

Scottish Marine and Freshwater Science

Volume 6 Number 1

Loch Linnhe and Firth of Lorn
MASTS Case Study Workshop Report

B Berx, A Gallego, M Heath and
The MASTS Community

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Scottish Marine and Freshwater Science Vol 6 No 1

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Published by Marine Scotland Science

DOI: 10.7489/1539-1

ISSN: 2043-7722

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This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science and collaborators from the MASTS community.

Loch Linnhe and Firth of Lorn

MASTS Case Study Workshop Report

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Marine Scotland Science, Marine Laboratory
375 Victoria Road, Aberdeen, AB11 9DB

Executive Summary

In February 2014, the Dynamics and Properties of Marine Systems (DPMS) Theme of the Marine Alliance for Science and Technology for Scotland (MASTS) organised a case study workshop on the Loch Linnhe and Firth of Lorn (LL&FL) system. Loch Linnhe is one of the largest sea lochs on the west coast of Scotland, and the Firth of Lorn provides a connection to the open ocean. During the workshop, a review of the current knowledge of LL&FL was undertaken in three subject areas: the physical environment, the aquatic ecosystem and the management and use. This review also identified a number of knowledge gaps and potential collaborations to address these. This report provides an overview of these discussions. A more comprehensive, scientific review of our knowledge of the LL&FL system will be published in the near-future.

Introduction

Loch Linnhe is one of the largest sea lochs on Scotland's west coast, stretching approximately 60 km in a SW-NE direction. The loch receives large freshwater inputs from the surrounding catchments and connects to the open ocean at the SW end via the Sound of Mull and Firth of Lorn (Figure 1). The loch itself can be regarded as having a fjordic character where interactions between meteorological forcing, freshwater input and sea bed topography control the circulation.

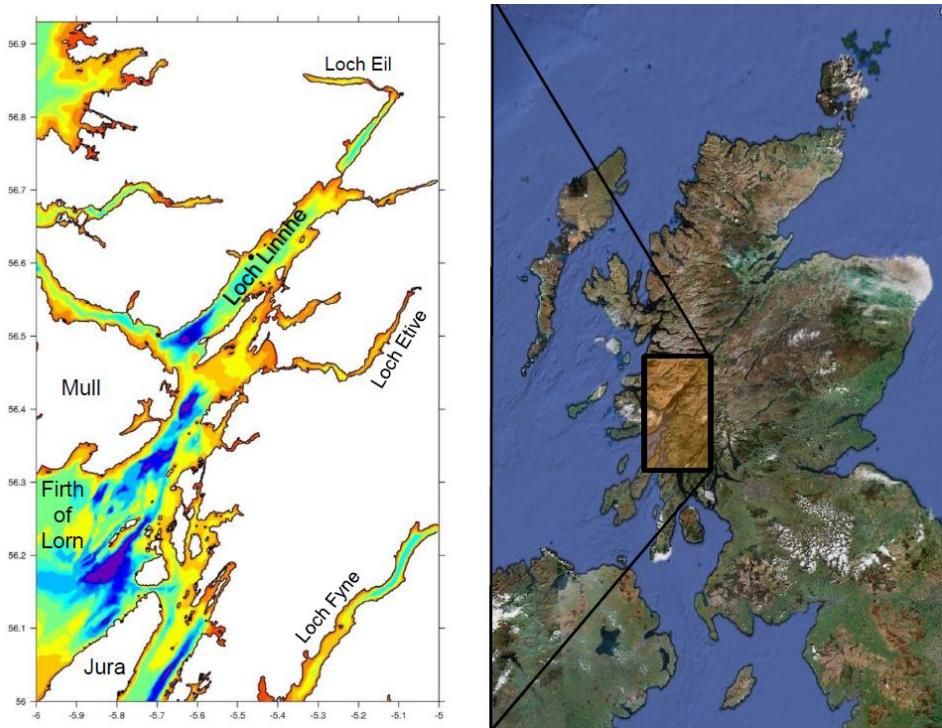


Figure 1: Map of Loch Linnhe and the Firth of Lorn (courtesy of A. Dale, SAMS).

