STRANGFORD LOUGH ECOLOGICAL CHANGE INVESTIGATION (SLECI)

Work Package 6.
Anthropogenic Contamination in Strangford Lough

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1 Introduction

Strangford Lough is a large marine lough in County Down on the east coast of Northern Ireland, approximately 15 kilometres east of central Belfast at its northernmost point. The main physical characteristics of Strangford Lough and its catchment are contained in Table 1. The Lough is almost land-locked, being separated from the Irish Sea by the Ards Peninsula to the east, with a connection to the open sea via an eight kilometre long channel called Strangford Narrows. Greatest depths occur in the Narrows and parts of the main axial channel of the Lough. The majority of the Lough is less than 10 metres in depth, and 30% of the Lough's surface area is intertidal.

Table 1. Physical characteristics of Strangford Lough and catchment

Catchment Area (km^2)	Length (km)	Maximum Width (km)	Surface Area LW (km^2)	Surface Area HW (km^2)	Max. Depth (m)	Volume (10^6 m^3)	Coastline (km)
771.5	30.0	8.0	106.2	182.8	66.0	1 251.5	240.0

The Lough is a drowned drumlin field, formed during the Ice Age, and its origins are reflected in its complex system of drumlins, which emerge to form islands and small rocky reefs, known locally as "pladdies". There is a well-defined gradient of sediment type from the Narrows into the main body of the Lough, fashioned by a combination of factors including geology, tides, currents, and exposure to wave action. Bedrock predominates in the Narrows, moving through cobble, gravel and sand to extensive mudflats in the northern part of the Lough.

This section of the report reviews inputs, nutrients, contaminants and xenobiotics in Strangford Lough. The primary industry carried on within the Strangford Lough catchment is agriculture, accounting for approximately 65% of the area (DARDNI pers. comm.). The latest available figures (June 1995) indicate that 2090 farms operate in the area, with land given over to arable production, livestock grazing and pig and poultry production. Livestock grazing is predominant in the southwest corner of the area, in the Quoile and Dibney river catchments, although grazing land accounts for at least 50% of the total area given over to agriculture in all catchments. On the Ards Peninsula cattle farming noticeably predominates over sheep production. The single major area for pig production is in the Dibney river catchment, while the majority of the poultry rearing is carried on in the north, within the Enler River catchment. Arable farming is found throughout the Lough's catchment; the crops are oats; wheat; barley; corn (to a limited extent) and potatoes. Thirty one percent of cultivated land is given over to cereal production, with the major cereal crop being barley. Potato culture is predominantly found in the Enler River catchment, as are cereals, although these crops are found throughout all areas to a lesser extent. There is thus a generalized picture of a relatively greater importance of crop culture in the north of the region, and of livestock grazing in the south.

The Lough has two major freshwater inflow points; the Comber River in the north west corner, and the Quoile River in the south west corner. The catchments of these two rivers are 82.30 and 242.34 km^2, respectively, representing 11% and 31% of the total Lough catchment. There are no major rivers on the Ards Peninsula, and for the purposes of this study, the Blackstaff (catchment 18.13 km^2) has been chosen as being representative of freshwater inputs on the eastern side of the Lough. These freshwater sources have only localized effects on salinity in the Lough, which is otherwise fully saline throughout its length.

In order to prevent flooding of reclaimed farmland, and of the town of Downpatrick, a barrage was built across the Quoile estuary in 1957 at Hare Island. The area up to six kilometres upstream of this barrage is known as the Quoile Pondage, and was designated as a National Nature Reserve in 1970, under the management of the DOE (Environment & Heritage Service, Natural Heritage). The area is owned by the Department of Agriculture. Construction of the barrage has modified environmental conditions within the Pondage; this is now the widest and most static reach of the river, and is effectively a semi-impounded lake, draining to the Lough twice daily at low tide. This impoundment, combined with a significant input of sewage effluent from the sewage treatment works (STW) at Downpatrick and from other works in the catchment and with agricultural runoff, mean that the Pondage has the potential to become eutrophic under certain conditions. The main anthropogenic sources of pollutants to the Lough are agricultural (organic waste and fertilizers) and domestic. Minor pollutants include chemicals and heavy metals from industry (primarily at Newtownards, Dundonald, Comber and Killyleagh); pesticides; antifouling paints and litter.

There are thirty six STWs in the Strangford Lough catchment, many of them small; seven of these discharge directly to the Lough or to the Quoile Pondage. These works serve a population of approximately 90975 population equivalent (pe) (DOE Water Service, pers. comm.). Of these seven STWs, the major works are those at Ballyrickard, serving Newtownards and Comber, at Killyleagh and at Downpatrick. These three works together account for 81% of the total population equivalent of the catchment. All of the directly discharging works, with the exception of those at Kircubbin and Portaferry, carry out secondary treatment. Kircubbin's effluent receives primary treatment, while effluent discharged from Portaferry into the relatively high energy area of the northern Narrows receives only coarse screening. The treatment requirements of these two works, plus the need for a new works to serve Greyabbey and Kircubbin in the northeast, are currently under consideration.

2 Inputs to the Lough

The EHS-EP monitor the inputs from Ballyrickard STW and the Quoile Rivers into Strangford Lough as part of the PARCOM input survey programme. Figure 1 shows the ‘List 1’ metal contaminants for Ballyrickard STW for 2001. Loadings of zinc and copper are the most abundant inputs at 105 and 185 kg per year respectively. Annual nutrient loadings from Ballyrickard STW are approximately 69k kg of nitrogen and 31k kg for phosphate (PARCOM values from EHS-EP 2001).

