Loch Linnhe
Introduction to the ecosystem
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Ecological research activity

Concentrate on:
- Loch Linnhe
- Lynne of Lorne
- Firth of Lorne

Won’t be covering:
- Loch Eil
- Loch Leven
- Loch Creran
- Loch Etive
Ecological research activity

- SAMS
- MSS
- SNH

- The Loch Eil Project (1979/80?)
- Firth of Lorne Study (1982?)
- SAMS sediment processes (1990’s)
- Artificial reef project (~2000)
- Loch Etive projects (2000’s)
- MPA surveys (Late 2000’s)
- Sea lice dispersal project (late 2000’s)

- Pulp mill impacts
- Fish farming impacts
- Biodiversity
- Biogeochemistry
- Sediment bio-chemistry
- Optics/primary production
- Fisheries (Nephrops)
- Juvenile fish habitat
- Micro-algal ecology
- Plankton ecology
- Benthos ecology
- Ecosystem modelling
Sea loch ecosystem model

(Ross et al 1992, 1993a,b, 1994, Gurney and Nisbet 1998)

STAMS Sea-loch Ecosystem Nutrient Loading Assessment Tool: Manual

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Main modelling conclusions

• Phytoplankton in sea lochs limited by light (due to high turbidity)
• Nutrient enrichment has little effect on phytoplankton (due to light limitation)
• Strong top-down cascade effects of changes in zooplankton productivity or immigration.
• Sea-lice treatment chemicals affecting zooplankton could have food web effects.
SOAFD (now MSS) Loch Linnhe field project

- Linked to ecosystem modelling
- Aim to quantify annual nutrient and plankton budgets
- 3 cruises in 1989 (Aora, Calanus, Clupea)
- 1 cruise in 1990 (Clupea)
- 13 cruises in 1991/92 (Lough Foyle)
- Primary production measurements by Plymouth Marine Lab (Nick Owens/Andy Rees/Malcolm Woodward)
- Major programme of instrument development (moored and underway nutrient auto-analysers, ARIES, self-recording OPC, moored fluorometers, serial sediment traps).
Essential elements of the 1991 field programme

- 3 moorings serviced by ship each month (RCM, T, S, NO₃, F_chloro, BeamAtt, SedTrap)
- T & S recorder at Corran Narrows
- Sea level recorders (Glen Sanda, Fort William, Loch Eil)
- 4 study sites visited monthly (hydro-chemistry, phytoplankton taxonomy, zooplankton net (30um) and OPC profiles, carbon, nitrate & ammonia uptake, zooplankton excretion and gut fluorescence, micro-heterotroph production, bacterial production, sediment nitrate & ammonia fluxes
- Vertical see-saw tows with ARIES (CTD, F, Beam, Light, O₂, OPC, 200um nets (DW and taxonomy), water sample (NO₃, NH₄))
- Horizontal 2m depth zig-zag tows with TowFish (CTD, F, Beam, OPC, zooplankton (30um nets), continuous NO3, water sample (NH₄, PO₄, SiO₄, POC, PON)).
- 24h intensive site studies in May and July
- Hydroacoustics
- Meteorology and irradiance (at DML)
- River flow and nutrients (HRPB)
2m depth zig-zag tows

- ~9h per survey
- Online data at 60sec intervals
- Water samples at 10 min intervals
See-saw data with ARIES

- T, S, F, Beam etc every 1 sec
- OPC integrated over 60 sec
- Water samples every 120 sec
- Net samples integrated over 120 sec
Surface data from zig-zag tows

- Chl bloom starts earliest in FoL and propagates landward
- Lowest nitrate concentrations in Outer Loch
Moored nitrate sensor data

Lismore mooring site, 15m depth
Daily averaged nitrate data

Lismore mooring site, 50m depth
Daily averaged nitrate data

Inner Loch mooring site, 15m depth
Daily averaged nitrate data

Inner Loch mooring site, 100m depth
Daily averaged nitrate data
Chlorophyll and beam attenuation at moorings

