



Marking farmed salmon with coded wire tags

Application note APC03

The feasibility of tagging and vaccinating all North Atlantic farmed salmon using NMT mass marking technology

Key features

- The coded wire tag (CWT) is a tiny, biologically inert, tag with no adverse impact on the fish
- Very rapidly, easily and inexpensively applied
- Huge coding capacity allows batch or individual identification
- Proven technology – about 50 million juvenile salmon currently tagged with CWT each year
- Automatic tagging equipment can also sort, grade and count fish, cost-effectively and without anaesthetic
- Incorporation of vaccination into automatic tagging lines currently under development
- Tags represent no human health risk
- Tremendous potential advantage for monitoring escapees and dispersion of escapees, stock husbandry, product traceability, improved vaccination efficiency and very precise grading.

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1. INTRODUCTION

1.1 Background

Production of farmed Atlantic salmon has increased tremendously in recent years. The production in the North Atlantic area was almost 600,000 tonnes in 1999, which is of the order of one hundred times the declared catch of wild fish. There is currently interest in a number of areas in marking all, or a significant proportion of, farmed juveniles before they are stocked in sea cages. This interest originated from concern over the ecological impact of farmed fish which escaped, and the potential to control and manage the situation if escapees could be readily identified and their source established. However, the potential advantages from the viewpoint of fish husbandry and quality control are now rapidly gaining appreciation. The interest so far has predominantly emanated from Europe, principally Norway (the largest producer of farmed salmon) and Iceland. However, interest is now developing in Canada, the USA and Chile.

This report represents a preliminary feasibility study for a programme of tagging all farmed salmon using NMT coded wire tags (CWT) and mass marking technology. It has been prepared by NMT and does not of course represent a specific proposal that such a scheme should be introduced; its aim is to explain how such a tagging programme might be achieved, what it could achieve and how, and what the costs are likely to be. If such a scheme is to be introduced it is of course essential that maximum benefit accrues all round; therefore the potential benefits to the salmon farming industry and to the consumer are also considered.

The CWT is a very small section of magnetised stainless steel wire (standard tags 1.1mm in length) that is injected into suitable tissue. An area of connective tissue and cartilage in the snout is the usual location selected for juvenile salmonids, and fish as small as 60mm can be tagged. The tag is marked with decimal numbers which allow batch or individual identification. Presence of the tag is determined using a magnetic detector but the tag must be recovered for decoding. Around 50 million CWT are currently put into hatchery-reared salmon each year, mostly on the US West Coast. They have also been used extensively on Atlantic salmon, with more than 12 million being used between 1990 and 1999 in 15 countries.

A system to automatically grade, sort, count, align, hold and coded-wire tag small fish has been developed and is in deployment for Pacific salmon in North America. This can handle and tag fish at a rate of up to 5,000 per hour and requires one operator plus an assistant. No anaesthetic is required. Development to incorporate vaccination into the operation is currently underway, supported by a \$2 million grant from the Advanced Technology Program of the US Department of Commerce.

1.2 Ecological concerns

Escapes, and perhaps intentional releases, occur at a level that results on occasions in large numbers of fish of farmed origin mixing with wild stocks in the high seas, in coastal waters, and in rivers. There is concern that these escapes and releases may have a significant impact on wild stocks in a number of ways, for example:

- through competition for food, space and spawning ground;
- by stimulating fisheries to develop that would also exploit wild stocks;

- by genetic interaction where escaped fish spawned with fish of local wild stocks;
- by acting as vectors of diseases and parasites.

In June 1994, NASCO passed a resolution "to minimise the impacts from salmon aquaculture on the wild salmon stock". In that document the following observation was made:

"Tagging or marking could be used in order to facilitate the identification of farmed salmon in the wild and their separation from wild fish, to determine the source of escapes and to assess the interactions of escaped farmed salmon with the wild stocks. The statistical significance of proposed tagging or marking studies should be assessed prior to implementation. The economic viability of tagging or marking large numbers of salmon produced in aquaculture should be evaluated."