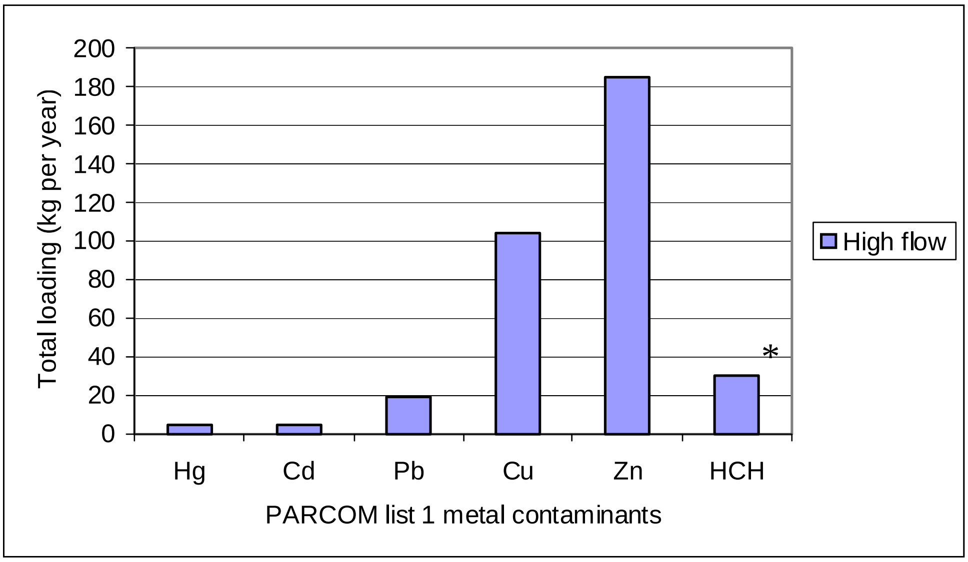

Figure 1. Annual loadings of PARCOM list 1 metals at Ballyrickard STW and the Quoile Rivers (PARCOM report 2001). * HCH concentration is in grams per year.

3 Nutrients

Nutrients are substances essential for primary production. However, at elevated nutrient concentrations a water body can become eutrophicated, i.e. “the enrichment of water by nutrients, especially by compounds of nitrogen and phosphorus, causing an accelerate growth of algae and higher forms of plant life to produce an undesirable balance of organism in the water concerned” (EEC 1991). Coastal Eutrophication has been identified by the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP:1990) as being the second most serious threat to the coastal marine environment (after coastal development). Nutrient sources to coastal marine environments are typically from terrestrial sources. Of particular importance as sources include intensive agricultural practices, industry and sewage treatment works.

The Department of Agriculture carried out a preliminary freshwater survey of the Strangford catchment for fourteen months during 1991 and 1992, and incorporated these data with nutrient data for the Lough itself, collected routinely by the Department of Economic Development, Industrial Research and Technology Unit (IRTU report TI 94/4318). Using nitrate as an indicator of the overall change in nitrogen, the Lough data showed a well-defined seasonal maximum of concentration in December and January. There was a spatial gradient in winter nitrate levels, with higher values at the inner stations, reducing to values comparable with Irish Sea levels in the Narrows. During the summer, nitrate levels fell throughout the Lough and remain low. By contrast to the winter spatial pattern, nitrate concentrations were slightly higher in the south of the Lough. This was probably due to the rapid utilisation of nitrate in the north of the Lough by the standing biomass of phytoplankton. In the southern end of the Lough, higher nutrient levels were not reflected in proportionately higher chlorophyll *a* concentrations (Figures 2 and 3). Presumably, a higher degree of turbulence and mixing in the lower reaches of the Lough made the area less favourable for algal growth, hence maintaining the nutrients supplied by the Irish Sea.

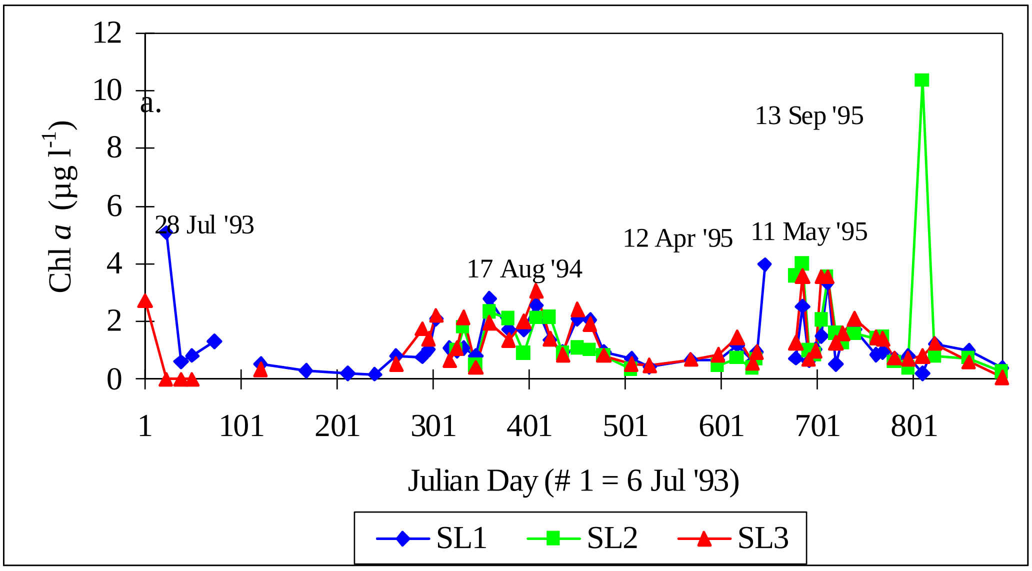

Figure 2. Chlorophyll a concentration for stations in the northern half of Strangford Lough.

