Chapter 4: Work Package 2: Develop an appropriate sampling protocol for assessment of the status of fish stocks in rivers for the WFD (and preliminary proposals for lakes)

4.1 Overview of chapter

This chapter deals specifically with developing a sampling protocol for assessment and subsequent monitoring of the status of fish stocks in rivers for the Water Framework Directive. The degree of variation in fish populations in relation to physical habitat variables at the reach scale was assessed. An attempt is also made to provide a set of recommendations for sampling fish in lakes.

4.2 Rivers – Introduction

Assessing animal populations requires a sampling strategy that balances the level of accuracy and precision with the level of sampling effort in terms of manpower and cost (Southwood & Henderson, 2000). The strategy adopted varies with the nature of the investigation, the target organisms and the importance (scientific, economic, political or otherwise) of the results. Cost-effective sampling needs to match the likely error in the resulting data to the costs involved. Such uncertainty in any population assessment can occur both as a result of inherent spatial and temporal variation in the target population and the error in catching/observing and counting individuals within a given area. Both sources of error must be taken into account when designing a sampling strategy.

The need to assess fish populations in rivers has increased in importance over the years as pressures on river ecosystems have grown, particularly since the middle of the 20th century. Populations of fish in many rivers have vanished or severely declined as a result of channel- and catchment-scale physical habitat alteration and disturbance, declines in water quality, construction of barriers to migration and overfishing, both within the river itself and of the marine stages of anadromous species (Pretty *et al.*, 2003). The negative impact of many of these factors is becoming more fully appreciated as fish populations decline to historically low levels, with serious impacts on commercial and sport fisheries. Knowing how populations respond to deleterious effects and to restoration efforts are therefore a pre-requisite to any management strategy. The assessment of fish through much of Europe has traditionally been instigated through environmental and social considerations rather than economic ones. Management of inland fisheries in Ireland has been motivated primarily by the requirement to maintain or promote angling (Irvine *et al.*, 2002). Currently there is no national monitoring programme for assessing the ecological status of fish in Ireland.

The application of electric fishing to sample salmonid populations in rivers has been in use for many decades, owing to the development of lightweight, safe and reliable electricity generators (Cowx, 1995). This technology has allowed the rapid expansion of research into the biology of salmonids, including the routine monitoring of populations for stock assessment purposes and for determining the health of populations and their habitats. The commonest approach to assessing salmonid populations is using electric fishing with a depletion methodology, where stop nets are placed at the downstream and upstream ends of a stretch of a given area to prevent immigration or emigration of fish, and fish caught are removed over successive sweeps (Zippin, 1956; Cowx, 1995). The final density of fish is estimated from the successive depletion over repeated sweeps conducted at a constant fishing effort.

Despite the relative ease of electric fishing compared to other more time-consuming or destructive methods (e.g. recording anglers' catches, direct observations underwater or from the bank, mark-recapture exercises, automatic fish counters, netting and redd-counting) the process is still costly in terms of manpower, equipment and time (Crisp, 2000). However, for rivers or streams, where little prior information exists and where their remoteness makes repeated visits difficult and the installation of fish counters impractical, then electric fishing is the most cost-effective method.

The time, cost and effort of estimating fish populations from a given river through electric fishing are related to the length and area of stretch fished and the particular methods used. As alternatives to depletion fishing, other methods of electric fishing include, point sampling (spot-fishing at individual replicate points, rather than sweeping a whole stretch), single-pass electric fishing and depletion electric fishing without stop nets (Cowx, 1995). All the latter methods are less time-intensive than depletion fishing, but generally only give semi-quantitative assessments of populations within a given stretch. The accuracy (how near to the true value an estimate is) and the precision (the replicability of the estimate) of the sampling programme will depend to a large extent on the spatial-temporal variation in fish populations of the river or stream. If this variation is high, then population assessments at a given time or place may fail to reflect the average density of fish over longer spatial and temporal scales. For these reasons, Elliott (1994) emphasises the need for a reliable estimate of baseline variation against which to assess the significance of ecological change. He expresses the view that regular quantitative samples must be taken over many years to ensure that the degrees of freedom for the between-years error are adequate for robust statistical analyses. The existence of such long-term data is limited in Ireland. Material from the Slaney catchment is considered for long-term variation in Chapter 2.

Salmonid populations can exhibit a patchy distribution in time and space as a result of many interacting factors at a range of scales. The inter-annual variation of salmonid populations in a given river is generally very large due to the high variation in recruitment success, despite the density-dependent nature of juvenile survival. This variation is also described for the Slaney catchment sites in Chapter 2 and is due to variation in the numbers of adult spawners (and hence recruitment of eggs and juveniles) and the success of juveniles in surviving their first few critical months (Elliot, 1994; Crisp 2000; Armstrong *et al.*, 2003). Both eggs and juveniles are also highly susceptible to wash-out from severe floods during spring and early summer and all stages are vulnerable to downstream displacement (and possibly death) by severe winter flooding. The exceptional flood on the Tolka river in November 2002 is an extreme example of such disturbance where thousands of tonnes of gravel and boulders were displaced downstream necessitating major drainage in spring 2003. Small-scale within-year movements include movements of fry and parr from redds to parr territory and from riffles to pools in winter (Bridcut and Giller, 1993; Crisp, 2000). Within a stretch, individual trout can also be territorial, living within a defined home range, or more mobile, moving along a stream for several kilometres (Bridcut and Giller, 1993, also see Chapter 6 of this report). Longer-scale temporal movements may involve migrations of juvenile and adult fish from headwater spawning tributaries to feeding and overwintering sites in downstream stretches of the river system, in lakes, estuaries and coastal marine areas (Jonsson, 1985; Elliot, 1994; Crisp, 2000; Armstrong *et al*, 2003).

Spatial variation in salmonid populations can be apparent at several scales. Small-scale differences in the physical structure of benthic habitat (for example, that between pools and riffles) can account for large changes in salmonid abundance and community composition within a single stretch. Even greater changes can occur over larger scales due to differences between stretches and between rivers in gradient, stream channel dimensions, spawning accessibility, water quality and interspecific competition (Crisp, 2000; Armstrong *et al.*, 2003).

Until recently, most non-salmonid fish species were regarded as non-migratory and considered to be in static populations with their locations in rivers defined by habitat preferences at reach scales, leading to classic longitudinal zonation patterns (Huet, 1959;

Lucas *et al*., 1998). However, many lotic fish species display strong small- and large-scale migration patterns (Wooton, 1992; Lucas *et al.*, 1998).

Although the spatio-temporal variation of salmonid and non-salmonid populations is now becoming better understood, little information exists about how to sample such populations accurately and precisely in a given river. The guidance on sample site selection given in Annex V of the Water Framework Directive reveals little about the appropriate distribution or density of sites to be sampled (Irvine *et al*., 2002). Sampling frequencies must be sufficient to satisfy the objectives of monitoring but not place unnecessary demands on scarce and costly technical resources (Irvine *et al*., 2002). There are no recommendations on the number of sites to survey on any river reach.