Over the past decades, the region has been the object of a number of research and observational programs by the marine research community. This interest has been driven in more recent years by research around aquaculture, with studies focusing on sea lice dispersal management (Salama et al., 2013; Salama & Rabe, 2013), plankton ecology (Heath, 1995) and relevant numerical modelling. Only a limited number of papers have reported on the physical oceanography of the region (Allen & Simpson, 1998a, 1998b). The region is, however, relatively data rich with several studies having collected time series observations of circulation, temperature and salinity. To date, most analyses have focused on the upper loch, rather than the more complex system including the main and other side lochs. Hydrodynamic modelling of the system has also been pursued by a number of researchers and is currently an area of active development. However, the existing scientific literature still lacks a complete review of the dynamics and variability of Loch Linnhe and the Firth of Lorn.

From a stakeholder perspective, flood forecasting and aquaculture-related topics remain of high importance but wider issues relating to marine spatial planning are moving up the agenda. In the context of new research developments, now is an ideal time to consider an integration of knowledge across all research fields: from physical oceanography to water quality and biology. The Scottish Government supports industry led targets for the expansion of finfish and shellfish aquaculture across the country. It is, therefore, likely that the assessment of aquaculture

potential and marine planning in the region will become important drivers for research.

On 25-26 February 2014, members of MASTS's DPMS Research Theme attended a workshop in Crieff to review our current knowledge of the LL&FL system and discuss areas of research required to address the challenges mentioned above. Although originally focussed on Loch Linnhe, it was decided to expand the spatial coverage of the workshop to include the Firth of Lorn because of the linkages between the two systems, the fact that considerable data also exist for the Firth of Lorn and because of the interests of the workshop participants.

This report will provide an overview of these discussions. The agenda of the meeting and list of attendees have been included in Appendix 1 and 2, respectively. An overview of related websites and literature published as peer-review manuscripts and internal reports is included in Appendix 3.

The Loch Linnhe System: What do we know about it?

Three invited speakers provided a background to the physical environment (Dr Andy Dale), the aquatic ecosystem (Prof Mike Heath) and the management (Dr Ted Schlicke) of the Loch Linnhe system. These overviews were supplemented by contributed presentations from other attendees. All contributions have been listed on the agenda. A brief overview will follow, and there is a plan to publish a more comprehensive report in the near future.

The Physical Environment

Loch Linnhe has a fjordic nature where sea bed topography (with shallow sills), freshwater input and meteorological forcing drive the circulation. Freshwater inflows are a key control of the dynamics of the Loch Linnhe system through determining surface stratification and controlling deep water renewal. Pulsed releases of freshwater from Upper Loch Linnhe through the Corran Narrows travel along the northern side out of the loch (due to rotation) as a bore. Understanding entrainment and mixing is key to understanding the dynamics of the inflows of coastal water and deep-water renewal. Hydrodynamic models of the area perform reasonably well, although the accurate representation of salinity gradients, exchange at the open boundary, and local topographic steering of winds are important processes which need to be included in the models. Circulation patterns in the Firth of Lorn have been less well studied but freshwater influence is apparent in the upper and central parts of the Firth. Towards the seaward end Atlantic and Irish Sea origin waters

become more influential. There are also important oceanographic features such as the Corryvreckan tidal race which leads to pulses of water exchange between the Firth of Lorn and the Sound of Jura.

The Aquatic Ecosystem

Studies have been conducted in the upper parts of the Loch into nutrients and algal production (Grantham, 1981). More intense ecosystem studies were conducted in the early 1990s. Recent ecosystem research in LL&FL has largely focused on quantifying the potential impact of anthropogenic contributions to the nutrient cycle (from local factories and fish farms). The upper and outer loch can be considered distinct in their biogeography: significant differences have been observed in the nutrient cycles and plankton communities.

Benthic surveys have been limited in spatial extent within Loch Linnhe (focused on Loch Creran), although a survey of the Firth of Lorn has recently been completed. Several species of marine mega-fauna, including porpoise and seals, are often recorded in the Firth of Lorn but become less frequent moving up the loch. There is a Special Area of Conservation (SAC) on Lismore for seals. Research at SAMS suggests there is a link between state of tide at the Great Race (Corryvreckan) and its use as a foraging site by seabirds and harbour porpoises (Andy Dale, SAMS).

