

RESTORATION GUIDANCE FOR WEST COAST SALMON AND SEA TROUT FISHERIES

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1. INTRODUCTION

This report is on the biological and physical habitat issues that affect the restoration of Atlantic salmon and sea-trout in rivers when stocks and the fisheries are affected by sustained declines. It was commissioned by the Management Group of the Tripartite Working Group (TWG). The purpose of the TWG, chaired by the Scottish Government, is to address issues common to salmon farming and wild salmon fisheries and to seek solutions for ensuring the maintenance of healthy stocks of wild fish whilst at the same time promoting a sustainable aquaculture industry. The TWG's focus is therefore on the western rivers of Scotland although many of the principles explored in this report are universal and can be used to address related issues over a wider range of circumstances.

The report aims (1) to make the scientific background accessible to those with an interest in the management of salmonids in order to support evidence-based policy-making and fishery management and (2) to home in on the fisheries of the western Scottish rivers in order to identify an approach to restoration justified by the scientific evidence. This should aid decision-making in the more general contexts of what is possible, what might be achieved, how long it would take and how risky it might be. This report therefore seeks to offer guidance on restoration activity in the freshwater environment and support for river management planning by local fisheries managers and other interested parties. It is beyond the scope of this Report to deal in detail with the marine environment although some guidance is offered on wild/farm salmon interactions.

Some of the issues involved in fisheries restoration cross-over with related fishery and environmental initiatives that have been raised previously. Thus, for example, The North Atlantic Salmon Conservation Organisation (NASCO) has prepared guidelines on salmon stock rebuilding¹ and habitat protection² and the Scottish Environmental Protection Agency (SEPA) promotes freshwater environmental restoration³ in the context of the EU Water Framework Directive. Scottish Natural Heritage (SNH) has designated some western salmon rivers as Special Areas of Conservation (SACs)⁴ under the EU Natura 2000 system (Habitats Directive)⁵ and coordinated efforts to enhance the conservation of salmon via the Salmon LIFE project⁶. The present report is complementary to previous and ongoing initiatives of this type; it deals more specifically with fishery restoration in the context of the practical management of salmon and/or sea trout fisheries in rivers that are impacted by long-term declines.

¹ http://www.nasco.int/pdf/nasco_cnl_04_55.pdf

² http://www.nasco.int/pdf/nasco_res_habitatpoa.pdf

³ <http://sepa.org.uk/>

⁴ http://www.jncc.gov.uk/ProtectedSites/SACselection/SAC_list.asp?Country=S

⁵ http://www.sepa.org.uk/air/process_industry_regulation/habitats/habitats_directive.aspx

⁶ <http://www.snh.org.uk/salmonlifeproject/pdf/LIFE%20Project%20Newsletter%201.pdf>

1.1 What is restoration?

Fishery restoration is one of a set of related concepts that also includes enhancement, mitigation and ranching.

Restoration aims to re-establish the functional integrity of rivers and the fish populations that they support.

Enhancement aims to increase the capacity of aquatic habitats to support fish and/or to raise the abundance of fish towards the limits imposed by the carrying capacity of existing habitat.

Mitigation aims to circumvent the effects of irremediable losses of productive capacity.

Ranching aims to increase fisheries by circumventing the limits of freshwater carrying capacity.

Each of these concepts represents a possible approach to achieving sustainable fisheries but only some of them have the capacity to address the central importance of the natural fish populations that sustain fisheries in the long run. Each approach differs with respect to the required level of intervention and the need for continuous or repeated action. Each also differs in the time-scales over which improvement can be expected or maintained. Most importantly of all, each incurs different levels of biological, and therefore economic, risk especially when viewed in a conservation setting.

Restoration is the most conservative of the management options. The objectives of restoration are to return the character and abundance of salmonid populations and their habitats to a natural state in order to promote self-sustainability in the long-term, to do this in a cost-effective manner and to minimise the future dependence of fisheries on management intervention (Box I).

BOX I

Fishery Restoration

- Promotes high environmental quality.
- Protects and restores aquatic ecosystems and habitats.
- Supports native populations of salmonids.
- Conserves natural diversity among native salmonids.
- Promotes widespread distribution of all life stages throughout accessible habitat.
- Promotes increased abundance at all life stages.
- Promotes the re-establishment of self-sustaining populations.
- Targets the re-attainment of self-sustaining fisheries of high economic value.

1.2 The conservation context for fishery management

The present distribution of salmon and trout is the result of the interaction of many factors. The basic picture emerges from the legacy of the last glaciation and, in particular, from Scotland's isolation from that part of Europe that remained ice-free. The high capacity of salmonids to re-colonise fresh waters from the sea means that, even today, they still dominate the Scottish fish fauna rather than other strictly freshwater species.

The original, post-glacial landscape has been refined and remodelled. Local environmental variation has played a part in this and this has changed over time. Some of the most prominent environmental changes have resulted from human activity of various kinds; these have often resulted in reduced abundance of salmonids and sometimes in local extinctions.

As a result of their varying histories and differences among the places in which they live, present-day populations of salmon and trout differ greatly from one another in important and recognisable ways. They differ for example, with regard to appearance, performance and the timings with which they appear in the fisheries. This diversity is substantial and interesting and aspects of it are of direct economic importance.

There are only two categories of effect that could generate the observed diversity. As for all other organisms, every aspect of the biology of fish is determined by their genetic make-up. However, the outcome of all the genetic processes – including survival and reproduction - is affected by the environment in which the fish live. Thus the fish we see and the fisheries they support are the product of interactions between each fish's genetic make-up and the environment in which it is expressed.

Much of the variation seen among both salmon and trout is due to environmental differences among the locations that the fish inhabit. However, a very substantial part is attributable to differences in the genetic constitution of fish living in different places.

The potential importance of this point has been recognised for many years. For example, based on what they saw around them, an explicitly genetic approach was advocated many years ago by Calderwood (1930) and later Menzies (1931), both of whom held the post of Inspector of Salmon Fisheries for Scotland. More recently, it has been experimentally demonstrated that many obvious and important characteristics including growth (Jonasson and Gjedrem, 1997), sea-age (Gjerde, 1984) and run-timing (Stewart, *et al.*, 2002) are strongly driven by genetic factors.

Variation in performance is extremely important for a number of reasons. For example, a large part of the economic value of the salmon fisheries depends on seasonal variation in run-timing because this makes extended fisheries possible. The Scottish fisheries are unusual in this respect and they compare favourably with all the other major, national fisheries. Scottish runs of spring salmon, for example, have no parallel in Norway, Canada or Iceland where the entire fishery is compressed into a shorter season centred on the summer months.

Therefore, if the genetic contribution to fish performance is substantial, it follows that genetics should be considered in all forms of fishery management. In particular, it follows that genetic considerations should dominate any attempts to restore the character of fisheries.

Beyond this, it is necessary to ask whether variation in the distribution of different types of fish is a random accident of nature or whether particular types of fish are genetically suited to particular local environments. If, as has been demonstrated (Garcia de Leaniz *et al.*, 2007),

some genetic types of fish are better suited than others to life in particular locations, it follows that genetic considerations ought to dominate attempts to restore the productivity of fisheries.

Finally, if fish tend to perform better in their native streams than they do in other streams as has been demonstrated in field experiments carried out in Ireland (McGinnity *et al.*, 2004), then a consideration of genetics ought to form the very foundation of all forms of fishery management.

1.3 The fishery context for management

The Scottish salmon and sea-trout fisheries are monitored by Marine Scotland Freshwater Laboratory (formerly Fisheries Research Services Freshwater Laboratory) and the results are reported in the Statistical Bulletin of Scottish Salmon and Sea Trout Catches⁷. The Bulletin is published each year and it updates a data set that was started in 1952.

Statistical analysis has shown that, overall, the numbers of fish caught are a usefully accurate depiction of the development of the fisheries. Some elements of the fisheries have shown marked declines in recent decades. For example, the status of spring salmon in the eastern rivers and the status of western stocks of both salmon and sea trout have declined and causative reductions in marine survival are clearly implicated.

These declines have been recognised and considered serious enough to require remedy. This has led to management initiatives to deal with particular aspects of the underlying causes. For example, the introduction of catch-and-release policies in the eastern spring fisheries has significantly reduced the removal by anglers of potential spawners at a time when in some catchments their numbers were only marginally adequate to maintain juvenile production.

The establishment of the TWG and its associated initiatives such as Area Management Agreements (AMAs)⁸ has fostered attempts to address the problems associated with high sea lice numbers in western coastal waters.

The purpose of this report, however, is to consider whether a broader context can be constructed in which a wider range of sound management measures can be deployed to promote the maintenance or, where necessary, the re-establishment of self-sustaining fisheries of high worth.

1.4 The context for this report

The aim of this report is to provide guidance on (1) assessing competing management options, (2) a scientific basis for a restoration rationale and (3) an appropriate range of management actions.

The main difficulty in providing advice on any fishery problem is that the underlying causes are often unknown. Furthermore, they are seldom single and the complex of factors and their relative importance differs among river stocks. This reduces the scope for providing unqualified scientific advice.

⁷ http://www.frs-scotland.gov.uk/Delivery/Information_resources/information_resources_view_documents.aspx?resourceId=2369

⁸ <http://www.tripartiteworkinggroup.com/content.asp?ArticleCode=2>

Even when the source problems can be pinpointed, they often cannot be remedied quickly, and in many cases they cannot be remedied at all. In the former case, time-scale will be a crucial factor if restoration is considered and temporary holding actions may be necessary. In the latter case, restoration may be considered unrealistic and alternative forms of management may have to be considered.

1.4.1 Particular problems associated with restoration of populations of anadromous fish

Salmon and sea trout rely on a sequence of distinct environments for growth and survival (Box II). Environmental quality varies independently in the freshwater and marine phases under the influence of quite different sets of controls. Indeed, both the freshwater and marine phases exploit sequences of separate environments, ranging from mountain streams to estuaries and from near-shore coastal waters to the sub-arctic ocean. In the course of passage between these locations, performance and mortality are affected by the separate quality of all the linking environments. The relative qualities of each one must be considered because the most limiting life-phase will cap the scope for restoration, or for any other form of fishery improvement that targets increased natural production.

BOX II

Key requirements of salmon and sea trout

- Adult fish require free and safe passage to natal streams.
- They require a river flow regime that is conducive to upstream migration.
- They need access to holding areas in rivers (pools), often for prolonged periods (months).
- Spawners require the presence of streambed gravels of appropriate grade.
- Salmonid eggs incubate for a prolonged period (three to five months) and the developing embryos require sub-streambed (interstitial) water of good quality and of adequate flow.
- Fry must find suitable habitat (i.e. "fry habitat") shortly after emergence from redds. In general, this habitat must be downstream of redds and it must be available within a short distance of the redds (a few hundred metres).
- Parr must have access to suitable habitat (i.e. "parr habitat") but are more capable of dispersing to find it.
- The migration of smolts is dependent on river flow and on free and safe passage.
- Post-smolts require a coastal environment of adequate quality although the nature of their requirements and any constraints on performance are not well understood.
- Sub-adults require access to adequate marine environmental conditions but, again, the nature of these requirements is not well known.
- Even when physical environmental quality and habitat availability are adequate, fish can still succumb to excessive predation, or to episodes of disease or excessive parasitic infection.

