Methods for Sampling Fish Populations in Shallow Rivers and Streams 1983

Methods for the Examination of Waters and Associated Materials

There are no proven methods yet for sampling fish populations in Deep Rivers, Lakes or Canals, but several methods are under study.

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About this Series

This booklet is part of a series intended to provide both recommended methods for the determination of water quality, and in addition, short reviews of the more important analytical techniques of interest to the water and sewage industries.

In the past, the Department of the Environment and its predecessors, in collaboration with various learned societies, have issued volumes of methods for the analysis of water and sewage culminating in 'Analysis of Raw, Potable and Waste Waters'. These volumes inevitably took some years to prepare, so that they were often partially out of date before they appeared in print. The present series will be published as series of booklets on single or related topics; thus allowing for the replacement or addition of methods as quickly as possible without need of waiting for the next edition. The rate of publication will also be related to the urgency of requirement for that particular method, tentative methods and notes being issued when necessary.

The aim is to provide as complete and up to date a collection of methods and reviews as is practicable, which will, as far as possible, take into account the analytical facilities available in different parts of the Kingdom, and the quality criteria of interest to those responsible for the various aspects of the water cycle. Because both needs and equipment vary widely, where necessary, a selection of methods may be recommended for a single determinand. It will be the responsibility of the users—the senior technical staff—to decide which of these methods to use for the determination in hand. Whilst the attention of the users is drawn to any special known hazards which may occur with the use of any particular method, responsibility for proper supervision and the provision of safe working conditions must remain with the user.

The preparation of this series and its continuous revision is the responsibility of the Standing Committee of Analysts (to review Standard Methods for Quality Control of the Water Cycle). The Standing Committee of Analysts is a committee of the Department of the Environment set up in 1972. Currently it has seven Working Groups, each responsible for one section or aspect of water cycle quality analysis. They are as follows:

1.0 General principles of sampling and accuracy of results
2.0 Microbiological methods
3.0 Empirical and physical methods
4.0 Metals and metalloids
5.0 General nonmetallic substances
6.0 Organic impurities
7.0 Biological monitoring
8.0 Sewage Works Control Methods
9.0 Radiochemical methods

The actual methods and reviews are produced by smaller panels of experts in the appropriate field, under the overall supervision of the appropriate working group and the main committee.

The names of those associated with this method are listed inside the back cover. Publication of new or revised methods will be notified to the technical press, whilst a list of Methods in Print is given in the current HMSO Sectional Publication List No. 5.

Whilst an effort is made to prevent errors from occurring in the published text, a few errors have been found in booklets in this series. Correction notes and minor additions to published booklets not warranting a new booklet in this series will be issued periodically as the need arises. Should an error be found affecting the operation of a method, the true sense not being obvious, or an error in the printed text be discovered prior to sale, a separate correction note will be issued for inclusion in that booklet.

L R PITTWELL
Secretary

1 July 1987

Warning to Users

The procedures given in this booklet should only be carried out by competent trained persons, with adequate supervision when necessary.

Local Safety Regulations must be observed.

Pay special attention to the advice given in the Legality and Safety Sections.

Operations should be conducted with due regard to possible local hazards, and portable safety equipment should be carried.

Care should be taken against creating hazards for one's self, one's colleagues, those outside the work place, or subsequently for maintenance or waste disposal workers. Where the Committee have considered that a special unusual hazard exists, attention has been drawn to this in the text so that additional care might be taken beyond that which should be exercised at all times when carrying out analytical procedures. Use only properly maintenanced apparatus and equipment of correct specifications. Specifications are given in manufacturers catalogues and various published standards.

Lone working should not be permitted.

The best safeguard is a thorough consideration of hazards and the consequent safety precautions and remedies well in advance. Without intending to give a complete checklist, points that experience has shown are often forgotten include; tidiness, use of correct protective clothing, escape routes and the accessibility of the correct and properly maintained first-aid, fire-fighting, and rescue equipment. If in doubt, it is safer to assume that the hazard may exist and take reasonable precautions, rather than to assume that no hazard exists until proved otherwise.

There are numerous handbooks on first aid and laboratory safety. Among such publications are: 'Guide to Safe Practices in Chemical Laboratories' and 'Hazards in the Chemical Laboratory', issued by the Royal Society of Chemistry, London: 'Safety in Biological Laboratories' (Editors Hartree and Booth), Biochemical Society Special Publication No. 5, The Biochemical Society, London, which includes biological hazards; and 'The Prevention of Laboratory Acquired Infection' Public Health Laboratory Service Monograph 6, HMSO, London.

It cannot be too strongly emphasised that prompt first aid can save life; but that incorrect treatment can make matters worse. It is suggested that both supervisors and operators be familiar with emergency procedures before starting even a slightly hazardous operation, and that doctors consulted after any accident be made familiar with the nature of the injury. Some very unusual parasites, viruses and other micro-organisms are occasionally encountered in samples and when sampling in the field. In the latter case, all equipment including footwear should be disinfected by appropriate methods if contamination is suspected. If an ambulance is called or a hospital notified of an incoming patient give information on the type of injury, as the patient may be taken directly to a specialised hospital.

Legality and Safety (See also Section 3)

General

1. The provisions of the Health and Safety at Work Act and the detailed information given in the relevant Health and Safety Executive publications should be carefully studied and put into effect; as should also the Water Authority Association Safety Advisory Broad Sheet 'Working in or near Water', and the National Joint Health and Safety Committee for the Water Services Health and Safety Guidelines No 6, 'Safety in Electric Fishing Operations'.

2. Personnel engaged in sampling must make themselves familiar with the safety equipment and procedures available to avoid physical injury etc; and, if used, with boats and motors.

3. Weather and, if applicable, tide conditions should be ascertained prior to sampling; but allow for unexpected changes and spates.

4. Before attempting to obtain samples, the sampler must be satisfied that both access to and the egress from the sampling point can be achieved with complete safety, bearing in mind the sampling and other equipment which may have to be carried.

5. Information on one's wheareabouts and an approximate timetable should be left with a reliable person prior to starting. If possible, ensure that this person is notified on return, to avoid placing the rescue services needlessly at risk. A written record or log is useful. In hazardous situations, provision of a 'safety man', who stays in a known safe place to keep watch on and for the sampler is recommended. Such a person should always summon help prior to going to the assistance of a sampler in distress, lest both should get into difficulties and be unable to summon help. A radio or telephone is recommended.

6. Lone working should not be permitted. When working as part of a group, each person should know the location of every other person and contact with each individual in the group must be made at regular intervals. A buddy system is useful.

7. Always ensure that at least one, preferably more, members of the party are familiar with the local terrain and its climatic hazards. In unfamiliar areas it is wise to consult the local organisations, such as Water Authorities, for information on hazards such as weirs and sluices.

8. Care may also be needed in some localities to guard against bacterial and parasitic infection, pathogenic fungal spores, plants with toxic or vesicant parts and harmful wildlife; nor must it be forgotten that exceedingly dangerous compounds ranging from toxic wastes, to flammable oils, high explosives and white phosphorus have been found both in bank and river bed deposits and that flammable gases such as methane and phosphines, alkyl mercury and arsenic directives and compounds such as chloromethyl sulphonium salts can be synthesized by natural organisms. Proper protective clothing and first aid equipment should be used when necessary.

9. In addition to the normal risks from falls, sampling on or close to open, deep or fast flowing water carries a risk, even if only slight, of drowning and, especially in cold weather, of hypothermia. Remedial action should be rapid; but do not abandon attempts at resuscitation unless medically advised, or other criteria overrule, because instances are known where the effects of hypothermia have modified the effects of drowning.

10. A life jacket should be worn at all times when working near or on fast flowing or deep water (more than knee deep). A life jacket is a safety garment which guarantees that an unconscious victim will float face uppermost.

Working on or from the Bank or when Wading

Sections 1 to 10 also apply

11. In cold weather, warmth and shelter should be available if the work is in exposed windy places or there is risk of falling into water. Always carry spare warm clothing.

12. Where sampling is from exposed road or railway bridges etc retroflective jackets must be worn. If a bridge or dock is narrow, look outs should be posted to give adequate warning of approaching traffic. Where there is no general public access, prior consultation with the owner is essential.

13. Quicksands and bogs are hazards, hence if ground is not known to be firm, it should be tested for firmness before being walked on or driven over. Duckboards, sand trays and similar devices may also be a help. Attention should also be given to unstable slopes and overhanging rock or structures.

14. If there is any risk of losing one's footing and if any of the following circumstances apply, the sampler must not enter the river unless wearing an approved buoyancy aid and then only if satisfied that it is safe to proceed.

a. Rivers where access is by steeply graded banks the slope of which continues up to the edge of the river.

b. When the river is more than 2 ft deep or when the bed of the river has an accumulation of soft (penetrable) mud. As a general rule, rivers which require the use of thigh waders would fall within this category.

c. The sampling point, although shallow, is just upstream of very deep water or falls.

d. Where the river is in flood or is so discoloured that any dangerous obstructions may be hidden from view.

15. Where river flow is fast, a catenary chain or rope should be hung downstream at water level.

16. A helmet or 'hard hat' should be worn if there is risk of falling objects or similar blows to the head.

17. Avoid quicksand or bog on the beach or bank, and cliffs or steep banks.

18 Field personnel should identify sites where access is considered unsafe. These sites should be notified to the Supervisor who will arrange either to eliminate or to change the sampling point or method of sampling, as appropriate.

