause of these variations in Ayrshire is unknown at present.

What is the scale of the current breeding population in the Firth of Clyde?

An attempt was made to assess the pre-breeding population during mid April 1999. 44 counters took part. Coverage was generally good but patchy in Ayrshire. This count was again co-ordinated with a count from Kintyre to Ardnamurchan, including the Argyll islands (Furness & Waltho 1999). The Firth of Clyde total of 10,543 birds were counted and 2,200 estimated for those sections not counted, giving an adjusted total of 12,743. Where possible (n=10,042) adult males, immature males and all females were separated. To estimate the number of breeding females from this sample, a number of females equal to the number of immature males (291) was subtracted from the total of all females (3610). This gives a figure of 3319 or 31.5% of the population. If this proportion is applied to the adjusted total of 12,743, the estimated number of potentially breeding females is 4014. As this will inevitably include a number of non-breeding females in any one year (Coulson 1984), it is likely that the current number of nesting females in any one year is approximately 3500.

Population Growth Rate

The average annual growth rate was determined for two data sets from the Firth of Clyde during 1987-1999, Rhu-Coulport and Horse Island (a 8 ha island off Ardrossan).

For the Rhu-Coulport section, the average growth rate of the autumn peak was 6.5% p.a. For Horse Island, the average growth rate of nests was 11.5% p.a. When the annual pattern of variation is compared, both sites show remarkably consistent year to year trends (Figure 3).

A number of simple models of population growth in the Firth of Clyde since colonisation were tested (Figure 4). The best fit model had an average growth rate of 8.5% p.a. based on input of 10 birds in 1908. The date and initial number of birds reflect the Harvie-Brown records cited earlier. This model predicted 17,500 birds in 1999 and this compares with a four-year average of 17,342 birds.

Comparisons

In the New Breeding Bird Atlas, Baillie (1993) estimated that Eider populations nationally had increased by 2-3% per annum between the two Atlas periods 1968-72 and 1988-91. This estimate was based upon long-term studies on the Ythan (Milne 1974) and Croquet Island (Coulson 1984). Calladine *et al* (1995) report growth rates of 8.5% per annum for the Isle of May from 1978-1994, and 11.3% for Inchmickery from 1987-1994.

It is interesting to note the average of 8.5% over 16 years at the Isle of May, matches the long-term average for the Firth of Clyde. 8.5% p.a. appears to be a consistent average for a population's intrinsic growth rate.

Clearly the 20th century has been very favourable to Eider in the Firth of Clyde. What factors will eventually limit the Eider here and at what level will the population reach its carrying capacity and stabilise?

Regular monitoring of this population will need to continue if we are to discover the answers to these questions.

Figure 1. Monthly breakdown of Eider Rhu - Coulport 1985 - 2000

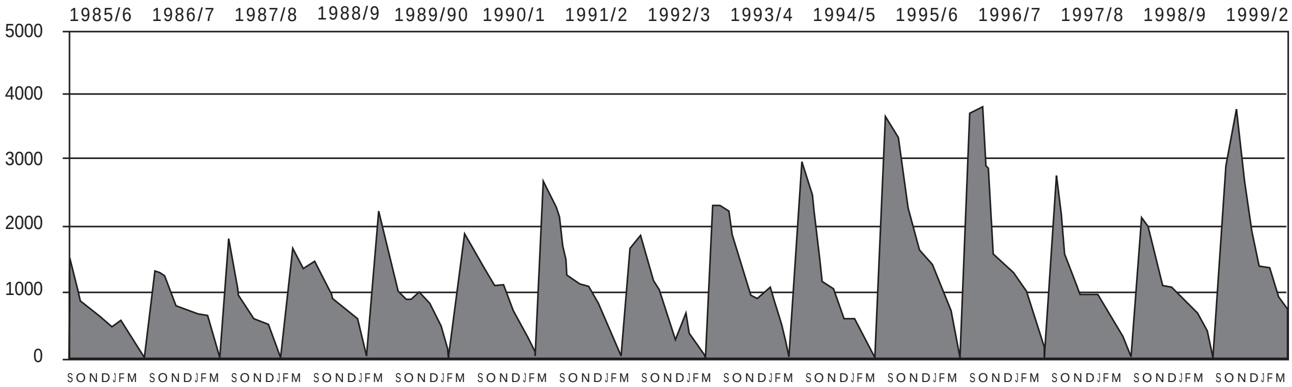


Table 2.

Count stretch	1996	1997	1998	1999	Mean
Clyde Estuary (Gourock - Craigendoran)	**2616**	**962**	**797**	**841**	**1304**
Craigendoran - Kilcreggan (Gareloch)	**3037**	**2419**	**2156**	**2261**	**2468**
Kilcreggan to Strone Pt (L Long/L Goil)	**1285**	**1331**	**2960**	**2164**	**1935**
Holy Loch to Toward Pt	**1021**	**2192**	**794**	**1504**	**1378**
Gourock - Largs	**1433**	**1175**	**1059**	627	**1074**
Toward Pt to Strone Pt (Loch Striven)	nc	415	336	299	350
Kyles of Bute (mainland) & L Riddon	nc	463	249	326	346
Bute	571	**763**	**949**	**1367**	**913**
Great Cumbrae	347	**776**	685	537	586
Outer L Fyne (L Gilp - Tarbert & Otter Ferry - Ardlamont Pt)	nc	258	196	232	229
Inner Loch Fyne (Otter Ferry to Port Appin)	nc	**1241**	**1362**	**1278**	**1294**
E Kintyre (Skipness - Southend)	nc	339	579	322	413
Arran	nc	155	318	278	250
Gogo Burn, Largs to Fairlie Pier	265	182	522	229	300
Fairlie Pier to Seamill	nc	415	325	348	363
Seamill to Saltcoats	**850**	**961**	486	680	744
Saltcoats to Stinking Rock Barassie	**1400**	**1510**	67	**789**	**942**
Stinking Rock to Pow Burn	**892**	**1006**	75	616	647
Pow Burn to Ayr Harbour	467	460	0	159	272
Ayr Harbour to Greenan Castle	nc	280	127	312	240
Dunure to Culzean	nc	nc	nc	38	
Maidens Harbour to Dipple	**1518**	**820**	246	653	**809**
Dipple to Girvan	nc	680	143	35	286
Girvan to Ballantrae	nc	430	58	301	263
Loch Ryan	nc	160	40	350	183
Actual Total	**15702**	**19393**	**14529**	**16546**	
Estimate for the rest of Argyll + Arran based on 1997 & 1998	3200				
Estimated Population	**18902**	**19393**	**14529**	**16546**	17342.5 17587

Figure 2. Trends in September Eider populations in Firth of Clyde

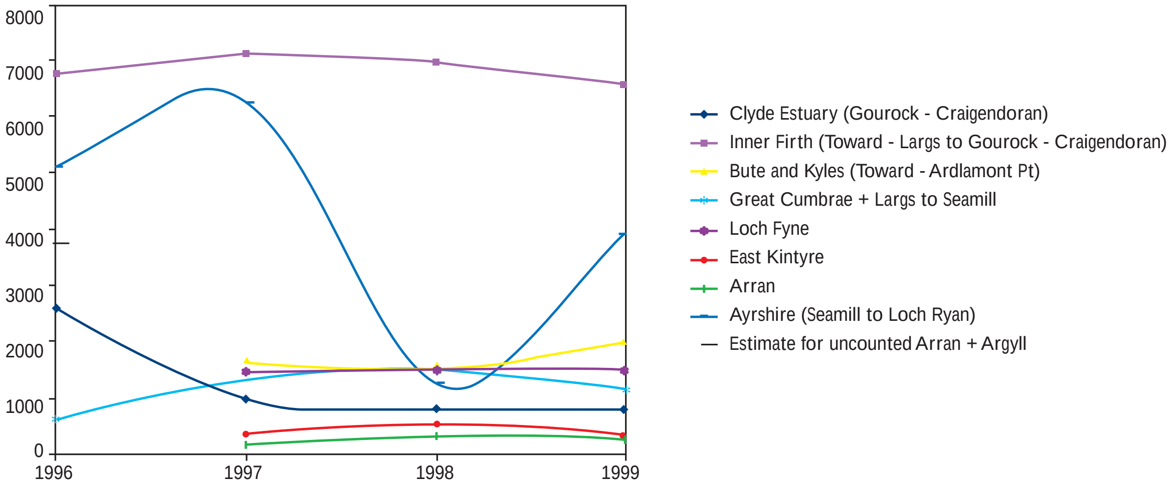


Figure 3. Eider population growth in the Firth of Clyde

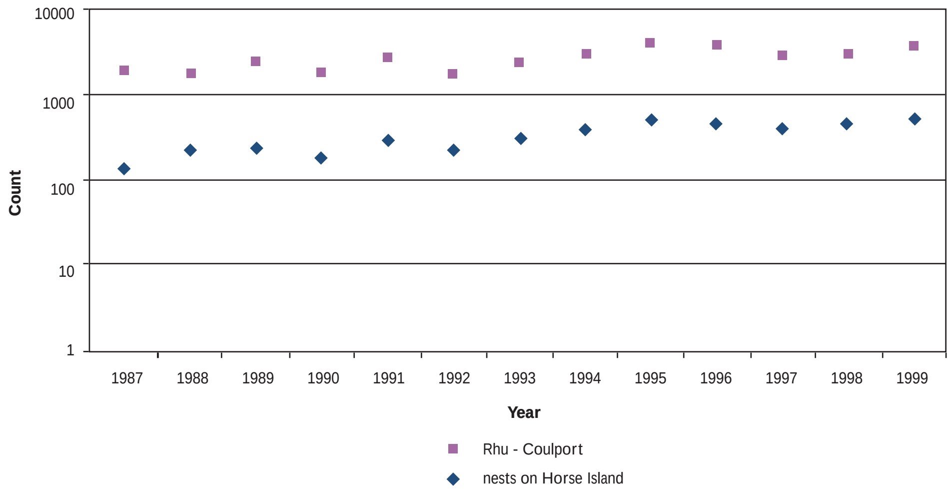
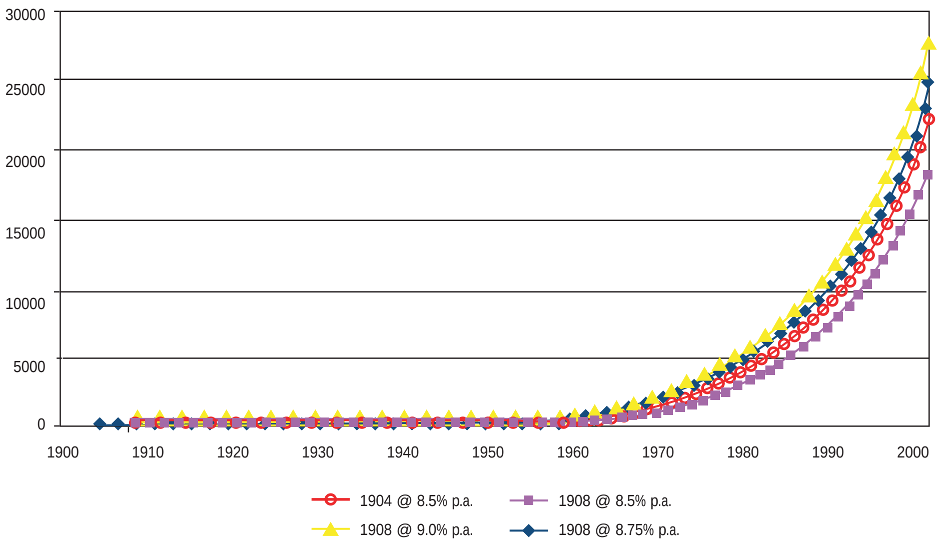


Figure 4. Models of Eider population growth in the Firth of Clyde during the 20th Century



Acknowledgements

I would like to thank all the people who have counted Eider in the Firth of Clyde in the last few years.