Several ecosystem models have been developed for the area, focusing on representing the nutrient cycle through the loch and the contribution of fish farms and effluent to the nutrient budget (Ross *et al*, 1993). More recently, connectivity modelling has been used to assess the potential of sea lice transmission and the impact of additional habitat provision from man-made structures (such as man-made reefs or local wind farm developments).

Uses and Management

The management of LL&FL focuses on supporting local aquaculture developments and regulating the disposal of waste via the system (industrial effluent and waste water). There are also local fisheries management issues, and a number of Marine Protected Areas (MPAs) have been created in the region. Several legislative directives drive management initiatives in the region, focusing on reducing adverse impacts to the system from human pressures.

In total, there are approximately 20 active salmonid farms in the LL&FL region divided in to 2 disease management areas (or three industry-planned farm

management areas). Sea lice (*Lepeophtheirus salmonis*) are one of the industry's main parasite challenges. Recently, a large multi-disciplinary project has focused on quantifying potential farm connectivity and sea lice dispersal within the system. Several flooding events have occurred in the upper loch and new methods for flood forecasting have been developed for the region.

A Meta-Data Catalogue for LL&FL

Presentations in the first two sessions of the workshop highlighted that LL&FL is a relatively data-rich region. As datasets are held by a number of different institutions/individuals, a meta-data catalogue of these data would be beneficial. An initial listing was drafted during the workshop (see Table 1 below) although attendees agreed that a more thorough overview should be collected after the meeting.

One particular application of data in LL&FL could be to provide a test-bed of ecosystem function assessment criteria: if ecosystem assessment tools do not work for relatively confined, data-rich ecosystems such as LL&FL, then can they be expected to work in larger regional assessments (such as North Sea scale)? However, LL&FL are clearly not fully self-contained systems and so their status will be linked to that of the wider Irish Sea and West of Scotland. The degree to which the LL&FL systems could be evaluated in isolation requires further discussion.

Table 1

Initial listing of available data within LL&FL.

Physical Environment	
Bathymetry	<ul style="list-style-type: none"> Observed quantities unlikely to change (change typically over a decadal scale). The outer part of Firth of Lorn well surveyed (INIS Hydro and MAREMAP), although substrate type not well known due to lower data quality. LL to be surveyed soon. Information on sill depths and side lochs from the Sea Loch Catalogue (Edwards & Sharples, 1986) (recent update by Marine Scotland Science (MSS) from digitised charts)
Freshwater Inputs (nutrients/suspended matter)	<ul style="list-style-type: none"> Scottish Environment Protection Agency (SEPA) have river gauge observations Catchment models: grid2grid model (2007-2012; MSS), eHYPE (1980-2012; SMHI; available online) FW temperature data - FFL data/Strontium data. Marine Optics data on organic and inorganic suspended particulates and coloured dissolved organic matter (U. Strathclyde, CEFAS and SEPA)
Temperature/Salinity	<ul style="list-style-type: none"> Survey data from MSS, SEPA and SAMS Tiree buoy oceanographic mooring (future uncertain). Glider observations from a number of deployments in LL&FL
Atmospheric inputs (hydrodynamic modelling)	<ul style="list-style-type: none"> NOC have the mesoscale model outputs. SAMS has model outputs from WRF simulation; and Met Office from the Unified Model. Weather station data from a number of field campaigns (MSS and SAMS).
Tides	<ul style="list-style-type: none"> Tidal diamonds and tidal models (e.g. OTPS) Number of current meter deployments (MSS/SAMS)
Circulation	<ul style="list-style-type: none"> Existing models based on POLCOMS, FVCOM case study, and several SAMS FVCOM models Tidal asymmetry for predicting sediment movement, used in Clyde by SEPA.
Aquatic Ecosystem	
Chemistry	<ul style="list-style-type: none"> This was a gap in expertise during the workshop (esp. pore water chemistry, speciation etc.). Observations of contaminants, nitrogen, phosphate and silicate mainly. Gather relevant data after workshop (Tim Brand, SAMS) Paul Tett has some digitised 1970's Loch Creran data available (Keystones?) 100% PP and ~90% nutrient data digitised.
Plankton	<ul style="list-style-type: none"> <i>Microplankton</i> (anything that does not have an embryo in its life cycle – Paul Tett). Extensive data from Creran, some from Etive and Spelve but a lot less from further up the loch system. Taxonomic data from U Strathclyde. Food Standards Agency collects water samples every fortnight for toxic algae monitoring but the non-toxic species are not routinely counted. <i>Zooplankton</i> – 1991 Loch Linnhe Project (LLP) and SAMS has a big archive from last couple of years and a lot of taxonomic analysis of Etive by Pond and Brierley. MSS have taken samples for sea lice which are still held. Need to collect annual and multi annual data