Sampling from Small Boats, Pontoons, Buoys and Piers

Sections 1 to 10 also apply

19. No boat, vessel, or pontoon is to be used without the knowledge of the appropriate Supervisor. If relevant, permission of the appropriate operations controller for the site must be obtained and observance of the site safety rules and rules relating to working in boats is imperative.

20. Do not use inflatable craft.

21. If the boat is taken ashore it should not be left unattended. Care should be exercised on the approach to any landing to ensure adequate water for the motor and reduce the risk of seriously damaging the boat on submerged or protruding obstacles. The use of a boat rope is recommended when recovering or launching the boat.

22. Before deploying the boat, the person in charge should be briefed on the operation, possible navigational dangers, weather, traffic and pick-up point.

23. Keep a watch on weed and debris which could foul propellers or intakes.

24. Personnel in the boat should wear protective oilskins as well as lifejackets. Warm protective clothing should be carried.

25. Try to keep the boat 'shipshape' at all times, as less accidents are likely in a tidy boat. A very common cause of danger is loose rope and odd bits of equipment lying around, plus loose coils of cable when electrofishing.

26. Keep to the centre-line of the boat and avoid standing-up whenever possible.

27. The single manning of vessels must not be permitted.

28. Before any activity is undertaken it must be clearly agreed who is in charge of the vessel. That person must be proficient in boat handling and have attended an approved training course on boat handling. If practical, boats should not be deployed during the hours of darkness, fog, heavy rain or any seriously reduced visibility.

29. Not more than one non-swimmer will be permitted in or on a vessel at any one time. Non-swimmers are not permitted to take charge of a vessel.

Persons in charge of a vessel must ensure the following:

a. The regulations are adhered to;

b. Safe loading and unloading procedures are used;

c. All occupants on a vessel conduct themselves in a manner which does not endanger themselves or others;

d. That the vessel is fit for its intended use and in good repair;

e. Keep a watch on the weather and be prepared to abandon work if it deteriorates seriously enough to make the use of the vessel hazardous. All scientific staff should be able to interpret weather forecasts and, when appropriate, a record of weather forecasts should be kept for planning purposes.

30. The person in charge must make sure that they know the carrying capacity, speed and endurance of the boat and that there is an adequate reserve of fuel. Obtain local knowledge of hazards (hidden obstacles, outfalls, weirs, currents, tides, quicksands etc).

31. The boat's equipment should consist of oars or paddles, pump, bailer, (torch if deployed at night and no navigational lights are fitted) small anchor and line, bow line, man overboard line and grommett, hand held distress flares kit and any other equipment which may be practically stowed in the boat to enhance the safety of personnel, such as a spare bung, a reserve fuel tank, a tool box (carrying basic tools such as pliers, screwdriver, adjustable spanner etc) together with a basic spares kit, plugs etc. Anyone using part of the spares kit should make it their duty to replace any items used up at the earliest possible opportunity. If the boat has an engine, the proper fire extinguishers must be carried. The person in charge should have clear ideas on what steps to take regarding safety and have a knowledge of the use of life saving and any fire fighting appliances carried.

Emergencies

Man Overboard

32. It is possible to fall overboard unobserved even when other people are on deck, and two aspects of the matter should be kept in mind—first, going over is very easy and second getting back is usually very difficult. If no steps or rope ladder are available, the simplest form of aid to allow a person with water logged clothing to get back on to a boat is a bight (loop) of rope for the foot. But unless the victim is agile and circumstances ideal it is wise to take the extra precaution of securing a line around the chest under the armpits. A member of the crew can keep shortening it so as to keep this line short to ensure that any ground made good is not lost. First a bight of rope is lowered to a length which allows the person in the water to get a foot in it and 'step' up by about six inches. Then the safety line is shortened in and made fast so that there is no risk of slipping back. Next the foot rope is shortened so that the person can raise himself or herself another six inches by the power of their own leg muscles and so on.

Apparent Drowning

33. If possible, while proceeding with the advice which follows, send for medical assistance and transport. This may be necessary with an unconscious victim. The modern method of artificial respiration is to use your own lungs to pump air into those of the victim. It is simple to do and easy to understand, far more so than any of the older methods.

Speed is important and the drill is as follows:

Lay the victim on the back.

Clear the mouth of anything that may be an obstruction and remove false teeth.

Tilt the head back by pressing the forehead with one hand while the other provides support under the nape of the neck. Now use one hand to hold the forehead back while its fingers pinch the nostrils to close the nose, and with the other hand control the jaw so that the mouth is sufficiently opened to mate with your own. Make sure the tongue has not dropped back to block the throat. Take a deep breath, open your mouth wide and seal your lips around those of the victim.

Exhale into the lungs until they are filled.

Remove your mouth and watch the chest fall. Then repeat.

If necessary, treatment can be begun in the water, and air can be delivered through the nose. The frequency of respiration should be about once every 5 or 6 seconds.

After inflating the lungs 5 or 6 times the patient should begin to look better, if the heart is working.

Heart massage may be necessary. Raise the legs above the level of the chest. Thump the breastbone hard with your fist. Start pressing the breastbone rhythmically at a rate of about once a second. If single handed, do that about 15 times before going back to forced respiration. Then after 5 lungs inflations go back to heart massage.

Effects of Cold (Hypothermia)

34. One danger that is not widely understood is that of hypothermia—a lowering of the body temperature due to immersion in cold water. If the rescued person needs no artificial respiration or heart massage, but seems shivery, unable to see, hear or speak properly, or not in normal control, then hypothermia must be considered likely.

Do not make the mistake of trying to warm anyone up rapidly; but at the same time any further loss of heat must be prevented. Time must not be wasted in removing or changing the victim's wet clothing, but wrap up and protect from the wind at once. This does not mean merely putting a blanket over the patient lying on a berth—it means cocooning so that all possible routes for heat loss are sealed off.

Sugar, sweetened condensed milk and other forms of sugar can be given, but do not give hot drinks or alcohol at this stage, nor a hot water bottle. Sudden heating may prove fatal. Restoration of breathing and blood circulation are of prime importance.

Get medical attention as quickly as possible.

Electrocution

35. Switch off the electricity supply involved. Send for expert help

36. Do not risk electrocuting yourself. Remember wet materials are conductors.

37. If necessary restore breathing and heart beat (see 33 above).

38. Treat shock (similar to 34 above).

Methods for Sampling Fish Populations in Shallow Rivers and Streams 1983

1 Performance Characteristics of the Method

1.1	Biota sampled	Fish
1.2	Habitats sampled	Shallow rivers and streams (maximum depth 1.5 m)
1.3	Type of sampler	Electro-fishing apparatus.
1.4	Basis of operation	Stun and/or attract by electric current and remove by handnet.
1.5	Form of data	Qualitative or relative abundance or quantitative.
1.6	Limitations of method	(i) Water depth: method restricted to shallow water (up to c.1.5 m). (ii) Reduced efficiency with increasing channel width. (iii) Reduced efficiency with increasing turbidity. (iv) Variable size selectivity depending on type of electro-fishing gear, species present, physical and chemical properties of river fished. (v) Decreasing catchability during repeated fishings in situations where probability of capture of fish is relatively low.
1.7	Efficiency of method	Variable, therefore should be separately estimated at each site for quantitative sampling.
1.8	Logistics of sampling	Generator and accessory equipment used by 3–5 people. Boat required in water deeper than 0.60 m.
1.9	Safety	Electric fishing is potentially hazardous. Personnel must be properly trained and only suitably designed equipment must be used. Health and safety guidelines to be followed at all times.

2 Introduction

2.1 Sampling of fish populations can be necessary for a variety of reasons. At its simplest, sampling can be required in qualitative studies on fish distribution where simple presence or absence of different species of fish is the only information required. A typical situation where this type of sampling would be carried out would be in a preliminary survey of a river system which was recovering from pollution, and where fish might be becoming re-established. More commonly, however, sampling is required to provide some quantitative information about the populations of fish present in a water. This might involve studies on growth and age composition where the sample would have to reflect as nearly as possible the size and age distribution of the population as a whole, or might be associated with studies on the numbers of fish present. This method deals primarily with sampling of populations to obtain quantitative information which enables estimates of population size and biomass to be made. Information of this type is required widely in fisheries investigations and in fisheries management work. Situations where the methods described here might be applied and the objectives which can be achieved are summarised in Table 1.

Table 1.

Situations Where the Method Could be Applied
1. Provision of basic information on the status of fish stocks, eg species present, size/age distributions, relative abundance of different species, and estimation of population numbers, together with variances, standard errors and confidence limits for such estimates.
2. Monitoring the effects of management actions such as re-stocking, culling, conservation measures.
3. Measuring changes in fish populations resulting from habitat perturbations such as land drainage schemes, river regulation schemes, etc.

Because of their sensitivity to pollution, fish, although mobile, are useful as indicators of water quality. Information on the numbers and species of fish present can be of considerable value when assessing the conditions of a water. However, fish can be absent for other reasons, such as an unsuitable substrate, and lack of fish does not necessarily infer poor water quality.

The simplest method of obtaining a reliable census of fish numbers if time permits, is to keep repeating fishing runs until no more fish are caught. However, this approach is not practicable in many situations, and recourse has to be made to estimates based on sampling a proportion of the population.