John Allan, R.H. Bailey, Jane Barker, Roger Broad, John Burton, Tom Callan, Tommy Daniels, Paul Daw, Bob Diamond, Aiden Doherty, Helen Doherty, Geoffrey Dunlop, Howard Embleton, Bob Furness, Iain Gibson, Eilean Graham, John Hamilton, Audrey Handley, Brenda Higgs, John Hodgson, Frances Hood, Ian Hopkins, Alan Howatson, Jean Howie, Peter Kirk, Ann Laing, Simon Lawrence, Eddie Maguire, Clelland McCallum, Mary McMillan, Bill Middlemiss, Susan Mills, Bob Nuttal, Moira Nuttal, Brian Orr, Duncan Orr-Ewing, Crystal Paterson, Steve Petty, Chris Roger, Ben Ross, Laurie Russell, Kate Sampson, Nigel Scriven, Geoff Sheppard, John Simpson, Tony Smith, Terry Southall, John Spooner, Peter Staley, Duncan Stevenson, Nicola Tallach, Sally Taylor, Peter Tupman, Audrey Walters, Alan Wood, Ruth Yates, Bernie Zonfrillo.

Thanks also to Zul Bhatia of RSPB for the Horse Island data.

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Appendix

Early records of breeding Eider in the Firth of Clyde 1900-1955

1921	female b/3 near head of Loch Fyne. W Stewart McWilliam, J.M. (1924) Breeding of Eider in the Clyde Area *Scottish Naturalist* 165
1924	first found nesting on Sgat Beag, entrance to Loch Fyne McWilliam, J.M. (1924) Breeding of Eider in the Clyde Area *Scottish Naturalist* 165
1925	first found nesting on Sgat Mor, entrance to Loch Fyne McWilliam, J.M. (1925) Increase of Eider Ducks in the Firth of Clyde. *Scottish Naturalist* 95-6
1928	female b/3 at St Ninian's Bay, Bute, 23rd June 1928. First breeding record for Bute. Robertson, J. (1928) The Eider nesting in Bute. *Scottish Naturalist* 125
1933	Three pairs in Lamlash Bay, Arran, 15th April 1933, but no record of breeding Baxter & Rintoul (1953). *The Birds of Scotland*
1937	a brood recorded at Portencross/Hunterston area by Glasgow Natural History Society on 3rd July
1939	nested on Inchmarnock Stuart, D. (1953) Notes on the birds of Bute *GWSBB* * 2: 14-18
1940	first nesting on west side of Bute Stuart, D. (1953) Notes on the birds of Bute *GWSBB* 2: 14-18
1942	nesting on Great Cumbrae by this year Gibson, J.A. (1957) *GWSBB* 6:5-6
c1945	nesting on Davaar at least by this date Gibson, J.A. (1955) Bird notes from Davaar Island *GWSBB* 4:21-22
1945	nesting on east side of Bute Stuart, D. (1953) Notes on the birds of Bute *GWSBB* 2: 14-18
1951	first nesting Pladda, Arran Gibson, J.A. (1954). The breeding birds of Pladda *GWSBB* 3:55-56
1951	first nesting record on Holy Island, Arran Eider nesting on Holy Island, Arran Gibson, J.A. *GWSBB* 1:16
1951	a few seen with young offshore, Skipness Cooper, P.E.D. (1953) Bird Notes from Skipness and Machrihanish *GWSBB* 2: 19-22
1955	nesting on Lady Isle Wilson, R. (1955) Lady Isle and its birds *GWSBB* 4:13-15
1955	first nest on Burnt Islands, Kyles of Bute Gibson, J.A. (1958) *GBB* 7:11

- GWSBB = Glasgow and West of Scotland Bird Bulletin,
- GBB = Glasgow Bird Bulletin.

Shellfish and Fisheries in the Firth of Clyde

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Introduction

In a period characterised by declining stocks of a number of fish in the waters around Scotland, fisheries for shellfish have continued to develop and have become increasingly important. This paper provides a short overview of the relative importance of the various fisheries for shellfish in the Firth of Clyde, particularly the Norway lobster (*Nephrops norvegicus*) fishery, and updates material presented at an earlier Royal Society of Edinburgh Symposium (Mason and Fraser, 1986). In the light of recent Scottish Executive initiatives, some discussion is also included on the management measures available for dealing with shellfish in this area. Some cultivation of bivalve molluscs continues to take place within certain sea lochs at the head of the Firth but this subject is not dealt with here.

For many practical purposes the Firth of Clyde can be taken to mean the non-estuarine waters inside of a line between Corsewall Point and The Mull of Kintyre. Unfortunately this definition does not completely correspond to those which arise from the methods used for recording fishery data. Data used in this paper mainly derive from the official statistics collected by the fishery officers of the SFPA aggregated for the statistical squares shown in Figure 1.

In common with other areas, catches from the Clyde of the main species of finfish have decreased in recent years. For example, cod landings are currently around 300 tonnes, less than a fifth of the figure recorded 20 years ago. Whiting, hake, and saithe appear to show similar trends and the only species showing a recent upward trend is the haddock for which modest landings of about 500 tonnes were recorded in 1998. In contrast, overall shellfish landings in the same period have been relatively stable around 4000 tonnes with higher than average returns in the last 5 years. In 1900, only a handful of shellfish species were landed, whereas 20 years ago the number had reached double figures. Nowadays around 20 different species (Table 1) regularly produce a combined value exceeding £16 million although the Clyde fishery continues to be dominated by the landings of *Nephrops* which are roughly an order of magnitude higher than the next most important species.

The exploited crustaceans in the Clyde

Small scale traditional fisheries, for two crustacean species, the lobster *(Homarus gammarus*) and the edible or brown crab (*Cancer pagurus*) have taken place in the Clyde for over a hundred years. Recent landings of lobsters have fluctuated mostly between 5 and 10 tonnes while those of edible crabs have rarely exceeded 40 tonnes. These landings cannot be described as significant when compared with similar fisheries in other parts of Scotland such as Orkney or the Outer Hebrides. Other species have increased in importance since the 1980's although still support relatively limited activity. Landings of the velvet swimming crab (*Necora puber*) reached 120 tonnes in 1997 while 20 tonnes of the squat lobster (*Munida rugosa*) were reported in 1999. Most of these species are taken by creeling from areas of seabed composed of rock (lobster and velvet crab) or cobble and muddy gravel substrates (edible crabs and squat lobster). Reference to sediment charts produced by the British Geological Survey and available for the Clyde Sea Area (British Geological Survey, 1985) show that these sediments are fairly limited in extent, particularly rock. The restricted distribution of the most favoured substrates for these species therefore provides a simple explanation for the modest fisheries supported in this region. It is unlikely that major expansion will be seen in the future, although maintenance of status quo effort levels should ensure continuation of the fisheries at the present level.

The Nephrops fishery

The principle fishery in the Clyde is for *Nephrops* (Bailey, Howard and Chapman, 1986) a particularly abundant crustacean that lives on the extensive areas of soft mud, sandy mud and muddy sand which predominate throughout much of the Clyde in subtidal regions below about 20m depth. Prior to the late 1950's the species represented an incidental bycatch which was discarded, but since then it has increased to present levels of between 3000 and 4000 tonnes and a value of around £8 million. Most of the landings derive from targeted trawling but a small creel fishery also operates in inshore areas particularly along the north and Kintyre coasts.

The numerous studies that have taken place on fishery practices, population biology, juvenile stages and diseases of Clyde *Nephrops* have provided a reasonable picture of its relationship with the environment and its response to fishing. A key feature of the species is its spatial variability in biological features which are manifest even within the Clyde. Most notably, growth rate and size of maturity is higher and stock density lower in the more northerly parts of the Clyde where soft muds predominate. Conversely, slow growth and high density is a feature of the population to the south of Ailsa Craig where the sediment is coarser and contains a higher proportion of sand. These observations have a bearing on the approaches used to provide quantitative estimates of abundance.

The most recent assessments of Clyde *Nephrops* (ICES, 1999) show that although mortality due to fishing has increased slightly in the last few years, the stock biomass has increased from a relatively low level in the early 1990s and is now fairly stable. Similarly, recruitment of young animals to the stock has been good and is currently higher than the low values of 1991 and 1992. In addition to these numerical modelling methods based on monitoring the commercial fishery, independent methods using underwater television are also carried out. These surveys of the Clyde broadly confirm the results from the quantitative assessments and reveal that *Nephrops* continues to be widespread throughout the Clyde and that its abundance has increased in the last couple of years. Interestingly, the 1998 survey revealed relatively high densities throughout the Clyde, even in areas normally characterised by lower abundance.

Exploited Molluscs in the Clyde

The other commercially important shellfish in the Clyde are the molluscs and the next five most important species by weight after *Nephrops* all belong to this group. The fact that the landings of these species are relatively low compared to *Nephrops* is again mainly related to the distribution of suitable sediment types. Most of these molluscs are associated with rock, sand and gravel substrates which are not extensively represented in the Clyde and overall population sizes are consequently modest compared with other parts of Scotland.

Of the bivalve molluscs, the scallop (*Pecten maximus*) continues to support the most important fishery. Catches of this species from grounds off the Ayrshire coast increased markedly in the 1960's and were sustained by exploitation of populations located around the Mull of Kintyre, Kilbrannan Sound and off the south coast of Arran. Landings were maintained around 500 tonnes for some years but dropped to below 200 tonnes in the late 1980's. Since then there has been a fairly steady increase to over 500 tonnes in 1999 and, encouragingly, the stock structure contains reasonable numbers of older scallops. The improvements reflect a general increase in scallop recruitment on the West Coast but diversion of effort to the Clyde during closures resulting from toxic algal events elsewhere account for some of the recent increase in landings; the impact of this effort transfer will need to be carefully monitored.

The queen (*Aequipecten opercularis*) has also been fished for many years in the Clyde but its population status and biology is less clearly understood. Landings of this species have often exceeded those of the king scallop, reaching over 1000 tonnes in some years but have been subject to wider fluctuations. At present, queen scallop landings are at a very low level but the reasons for this are not clear.

Fisheries for a number of other bivalves have developed more recently and are presently operating at a relatively small scale. For example, 80 tonnes of razor clams were reported as landed in 1997 mainly from hand gathering by divers working shallow sandy bays throughout the Firth. This figure has dropped in the last couple of years but the accuracy of information available for this fishery is questionable and the data available on distribution and size of razor clam populations are sparse. Studies of age structure in other populations in Scotland suggest that some of these animals are long lived and may be the products of sporadic recruitment events. If so, this has serious implications for the way these species are exploited and it is hoped that ongoing studies of razor clams in the Clyde will provide much needed information.

Two gastropods also figure in the Clyde's fisheries and have been relatively important in recent years. Periwinkle gathering on the rocky foreshore is a traditional activity which goes back many years and landings of around 500 tonnes have been fairly common. Participants are drawn from various backgrounds outside those associated with regular fishing and itinerant groups from around the UK sometimes visit the Clyde. Since 1993 the landings have been below 400 tonnes but it is not clear why this is and quantitative information on overall winkle abundance is not available. The fishery for whelks (mainly *Buccinum undatum*) is much more recent, developing mainly in the 1980's and producing sporadic landings influenced largely by market conditions. A peak of nearly 300 tonnes was landed in 1997 when buyers found good outlets in the Far East. Since then landings have dropped but this is true elsewhere in Scotland also and seems to reflect market collapse rather than a problem with stocks of whelks.

Management opportunities for shellfish in the Clyde

Stocks of shellfish in the Clyde are managed by a variety of measures, some of which apply more generally across Scotland. Single species UK licenses are used to limit access to scallop and *Nephrops* fisheries, with the latter also subject to output controls in the form of EU TACs. The majority of exploited shellfish species are, however, not presently covered by such access or catch limitations and considerable reliance is placed on measures which attempt to reduce the catches and landings of immature individuals. These Technical Measures, as they are known, are species specific and include gear regulations (such as minimum mesh sizes) and minimum landing sizes. Perhaps surprisingly there are some species, for example periwinkles which are not specifically covered by any fishery regulations at all, despite their relative importance.