In 1999, a document entitled "Environmental objectives for Norwegian Aquaculture – new environmental objectives for 1998-2000" was prepared by a consortium of six Norwegian authorities including the Directorate of Fisheries, the Norwegian Animal Health Authority, the Norwegian Board of Health and the Directorate for Nature Management. The contained the following recommendations:

E4. Escaped, cultivated fish should be able to be identified and traced back to their place of origin.

E5. Technology for mass marking of fish should be looked into and a suitable method of implementation should be tried out.

A study set-up to address E5 concluded that:-

"If hatchery produced fish in Norway are going to be tagged, use of coded wire tags is the best developed and tested method".

NASCO (see above) has maintained its interest in this issue. In April 2000 a Working Group to develop guidelines for containment was held between NASCO and the North Atlantic Salmon Farming Industry (NASFI) and they recommended that:

"Methods which would allow farm salmon to be tagged in a cost-effective manner, and which would address the industry's concerns about welfare of the fish and food safety aspects, and which would facilitate better identification of farm salmon in the wild, should be considered further".

Finally, in the ICES Advisory Committee on Fishery Management report to NASCO on North Atlantic Salmon Stocks dated May 2000 the following observation is made:

"Furthermore, ICES recommends that additional research into the behaviour, movements and survival of escaped salmon in the salmon farming industry in all areas of the North Atlantic be conducted. A universally applied marking system that would allow escapees to be readily identified when captured in fisheries and/or stock assessment programmes would be beneficial, since the relatively few farmed salmon observed in scanned catches

and the monitoring facilities in many areas makes inferences over large geographical areas impossible at this time.”

1.3 Advantages for husbandry and quality control.

There are a number of potential advantages in being able to identify fish at various stages in their rearing and marketing history. Although individual identification without having to handle the fish would be ideal, no cost-effective system can offer this nor is one likely to be developed in the foreseeable future. However, although the CWT has been recovered from the animal before its code can be determined, the system offers several major benefits. If a coded wire tag were to be implanted at the same time as the fish were vaccinated prior to salt-water transfer, the presence of CWT (determined using a magnetic detector without having to recover the tag) could be used to demonstrate vaccination status. Fish which died or were sacrificed could be identified to a particular batch, hatchery and vaccination date and its history since could be detailed.

Concerns over food safety, such as Salmonella in eggs, BSE in beef, use of therapeutic chemicals and use of genetically modified organisms, means that full traceability of products is becoming increasingly important. The use of coded wire tags as proposed here would allow any individual salmon, sampled at any stage in its rearing or marketing history, anywhere in the world, to be identified with respect to juvenile rearing site, vaccination and other treatment history, marine site, dates of stocking and harvesting, and any other relevant details. This could represent a critical part of an overall product traceability programme.

1.4 Current production of farmed salmon

The total production of farmed Atlantic salmon in the North Atlantic area in 1999 was about 586,000 tonnes. Of this, about 415,000 tonnes was produced in Norway, and 112,000 tonnes in Scotland. Other significant producers are Faroes, Canada, Ireland, USA and Iceland ; the figures for 1999 are presented in Table 1.

Table 1. Production of farmed Atlantic salmon in 1999 (in tonnes fresh weight).

a) North Atlantic area		b) Elsewhere	
Norway	415,000	Chile	150,000
GB (Scotland)	111,918	USA West Coast	5,000
Faroes	37,000	Canada West Coast	39,000
Canada	22,537	Australia	10,000
Ireland*	18,234	Turkey	1,000
USA	12,194	Other	500
Iceland	3,133	Total	205,500
Total	585,684		

*includes N. Ireland

Smolt production for marine farms in the north Atlantic area is of the order of 300 million per annum.

Salmon farming in Scotland involves about 73 companies using 104 sites to produce smolts, and 132 companies operating at 283 marine sites. In Norway in 1998 it is understood that there were of the order of 250-300 freshwater sites producing smolts for about 800 marine sites.

It is stressed that these and other statistics used in this paper are drawn from a range of sources and refer to a range of years. Production is rapidly increasing, in Norway for example at about 10% per year. The figures are used here only for indicative purposes for consideration of logistics.