It is a requirement of most of the methods used for estimating the numbers of fish in a population that a relatively large proportion of the fish in the area being sampled is caught. Large scale qualitative surveys may also capture considerable numbers of fish. It is likely, therefore, that extensive surveys of fish populations could be damaging to the stock if the fish caught were killed. The methods described here are therefore constrained by the need, wherever possible, to return alive and unharmed to the water all the fish caught.

2.2 **Interpretation of Population Size Estimates.** The methods described below give a reliable assessment of the fish populations present at the site on the day of sampling. Care must be taken in the extrapolation of results to the population in the larger area from which the sites have been chosen. In any circumstances where an estimate of the total stocks over a large area of water is required a mean value obtained from a number of sites will provide an estimate which in most cases will be sufficiently accurate for fisheries management purposes. However, the reliability of such an estimate will depend on the number of sites sampled, whether they are representative of the variety of habitats present and the size of the sum of the area sampled relative to the total size of the area being assessed. Experience suggests that the total area sampled should be at least 5% of the total area being assessed, and never less than 1%. For strongly clumped populations such as those of shoaling species the estimates will be less reliable than for more evenly dispersed populations (given equal sampling effort) and the dispersion pattern of the fish, as judged from the data from a number of sites, should be examined carefully before drawing firm conclusions based on the quantitative results. In large rivers coarse fish populations may undergo very pronounced seasonal clumping and care must be taken to allow for such seasonal factors when planning survey programmes.

2.3 In comparison with large rivers and lakes, small rivers are relatively easy habitats to sample, and the method most commonly used is electro-fishing. This technique is generally applicable in streams and rivers up to 15 m wide with a maximum depth of about 1.5 m.

2.4 The use of electricity to catch fish is a basic fishing method with a very wide range of applications. For compiling species lists in different watercourses it is probably the most generally applicable and most efficient of all sampling methods (although in very fast flowing or turbid rivers difficulties may be experienced if stunned fish are swept downstream before they can be removed by handnet). Relative abundance data can also be collected for species of comparable sizes but the method is less efficient for the capture of smaller fish and thus the small species and fry of large species are proportionately under-represented in quantitative samples. Fully quantitative data can be obtained for fish above a critical size by estimating numbers and catch efficiencies for each species separately and also calculating numbers and catch efficiencies separately for different size groups within each species where necessary.

2.5 The stunning and/or attraction power of any of the current forms used for electro-fishing is related to the characteristics of the gear, the conductivity of the water and the potential difference along the length of the target fish. The orientation of the target fish in relation to the potential gradient is also a factor. Fish facing towards the anode will be more readily stunned than if facing away or side-on. At any one location large fish will be more readily stunned than small fish.

3 Legality and Safety

3.1 **Legal Aspects.** Both the possession and use of electrical devices to sample fish is restricted, in England and Wales, by the Salmon and Freshwater Fisheries Act, 1975, Sections 5(i), 5(2) and 5(4), to scientific and management purposes, subject to written permission from the appropriate Regional Water Authority. Similar restrictions apply in Scotland and Northern Ireland. Permits to use electro-fishing gear in Scotland must be obtained from the appropriate District Salmon Fisheries Board if salmon are being sampled, or from the Department of Agriculture and Fisheries for Scotland where there is no District Board, or when trout or freshwater fish are to be sampled. In Northern Ireland, written permission must be obtained from the Department of Agriculture for Northern Ireland.

There are similar legal restrictions on the use of nets, and prior permission for their use must be obtained from the bodies mentioned above.

In all cases, permission must also be obtained from the owner of the fishing rights on the water concerned, otherwise an offence may be committed under the Theft Act, 1986.

3.2 **Safety.** Electric fishing is potentially hazardous as voltages in excess of 200 are used, hence only trained personnel with appropriate equipment strictly adhering to 'health and safety' guidelines should be used. Design criteria and codes of practice for operators are given in:—

'National Joint Health and Safety Committee for the Water Service. Safety in Electric Fishing Operations. Health and Safety Guidelines No 6, 32 pp 1983.'

The following advice is also useful:—

'Hartley, W G (1975). Electrical fishing apparatus and its safety. Fish Mgmt *6*: 73–77.'

Points of particular importance are:—

(i) Generators used for electro-fishing must not be earthed, and should be used only for electro-fishing. The generator must be labelled with an appropriate warning to this effect.

(ii) Power must not be fed direct from the generator to the electrodes, but must be fed via a control box.

(iii) Outputs from the control box should be via non-interchangeable, polarised connectors so that anode, cathode and control circuit connectors are separate and not compatible with one another.

(iv) Power must not be fed direct from the control box to any fishing electrode, but must be switched on each pole by an interrupting device controlled from a safety, extra-low voltage (< 50 v) control circuit employing electro mechanical relays or a pneumatic system designed to fail safe. This control circuit must be consciously maintained by the electrode operator and must immediately interrupt the power supply to the electrode when released. (*Note.* As well as being a safety device, an on-off circuit of this type can facilitate the actual fishing operation).

(v) Electrical connections within the electrode handle and low voltage control switches must be waterproofed. (Control switches to BS 3490).

(vi) Fishing electrodes must never be energised unless immersed in water.

(vii) Landing net handles, buckets and fish containers must be of non-conducting materials.

(viii) Appropriate personal buoyancy aids must be worn when fishing from boats or near deep or fast-flowing water.

(ix) Waders should be sound and free from leaks.

(x) Prior to use, equipment should be thoroughly inspected, paying particular attention to generator electrical control gear and cable insulation. Mechanical operation of safety switches should be checked before energising the equipment.

(xi) Electric fishing gear should be checked for mechanical and electrical faults at intervals related to degree and condition of use, but not greater than 6 months. These checks must be carried out by suitably qualified technicians.

4 Equipment

4.1 For qualitative sampling by electro-fishing including assessments of relative abundance, the basic gear consists of a portable electrical generator capable of supplying 200–300 volts, linked via a control box to electrodes in the water which form the active fish-stunning elements (Figs 1 and 2). The control box regulates the flow of current to the electrodes, and may also rectify an AC input to produce DC output, preferably in the form of pulses. Hand nets with insulated handles are also needed for removing stunned fish from the water.

4.2 For quantitative surveys of fish populations, unless adequate natural barriers are present, the survey area will have to be bounded by stop nets. These need to be rigged in such a way as to provide a good seal against immigration to and emmigration from the survey section. As small a mesh size as is practicable should be used. A stop net with 20 mm knot-to-knot mesh (10 mm bar) will generally retain fish greater than 10 cm in length, but this would only permit valid population estimates for fish exceeding this size.

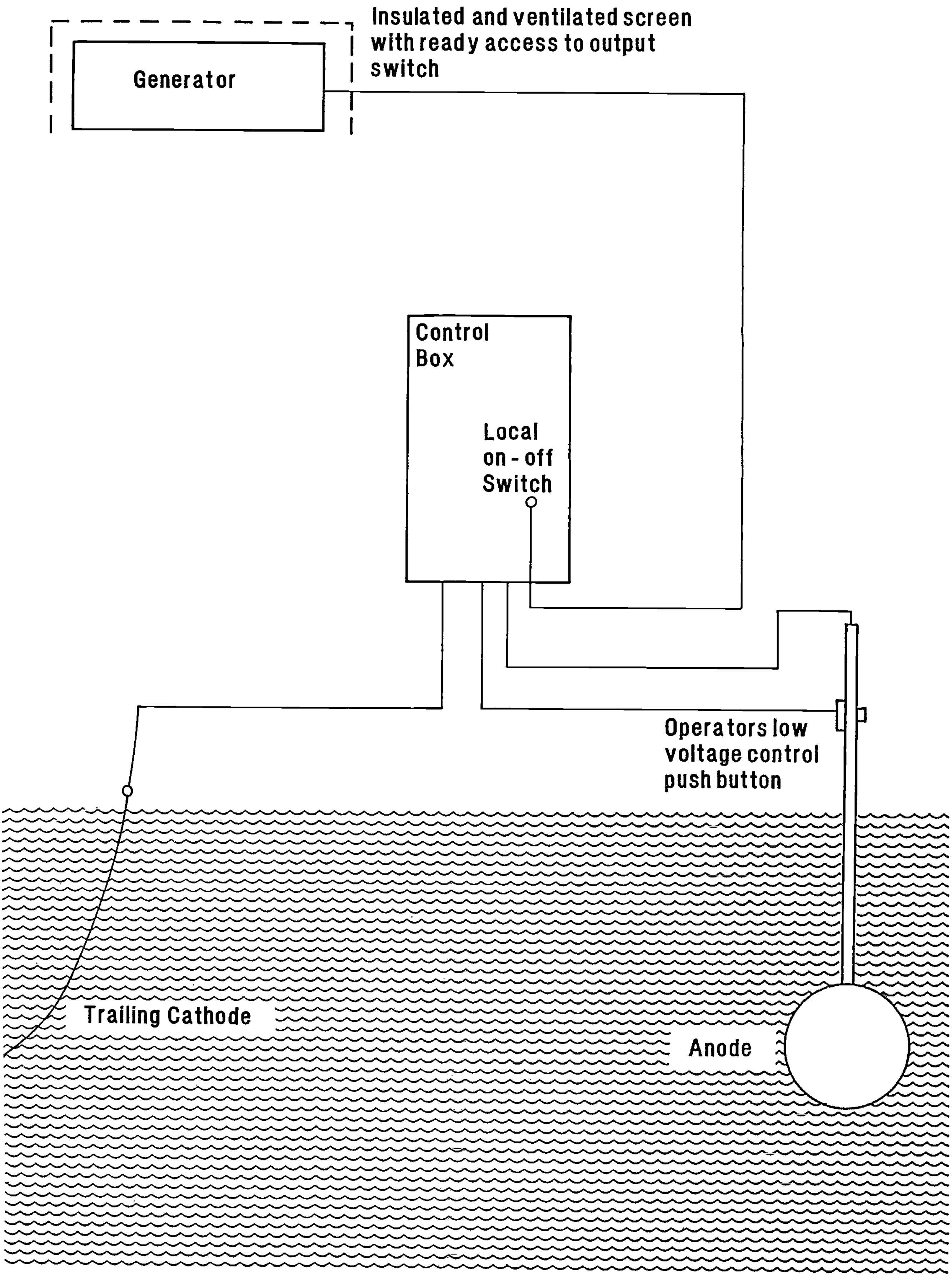
4.3 Quantitative surveys usually require fish to be held for sometime while they are measured or while additional sampling runs are carried out. Satisfactory holding tanks, bins, etc with forced aeration are therefore also required for such surveys, plus measuring and weighing equipment, and a suitable fish anaesthetic.