Very few controls at the present time apply uniquely to the Clyde Sea area (input controls limiting the size of demersal trawlers being one of the exceptions) although opportunities within the competence of Scotland's devolved status do exist. The statutory instruments offering the greatest possibilities for Clyde specific measures are the Inshore Fishing (Scotland) Act 1984 and the Sea Fisheries (Shellfish) Act 1967 (through recent developments in the provisions covering Regulating Order legislation).

Conclusions

Nephrops continues to dominate the shellfish scene in the Firth of Clyde and, given the low abundance of finfish species, represents the mainstay of the Clyde fleet generally. Our understanding of the Clyde *Nephrops* population is building up through the growing body of scientific work. Routine surveys and assessments suggest the stock is sustainable at present levels of fishing effort. Numerous other shellfish are also exploited in the Clyde and diversification has increased in the light of the aforementioned declines in finfish – for many of these newer targets, state of stock information is more limited. It is the case, however, that the magnitude of the *Nephrops* fishery owes much to the widespread distribution of soft muddy substrates within the Clyde and it seems unlikely that species found on the less well represented substrates could ever assume the same importance. Recent initiatives and new emphasis within Scotland should facilitate improved management in inshore areas. Together with the Inshore Fishing (Scotland) Act, the development of Regulating Order legislation offers interesting possibilities for local shellfish management which could perhaps be applied within the Firth of Clyde.

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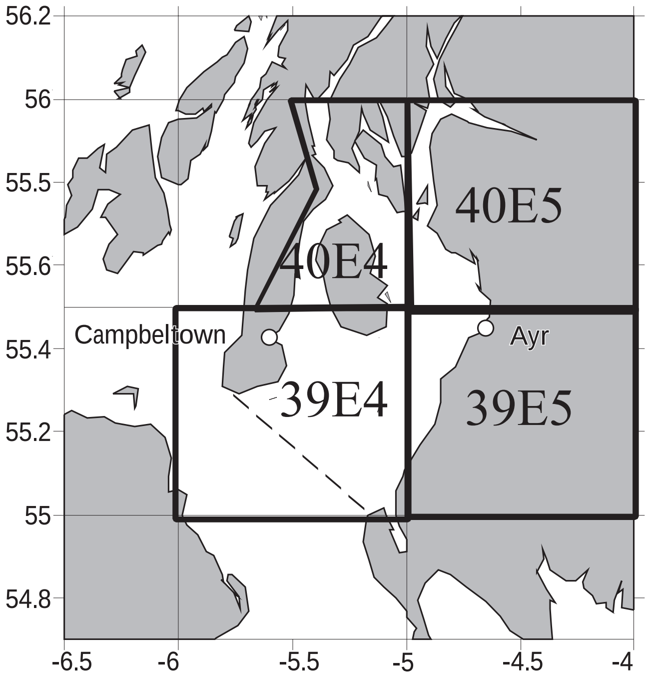

Figure 1. Positions of the statistical squares aggregated together to provide landings information for the Firth of Clyde. Note, 'split square' data are available for 40E4 (i.e. 'true Clyde' data) but not for 39E4. Dashed line shows the limits of the Firth of Clyde adopted for some legislative purposes.

Table 1. Landings (tonnes) of shellfish species from the Firth Of Clyde (ranked by weight). Figure shown for each species is the *maximum annual value* in the period 1990 - 1999.

Shellfish Species	**Landings** (tonnes)
Nephrops	4190.7
scallop	547.2
periwinkle	508.9
whelk	290.0
queen	243.9
squid	160.2
velvet crab	116.5
edible crab	101.6
mussel	91.0
razor clam	82.1
squat lobster	22.8
shore crab	21.6
lobster	13.3
cockle	10.3
octopus	9.6
crawfish	5.0
brown shrimp	1.1
pink shrimp	0.3
oyster	0.2

Environmental effects of fishing and evaluation of methods for the rapid assessment of the impacts of otter trawls

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Introduction

There has been increasing concern about the detrimental effects that commercial fishing can have on the environment, concern which is appropriate on global, regional and local scales. Apart from depleting target stocks, fishing activity can directly or indirectly impact many non-target species, including birds, reptiles and sea mammals. Mobile fishing gear such as trawls and dredges can significantly alter seabed habitats and communities. Many studies have tried to assess the impact of such fisheries but traditional methods are slow and reports can take several years to complete.

In the Clyde Sea area (Scotland) the major fishery is for the Norway lobster, *Nephrops norvegicus*, also known as 'scampi' or 'langoustine', a small member of the lobster family that lives in burrows in the muddy substrate that predominates in the region. They are caught mainly by otter trawls (Fig. 1), although some are taken in creels. Fishing is an important industry and it is vital to the long-term survival of the industry and the environment for the right balance to be achieved between exploitation and conservation. This short paper highlights some effects of fisheries, briefly examines the socio-economic aspects of the Clyde *Nephrops* fishery and introduces a current project evaluating new methods aimed at providing a rapid assessment of the impact of towed fishing gear.

How fishing affects the environment

Expansion of the global fishing industry and advances in fishing technology now leave mankind with the potential to reduce target populations to a fraction of their pre-exploited levels and in so doing cause long term and possibly irreparable damage to non-target species, their habitats and associated communities. Concerns have rightly spawned a multitude of studies on the effects of fishing, the full scope of which cannot be addressed here. Instead I will focus on the more serious and high-profile effects but refer you to some recent reviews for a broader account of the subject (Jennings & Kaiser, 1998; Hall, 1999; Moore & Jennings, 2000).

Changes to populations and communities

Obviously, a fishery directly affects the target species. When a fishery starts it is mostly the larger, older individuals that are caught first, resulting in a decrease in the average size and age of the population. The population as a whole is quite responsive and tends to compensate for this loss by growing faster and reaching sexual maturity at an earlier age, thus maintaining the overall biomass. However, if there is too much fishing, the fishery removes more than the population can produce, resulting in a collapse of the stock. Natural factors such as poor breeding years and poor food supply can exacerbate the problem, so populations can fall even if fishing pressure is quite light.

Non-target species can be affected in a similar way, but some actually benefit from a fishery. Dead animals thrown back into the sea or injured by fishing gear can provide a bountiful supply of food for scavengers such as hermit crabs or sea birds and in areas which are regularly fished their populations can actually increase (Kaiser et al., 1998; Moore & Jennings, 2000; Tasker et al., 2000). Intensive fisheries tend to change the structure of communities, reducing the proportion of top predators in favour of animals further down the food chain.

Gear Selectivity and Discards

Some fishing gears are highly selective, such as the rod-and-line fisheries that target Tuna. However, towed gears like trawls and dredges are indiscriminate, catching anything in their path. Along with the target species there might be a by-catch of other marketable species, but there can also be a significant proportion which have no market value like sea urchins, anemones and crabs. These are thrown back into the sea along with any small individuals of the target species and few of these 'discards' survive. Fig. 2 shows the ratio of landings to discards for different types of fisheries revealing that some fishing methods are very poor at targeting the right animals, with up to 80% of everything that is caught being dumped back into the sea (Alverson et al., 1994)

Damage to organisms and habitats

Fishing gears that are towed along the seabed cause physical damage to animals and plants. Sea urchins may be crushed, starfish frequently shed or lose arms and the shells of bivalves and gastropods can be broken. Some free-standing organisms such as sea pens and eelgrass are broken or uprooted by the trawl and it can be almost impossible for them to re-establish themselves in areas that are trawled regularly (see p. 24 of Moore & Jennings, 2000).

There is also the problem of 'ghost fishing' where lost or discarded gear (lines, nets and traps) continue to catch animals (Kaiser et al., 1996). Modern materials do not rot easily so this ghost fishing can continue for years. Some animals, particularly birds and sea mammals, become entangled in fishery related debris and subsequently drown.

Bottom trawls and dredges physically disturb the seabed turning over stones or cobbles and exposing the animals that live under them. Trawl doors act like ploughshares on sand and mud substrata, exposing burrowing animals and uprooting free-standing organisms. The impact of such gears on the sea bed has been likened to the clear-felling of forests, a terrestrial disturbance recognised as a major threat to biological diversity and economic stability (Watling & Norse, 1998).

Socio-economic value of fisheries

The benefit of fisheries is that they have great socio-economic value, bringing work and revenue to local economies. Table I highlights some details of the Scottish and Clyde *Nephrops* fishery in comparison with global fisheries. For the Clyde Sea area, *Nephrops* is by far the most valuable species, the next being haddock at *c.* £0.5 M with landings of 600 T. The Scottish *Nephrops* fishery accounts for about a third of the world landing of this species (figures are approximate. Sources: FAO, 1998; Fisheries Research Services unpublished data for *Nephrops* fishery in 1998, Furness et al., 1988).

Table I.

World marine capture fisheries		*Nephrops* Scotland	Clyde Area
Value	£50 bn	£43 M[†]	£6.5 M
Vessels	1.2 M	540[*]	80
Landings	87 M t	20,000 t[†]	4,000 t
Discards	25%	up to 75%	up to 75%

[*]landing ≥10 t into Scotland, [†] from UK vessels landing into Scotland

Like many shrimp or prawn fisheries, the proportion of discards in the *Nephrops* fishery is high. As elsewhere, fishing effort in the Clyde Sea area is concentrated on the more productive grounds (Marrs et al., 2000), so in these areas the seabed can be subject to a great deal of disturbance.

Preservation vs exploitation

There is an apparent conflict of interest between those who would preserve the sea bed and those who would exploit its resources. However it is local fishermen themselves who are perhaps most aware of the need to maintain the stocks in order to protect their livelihood. It is certainly not in anyone's long-term interest to cause irreparable damage to the sea bed, but who is to say how much damage is being done? We need to assess the impact of fishing on the physical and biological characteristics of this ecosystem and to monitor these impacts over time.

Assessing trawl damage to the sea bed

Traditionally, such assessments have been made by taking sediment samples and identifying and counting the myriad of small organisms found in the substratum. This process is slow and costly, being highly labour intensive and often taking several years to complete. At UMBSM we have been working on a project evaluating survey methods which might speed up this process, enabling surveys to be completed in weeks to months rather than years. The project (DG-XIV Study Project 98/017) is funded by the EC and carried out in conjunction with partners in Crete who are doing similar work in the Aegean Sea.

In the Clyde Sea we have selected study areas that we know are subject to different fishing effort, categorised as heavy, moderate and light. Each area has been surveyed by two acoustic, two visual and two physical sampling methods.

Acoustic methods

Sidescan sonar produces an acoustic image of the seabed, similar to a photograph but using sound rather than light. It has proved to be effective at detecting marks left by trawl gear, particularly the furrows and berms formed by the otter boards as they drag along the seabed. Fig. 3 contrasts sidescan images from trawled and untrawled areas. An area of 1 sq. nautical mile can be surveyed in about 2 hours by this method.

RoxAnn™ is another acoustic method which re-interprets the signal from a standard ship's echo sounder and characterises the underlying sediment according to its roughness and hardness. Although differences were detected between our study sites we could not attribute these directly to trawling as each site has a slightly different type of sediment. Trawling effects may be present but masked by the differences in sediment type. Further analysis is needed to verify this or show that RoxAnn™ cannot differentiate between grounds such as those we have studied on the basis of their recent trawling history.

Visual methods

A towed video sledge has been used to record video transects of the study sites which can then be scored according to the amount of biogenic (natural) or anthropogenic (man-made) disturbance observed. Holes and spoil-mounds formed by burrowing animals are distinctive and clearly differ from the disturbance caused by a trawl which is seen as 'freshly tilled' mud or areas that have been 'swept flat' by the net.

More detailed visual images of sediments have been obtained using a remote operated vehicle (ROV) fitted with a video camera. This can survey a few square metres in a matter of minutes and enables *in situ* measurements to be taken of sediment features (Fig. 4).