1.3 Occurrence of salmon of farmed origin in catches and stocks

Several investigations have indicated significant levels of escaped farm salmon in high seas and home water fisheries at times. Until 1986 the occurrence in catches at Faroes was low, less than 5%. However, in the four seasons 1989/90 to 1992/93 the level ranged from 27 to 44%. Levels at West Greenland have been much lower, estimated at less than 2%. In Norway, 47% of the coastal fishery catch and 20% of the fjord fishery catch was of farmed origin in 1993. The level varied in 1993 between areas in Scotland, being highest in the north and west coastal fisheries (20-37%).

In 1991 a survey of emerging fry was undertaken in several Scottish North and West Coast rivers, analysing the fish for the presence of a pigment used in salmon farming. This pigment does not occur in wild salmon, but is passed on to juveniles through the egg yolk; presence in a juvenile therefore indicates that its mother was of farmed origin. In three rivers (Kerry, Dionard and Torridon) over 10% of fry contained the pigment, with over 1% on ten others of the total of the 16 rivers examined. As only about 65% of a sample of escaped fish contained the pigment, and as this method does not indicate the occurrence of spawning by male escapees, the results obtained are likely to be a significant under-representation of the true level of natural breeding by escaped farmed fish.

Incidence of escapees has generally been lower in recent years. However, with the rapidly increasing production, numbers of salmon in captivity are vastly greater than wild stocks, so that a small percentage escaping can still represent a significant level relative to wild fish. Over half a million escapees are estimated for Norway in both 1998 and 1999, and in 1999 almost 25% of the Norwegian "wild" catch was of farm origin.

2. THE REQUIREMENT

If all smolts stocked into North Atlantic marine farms were to be tagged, about 300 million tags would be involved per year. In order to provide appropriate information to be of use to managers of wild salmon stocks, it would be necessary to be able to identify the year of smolting and the marine site involved from the tag. About 280 marine sites are involved in Scotland and 800 in Norway; it is likely that of the order of 1500 sites are involved Europe-wide. Any tagging system must therefore incorporate provision for encoding with many thousands of unique codes.

It would be essential that a tagged fish could be recognised without the requirement for killing. It is not essential for the tag to be decodable in live fish. It would be important, however, that marked farmed fish can be separated from marked wild or ranched fish.

It is clearly essential that the marks be inexpensive to purchase, inexpensive and fast to apply, cause no trauma to the fish, cause no disfigurement to the fish, and represent absolutely no human health hazard.

If the tagging system is also used as an aid to regulate and monitor production, as a certificate of vaccination, or for product tracing, the following points are also important:-

- the marks must have a high retention rate;
- detection of the tags must be fast and simple;
- tags should not be re-usable or transferable between fish;
- counterfeiting of tags must be effectively precluded;
- tagging machines should have tamper-proof mark counters.

The coded wire tag (CWT) system manufactured by NMT satisfies all the requirements. No other system comes close to doing so.

3. A POSSIBLE APPROACH

3.1 Outline

The proposal is that ultimately all salmon smolts that are to be stocked into marine rearing facilities should be marked with a CWT. The decimal coding of each batch of tags would uniquely identify the date of tagging, the rearing station and the marine site involved. Typically tags would be supplied in spools of 10,000 bearing a single code. Any number of spools can be produced bearing the same code for different size batches. This would allow differential marking of different treatment groups e.g. by genetic origin or husbandry history.

The marking protocol would clearly have to be established by the appropriate bodies in each country. It is likely that the tagging would be undertaken by a specialist contractor, who would be supplied with appropriate numbers and codes of tags. Tags would be applied prior to smolting. The obvious opportunity is when fish are being graded and vaccinated; indeed there is likely to be scope for cost-effective multitasking by the one machine (see below). Tags appropriate to the marine site would be used on different batches of fish.

3.2 Type of tags

Standard length (1.1 mm x 0.25 mm diameter) or one and a half length (1.55 mm x 0.25 mm) CWT are suggested, though a coding system would be developed that was unique to farmed Atlantic salmon (e.g. a specific master word, or alpha-numeric code format). This would be desirable to ensure ready identification of farmed fish, and to protect existing allocations under the present formats. The optimal format would require careful consideration and consultation.