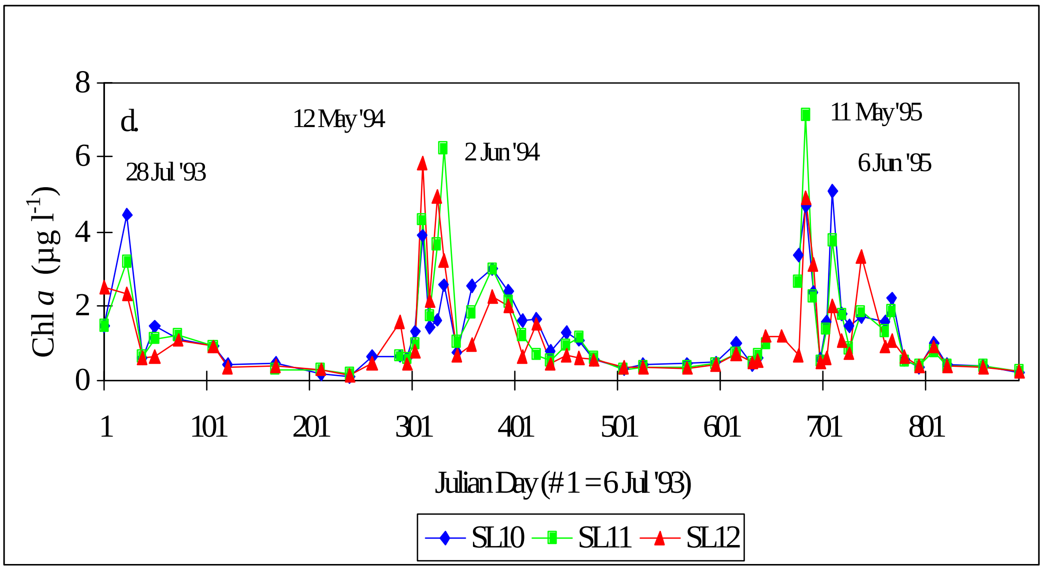

Figure 3. Chlorophyll a concentration for stations in the southern half of Strangford Lough.

The freshwater survey carried out by DANI identified a proportionately higher nitrate-nitrogen load in rivers in the north and east of the catchment, and particularly in the Blackstaff River on the Ards Peninsula. The report of this work attributed this difference to a higher predominance of cereal cultivation in the catchments of these rivers, while elevated concentrations of total phosphate (TP; equivalent to dissolved and particulate organic and inorganic phosphate) were accounted for by the presence of sewage works in the Quoile and Blackwater catchments.

This survey also observed high primary productivity in the Quoile Pondage, with chlorophyll *a* values in excess of 400 µg per litre recorded in September 1991. Calculation of the ratio of N:P showed that algal production in the Pondage was most likely to be limited by nitrogen availability, rather than by phosphorus. The report notes that saltwater incursion into the Pondage was observed as far upstream as the Quoile Quay. Wood and Carter (1978) also found stratification in the lower reaches of the Pondage, and this was associated with oxygen depletion in the bottom layers. This stratification and resultant oxygen depletion was also observed by two postgraduate students working in the Pondage in the summer of 1994 (O'Sullivan 1994 and Thompson 1994). These workers also noted the symptoms of anoxia, namely, black, reduced sediments and the production of hydrogen sulphide within the sediments.

The conclusions of the DANI survey were that Strangford Lough receives a greater proportion of its nitrogen loading from catchment-derived activities (primarily agriculture), than from sewage or industry. The Quoile Pondage was considered eutrophic, and it was pointed out that in this brackish environment, nitrate rather than phosphate may be the factor limiting production.

These conclusions were largely confirmed by a nutrient balance simulation (Kirk McClure Morton 1994) carried out under contract to the DOE. This model indicated that the rivers Quoile and Comber had significant effects on nitrate concentrations, with levels rising from a background level of 150 µg per litre to over 330 µg per litre in the vicinity of the river inflow. It was concluded on the basis of the simulation, that the Comber River had the greater effect, due to the shallowness of the water at the head of the Lough. The River Blackstaff and other small stream inputs also caused locally raised nitrate levels. In terms of phosphate loads, the main body of the Lough was shown to exhibit levels close to the background Irish Sea level of 0.025 mg per litre, while concentrations were raised in the vicinity of the Ballyrickard STW.

A marine and freshwater water quality monitoring survey was carried out as part of joint DARD/EHS/QUB collaboration between July 1993 and December 1995 (marine sites) and April 1991 and April 1992; April 1994 and December 1995 (freshwater sites). The purpose of this work was to determine the trophic status of Strangford Lough and the Quoile Pondage; to partition loads between sources and to make management recommendations where appropriate.