This investigation is an attempt to quantitatively assess the degree of sampling error in two rivers, one with little longitudinal physical or chemical variation over the study length (Douglas river) and the other (Curraheen river) with marked longitudinal physical/chemical changes, and to describe the most appropriate sampling strategy for salmonids in southern Irish rivers.

Aims and objectives

The aim of this work package is to develop an appropriate sampling protocol for the assessment of the status of fish stocks in relation to water quality in rivers.

In order to develop a robust and accurate monitoring protocol for the EU Water Framework Directive's ecological assessment for fish in rivers, it is necessary to evaluate the degree of variation in fish populations in relation to physical habitat variables at the reach scale. This would allow a statistical assessment of the minimum number of sample stretches (or the minimum length of river) needed for appropriate sampling of the fish populations in order to deliver an accurate representation of the fish stock within the river.

4.2.1 Methods

Study area

Two rivers were selected for this aspect of the study – the River Douglas, a tributary of the River Araglin, East Cork and the Curraheen River, a small tributary of the River Lee, which flows into Cork City (Fig. 4.1).

River Douglas

The River Douglas is an unpolluted headwater tributary of the River Araglin and subsequently the Munster Blackwater (Lehane, 2000), with a catchment area of 21.5 km^2. Catchment land-use is entirely rural and consists of moorland, plantation forestry, natural woodlands and low-intensity agriculture (Clenaghan, 1996). Average stream gradient is 30m per km (Clenaghan *et al*., 1998; Lehane, 2000). Previous research has shown that the River Douglas has relatively high densities of resident brown trout, with lower densities of Atlantic salmon (Clenaghan, 1996; Lehane, 2000). European eels and brook lampreys are also found in the river. Roach and dace introduced to the Munster Blackwater in 1989 (see Chapter 1) appear not to have colonised this tributary.

River Curraheen

The River Curraheen is a tributary of the River Lee, located to the west of Cork City, Co. Cork. The catchment (approximately 38km^2) can be divided into three main areas, with upper reaches dominated by rough pasture and forest, middle sections that are primarily agricultural, and lower, urban, reaches that flow past the outskirts of Cork City. The average gradient is 14m per km. Little work has been carried out on this river to date and therefore no previous information was available on its ecology. However, EPA chemical analyses that were carried out from 1995 to 1997 at one site on the lower reaches of the River Curraheen, are summarised in Table 4.1. The Curraheen River is subject to inputs of domestic and agricultural wastes as it flows into Cork City. Water chemistry therefore changes considerably as it flows downstream. Although dominated by brown trout and salmon, previous small-scale fishing of the stream found low densities of three-spined stickleback, eel, brook lamprey and stone loach.

Table 4.1: Summary of the chemical water quality of the Douglas River, 1991-1993 and the River Curraheen, 1995 to 1997.

Parameter	Curraheen	Douglas
pH	7.3	7.18
Conductivity (mS Cm-1)	330	139.6
Temperature (oC)	1	9.9
Dissolved Oxygen (%)	79	100
Dissolved Oxygen (mg/l)	9	11.54
Total Ammonia (mg/l)	0.54	0.089
Oxidised Nitrogen (mg/l)	6.78	-
Alkalinity (mg/l)		

Fieldwork

Fieldwork was carried out over a 10 week period from July to September, 2001, when stream flows were moderate to low. Sampling at this time of year also allows the quantification of all ages, including young-of-year trout and salmon. Macroinvertebrate sampling and habitat assessment was carried out at the same time as the fish stock assessment. Fifteen consecutive 30m stretches (based on an average of seven times the channel width) were selected along each river for sampling of fish populations during July/August (River Douglas) and September (River Curraheen). Stretches were fished in an upstream manner (at a rate of one to three stretches per day) beginning at stretch 1, which was the furthest downstream. Stop nets were used to enclose each site prior to sampling. Electrofishing of each stretch was carried out using either a pulsed D.C. backpack powered by a Safari 12 volt battery or a Honda WFC3i bankside generator set. The backpack unit was used in stretches where dense riparian vegetation made the use of the bankside generator impractical. Standard methodologies as described in chapter 2 were followed for this work package.

To assess the overall water quality at each study stretch, macroinvertebrate communities were also sampled. Three two-minute kick samples were taken at each stretch, disturbing the substrate in proportion to the habitat occurrence. All available habitats were sampled, with large stones and detritus washed prior to removal from the sample. The sample was then transferred to a white tray for examination (Kelly, 2001). Taxa were identified and placed into relative abundance categories, according to the EPA Q-value methodology and a Q-value rating established in the field. The samples were retained for subsequent sorting and more detailed identification and quantification in the laboratory. Conductivity measurements were also taken to assess changes in overall water chemistry.

Data Analysis

The size of each salmonid age class was calculated from length-frequency histograms, for each river individually. The estimated density of each age class for each species was then calculated per stretch fished using the Zippin multiple-pass depletion method (Zippin, 1958). Biomass for each age class was calculated from the mean weight per age class and the density of the age class from each stretch. Total biomass was calculated from the sum of each age class biomass.

The relationship between physical habitat variables and salmonid abundance was explored using Pearson correlation analysis on log-transformed data using individual mean measurements from each stretch. The degree of variation in abiotic and biotic parameters for each river was assessed using the coefficient of variation for each parameter (standard deviation divided by mean value, for the fifteen stretches for each river), expressed as a percentage.

The required sample size needed to estimate (within 95% confidence limits), the density of trout and salmon, within a given accuracy (expressed as percentage of the true mean) was calculated according to the following formula (Eckblad, 1991):

$$\textbf{Required sample size, n,} = \frac{(\text{t-value})^2\ (\text{sample variance})}{(\text{Accuracy x sample mean})}$$

where t-value is the value taken from the t-distribution with a specified level of significance (in this investigation, with 14 degrees of freedom at probability level 0.05, the t-value is 2.145). The number of samples required for different levels of accuracy can then be shown graphically.

The accuracy of estimating fish abundances with single-pass electrofishing was assessed by correlating the densities of salmonids estimated from the first electrofishing pass (numbers caught divided by area fished) with densities estimated from the triple-pass depletion method, for each site.

4.2.2 Results

Physical Habitat

The mean depth and velocity varied greatly between stretches for both rivers (Figs. 4.2 and 4.3, Table 4.2). The mean depth and velocity for the Curraheen showed a general decline in an upstream direction, but no such trend was evident for the Douglas. The Douglas had an overall greater percentage of riffle per stretch than the Curraheen (Figs. 4.2 & 4.3, Table 4.2). As a result of higher physical variation between neighbouring stretches and more pronounced longitudinal change, the coefficient of variation for all physical parameters was greater in the Curraheen than the Douglas (Fig. 4.4).

Table 4.2: Mean physical habitat variables for each stretch, Douglas and Curraheen rivers (sites are numbered in an upstream direction).