	<p>sets. CPR survey data further offshore.</p> <ul style="list-style-type: none"> • <i>Ichyoplankton</i> – some data from 1990 and SAMS jellyfish surveys, recent SAMS report on the ichthyoplankton suggests Firth of Lorn is not so important as a spawning area but acts as a nursery to larvae which are transported in from further offshore (this is in line with earlier suggestions in the literature). Mike Heath has a large collection of otoliths somewhere (1970's Da Silva looking at juvenile herring in loch Creran). • <i>Jellyfish</i> monitored over two years (C. Fox, Davidson, & Beveridge, 2014) • Distribution of <i>cirripede larvae</i> has been studied in the Firth of Lorn (Raeanne Miller, PhD, SAMS).
Benthos	<ul style="list-style-type: none"> • Not a huge amount available for the main loch, depth restrictions on benthic surveys on the outer loch (contact Dave Hughes at SAMS) • LLP 1991 - infaunal biomass data from core samples (muddy sites only). Some rock/sand samples from 1991 but these have been lost. • British Geological Survey has conducted inshore surveys (MSS may have some LL data). SEPA – grab samples, benthos report document/s to be uploaded (possibly for successive years). Quite a lot of benthic surveys conducted in the wider Firth of Lorn by Scottish Natural Heritage (SNH) in relation to Marine Protected Areas. SAC sites in the Firth of Lorn and Loch Creran will need monitoring on a regular basis. • Rocky shore and sandy beach surveys conducted over a number of years at several sites within the Firth of Lorn (Mike Burrows, Clive Fox from SAMS). Autumn beam-trawl surveys at Tralee (2009 onwards)
Fish & Shellfish	<ul style="list-style-type: none"> • Juvenile herring assessment survey up to the mid 1980's. • Data from a number of trawl surveys conducted by SAMS (SMBA as it then was) in the 1980s (John Gordon reports in SMBA Internal Reports series). • Summary of early studies relevant to use of Firth of Lorn by juvenile fish (C. J. Fox & Lappalainen, 2014) Inshore fisheries data on Loch Creran (1960's through to mid-90's?) –now only a single vessel active in this area as far as we know. • No commercial fisheries operating in the LL system, was a spurdog fishery in Loch Etive which is connected to the Firth of Lorn but this was fished out in 70's. • More recent fisheries activity data from Scotmap inshore commercial fisheries shows activity in the Firth of Lorn and Loch Linnhe (mainly crab and lobster pots and Nephrops creeling; Nephrops trawling in outer Firth of Lorn but also some scallop dive activity). • Amateur angling also quite popular in the area and a possible source of data – common skate known to occur in the Sound of Mull, spurdog throughout Firth of Lorn and Loch Etive. Scottish Sea Angling Conservation Network ran a spurdog tagging program in the area. • Salmon – aggregated by region so not specific for each river. • Wild fisheries trust – North, South and West banks of the Linnhe, some association with Lochaber Fisheries Trust. • MSS data on wild fish populations from rod catch information, and tracking reared fish.
Birds	<ul style="list-style-type: none"> • This was a gap in expertise during the workshop.