4.4 The principles involved in electro-fishing and the basic gear available, are described by Hartley (1975, 1980), Weiss (1972), Weiss & Cross (1974), Vibert (1967) and Edwards and Higgins (1973), and are essentially as follows:—

(a) **Smooth Direct Current (Figure 1)**

Fish caught in the electrical field swim involuntarily towards the anode, which is mounted on a hand-held non-conductive pole. The cathode is static except when fishing from a boat. DC is very useful in small shallow streams in that it first attracts fish from behind stones and weedbeds and they are stunned as they approach the anode but has the disadvantage of requiring a large generating

Figure 1 Typical components of a pulsed DC fishing apparatus



capacity in wider, deeper and more conductive waters. Fish caught in the electrical field recover quickly when the current ceases and the smooth current causes very little physical and physiological damage.

(b) **Alternating Current (Figure 2)**

AC is usually used with two active electrodes (as distinct from one static as in DC fishing). Fish caught in the current alternating between the electrodes are stunned but do not exhibit involuntary swimming actions. The main advantage of this method is that it permits the use of smaller portable generators (0.5 KVA – 2.5 KVA). One disadvantage is that stunned fish often lie on the river bed and recovering these fish with the handnet can be extremely difficult in deep or tubid water. Over-exposure to an alternating current can cause severe physical and physiological damage to the fish. For this reason, AC is not really suitable where several repeat fishing runs are required.

(c) **Pulsed Direct Current**

This current is obtained by rectifying an alternating current with the objective of providing a square wave form current at 10–100 pulses per second, with each pulse having a duration of 2–100 milliseconds. This type of output has considerable practical advantages, as it retains some of the fish attraction capacity of DC, but generally requires a lower power input to maintain a satisfactory fishing voltage (200 + volts) at the electrodes. This permits the use of smaller and lighter AC generators, giving some of the benefits of DC, but without the weight penalty of the much heavier equivalent DC generators. Equipment which allows the pulse width to be varied is particularly useful, as reduction of the pulse width enables even quite small output generators to maintain an effective voltage in quite highly conductive water. Even so, for water deeper than about 0.6 m, a generator of 1.5 KVA capacity or greater is usually necessary.

For electro-fishing in shallow rivers and streams, an apparatus based on an AC generator providing pulsed DC output via an appropriate control box should be used, as this is likely to provide the most effective form of current for the fish-catching operation.

5 Procedures

5.1 Qualitative Sampling by Electro-Fishing

For qualitative sampling only (species lists and relative abundance) stop nets are not necessary and a single fishing only is required along the length of river concerned. The length of site need not be fished, and fishing can stop when a sample of pre-determined size has been obtained.

5.1.1 Rivers < 15 m Average Width and < 0.6 m Average Depth

Rivers of this size can be fished satisfactorily by wading, preferably using two fishing electrodes. Details of the procedure are given in Section 5.2.1 below.

5.1.2 Rivers < 15 m Average Width and with Average Depth 0.6 m to 1.0 m

Electro-fishing is again appropriate, but a boat should be used. General details of the procedure are given in Section 5.2.2 below.

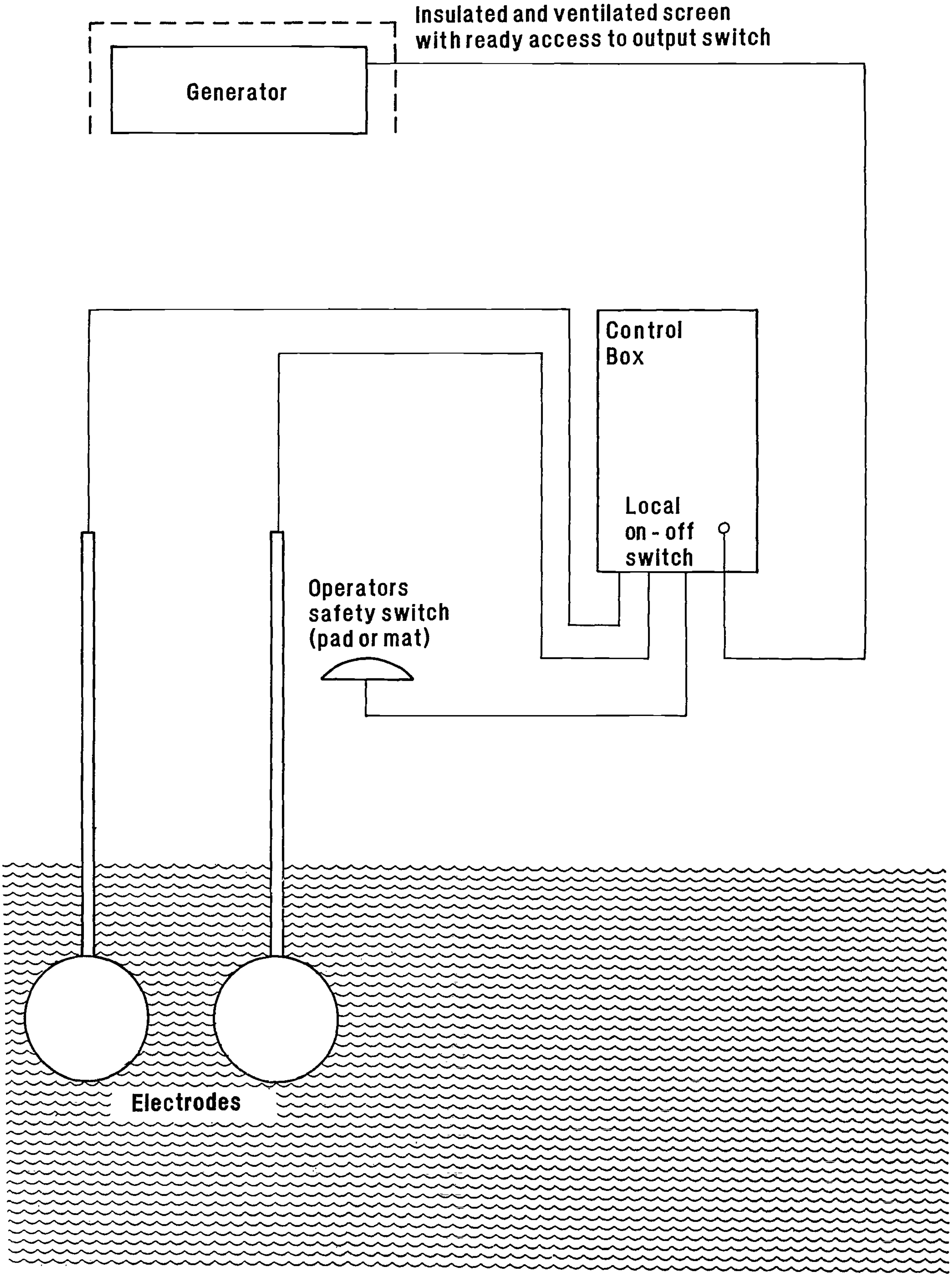
5.2 Quantitative Sampling by Electro-Fishing—Catch Depletion Method

In all such surveys the aim should be to catch as large a proportion of the population as possible. The population estimates are based on multiple sequential catches, and basic assumptions of the calculations used are that fishing effort remains constant for each sampling run, and that there is no emigration from or immigration to the sampling area during the duration of the survey.

5.2.1 Streams and Rivers not Exceeding 15 m Average Width and Average Depth < 0.6 m

(a) Length of site: typicially in the range of 50 m to 200 m, but should be at least 10 times as long as the average width, and should be as representative as possible of that part of the river, containing both pool and riffle habitats. For evenly

Figure 2 Typical components of AC fishing apparatus



dispersed populations (eg young salmonids in nursery streams) relatively short lengths are usually satisfactory but for strongly—clumped populations (eg coarse fish in a stream with variable habitat) longer sampling lengths are necessary.

(b) Fishing Strategy: minimum of three catches required, except when the 2nd catch is very much smaller than the 1st, and field estimates of population size indicate (a) that the population size exceeds 200, and (b) that the probability of capture of an individual fish is greater than 0.6 (see Section 7(a)). Under these circumstances a 3rd fishing need not be carried out.