2. ASSESSING THE MANAGEMENT OPTIONS

A number of related and potentially overlapping management options exist. Unfortunately, the terms applied to the various types of management actions are often used without being adequately defined and sometimes they appear to be used interchangeably, such that the differences between the various options are obscured. Properly defined, the various

categories of management constitute a set of different but related actions, with related and often overlapping goals. Each of the activities may be found to have a role to play in fishery management - particularly if short-term economic gain is an imperative - but each has strengths and limitations.

2.1 Possible approaches

In the extreme case, ranching targets temporary increases in a fishery's performance irrespective of its starting condition. Mitigation recognises the root cause of the fishery problem but attempts to circumvent it by applying methods that must be practised in perpetuity. Enhancement attempts to circumvent limits on natural productivity and, again, must be practised continuously to maintain any gain. Restoration alone takes a long-term view of both habitat and fish populations and offsets this against the lower net management costs associated with permanent resolution of the fishery problem.

Box III

Key features of restoration

- Minimises risk to natural genetic diversity.
- Promotes natural functionality.
- Provides ancillary environmental benefits.
- Provides ancillary benefits for other species.
- Targets the root causes of pressures on the fishery.
- Targets permanent resolution of pressures on the fishery.
- Targets self-sustaining fisheries.

Re-introduction is a special case of restoration, in which previous problems with environmental quality or habitat availability have been resolved but where no wild, native fish remain to re-establish a fishery.

Within the context of restoration, some of the other approaches to fishery improvement might be employed, in order to meet shared aims that are associated with different time scales. For example, when marine mortality rates are unusually high, enhancement might be attempted with a view to increasing parr and smolt numbers, in order to increase the number of returning adults. The most common form of enhancement uses hatcheries to improve on natural rates of survival between the egg and fry stages.

2.2 Restoration as an option

Consideration of a restoration programme will follow the recognition that a rod fishery has declined due to an underlying decline in the exploited stock. There are several possible interacting issues that must be considered in order to decide whether restoration is necessary or appropriate and whether it is likely to be successful or cost-effective. It is very likely that informed answers to all the questions will not be available, but even partial answers for some of them will help.

The first difficulty regards the basis on which rod fisheries are compared across years. All fisheries vary from year to year and all show short runs of years when catches are less than average. Obviously, timely consideration should aim to pre-empt declines in fisheries but, formally, a long-term decline in catches (or some other indicator of adult abundance) indicates that restoration should be considered.

On its own, however, a sequence of unexplained poor fisheries is not sufficient to justify action. Thus, for example, high marine mortality rates will result in low adult numbers with a commensurate negative effect on fisheries. However, juvenile numbers need not be affected to the same extent. When their numbers are fewer and competition is less intense, a greater proportion of juveniles survive to become smolts. Restoration is specifically indicated when poor or declining fisheries are associated with falling numbers of juveniles.

Even in the presence of a long-term decline in catches and low numbers of juveniles, restoration may not be appropriate. It is important to consider the cause of the decline and, in particular, where in the life-cycle any bottleneck occurs.

Currently, there is a single outstanding issue of this type; low marine survival rates are affecting the production of many populations of salmon and sea trout.

The underlying cause for low marine survival rates is not properly understood; it may well be that different causes or multiple factors are implicated. In the particular case of the western fisheries, the TWG has fostered AMAs in order to minimise the potential impact of aquaculture on wild fish, with particular regard to sea lice production. In addition, and particularly for salmon, long-term changes in the ocean environment have been implicated in reducing marine survival to current low rates.

Irrespective of cause, restoration in fresh water cannot directly address problems caused by a marine bottleneck on production; the marine restriction must first be removed or reduced.

2.3 Application of the restoration approach

Several difficulties are associated with the restoration approach that will require acceptance or resolution at the outset.

Crucial limits on knowledge

- Behavioural and performance diversity is important in the fishery context. Many aspects of diversity are genetically determined e.g. resident trout v. sea trout; grilse v. multi-sea-winter (MSW) salmon; early- v. late-running salmon. The distribution of behavioural and performance diversity is linked to genetic population structuring. At present, the relationships are sufficiently well-understood to demand advocacy for a conservative approach to fishery management but understanding is not currently sufficient to support an interventionist approach.

Limitations of scope

- There is a low likelihood of being able to fully restore some physical/ chemical processes in degraded catchments. For example, in many instances it will not be possible to restore natural drainage patterns in agricultural land or to reduce nitrogen loadings to natural levels.
- There are conceptual difficulties (see later) regarding the restoration of native or quasi-native salmonid populations to catchments in which fish numbers have been severely reduced and, especially, where populations have been eliminated.
- Many of the physical and biological processes to be addressed in restoration show high levels of natural variation and low levels of predictability.
- Relatively long time-scales are associated with many natural processes. For example, any attempt to demonstrate the re-establishment of self-sustaining salmon populations requires a minimum of two life-cycles (around 10 years) of monitoring. Among the physical processes, the least frequent events tend to be of greatest ecological effect (e.g. the 100 year return flood).

Potentially competing interests

- In many settings, the scope for restoration of fisheries will be constrained by the competing needs of other users of the natural resources of river catchments (e.g. farming, forestry, industry and urbanization).
- In the particular context of the TWG, these constraints probably extend to the marine environment, to include ecological effects of salmon aquaculture on wild salmonids and the additional genetic effects of escapees which may have adversely affected wild salmon. Trout may also have been adversely affected because levels of interspecific (i.e. trout x salmon) hybridisation are increased in the presence of escaped farm salmon (Youngson *et al.*, 1993).

Although the restoration approach can be recommended as the most appropriate back-drop to fishery management, the difficulties it poses mean that other, less holistic, approaches to management are certain to be considered. In these cases, the restoration approach can be used as a benchmark against which to judge the merits and the downsides of less comprehensive approaches. However, management decisions in favour of any of the lesser options should not be made in ignorance of the risks incurred. In view of this, and given the unique nature of each fishery context, it may well be necessary to seek expert advice on a case-by-case basis.

3. HANDS OFF OR ACTIVE MANAGEMENT?

There are two broad approaches to managing the restoration of salmon and sea trout populations and the fisheries they support – hands-off or active.

The *hands-off* approach will consider that no further action is required if a bottleneck on fish production has been removed or countered.

The hands-off approach:

- Relies on the natural dynamics of local fish populations to restore high levels of uptake of freshwater habitat.
- Assumes the restoring populations will be the residual populations of the river in question.
- Assumes that if residual fish are absent, the restoring populations will be populations in other, nearby rivers.
- Will require that the restoring populations are sufficiently robust to contribute in this way.
- Is not appropriate if restoring populations are not available.

The hands-off approach cannot result in fishery benefits in less than two life-cycles (around 10 years for salmon). If the affected fish populations are severely depleted, it may not provide substantial benefits within even longer time-frames.

Hands-off management does have several simple benefits:

- It makes no assumptions about the potential fishery value of any river restoration measures that have been carried out.
- It makes no assumptions regarding the permanence of any potential benefits of previous measures.
- It makes no assumptions about the future sustainability of fisheries under new pressures.

- It is free of cost.
- It makes no assumptions about the numbers, species or types of fish that restored habitat might support.
- It is essentially risk-free in the context of genetic conservation.

The active approach to fishery restoration encompasses some or all of the following elements:

- Support for native fish populations and their capacity to take up vacant habitat or to re-colonise restored habitat.
- Rehabilitation of natural processes in degraded rivers in order to increase their capacity to support native salmonid populations.
- Creation of river habitat to compensate for permanent or long-term losses of natural habitat.
- Creation of key habitat to remove or reduce habitat bottlenecks for fish production.
- Re-introduction of salmon and/or sea trout to rivers where they no longer exist.

Sections 4 and 5 deal in greater detail with the practical context for active fishery restoration

4. RIVER PROCESSES AND FISHERIES

4.1 River processes and fish production

The nature and condition of catchments, streams, rivers and riparian zones determine the nature of a set of hydrological processes that are of central importance in a fishery context. The processes are intrinsically variable and dynamic. For example:

- Catchments store precipitation.
- Catchment processes modulate high flow events.
- Catchment processes modulate low flow regimes.
- Catchment processes modulate water temperature extremes.
- Rivers transport and grade sediments.

These processes, coupled with geomorphology, soils, vegetation and climate, determine natural environmental quality and habitat distribution and, therefore, set an upper limit on the potential production of juvenile fish.

Natural episodes of disturbance caused by high river flow play a key role in maintaining the distribution and diversity of the morphological features of river channels, the habitats they provide and the fish production supported by the habitats. Depending on the particular combination of opposing effects produced - for example, by impoundment, abstraction and drainage - flow regimes in degraded rivers can be much more or much less dynamic than natural regimes. Both conditions are likely to be unfavourable for fish.

Degradation of rivers results from human impacts on catchments that cause changes to river processes. These include changes to rates and ranges of river discharge, rates of sediment throughput, temperature regimes and water quality. All these changes can affect salmon and trout adversely. In some cases, negative effects are direct but in others they are indirect for example, via changes in the ecology of potential prey species.

In degraded rivers, natural river processes are compromised. Because these processes determine the condition (which is used here to mean the quantity, quality and availability) of habitat, river degradation compromises many or all aspects of river habitat that are important

in the context of salmon and sea trout. If those key habitat types that limit production are adversely affected, the productivity of salmon and sea trout populations will be reduced.

More specifically:

- The river habitat requirements for eggs, fry, parr and adults differ.
- The condition of the limiting habitat type caps the overall potential for freshwater production (viz. smolt production).
- Any reduction in the condition of the limiting habitat type will reduce potential smolt production, irrespective of the condition of other habitats.
- Increases in the condition of limiting habitat will increase potential smolt production, but only up to the point where another habitat type becomes limiting.

BOX IV

Habitat/environmental degradation of rivers

- Impoundments drown potentially productive stream habitat.
- Dams and impoundments impede access to potential habitat.
- Poorly-engineered road culverts have the same effect.
- Dams may impede migratory access to seasonal fisheries (e.g. lochs)
- Water abstraction reduces discharge, particularly at low summer flows, to the detriment of fish.
- Impoundment, channelisation and forestry can alter the hydrological regime in complex ways, often to the detriment of fish.
- Changed hydrological regimes alter sediment dynamics, also to the potential detriment of fish.
- Changed hydrological regimes, alter the temperature regime potentially to the detriment of fish.
- Agricultural drainage and drainage associated with urbanisation alter the hydrological regime, speeding the passage of water through catchments and, in flood conditions, increasing peak discharge rates beyond natural limits.
- Channelisation reduces habitat diversity and reduces the availability of key habitat types for fish.
- Agricultural and domestic run-off raises stream nutrient levels, enhancing the growth of stream plants, potentially lowering stream velocity, decreasing dissolved oxygen and altering sediment dynamics - both potentially to the detriment of salmonids.
- River courses are naturally dynamic. Ill-judged bank defences displace and may increase bank erosion and therefore sediment input.
- Gravel extraction alters sediment dynamics and, in particular, it increases stream loadings of fine sediment.
- "Poaching" by livestock with free access to streams increases loadings of fine sediment and nutrients.
- Conifer plantations increase stream acidity to the detriment of fish.
- Poorly managed forestry plantations over-shade riparian herbage, reducing bankside shelter for fish and reducing the abundance of prey species.
- Poorly designed and managed intakes may lead to disruption of natural sediment movement patterns and loss of juvenile and adult fish.