Douglas River	% Riffle	% Glide	% Pool	Width (m)	Depth (m)	Velocity (ms^{-1})	Discharge ($m^3\ s^{-1}$)
Site 1	55	40	5	5.21	0.20	0.08	0.09
Site 2	75	25	0	5.28	0.13	0.15	0.10
Site 3	80	0	20	5.89	0.16	0.24	0.23
Site 4	65	20	15	3.93	0.21	0.26	0.22
Site 5	80	10	10	3.94	0.24	0.20	0.18
Site 6	80	10	10	5.83	0.17	0.26	0.26
Site 7	75	20	5	4.65	0.13	0.25	0.15

Site 8	95	0	5	5.04	0.15	0.17	0.13
Site 9	60	40	0	4.87	0.14	0.21	0.14
Site 10	20	40	40	5.29	0.20	0.11	0.12
Site 11	75	20	5	4.64	0.16	0.16	0.12
Site 12	100	0	0	5.77	0.13	0.14	0.11
Site 13	60	40	0	4.48	0.17	0.17	0.13
Site 14	85	10	5	5.01	0.14	0.18	0.13
Site 15	40	40	20	4.39	0.19	0.14	0.12
Curraheen River	**% Riffle**	**% Glide**	**% Pool**	**Width (m)**	**Depth (m)**	**Velocity (ms^{-1})**	**Discharge (m^3 s-1)**
Site 1	15	80	5	5.85	0.29	0.17	0.28
Site 2	20	80	0	6.46	0.24	0.20	0.31
Site 3	40	60	0	6.10	0.20	0.19	0.24
Site 4	100	0	0	6.79	0.14	0.23	0.22
Site 5	50	40	10	3.96	0.23	0.27	0.25
Site 6	40	30	30	5.24	0.23	0.13	0.16
Site 7	30	70	0	5.16	0.15	0.12	0.09
Site 8	40	40	20	4.18	0.22	0.10	0.09
Site 9	30	70	0	4.10	0.23	0.08	0.08
Site 10	100	0	0	4.64	0.09	0.17	0.07
Site 11	50	40	10	3.12	0.12	0.11	0.04
Site 12	45	40	15	4.37	0.16	0.13	0.09
Site 13	95	0	5	2.66	0.09	0.17	0.04
Site 14	80	15	5	1.71	0.13	0.20	0.04
Site 15	30	40	30	3.33	0.19	0.09	0.06

Water chemistry and invertebrate communities

The conductivity of the Douglas was lower than that of the Curraheen, for all stretches (Fig. 4.5). The conductivity for the Douglas was also very similar for all stretches, in contrast to the pattern in the Curraheen, where there was a marked upstream stepwise decline in conductivity (Fig. 4.5). This change in overall water chemistry was reflected in the invertebrate communities. The taxon richness in the Douglas, although somewhat variable between stretches, did not exhibit any longitudinal trend. The Q-value, equally, was the same (Q4-5) for all stretches. The Curraheen, however, exhibited a strong gradient in invertebrate community with taxon richness in the five stretches furthest upstream being markedly higher than those downstream. The Q-value showed the same pattern, with the downstream stretches having a uniformly low Q-value as a consequence of pollution, the midstream stretches having a low but variable Q-value and the five upstream sites having a uniformly high Q-value (Fig. 4.5).

Fish abundance

Both the rivers Douglas and Curraheen were dominated by trout and salmon. Other fish species occurring included eel, 3-spined stickleback, brook lamprey and stoneloach. The abundance of these species at each site was recorded as 5 abundance categories (Table 4.3) The numbers and diversity of species other than trout and salmon was higher in the River

Curraheen than the Douglas. Particularly high numbers of stickleback were found in the two sites furthest downstream in the Curraheen (Q3). Little trend was evident in densities of other species along either river (Table 4.3).

Table 4.3: Abundance (number per site) of other fish species in the rivers Douglas and Curaheen.

Douglas	Site Number														
Fish species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Eel	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1
3-spined Stickleback	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stoneloach	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lamprey	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curraheen	**Site Number**														
Fish species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Eel	2	1	1	0	1	0	0	1	1	1	1	1	2	0	1
3-spined Stickleback	5	4	3	0	1	1	2	1	0	1	0	2	3	2	0
Stoneloach	2	0	1	0	2	2	2	0	0	0	1	1	2	2	1
Lamprey	0	0	1	0	1	0	0	0	1	0	1	1	1	0	1

Note: abundance categories are outlined below

Score	0	1	2	3	4	5
Abundance (no. per site)	Absent	1-10	11-50	51-100	101-200	>200

Salmonid abundance

The length-frequency distributions for brown trout for the two rivers are shown in Fig. 4.6. The difference in size between young-of-year trout (henceforth 0+) and older trout was clear for both rivers. The difference between one-year old (1+) and older fish (2+) was obscure for the Douglas, although somewhat clearer for the Curraheen. Trout in the Douglas were also smaller than the equivalent age-class in the Curraheen (Fig. 4.7). Two age classes were apparent for salmon in both rivers (0+ and 1+), with salmon smaller in the Douglas than the Curraheen for the equivalent age class, as for trout (Fig. 4.7).

The density of each age class of trout for the Douglas was moderately variable between stretches (Fig. 4.8). Total biomass showed a greater variability. Density and biomass for salmon was more variable between stretches than for trout (Fig. 4.8). The density and biomass of trout and salmon in the Curraheen was, in contrast, much more variable between stretches, with particularly high densities of 0+ trout in the upstream stretches (Fig. 4.9). Trout density was generally much higher in the Douglas. Trout biomass was highest for individual stretches in the Curraheen (Fig. 4.8 & 4.9) as was the variation in physical habitat. The coefficient of variation of salmonid abundance was far greater in the Curaheen than the Douglas (Fig. 4.4).

Much of the variation in salmonid abundance in the two rivers can be attributed to variation in physical habitat, both locally, between stretches (Douglas and Curraheen) and along the river (Curraheen only). Correlations between salmonid abundance and physical habitat parameters of stretches are shown in Table 4.4. The total density and biomass of trout and the density of 1+ trout in the Douglas were negatively correlated to the percentage of riffle and positively correlated to the percentage of glide within a stretch. In the Douglas, the percentage of pool did not correlate significantly with any salmonid metric. Mean depth positively correlated with 1+ and 2+ trout and trout biomass. Mean velocity negatively correlated with total trout density and biomass and the densities of 0+, 1+ and 2+ trout (Table 4.4). Relationships between salmon abundance and physical factors were weak. Mean velocity was negatively correlated with total salmon biomass and the density of 1+ salmon (Table 4.4).

In the Curraheen, the percentage of riffle positively correlated with total density, biomass and density of 0+ salmon, but showed no relationship to trout densities. In contrast to the Douglas, percentage glide correlated negatively with total salmon density and density of 0+ salmon. Similarly, percentage pool was strongly positively correlated with total trout density and biomass and densities of 1+ and 2+ trout, a marked contrast to the Douglas. Depth showed no relationship to trout abundance, but was negatively associated with salmon 0+ density. Velocity was positively correlated with total density and biomass of salmon and 1+ density (Table 4.4).

Table 4.4: Pearson correlation coefficients between salmonid (density and biomass) and physical parameters, Douglas and Curraheen Rivers. Significant (P<0.05, two-tailed test) correlations are indicated in bold type.