(c) Field Procedure: whenever possible sites should be selected prior to the date of the survey so that there is a minimum of disturbance immediately prior to the commencement of sampling. Upstream and downstream stop nets should be placed in position simultaneously as soon as the team arrives on site. Exact length and mean width of the site can then be measured. The generator and control box are placed on the river bank at the mid point along the site and the cathode placed in the water. The anode(s), which should be connected to the control box by a cable at least half the length of the site, is (are) then taken down to the lower stop net. The number of anodes used depends on the width of the stream. Channels of average width < 5 m can be fished with a single anode, although the use of two is preferable. Streams of average width 5–10 m require a minimum of two anodes if a satisfactory fishing efficiency is to be achieved, and three anodes should be used in river 10–15 m wide (Kennedy and Strange, 1978, 1981). Two operators are required per anode, one person wading slowly upstream fishing with the anode by sweeping it from side to side across the stream and the other using a net with an insulated handle to pick up stunned fish. There are circumstances where fishing downstream rather than upstream may be more appropriate, for example in very fast-flowing rivers where driving fish downstream for capture in the lower stopnet may be the most effective capture method. When more than one anode is being used, the operators should take care to work as a team and their sweeping movements should be synchronised so as not to leave a large gap between the anodes through which fish could escape. In addition to the fishing pairs, another operator is required to walk along the bank, freeing the anode cable(s) from snags and carrying buckets to take fish back to holding facilities on the bank. Working upstream ensures that the operators are fishing in clear and undisturbed water, and helps by bringing stunned fish drifting downstream towards the operators. The anodes must be kept clear of the cathode and of silt on the river bed as this could draw too much current and overload the gear.

Fish from each sampling run must be kept separate and must not be returned to the sampling site until the whole operation is completed. The fish are identified and the numbers and individual lengths of the fish taken in each sampling run are recorded. If biomass estimates are to be made the individual weights of a representative sample of each species should also be recorded so that length-weight relationships can be calculated. Samples of scales can also be taken for age determination where appropriate.

The total number of sampling runs carried out can only be decided on the basis of the results on the day. Normally three catches will be required. However, if very few fish are caught on the second run compared with the first, and the operators are satisfied that most fish in the site have been caught, there is little point in carrying out a third run. Conversely, more than three runs will be necessary if a satisfactory pattern of catch depletion is not evident over the three runs. It is not uncommon when dealing with fishes of a somewhat cryptic habit for more fish to be taken in the second run than in the first. If this happens a fourth catch, or possibly even more, may be necessary. Care should be taken to check the security of the stop nets between each sampling run.

As a general guide, to obtain reliable estimates of population size from a three catch survey, a fishing efficiency of not less than 50% is required (see Section 7(a) for a method for estimating fishing efficiency in the field). Where efficiency is less than this, additional sampling runs are required. If efficiency is as low as 30%, depletion estimates become unreliable, and mark—recapture techniques are likely to give better results. (See Section 5.4)

5.2.2 Stream and Rivers not Exceeding 15 m Average Width with Average Depth 0.6 m–1.0 m

(a) Length of site and fishing strategy: the same as for shallower rivers (See 5.2.1(a))

(b) Field Procedure: Stop nets are placed simultaneously in position and the length and mean width of the site are then determined. A boat, preferably a flat-bottomed punt, is used to carry the generator and control box, cathode, anodes, hand nets, and bins of water for retaining captured fish. The number of anodes used depends on the width of the channel; two is the minimum requirement, but in rivers or canals exceeding 10 m wide it is better to use 3 or 4 anodes, provided that there is adequate room in the boat for the required number of personnel. When two anodes are being used, the operation can be carried out by a basic team of four persons, but five or six operators may be needed where bank obstructions cause difficulties in controlling the passage of the boat. One or more persons on each bank control the boat by means of ropes attached to the bow and stern. Fishing takes place while working the boat broadside across the stream from bank to bank and can progress in either an upstream or downstream direction between the stopnets. The same direction should be adopted for all fishings at any one site. Upstream fishing has the advantage that the operators are continuously moving into clear, undisturbed water where sighting of stunned fish is easier. However, in circumstances where the strength of the river flow makes it impracticable to pull the boat upstream, then downstream fishing should be employed. With the latter, many fish will either drift, if stunned, or be driven into the downstream stop net from which they should be removed and included with the catch. The anodes should be operated over the side of the boat facing the direction of movement, with an operator with a hand net working each anode. Great care is required with several operators in the boat, and electrode cable lengths should be kept to a minimum to reduce the risks of personnel tripping and falling. Boats used regularly for electro-fishing can be permanently wired, with cables in conduits and with waterproof plugs and sockets, to keep loose cable to a minimum. The fish caught are placed in bins on the boat until the fishing run is completed and are then transferred to alternative holding facilities to await examination. While one or two persons commence examination of the catch, the remainder of the team prepares the equipment either for a further fishing or for transportation to another site.

5.3 Special Situations

Fishing electrodes have only a limited effective radius and fish outside this radius remain mobile and in large water bodies may easily evade capture. The following methods may be used to overcome this problem.

(a) Electro-fishing with two boats: Where a river is too wide for effective coverage by a single boat and too shallow or fast-flowing or otherwise unsuitable for seine netting, one can consider the use of two boats. These are linked end to end across the river and worked in tandem. Each boat has its own set of electro-fishing gear, and thus additional operators are required. Owing to increased difficulty in controlling two boats in fast flowing water, the velocity of the current will impose greater limitations than when only a single boat is used, and great attention needs to be paid to operator safety.

(b) Combined multiple electrode/netting technique: for use where the water is too wide, too deep and too turbid for effective electro-fishing. A number of electrodes arranged to give adjoining fields are suspended in the water and moved slowly downstream between the stop nets. AC is fed to the electrodes to drive fish downstream into a net fitted with a large bag which is positioned upstream of the lower stop net. The net is retrieved so as to retain the fish and the operation is repeated.

(c) Multiple-lane technique: For use where the water is too wide for the approach recommended in 5.3(b) above. The section to be fished is either stop netted and then divided into two or three lanes using nets set at 90° to the stop nets or is divided into a large number of short lanes running from bank to bank. Each lane is electro-fished in turn as recommended in 5.3(b).

5.4 Mark-Recapture Method for Estimating Population Size

Where fishing efficiency (ie probability of capture) drops below 50%, and depletion method estimations are likely to be unreliable, the mark-recapture method of estimating population should be considered. Kennedy and Strange (1981) have found that efficiencies down to 30% give reliable population estimates with this method.

Field procedures are basically as described above, using electro-fishing. Fish from the first catch are identified, counted, measured, and then marked in some way before being returned to the survey site, distributing them thoroughly. After allowing a recovery period during which the marked fish can disperse evenly through the section (at least one hour), the section is fished a second time. Fish from the second catch are again identified, counted, measured, and checked for the presence or absence of a mark. The method of marking used should cause minimum harm to the fish. Clipping of the adipose fin can be used for salmonids, but the best method of marking coarse fish and eels is the injection of dye spots, eg Alcian Blue, using a 'Panjet' injector (Hart and Pitcher, 1969).

Stop nets must be left in position between the fishing runs.

6 Care of fish to be Returned Alive

6.1 Effects of Stunning

All types of electro-fishing equipment can damage or kill fish. Large fish receive a greater shock than small fish though small fish suffer more from the total stress of capture and holding in tanks.

(a) Alternating current (AC) electro-fishing: This is generally believed to cause more damage to fish than other types but if care is taken not to over-expose fish to the electrical field the actual losses are usually low (< 5%) and acceptable. The output cannot usually be varied, so powerful generators should not be used in small shallow rivers.

(b) Pulsed direct current (DC) electro-fishing: This is believed to cause less damage to fish than AC gear. Equipment with a variable output allows lower power to be used in small shallow waters, thus avoiding unnecessary damage to small fish.

(c) Smoothed direct current electro-fishing: Since fish are attracted to the anode(s) and may be caught before they are fully stunned, smooth DC causes less damage to fish than other types of gear.

(d) With both AC and pulsed DC gear, two practices can reduce the risk of damage from electro-fishing. Firstly, electrodes should be kept at a distance from stunned fish while the fish are being retrieved. Combined net-electrodes should be avoided. Secondly, when a large number of fish are stunned in a small area of river, electro-fishing should cease until the stunned fish have been removed.

6.2 Holding of Captured Fish

After capture, fish will normally be transferred to bins with a capacity ranging from 50–60 litres. Fish should not be held in such bins for long periods (20 minutes) nor should they be overcrowded, particularly in hot weather.

On the river bank, fish should be held in larger tanks; those with a capacity ranging from 100–200 litres are convenient because they can be carried easily when empty. Stress and post capture mortality of fish can be minimised by oxygenating or aerating the tank water, changing it at 30 minute intervals, and siting tanks in the shade. Damage can also be minimised by holding large fish, eg pike, large chub, bream and carp in separate bins from smaller species or small fish. In addition, fish with heavy mucus coverings such as eels, pike, tench and bream tend to lose mucus and foul the water and should be held separately from other species. Fish can also be held in cages or keep boxes, placed in the river, provided that these are kept well away from the electrodes.

6.3 Handling Fish

6.3.1 Handnets

(a) Polymesh nets (maximum mesh diameter c.6 mm) are recommended. They retain all but very small fry and can be moved vigorously through water. They are soft and cause little damage to fish.

(b) Micromesh nets (maximum mesh diameter c.2 mm) retain all sizes of fish but cannot be moved vigorously through water. They are soft and cause little damage to fish.

(c) Larger mesh nylon nets do not retain small fish and can entangle medium size fish by their gills and damage them. These nets are more abrasive than the other nets described and cause slightly more damage to fish.