Physical sampling

A small 2 metre wide beam trawl has been used to collect samples of the 'epibenthic megafauna' at each site, that is the large animals which live on the sea bed and are most vulnerable to the effects of trawling. By comparing the catches between sites it is possible to see if the communities differ according to different fishing pressure. The damage load of certain species has also been studied. Trawl-damaged starfish tend to lose or shed one or more of their arms which eventually regenerate, while the shells of whelks hold numerous scars showing where previous damage has been repaired (Fig. 5). The damage assessment is trying to find out if the frequency of damage is related to the intensity of fishing.

The physical, mechanical and chemical properties of the sediments from each site have also been studied, using sediment samples taken by a coring device. In trawled areas the upper sediments are subject to frequent re-suspension and re-settlement, so it is likely they will have different properties to those that have lain undisturbed.

Conclusion

Apart from the RoxAnn™, the methods selected for rapid assessment of the impact of otter trawls appear to be effective, each having its own particular application. Sidescan sonar can detect the presence or absence of trawl marks over relatively large areas. Video methods allow visual appraisal of benthic communities and habitats while physical samples allow more quantitative assessment of community structure and the physico-chemical properties of sediments. The suite of methods will enable a comprehensive assessment of the impact of otter trawls but can be used in various combinations to tailor a survey according to its aims, budget and time frame. Such surveys will play an important role in the process of deciding the right balance between exploitation of resources and preservation of the environment.

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Figure Legends

Figure 1. Otter trawl rig, showing component parts.

Figure 2. The ratio (by weight) of discards to landings in some major world fisheries (after Alverson et al., 1994)

Figure 3. Comparison of sidescan sonar images from a) a heavily fished area and b) an unfished area in the Clyde Sea. Trawl marks are clearly visible in a) but not b).

Figure 4. Images taken by an ROV showing a) a fresh trawl mark in a heavily fished area, and b) undisturbed sediment in an unfished area of the Clyde Sea. The wire cube is used as a reference grid to enable *in situ* measurements to be made of objects and features.

Figure 5. A whelk (*Buccinum undatum*) photographed 37 days after being damaged by a trawl. The damaged area on the last whorl had been rapidly repaired. The original break line is picked out in pencil.

Figure 1.

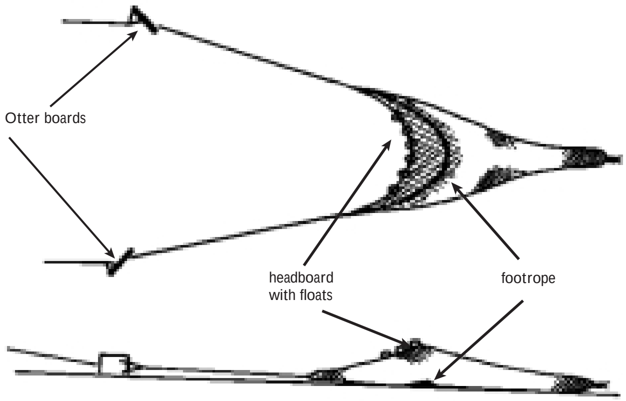


Figure 2.

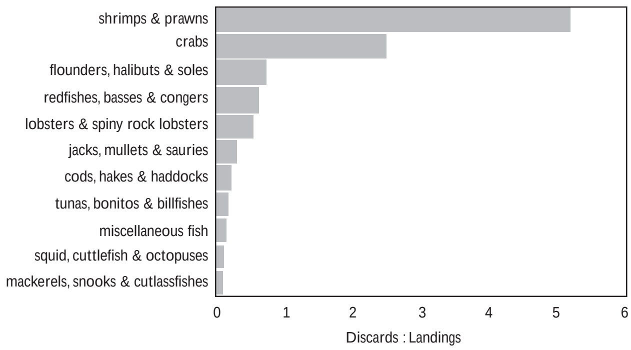


Figure 3.

a)

b)

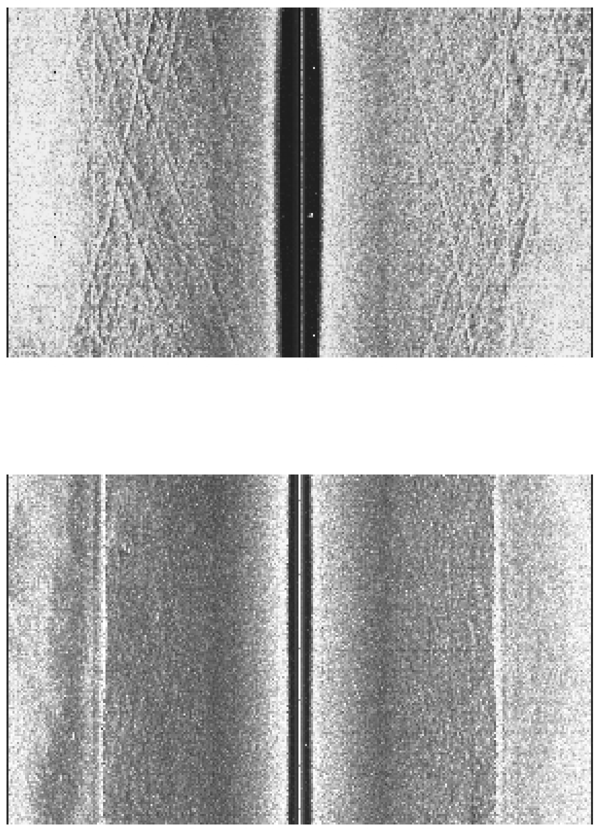
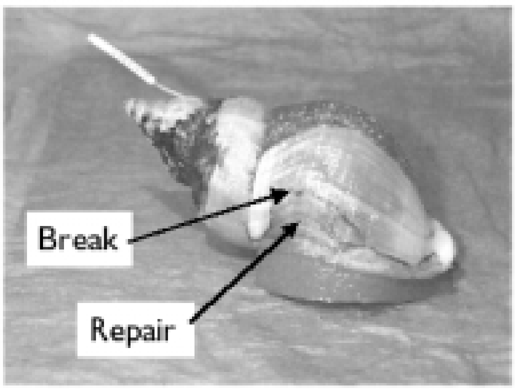


Figure 4.

a)

b)

Figure 5.



Collaborative Fisheries Research Involving Commercial Fishing Fleets

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Abstract
This paper documents the history of collaborative research with commercial fishing fleets by scientists at the University Marine Biological Station Millport. A résumé of each of the contracts undertaken to date is given and the importance and relevance of such studies are discussed.

A History of Collaborative Research with Fishers at Millport
The University Marine Biological Station Millport (UMBSM) has traditionally enjoyed a good relationship with the local fishing fleet. Prior to the 1990s the level of collaboration was limited to requests to leave areas free from fishing for short periods whilst experiments were carried out, or occasional requests for material when the marine station research vessels, *RV Aora* and *RV Aplysia,* were not available.

Since the early 1990s, the Marine Station has been successful in the procurement of a series of European Commission-funded research projects variously under the management of Dr Jim Atkinson and Professor Geoff Moore, some of which are ongoing. Two of the initial projects (IMBC *et al*. 1994; Marrs *et al.*, 1996) concerned stock assessment of *Nephrops norvegicus.* This species, which has a variety of common names including scampi, Dublin Bay prawn, langustine and Norway lobster, is the main species fished in the Clyde Sea area (see Bailey, this volume).

It was whilst undertaking these initial contracts, that the staff at the Marine Station became aware that the best way to increase the credibility of the research being carried out at the Marine Station with the people with whom it was likely to have the greatest impact, i.e. fishers, was to directly involve the fishing fleet in the work.

Thus, the first contract to involve the commercial fishing fleet directly commenced in April 1997. This project investigated the fate of undersized *Nephrops* and 'heads' discarded from fishing vessels and was undertaken by Dr Sabine Wieczorek. Shortly after this, funding became available for two PhD projects concerned with fisheries research, from the bequest of the eminent Millport scientist, Dr Sheina Marshall. One studentship, awarded to Ms Melanie Bergmann, was closely aligned with the EC-funded project and studied the fate of incidentally caught non-target invertebrates discarded from *Nephrops* trawlers. The second studentship, awarded to Mr Jason Combes, was to study the biology and fisheries ecology of two crustacean species, the velvet swimming crab *Necora puber* and the squat lobster *Munida rugosa,* both of which have a relatively recent history of commercial exploitation. Extra financial support for this project was supplied by PESCA funding, facilitated by the Highlands Council, Highlands Enterprise and the West of Four Fishermen's Association. Jason worked further afield than the Clyde Sea, working with creel fishers in Skye, the Summer Isles and the Western Isles, as well as undertaking studies in local waters.

Following the successful collaboration between Sabine and Melanie and a few local *Nephrops* trawler skippers, a more vessel-intensive project was attempted which involved 20 trawlers from the fishing ports around the Clyde. Again funded by the European Commission, this project mapped the fishing effort and landings of the Clyde *Nephrops* fleet during 1998/99 with a view to improving the stock assessment of this species. A pilot study only, this project was very successful, and proved to be the most detailed study of its kind to have been completed in Europe to date. Further funding has been obtained from the EC to continue this work. This contract is ongoing (April 2000 - March 2002), and again involves 20 fishing vessels - 15 of which are new to the study. Both contracts were undertaken by Dr Sue Marrs, with technical support from Mr Tom Stevenson.

Two new projects have recently commenced relating to the *Ensis* or razor clam fishery, which has emerged over the last 3-5 years in Scotland. Dr Chris Hauton began an EC-funded contract in April 2000 and is investigating the impact and efficiency of hydraulic dredging for these molluscs. Working in conjunction with this study a PhD studentship, awarded to Ms Samantha Jones, is concerned with the ecology of *Ensis* spp. and the operation of the hand-picked fishery using SCUBA diving. Funding for this studentship comes from a variety of sources including Scottish development agencies and fisheries organisations. Both projects involve collaboration with commercial fishers.

Collaborative Research on the Clyde *Nephrops* Fishery
Due to the location of UMBSM, the Clyde *Nephrops* ground is one of the most extensively studied in Europe. With official landings in the region of 4,000 tonnes per annum, this small area provides approximately 7% of the world landings. Ninety-five percent of the *Nephrops* landed from the Clyde Sea area are caught using otter trawls (for an illustration of the gear see Coggan, this volume, Figure 1). During the trawling process non-target species and undersized *Nephrops,* known as discards, can also be caught.

Regular sampling on commercial trawlers during 1997-1998 provided the first assessment of the catch and discard composition from commercial *Nephrops* trawlers in the Clyde Sea area. Invertebrates represented up to 90% by volume of the discards with crustaceans (swimming crabs, squat lobsters) and echinoderms (starfish, brittlestars) being the most important groups. Trawling and sorting of the catch caused both physical damage and physiological stress. Invertebrate groups with protruding limbs such as brittle stars and some crustaceans were more prone to damage than those with hard protective shells such as hermit crabs or scallops. Although a significant number of animals may be alive when discarded, long-term (21 days) survival experiments revealed higher mortalities than previous shorter duration (5 day) studies had reported. All trawled brittlestars died within 2 weeks, whilst all hermit crabs and whelks survived. Physical injury increased mortality rates of swimming crabs and rendered starfish more susceptible to bacterial infection and subsequent death (Bergmann, in prep).

Discard utilisation experiments showed that discarded material was rapidly consumed by scavengers. Seabirds, if given a choice, would preferentially select roundfish (e.g. juvenile whiting, cod or herring) over crustacean discards. Although if offered singly, crustaceans would be eaten, particularly by juvenile seabirds. Observations at the seabed using SCUBA in shallow (<30m) water and underwater television with infra-red lights in deeper (40-110m) waters demonstrated that non-living discard material was consumed within 24-48 hours. Fast moving crab species were consistently recorded as the first to arrive with slower moving species, such as starfish and common whelks, arriving later. *Nephrops* were observed consuming discarded conspecifics and other species. There was no evidence of mid-water utilisation produced by this study, but the possibility cannot be rejected (Wieczorek *et al.*, 1999).