Chlorophyll at 15m

Inner Loch mooring site, 15m depth
Daily averaged chlorophyll data

Lismore mooring site, 15m depth
Daily averaged chlorophyll data

Beam attenuation at 15m

Inner Loch mooring site, 15m depth
Daily averaged beam attenuation

Lismore mooring site, 15m depth
Daily averaged beam attenuation

River spate
Vertical attenuation of irradiance

- Water clarity related to river discharge
- Water clarity controls phytoplankton blooms
Understanding of optical properties and flushing requires a good knowledge of hydrology.
Primary production studies (Rees et al. 1995)

- Water sampled from 6 depths equivalent to prescribed % surface irradiance (100, 60, 30, 16, 3, 0.3%)
- Samples spiked with 14C or 15N (nitrate or ammonia).
- On-deck SW flow-through incubator with light screens.
- Uptake measured by isotope uptake into particulate material.
- Uptake profiles used to estimate daily primary production
Annual primary production rates

- Total PP increases with distance landward
- New production highest seaward
- Proportion of PP due to recycling highest landward
- Deficiency of carbon uptake relative to nitrogen at seaward locations
Zooplankton biomass spectra from OPC data (Heath 1995, 1996)

Annually averaged spectrum in Loch Linnhe
Salt balance box model to estimate flushing rate and non-conservative fluxes (Heath 1995)

- Rate of change in salt content of the loch
  \[
  \frac{dS}{dt} = \frac{[(E-R-F)S_m - (KDS)]}{V}
  \]
  \(E=\) evaporation volume in time interval \(t\); \(R=\) rainfall volume; \(F=\) river inflow volume; \(S_m=\) of outflowing water; \(DS=\) salinity difference between loch and open sea; \(K/V=\) tidal flushing rate

- Rate of change in some non-conservative material \(Y\) in the loch
  \[
  \frac{dY}{dt} = \frac{[(E-R-F)Y_m - (KDY) + (FY_F) + (RY_R) + B_Y]}{V}
  \]
  \(B_Y=\) non-conservative flux of \(Y\) – eg growth-mortality
Sink/source flux of zooplankton size classes

Advection

Mixing

Growth and mortality

Mixing rate $K/V$

Zooplankton annual rate (growth-mortality)

Annual average flux ($d^{-1}$)

Log$_{10}$ particle volume ($mm^3$)
Sink/source fluxes for other parameters

• Inorganic Nitrogen – see presentation by Yi Ming Lai
  – Inner basin net source of nitrate, net sink for particulate N. Inner basin = net heterotrophic
  – Outer basin net sink for nitrate, net source of PON. Outer basin = net autotrophic

• Phosphate

• Silicate
Calanus C4-C5 and C6 size classes from OPC data

Copepodite stages 4-5

Copepodite stage 6
Calanus demography from net samples

- *C. finmarchicus* and *C. helgolandicus* overwinter in the Inner Loch but not in the Outer Loch.

**Inner loch**

**Outer loch**

**Lismore**

**Firth of Lorne**
Different vertical patterns of zooplankton

May at Lismore
OPC profiles 22-23 May 1991 at Lismore, calibrated as Calanus stages
C6 and chlorophyll

July in the Inner Loch
OPC profiles 16-17 July 1991 in Inner Basin, calibrated as Calanus stages
C6 and chlorophyll

C6 and salinity

Time (over a 24h period)
Dominant copepod species

- Inner loch dominated by *Acartia* and *Pseudocalanus* species
- Outer loch dominated by *Calanus* and *Pseudocalanus* species
Space-time patterns in macroplankton abundances

Jellyfish

Cephalopod larvae

Gadoid fish larvae

100,000 mm$^3$ m$^{-3}$

0.0015 m$^{-3}$

0.0124 m$^{-3}$
Summary

- Wealth of ecological data extending back to 1970’s
- Clear differences between basins – Corran Narrows acts as a bio-geographic boundary
- Spring bloom timing regulated by turbidity
- River runoff linked to turbidity
- Landward/seaward gradients in primary production and recycling of nitrogen
- Clear sink/source properties for different plankton classes
- Nitrogen sink/source properties – inner basin net-heterotrophic, outer basin net-autotrophic
- Seabed sediments and benthos…. 