All the detrimental activities listed in Box IV arise from long-established uses of catchment resources. The impact of some of the activities could probably be reduced by simple good practice. However, the scales involved in most of the activities suggest that large gains in habitat condition may not be possible at all and, in most cases, it will not be possible to make

rapid gains. Indeed, some activities have caused adverse effects which are probably irreparable (e.g. agricultural land-drainage and flooding of valleys for hydro-power).

All catchments are intrinsically different and a multiplicity of interacting processes is involved in determining the quality of local river habitats/ environments. The prospects for river restoration will therefore be context-specific and prediction of outcomes will necessarily be imprecise.

The main questions to be addressed are:

- Can river restoration be specifically targeted on fishery restoration?
- Can river restoration be practised on sufficiently large scales to counter adverse effects of competing activities?
- Can river restoration be practised on large enough scales to provide tangible fishery benefits?
- Can river restoration provide tangible benefits to fisheries on a realistic time-scale?

4.2 River habitat restoration for fishery benefits

Formal assessment of the condition of salmon and sea trout habitat in rivers requires:

- A working definition of key habitat types.
- Assessment of the quantity of each habitat type.
- Assessment of the quality of each habitat type.
- Assessment of the distribution of each habitat type.
- Assessment of habitat access for salmon and sea trout (i.e. barriers to the upstream migration of adult fish and therefore to habitat uptake by juveniles).
- Assessment of the availability of successive habitat types to fish as they advance through their life-cycle (i.e. connectivity).
- Identification of the limiting habitat type that caps fish production.
- Assessment of the channel morphology and stability (i.e. departure from so called 'best channel condition')

The identification of barriers to adult movement is relatively straightforward. Disused man-made barriers can often be removed at low cost, and alleviation of barriers still in use is often technically feasible. Coupled with assessment of the condition of the potential new habitat, the costs of barrier removal can be compared with the expected gains in fish production.

It should be noted that the removal of natural barriers is not covered by the concept of restoration. In addition, while natural barriers may well close off potentially productive habitat for migratory fish, the same barriers often protect vulnerable populations of non-migratory fish that are of potential conservation value.

4.3 Physical habitat condition assessment

Changes in land use, river flow, sediment input regime and man-made structures (e.g. bank protection, bridge footings and croys) all have the potential to influence the stability and function of river channels and their associated habitat features. However, the response of a river channel to either natural or man-made disturbances depends on the type of stream (e.g. high gradient or low gradient). The ability to recognise the broad responses of different types of rivers and channel types to different kinds of disturbance is therefore important in evaluating the potential for natural recovery or active restoration (Rosgen, 1996).

River channel and habitat condition assessment requires consideration of a multiplicity of factors. Habitat features considered most pertinent to fish range from micro-scale features (e.g. embeddedness of sediment) to macro-scale features such as channel morphology and bank structure. Assessments are usually first made on channel morphology, bank-side structural features, and riparian vegetation. A comprehensive assessment incorporates features in a series of sampling reaches within the context of a range of selected features of the broader catchment.

For the purposes of characterising river channels (including the riparian zone) a wide range of different assessment tools are available. Most Fishery Boards and Fishery Trusts use the Scottish Fisheries Coordination Centre (SFCC) Habitat Survey⁹ methods; some independent consultants use the River Habitat Survey (RHS) protocol¹⁰. Both methodologies have similar features that are designed to characterise, in broad terms, the physical structure of stream and river channels at the reach scale. The SFCC survey approach gathers more information on aspects that are thought to be important for fish habitat than the RHS protocol.

The SFCC Habitat survey methodology is applied widely and is likely to continue to be applied extensively in the future but it was not particularly developed to address the issue of restoration. In this regard, the protocol makes no distinction between high and low gradient streams, it does not assess habitat against expected conditions and it does not deal with connectivity of habitats. The data generated therefore are not suited to examining the river processes that limit natural habitat creation and determine its functionality and maintenance.

In the context of habitat restoration, specifically the SFCC and RHS protocols are of limited utility in the following key areas:

- Characterisation of regional reference conditions.
- Characterisation of the existence and severity of physical habitat impairment at relevant spatial scales.
- Identification of sources or causes of impairment.
- Evaluation of the long-term effectiveness of management actions.

Formal assessment of river habitat of sufficient scope to be a reliable guide to restoration management is a major undertaking. Biologists and river managers currently do not have access to a rapid, cost effective and scientifically valid method to assess the functional integrity of streams and rivers, although potentially suitable methods have been developed elsewhere (see e.g. Tables I and II).

However, in the context of this report, formal assessment of physical habitat condition in many rivers is unlikely to provide answers of sufficient clarity to support immediate, targeted or cost-effective fishery management because:

- General habitat classification lacks the precision necessary to accurately predict the potential number of salmon or sea trout that might be supported by restored habitat.
- Paradoxically, some degraded habitats can be shown to be among the most productive of fish – e.g. some canalised (but also nutrient-enriched) agricultural streams.
- The preferred habitats of juvenile salmon and sea trout differ.

⁹ <http://www.sfcc.co.uk/pdfs/SFCC%20Habitat%20Training%20Manual.pdf>

¹⁰ <http://www.irpi.to.cnr.it/documenti/RHS%20manual%202003.PDF>

- The distinction between migratory sea trout and non-migratory brown trout is not clear. In particular, the role of habitat quality in modelling the life style of individual trout is unknown.

For all of these reasons, in most instances formal habitat assessment is not likely to pin-point the habitat category that limits overall levels of fish production nor, therefore, the key target for potential restoration.

More generally, however, formal assessment of river habitat will aid management by identifying:

- Obviously degraded areas of habitat.
- Areas at risks of continued deterioration.
- Areas of apparently good habitat quality.
- Habitat areas that merit special protection.
- Areas where habitat restoration, enhancement or creation might be feasible.
- Areas of uncertain status that might be investigated further using different techniques e.g. to investigate river processes.

Resource constraints or management imperatives may demand an intuitive approach to habitat assessment. However, in the absence of a formal approach, the risks are that:

- Management actions will be mis-targeted.
- Works will be undertaken on too small a scale to provide tangible fishery benefits.
- Inadequate prior assessment and/ or inadequate monitoring will result in uncertainty regarding outcomes.
- Lack of understanding will impede effective re-targeting of resources.
- Lack of understanding will impede learning and transfer of knowledge.

4.4 Methods for river restoration

A wide range of adverse, or potentially adverse, effects is evident across the range of Scottish rivers. Some effects are river-specific (e.g. acidification, abstraction) but most result from widespread human activity and are therefore general.

Some of the most common adverse effects are listed below (Table III), with compensatory or restorative action for fishery management, target outcomes and potential risks.

Some local restoration measures are likely to be extremely cost-effective. For example, the adverse effects of unused dams can be addressed at low cost and restrictive culverts, or poor practice in the use of heavy machinery near water courses, can be addressed by continued provision of sound advice to practitioners. In many rivers, however, these actions are unlikely to result in large fishery benefits when considered at the catchment scale.

All the available approaches are to be recommended as part of any long-term plan to improve or re-establish salmon and sea trout fisheries. However, many of the approaches are costly to execute, many offer uncertain rewards and most cannot be realistically practised on sufficiently large scales to produce tangible returns for management.

In the bioregional context of the TWG, neither the declines in salmon or sea trout catches, nor the declines in juvenile abundance, can be plausibly attributed to changes in any aspect of freshwater habitat. Furthermore experimental and monitoring work has pin-pointed low

rates of post-smolt marine survival as the crucial restriction on spawners and the limit on juvenile uptake of freshwater habitat¹¹.

Management of freshwater habitat will not resolve restrictions on production caused by a bottleneck in the marine environment. Freshwater habitat restoration might have some potential to raise smolt production in most rivers - including western rivers. If greater numbers of smolts go to sea more adults are expected to return. Habitat measures could therefore be considered as possible mitigation actions for bottlenecks in the marine phase. However, the validity of the mitigation approach is conditional on existing habitat being fully occupied by juvenile fish, and its success requires that excess fish are available to populate new areas. In the case of many western fisheries, monitoring studies indicate that neither of these conditions can be fulfilled. In such cases, management of freshwater habitat cannot be expected to result in the desired fishery response.

4.5 Legislative considerations

4.5.1 Protected sites

Until recently, the Wildlife & Countryside Act 1981 (as amended) was the primary legislative tool for protecting the natural heritage, including the management of protected aquatic habitats and species, such as freshwater pearl mussel (*Margaritifera margaritifera*). The Nature Conservation (Scotland) Act 2004 has strengthened these provisions and, more importantly, placed a statutory duty on all public bodies, including those involved in the management of fisheries, to further the conservation of biodiversity. This means that public bodies must examine not only how they run their businesses and incorporate actions to conserve biodiversity into these but also how their functions can help to deliver biodiversity conservation objectives. The duty puts the onus on public bodies to take biodiversity into account in all decision making. This has clear implications for Local Authorities, SEPA and others.

In addition to domestic legislation, a number of international nature conservation and water resource management agreements and Directives are directly relevant to the restoration of fish populations and their habitats within Scotland. The Habitats Directive is transposed into Scottish law by means of The Conservation (Natural Habitats, &c.) Regulations 1994 and The Conservation (Natural Habitats, &c.) Amendment (Scotland) Regulations 2004 (together referred to as the 'Habitats Regulations'). Taken together with the 1979 Birds Directive, it provides a framework of sites, collectively known as 'Natura 2000', to protect our most seriously threatened habitats and species. In addition to sites and species within the Natura 2000 series, both the Habitats and Birds Directives require member states to protect a smaller number of species regardless of their location. A list of 'European Protected Species' [EPS] of plants and animals' is provided in Annex IV of the Habitats Directive. Species that may be affected by riparian management measures, for example bats (all species) and otter (*Lutra lutra*), are included in this list.

Where a proposed management intervention, whether the addition of fish or the modification of their habitat, is within or likely to have an effect on a Natura site the competent authority has a duty under Regulation 48 of the Habitats Regulations to:

- determine whether the proposal is directly connected with or necessary to site management for conservation; and, if not,

¹¹

http://www.marlab.ac.uk/Delivery/Information_resources/information_resources_view_documents.aspx?resourceId=31140&parentId=37&parentName=Reports

- determine whether the proposal is likely to have a significant effect on the site either individually or in combination with other plans or projects; and, if so, then;
- make an appropriate assessment of the implications (of the proposal) for the site in view of that site's conservation objectives.