(d) Use of handnets: handnets should not be overloaded with fish, since the total weight of the fish damages those lying against the net. Large fish should be transferred separately from small fish.

6.3.2 Anaesthetising Fish

(a) Fish should be anaesthetised before they are measured and weighed and/or scale samples removed for ageing. Suitable anaesthetics are MS222 (tricaine methane sulphonate, Sandoz Ltd) used at a concentration of between 1:10,000 and 1:20,000, or benzocaine used at a concentration of between 1:20,000 and 1:30,000. These rapidly produce anaesthesia, but this should not be maintained for more than 15 minutes before removing the fish and placing them in fresh water. Appropriate doses of benzocaine should be made up by dissolving it in alcohol before use, since it is not water soluble. MS222 solutions should be freshly prepared.

(b) Practical usage of anaesthetics
Anaesthetics reduce the oxygen consumption of fish, so if fish have to be held at high density, eg for transport, they may be anaesthetised at high density in small containers (eg 20 × 100 gramme fish in 5 litres of water). However, such small quantities of water soon become fouled and heat up rapidly in hot weather. The water plus anaesthetic should therefore be changed at intervals, depending on the ambient temperature. Fish should be allowed to recover their equilibrium and swimming ability by transferring them to clean water before their release.

(c) Safety and the Use of MS222
If used correctly, MS222 will not harm fish permanently but is believed to be carcinogenic to man and in any case can numb the hands. The wearing of rubber gloves is recommended when using MS222 solutions. Care is required when disposing of MS222 solutions, and whenever possible they should be discharged to sewer or a soakaway.

6.3.3 Work Surfaces

When measuring and weighing fish, all work surfaces on which fish will be placed should be smooth and kept wet. Soft foam rubber which is kept well wetted is a very suitable surface on which to handle fish.

7 Data Analysis

A general account of the methods available for estimating animal abundance is given in Seber (1973.) There are several methods which can be used for calculating population sizes from data collected during multiple catch surveys. Before any of these methods of estimating population size can produce reliable results, certain conditions have to be met, viz:—

1. A large proportion of the available fish population has to be caught with each sampling run, ie fishing efficiency must be high (probability, p, of capture of an individual fish should >0.5).
2. Equal effort is expended on each fishing.
3. The stop nets prevent movement of fish to or from the survey site.

The majority of methods also assume that all fish are of equal catchability, and that there is no change in catchability between sampling runs. In fact it is well established that different sized fish have different vulnerability to electro-fishing, with large fish being more readily caught. To prevent errors being introduced to the estimates because of this, it is necessary to measure each fish caught, and then to carry out separate catch efficiency and population estimates for different size groups of fish. As mentioned previously stop net mesh size is a relevant factor, and reliable estimates can only be made for size groups of fish too large to pass through the nets.

There is also evidence that the vulnerability of fish to electro-fishing may change after exposure to the electrical field on an earlier sample run (Cross and Stott, 1975). However, there is one computer-based estimating method (CAPTURE, see Otis etal, 1978; White et al, 1982) which can compensate for varying catchability.

(a) **Population estimates:** Taking the simplest case, where only two fishings have been carried, the population (N) enclosed by the stop nets is given by:—

$\hat{N} = C_1^2 / (C_1 - C_2)$ (from Seber & Le Cren, 1967)

where C_1 = catch from first fishing and C_2 = catch from the second fishing. (Fish from the 1st fishing are retained while the 2nd fishing is carried out).

The probability of capture (p) for any fish in a single fishing is given by:—

$$\hat{p} = (C_1 - C_2) / C_1$$

This is a measure of the efficiency of the fishing operation.

The variance of $\hat{N}$ is given approximately by

$$\mathrm{Var}(N) = \frac{\hat{N}q^2(1+q)}{p^3} + \frac{2q(1-p^2-q^3)}{p^5 - b^2}$$

$$\text{where } q = 1 - p, \text{ and } b = \frac{q(1+q)}{p^3}$$

95% confidence limits for N are then given by

$$\hat{N} \pm 1.96\sqrt{\mathrm{Var}(\hat{N})}$$

(See Section 8 for a worked example).

As stated in Section 5.2.1(16) this estimator of N is only likely to be reliable (ie not biased) in cases where $N > 200$, and where $p > 0.6$.

If a population estimate calculated in this way gives a result < 200, the estimate should be recalculated using the method given in Seber and Whale (1970).

The value M is calculated from:

$$M = \frac{(C_1 - C_2 + 2)}{(C_1 + 1)(C_1 + 2)}$$

The estimate of N is then given by:

$$\hat{N} = \frac{1}{M} - 1$$

The probability of capture, p, is estimated by:

$$\hat{p} = 1 - \frac{C_2}{(C_1 + 1)}$$

(See Section 8 for a worked example)

In the more usual situation, where three or more fishings have been carried out, several methods of estimating N are available. All are based on the same principle, namely that catches are based on population size and catch efficiency. As fish are removed, provided that catch efficiency remains constant, subsequent catches decrease at a constant rate. The rate of catch decline enables one to calculate the initial population size.

Regression method: The simplest method of using survey removal data to estimate population size is the regression method described by Leslie and Davis (1939). Methods for calculating the confidence limits of N are given by De Lury (1951) and Seber (1973). The number of fish caught in the i th sample is plotted against the total of the previous catches (the cumulative catch, n_i). A line is fitted to the points, either by eye or by using least squares regression calculations, and the point at which the line cuts the abscissa gives an estimate of the total population. (See example in Section 8). The slope of the line gives the probability of capture, p. This method has a number of drawbacks, including the difficulty of calculating confidence limits, which involves solving the roots of a quadratic equation, and is not therefore an appropriate method for general use. However, it is a useful means of carrying out guide checks in the field to obtain an approximate estimate of p, and therefore of fishing efficiency, when deciding whether or not additional sampling runs are required.

Maximum likelihood estimates: The maximum likelihood model most commonly used is that originally proposed by Moran (1951) and described by Zippin, (1956, 1958), and in a review of methods for estimating fish population size from survey removal data, Cowx (1983) concluded that this was the most convenient and satisfactory method.

The estimator of the population size is

$$\hat{N} = \frac{T}{(1 - q^k)} \qquad (1)$$

where T is the total catch, $q = (1 - p)$ where p = the probability of capture of an individual fish, and k = the number of sampling runs.

Zippin (1956) gives graphs which facilitate the calculation of $(1 - q^k)$ for values of k = 3, 4, 5 or 7. Firstly one calculates the value of the ratio R,

(where $R = \frac{q}{1-q} = \frac{q}{p}$)

$$R = \frac{\sum_{i-1}^{k} (i-1)C_i}{T}$$

where C_i is the catch taken in the i th fishing.

The value of $(1 - q^k)$ equivalent to the calculated value of R is obtained from the appropriate graph (see Fig. 3), and when this value is substituted in equation (1), N can be calculated.

The variance of $\hat{N}$ is given by

$$Var(\hat{N}) = \frac{\hat{N}(1 - q^k) q^k}{(1 - q^k)^2 - (pk)^2 q^{k-1}}$$

and approximate 95% confidence limits are given by $\hat{N} \pm 1.96 \sqrt{Var(\hat{N})}$

(See Secton 8 for a worked example).

Recently Higgins (1985) has published details of an interactive BASIC computer program which is designed to estimate population size using the Zippin method.

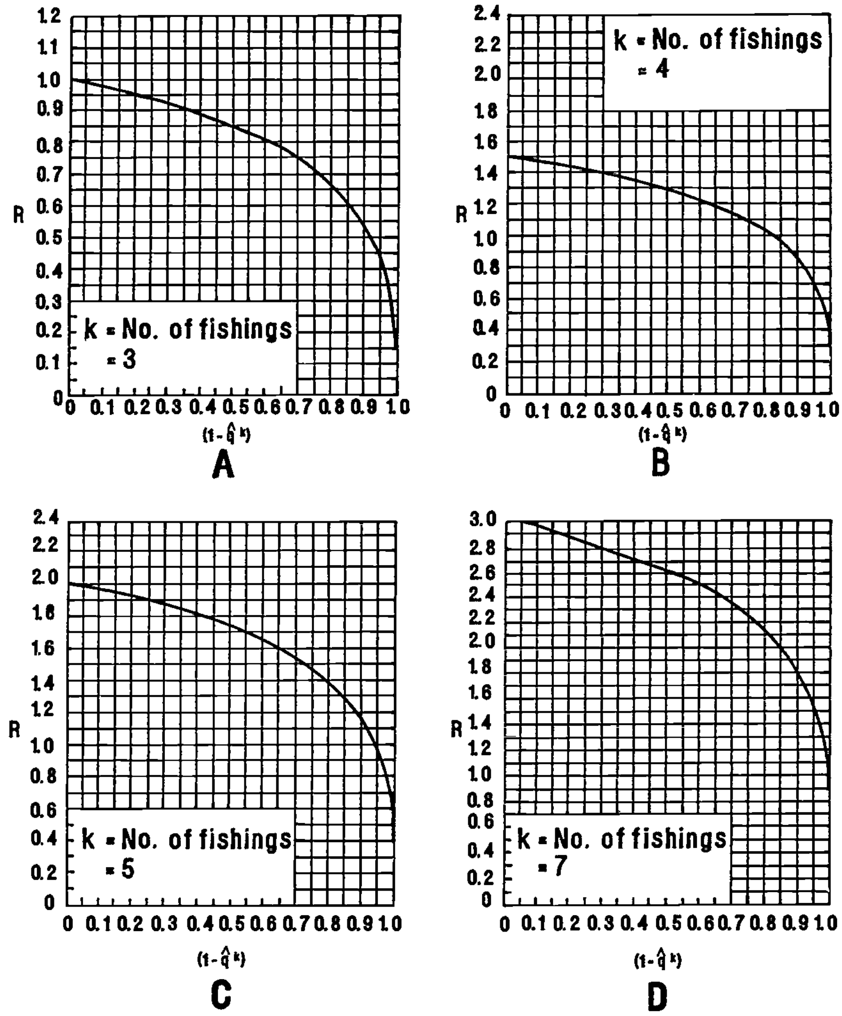


Fig. 3 GRAPH FOR ESTIMATION OF $(1-q^k)$ (after Zippin, 1956)