The principal conclusions of this work were that:

- The Irish Sea is the largest source of nitrogen and silicate loading to Strangford Lough. The total annual anthropogenic load of DIN and

SRP (excluding the Irish Sea and airborne deposition) to the Lough are 1 201 and 116 tonnes, respectively (Figure 4)

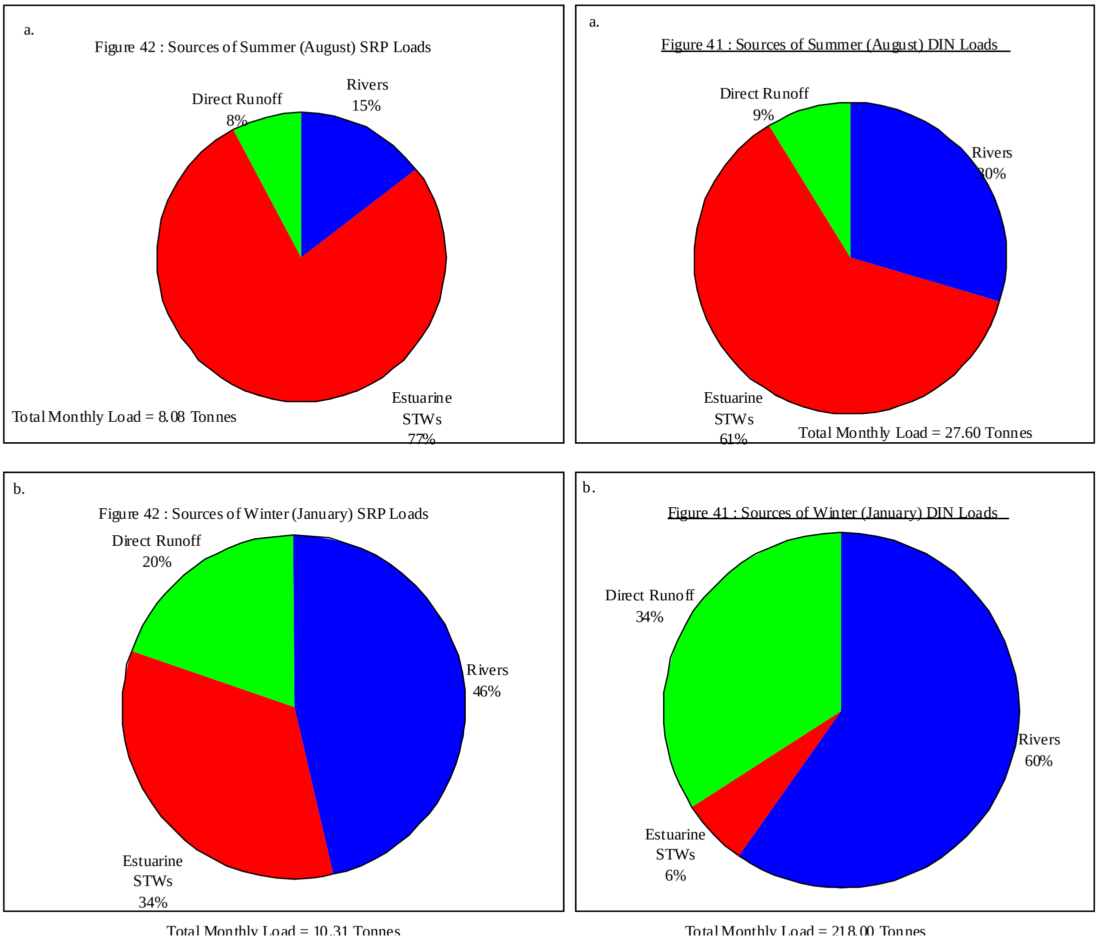

Figure 4. Sources of nutrient loadings of SRP (Surface Reactive Phosphorus) and DIN (Dissolved Inorganic Nitrogen) in Strangford Lough (1993-1995).

- The absolute DIN load is significantly higher in the winter than the summer months, reflecting the fact that the rivers and direct runoff account for the majority of the annual anthropogenic load. The relative contribution of the coastal sewage treatment works is greater during the months of low rainfall.

- The absolute SRP load is slightly higher in the winter months. The majority of SRP load to the Lough derives from coastal sewage treatment works, and 51% of the total anthropogenic load is sourced from the Ballyrickard STW. The output of SRP from STWs is closely related to the rainfall and fluvial flow rates.

- Temporal variation in the concentration of nitrate and ammonia was observed, and this was attributed to seasonal variation in external loadings, and to the effects of biotic processes on the concentration of these nutrients.

- The seasonal cycle of biologically available phosphate was less pronounced than that of DIN, although some summer depletion and autumn regeneration was observed, and this was attributed to seasonal variation in external loadings, and to the effects of biotic processes on the concentration of this nutrient.

- Dissolved inorganic nitrogen and SRP concentrations were highest in the north of the Lough during the winter, and highest at sites in the south of the Lough during the summer. This distribution was related to spatial variation in loadings, in biological uptake and in hydrographic conditions (Figure 4)