River	Physical parameter	Brown trout					Salmon			
		Total density	Total biomass	0+ density	1+ density	2+ density	Total density	Total biomass	0+ density	1+ density
Douglas	Riffle (%)	**-0.64**	**-0.71**	-0.17	**-0.80**	-0.44	0.26	-0.03	0.31	-0.38
	Glide %)	**0.60**	**0.68**	0.19	**0.73**	0.44	-0.13	0.16	-0.17	0.38
	Pool (%)	0.33	0.36	0.04	0.45	0.20	-0.30	-0.18	-0.33	0.17
	Depth (m)	0.42	**0.63**	-0.09	**0.62**	**0.55**	-0.40	-0.24	-0.42	0.07
	Velocity (ms^{-1})	**-0.72**	**-0.61**	**-0.65**	**-0.60**	**-0.55**	-0.32	**-0.56**	-0.26	**-0.69**
Curraheen	Riffle (%)	-0.094	-0.294	0.004	-0.215	-0.408	**0.604**	**0.519**	**0.651**	-0.099
	Glide %)	-0.134	-0.027	-0.171	-0.050	0.084	**-0.547**	-0.414	**-0.595**	0.115
	Pool (%)	**0.608**	**0.868**	0.438	**0.716**	**0.886**	-0.195	-0.316	-0.197	-0.034
	Depth (m)	-0.108	0.231	-0.220	0.024	0.488	-0.492	-0.398	**-0.575**	0.304
	Velocity (ms^{-1})	-0.392	-0.429	-0.303	-0.491	-0.372	**0.557**	**0.665**	0.457	**0.626**

Sampling efficiency

The cumulative mean densities of trout and salmon were calculated from stretches 1 to 15, for each age class and species, for both rivers. This demonstrated how the mean densities changed according to how many sample stretches were used to calculate the mean. The number of samples above which the cumulative mean varied by less than 10% (i.e. the number of samples necessary to stabilise the mean) was also calculated. For trout in the Douglas, this was 11 for 0+ trout, 10 for 1+ trout, 11 for 2+ trout, 10 for total trout density and 10 for trout biomass (Fig. 4.10). For salmon, this was 14 for 0+ salmon, 13 for 1+ salmon, 14 for total salmon density and 10 for salmon biomass (Fig. 4.10). For the Curraheen, the variability of trout density and biomass was so great that the cumulative mean did not stabilise within the 15 samples (Fig. 4.11). For salmon, the number of samples necessary to stabilise the mean was 14 for 0+ salmon, 11 for 1+ salmon, 14 for total salmon density and 14 for salmon biomass (Fig. 4.11).

The number of samples needed to estimate, within 95% confidence limits, the density of trout and salmon within a given accuracy, expressed as percentage of the true mean for both rivers is shown in Fig. 4.12. For example, for a true mean of 100 fish per 100m^2, an accuracy of +/- 50% would give an estimate of between 50 and 150 fish per 100m^2. An accuracy of +/- 100% would give an estimate of between 0 and 200 fish per 100m^2. The number of samples needed to estimate the true mean of trout and salmon was much greater in the Curraheen, owing to the greater variability (physical and biological variables) between sample stretches (Table 4.5). For example, 10 samples (i.e. 300m length of stream) were sufficient to estimate the true mean total density of trout to within an accuracy of +/- 30% for the Douglas and approximately +/- 90% for the Curraheen (Fig. 4.12). Ten samples gave an estimate of the true mean total density of salmon to within an accuracy of just under +/- 50% and 70% for the Douglas and the Curraheen respectively (Fig. 4.12).

The minimum number of sites required to achieve a certain precision of the mean for sites in the Douglas and Curraheen rivers is shown in Table 4.5.

Table 4.5: Minimum number of sampling sites required to achieve a certain precision of the mean on the Douglas and Curraheen rivers.

Coefficient of variation	No. sampling sites			
	Trout (Douglas)	Trout (Curraheen)	Salmon (Douglas)	Salmon (Curraheen)
0.2	1	14	3	8

0.4	2	25	6	14
0.6	5	56	14	31
0.8	22	224	55	123

Single-pass vs three-pass electrofishing

The density of salmonids caught in the first electrofishing pass for each stretch, for both rivers, was correlated against the density estimated by the Zippin multi-pass deplete fishing method (Zippin, 1956). There was a significant correlation ($P<0.05$) between single- and multi-pass estimated densities for brown trout, for all age classes, for both rivers (Fig. 4.13), although the correlation between the two estimates was weaker for 0+ trout than other age groups. Correlations were also weaker for the Douglas than for the Curraheen (Fig. 4.13). Similarly, the two estimates of salmon density were significantly correlated with each other, for both rivers, with correlations for the Curraheen being greater than for the Douglas (Fig. 4.14).

4.2.3 Discussion

This investigation has shown that salmonid populations are highly spatially variable, both between neighbouring stretches along an unpolluted river and along the length of a river with considerable longitudinal chemical variation (enrichment). Much of the variation in salmonid population density and biomass, in both rivers, was attributable to physical variation between stretches (local-scale variation) in mean depth, velocity and percentage of pools, riffles and glides. However, the relationship between physical attributes and fish populations differed subtly between the Douglas and Curraheen rivers. In the Douglas, trout density was strongly negatively associated with the percentage of riffle within a stretch and positively associated with the percentage of glide within a stretch. There was little association between trout or salmon abundance and the percentage of pools within a stretch. Mean depth was positively correlated with the density of larger trout and total trout biomass. Mean velocity was strongly negatively associated with abundance of trout of all age groups and also with total salmon biomass and 1+ density. In the Curraheen, however, there was a much stronger contrast between trout and salmon in the habitat associations. Trout showed a very strong positive association with the percentage of pool within a stretch, though little association with other physical variables. Salmon were positively associated with percentage riffles and negatively associated with percentage glide. They were also negatively associated with mean depth and positively associated with mean velocity.

These results demonstrate the complex nature of the relationship between local-scale habitat variables and salmonids. Such relationships between physical habitat and salmonid abundance are supported by many other studies. Trout are generally found to prefer slower, deeper water and salmon faster and shallower water (Kennedy and Strange, 1982; Heggenes *et al*, 1999 Crisp, 2000; Armstrong *et al*., 2003). Differences between age groups within a species are also apparent. Fry tend to be more abundant in shallow water, with fish being found in deeper water, as they grow older (Kennedy and Strange, 1982). However, these general findings do not apply to all systems.

Some studies have found gradient to be uncorrelated with salmonid abundance, with local-scale physical factors, particularly the percentage of pools in a system, being more important (Riley and Fausch, 1995; Issak and Hubert, 2000; Stichert *et al*, 2001). Previous studies on the Douglas river have shown the percentage of pool habitat in a stretch to be the dominant factor in the abundance and distribution of salmon and trout, with water current speed explaining little of the variation (Elso and Giller, 2001; Lehane *et al*., 2001). In this current study, fish in the Douglas were negatively associated with percentage of riffles and current speed. The inconsistencies between the current and previous studies may be due to small differences in methodology, hydrological conditions, temperature or study locations within the Douglas river, demonstrating the difficulty in defining precisely the response of salmonids to measured physical factors.