In most cases interventions such as this will be contribute to the conservation management of the site, but nonetheless determination of significance will still be required. It is important to note that the determination of significance is more of a coarse sieve to decide whether a more detailed appropriate assessment is required. If there is insufficient information to answer this question it must be assumed that there will be a significant effect and an 'appropriate assessment' will therefore be needed.

4.5.2. The Controlled Activity Regulations

New regulatory regimes required by the Water Framework Directive [WFD] and transposed in further detail in Section 20 of the Water Environment and Water Services Act 2003 have been introduced by secondary legislation – these are the Water Environment (Controlled Activities) (Scotland) Regulations 2005 [CAR]. CAR establishes measures to regulate activities for the purposes of protection of the water environment, as required by the WFD and will facilitate the achievement of environmental objectives set out in river basin management plans. CAR also introduces controls over abstraction, impoundment and building, engineering and other works that impact on the physical quality of aquatic habitats. CAR consents will be required for many of the physical, habitat improvement, works that may form part of a restoration programme.

5. RESTORATION OF FISH POPULATIONS

In the context of the TWG, freshwater habitat management, as dealt with in Section 4, is not likely to prove an effective response to current pressures in the western fisheries. Whilst levels of marine mortality remain high, the primary options for improving salmon and sea trout populations, stocks and fisheries will probably involve managing the fish themselves.

Where residual native fish remain, a passive approach may well be the most rational fishery management response while the source problems cannot be identified, if they cannot be countered, or if they are considered likely to ease on an acceptable time scale. A passive approach may include efforts to minimise losses to fisheries (e.g. catch and release) in order to maximise levels of egg deposition.

Enhancement of native fish populations via the application of appropriate hatchery approaches is an established and potentially effective means of raising numbers of juvenile fish, conserving native populations as an interim measure while they are constrained by marine conditions, and promoting speedy recovery of fish populations when they become freed of former marine constraints (e.g. Youngson, 2006).

Where residual native fish are absent but appropriate donor stocks remain, re-introduction of fish populations has the potential to support the development of new fisheries – but only if the cause of the original extinction has been removed or alleviated. Re-introduction will not be an effective fishery measure if marine mortality rates continue at their present high level.

The remaining option is ranching. Ranching is a management technique rather than a concept and it covers a potentially wide range of applications. Ranching eliminates any restrictions on the natural productive capacity of rivers by rearing fish under hatchery/aquaculture conditions and liberating them, typically at the smolt stage. Under some circumstances, ranching might form a legitimate part of an enhancement or re-introduction programme, as above.

Although ranched smolts can be released in large numbers, it must be noted that they will also suffer high rates of marine mortality under current marine conditions. In general, rates of mortality in ranched smolts will be proportionally greater than for wild smolts because captive-rearing tends to be associated with reduced performance (i.e. high mortality rates) in the post-release phase.

In practice, ranching has sometimes included the liberation of fish obtained from commercial fish farms. Because of the genetic equivalence of released and escaped aquaculture fish, no circumstances can be envisaged in which it would be possible to recommend or support the release of fish farm stock in pursuit of fishery objectives.

5.1 Management of residual spawners

5.1.1 Catch and release

Catch and release is a simple and effective means of increasing spawner numbers and has obvious benefits in maintaining numbers where adult abundance is low. Although the approach has sometimes proved contentious, it is simple, effective, conservative in application and inexpensive. Full-scale suspension of fisheries achieves the same goal as catch and release but at the expense of loss of the fishery income required to support management and with the loss of catch and catch rate data which are important as a first line approach to monitoring the progress of fisheries.

In the context of broodstock management, it should be noted that fish identified as escapees from aquaculture should not be included in broodstock collections (or released after capture), in line with the principles in NASCO's Williamsburg Resolution.

5.1.2 Management intervention

There is a range of more interventionist techniques for fish management that might be brought into play to address the particular difficulties associated with restoration. All of these involve the amplification of fish numbers but each differs in concept and design.

In traditional hatchery work, for example, adult fish are captured before spawning, and subsequently protected. Eggs are stripped at spawning time, and subsequently protected. The resulting progeny are planted out, typically at the unfed fry stage, and dispersed among appropriate locations. A much wider range of more complex culture techniques can be utilised to provide greater degrees of protection and amplification. However, there are potential conflicts between the use of aquaculture techniques and the conservation of fish populations and fisheries (Boxes V and VI) that arise from the recognition that genetic considerations are central to the management of restoration. In general, the extent of the potential conflicts increases with the extent of the intervention. Meticulous consideration is therefore required to match management works to fishery and conservation needs in order to optimise the outcome of any intervention that is required.

BOX V

Potential adverse effects of hatchery-reared fish on wild fish stocks (adapted from White, 1994)

- Deleterious genetic alteration of native populations
- Increased predation (e.g. predator attraction)
- Competition with wild fish for food and space
- Antagonistic behaviors that are disruptive for native fish
- Disease and parasite transmission

BOX VI

Possible reasons for poor post-release survival and reproduction of hatchery-reared fish. (Adapted from White, 1994)

Morphology

- Deformity
- Hyperbuoyancy
- Aberrant skin colour

Physiology

- Low energy stores
- Poor stress resistance
- Poor stamina
- Inability to cope with natural conditions
- Disease

Behaviour

- Vulnerability to predation
- Low ability to cope with winter conditions
- Inappropriate habitat occupation
- Inappropriate timing of local movements
- Vulnerability to angling
- Weak territorial behaviour

5.1.2.1 Genetic considerations

Research on the inherent nature of salmon and trout, and how this affects the character, survival and reproductive success of local stocks is still in its infancy. However, over the last 10-20 years advances in understanding have emphasised the practical implications of the genetic context for salmonid management. This information has been recently reviewed in the context of salmon fishery management by Verspoor *et al.* (2007) and by Ferguson (2006) in the related context of the stocking of trout.

Inherited genetic make-up varies greatly among individual salmon or trout and the genetic make-up of local breeding populations can often be shown to differ markedly from place to place. Additional complexity arises from the interaction of genes with all the facets and variations of the freshwater and marine environments to which both sea trout and salmon are exposed. Genetic variations affect the ability of particular fish to survive and to reproduce (i.e. their “fitness”) in particular circumstances. Genetic principles must therefore be taken into account in managing self-sustaining fisheries, particularly when enhancement or restoration is proposed.

The main genetic principles for management are listed below and they apply equally to salmon and sea trout.

- Different river systems have different breeding populations of fish.
- All but the smallest river systems are likely to have more than one breeding population.
- Breeding populations are more or less adapted to the conditions of their local environments.
- Management should aim to target local breeding populations.
- Fish taken from their native environment can be expected to be less fit when transplanted elsewhere and, where a local breeding population exists, to be less fit overall than native fish.
- Reproductive mixing of native and non-native fish leads to hybrid progeny which will show intermediate fitness but this will still be reduced relative to native fish.

In the context of restoration, these considerations indicate that:

- Depleted populations should be allowed to recover spontaneously, or with only minimal intervention, where the causes for the declines can be removed.
- If a population is at risk of continued depletion, a programme of supportive breeding and stocking of cultured native fish should be considered.
- Where a population is at risk of extinction and the causes are unknown or irremediable, gene banking offers a possible holding option.
- In the case of extinct populations, the most cost-effective and least risky method for restoration will be by natural re-colonisation supported, if required, by supportive breeding of natural colonisers.

More generally, for genetic and other reasons, indiscriminate stocking cannot be considered a valid approach with any likelihood of permanent success; on the contrary, it has the proven potential to do substantial damage (Box V).

5.1.3 Traditional hatchery work

Under natural conditions, mortality of salmon and trout occurs at every life-stage due to competition and to predation by fish and other species. However, the greatest numerical losses occur between spawning in autumn and the end of the first summer of free swimming life. The known potential causes of the losses are:

- The natural production of genetic combinations that are unable to survive under natural conditions (i.e. “genetic load”).
- Predation of adult females at spawning time e.g. by otters.
- Predation of eggs at spawning e.g. by attendant fish.
- Over-winter washout of nests.
- Egg mortality due to unfavourable incubation environments – e.g. low oxygen availability.

- Lethal competition among emergent fry.
- Lethal competition of emerging fry with older fish.

All of these potential sources of loss can be reduced or avoided by the use of traditional hatchery techniques. The costs of the traditional hatchery approach can be relatively low and the technology is tried and proven.

Traditional hatchery work may therefore have a role to play in the particular context of restoration. Potential roles can be developed to buffer and support depleted native populations and to accelerate the recovery of native fish numbers in depleted river systems.

As with other forms of intervention, no form of hatchery work can directly address a marine bottleneck on production. Hatchery work will not affect the proportion of adults returning from the sea and can, at best, produce marginal increases in adult numbers in roughly inverse proportion to marine mortality rate. In the extreme case, for example, the return on hatchery work will be near-zero if marine mortality rate approaches 100%.

The single operational difficulty associated with hatchery work is that capturing adults in well-stocked systems is relatively straightforward but, in depleted streams, capturing a large proportion of low adult numbers is not. From a practical point of view, the main risks of hatchery intervention are high mortality rate due to operational failings or total mortality resulting from catastrophic technical failure.

In addition, there are other important but less tangible risks associated with traditional hatchery work including the detrimental effects of:

- Inappropriate breeding patterns or mate matching imposed in artificial matings.
- Atypical temperature regimes as they affect egg incubation times and hatch dates: mismatch of hatchery fry development with the natural stream temperature regimes to which they are returned.
- The inadvertent return of hatchery progeny to inappropriate (non-native) locations within catchments.

These and other related issues have been considered in detail by Youngson (2007) in the context of salmon management, although most of the issues will pertain equally to sea trout.

5.1.4 A rationale for supportive breeding

In the context of restoration, traditional hatchery work may be viewed as the simplest form of supportive breeding although, in practice, the concept of supportive breeding has seldom or never been implicit in traditional hatchery rationales. Supportive breeding is therefore a more explicit concept with a precisely expressed aim. Supportive breeding makes use of a set of procedures that include hatchery work but also take advantage of other forms of fish culture to protect and/or amplify residual fish populations. A supportive breeding programme for restoration must:

- Use native fish from the targeted breeding population in order to avoid “outbreeding depression” i.e. the negative effects on progeny fitness associated with the crossing of dissimilar, incompatible individuals. An understanding is required of the structuring of the stock in the river of concern into breeding populations, along with a capacity to determine if candidate brood fish are native. In the particular context of the west coast fisheries, crucial difficulties are associated with the inclusion of unrecognised first-generation escapees from aquaculture or second-generation aquaculture escapees, or their hybrids with wild fish, among hatchery broodstock. This problem can be partially resolved by scoring external characteristics (including scale reading)

for evidence of aquaculture origin or by consideration of where and when potential brood fish are captured. Provenance can be established with greater precision by DNA testing where there is genetic baseline information on the population.

- Contribute more individuals to the next generation than are lost by the removal of breeders to produce those individuals. At the same time, however, the scope for unnatural selective mortality and non-genetic developmental changes that reduce fitness (Box VI) should be minimized and the greatest possible scope given for natural selective mortality to operate. The latter case can be promoted by stocking early in the life cycle at the eyed ova or unfed fry stage.
- Maintain high levels of genetic variability in order to avoid “inbreeding” effects associated with low numbers of broodstock.