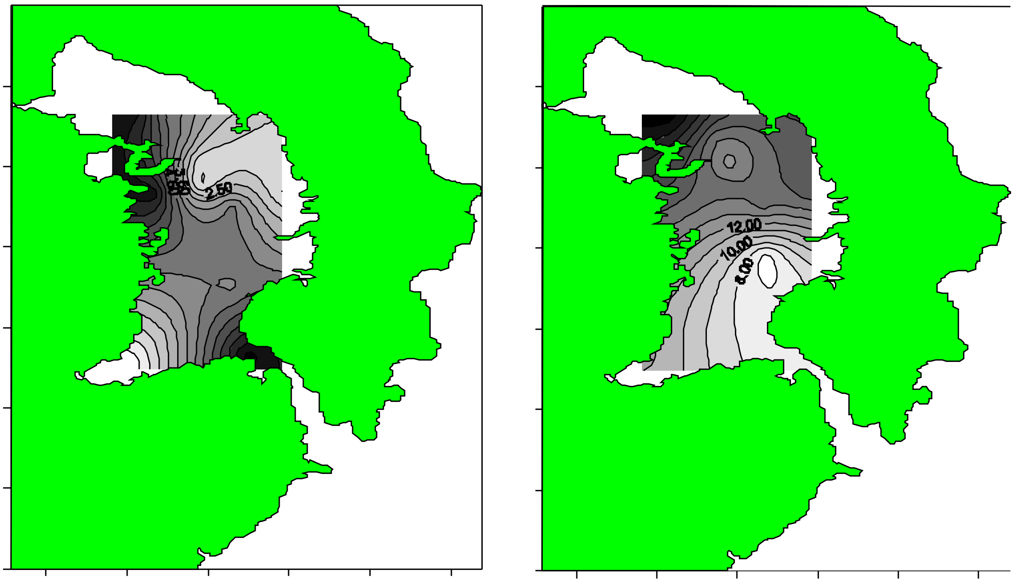

Figure 5. Summer and Winter N:P Ratios

- Strangford Lough is not classified as either a sensitive or polluted water body under the definitions of the UWWT and Nitrates Directives, respectively, on the basis of observed biological response. The Quoile Pondage is hypernutrified, and exhibits clear signs of eutrophication. It might also important to note that the available the input data reviewed above does not consider particulate inputs nor internal sources such as sediment or water column remineralisation which may make a substantial contribution to dissolved inorganic nitrogen.

4 Heavy Metals

Prior to industrialization, geological weathering of the rocks and soils within the catchments of coastal waters was the predominant source of trace metals to inshore marine sediments. These concentrations are considered as a baseline level (Forstner and Wittman 1979 in Charlesworth and Service 2000). Since the onset of the industrial revolution (1760-1830), inputs have increased and have resulted in higher concentrations in the sediments relative to the baseline levels. Furthermore, during the 20^{th} century, the amount of man-made organic contamination also increased substantially. Sediments that have undergone increases in metal and artificial organic compound concentrations due to anthropogenic activity may be considered as contaminated.

Metal contamination of marine water and sediments occurs directly through the introduction of anthroprogenic particles, such as sewage particles, and/or by introduction of metals in the dissolved phase; metals in the dissolved phase can become associated with fine-grained particles in suspension, and are subsequently deposited onto the seabed (Charlesworth and Service 2000). Marine animals, especially filter-feeders, may accumulate contaminants from ingested food material and seawater to concentrations greatly in excess of those found in their environment (Gault *et al*. 1983). Consequently other organisms, including humans, maybe exposed to lethal or sub-lethal levels of specific toxins.

5 Contamination in Strangford Lough: Superficial sediments

Three studies have examined the level of metal contamination in Strangford Lough. The first study was part of a wider investigation into the effects of physical disturbance on the benthic ecology of Strangford Lough. Service (1993) collected superficial sediment samples from 32 stations for heavy metal analysis. These values for were compared to unpublished data from a 1990 survey of the North Channel Sewage Sludge Disposal Ground (DOENI) as a reference site outside Strangford Lough (Service 1993).

Overall, the metal concentration values for the reference site showed little deviation from those obtained for Strangford Lough. However, high concentrations of chromium were detected at three stations in Strangford Lough and these were associated with tannery waste via a sewage outfall at Killyleagh. Service (1993) state that the Killyleagh outfall generated more than 10 tonnes of chromium *per annum*, although during the early 1990s this declined to nearer 1 tonne *per annum*. The station closest to the Killyleagh outfall, although not having particularly high concentrations of chromium (possibly a current effect), did have a high mercury loading that was also derived from the sewage outfall. At only one Strangford Lough station was cadmium found in excess of the detection limit (0.3 $\mu g\ g^{-1}$ dry wt). Interestingly, this station had a particularly high organic carbon fraction in the sediment, which was probably derived from the large amount of partially decaying algae that gathered in the area.

Service (1993) concluded that with the exception of chromium and mercury, all other metals show strong co-correlation and are therefore from a common, geochemical weathering source. By contrast, chromium and mercury are most likely to originate from the point source outfall at Killyleagh.

Charlesworth and Service (2000) compared the metal contamination in loughs Carlingford, Belfast and Strangford adopting a geochemical normalisation approach. This revealed that apart from mercury and some isolated stations, metal concentrations were within the same range for all three sea loughs.

Belfast Lough was the most contaminated with metals commonly associated with anthropogenic discharges and that these metal are largely in the non-residual form and so biologically available. This probably reflected the relatively large domestic and industrial inputs to this Lough. In Strangford Lough, a sampling station close to the mouth of the Quoile River had much higher concentrations of Pb and Cu than in the rest of the Lough. This localized lead enrichment was thought to result from the lead-rich outcrops within the immediate vicinity. The chromium enrichment near Killyleagh was also apparent. Despite these isolated contaminated sites, Charlesworth and Service (2000) concluded that due to the low metal-to-aluminium ratios and apparent close association between the metals and the detrital minerals, that the sediment metal concentrations are close to or at background levels in Strangford Lough.

Due to history of industrial inputs at Killyleagh (see above) and recent construction, this site was the recipient of a more detailed survey by EHS. In May 2000, a licence was issued for intertidal mudflat reclamation at Killyleagh Bay. The reclamation was carried out by progressive infilling using 19,900 tonnes of quarry faced stone and 2,00 tonnes of granular stone. The weight of the infill material caused a lateral surcharge, 1 m high, of sediment into the bay covering an area approximately 100 m^2. Concerns were raised that the re-profiling of the bay and associated sediment displacement may have released elevated concentrations of sediment-bound metals, from historical industrial inputs, to the wider Strangford Lough environment. In response to these concerns, the EHS funded a study of the surface and sub-surface sediment contamination from in and around Killyleagh Harbour.