It would be proposed that sequentially-numbered batches of tags could also be made available to allow identification of small batches of fish for husbandry purposes. The rationale here is to ensure that the maximum possible benefit from tagging is available to all parties, including the fish farmer.

3.3 The mass marking machine.

While hand-tagging using NMT Mark IV injectors has been used to tag of the order of 50 million juvenile salmon per year, using such an approach to tag 300 million fish in a matter of weeks each year would pose major logistical problems. What makes this proposal viable is the availability of the NMT mass marking technology.

The mass marking machine was originally developed to address the requirement to remove the adipose fin from hundreds of millions of juvenile chinook and coho salmon each year on the Pacific Coast of North America, following a decision that all hatchery-reared fish for release to the wild would be marked in this way. The opportunity was taken to incorporate coded wire tagging into the process, though it was not the intention to CWT all fish in that application.

The process is computer-controlled throughout and at no time are the fish touched by hand or anaesthetised. The machine uses a patented volitional entry device at two stages of the process. First, fish enter the sorter by swimming against the flow. This determines the length of the fish to within 1.0 mm using video imaging, and sorts them into of seven size classes. Five of these are fed to individual clipping and tagging lines; the other two classes, too small and too large, are rejected for later processing. The fish distributed to each line again pass through a volitional entry device into the clipping and tagging chamber. Here the fish is firmly but gently held. The adipose fin is removed using a clipper guided to the correct location by automatic video imaging; the imaging system also acts as a quality control, to check that the fin has been effectively excised. A coded wire tag is injected into the snout at the same time. The fish then passes through a CWT quality control device which checks that it contains a properly magnetised tag; any that are not properly tagged are rejected and the system computer is informed. A five-line trailer is capable of clipping and tagging up to two fish per second, or 40,000 per eight hour shift.

It became apparent early on that this fish handling system could potentially be adapted to perform a range of tasks, including vaccination, in one pass. However, in order for the machine to overcome problems associated with some other attempts to develop automatic and semi-automatic vaccination machines, significant development was required. This is currently underway and includes achieving a very accurate location for needle penetration, accurate needle penetration depth, and carefully controlled dosing. These can be achieved as the equipment is capable of determining the length of the fish within close tolerances, and allocating them to different processing lines. The scope for this technology to be incorporated into stand-alone grading and grading/vaccination machines is also being assessed.

3.4 Location of tag

Positioning the tag in a non-eaten part of the fish would be prudent. The obvious choice of site would be the area of connective tissue and cartilage in the snout, as is generally used for wild salmonids. This has the following advantages:-

- it is a well established benign tag location;
- fish can be tagged at high speed - in excess of 800 per hour using a Mk IV injector, or up to 5,000 per hour with a mass marking machine;
- the tag is located well away from parts of the fish that are usually eaten.
- it is possible to recover the tag without affecting the market value of the fish.

3.5 Use of secondary mark?

The existing standard protocol for use of CWT on both Atlantic and Pacific salmon involves removal of the adipose fin to indicate a tagged fish. This is **not** proposed here for the following reasons:-

- even such minor mutilation may be unacceptable to fish farmers and buyers;
- such marked farm-origin fish could "swamp" smaller numbers of marked wild fish, making wild mark recovery more difficult;
- it would make it difficult to distinguish between tagged farmed fish, tagged ranches fish and tagged wild fish;
- new tag detection methods make a secondary mark unnecessary.
- fin clipping would represent an additional cost.
- the requirements of this proposal can be satisfied without a secondary mark.
- escaped farmed fish are often identifiable from external characteristics.

3.6 How would farmed escapees be detected and monitored?

In the absence of a secondary mark (e.g. adipose fin clip) how would fish of farmed origin be detected?

The first way is as at present, from external characteristics including body-shape and fin abnormalities. The presence of a tag could then be confirmed using a detector. If it were considered desirable to identify the source of the fish, the tag could be recovered.