Landings from the *Nephrops* fishery are restricted by a Total Allowable Catch (TAC or quota) set by the European Commission for each stock, based on the size of the stock and previous levels of fishing effort. Current stock assessment techniques for *Nephrops* use methods that are based on length measurements, landings data and population characteristics such as growth rates and size of the animal at reproductive maturity. The techniques are applied to statistical rectangles of size 30km x 30km and are considered to work well for stocks that are uniform at this scale. The Clyde Sea area, however, has complex sedimentology. Differences in the sediments in which *Nephrops* burrow has been shown by earlier studies to correlate with differences in the growth of *Nephrops* (Tuck *et al.*, 1997). It may be more appropriate to relate the stock assessment to sediment type rather than arbitrary squares; however, official landings data are at best only allocated to statistical squares.

The effort mapping projects use satellite-based position data loggers that record latitude and longitude every ten minutes. These loggers were fitted to 20 vessels operating around the Clyde during 1998 - 1999. Using the output from the loggers, the location of trawling was accurately mapped for 18 of these vessels. Complimentary landings logbooks were filled out by the skippers and daily landings could be accurately allocated to trawl position. Total landings from these vessels accounted for *ca* 20% of the total landings for the entire fleet. Landings from the participating vessels were scaled to the whole fleet and these data were used to run standard stock assessments relating the landings to sediment type. The ability to apply more appropriate growth parameters to the landings data should produce a more accurate stock assessment and provides more detailed information on the state of exploitation of the stock (Marrs *et al.*, 2000). A second survey is ongoing, this time also including vessels that operate to the west of the Kintyre Peninsula.

Studies on New and Emerging Fisheries

As well as detailed investigations into an established fishery, UMBSM has been aware of recent trends in the fishing industry and has taken steps to provide baseline data where none is available. The velvet swimming crab creel fishery is regulated; however, there is little information on the biology of the species in Scotland. The squat lobster fishery is still, as yet, in its infancy and is unregulated. Data on fishing effort and landings of both these species are being collated from a combination of fishers logbooks, producer organisation records and fishery office returns. Biological parameters including, growth, moulting, natural mortality and fecundity have been investigated, and a large-scale tagging programme has provided data on migration, sex ratios and recruitment. Data analyses are still underway, but when completed, these results will form a basis for future stock assessments (Combes, in prep).

The most recent fishery to be investigated by UMBSM scientists is that of the razor clams. There is currently very little baseline biological data to underpin regulation of the fishery for *Ensis* species. This, has led to concerns being expressed at both local and international levels over the sustainability and impact of the fishery.

Although both projects in relation to the razor clam fishery are very much in the preliminary stages, investigations into the basic biology of razor clams are underway with special reference to geographical trends in spawning and recruitment. To ensure a wide relevance to the Scottish fishery the population biology project is working with the assistance of commercial razor clam divers in the Clyde Sea area, the Highlands and Islands and the Western Isles. The hydraulic dredging project is, with co-operation of commercial fishers, investigating the types of gear used, their efficiency for the target species and the potential impacts, on both the target species and the environment. Collaborative work with local fishers, who are developing new dredge designs aimed at reducing the impact of this fishery on the environment, are also being carried out. The combined results of both studies will ultimately generate management recommendations with which to provide a framework for the future regulation of this fishery.

The Relevance of Collaborative Research

Whilst such collaborative projects with fishing fleets provide a wealth of information that hitherto has not been available, it is essential that the results are brought to the attention of fisheries managers. In Scotland, much of the scientific and technical advice for fisheries management is supplied to the Scottish Executive by the Marine Laboratory in Aberdeen (MLA). MLA has been involved to a varying degree in all the collaborative fisheries research undertaken at UMBSM to date. As well as ensuring that the results of research studies may be integrated into actual management processes, the involvement of MLA gives UMBSM access to a wide range of technical expertise and equipment.

Communication with the fishers themselves is of vital importance to the success of these collaborative projects. To this end, fishers participating in research projects are provided with feedback on the data that either they have supplied, or that has been collected by scientists on board their vessels. To fuel the communication link between local fishers and scientists at UMBSM, an open day for the local fishing fleet was held in February 1999, showing the products of some 20 years of fisheries related research. Following the success of this meeting a second open day has been requested by the local fishers and will take place in the near future.

It is clear from the above that UMBSM is deeply committed to research that is of practical relevance to local fisheries. We see great strength emerging in partnership between scientists and fishers to the benefit of all concerned. The pressure is forming now for local management of fished resources and it is only with the involvement of all concerned parties at grass-roots level in decision making that sensible working solutions to fisheries management problems will emerge (Moore, 1999).

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Fluxes of Nutrients and Organic matter in the Clyde Sea – an overview

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Introduction

The relationship between input of organic matter and nutrients to the coastal zone and the development of eutrophication is of current national and international concern. Problems are frequently most acute in coastal areas where the effects of vertical mixing and horizontal exchange are reduced, either by the natural topography and hydrography (e.g. estuaries and coastal embayments), or by man made structures (e.g. barrages, lagoons). Within a UK context, Scottish fjordic sea lochs are perhaps the most extreme examples of natural restricted exchange environments. The presence of an entrance sill, over-deepened basins and strong, freshwater-determined stratification imposes constraints on vertical mixing between surface and deep waters and horizontal exchange with the open sea (Figure 1.) In some lochs the deep basins may retain water isolated from coastal exchange for several years (Edwards and Eddelsten, 1977). Planktonic ecosystem function and biogeochemical cycling in these environments is fundamentally different from that in other estuarine types. In the extreme, sea lochs are predisposed to increased storage of nutrient and organic inputs, making some of them particularly susceptible to eutrophication, development of algal blooms and hypoxia. One of the key challenges facing regulators and planners in these environments is the determination of critical thresholds above which catastrophic changes to biogeochemical status, biological community structure and ecosystem function occur. This is a multidisciplinary problem requiring both an understanding of how sea loch systems respond to natural forcing, in addition to knowledge of the specific effects of anthropogenic perturbation.

The Clyde Sea is the largest Scottish fjordic system, bounded at the seaward extremity by a sill which constitutes the Great plateau, encompasses several deep basins including the Arran Deep and deep basins of associated smaller sea lochs and receives natural and industrial drainage from a large catchment mainly via the Clyde estuary and Inner Firth. It is a coastal area that supports a range of frequently conflicting uses. It supports important fisheries, contains nationally important habitats for seabirds and provides amenities for recreation and tourism. At the same time it receives a suite of anthropogenic contaminants that include sewage, heavy metals, radionuclides amongst others. This presents regulators and coastal zone managers with issues of sustainability and resilience of ecosystems and the need to develop policy that balances amenity and commercial uses. Such policy development requires a fundamental understanding of the underlying physical, biological and chemical processes which determine the fate and consequences of inputs. This paper provides a short overview of current knowledge of the interaction between physical, chemical and biological processes within the Outer Firth of the Clyde Sea and their role in determining the fluxes and fate of allochthonous and autochthonous organic and nutrient inputs to the system based on some recent and ongoing studies at Dunstaffnage and from the published literature.

Physical controls

The seasonal cycle of stratification and exchange with the adjacent North Channel play a critical role in determination of pelagic seasonal cycles, nutrient budgets and the fate of inputs to the Clyde Sea. The basin is stratified throughout most of the year with bottom water (>60m) in the Arran Deep becoming isolated from the surface circulation for periods of up to 6 months (Rippeth et *al*, 1996). Horizontal surface exchange is modulated by density differences across a thermo-haline front occurring over the Great Plateau, which separates well-mixed North Channel water from the stratified Outer Firth. The exchange with the North Channel is highly seasonal with maximum exchanges taking place between October and April. Modelling studies (Rippeth and Jones, 1995) suggest that lowest exchange takes place in the months of July, August and September (Figure 2).

Nutrient inputs

Riverine, sewage and industrial inputs are the principal, non-marine sources of nutrient input to the Clyde Sea area contributing about 24 x 10^3 tonnes of nitrogen and 0.95 x 10^3 tonnes of phosphorus annually (from Haig, 1986). Most of this enters via the Clyde Estuary and Inner Firth that drains a heavily populated (> 1 million) and industrialised catchment in addition to the fertile agricultural Clyde Valley. A smaller but significant input enters directly into the Outer Firth via the Ayrshire coastline and there are numerous diffuse and unquantified sources throughout the basin. Until it ceased in 1998, as a result of EU legislation, sewage sludge dumping in the Outer Firth also contributed approximately 2.99 x10^3 tones of nitrogen (N) and 0.55 x 10^3 tonnes of phosphorus (P) annually (Haig, 1986). Clyde Sea nutrient concentrations are consequently enriched with respect to nitrogen and phosphorus relative to fjordic systems elsewhere on the Scottish west coast where there is less industrialisation, populations are smaller and rivers drain less fertile upland areas. Riverine inputs of nitrogen are related to flow and season whilst phosphorus inputs appear more variable. In consequence the N:P ratio of riverine nutrient inputs varies seasonally but, with the exception, of the summer months usually exceeds the Redfield ratio as do winter N:P ratios in the estuary and inner Firth. In contrast, the outer firth and more oligotrophic northern sealochs (e.g. Fyne) have winter N:P ratios which are lower than the Redfield ratio (from data in Haig, 1986). Differences in the nutrient balance between different regions of the Clyde system raise the possibility of switches between N and P limitation of algal growth and related influences on microplankton community composition.

Phytoplankton

Previous seasonal studies in the Clyde Sea (Jones *et al,* 1995) and recent continuous measurements of chlorophyll fluorescence from moored instruments deployed between July 1999 and August 2000 have shown a classical temperate cycle of phytoplankton biomass occurs in the Outer Firth (Figure 3). The spring bloom occurs as a succession of peaks between March and late-April reaching a maximum, near-surface chlorophyll *a* concentration of about 10 mg m^{-3}. Chlorophyll concentrations between late May and August are low (~ 1 mg m^{-3}) but in early August and September a surface autumnal bloom occurs which may be of a similar magnitude to the spring peak. Sporadic measurements of primary production in the outer Firth suggest spring production can reach and possibly exceeds ~ 350 mg C m^{-2} d^{-1} and autumn levels reach 250 mg C m^{-2} d^{-1}. Large diatoms dominate the spring bloom but smaller autotrophic flagellates become more important during the summer.

Increase in autotrophic flagellates is frequently accompanied by an increase in heterotrophic flagellates. Within the outer basin the horizontal distribution of chlorophyll is generally fairly uniform but data suggests that the spring bloom occurs earlier in the highly stratified inner reaches and adjoining sealochs than in the seaward extremities. Conversely, highest chlorophyll concentrations are associated with the sill region in late spring and summer (Jones *et al,* 1995).

Nutrients

Nutrients in the water above sill depth are highest in winter. Evidence of the influence of enriched estuarine input is sometimes seen as a high nitrate plume at the entrance to the Inner Firth. Nutrients decline with the onset of the spring bloom. Nitrate concentrations fall to undetectable levels in late spring and summer whilst phosphate and silicate are always present at low but detectable levels (Figure 3).

Fate of Organic and Nutrient Inputs

Spring primary production is transferred from the euphotic zone to the deep waters of the Arran Deep by sinking and by mesozooplankton grazing. Degradation of this organic material, at depth, by bacteria and benthic animals results in both consumption of oxygen in the isolated deep water and in the release and accumulation of nutrients. During the period of deepwater isolation, oxygen concentrations are reduced to about 50% saturation (Wilson, 1994). During the summer, the deep waters become relatively enriched with phosphorus and silicate relative to nitrogen (Jones *et al,* 1995). This might be attributed to a reduction of nitrogen sedimentation flux due to decreasing relative nitrogen content of the organic input as phytoplankton become more nitrogen limited, reduction in the sinking flux due to the increase in importance of microflagellates within the microplankton and as a result of more rapid recycling and consequent retention of nitrogen in surface waters in more microbial-dominated food webs. There is also possibility of nitrogen loss to the atmosphere by denitrification in the anoxic sediments but this has not yet been quantified.