Examination of subtidal sites upto 600 m from the shore indicated that the metal concentration declined rapidly from the outfall point source and the contamination is localized. Furthermore, through the testing of surface and sub-surface (20 cm depth), the study found no evidence to suggest that metal concentrations in the surface layer were significantly different in deeper sediments. Therefore, there was no evidence that re-suspension of the sediments in Killyleagh Bay would result in any increased metal availability elsewhere in Strangford Lough. Analysis of the sediments from in and just outside the Killyleagh harbour found that with the exception of small concentrations of Tri-Butyl Tin, all trace organic contaminants were below the detection limit.

6 Contamination in Strangford Lough: Shellfish

Mytilus edulis and *Crassostrea gigas* have been regularly sampled in Strangford Lough and tested for metal accumulation since at least 1978. Initially as a series of research studies Parker (1978). Gault, Tolland and Parker (1983) reported on a “musselwatch” style survey of Northern Ireland’s coastal waters. In 1985 one area (Ardmillan Bay) within the Lough was designated under the EC Shellfish Waters Directive (Shellfish Water 76/923/EEC). This started an annual programme of monitoring contaminants in oyster flesh and the continuation of mussel sampling at 4 sites within the Lough. In 1999 water sampling metals was added to the programme by EHS-

EP and at this time two new sites came under this directive. The subsequent adoption of the EC Shellfish Hygiene Directive (Shellfish Hygiene 91/492/EEC) has also meant that all shellfish aquaculture sites actively producing for the market must analysed for trace contaminants annually.

Summarizing the monitoring data indicates that other than chromium, heavy metal contamination was low in shellfish collected from Strangford Lough. Only chromium contamination was apparent for mussels collected near Killyleagh (Gault *et al*. 1983). Average chromium levels for Northern Ireland were 4.2 $\mu g\ g^{-1}$ (dry wt), yet mussels from Killyleagh contained 317.54 $\mu g\ g^{-1}$ (dry wt) of chromium. Using a combination of data from the various statutory monitoring programmes it is possible to exam temporal trends in metals in Strangford Lough. Using data over the last 20 years where seasonal data is also available (this is important as spawing in mussels can affect concentrations) reveals that the concentration of heavy metals in mussels appeared to be fairly consistent between years, although it is clear that Hg and Cr have declined (Figure 6).

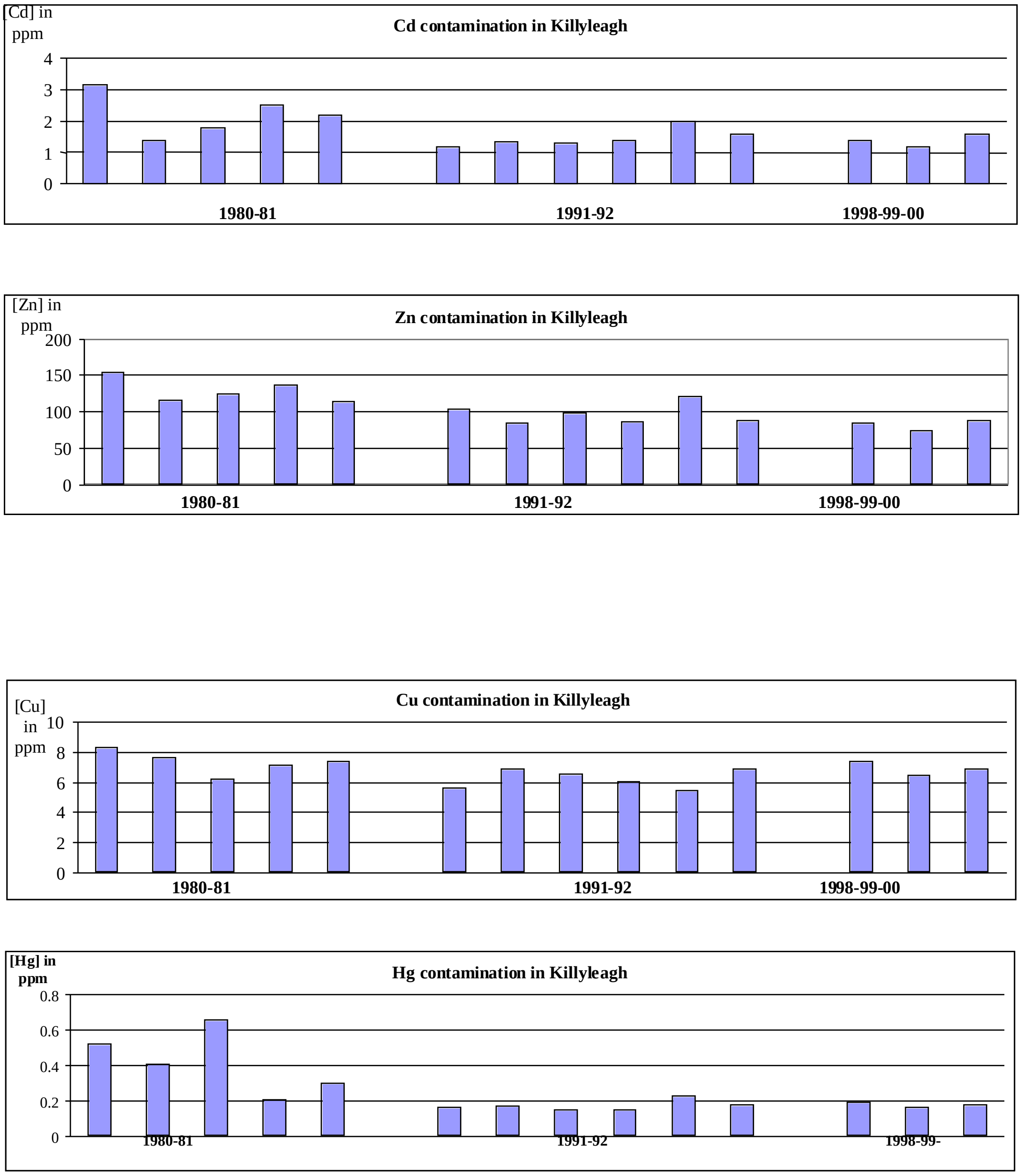

Figure 6. Heavy metals contamination in Killyleagh from 1980 to 2000.