If the basic conditions for sampling outlined at the beginning of this Section are not met, for example if the proportion of the remaining population taken in successive catches does not remain constant, the simpler methods of calculating population size are likely to fail, or give unreliable results with very wide confidence limits. Carle and Strub (1978) have developed a method which they call 'maximum weighted likelihood', and which they claim does not fail when these conditions are not met. Their model does not permit a direct solution for N, and an iterative (ie trial and error) procedure has to be followed to obtain an estimate of N. See Section 8 for a worked example. This process is tedious if carried out longhand, but can be done simply and easily on a programmable calculator or microcomputer. A more sophisticated model has been developed by Otis et al (1978) using maximum likelihood procedures, and which allows for changes in probability of capture with successive fishings. This procedure is again an iterative one, and uses a computer program CAPTURE, which has to be run on a main-frame computer.

(b) **Choice of method**: To a considerable extent the choice of method depends on the degree of precision required. For most practical purposes, the Zippin method based on three fishings should give acceptable results, although if it is suspected that some of the sampling assumptions may not have been met, it would be better to adopt Carle and Strub's method. Zippin's method is easily biased by failure to comply with these assumptions, leading to unreliable estimates of N and wide confidence limits.

In investigations where a high degree of precision of estimate is required, more than three fishings should be carried out, and the use of the CAPTURE program for calculating the results considered. However, one has to weigh carefully the real benefits to be gained in spending time refining an estimate. The extra time may well be better spent in fishing additional sites.

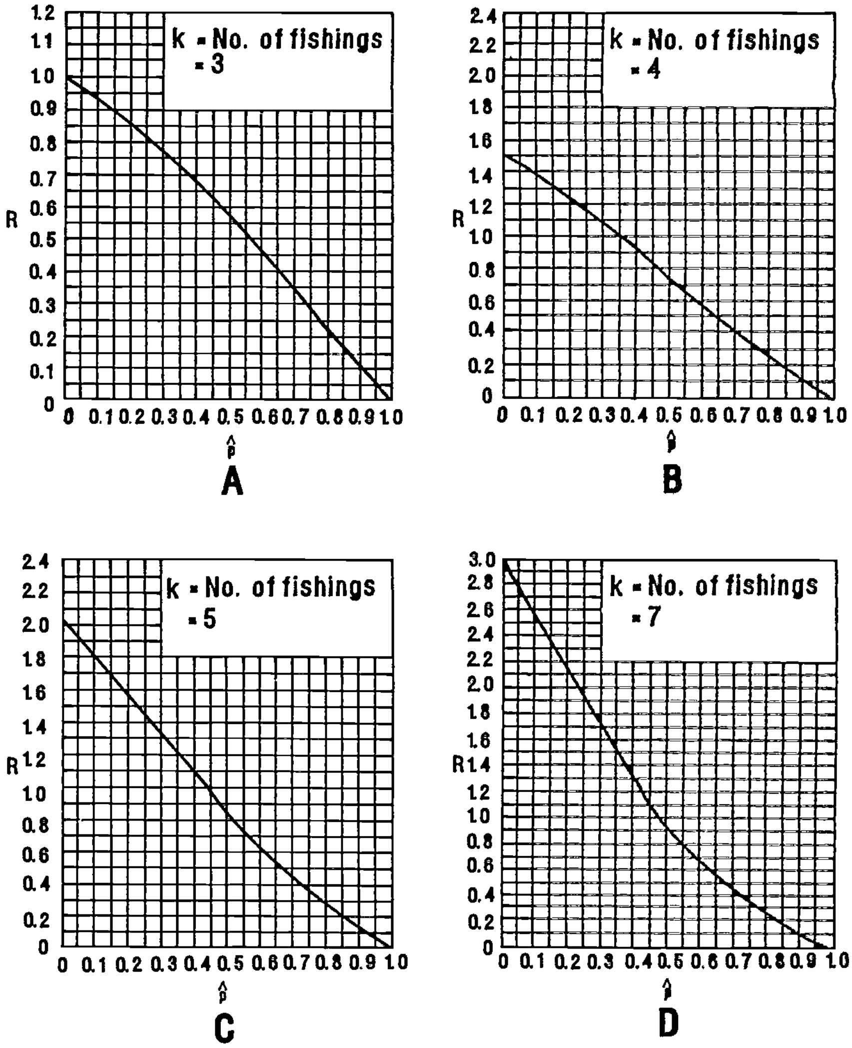


Fig. 4 GRAPH FOR ESTIMATION OF p FROM THE RATIO R (after Zippin, 1956)

(c) **Mark—recapture estimates:**

Population size can be calculated from the formula:—

$$\hat{N} = \frac{MC}{R}$$ (Robson & Regier, 1971)

Where $\hat{N}$ = estimate of population size,
M = total number of marked fish released
C = total number caught in second fishing
R = number of marked fish recaptured

The standard error of $\hat{N}$ is given by:—

$$S.E(N) = \hat{N}\sqrt{\frac{(\hat{N}-M)(\hat{N}-C)}{MC(\hat{N}-1)}}$$

Upper and lower confidence limits are given by

$$\hat{N} \pm 1.96\sqrt{(S.E(\hat{N}))}$$

This estimator tends to be negatively biased, ie the estimates $\hat{N}$ tend to be less than the actual value of N. This bias is negligible where the product MC > 3N. Sufficient effort should therefore be put into the second fishing to ensure that enough fish are caught. Quick calculations of $\hat{N}$ can be carried out in the field to check whether this condition has been met.

8 Worked Examples of Population estimation methods

Example 1 Two-catch estimate (From Seber & Le Cren, 1967)

Catch data Catch 1 (C_1) = 170
Catch 2 (C_2) = 40

Then $$N = \frac{C_1^2}{C_1 - C_2} = \frac{170^2}{170-40} = \underline{\underline{222}}$$

Probability of capture, $$p = \frac{C_1 - C_2}{C_1}$$

$$= \frac{170-40}{170} = \underline{\underline{0.765}}$$

$$Var(\hat{N}) = \frac{\hat{N}q^2(1+q)}{p^3} + \frac{2q(1-p^2-q^3)}{p^5 - b^2}$$

$$q = 1 - p = 0.235$$

$$b = \frac{q(1+q)}{p^3} = \frac{0.235 \times 1.235}{0.235^3}$$

$$= 22.363$$

$$\therefore Var(\hat{N}) = \frac{222(1.235)}{0.765^3} + \frac{2 \times 0.235(1 - 0.765^2 - 0.235^3)}{0.765^5 - 22.363^2}$$

$$= \underline{612.0}$$

Approximate 95% confidence limits are given by

$$\hat{N} + 1.96\sqrt{Var(N)}$$

$$= \hat{N} \pm 1.96\sqrt{612}$$

$$= \underline{222 \pm 48}$$

Example 2 Two catch estimate where N < 200 (from Seber & Whale, 1970)

Catch data Catch 1 (C_1) = 65, Catch 2 (C_2) = 15

Then $$M = \frac{(C_1 - C_2 + 2)}{(C_1 + 1)(C_1 + 2)} = \frac{52}{66 \times 67} = \underline{\underline{0.0118}}$$

$$N = \frac{1}{M} - 1 = \frac{1}{0.0118} - 1$$

$$= \underline{\underline{84.7}}$$

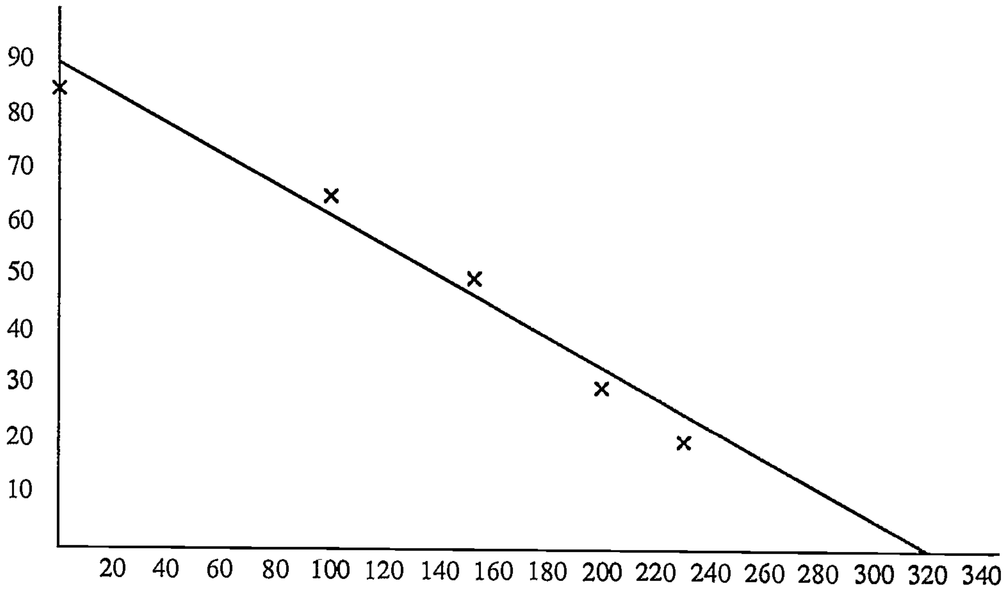
$$\hat{p} = 1 - \frac{C_2}{(C_1 + 1)} = 1 - \frac{15}{66}$$

$$= \underline{\underline{0.773}}$$

Example 3 Leslie and Davis Regression Method

Catch Data

Catch No	No of fish caught (c_i)	Previous total Catch (n_i)
1	85	0
2	65	85
3	48	150
4	30	198
5	24	228