Simple box models have been used to investigate the way that the seasonality of water exchange between the Outer Firth and North Channel combines with the seasonal production cycle and patterns of nutrient input to determine fate of nutrient inputs (Rippeth and Jones, 1997). The studies have demonstrated the close interaction of physical and biogeochemical cycles in controlling the fate of nitrogen inputs to the Outer Firth, with the Clyde system alternating between being a net exporter of nitrogen during the winter months and a retainer and store for nitrogen during the summer when cross-sill exchange is slow and deepwater is isolated (Figure 4). The study also highlighted the potential importance of the riverine inputs in determining the nitrate concentration and hence productivity of the surface layers at that time.

Conclusions

1. Simple models suggest that the fate of nitrate inputs to the Clyde Sea is strongly influenced by seasonal changes in the coupling between physical and biogeochemical processes, particularly primary production, sinking and organic degradation in the water column and sediments. The fate of other anthropogenic inputs that have a strong interaction with phytoplankton or other "biological" particles may be similarly controlled.

2. The extent of transfer of material between the surface waters and deep isolated water in summer would appear to be an important factor determining the fate and consequences of inputs at this time. Phytoplankton community structure and nature of the grazing food web, through its effect on sinking flux and rates of recycling, may be important in determining vertical transfer.

3. Tools which allow the prediction and management of the effects of nutrient inputs to the Clyde Sea require further fundamental scientific research work to refine our knowledge of water circulation and mixing and to understand the relationships between nutrient inputs, planktonic community structure and function and biogeochemical cycling. Work towards this objective has now begun as part of the recently funded European programme OAERRE (Oceanographic Applications to Eutrophication in Regions of Restricted Exchange).

Acknowledgements

Funding from the NERC to the CCMS Restricted Exchange Environments (REEs) programme, EU *PROFILE* (contract MAS2-CT93-0054) and OAERRE (contract EVK3-CT-1999-00002) programmes supported some of the work reported in this paper.

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Figure 1. Circulation and renewal in a silled sea loch

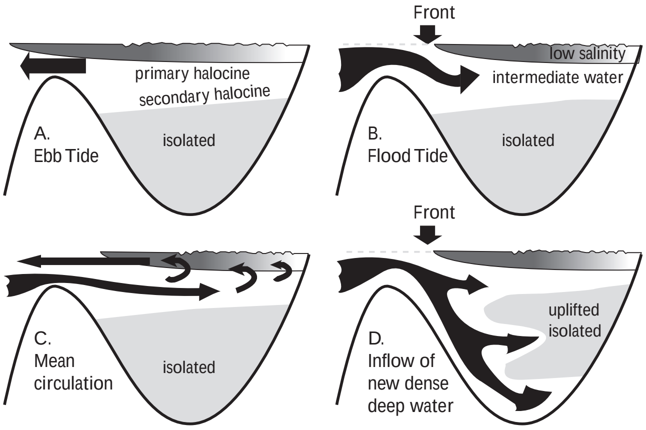


Figure 2. Cross sill exchange across the Great Plateau (Data from Rippeth and Jones, 1997).

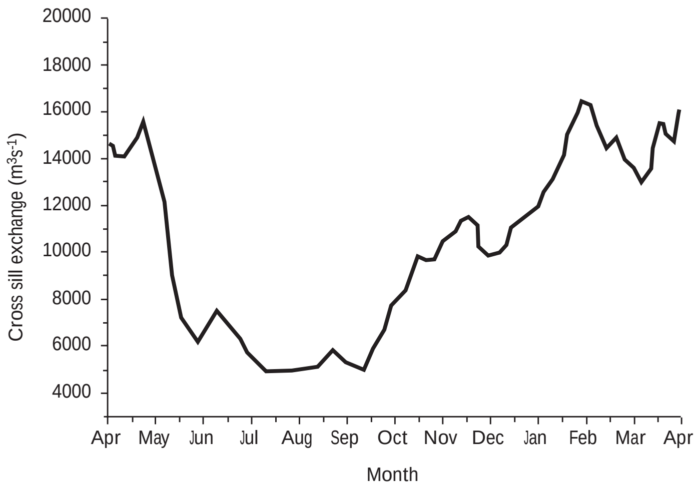


Figure 3. Seasonal variation of chlorophyll and nutrients in the Clyde Sea. A. 0 - 10m: B. > 100m.

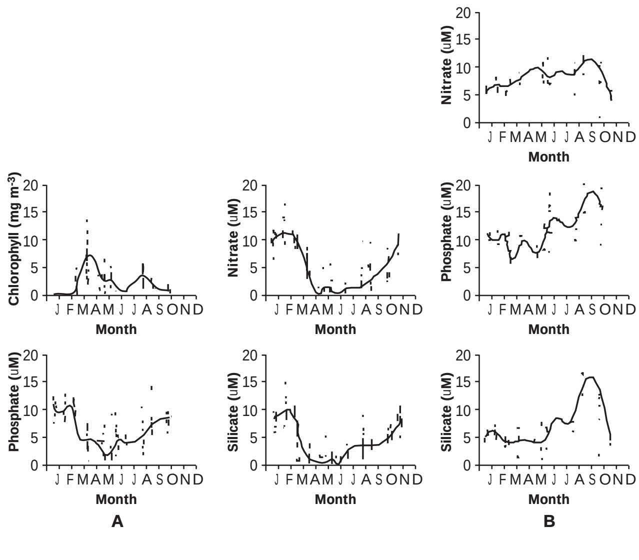
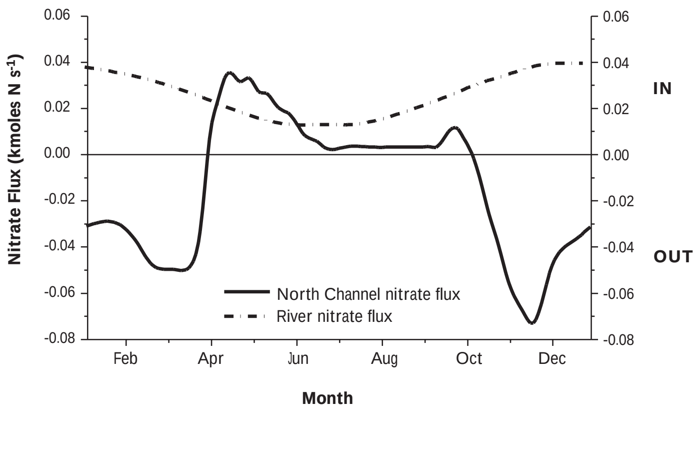


Figure 4. Seasonal fluxes of nitrate N in the Outer Firth of Clyde from marine and riverine sources (from Rippeth and Jones, 1997). Negative flux indicates export of notrogen form of the Clyde system.



Glossary of Technical terms

Chlorophyll: The green pigment in plant cells responsible for fixing the sun's energy and converting it into new plant material by the process of photosynthesis. Because it is only found in plants and is easily measured its concentration is often used as a measure of the amount of phytoplankton in the water.

Eutrophication: Enrichment of water by nutrients, causing an accelerated growth of algae and higher plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned.

Mesozooplankton: Shrimp like planktonic animals some of which feed on phytoplankton.

Microplankton: A collective term for the planktonic assemblage of photosynthetic phytoplankton, non-photosynthetic heterotrophic flagellates, protozoa and bacteria.

Phytoplankton: Microscopic (<0.001 – 0.2 mm) free-floating plants. The main types in the sea are the dinoflagellates and microflagellates, which can propel them selves through the water, and diatoms, which have silica cases and cannot swim. All contain the green pigment chlorophyll and a range of other coloured pigments, which are involved in photosynthesis.

Stratification: Horizontal layering of the sea due to vertical density differences caused either by warming of the sea surface by the sun or diluting the sea surface with fresh water. Strong stratification inhibits mixing between different layers.

Faecal Indicator Organism Sources and Budgets for the Irvine and Girvan Catchments, Ayrshire

A report to West of Scotland Water, the Scottish Environment Protection Agency and South Ayrshire Council, June 1999

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Executive Summary

Recent studies suggest that catchment derived sources of faecal pollution may affect compliance of bathing waters against EC Directive 76/160/EEC standards. The contribution of faecal indicator organisms from river and stream catchments with differing mixtures of land use is of particular interest. The Irvine study builds on previous catchment investigations, funded by the Environment Agency and Water companies in England and Wales, with complementary land use types including entirely forested areas and high intensity livestock farming. The project was funded by West of Scotland Water, the Scottish Environment Protection Agency and South Ayrshire Council.

Study aims and execution

The main aims of the study were to: (i) quantify faecal indicator budgets to coastal waters adjacent to the catchments of the River Irvine and Water of Girvan, (ii) investigate the impacts of land use on stream water quality within the Irvine catchment, (iii) examine potential impacts on marine water quality, and (iv) extend the empirical data base for predictive water quality models based on land use and other predictor variables.

Two field surveys were undertaken in the Irvine and Girvan catchments during the summer of 1998: (i) environmental microbiology including analysis of sewage effluent, stream and marine water quality, the parameters measured being total and faecal coliforms, and faecal streptococci during base flow and high flow conditions; and (ii) farm and land use surveys of the Irvine catchment.

Results

Faecal indicator budgets for the Irvine catchment revealed sewage effluent from the Irvine and Garnock valley sewers to be the major source of organisms, delivering 87 to 91% of the indicator organism load to adjacent coastal waters.

Riverine faecal indicator sources are dominated by periods of high flow response to rainfall. Such conditions were prevalent for approximately a quarter of the eight week study period and produced 98% of the faecal indicator load estimate for the riverine component of the Irvine catchment. Riverine faecal indicator loading is dominated by the River Irvine, Garnock Water and other streams providing a relatively minor component. High flow delivery was responsible for over 93% of the load estimate for Water of Girvan.

Loading from the combined sewer overflow system to the River Irvine (i.e. Low Green Gatehead tank and 42 modelled sites) accounted for between 0.77% and 1.14% of the total faecal indicator load estimates, and between eight and ten percent of the riverine load. However, temporal loading analysis suggests that the CSO systems might account for almost the entire local faecal indicator load of the River Irvine during the early stages of hydrograph events.

Treatment scenario analysis suggests that additional treatment, such as activated sludge and disinfection, would significantly reduce bacterial contributions from the Irvine and Garnock valley sewers. However, storm overflow effluent inputs, direct to sea, are still likely to provide significant bacterial inputs during storm events.

Calculation of microbial concentrations in the River Irvine with and without CSO inputs suggested that CSO removal would have little effect on high flow microbial concentrations in the river.

Faecal indicator budgets for inputs to the sea near Girvan were dominated by untreated sewage from Girvan. Trade effluents provided a relatively small component of the budgets. Treatment of sewage would reduce faecal indicator load significantly leaving the riverine source at high flow as the dominant input. In the case of faecal streptococci, trade effluent from Grangeston may remain as a significant source.

Examination of nine years of daily mean discharge data for the River Irvine showed that median daily mean discharge in the River Irvine for August 1998 was significantly elevated compared to the nine year median. However, discharge in August 1998 was slightly less extreme than that in August 1992. The September 1998 median daily mean discharge was not significantly different from the nine year median for this month.

Regression modelling showed the proportion of improved pasture in subcatchments of the Irvine catchment system to be the dominant predictor of geometric mean base flow and high flow bacterial concentrations in rivers and streams. Other significant predictors include the proportions of built-up land and rough grazing in subcatchments, with multivariate models explaining over 70% of the variance in mean bacterial concentrations.

Multivariate regression models, combining data from the Irvine, Staithes, Nyfer and Ogwr catchments, showed proportions of improved pasture, forestry and built-up area in subcatchments to be significant predictor of geometric mean microbiological concentrations in streams at high flow. These results are similar to previous investigations.