In the context of the second requirement, above, the greatest potential gain can be realised by capturing older juveniles and rearing these to maturity. The advantage of capturing and rearing juveniles arises since many of these fish will otherwise die before reaching breeding age. The down side is a reduction in natural selective mortality and the high economic costs of captive production. In principle, the recruitment gain from supportive breeding could be several fold using captured adults as broodstock and several tens of fold rearing captured juveniles on to the adult stage. The latter case, however, is associated with increased risks of inbreeding, loss of genetic diversity and changed patterns of selective mortality. In each application, the balance of advantage will depend on the starting condition of the targeted population and on the design of the breeding programme.

Inbreeding and the loss of genetic diversity will become increasingly problematic as:

- The number of brood fish used relative to the number of wild breeders decreases.
- The number of times the same individuals are used for breeding increases.
- The relative proportion of stocked to wild juveniles increases.

Inbreeding can be minimised by:

- Using large numbers of breeders.
- Crossing each male and female with 5 or more other fish.
- Using each brood fish only once.
- Limiting a programme to a relatively short period of a few years.

However, in particular circumstances there may be a case for acting outside these guidelines. Optimising the approach taken will be conditioned by the specific circumstances surrounding each restoration programme and it may be necessary to seek specialist advice in breeding programme design.

5.1.5 Gene-banking

Gene-banking aims to preserve breeding populations by bringing all or part of the life-cycle into culture and attempting to maintain adaptive character and capacity intact. For salmonids, only living gene-banks are possible because salmonid eggs cannot be preserved (although sperm can be cryopreserved, as for mammals).

The objective in gene-banking, used as a temporary method of stopping a population from going extinct, is to minimise genetic change during the banked period. This is achieved by maximising the numbers of breeders kept in culture (general recommendations are to keep a minimum of 25 males and 25 females), reducing mortality and minimising the number of

generations in culture. The facility should preferably be quarantined and located on a protected water supply to reduce the risk of infectious disease. To further reduce this risk, gene banks should be duplicated in separate locations.

5.1.6 The case of extinct populations

Restoring any breeding population represents a substantial challenge but the science of restoring lost salmon or trout populations is poorly developed. Numerous attempts have been made over the last century to restore or establish new populations but most have been unsuccessful. What little evidence is available suggests that restoration will be easier in some situations than in others, depending on species, the type of population to be restored, and the location in question. Understanding of these issues will be enhanced if future restoration programmes are properly designed and monitored.

5.1.7 Natural re-colonisation

Salmon and trout populations were naturally restored to northern Europe following the last ice age. This demonstrates that, in some circumstances, restoration can be expected to result from natural dispersion. Although the pace of natural dispersion may transcend management time frames, in some cases natural restoration has occurred on time scales that are much shorter e.g. years or decades. For example, stretches of many tributaries of the River Tweed have been opened up by the removal of dams and weirs and natural re-colonisation has proved a rapid and cost-effective means of restoring fish populations to these areas (R. Campbell, pers. comm.).

Although most salmon and sea trout home with high precision, some fish stray and some of these are likely to spawn opportunistically in stream locations that are vacant or under-used. Enhanced dispersion can be expected to occur where physical barriers to fish movement are lacking and distances between the spawning areas of populations are relatively small. This is suggested both by observations of straying among river systems as well as of recolonisation of river systems whose stocks have become extinct. Most instances have been recorded where the restored rivers have only been a few or few tens of kilometres from other inhabited river systems. It may be more likely where potential source populations are healthy; and it may be more likely for sea trout populations than for salmon, given the greater propensity for introductions to establish new populations of the former.

In management terms, the particular merit of natural recolonisation is that strayers are self-selected and inherently disposed to occupy and breed in the new habitat. On this basis, they should be used preferentially as the basis for a supportive breeding programme on the assumption that the performance of their progeny will match or exceed that of other non-native fish.

5.1.8 The introduction of non-native fish

Any restoration programme based on the introduction of non-native fish will fundamentally differ from a programme based on natural recolonisation - the selection of fish will be by the fisheries manager. Identifying those source populations that are most similarly adapted to the lost population represents an insuperable challenge because local adaptation encompasses various inherited traits in eggs, juveniles and adults, and any one of these traits may be the key to the adaptive success of a non-native population in the new environment. Unfortunately, while we have examples where traits are likely to be involved in local adaptation, we have no understanding of all the traits that contribute to adaptation in different contexts.

In the absence of this understanding, the recommendation is to use source populations that:

- Are geographically close to the location to which fish are to be introduced.
- Come from a stream environment that is similar.
- Show appropriate or matching biological traits.
- Come from the same evolutionary lineage, when this can be determined.

5.1.9 Legislation relating to the introduction of fish in Scotland

Legislation which regulates the introduction (i.e. stocking) of all species of freshwater fish within Scotland came into force on 1 August 2008. Section 35 of the Aquaculture and Fisheries (Scotland) Act 2007 inserts a new section 33A into the Salmon and Freshwater Fisheries (Consolidation) (Scotland) Act 2003, making it an offence for any person to intentionally introduce any live fish or spawn of any fish into inland waters, or possess such with the intention of introduction without previous written agreement of the appropriate authority. The principal aim of the new provisions is to protect native biodiversity from the consequences of introductions of non-native fish into Scottish freshwaters. They will also assist in delivering sustainable fisheries and will provide necessary records to assist in fish disease prevention and control.

6. SELECTING AND PRIORITISING RESTORATION ACTIONS

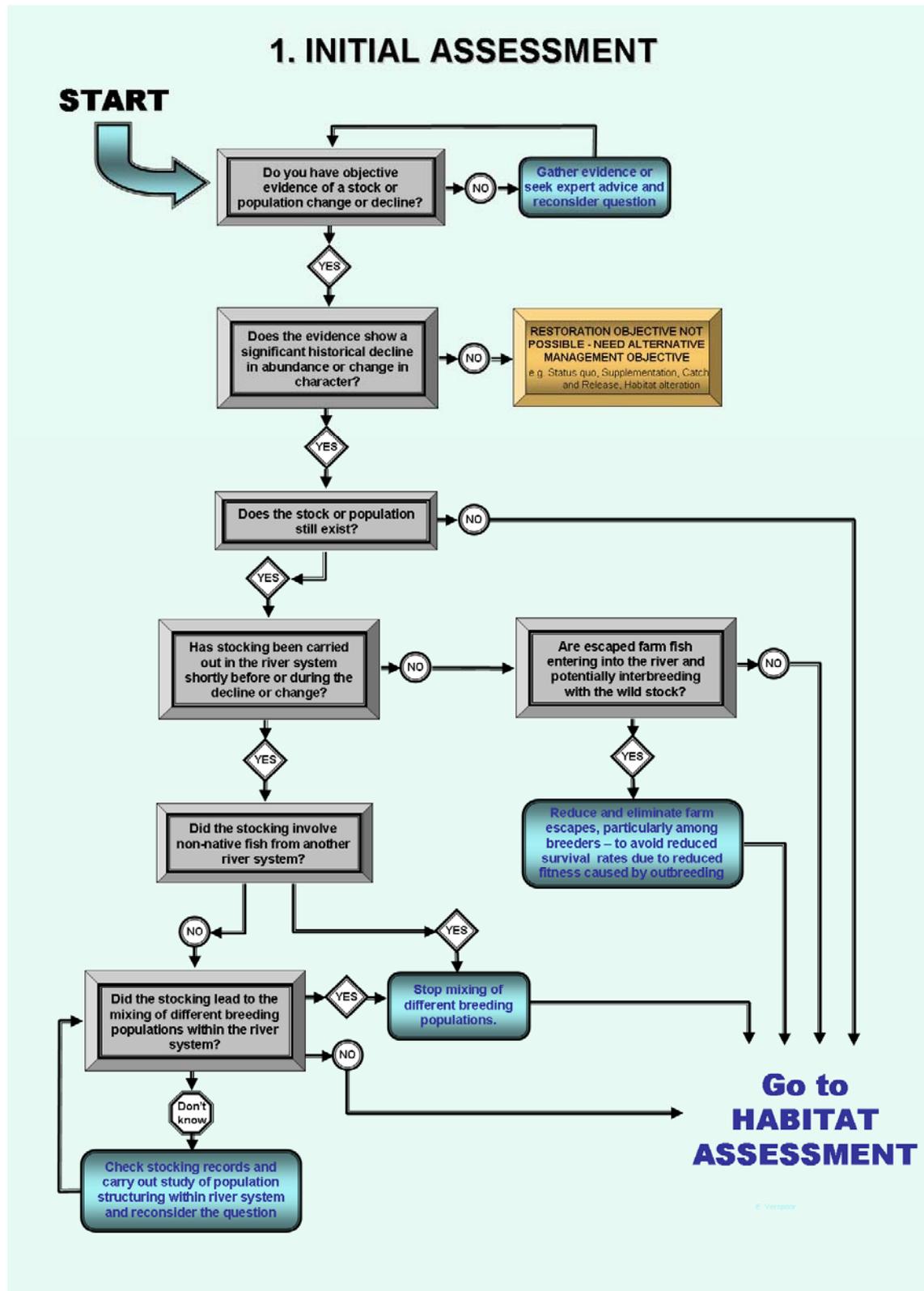
As Leo Tolstoy states at the start of *Anna Karenina*, “Happy families are all alike; every unhappy family is unhappy in its own way”. Using this as a metaphor in the context of depleted salmon or sea trout stocks, it is clear that there need not be a single cause or a universal solution to fishery problems that present in the same way. To develop a management response that is well-matched to the specifics of the situation to be addressed require parallel considerations of:

- the potential causes of failure or poor performance,
- possible management options
- the need for supporting information

The decision key in Boxes VII – IX demonstrates this process via three flow charts.