Habitat segregation between trout and salmon was much more pronounced in the Curraheen than in the Douglas, with trout in the Curraheen strongly associated with the percentage of pools (although not mean current speed or depth) and salmon associated with the percentage of riffles and high current speed. Such habitat segregation between the two species is also reported for headwater streams (Crisp, 2000; Armstrong *et al*., 2003). The difference between the Douglas and the Curraheen may be due to many factors such as water quality, food availability and stream morphology.

These physical and biological differences may change the response of the salmonids to local-scale physical habitat variation in many complex ways. For example, the presence of larger resident trout in the Curraheen (particularly older age groups which are rarer in the Douglas) may force salmon into competition and predation refugia associated with shallow, faster-flowing waters, whereas the generally smaller trout in the Douglas may not have the same impact.

Although small-scale physical factors, such as riffle-pool architecture, control the behaviour, distribution and abundance of salmonids within a stretch, larger-scale spatial and temporal factors, such as those that operate between tributaries within a catchment and between years will determine the overall abundance and productivity of salmonids within a river (Milner *et al.,* 1995). Salmonids are highly mobile species, even within the portion of the population that is resident within freshwater (see chapter 6). Many types of population movement exist, from very local riffle to pool movements by salmonid parr as they grow, spawning tributary to downstream reaches, stream to lake and, finally, stream to sea (Jonnson, 1985; Heggenes, 1988; Elliot, 1994; Crisp, 2000; Armstrong *et al.*, 2003). All such movements can confound measurements of density in a stretch or even an entire tributary at a given time, with inter-annual variation greater than between-reach variation (Meador and McIntyre, 2003). Other between-tributary or catchment factors exerting a greater effect on salmonid abundance than small-scale physical spatial variation include temperature (Stoneman and Jones, 2000), pH (Turnpenny *et al.,* 1987; Kelly-Quinn *et al.,* 1996), oxygen (Eklov *et al.,* 1999) and water quality (Heaney *et al.,* 2001).

Given the spatial and temporal variation in salmonid and non-salmonid populations, assessing their population densities presents an enormous challenge. Reasonably accurate information can be had for salmonid populations for a given stretch, reach or tributary, by intensive multi-pass depletion electric fishing.

The level of sampling intensity used, then, must be determined by the objectives of the study, the importance of the results and the availability of resources. Multi-pass depletion electric fishing, although probably the most accurate way of assessing a population at a given place and time, nonetheless is not infallible and there are several types of potential error and bias associated with factors such as fish size (Zalewski and Cowx 1990), river width (Kennedy and Strange 1982), insensitivity to electricity (Penczak, 1985; Bohlin and Cowx, 1990). Electric fishing efficiency can also decline between successive runs as fish become accustomed to the electric pulses (Cowx, 1995). Benthic species such as minnow, stoneloaches, sticklebacks, eels and lamprey juveniles rarely swim towards the anode (galvanotaxis) where they can be easily netted and instead become lodged under stones, boulders and vegetation, strongly reducing their catchability.

Perhaps the greatest inaccuracy involved in multi-pass deplete electric fishing is through the limited stream area that can be fished for a given sample effort. Although accurately assessing the density of fish in the limited area sampled, the results should not be assumed to be indicative of the abundance of fish throughout the stream.

Single-pass electric fishing over a measured length of channel without the use of stop-nets will not catch all the fish in a given stretch, however it has the advantage of being quicker and thus allowing a greater area to be sampled (Lobon-Cervia and Utrilla, 1993).

Single-pass time-based (5 minutes) semi-quantitative assessments have been used in Northern Ireland, since 1983 to monitor salmonid populations, as a practical alternative to conventional assessment methods using stop-nets (Crozier and Kennedy, 1994). Such semi-quantitative estimates are recommended where comparative data are sufficient, such as when spawning success or total abundance is compared between tributaries of a system or between successive years (Crozier and Kennedy 1995; Wyatt, 2002). Up to 15 sites can be fished in a day using this method, allowing a great many sites to be fished in a season, and estimates to be made for recruitment from a whole river system (Crozier and Kennedy, 1995).

Mitro and Zale (2000) investigated the accuracy of single-pass electrofishing methods compared to multiple-pass methods. They found that increasing the number of sites sampled by three and reducing the sample effort at each site by three (i.e. from three-pass to single-pass) increased the precision of sampling by 48%. Double-pass methods were examined by Heimbuch *et al.* (1997) and were found to reduce sampling time without reducing precision greatly. Reynolds *et al*. (2003) found that single-pass fishing in Western Oregon (USA) streams occasionally underestimated species richness by missing cryptic, mobile or rare species, but it usually estimated species richness and relative abundance as well as the intensive protocol. Importantly, single- and triple-pass population estimates tracked the same trends in population size at one site for 5 years.

The accuracy of single-pass fishing methods will depend on several factors. The heterogeneity of the site and the kinds of habitat encountered will dictate the ease of fishing. For example, boulders, deep pools, macrophyte beds and riparian tree root mats will make a stream more difficult to fish, by providing refugia for fish and making them more difficult to access with a net. Fishing quantified by time, rather than by area may bias fishing in the more complex and less accessible streams. Temperature and conductivity of the stream can also affect the catchability of fish, through the response of fish to electrical stimulus.

This current investigation found that the relationship between single-pass and multi-pass depletion density estimates varied with salmonid species, age-group and stream, indicating that calibrating the 'final' density for a stretch (i.e. that obtained from multi-pass deplete methods) from single-pass estimates is likely to lead to further inaccuracies. A minimum length of 30m in a stream with a mean width of 4 to 5m wide is clearly insufficient to adequately sample salmonid densities in a river, either in one with little longitudinal change or one with large change in abiotic, physico-chemical and biological status. We have found that an estimate of the mean accurate to within 50% would be attained by between 5 and 10 survey sites measuring 30m in length (i.e. between 150 and 300m length of river) on the Douglas and >20 survey sites for the Curraheen. Analysing the number of survey sites needed to stabilise the mean density (i.e. when successive cumulative means varied by less than 10%) revealed that this occurred for 10-11 survey sites stretches for trout and 12-14 survey sites for salmon in the Douglas. For the Curraheen river, the mean density and biomass of trout failed to stabilise over the 15 survey sites, owing to the large longitudinal variation in abundance. The mean of salmon density and biomass stabilised at between 11 and 14 survey sites. Employing a multi-pass depletion sampling method, two people can generally estimate fish populations from 2-3 sites of this length per day, once the site is identified and equipment installed by the river. Sampling 5-10 sites would thus take from 2-5 days to complete. This level of sampling intensity would be extremely costly and may not be acceptable as a monitoring tool for the WFD.

The WFD requires a methodology (with known accuracy and precision) with which to assess and compare fish communities (specifically abundance, composition and age structure) at sites in rivers over time. CEN (2003) states that in order to ensure that conclusions on abundance and age structure are valid for the target fish population, a sufficient number of sites should be surveyed. This number depends on the spatial variation (CV) among sites and whether assessing temporal trends or comparisons between populations is the main aim. For comparisons among fish populations the minimum number of sites for different CVs is shown in Table 4.6.