Where farmed fish are perceived to represent a major part of the stock, or where it is desired to ascertain exactly the level of farmed fish in the stock, landings or rod catches could be scanned for tags using a tunnel detector, wand detector or portable sampling detector. Landings of several hundreds of fish could be checked in a few minutes and any found to contain a tag could be separated. Techniques are available whereby CWT can be removed from the snout cartilage via the roof of the mouth of dead fish, causing minimal disfigurement of the fish.

The numbers of fish that must be scanned and the numbers of tags that must be recovered from a sample to achieve statistical significance vary with the level of tagged fish in the population. This is discussed in more detail in Annex A, but in general terms the higher the proportion of tagged fish the smaller the sample size can be. Even small samples with no tag recoveries made can however be useful in indicating that marked fish do not represent a high proportion of the stock.

Thus catches or samples of just a few tens of fish which can be scanned for marks make a useful contribution. Samples running into hundreds clearly will give a more reliable indication, however.

Situations where reasonable numbers of fish might be scanned include commercial catches at the point of landing, fish merchants, large sport fisheries, experimental fishery catches (e.g. Faroës), smokehouses handling wild catches, seizures of illegal catches, fish kills, experimental traps (e.g. Burishoole in Ireland, Bushmills in N. Ireland, Montrose in Scotland, Dee (Chester) in Wales, Lune in England), broodstock collecting exercises, and programmes aimed at recovering escaped fish.. The last three situations (traps, broodstock collection and recovery of escapees) would allow removal of farm-origin fish from the breeding population with any wild fish being released. Large-scale catch-scanning programmes are already operated in many areas to recover coded wire tags, conventional tags or biological information, and extending such examinations to detect and recover tags from farm escapees would be straightforward. Up to 2 million CWT per year have been put into Atlantic salmon in the wild (wild and hatchery fish) in 15 countries and clearly there have been extensive catch scanning programmes in place to make recoveries.

In situations where farm escapees occur at a level that suggests that selective removal from spawning stocks is desirable, having all farmed fish tagged would greatly aid the conclusive identification of wild and farm origin salmon.

3.7 Advantages to the industry

While it is inevitable that a tagging scheme would represent some (hopefully minor) inconvenience to the fish farmer, there are a number of ways in which the scheme might offer positive advantages to the industry. These include:

- Vaccination can be achieved at low cost, with minimal trauma and without anaesthetic, more effectively than hand methods.
- The presence of a CWT could be used to indicate vaccination status.
- Very accurate grading can be achieved at the same time that the fish are tagged and vaccinated.
- The machine produces an accurate record of the size (within 1.0 mm) of all fish processed and sorted.
- Allocation of tags could be used to control the production on each farm and by each country, preventing over-production. In Norway, 10% overproduction appears to lead to a 25% fall in first-sale prices. The small cost of the scheme (calculated at 1% of

costs of production) could therefore be more than outweighed by the advantages of production and price control.

- Fish believed to have been stolen, or being marketed in an unfit state or in a non-approved manner could be traced back to the unit of origin. In this way honest and honourable operators would be protected.
- Farmers could use tagging data for husbandry purposes or trial evaluation.
- Offering product traceability could be a huge PR coup for the industry (see Section 1.3).
- Those responsible for escapes would be correctly identified, protecting blameless farmers from accusation.

3.8 Costs

Operating costs would be dependent upon the logistics of deploying the equipment, including the number of sites involved and their remoteness with respect to transport of equipment, the scope for spreading operations over several months, staff costs, and details of agreements with partners in each country. To some extent too the cost will depend upon which operations the equipment would perform at one time, though the marginal cost of each operation is fairly minor once the equipment is deployed. From experience in North America, NMT estimates that a large-scale operation (100 million plus fish per year), involving sorting/grading, counting, coded wire tagging and vaccination would cost of the order of 10 cents US per fish, including the cost of the tag, equipment and personnel but excluding the cost of the vaccine itself. The true cost could vary either way from this estimate but hopefully it is sufficient at this stage.