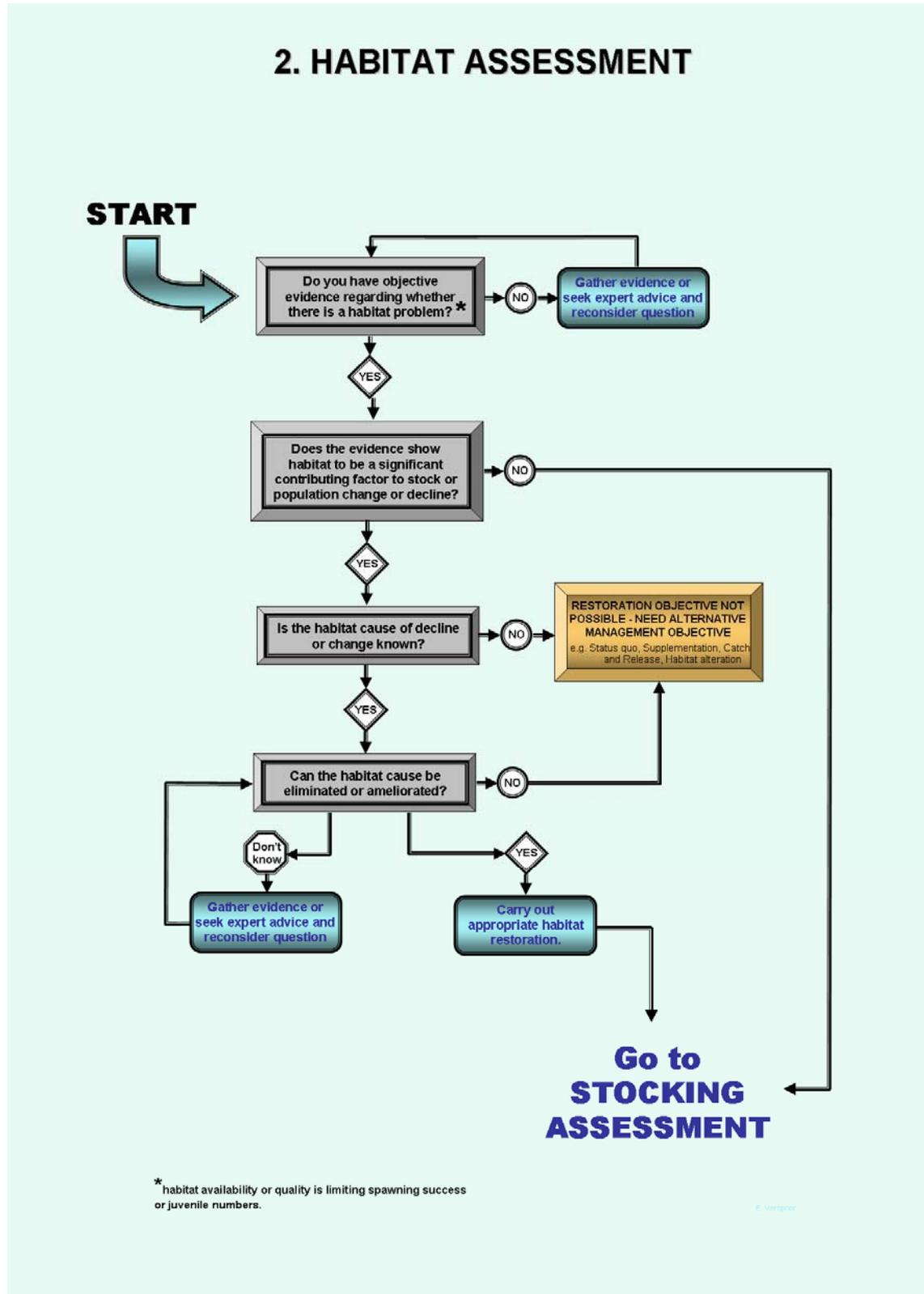
BOX VII

Decision key: 1. Initial assessment



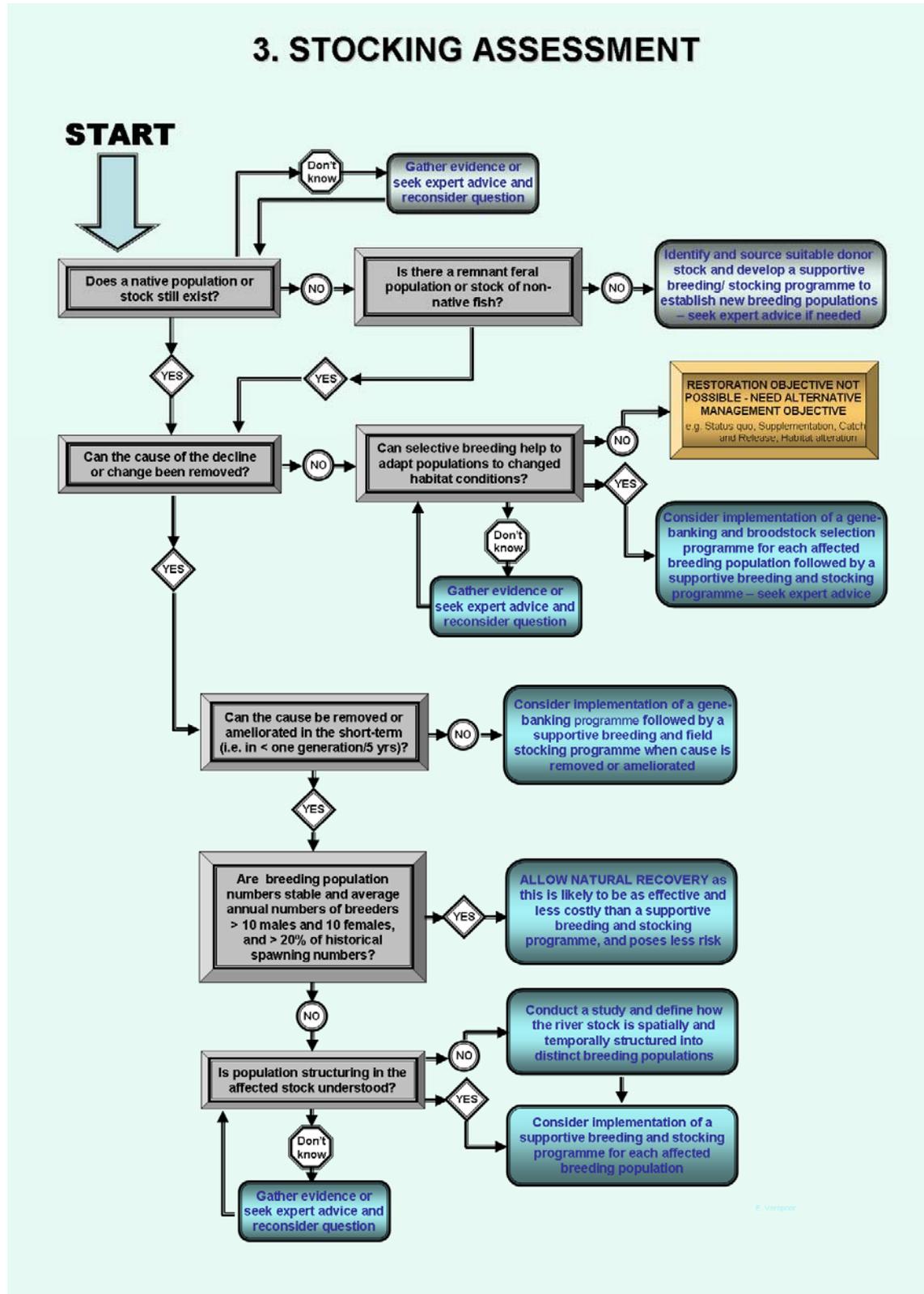
BOX VIII

Decision key: 2. Habitat assessment



BOX IX

Decision key: 3. Stocking assessment



7. MONITORING AND EVALUATION OF OUTCOMES

Any restoration project should include monitoring and evaluation in order to provide more extensive information for future fisheries management. From a strictly scientific point of view, there is no point in undertaking remedial work on habitat or supportive work on fish populations if it will not be possible to assess the outcome. Fishery managers may not feel so strictly bound by this requirement. However, it is also necessary to consider the same point on purely economic grounds because a robust view of the degree of success achieved by any management action will:

- Inform cost-benefit appraisal of repeat exercises.
- Indicate the potential for the application of similar measures to other locations.
- Allow informed re-assessment of alternative management options from a cost-benefit point of view.

7.1 Developing a monitoring and evaluation plan

The effects of restoration and recovery of rivers are complex and long-term. Assessing improvements to habitat availability is feasible based on physical measurements alone. Demonstrating that these or any other works affect fisheries is a much harder task because of the innate variability of all measures of fish production and abundance. Monitoring should be conceived during the planning phase and guided by a series of predetermined criteria and checklists. Effective monitoring and assessment programmes are expensive. Nevertheless, project sponsors, funders and fishery managers should consider the requirement for adequate monitoring and establish standardized monitoring and assessment guidelines using a suite of predetermined indicators within appropriate timeframes. In an effort to reduce costs, a pulsed monitoring strategy that consists of short term (3-5 years) high intensity studies separated by longer periods (10-15 years) of low intensity data collection may be an effective means of implementing an informative programme at reasonable cost.

Linked to monitoring is adaptive management. Even the best plans, designs and standards of implementation will result in unforeseen problems. Consequently, most restoration efforts will require some form of mid-course adjustment.

Ideally, a monitoring and evaluation plan should be developed in conjunction with the original process of developing a restoration plan. A checklist for the development of a sound plan has been suggested by the National Research Council (NRC, 1992) and includes the following elements:

- Clear goals and objectives that provide the basis of science-based investigation
- Appropriate allocation of resources for data collection, interpretation and analysis.
- Quality assurance procedures and independent peer review.
- Flexibility that allows modifications where changes in conditions or new information suggests the need.

Project evaluation is necessarily linked to the results of monitoring and involves a wide range of possible approaches. It is intended to determine whether restoration has achieved the different goals of a project and may involve the structure and function of habitats or the performance of different species or fisheries. Depending on local circumstances, the time scale involved may range from months to years. Consequently, evaluation may require a management commitment significantly longer than the restoration programme.

8. CONCLUSIONS

Over the past 20 years or more, substantial reductions have occurred in the abundance of Atlantic salmon (Vollestad *et al.*, 2009) and sea trout¹² in many of Scotland's west coast rivers. Both the juvenile and adult stages of both species are affected and the declines are reflected in the performance of fisheries in many rivers and freshwater lochs in the region (Butler and Watt, 2003).

Since the cause(s) of the declines have not been clearly identified, the risk of further, future declines is not known. Similarly, the prospects for spontaneous recovery are unclear but the depressed state of spawning stocks of native fish in many places indicates that a rapid recovery is unlikely.

The decline in fisheries has had substantial regional economic impacts, and drives a strong political will to take action to restore natural stocks of salmon and sea trout to their previous abundance. However, there has also been increasing pressure to improve the economic performance of fisheries on shorter timescales than the underlying biology allows and to intervene without adequate assessment of the known biological and economic risks.

The present report focuses on a number of important and basic concepts in order to generate a range of management options that are likely to be generally applicable from the strategic and operational points of view. Due to their differing biologies, salmon and sea trout have different vulnerabilities to the same types of stressor. In the same general circumstances, therefore, the two species may be impacted in different ways, they may need more or less management support and the support required may be of different kinds. It is clear, therefore, that fishery restoration will require complex multidisciplinary endeavor. In a wider context still, options for restoration may be affected by legislation that deals with a range of other fishery and non-fishery aspects of river management (Appendix I) and liaison with these interests will be essential.

The first priority of restoration management is to identify the most likely cause(s) of fishery declines in order to formulate clear and realistic goals. It is necessary to identify the causative factors for the declines in order to address them or to work around them. If the causative factors are not pinpointed, resources are likely to be misdirected and attempts at restoration are likely to prove futile or even damaging. By contrast, if the primary cause(s) of fishery decline can be identified and resolved, this report shows that the science background is sufficiently well-developed to support development of a matching management strategy for restoration.