Table 4.6: Minimum number of sampling sites required (after CEN, 2003)

Coefficient of variation	Minimum number of sampling sites
0.2	3
0.4	4
0.6	9
0.8	16

Results clearly show that the number of sites required in a stream with low longitudinal variation is less than that for a stream with high longitudinal variation (habitat and environmental stress).

This study has revealed a coefficient of variation in salmonid abundance from 30m (mean width 4 to 5m) stretches between 40% and 70% for the river Douglas and between 100% and 140% for the Curraheen.

Evaluating fish populations across different rivers may only require relative (i.e. semi-quantitative) methods to deliver results of sufficient precision. Reducing variation by sampling a greater length of river, whilst still employing a multi-pass depletion methodology would, as discussed above, prove extremely costly in terms of manpower. Adopting single-pass, semi-quantitative techniques over a longer stretch would reduce sampling variation and increase accuracy and precision, without increasing sampling effort too greatly, however this method has a number of disadvantages which have already been outlined above.

Where many fish species need to be sampled or monitored within a single river, a variety of methods may be needed for assessing populations. Alternatively, correction factors can be applied to different fish species abundance obtained for a particular fishing method to allow for variation in fishing success (Cowx, 1995; Miranda and Schramm, 2000). In spatial and temporal monitoring programmes, focusing on relative differences and trends or change in fish assemblages rather than absolute abundance estimates can reduce the bias of a particular method (Wills and Murphy, 1996).

Variation in the success of a given sampling technique in accurately assessing populations of different fish species is due to differences in sizes, behaviour, spatial and temporal dispersal patterns and habitat preferences of different species. Small species such as minnow, stoneloach and brook lamprey, along with the juvenile stages of larger fish, are difficult to catch as they easily slip through the nets with large mesh size typically used for electric fishing in rivers and exhibit different sensitivity to the electric current. Species such as gudgeon, stoneloach, brook lamprey and eel also tend to hide under stones or among tree roots and marginal vegetation when stunned, rather than swim to the anode like larger fish.

The length of the sample stretch to be fished depends not only on small-scale variation in abundance for a given river, but also on the longitudinal change in fish abundance. Where such a change is apparent, such as that due to water chemistry in the Curraheen, segregation of the channel into different water body types will be necessary. It is for this reason that CEN

(2003) recommends that sites should be representative of the available habitats (physical and environmental stresses) within the watershed and each site should include at least one riffle, glide, pool sequence.

4.2.4. Conclusions

1. Salmonid densities and biomass in the two study rivers were associated with local-scale physical variation in the mean depth, velocity and percentage of habitat type (pool, riffle and glide) between stretches.
2. In the Douglas river, abundance of trout was negatively associated with mean velocity and the percentage of riffle within a stretch and positively correlated with mean depth and the percentage of glide within a stretch. The abundance of salmon was negatively correlated to mean velocity.
3. Habitat associations of trout and salmon were more strongly contrasting in the Curraheen river. Trout showed a strong positive association with the percentage of pool within a stretch, though little association with other physical variables. Salmon were positively associated with mean velocity and the percentage of riffle and negatively associated with mean depth and the percentage of glide within a stretch.
4. Salmonid populations were highly variable between sample stretches, both as a result of between-stretch differences in physical habitat (both rivers) and as a result of directional longitudinal environmental change along the river (Curraheen only). The coefficient of variation in salmonid abundance from the 30m sample stretches ranged between 40% and 70% for the Douglas and between 100% and 140% for the Curraheen.
5. An estimate of the mean salmonid density, accurate to within 50%, would be attained by sampling between 5 and 10 stretches (i.e. between 150 and 300m length of river) on the Douglas and greater than twenty stretches on the Curraheen (>600m).
6. The number of sample stretches in the Douglas needed to stabilise the mean density (i.e. when successive cumulative means varied by less than 10%) was between 10 and 11 for trout and 12 to 14 for salmon. For the Curraheen, the mean density of trout failed to stabilise over the 15 sample stretches, owing to the large longitudinal variation in abundance. The mean of salmon density and biomass stabilised at between 11 and 14 sample stretches.

7. Using single or multi-pass depletion fishing in unpolluted streams <5.0m mean width, at least 300m of river would, therefore, need to be sampled to obtain a good estimate of the salmonid populations in a river with only small longitudinal variation. In a river with greater longitudinal variation such as one with a physical habitat and/or pollution gradient along its length, e.g. the Curraheen. Survey sites representing each zone (each water body type) must be sampled.
8. Densities of salmon and trout estimated from single-pass fishing correlated significantly with densities estimated by the Zippin multi-pass depletion method. However single-pass fishing methods may be adequate for salmonids but inadequate for WFD purposes where all species must be monitored.

4.2.5. Recommendations

1. Single-pass, semi-quantitative electric fishing would be a more cost effective method than multi-pass depletion fishing for assessing populations over a large number of different rivers, however multi-pass is the preferred option as it reduces the risk of missing rare species and possible misclassification of sites in the context of WFD.
2. We recommend standardising by length of stretch fished, as streams differ widely in their ease of fishing. A sample length of between 300 to 450m (i.e. between 10 and 15 sample stretches of 30 to 45m in length) is ideally required for a typical unpolluted gravel bed river with a mean width of 5metres. Such a length would also encompass several different riffle/glide/pool sequences along the river, thus reducing the error obtained from sampling a single pool or riffle of unusual physical dimensions or nature.
3. For rivers with a high level of longitudinal variation in fish abundance, such as that due to pollution, physical habitat variation or human disturbance, then a greater sampling effort is required. Sampling sites must be a minimum of 10 to 20 times the river width (CEN, 2003).
4. The location of sampling stretch will generally be contingent on access and also depend on the reasons for monitoring (eg, determining populations above a migration barrier). However, the sample stretch must be put into a river-wide context (CEN, 2003). Knowledge of spatial dynamics of fish populations is required in order for a sample stretch to be sited appropriately along the river.

4.3 Lakes - Introduction

In addition to rivers Annex V of the Water Framework Directive (WFD) specifies a 3-year sampling frequency for fish stocks in lakes and transitional waters. Member states will be required to investigate fish communities (composition, abundance and age structures). Existing techniques to survey fish stocks in lakes in Ireland involve netting surveys and Catch Per Unit Effort (CPUE) estimates. A semi-quantitative sampling technique, using gillnets of different mesh size arranged in gangs (multi-panel nets) was developed in the late 1970s by the Central Fisheries Board (O' Grady, 1981) to assess trout stocks (trout > 20cm in length) on selected lake fisheries. Other species are also captured as by catch during these surveys which have proved to be an effective management tool in illustrating the fluctuations in fish stocks over time (Delanty and O'Grady, 2001). An extensive database has been developed based on this method. A specialised multi-meshed monofilament survey net is used in Sweden for fish stock assessment and the technique is being assessed for adoption as a suitable standard for the purpose of the WFD (Appelberg, 2000). However, both these methods are labour intensive and can result in high mortalities of the fish captured. Their use in privately owned lakes, or waters with rare, endangered (e.g. char) or designated species (e.g. Shad) is likely to be considered unacceptable. Development of "non-destructive" methods for fish stock assessment is urgently required for application in these situations.