Estimate of N = $\underline{\underline{320}}$

Probability of capture, $p = \frac{C_i}{n_o} = \frac{85}{320} = \underline{0.26}$

Example 4 Zippin Maximum Likelihood Estimates

Using the catch data given in Example 3,

total catch $T = C_1 + C_2 + C_3 + C_4 + C_5 = \underline{252}$

Est. N is given by $\frac{T}{(1 - q^k)}$

First calculate the ratio R from $R = \frac{\sum_{i-1}^{k} (i-1) C_1}{T}$

$$R = \frac{(1-1)85 + (2-1)65 + (3-1)48 + (4-1)30 + (5-1)24}{252}$$

$= \underline{1.377}$

Using the graph for k = 5 (Fig 3)

the equivalent value of $(1 - q^k) = 0.80$

$\therefore N = \frac{252}{0.8} = \underline{315}$

From Fig 4, the estimated value of $p = \underline{0.27}$

$$\text{Var}\,\hat{N} = \frac{N\left(1-q^k\right)q^k}{\left(1-q^k\right)^2 - (pk)^2 q^{k-1}}$$

$$= \frac{315 \times 0.80 \times 0.73^5}{0.8^2 - (0.27 \times 5)^2 \times 0.73^4}$$

$$= \underline{427}$$

$$95\% \text{ Confidence Limits} = \hat{N} \pm 1.96\sqrt{\text{Var }\hat{N}} = \underline{315 \pm 40}$$

Example 5 Carle and Strub Maximum Weighted Likelihood Estimates

The maximum weighted likelihood estimate of the population size N is the smallest integer < T which satisfies the inequality equation:—

$$\frac{(N+1)}{(N-T+1)} \prod_{i=1}^{k} \left(\frac{KN - X - T + i}{KN - X + 1 + i}\right) \leq 1$$

where N, K, i and T are as defined previously, and $X = \sum_{i=1}^{k} (k-i) C_i$

Using the catch data given in example 3,

$X = (5-1)85 + (5-2)65 + (5-3)48 + (5-4)30 + (5-5)24 = 661.$

Values of k, T, X and predicted values for N are substituted in the equation until it is balanced. For example, continuing with the data given in Example 2 ($k = 5$, $T = 252$, $X = 661$), and assuming $N = 305$,

$$\frac{(305+1)}{(305-252+1)} \cdot \left(\frac{(5 \times 305) - 661 - 252 + 1}{(5 \times 305) - 611 + 1 + 1}\right) \cdot \left(\frac{(5 \times 305) - 661 - 252 + 2}{(5 \times 305) - 661 + 1 + 2}\right) \ldots \text{etc}$$

$$= \frac{(306)}{(54)} \cdot \frac{(613)}{(866)} \cdot \frac{(614)}{(867)} \cdot \frac{(615)}{(868)} \cdot \frac{(616)}{(869)} \cdot \frac{(617)}{(870)} = \underline{\underline{1.012}}$$

This solution is greater than 1, so the calculation is repeated with different values of N.

When $N = 310$, the equation solves to 0.9955
When $N = 308$, the equation solves to 1.002 (> 1)
When $N = 309$, the equation solves to 0.999 (< 1)

Therefore, the smallest integer which satisfies the expression is 309, and this is the maximum weighted likelihood estimate of N.

Probability of capture, p, can be estimated by:—

$$p = \frac{T}{kN - x} = \frac{252}{(5 \times 309) - 661} = \underline{0.285}$$

Estimates of variance and confidence limits of $\hat{N}$ can be calculated using the procedure described in Example 4 above.

Example 6 Mark—Recapture Estimates

Number of marked fish released, $M = 80$

Total number of fish caught in 2nd fishing, $C = 110$

Number of marked fish recaptured, $R = 35$

$$N = \frac{MC}{R} = \frac{80 \times 110}{35} = \underline{251}$$

Standard error $\hat{N} = \hat{N}\sqrt{\frac{(\hat{N} - M)(\hat{N} - C)}{MC(N - 1)}}$

$$= 251\sqrt{0.01096}$$

$$= \underline{26.28}$$

Approximate 95% confidence limits for $\hat{N}$

$$= \hat{N} \pm (1.96 \times S.E.N)$$

$$= \underline{\underline{251 \pm 52}}$$

Product $M \times C = 8800$. This exceeds $3\hat{N}$ by a considerable margin. The bias of this estimate of N should therefore be negligible.

References

Bohlin, T (1982). The validity of the removal method for small populations—consequences for electro-fishing practice. *Rep. Inst. Fresh. Wat. Res.* Drottningholm, **60**, 15–18.

Carle, F L & Strub, M R (1978). A new method of estimating population size from removal data. *Biometrics.* **34**, 621–630.

Cowx, I G (1983). Review of the methods for estimating fish population data size from survey removal data. *Fish. Mgmt*, **14**(2), 67–82.

Cross, D G and Stott, B (1975). The effect of electric fishing on the subsequent capture of fish. *J. Fish Biol.*, 7, 349–357.

De Lury, D B (1951) On the planning of experiments for the estimation of fish populations *J Fish, Res. Bd. Can.*, **8**, 281–307.

Edwards, J L & Higgins P J (1973). *The effects of electric currents on fish.* Georgia Inst. of Tech. Report for Game and Fish Division, Dept., of Natural resources, Atlanta, and Sport Fishing Institute, Washington DC.

Hart, P J B and Pitcher, T J (1969) Field trials of fish marking using a jet inoculator. *J Fish. Biol.*, **1**, 382–385.

Hartley, W G (1975) Electrical fishing apparatus and its safety. *Fish. Mgmt.*, **6**, 73–77.

Hartley, W G (1980) The use of electrical fishing for estimating stocks of freshwater fish. In 'Guidelines for Sampling Fish in Inland Waters'. *EIFAC Tech. Pap., No. 33*, 91–95.

Higgins, P J (1985) An interactive computer program for population estimation using the Zippin method. *Aquacult. and Fish. Mgmt*, **1**, 287–295.

Kennedy, G J A & Strange, C D (1978) *Population estimation by electric fishing; theory and practice.* Dept of Agriculture for N. Ireland, Fisheries Research Leaflet No. 13, 15 pp.

Kennedy, G J A & Strange, C D (1981) Efficiency of electric fishing for salmonids in relation to river width. *Fish. Mgmt.*, **12**, 55–60.

Leslie, P H & Davis, D H S (1939) An attempt to determine the absolute number of rats in a given area. *J. Anim. Ecol.*, **8**, 94–113.

Moran, P A P (1951) A mathematical theory of animal trapping. *Biometrika*, **38**, 307–311.

National Joint Health and Safety Committee for the Water Service, 1983. Safety in Electric Fishing Operations. *Health and Safety Guidelines No. 6.* 32 pp.

Otis, D L Burnham, K P White, G C & Anderson, D R (1978) Statistical inference from capture data on closed animal populations. *Wildlife Monograph No. 62.*, publ. Wildlife Society Inc., 135 pp.

Robson, D S & Regier, H A (1972) Estimation of population number and mortality rates. In: *Methods for the Assessment of Fish Production in Fresh Waters* (Ed. W E Ricker). pp. 131–166. Blackwell Scientific Publications, Oxford.

Seber, G A F (1973) *The estimation of animal abundance and related parameters* Griffin. London pp 506.

Seber, G A F & Le Cren, E D (1967) Estimating population parameters from catches large relative to the population. *J Anim. Ecol.*, **36**, 631–643.

Seber, G A F, & Whale, J F (1970) The removal method for two and three samples. *Biometrics*, **26**, 393–400.

Vibert, R (Ed.) (1967) *Fishing with Electricity: Its Application to Biology and Management.* Fishing News (Books) Limited, London. 276 pp.

Weiss, D M (1972) A high power pulse generator for electric fishing. *J Fish. Biol.*, **4**, 453–459.

Weiss, D M & Cross, D G (1974) A design for fishing electrodes for use in freshwater. *Fish. Mgmt*, **5**, 114–116.

White, G C, Anderson, D R, Burnham, K P & Otis, D L (1982) *Capture—recapture & removal methods for sampling closed populations*. Los Alamos Natinal Laboratory, New Mexico, 235 pp.

Zippin, C (1956) An evaluation of the removal method of estimating animal populations. *Biometrics*, **12**, 163–189.

Zippin, C (1958) The removal method of population estimation. J Wildl. Mgmt., 82–90.

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SW1P 3PY
England

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