Marine water quality showed deterioration during rainfall event conditions. This pattern was particularly evident at Irvine beach, where geometric mean total coliform and faecal coliform concentrations during event conditions exceeded the *Imperative* concentrations used for compliance assessment in the EC Directive (10,000 total coliforms and 2,000 faecal coliforms 100ml $^{-1}$). Significant reductions in mean total dissolved solids concentration in marine samples was also associated with event conditions, indicating the high loading of freshwater sources (sewage and riverine) to adjacent coastal waters during hydrograph events. This pattern was less evident at Girvan, where the magnitude of freshwater inputs is lower.

Minimum reductions in high flow microbial concentrations in the River Irvine required for *Imperative* 'Pass' conditions at Irvine beach were estimated at 81% to 83%. Calculations suggested that removal of CSOs would not provide a sufficient reduction. Similar calculations for Saltcoats suggested that minimum reductions of microbial concentrations in local freshwater inputs of 67% to 72% would be required.

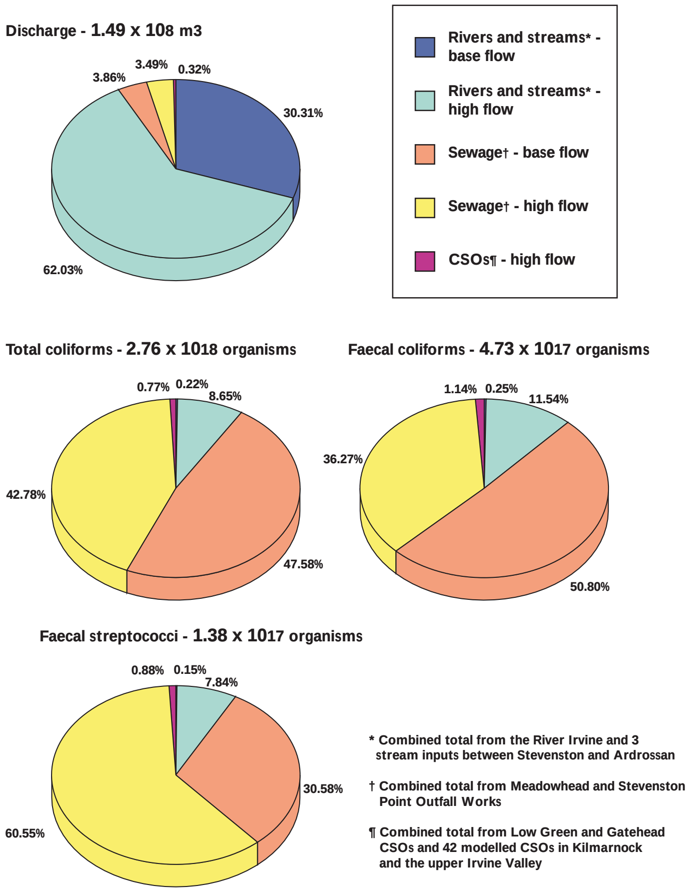
Implications and remediation potential

Treatment of sewage effluent from the Irvine and Garnock valley sewers and Girvan could significantly reduce the faecal indicator load from these sources. This is likely to have a positive effect on coastal water quality, particularly during dry weather conditions.

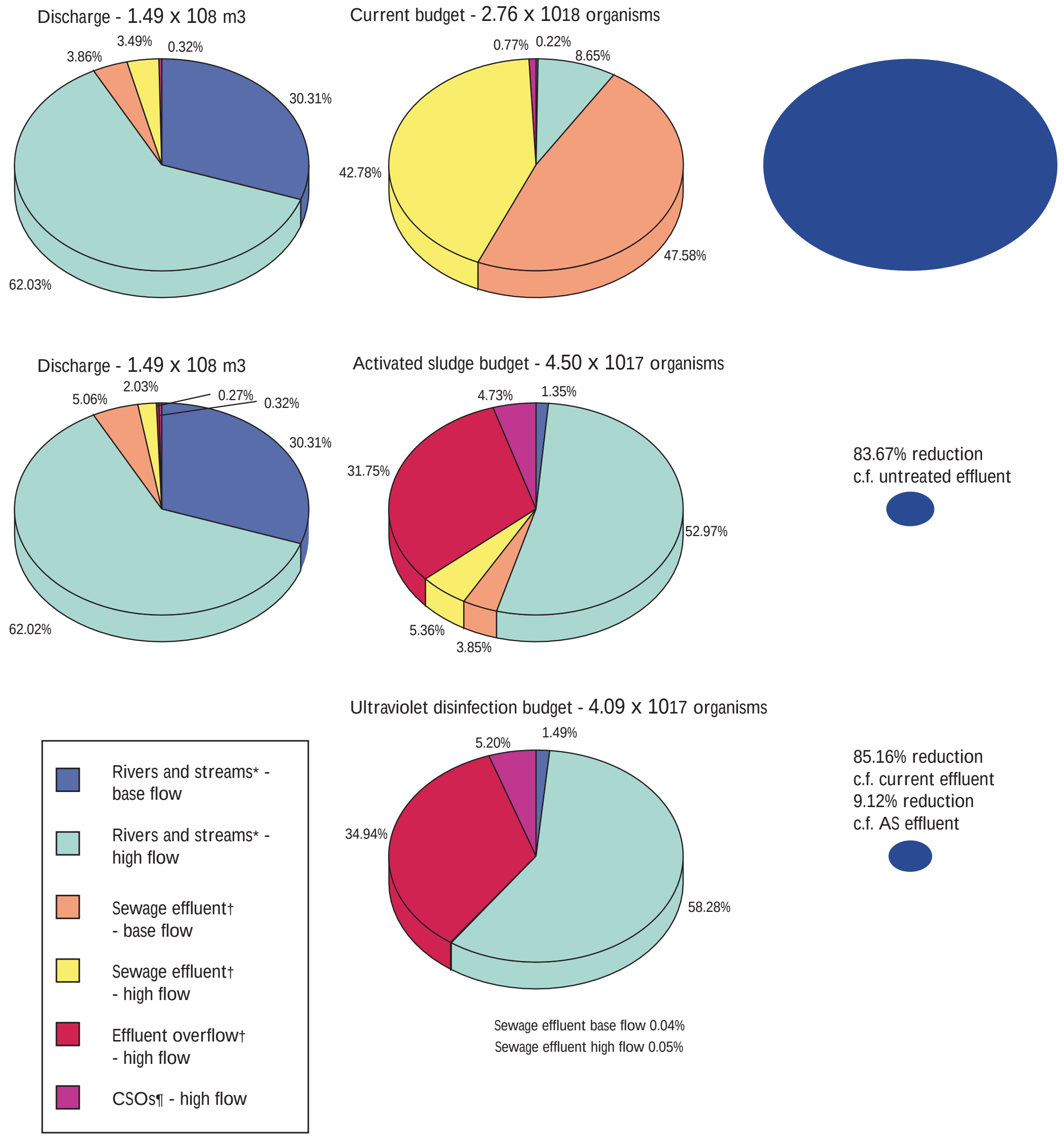
Riverine faecal indicator sources, including inputs from combined sewer overflows, will remain after treatment of main sewage discharges. The loading from the River Irvine system is relatively large, and mainly associated with episodic hydrograph events, and will continue to impact on marine recreational water quality. This pattern is also evident at Girvan.

Remedial action to reduce spills of sewage to the urban sections of the River Irvine, from sources such as Low Green and Gatehead Tank, may reduce the high flow faecal indicator loading of this river. However, such action is unlikely to produce sufficient reduction in microbial concentrations in the River Irvine to improve compliance at Irvine beach.

The Irvine catchment study has extended the land use range to include some highly afforested and high intensity livestock subcatchments in a data set which now incorporates information from five UK catchment systems, and is being applied to the development of generic water quality models. The results of multivariate predictive modelling using the data acquired further demonstrate the feasibility of using this approach to estimate faecal indicator concentrations in discharges to coastal waters from 'catchment derived' non-point sources.



Discharge and faecal indicator organism budgets for main sources discharging to the coast near Irvine and CSO's discharging to the River Irvine

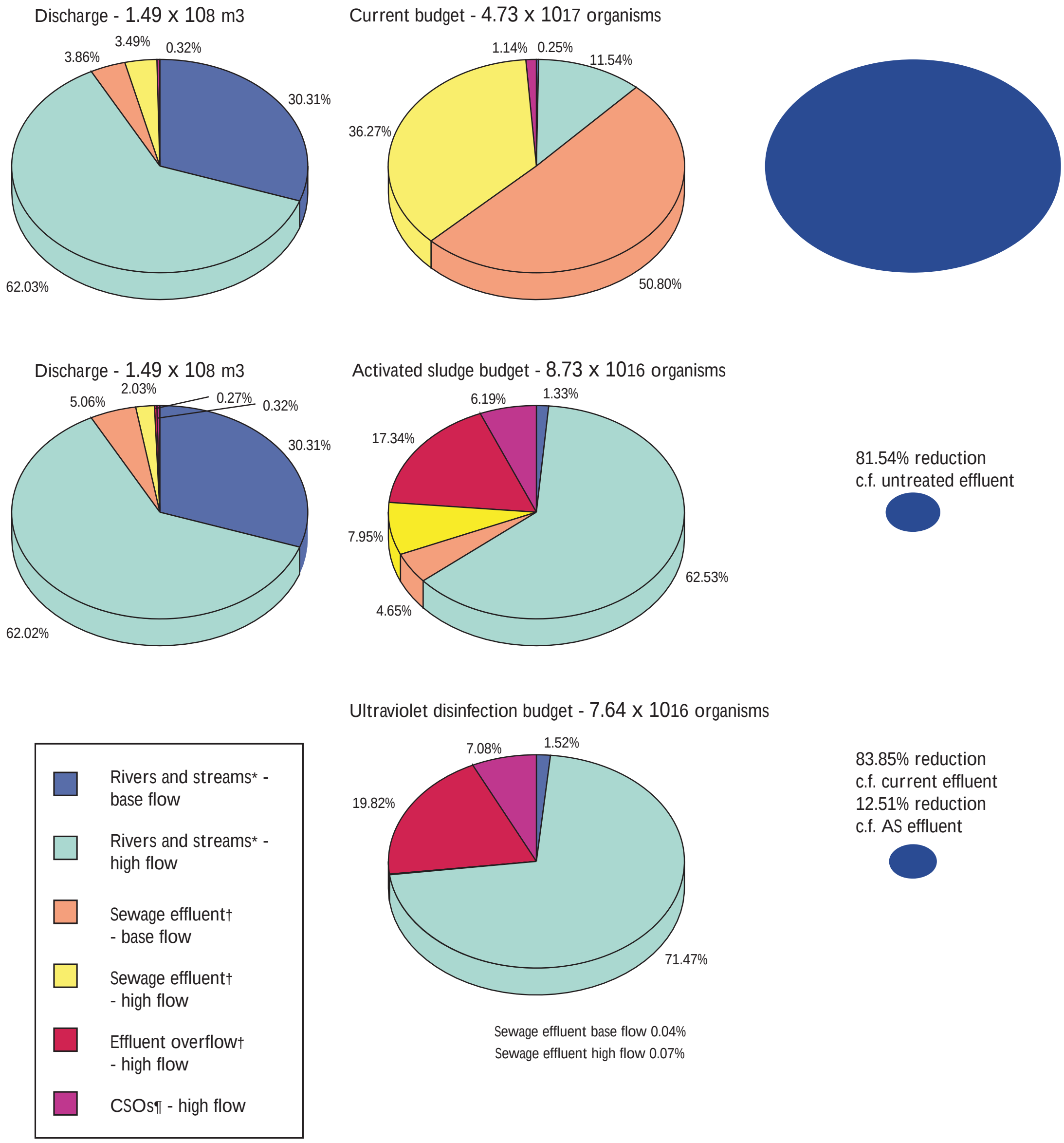


* Combined total from the River Irvine and 3 stream inputs between Stevenston and Ardrossan

† Combined total from Meadowhead and Stevenston Point Outfall Works

¶ Combined total from Low Green and Gatehead CSOs and 42 modelled CSOs in Kilmarnock and the upper Irvine Valley