Assessment of fish stocks in many lakes in the world has employed hydroacoustics (Duncan *et al*., 1998; Baroudy and Elliott 1993; MacLennan and Holliday 1996; Hughes and Hateley, 2002). Hydroacoustics is the use of high frequency sound to measure the densities, spatial distributions and sizes of fish. It has several advantages over the more traditional fish sampling methods:

- Rapid and continuous sampling of the water column over large areas
- Low sampling variance
- Cost-effectiveness
- Low fish avoidance
- Non-invasive

Hydroacoustic methods for sampling fish in very deep waters are well established (MacLennan and Simmonds, 1992) and are becoming more common in shallow waters (Kubecka *et al*., 1994). Few studies, however, have tackled the problems of assessing fish stocks adequately in water bodies which have intermediate depths and extensive shallow littoral waters (Hughes and Hately, 2002).

Hydroacoustic techniques, which could provide a significant reduction in costs of monitoring are not widely developed in Ireland but have been used successfully in Lough Erne (Rosell, 2000).

Aims of workpackage

This workpackage attempts to compare both techniques (gill-netting and hydroacoustics) on two lakes, and attempts to provide preliminary recommendations for sampling fish in lakes which is a requirement of the project.

4.3.1 Study area

Two lakes, one “shallow” (Lough Sheelin) and one “deep” (Lough. Melvin), were chosen for this study.

<u>Lough Melvin</u>

Lough Melvin is situated in the north-west of Ireland bordered by the Counties of Leitrim and Fermanagh. It is 12km long with a maximum width of just under 3km and has a surface area of 2125 hectares. Twenty eight percent of the lake is greater than 10m in depth with a shallower area around the islands in the Fermanagh section and at the western end 46% of the lake is <5m in depth. A deep trench runs east-west from Rossinver Bay towards the Drowse river outflow and has a maximum depth of 45 metres (Ferguson, 1986; Girvan and Foy, 2003). The geology of the catchment is dominated by carboniferous rocks predominantly sandstones and shales.

Lough Melvin has a unique salmonid fish community which originates from the end of the last Ice Age (13,000 years ago). Three varieties of trout occur in this lake, sonaghen (*Salmo nigripinnis*), gillaroo (*Salmo stomachius*) and ferox (*Salmo ferox*). These have been found to be genetically distinct species and can be readily identified on the basis of their morphological and meristic features (Ferguson, 1986; Ferguson and Taggart, 1991).

The water quality of Lough Melvin has been surveyed intermittently since 1990 and the lake has consistently demonstrated mesotrophic characteristics (Champ, 1998, McGarrigle *et al*, 2002; Girvan and Foy, 2003). The water in Lough Melvin is heavily peat stained which is thought to be the principal factor limiting primary production; the algal crop did not appear to change in diversity or abundance between 1990 and 2001/2002, but recent monitoring work on the lake has shown a substantial shift towards phosphorus enrichment with mean total phosphorus concentrations in the open water increasing from 19µg to 30µgP/l since 1990

(Girvan and Foy, 2003). There is evidence that blue green algal blooms are now more severe than previously.

<u>*L. Sheelin*</u>

Lough Sheelin is situated in County Cavan. It is 7km long has a surface area of 1900 hectares. Lough Sheelin is a shallow lake with a mean depth of 4.4m and a maximum depth of 15m (John *et al*, 1982) and fifty one percent of the lake is less than 5m in depth (Champ, T., CFB, *pers. comm.*). The geology of the catchment is predominantly carboniferous limestone but Silurian/Ordovician formations underly the western and northern drainage basin.

In the 1960s and 1970s Lough Sheelin was one of Ireland's top trout angling lakes, managed and developed by the Inland Fisheries Trust (now the Fisheries Boards). Phosphorus originating from intensive agricultural developments has caused progressive enrichment of Lough Sheelin (Champ, 1998 & 2003), the trout population has diminished and the fish stock is now dominated by cyprinids (O' Grady, CFB, *pers comm.*).

4.3.2 Methods

<u>*Gill netting*</u>

The method involves the use of standard "gangs" of gill nets ranging in mesh size from 5 to 12.5cm stretched mesh increasing at 1.25cm intervals. Each gang is composed of seven individual gill nets of 27.5m in length (O' Grady, 1981) joined end to end to create a single unit. These gangs were designed to capture brown trout of 19.8cm and greater. The netting sites were chosen by dividing the lakes into a numbered grid system of squares (250 by 250m), using an Ordnance Survey map (1:50,000). The specific sites were then chosen by random number generation. The nets were set at random at 30 sampling sites and fished over night (Delanty and O' Grady, 2001).

Of the 30 sites sampled, 15 were fished from the lake bed upwards into the water column to a height of 2m (on Lough Melvin only). These are referred to as bottom-fishing or sinking nets (bottom line weighted to sink the nets). The other 15 sites were set to fish from the water surface downward into the water column for a depth of 2m and are referred to as floating nets (extra buoyancy is added along the top line of these gill nets). "Sinking nets" were set at sites close to the shore or in shallow waters, while "floating nets" were set in deeper waters (Delanty and O' Grady 2001).

The netting surveys were completed over three days on each lake (July 2001-Lough Melvin and March 2002-Lough Sheelin) using three boat crews each servicing five gangs of nets on two consecutive nights.

All fish captured were identified, measured (fork length) and weighed. A subsample of fish was examined for weight, sex, degree of maturation, stomach contents and scales were removed for ageing (operculii were removed from perch and otoliths were removed from char). A subsample of cyprinids was returned to the lab for identification using pharyngeal teeth (Delanty and O' Grady, 2001).

Hydroacoustics

Scientific echosounders transmit short bursts of directed, high-frequency sound into the water using a beam-forming transducer. Sound propagates in the water as a pressure wave; any object whose density differs from that of the water (e.g. fish) scatters a fraction of the pressure wave back to the transducer (scattered sound = echo). With the aid of acoustic data processing software, the return echoes are used to measure fish densities, map fish spatial distributions and measure the size of individual fish targets. Acoustic beams are most sensitive directly below the transducer and less sensitive on the edges. A small fish will appear larger on the axis than a big fish on the edge so it is important to know where a fish is located in the acoustic beam. Calculating fish densities from acoustic data requires information on the amount of sound energy scattered by individual fish (target strength). The swim bladder is the primary soundscattering component of fish. Changes in the shape and orientation of the swim bladder strongly influence the target strengths of individual fish.