	<ul style="list-style-type: none"> National ringing survey (Clive Craik at SAMS)
Mammals	<p>Seal data Sea Mammal Research Unit and SNH (not much in way of cetacean activity although increasing numbers of harbour porpoise have been observed by wildlife tour operators in Firth of Lorn in recent years, David Ainsley pers. comm.)</p> <p>Could be supplemented by data holdings at SMRU and MS Licensing (seal shooting)</p>
Uses and Management	
Urban input	<ul style="list-style-type: none"> SEPA has monitoring information on discharges Marina construction/invasive species (Liz Cook, SAMS; Lyndsay Brown, MSS). SAMS have been conducting research into whether marinas form habitat for benthic stages of jellyfish – data have been collected from a number of marinas in the FL (Clive Fox, SAMS). Offshore structures as habitat/stepping stones (Tom Adams, SAMS)
Aquaculture	<ul style="list-style-type: none"> Documented on http://aquaculture.scotland.gov.uk/ website, including monthly biomass/feed and chemical use by individual farm. Sea lice work over the last few years – have trawl data, settlement phase data, Scottish Salmon Producers Organisation data (http://scottishsalmon.co.uk/tag/fish-health-management/), wild captures (http://www.scotland.gov.uk/Topics/marine/Publications/stats/SalmonSeaTroutCatches), footprint/chemical residues from seabed (http://aquaculture.scotland.gov.uk/). Marine analytical unit commissioned – economic value of aquaculture and fisheries to local community. Shellfish cultivation +40 sites in greater LL area location on http://aquaculture.scotland.gov.uk/ website, SAMS have done some assessment of mussel farm impacts on benthos – Scottish Aquaculture Research Forum (SARF) project report. CAR licence applications held by SEPA
Human Pressures	<ul style="list-style-type: none"> Scottish Marine Atlas (MS) Sound of Mull Planning Pilot; Loch Etive spatial management plan Loch Creran and Firth of Lorn SAC documents. Scotmap data SAMS may be able to contribute information on economic benefits of ecosystem in future (Jaspar Kenter)

Gaps and Funding Sources

The workshop highlighted that there is quite a large amount of archived samples (mainly plankton) which could form the basis of further studies. Linking sample owners to analyst resource could remedy this. For example student projects could assist, although short-term student projects are problematic because of the amount of training in identification required. Discussions focused on the necessary activities/analyses needed to address the main drivers of scientific research in the system. Aquaculture, marine spatial planning and legislative frameworks have provided the main impetus for this (in addition to scientific curiosity). Funding sources identified included MASTS, research studentships, research council grants,

and EU calls (although for the latter this would need to be influenced early in the research programme definition).

Some other potential avenues for collaboration were discussed:

Physical Environment

- Influence of the spatial boundaries of hydrodynamic models with respect to particle tracking, i.e. reduce likelihood of particles accumulating at the boundaries.
- Non-hydrostatic model developments to study fine-scale processes and fronts in the LL&FL system.
- Non-linear processes such as bores travelling out of the loch from the Corran Narrows and other side lochs.
- Sediment transport by near-bed currents.
- Wave modelling.
- The Firth of Lorn has been proposed to Defra as a coastal monitoring observatory to contribute to Marine Strategy Framework Directive (MSFD) indicators (Tett and Fox, SAMS). The proximity to the SAMS Marine Laboratory would make this potentially quite cost-effective.
- The loss of the Tiree passage oceanographic mooring due to funding cuts needs addressing. This mooring provided one of the few fixed monitoring sites on the Scottish west coast and provided insights into links between offshore processes and the coastal zone (Inall *et al*, 2009).

Aquatic Ecosystem

- LL&FL as a test-bed for ecosystem health assessments: this would give the opportunity of existing qualitative tools to provide the necessary assessment information, highlight missing datasets and assist development of improved assessment tools. The degree to which the LL&FL can be considered an isolated system requires further discussion.
- LL&FL to provide insights in coastal ecosystem energy and nutrient budgets (through ecosystem modelling).
- The seasonal patterns of zooplankton in LL and FL.
- Influence of land use changes: based on data in Loch Creran, there is an opportunity to investigate changes in 1970s, 1990s and 2000s and the impact of climate change, land use change and fish farming on water quality in the LL&FL system.
- Taxonomy of phytoplankton, zooplankton and nutrients – many opportunities to further extend these data based on archived samples held at SAMS, MSS and others.