Using the following figures for Scottish farmed salmon (Scottish Office, 1993) :-

- mean survival from smolt to harvest, 1984-91, = 68.6% (range 57.9 - 86.5% between years);
- mean weight of fish at harvest in 1993 = 2.94 kg

we can calculate that each kg of harvested salmon requires 0.5 smolts to produce it. The cost of tagging and other processing therefore works out at 5 cents per kg of harvested salmon. The first-sale price of farmed salmon in Norway ranged from 26 NOK to 34 NOK (approximately \$4.00 – 5.20 US) per kg in 1995-96. The cost of grading, counting, tagging and vaccinating (excluding the cost of the vaccine) would therefore be of the order of 1% of the first-sale value of the harvest - but see "advantages to the industry" above.

The overall cost of processing 300 million smolts p.a. at 10¢ per fish would be of the order of \$30 million per year.

It must be noted that the costs quoted above are for a scheme involving more than 100 million tags per year. Costs per tag would be somewhat higher for any scheme involving many fewer tags.

3.9 Would marking part of the total farmed stock suffice?

In view of the cost and logistic complications of marking all farmed stock, the option of marking only a part of the stock must be considered. Would it provide the answers that are being sought, if for example, 10% of stock was marked? There are several reasons why it would be less effective than tagging of all fish, but it may still be a viable option.

First it would be important to ensure that the 10% of stock that was marked was representative of the whole, and was randomly mixed with it in each cage. This could be difficult to achieve. Second, it would be necessary to know that 10% had been marked; this would impose a significant requirement for checking and sampling. Third, when checking for occurrence of origin of farmed fish among wild stocks, samples of ten times the size would be required to obtain statistical significance. Thus the sample sizes in tables 2 and 3 (Annex A) would have to be increased tenfold. At the lower levels of proportion of farmed fish at least, many of these sample sizes become unrealistic. Alternatively, numbers of recaptures become reduced to a few individuals with no statistical significance.

Probably the strongest argument against partial marking would be that it would not offer effective product traceability or other potential advantages to the farmers. It is therefore suggested that a full tagging programme should be considered, as the medium-term aim. On the other hand, partial marking could provide much of the information required and could be a very realistic interim stage that would allow exploration of the costs and logistics of a full tagging programme. A partial tagging programme could be implemented using conventional tagging systems rather than mass marking; it could thus be started with a reduced lead-in time. It is likely that partial tagging will be examined as an option for any large-scale programme.

3.10 Could NMT meet the demand for tags and tagging equipment, and when?

NMT currently satisfies a demand for about 65 million CWT per annum, and associated tagging and detecting equipment. Stepping-up production to three or four times this would require additional manufacturing capacity, but this could be commissioned rapidly if the scheme were to be promoted. Large-scale tagging hardware, and the associated equipment could be supplied within one to two years. The requirement for tag detection equipment would depend upon how scanning and farm checking operations were to be proposed, but again no problem is foreseen. We therefore suggest that all supplies for a full-scale operation could be available within two years of a firm decision to proceed, and that a pilot scale operation could be mounted within months. These estimated lead-times are based on “conventional” coded wire tagging procedures not involving automatic vaccination. Timing of availability of the proposed automatic tagging and vaccination system would be subject to discussion and negotiation.

3.11 Robustness of the operation.

The NMT protocol for tag coding and quality control is impeccable and no wrongly-coded tags have been distributed in the 30 year history of the method. The Mark IV machines which are used as such and are also incorporated into the mass marking machine, are very robust and are designed and manufactured with continuous field operation in mind.

3.12 Animal welfare issues

All livestock farming activities and the associated treatment of animals are the subject of increasing concern regarding the welfare of the animals. Clearly any marking technique must be considered from this viewpoint.

The coded wire tag, being small, biologically inert, and completely enclosed in tissue represents the most benign of all existing fish tagging methods. Histological studies have demonstrated that there is no adverse tissue reaction to the presence of the tag, while other investigations have shown there is no effect upon survival, growth or behaviour. These observations contrast with those for some other marking methods, particularly those involving permanent penetration of the skin. We are confident that the CWT system will satisfy the most vigorous examination of animal welfare issues.