Chromium was abundant is Strangford Lough due to an input of domestic sewage and tannery effluent via the sewer at Killyleagh. During the 1908's, this outfall contributed approximately 40 kg of trivalent chromium per day at concentrations between 0.05 and 49.5 mg l^{-1}. Background levels of chromium in the sea are typically about 0.2 μg l^{-1} (Burton 1976). The most toxic form of chromium are the hexavalent ions. A seawater concentration of 4.5 mg l^{-1} of hexavalent chromium has been shown to produce abnormal development in embryos of *Mytilus edulis*, while similar abnormalities were induced by only

5.0 $\mu g\ l^{-1}$ of copper or mercury. Consequently, mussel embryos are relatively insensitive to dissolved chromium. Gault *et al*. (1983) suggests that most of the mussels from Killyleagh were of such poor condition it may be speculated that chromium, perhaps in combination with other elevated metal concentrations, was having an inhibitory effect on their growth although recruitment probably continued.

7 Tributyl Tin (TBT) and Imposex in the dog whelk *Nucella lapillus*

In the mid 1980's DOE Northern Ireland commissioned studies in to the possible effects of TBT on oysters in the lough. This was based on the suggestion that the phenomena of double shelling in Pacific Oysters *Crassostrea gigas c*ould be attributed to TBT level. The results of this work were somewhat inconclusive in particular double shelling was also found to be linked to high suspended solid loads.

Imposex is the development of male characteristics in female gastropds and has been strongly associated with the use of tributyltin (TBT) based marine antifouling paints. Dogwhelks (*Nucella lapillus*) have been extensively used as a bioindicator of TBT in the environment (Bright *et al*. 1989, Smith and McVeagh 1991 in report TI 96/2717).

A report instigated by EHS found that generally the North coast, Antrim coast and East Down (Strangford Lough) populations of dogwhelk showed no serious imposex, with levels mostly within the 'A' or 'excellent' ADRIS classification (IRTU/EHS report TA 96/2717). Belfast Lough and Carlingford Lough appeared to be the main two hotspots, both are subject to heavy shipping traffic of vessels in excess of the 25 m ban and hence possible legal sources of TBT antifoulants. Strangford Lough rated overall as excellent within the ADRIS classification scheme. These imposex results were considered encouraged by the authors considering reports prior to 1994-96 of double-shelling in commercial oyster beds (IRTU/EHS report: TA 96/2717).

Age-related imposex has also been reported in populations of whelks (*Buccinum undatum*) from sites in Strangford Lough with older individuals showing higher percentage of imposex than younger individuals. Allowing for accumulation, an actual decline was apparent in the prevalence of imposex; this was attributed to the 1987 ban of TBT on boats less than 25 metres in length (Edwards 2003).

8 Organochlorine and PCB residues

Organochlorine pesticides and polychlorinated biphenyls (PCB) are monitored at several sites in Strangford Lough for the EC Shellfish Waters Directive (Council Directive 79/923/EEC) and the UK National Marine Monitoring Programme. Both monitoring programs consistently found that in recent years the concentrations of both groups of chemicals are below the detection limit.

9 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons are one class of chemical pollutants that are currently known to have adverse effects on the environment and the organisms within. Most PAHs are naturally derived, although a small fraction is generated (via incomplete combustion) and released by human activities; these have been shown to have both carcinogenic and mutagenic effects in organisms (Woodhead *et al*. 1999). Each individual source is characterized by a specific molecular pattern, allowing the source of these compounds to be established (Guinan *et al*. 2001). PAH ratios have been commonly used as a means of differentiating between those of pyrogenic and petrogenic origin. To establish the concentration and sources for PAHs in two sea-loughs in Northern Ireland, Guinan *et al*. (2001) collected and analyzed sediment and mussels from Strangford Lough and Larne Lough.

The total concentration of PAHs in Larne Lough ranged between 83 and 2,300 ng g^{-1} with the exception of two stations with concentrations of 12,200 and 23,000 ng g^{-1}. The high concentrations of PAHs at the two stations was due to the presence of coal particles in the sediment. The concentration of PAHs in sediments collected in Strangford Lough ranged from 307 and 1,260 ng g^{-1}; the station nearest to the sewage discharge pipe near Killyleagh had the maximum value. The concentration of remaining samples at both Larne and Strangford show no distinct spatial trend with regard to anticipated point sources suggesting that geochemical constraints may be a factor in determining concentrations of PAHs in both sea-loughs. Guinan *et al*. 2001 stated that as no relationship exists between organic C and total PAHs in Strangford Lough, and that it is difficult to compare the two lough in terms of contamination status by comparing concentrations of PAHs at the same organic level.

A number of factors determine the concentration and distribution of PAHs in the marine environment. Organic contaminants in coastal systems are present in several forms including those bound to dissolved organic matter, absorbed to suspended particulate matter and associated with surface sediments. Particle size and organic carbon have been shown to influence the concentration and therefore distribution of PAHs in sediments. Positive, significant relationships were found between % silt/clay and total PAHs for both sea-loughs, but the relationship between organic C and total PAHs was only significant for Larne Lough. The percentage silt/clay fraction explains 61% and 65% of the variation in total PAHs in Strangford and Larne Loughs respectively. Organic C concentrations explain 81% of the variation in total PAHs in Larne Lough. The results suggest that in Larne Lough, organic carbon plays a role in controlling PAH levels in the sediment, and to a lesser degree % silt/clay. The lack of this relationship in Strangford Lough may be related to productive and varied benthic communities that contribute to the organic C level and thereby mask the relationship between PAHs and organic C.