Uses and Management

- How can aquaculture carrying capacity be increased without damaging the ecosystem?
- What are the cumulative impacts on the water bodies in the LL&FL system?
- Cumulative impacts framework under development by SEPA, in collaboration with industry and SASF.
- The Ministerial Group for Sustainable Aquaculture's Science and Research Working Group (MGSA S&RWG) has highlighted between farm transmission mechanisms as a high priority for improvements in aquaculture health and welfare (<http://www.scotland.gov.uk/Publications/2014/07/4459>).

Cross-Disciplinary

- What are the top-down controls of zooplankton on the phytoplankton community and does aquaculture impact zooplankton community structure (through ecotoxicology of treatments). Ecotoxicological analysis has only been performed on one species, typically chemicals do not persist. However, emamectin benzoate peak concentration in environment occurs after 180 days, so some treatments persist more than others. Will this have ecosystem effects; is this included in the license assessment? Each license has a maximum chemical use component, maximum concentration of chemical in sediment determined by current i.e. energy of environment.

Research Ideas

- Denitrification rates (self-cleansing mechanism).
- Accurate representation of salinity gradients in hydrodynamics models.
- Bio-optics i.e. light penetration - has this changed with changes in land use? And has this effected primary production (comparison with Loch Eil and 1991 LLP data)
- Have changes in benthic filter feeders impacted primary productivity (investigation of Loch Creran data, insufficient data on the LL&FL system as a whole).
- What is the driver for the moderate benthic status in the LL&FL system, as determined by Water Framework Directive assessments?
- Monitoring changes in the SACs over time – is protection of these sites working?

Concluding Remarks

In February 2014 researchers of the MASTS scientific community reviewed our current knowledge of the LL&FL system and discussed data sources, research

topics and possible future collaborations during a MASTS organized workshop. This report has provided an overview of the meeting. In addition to this report, several other outputs are expected from this case study workshop:

- A meta-data catalogue: after the meeting, this has been initiated through a Google form.
- Literature database: a database of relevant publications has been established (Appendix 3).
- Linking of sample owners and potential analyst resource through small-scale projects.
- Report summarising our knowledge of the LL&FL systems for publication in a non-peer review report series (such as the Scottish Marine and Freshwater Science report series by Marine Scotland Science).
- Overview of gaps and potential projects (included above).

Although initially a stakeholder engagement event was also included in the LL&FL Case Study overview, it was decided not to pursue this further as several stakeholder events were already planned, with a danger of duplication of efforts and over-whelming stakeholders.

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Appendix 1

Agenda MASTS Loch Linnhe and Lynn of Lorn Workshop, 25-26 February 2014, Crieff.

Tue 25th Feb

12noon – Arrive at Crieff Hydro

12.30-1.30pm – Lunch

1.30-3pm – Session 1:

- Housekeeping; introduction to the workshop; aims and objectives (5 min)
- Loch Linnhe project 1991 video (20 min)
- The Loch Linnhe system: what do we know about it? (20 min introductory presentations + questions)
 - The physical environment – Andy Dale (SAMS)
 - The aquatic ecosystem – Mike Heath (U Strathclyde)
 - Uses and management – Ted Schlicke (SEPA)
- Brief summary/discussion

3-3.30pm – Coffee break

3.30-5.30pm – Session 2:

- Past, present and planned research in Loch Linnhe (10 min presentations; see suggested order *)
 - “Capturing” dataset information
 - “Capturing” literature, inc. “grey” literature
 - “Capturing” what we have found out

7pm – Dinner

Wed 26th Feb

9-10.30am – Session 2 (cont.)