Comparison of discharge and total coliform budgets for main sources discharging to the coast near Irvine andCSOs discharging to the River Irvine under present conditions and two treatment scenarios for sewage effluent



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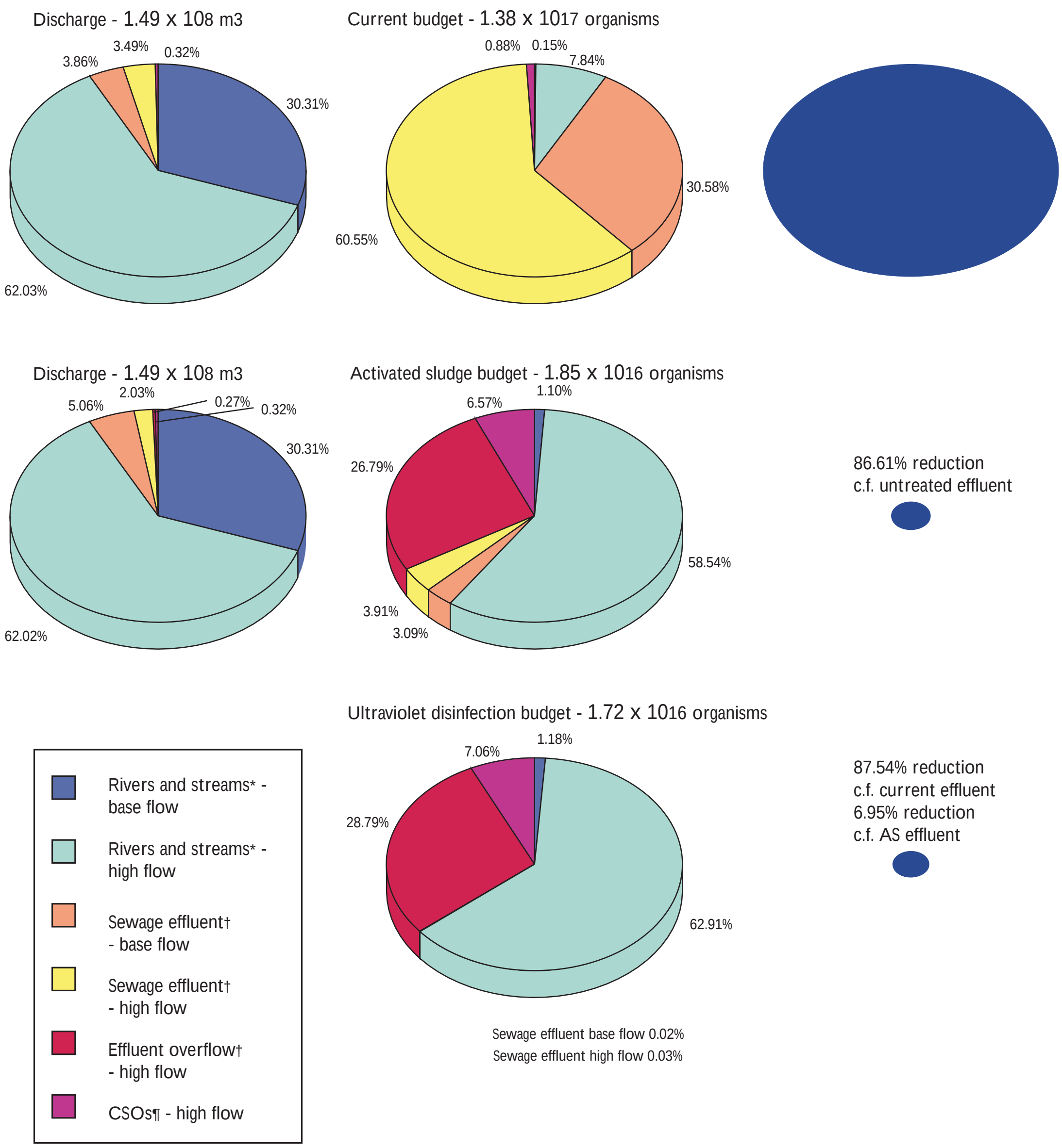
Comparison of discharge and faecal coliform budgets for main sources discharging to the coast near Irvine and CSOs discharging to the River Irvine under present conditions and two treatment scenarios for sewage effluent



* Combined total from the River Irvine and 3 stream inputs between Stevenston and Ardrossan

† Combined total from Meadowhead and Stevenston Point Outfall Works

¶ Combined total from Low Green and Gatehead CSOs and 42 modelled CSOs in Kilmarnock and the upper Irvine Valley

Comparison of discharge and faecal streptococci budgets for main sources discharging to the coast near Irvine and CSOs discharging to the River Irvine under present conditions and two treatment scenarios for sewage effluent

Maerl – a spectacular Firth of Clyde habitat

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Pioneering marine biologists were drawn to study the diversity of organisms found in the Firth of Clyde throughout the 19th century. In 1885, naturalists decided to study this diversity in detail and moved a floating laboratory (the 'Ark') from the relatively impoverished waters of the Firth of Forth to Millport on the Isle of Cumbrae. The move proved a great success and one of the numerous advances made over the next decade was the discovery of local maerl communities. The proximity of a range of marine habitats located within sheltered waters clinched the decision to establish the first Scottish marine biological station in Millport in 1896. Since these early beginnings we have learnt that the fjordic west coast of Scotland has the lion's share of European maerl beds and that the Firth of Clyde is no exception. Maerl beds remain poorly known, however, since few people have ever seen these attractive habitats. They have never featured on natural history programmes, are predominantly subtidal and often occur in remote areas. So what exactly are these elusive marine habitats?

At exposed sites in western Ireland and Scotland one may encounter maerl washed up to form glorious white beaches known locally as coral sand. On such beaches the maerl looks like coral since it too has a hard calcareous skeleton that bleaches white on exposure to air. In life, maerl is red or pink in colour and is constructed through the growth of unattached seaweeds termed "coralline algae". These coralline algae form calcareous gravel deposits that occur in isolated, clean coastal environments from tropical seas right up into Arctic waters. As with all seaweeds, living maerl requires light for photosynthesis and so is restricted to depths of 24m in the relatively turbid waters of the Firth of Clyde. Coralline algae are in fact the deepest-living plants known to Man with maerl extending beyond 100m in clear waters around offshore Atlantic islands, such as Madeira. Banks of maerl build up slowly as coralline algal fragments grow and accumulate to form a mixed sediment of interlocking individuals. The key to the importance of these habitats is that the complex calcareous sediment provides shelter and/or food for a rich assemblage of invertebrates (Figure 1), unusual seaweeds and juveniles of commercial fish such as cod. Divers that are fortunate enough to have seen maerl grounds *in situ* agree that they are highly appealing areas of special biological interest.

Along the NE Atlantic coast, including the Firth of Clyde, maerl generally occurs in sheltered areas where currents are strong enough to allow a high rate of water exchange. Typical Clyde areas include the Tan Buoy, between the Cumbrae Islands, and Otter Spit, in Loch Fyne, where the maerl is sheltered from disturbance by strong wave action and tidal currents prevent the seaweeds from being buried by silt. The main maerl-forming species in Scotland are *Phymatolithon calcareum* and *Lithothamnion glaciale.* The hard calcareous skeleton of these two species forms an effective defence against rapacious herbivores such as sea urchins and limpets. This investment in a thick carbonate skeleton is energetically costly for these algae, however, and results in extremely slow rates of growth (about 1mm a year is typical). Fist-sized lumps of maerl can be over 100 years old and recent radiocarbon dating research has shown that one maerl bed off the Isle of Bute is over 5000 years old. The incredibly slow growth of these habitats makes them highly vulnerable to human impacts.

Although maerl is a resource that has been exploited in the seas around Europe for centuries, it is only recently that we have become aware of the vulnerability of this unique "living sediment" to human influences. Global threats to maerl include habitat removal, such as in Brittany, Cornwall and SW Ireland, where it is dredged as a source of lime and trace minerals for agricultural fertiliser. Nutrient enrichment caused by agricultural runoff and/or sewage has reduced the extent of maerl beds in the Bay of Brest, Brittany whilst increased organic sedimentation has killed off maerl beds under mussel and salmon farms in Galicia (Spain) and Shetland respectively.

Clyde maerl beds appear not to have been damaged by habitat removal, nutrient enrichment or mariculture but there have been detrimental effects due to fishing. Throughout the Scottish west coast, the coarse, gravelly nature of maerl sediments, coupled with high rates of water exchange, makes maerl an excellent habitat for recruitment and growth of the scallop *Pecten maximus* (Figure 2). Recent research in the Firth of Clyde has shown that scallop dredging has caused extensive damage to maerl beds over the past 40 years which has led to a decline in associated organisms, such as the gaping file shell *Limaria hians* (Figure 3). Scallop dredges are particularly detrimental to maerl since they bury the surface layer of living algae upon which regeneration of the habitat depends.

The marine biological importance of maerl habitats has been steadily gaining international recognition in recent years. Management of the exploitation of key maerl-forming species became obligatory under the EC Habitats Directive in 1992 and maerl is included as a key habitat in the UK Biodiversity Action Plan. Maerl is particularly rare in England where local awareness of the richness and vulnerability of a maerl bed in the Fal estuary, Cornwall led to the formation of a voluntary marine reserve in 1983. Although damage has occurred at many Scottish maerl sites, recent scientific surveys show that the west coast still supports some of the best examples of maerl habitat in Europe. It is encouraging that two of the proposed Scottish Special Areas of Conservation (Sound of Arisaig and Loch Maddy) include maerl habitats. Protective measures cannot come too soon as the rate at which damage is occurring to these unique habitats is of serious concern throughout the coastal states of Europe.

A six year study based at Millport marine station has shown that local maerl beds are fragile systems that provide havens of high biodiversity and are useful monitors of direct and indirect anthropogenic impact. While it is true that many Clyde maerl beds have been heavily impacted by scallop fishing, the Victorian founders of Millport Biological Station would be gratified to know that undamaged maerl habitats still persist in the Firth of Clyde. Regions such as the Otter Spit area of Loch Fyne remain of considerable marine biological interest and should be protected for the future. Here the Firth of Clyde Forum can play a vital role, allowing those who use local resources to formulate sensible, mutually beneficial management strategies. In the case of maerl beds, for example, it makes sound economic sense to protect small areas such as the Otter Spit region to ensure that mature, fecund scallops provide spawn to re-seed wide areas of the Firth of Clyde where the marine habitats are less sensitive to the effects of scallop dredging.

Acknowledgements

Local fishermen, the Clyde Port Authority and my colleagues at the University Marine Biological Station, Millport are thanked for their help with this research, which is funded by the European Commission as a Study Project under the Common Fisheries Policy contract PEM/98/018.

Figure 1. A juvenile feather star (*Antedon bifida*) on maerl (*Phymatolithon calcaereum*) at -10m at Otter Spit, Loch Fyne.

Figure 2. A juvenile scallop (*Pecten maximus*) recently recruited to maerl at -12m at Otter Spit, Loch Fyne.

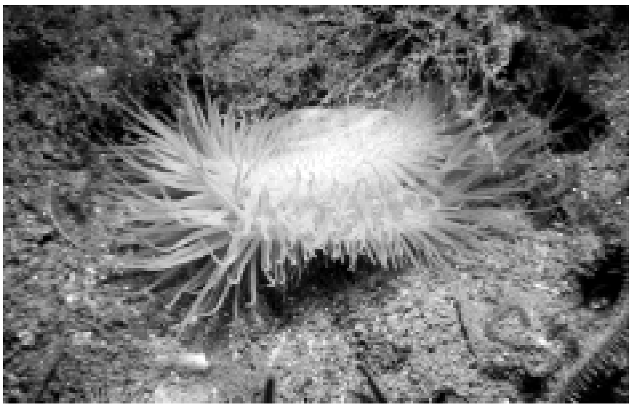

Figure 3. Gaping file-shells (*Limaria hians*) are common at Otter Spit, Loch Fyne but are highly susceptible to scallop dredging.

Further reading

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