Various potential causes of the fishery declines – both historical and contemporary - can be identified but the nature of the actual cause(s) remains unclear and contentious. There is evidence that the primary cause of stock decline lies in some aspect(s) of the marine environment that has declined in quality¹³. Further, the evidence suggests that salmon farming is implicated in the declines in the fisheries due to adverse effects on some aspect of the marine environment. However, catch records indicate that the broader scale fishery declines commenced before salmon farming became established. Moreover, declines in abundance are a feature of many fisheries in other regions that are not obviously affected by

¹² <http://www.frs-scotland.gov.uk/FRS.Web/Uploads/Documents/Coll0102.pdf>

¹³

http://www.marlab.ac.uk/Delivery/Information_resources/information_resources_view_documents.aspx?resourceId=31140&parentId=37&parentName=Reports

salmon aquaculture¹⁴. A number of different adverse causes may therefore be implicated in historical trends for decline and all or some of these effects may now be preventing or impeding recovery.

From a management perspective, it is highly desirable to understand this background. Even in the absence of sufficient understanding, it will still be essential to take a view on the background in order to target restoration resources in a rational manner. It will also be necessary to reach a consensus view among the multiplicity of interests involved because of the fragmentary nature of freshwater fisheries management and the likelihood that any individual management actions will interact across rivers and fisheries.

This report has assessed the options for restoration among the other possibilities for management intervention. However, it is not currently possible to recommend a specific approach, for either salmon or sea trout, because the underlying problem(s) remain undefined.

In conclusion, therefore, there is a need for a scientific assessment of factors affecting marine survival of Atlantic salmon and sea trout within the TWG bioregion. Based on this assessment, restoration may be focused towards appropriate and realistic interim management goals, and the wide range of possible management actions can be refined to provide a set of management scenarios and tools for fisheries managers and biologists which are appropriate, cost effective and scientifically sound. Separate scenarios will be required for salmon and for sea-trout. These scenarios and the set of fisheries management tools will need to be refined by stakeholders based on an assessment of benefits, risks, time-scales and costs in the particular context of each management unit. Overall, a consensus view should be sought that will lead to widespread adoption of compatible actions across management units and fisheries by way of a generalised interim restoration plan. The developing situation should be reviewed regularly, based on marine environmental data collection, feedback from the fisheries and the emerging outcomes of any restoration work.

9. ACKNOWLEDGEMENTS

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¹⁴ http://www.frs-scotland.gov.uk/Delivery/Information_resources/information_resources_view_document.aspx?resourceId=23692&documentId=3150

10. REFERENCES

- Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. (1999) *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish*, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.
- Butler, J.R.A. and Watt, J. (2002). Assessing and managing the impacts of marine salmon farms on wild Atlantic salmon in western Scotland: identifying priority rivers for conservation. In: Derek Mills (ed.) *Salmon at the Edge*. Blackwell Science Ltd.
- Calderwood, W. L. (1930) *Salmon and Sea trout*. Edward Arnold & Co, London. 242 p.
- Garcia de Leaniz, C., Fleming, I. A., Einum, S., Verspoor, E., Jordan, W. C., Consuegra, S., Aubin-Horth, N., Lajus, D., Letcher, B. H., Youngson, A. F., Webb, J. H., Vollestad, L. A., Villanueva, B., Ferguson, A. and Quinn, T. P. (2007) A critical review of adaptive genetic variation in Atlantic salmon: implications for conservation. *Biological Reviews*. 82 (2) 173-211.
- Gjerde, B. (1984) Response to individual selection for age at sexual maturity in Atlantic salmon. *Aquaculture* 38 229-240.
- Jonasson, J. and Gjedrem, T. (1997) Genetic correlation for body weight of Atlantic salmon grilse between fish in sea ranching and land-based farming. *Aquaculture* 157 (3-4) 205-214.
- McGinnity, P., Prodohl, P., Maoileidigh, N. O., Hynes, R., Cotter, D., Baker, N., O'Hea, B. O. and Ferguson, A. (2004) Differential lifetime success and performance of native and non-native Atlantic salmon examined under communal natural conditions. *Journal of Fish Biology* 65 (1) 173-187.
- Menzies, W. J. M (1931) *The Salmon: Its Life Story*. Edinburgh/London, William Blackwood & Sons Ltd. 213p
- NRC (National Research Council) (1992). *Restoration of aquatic ecosystems*. National Academy Press, Washington, D.C..
- Rosgen, D. L. and Lee, H. (1996) *Applied River Morphology*. Silvey; published by Wildland Hydrology Books, 157649US Hwy 160, Pagosa Springs, CO 81147.
- Stewart, D. C., Smith, G. W. and Youngson, A. F. (2002) Tributary-specific variation in timing of return of adult Atlantic salmon (*Salmo salar*) to freshwater. *Canadian Journal of Fisheries and Aquatic Sciences* 59 (2) 276-281.
- Verspoor, E., Stradmeyer, L. and Nielson, J. (Eds.) *The Atlantic Salmon: genetics, conservation and management*. Blackwell Publishing Limited. 500p.
- Vøllestad, L. A., Hirst, D., L'Abbe'e-Lund, J. H., Armstrong, J. D., MacLean, J. C., Youngson, A. F. and N.C. Stenseth (In press). Divergent trends in anadromous salmonid populations in Norwegian and Scottish rivers. *Proc. Roy. Soc. B.* (Available on-line from 24 Dec 08 at Royal Society website).
- Youngson, A. F. (2007). *Hatchery work in support of salmon fisheries*. Scottish Fisheries Research Report No. 65. Fisheries Research Services. Scottish Executive. 21p.

Youngson, A.F , Webb, J.H., Thompson, C.E . and| Knox, D. (1993). Spawning of escaped farmed Atlantic salmon (*Salmo salar*): Hybridization of females with brown trout (*Salmo trutta*). Can. J. Fish. Aquat. Sci. 50: 1986-1990.

11. FURTHER READING

Bryant, M. D. (1995) Pulsed Monitoring for Watershed and Stream Restoration. *Fisheries* 20 (11) 6-13.

Byrne, C. J., Poole, W. R., Dillane, M. G. and Whelan, K. F. (2002) The Irish sea trout enhancement programme: an assessment of the parr stocking programme into the Burrishoole catchment. *Fisheries Management and Ecology* **9**, 329-341.

Egglshaw, H. J., Gardiner, W. R., Shackley, P. E. and Struthers, G. (1984) Principles and Practice of Stocking Streams with Salmon Eggs and Fry. Scottish Fisheries Information Pamphlet Number 10. ISSN 0309-9105.

FRM Ltd (2001) Feasibility Study of the Development of a Salmonid Stock Restoration Support Facility for the West Coast of Scotland. Report prepared for the Atlantic Salmon Trust. 161p.

Giles, N. and Summers, D. *Helping Fish in Lowland Streams*. The Game Conservancy Trust, Fordingbridge, Hampshire. 36p.

Ferguson, A. (2007) Genetic impacts of stocking on indigenous brown trout populations. Science Report SC040071/SR (Prepared for the EA).

Forestry Authority (2000) *Forests and Water Guidelines*, Forestry Commission. 32p.

Harris, G. (1997) The Identification of Cost Effective Stocking Strategies for Atlantic Salmon. A Guidance Manual for Fisheries Managers. R&D Note 361. National Rivers Authority.

Harris, G. and Milner, N. (Eds.) (2006) *Sea trout: biology, conservation and management*. Proceedings of the First International Sea Trout Symposium, Cardiff, July 2004. Blackwell Publishing. 499p.

Hunt, R. L. (1993) *Trout Stream Therapy*. Madison: University of Wisconsin Press. 74p.

Hunter, C. R. (1991) *Better Trout Habitat – a guide to stream restoration and management*. Montana Land Reliance. 320p.

NASCO (2002). *Habitat Protection and Restoration*. Report of a Special Session of NASCO Torshaven, Faroe Islands, June 2002.

Poole, W. R., Bryne, C. J., Dillane, M. G. and Whelan, K. P. (2002) The Irish sea trout programme: a review of broodstock and ova production programmes. *Fisheries Management and Ecology*, **9**, 315-328.

Roni, P. and Quimby, E., (2005) *Monitoring stream and watershed restoration*. American Fisheries Society, Bethesda, Maryland, USA. 330p.

Ward, D., Holmes. N. and Jose, N. (eds) (1994) *The New Rivers and Wildlife Handbook*. Published by the Royal Society for the Protection of Birds, Sandy, Bedfordshire. 426p. ISBN 0 903138 70 0.

White, R. J. (1994). Hatchery versus Wild Salmon. In: A Hard Look at Some Tough Issues. Proceedings of the New England Atlantic Salmon Conference, Danvers, MA, April 22-23, 1994. Silver Quill Books, Camden, Maine. 90-115.

Soulsby, C. (2002) *Managing River Habitats for Fisheries: a guide to best practice*. Published by the Scottish Environment Protection Agency. Stirling. 32p.

Scottish Native Woods (2000) *Restoring and Managing Riparian Woodlands*. Published by Scottish Native Woods, Aberfeldy, Perthshire. 36p. ISBN 0 9529283 2 9.

The Salmon Advisory Committee. Assessment of stocking as a salmon management strategy. Ministry of Agriculture, Fisheries and Food, Scottish Office Agriculture and Fisheries Department and Welsh Office Agriculture Department (1991) 18p.

Waters, T. F. (1995) *Sediment in Streams: Sources, Biological Effects and Control*. Monograph No 7. American Fisheries Society, Bethesda, Maryland, USA. 251p. ISBN 0913235970

Woolsey, S. *et al.*, (2007) A strategy to assess river restoration success. *Freshwater Biology* (52) 752-769.

Copies of these books and papers are held at the Marine Scotland Freshwater Laboratory in Pitlochry.

TABLE I

Rapid visual habitat assessment guide for high gradient streams (adapted from Barbour *et al.*, 1999)

Habitat	Condition Category			
Parameter	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/Available Cover	Greater than 70% of substrate favourable for epifaunal colonisation and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential	40-70% mix of stable habitat; well suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of new material, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
2. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
3. Velocity/Depth Regime	All 4 velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (slow is <0.3 m/s, deep is >0.5m)	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by one velocity/depth regime (usually slow-deep).
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% (20-50% for low-gradient) of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% (50-80% for low-gradient) of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition in pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% (80% for low-gradient) of the bottom changing frequently; pools almost absent due to substantial sediment deposition.

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yrs.) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelised and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelised and disrupted. In stream habitat greatly altered or removed entirely.
7. Frequency of Riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5-7); variety of habitat is key.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7-15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15-25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
8. Bank Stability (score each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has active erosion areas.
9. Bank Vegetative Protection (each bank)	More than 90% of the stream bank surfaces and immediate riparian zone covered by native vegetation, including trees, under story shrubs, or non-woody macrophytes;	70-90% of the stream bank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-	50-70% of the stream bank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble	Less than 50% of the stream bank surfaces covered by vegetation; disruption of stream bank vegetation is very high; vegetation has been removed to 5 cm or less in average stubble height.