3.13 Human health issues

As stated in Section 2, it is essential that any marking system represents no hazard whatsoever for human health. The coded wire tag is a tiny, biologically inert section of stainless steel wire (see sample on front cover). It represents no hazard to humans if ingested, and in any case would be injected into tissue (the nasal cartilage) which is not commonly consumed in any country or culture. Up to 45 million CWT are put into Pacific salmon released to the wild each year in North America. The Japanese, who are fastidious over food hygiene and safety and consume most edible parts of fish, readily accept landings of salmon with CWT and are now using this marking system in their own investigation. We are confident that the CWT system will satisfy the most vigorous examination of human health concerns.

Further, in allowing individual fish traceability, the CWT system would make a major potential contribution to the interests of consumer safety and reassurance. Thus routine checks, or special checks of batches or individual fish of concern, at any stage in the rearing, wholesaling or retailing process, would allow the full rearing and husbandry history to be accessed.

4. CONCLUSIONS

From the above consideration it is concluded that coded wire tags deployed using the NMT Mass Marking technology represents a realistic, cost-effective and safe approach to marking all farmed salmon. The scope for tagging to be integrated with grading and vaccination could represent a major cost-saving opportunity. The potential for learning about the dispersion and migration of escapees, quality control and product traceability is tremendous.

It is stressed that the approach to tagging and associated operations discussed above is indicative only and that there is great flexibility possible in the overall planning and implementation of such a scheme. NMT will be delighted to discuss any aspects of this study and of their fish marking and handling technology with any interested party.

ANNEX A. STATISTICAL TREATMENT OF SAMPLING FROM ESCAPED FARM FISH AMONG WILD STOCKS

If sample sizes and proportions of escapees are large enough so that a considerable number of marked (farmed) fish are recorded, the statistics are straightforward and confidence limits can readily be calculated on the estimate of the proportion that is of farmed origin.

A reasonable target for the reliability of an estimate of the proportion of a stock that is marked might be 95% confidence limits that are $\pm 20\%$ of the estimate e.g. 0.15 ± 0.03 . In Table 2 the number of recaptures of marked fish, and the sample size needed to attain this target, are shown for a wide range of estimated levels of occurrence. Use of such a table during catch scanning exercises would allow sampling to stop when an adequate result was obtained.

Table 2. Numbers of recoveries needed and sample sizes required to give 95% ci of $\pm 20\%$ of the estimate of proportion marked.

Proportion of population estimated to be marked	Marked recoveries needed	Sample size needed
0.05 \pm 0.01	90	1800
0.10 \pm 0.02	90	900
0.15 \pm 0.03	80	534
0.20 \pm 0.04	80	400
0.25 \pm 0.05	70	280
0.30 \pm 0.06	70	234
0.35 \pm 0.07	60	172
0.40 \pm 0.08	60	150
0.45 \pm 0.09	55	123
0.50 \pm 0.10	50	100
0.55 \pm 0.11	45	82
0.60 \pm 0.12	40	67
0.65 \pm 0.13	35	54
0.70 \pm 0.14	30	43
0.75 \pm 0.15	25	34
0.80 \pm 0.16	20	25
0.85 \pm 0.17	15	18
0.90 \pm 0.18	10	12

It is likely that many samples would contain no tagged fish; clearly the larger such a sample is, the greater the confidence that the proportion of marked fish in the stock is very low. In Table 3 sample sizes containing no marked fish are plotted against the tagged proportion that would show at least one marked fish on 95% of occasions in such a sample. Thus, for example, if a sample of 300 fish contained no marks, one has 95% confidence that the true proportion of marked fish in the population is less than 1%.

Table 3.

Size of sample without a tag	95% likelihood that tagged proportion is less than:-
600	0.5%
300	1.0%
150	2.0%
100	3.0%
75	4.0%
60	5.0%
30	10.0%
15	20.0%
10	30.0%
6	50.0%

These examples are simplified, and assume that any escaped farmed fish are randomly mixed with the wild stock being sampled. In practice such fish may well be clumped, and detailed sampling protocols would need to be derived in order to develop the optimal sampling strat