10.30-11am – Coffee break

11-12.30pm – Session 3:

- Taking stock:
 - Data inventory
 - Literature listing

12.30-1.30pm – Lunch

1.30-3pm – Session 4:

- Anton Edwards – the SARF perspective (10 min)
- Gap analysis and future projects

3-3.30pm – Coffee break

3.30-4pm – Wrap-up session

4pm – Depart

* Suggested order/subject of presentations for Session 2:

- John Howe – bathymetric surveys
- Andy Dale – physics
- Dmitry Aleynik – hydrodynamic models
- Tim Brand – nutrients and trace metals
- Keith Davidson/Clive Fox – ecosystem monitoring
- Tom Wilding – benthos
- Steven Benjamins – charismatic wildlife
- Tom Adams – connectivity modelling
- Paul Tett – water quality modelling
- Jenny Wright – physics
- Nabeil Salama – connectivity and pathogen modelling
- Mike Heath – historic work in Loch Linnhe
- Yi Ming Lai – the NERC project
- SEPA – monitoring and other
- Anton Edwards – peripheral exchanges
- Sofie Spatharis – metacommunities
- Darren Price – hydrodynamic model developments
- Alastair Lyndon – benthos

Appendix 2

List of Attendees (including affiliation and contact email)

<u>First Name</u>	<u>Surname</u>	<u>Institution</u>	<u>Email</u>
Tom	Adams	SAMS	Thomas.Adams@sams.ac.uk
Dmitry	Aleynik	SAMS	Dmitry.Aleynik@sams.ac.uk
Andrew	Berkeley	SEPA	andrew.berkeley@sepa.org.uk
Andrew	Dale	SAMS	Andrew.Dale@sams.ac.uk
Keith	Davidson	SAMS (Day 1)	Keith.Davidson@sams.ac.uk
Anton	Edwards	SARF and USTAN	anton.edwards@icloud.com
Clive	Fox	SAMS	Clive.Fox@sams.ac.uk
Yi Ming	Lai	STRATHCLYDE	yiming.lai@strath.ac.uk
Alastair	Lyndon	HW	A.R.Lyndon@hw.ac.uk
Greg	Moschonas	SAMS	Greg.Moschonas@sams.ac.uk
Darren	Price	CH2MHill (Halcrow)	Darren.Price@ch2m.com
Nabeil	Salama	MSS	Nabeil.Salama@scotland.gsi.gov.uk
Ted	Schlicke	SEPA	Ted.Schlicke@SEPA.org.uk
Sofie	Spatharis	GLASGOW	Sofie.Spatharis@glasgow.ac.uk
Paul	Tett	SAMS	Paul.Tett@sams.ac.uk
Jenny	Wright	MSS	J.Wright@MARLAB.AC.UK
Organisers			
Bee	Berx	MSS	B.Berx@MARLAB.AC.UK
Alejandro	Gallego	MSS	A.Gallego@MARLAB.AC.UK
Mike	Heath	STRATHCLYDE	M.Heath@strath.ac.uk
Directorate			
John	Thompson	MASTS	ibt5@st-andrews.ac.uk

Unable to attend			
Steven	Benjamins	SAMS	Steven.Benjamins@sams.ac.uk
Tim	Brand	SAMS	Tim.Brand@sams.ac.uk
John	Howe	SAMS	John.Howe@sams.ac.uk
David	McKee	STRATHCLYDE	david.mckee@strath.ac.uk
Berit	Rabe	MSS	b.rabe@marlab.ac.uk

Appendix 3

List of Relevant Websites and Publications

Websites

Marine Scotland Science

<http://www.scotland.gov.uk/Topics/marine/science>

Scottish Environment Protection Agency

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

Scottish Natural Heritage

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

Scottish Association for Marine Science

<http://www.sams.ac.uk/>

Scottish Aquaculture Research Forum

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

Scottish Salmon Producers Organisation

<http://scottishsalmon.co.uk/tag/fish-health-management/>

Wild Fish Catches

<http://www.scotland.gov.uk/Topics/marine/Publications/stats/SalmonSeaTroutCatches>

The Ministerial Group for Sustainable Aquaculture's Science and Research Working Group (MGSA S&RWG)

<http://www.scotland.gov.uk/Publications/2014/07/4459>

Publications

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The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

ISBN: 978-1-78544-067-0 (web only)

Published by The Scottish Government, January 2015

Produced for The Scottish Government by APS Group Scotland, 21 Tennant Street, Edinburgh EH6 5NA
PPDAS43188 (01/15)

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