Habitat	Condition Category			
Parameter	Optimal	Suboptimal	Marginal	Poor
	vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	half of the potential plant stubble height remaining.	height remaining.	
10. Riparian Vegetative Zone Width (each bank riparian zone)	Width of riparian zone >18 m; human activities (i.e., roadbeds, clear-cuts, lawns, grazing or crops) have not impacted zone.	Width of riparian zone 12-18 m; human activities have impacted zone only minimally.	Width of riparian zone 6-12 m; human activities have impacted zone a great deal.	Width of riparian zone <6 m: little or no riparian vegetation due to human activities.

TABLE II

Rapid visual habitat assessment guide for low gradient streams (adapted from Barbour *et al.*, 1999)

Habitat	Condition Category			
Parameter	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/Available Cover	Greater than 50% of substrate favourable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are <u>U</u> new fall and <u>U</u> transient).	30-50% mix of stable habitat; well suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of new material, but not yet prepared for colonization.	10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 10% stable habitat; lack of habitat is obvious; suitable substrate unstable or lacking.
2. Pool Substrate Characterization	Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat; no submerged vegetation.	Hard-pan clay or bedrock; no root mat or vegetation.
3. Pool Variability	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present.	Majority of pools large-deep; very few shallow.	Shallow pools much more prevalent than deep pools.	Majority of pools small-shallow or pools absent.
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% <20% for low-gradient	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% (20-50%	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% (50-80% for	Heavy deposits of fine material, increased bar development; more than 50% (80% for low-gradient)

Habitat	Condition Category			
Parameter	Optimal	Suboptimal	Marginal	Poor
	streams) of the bottom affected by sediment deposition.	for low-gradient) of the bottom affected; slight deposition in pools.	low-gradient) of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
6. Channel Alteration	Channelisation or dredging absent or minimal; stream with normal pattern.	Some channelisation present, usually in areas of bridge abutments; evidence of past channelisation, i.e., dredging, (greater than past 20 yrs.) may be present, but recent channelisation is not present.	Channelisation may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelised and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelised and disrupted. In stream habitat greatly altered or removed entirely.
7. Channel Sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line. (Note - channel braiding is considered normal in coastal plains and other low-lying areas. This parameter is not easily rated in these areas.	The bends in the stream increase the stream length 2 to 3 times longer than if it was in a straight line.	The bends in the stream increase the stream length 2 to 1 times longer than if it was in a straight line.	Channel straight; waterway has been channelised for a long distance.

Habitat	Condition Category			
Parameter	Optimal	Suboptimal	Marginal	Poor
8. Bank Stability (each bank)	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosion features.
9. Bank Vegetative Protection (each bank)	More than 90% of the stream bank surfaces and immediate riparian zone covered by native vegetation, including trees, under story shrubs, or non-woody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the stream bank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the stream bank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the stream bank surfaces covered by vegetation; disruption of stream bank vegetation is very high; vegetation has been removed to 5 cm or less in average stubble height.
10. Riparian Vegetative Zone Width (each bank riparian zone)	Width of riparian zone >18 m; human activities (i.e., roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 m; human activities have impacted zone only minimally.	Width of riparian zone 6-12 m; human activities have impacted zone a great deal.	Width of riparian zone <6 m; little or no riparian vegetation due to human activities

TABLE III

Common fishery management responses to degradation of river habitats and their potential impacts

Problem	Action	Target impacts	Non-target impacts
Degradation of spawning areas caused by deposition of fine sediments.	Gravel cleaning ^{15 16}	Removal or reduction in proportion of fine sediment and increased rates of egg survival.	De-stabilisation of spawning gravel, liberation of fine sediments and degradation of habitats further downstream.
Loss of spawning gravel caused e.g. by clear-water erosion.	Rock, gabion or log-sill weirs ¹⁷	Retained gravel provides spawning habitat.	Potential instability of structures, failure to retain sediment of suitable grade, blockage of fish movements at low flows and increased rates of bed and bank erosion.
Natural inputs of spawning-calibre gravel reduced by dams or gravel abstraction.	Material added directly to the channel ¹⁷	Increase in quantity and distribution of spawning areas.	Inundation of riverbed features. Retained materials do not constitute spawning grade gravel.
Transitory physical barriers to migration.	Removal of debris dams ¹⁷	Free migration; reduced risk of predation.	Temporary reductions in streambed stability; loss of spawning gravels; loss of fish habitat associated with woody debris; release of fine sediment.
Poorly designed culverts resulting in low depth and high velocity of stream flow and perched or elevated designs.	Replacement or modification using fish-friendly design ^{17, 18}	Access to habitat for migratory fish.	None.
Dams without adequate bypass provision that obstruct fish migration.	Partial or complete removal or installation of effective by-pass arrangements ^{17, 17, 18}	Access to habitat for migratory fish. Access to areas (e.g. lochs) that may have potential to support a fishery.	Temporary effects include sediment release and loss of (artificial) pool habitat. Associated intakes may require additional screening.
Loss of channel features; reduced complexity of juvenile habitat.	Placement of rocks, boulders or wood (LWD) or wooden structures (e.g. half-logs, Christmas trees, floating log	Restoration of habitat condition for juveniles and/ or adults.	Unpredicted channel response, erosion and/or fine sediment accumulation. Rocks may be

¹⁵ http://www.sepa.org.uk/water/habitat_enhancement/best_practice_guidance.aspx#Managing

¹⁶ http://www.sepa.org.uk/water/habitat_enhancement/best_practice_guidance.aspx#Farming

¹⁷ Notes for Guidance on the provision of fish passes and screens for the safe passage of salmon. Published by SOAFD, Edinburgh, 1995.

¹⁸ www.sepa.org.uk/water/regulations/guidance/idoc.ashx?docid=813bf507-416f-4186-96d1-

	covers, log deflectors and weirs) into channel. Boulders placed in base of channel provide cover, scour holes and areas of reduced velocity ¹⁷ .		mobilised under high flow conditions; boulders may be undercut or buried.
Canalisation, bank and flood defences causing loss of channel features, isolation of floodplain, increased bed erosion and/or coarsening of channel bed sediments.	Reduce maintenance or abandon banks. Breach or remove levees ¹⁹ .	Increase in channel feature complexity and increase in fish holding and production capacity	Unpredictable channel response.
Water-use activities that result in extreme flow rates or inappropriate flow regimes.	Delivery of appropriate hands-off and compensation flows ²⁰ .	Increase in habitat condition for both juvenile and adult fish. Increase in access to habitat for migrating adults.	Flow management may lead to changes in channel form via alteration of sediment dynamics.
Land-use activities that result in episodes of extreme high water temperature.	Restoration of riparian herbage and tree cover, maintenance of flows, where applicable ^{20, 22} .	Reduction in levels of thermal stress including lethal stress; tree roots and overhangs also offer shelter and refuge, including refuge for large fish in small streams.	None – although excessive shading is adverse for juvenile fish.
Loss of riverbank integrity due to overgrazing, poaching by livestock, machinery routes or forestry.	Reduction of rates of riparian grazing and stock access to water via fencing and grazing management ^{20, 20} . Boulder and log armouring, brush matting, geo-textiling, riprap, Christmas tree revetments, grazing reduction (via fencing), staking and planting of deciduous cuttings ('live stakes') and rooted tree stock ²⁰ . Application of appropriate forestry management protocols ²¹	Stabilisation preceding restoration of equilibrium conditions in channel conformation and sediment dynamics.	None. Unpredictable channel response. None.

¹⁹ http://www.sepa.org.uk/water/habitat_enhancement/best_practice_guidance.aspx#Managing

²⁰ http://www.sepa.org.uk/water/habitat_enhancement/best_practice_guidance.aspx#Farming

²¹ [http://www.forestry.gov.uk/pdf/FCGL002.pdf/\\$FILE/FCGL002.pdf](http://www.forestry.gov.uk/pdf/FCGL002.pdf/$FILE/FCGL002.pdf)

Over-shading by native trees causing suppression of under-storey vegetation and reduced growth of stream plants to detriment of fish production	Selective coppicing ^{a, 22}	Reduction of dense shading to restore stream production, bank integrity and provide close cover for fish.	None.
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²² [http://www.forestry.gov.uk/pdf/FCGL002.pdf/\\$FILE/FCGL002.pdf](http://www.forestry.gov.uk/pdf/FCGL002.pdf/$FILE/FCGL002.pdf)

APPENDIX I

Advice and regulation

Before commencing fishery restoration work it is important to seek expert advice and be cognizant of relevant legislation. Any works, including fishery restoration efforts, in or around rivers and other water bodies in Scotland are subject to statutory regulation. Failure to take expert advice, consult fully with other stakeholder interests or comply with the legislation may lead to inappropriate actions, delays in implementation and, in some cases, the possibility of prosecution. Some relevant organizations are listed below.

- **Scottish Environmental Protection Agency (SEPA)** is the principal environmental regulator responsible for licensing of discharges to air, water and land. SEPA are also responsible for the implementation of the Water Framework Directive (WFD) and through this the Controlled Activities Regulations (CAR) and the development of Area River Basin Management Plans.

Contacts and advisory documents can be found at:

<http://www.sepa.org.uk/default.aspx>

http://www.sepa.org.uk/water/habitat_enhancement/best_practice_guidance.aspx

http://www.sepa.org.uk/water/river_basin_planning/restoration_fund.aspx

- **Scottish Natural Heritage (SNH)** has responsibility for natural heritage issues and the implementation of the Habitats Directive and the Species Directive.

Contacts and advisory documents can be found at:

<http://www.snh.org.uk/>

- **Local Authorities** are responsible for local planning issues.

Contacts and advisory documents can be found at:

http://www.direct.gov.uk/en/DI1/Directories/DevolvedAdministrations/DG_4003604

- **District Salmon Fishery Boards (DSFB)** are responsible for the protection of salmon and sea trout fisheries. DSFBs are also responsible for regulating introductions of salmon and sea trout in their districts under the Aquaculture and Fisheries (Scotland) Act 2007.

Contacts and advisory documents can be found at:

<http://www.asfb.org.uk/asfb/asfb.asp>

- **Marine Scotland Freshwater Laboratory** is responsible for monitoring the status of migratory and freshwater fish populations in Scotland and conducts research in support of scientific advice provided to the Scottish Government in order to help protect fish and promote the development of sustainable fisheries. The Laboratory is also responsible for regulating introductions of fish in freshwater under the Aquaculture and Fisheries (Scotland) Act 2007.

Contacts and further information can be found at:

<http://www.frs-scotland.gov.uk/>

<http://www.scotland.gov.uk/About/Directorates/Wealthier-and-Fairer/marine-scotland>

- **Rivers and Fishery Trusts of Scotland (RAFTS)**

Contacts and advisory documents can be found at:

<http://www.rafts.org.uk/>

- **Scottish Water**

Contacts and advisory documents can be found at:

http://www.scottishwater.co.uk/portal/page/portal/SWE_PGP_HOME/SWE_PGE_HOME

- **The Atlantic Salmon Trust** is a UK based organisation with Atlantic wide interests which champions the wild salmon and sea trout. The Trust addresses concerns many people have about the decline of fish stocks, as well as the need for practical research into the problems that have become apparent.

Contacts and advisory documents can be found at:

<http://www.atlanticsalmontrust.org/>