Using the ratios of particular compounds, the predominant origin of PAHs can be determined. In Larne Lough, all PAH compounds, except perylene, are correlate together, which suggests a common source to most of the PAH compounds and particularly those of anthropogenic origin. In Strangford Lough, all but naphthalene correlated with each other**.** Guinan *et al*. 2001 concluded that in both Larne Lough and Strangford Lough, there was a small petrogenic imprint over a dominant pyrogenic origin. Furthermore, the results indicated that the 2-3 ring PAHs were more abundant in Larne Lough than in Strangford Lough, by contrast, the 5-6 ring PAHs have a greater abundance in Strangford Lough. This ratio of 2-3 ring versus 5-6 ring PAHs suggests that Larne Lough receives more inputs from petrogenic sources than Strangford.

The concentration of PAHs was also measured in mussel flesh collected from the two sea-loughs. In Larne Lough, the total PAH concentration varied between 108 and 184 ng g^{-1} and ranged between 95 and 128 ng g^{-1} in Strangford Lough. The concentrations found in the mussels from the two sea-lough were low in comparison with other studies of mussels from contaminated sites. However, Guinan *et al*. 2001 suggested that the differences in PAH concentration were more likely to be a result of differing condition within the mussel populations at each site. Equally, differences relating to the lifecycle stages, as observed elsewhere (Jacob et al. 1997, Law *et al*. 1999 in Guinan *et al*. 2001), may also have been responsible for variation in the PAH concentrations.

Guinan *et al.* 2001 concluded that sediments in both loughs appeared to be contaminated to a similar degree. The PAH sources in both sea-lough were dominated by pyrogenic inputs, suggesting that diffuse inputs such as atmospheric deposition maybe the major source. Small variations in total PAHs in mussels between sites and lough were probably caused by different physiological conditions in the mussel populations.

10 Artificial radio-chemical contamination in Strangford Lough

Low-level radioactive waste in liquid form has been discharged into the Irish Sea from the BNFL (British Nuclear Fuels Limited) reprocessing complex at Sellafield (Cumbria) for over four decades. The discharges are subject to controls under the Radioactive Substances Act (1993). The concentrations of radiocaesium (Cs), plutonium (Pu) americium (Am) and technetium (Tc) were measured in seawater, sediment and biota from the Lough; these values were then compared with concentrations in similar samples from the north-western Irish Sea by Legderwood *et al*. (2001).

Ledgerwood *et al.* (2001) stated that despite the considerable reduction in the levels of Sellafield discharges since the mid- to late 1970s, traces of radiocaesium, plutonium and americium from Sellafield are still detectable in seawater, sediment and biota in Strangford Lough. Comparison with previous surveys and with time series data gathered over the last two decades, conclusively demonstrates that ^{137}Cs concentrations in the Lough have already peaked and are now in steady decline – this rate of decline was identical to that observed in the general western Irish Sea.

By contrast, plutonium concentrations show little variation with respect to previous surveys, although overall, the concentrations were very low. Ledgerwood *et al*. (2001) also found that ^{99}Tc concentrations within the Lough were approximately five times higher than those prevailing in the western Irish Sea prior to the commencement of the EARP operation in 1994, but on the other hand were lower than those measured further south along the eastern coast of Ireland. Ambient gamma dose-rates over intertidal sediments in the Lough are very similar to those found elsewhere in Northern Ireland, and are predominantly of natural origin. The overall effective dose from artificial radioactivity, including shellfish consumption and recreational use of the Lough, is of a negligible radiological significance.

From a radioecological point of view, Strangford Lough appears to behave as an extension of the NW Irish Sea. This in not unexpected, since the turn-over rate of waters within the Lough is sufficiently rapid to ensure the at both dissolved and particle-reactive radionuclided concentrations mirror those prevailing in the NW Irish Sea.

11 Conclusion

Of the reviewed studies, only two areas of contamination are apparent. Firstly, the Killyleagh outfall appears to have been responsible for localized enrichment of mercury and particularly chromium in the superficial sediments (Service 1993). Consequently, this is probably related to the substantial bioaccumulation of chromium in mussels collected from Killyleagh. Interestingly, this accumulation was not as apparent in oysters. In 1994, the tannery responsible for the chromium output closed; the annual discharge of the outfall was reduced ten-fold thereafter. The second element of contamination is derived from Sellafield discharges, although most radionuclide concentrations are comparable to the Irish Sea (Ledgerwood *et al*. 2001) and probably represent no risk to the communities present in Strangford Lough.

Small and localized metal enrichments have also occurred via the lead-rich rock outcrops near the Quoile and sewage outfall at Newtownards. Despite this, the majority of Strangford Lough has metal concentrations close to background levels and can therefore be considered uncontaminated (Service 1993). Chlorinated hydrocarbon and TBT contamination was generally low in Strangford Lough. What little enrichment was present seemed to be associated with sewage discharges from the urbanized areas.

12 The Future

Development of more robust analytical quality control procedures and more solid statistical approach will need to be adopted if detection of trends in contaminants at other than very coarse levels. To this end the UK National Marine Monitoring Plan has put in place guidelines to ensure this is achieved. In 1999 DARD included one station in Strangford Lough as an NMMP site.

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