The hydroacoustic equipment was a Simrad EY 500 split-beam sonar operating at 120kz with the variable pingrate set at 10 and an interval of 0.1 seconds. Pulse duration was set to "medium" and bandwidth to its "wide" setting. Raw data were gathered and replayed for analysis, displayed at TVG (Time Varied Gain) set to 40logR for single fish detection as tracks. A circular 7^{o} beamwidth transducer was mounted on a pole and bracket housing and suspended 0.5m from the side of the boat and 0.4m below the water surface. A horizontally beamed elliptical (2.5 X 10 degree beam) transducer was tested on L. Melvin and L. Sheelin.. Echo signal processing was through the Simrad EY500 "replay", recording fish traces from echograms, supported by Target Strength analysis. Single echo detection was carried out with threshold of –70db in Lough Sheelin and –50db in Lough Melvin.

Each lake was divided into regions of approximately 1 km square each containing at least 2 km of sonar track. Given the angle of the conical beam at 7.2 degrees, the mean depth and length of each segment of 500 pings, length of each analysed segment varied from 150m to 350m depending on the depth. Shallow transects give a shorter ping return time and the sounder was set to ping as soon as the previous one was returned. The total insonified area can be cumulatively estimated in each square from the segments. This enables estimation of the total number of fish targets per hectare for each analysis square.

The SIMRAD vertical sounder data was replayed to give a printout with log interval of 500 pings and a navigation interval of 50 pings. This gives a transect plot with navigation data every 50 pings and short divisions of the trace with analysis of the target strength distribution every 500 pings. This trace was used to manually verify each target as a single target and give a fish count per hectare. Threshold for a fish target was set at –50db in Lough Melvin, This will miss some smaller fish, but the large mesh size selection of the net gangs justifies this. In Lough Sheelin, there were clearly very significant numbers of individual fish targets down to –60db or less, presumed to be mainly small roach.

Vertical sonar is not considered to be a viable method for the larger lowland lakes with extensive areas of depths less than 15m (Hughes, EA, *pers comm.*) (but was found to deliver satisfactory results in the deeper areas of Lough Melvin) as this would result in avoidance by fish and under sampling of the upper water layers, therefore a horizontal transducer was used on the Lough Sheelin survey.

4.3.3 Results

Gill netting

A summary of the survey findings in relation to all fish species is presented in Appendix 9. The principal fish species in Lough Melvin are trout, rudd, perch, char and salmon. The main fish species present in Lough Sheelin are trout, perch, roach, pike, bream and roach/bream hybrids.

Hydroacoustics

Lough Melvin

Numbers of fish per hectare for each analysis square (Fig. 4.15) are highly variable, ranging from zero fish recorded to almost 200 per hectare. The average fish density works out at 56 individuals per hectare and is almost certainly an underestimate, due to the inefficiency of the narrow vertical sonar beam in shallow water and the probable undercounting of very small fish. Several shallow water "boxes" had a count of zero, where the nets actually caught significant numbers of fish.

From the fish capture data in the nets in those "boxes" where there were both nets and sufficient sonar data, an attempt was made to correlate fish densities between netting and acoustic counts. (Figs 4.16 to 4.18). All the R square values were positive, ranging from 0.05

to 0.3. There does not appear to be a strong statistical relationship, though there are grounds for optimism that data have some meaning in the deeper water, higher numbers of fish in nets correlating, if not significantly, with more in the sonar counts.

Lough Sheelin

The fish stock survey on L. Sheelin was conducted from (12 to 14 March 2002), unfortunately strong winds militated against the gathering of meaningful acoustic data. Some acoustic survey tracks were attempted despite the weather conditions, using vertical pointing beams and the same SIMRAD EY500 and 7^o beamwidth split–beam transducer as used in Lough Melvin. Horizontal beaming, the only practicable means of surveying such a shallow lake, resulted in echo traces which were completely obscured by noise from bubbles.
Figure 4.19 shows an echogram in one of the few parts of the lake greater than 10m deep, and shows that at these depths, fish are clearly visible on the records. It is interesting that the fish themselves have very low target strengths, down to –60db or lower at `120kHz, and that on the few trace portions readable (all in the central deep area) fish densities per unit area were very high indeed, reaching many hundreds or even thousands of small fish targets per hectare In all probability the bulk of these fish were roach as it is known that roach congregate in the deeper water over winter and into spring (O' Grady, *pers comm.*). Figure 4.20 also shows the problem of wave action entraining bubbles into the surface layer – down to 4m or more, obscuring any fish echoes in the surface layer. Only fish in the water below 5m are visible.
Figure 4.20 shows an extreme example of shallow water with wave action (winds were in excess of Force 5 and reached force 8 on occasion during the three days), where bubbles are being entrained all the way to the bottom at 3m or more. Clearly, a subsurface horizontal beaming echo-sounder will not be of use in adverse weather conditions due to the echo-reflectivity of the entrained bubbles.

4.3.4 Discussion and conclusions

The objective of this module was to examine the results of two fish stock survey methods. Previous netting surveys have been conducted on Lough Sheelin in March and Lough Melvin in July. It was important, therefore, for comparison of the stock assessments with previous data that the netting surveys should be conducted at the same time using the same procedures.

The hydroacoustic technique also requires the use of selective deployment of gill nets to sample and therefore "ground truth" the target species encountered by this technique. The intention of running both methods in tandem in this study was that the gill nets deployed would deliver the ground truth element of the acoustic survey thereby eliminating the need for an additional “targeted” netting effort.

The traditional netting survey technique, based on random selection of the netting sites does not facilitate direct comparison of the methods. Given a short sampling period, deep water, and a structured approach to the netting it would be possible to correlate fish in nets with sonar counts. Ideally, nets would be set in each of the analysis boxes, and the sonar track and netting survey would be designed together.

Storm conditions affected the fishability of the nets on one of the days on Lough Sheelin. Excessive movement of the boat also compounded sampling difficulties using the sonar. This impacted on the hydroacoustic procedure on both lakes but was more pronounced with the horizontal system on Lough Sheelin. During one short period of calm conditions which persisted for several hours, it was possible to survey perhaps two thirds of the Lough Sheelin using the hydroacoustic equipment. Hydroacoustic surveys were conducted on both lakes in daylight hours and because dates were fixed it was not possible to be selective for calm conditions.

It is clear that in order to survey a shallow lake like Lough Sheelin and obtain meaningful fish counts, calm conditions are necessary. This applies particularly to shallow lakes, in contrast to deep lakes where wave action will still entrain bubbles but to a far shallower depth in proportion to the water column depth. In future, consideration should be given to carrying out such surveys at night or early morning in summer, to avoid wind and wave action as much as possible as recommended by the Environment Agency of England and Wales (Hughes, S, *pers. comm*).

It is also clear that, given the occasional very high numbers of extremely small targets, presumed to be small rudd, the standard gill netting mesh range of the trout survey method are operating as intended (net gangs designed to avoid capturing small fish) and the inclusion of smaller mesh nets would be necessary to sample the full range of age classes as required by the Water Framework Directive.

4.3.5 Recommendations

- Test acoustic estimates with nets using a structured rather than a random distribution and design the sonar track and netting survey together.
- Calm conditions are necessary for hydroacoustic surveys

- Ideally hydroacoustic surveys should be conducted during early morning or at night to avoid wind and wave action and when fish are more evenly distributed through the water column (to avoid shoaling fish) (Hughes, *pers. comm.*), however this may have significant health and safety implications and requires further consideration and evaluation.