2.4—less than 15% of the catch rate for the fly seine. Therefore, this alternative also was not feasible.

Test for presence of hatchery fish.—The question of mature female striped bass of non-Hudson River origin and the requirement of equal probability of capture for hatchery and wild fish apply to this alternative just as they did to the alternatives involving estimation of the proportion. Also, the previously discussed catch rates for sampling downriver of the spawning grounds are applicable here. However, the required sample size is an order of magnitude less, which makes hypothesis-testing feasible whereas estimation is not.

The mean catch per fly-seine haul was 16.2 striped bass larger than 300 mm, and the predicted catch per haul of mature female striped bass was 0.29. Therefore, to collect 161 mature females, 555 hauls would be required. At four seine hauls per 8-h day, the required sampling effort would be 139 boat-days. This would require two boats and crews working for about 60 d and is therefore considered a feasible alternative.

With the 12-m trawl, the average catch per tow of all mature female striped bass was approximately 0.05. Therefore, 3,360 tows, or 420 boat-days at eight tows per day, would be needed to collect the required 161 striped bass. This would be an unacceptably high level of effort.

Discussion

The results from this case study illustrate some important points that may be relevant to a wide variety of mark–recapture experiments. The sampling effort required to produce reasonably precise parameter estimates was very high. However, the required precision of such estimates depends on the purpose of the study and the intended use of its results. If a lower level of precision is adequate, the required sampling effort can be reduced. For example, if a relative error of 50%, rather than 25%, had been acceptable in the Hudson River study, we could have satisfied our sampling requirement by inspecting 1,500 rather than 6,100 fish for tags.

Another point worth noting is the trade-off between satisfying the statistical assumptions and being able to collect an adequate number of fish. Obtaining adequate sample sizes would have been much less of a concern if the study had targeted young-of-year fish because they are more abundant and geographically less dispersed than older striped bass. However, newly released hatchery fish appear to exhibit different distribution patterns than their wild brethren, which violates a key assumption of the statistical method. Meeting assumptions only, or satisfying sample size requirements only, is inadequate; both must be considered.

The foregoing case study also illustrates that even with a relatively simple goal, a substantial amount of information may have to be compiled and analyzed to identify attainable objectives. We started with seven alternative objectives, each of which seemed reasonable, and found five to be infeasible. Although the effort required to conduct a thorough planning study of this type appears substantial, it is very small compared to the effort that can be saved by avoiding a sampling program with an unattainable objective.

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Random-Sampling Design to Estimate Hatchery Contributions to Fisheries

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Abstract.—This report describes sampling methods used to study the effectiveness of hatcheries that rear Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss*. Effectiveness is measured as the contribution of hatchery fish to the fishery. To determine fishery contribution, fish from hatcheries must be marked. Fish for marking are obtained by netting all rearing environments or by using mechanical sampling devices. Information recorded for a marking study should include numbers of fish marked, location and dates of marking, species, race, stock, brood, mark type, purpose of marking, mark retention, and numbers of fish released. When fish are marked with a coded wire tag, counters on the tagging machine are used to determine the number of fish marked. Mark retention can be estimated by separately holding marked fish for examination before release; the precision of the estimate will depend on the numbers of fish examined. Release numbers can be determined by electronic counters, by subtracting deaths that occur between the time of marking and release, or by sampling the population at release. Sampling of major fisheries on the Pacific coast of North America is well established and has occurred routinely since 1963, but sampling of hatchery returns is not as well established. All fish returning to a hatchery should be examined for marks. A systematic sample of unmarked fish is recommended to allow an estimate of the age distribution of returning fish. The precision of the estimate will depend on the number of fish sampled. Potential straying of marked fish may be assessed by sampling at other hatcheries and streams adjacent to the expected return site.

Seven species of anadromous salmonids are reared at public and private hatcheries on the Pacific coast of North America: Chinook salmon *Oncorhynchus tshawytscha*, coho salmon *O. kisutch*, sockeye salmon *O. nerka*, pink salmon *O. gorbuscha*, chum salmon *O. keta*, steelhead *O. mykiss*, and cutthroat trout *Salmo clarki* (Clemens and Wilby 1946). The hatcheries are a direct result of fishing pressures greater than natural salmonid runs could sustain, and of destruction or impairment of salmonid habitat through pollution, mining, logging, agricultural practices, and dam construction (Laythe 1948; Craig and Hacker 1950; Hagen 1953; Larkin 1970). To rebuild lost populations, there have been massive expenditures for fish passage and protection facilities as well as for propagation in hatcheries (Laythe 1948; Larkin 1970; Wahle and Smith 1979).

Given the demand for salmonids and the expenditures to meet this demand, it is imperative to measure the success of salmon propagation (Paulik 1963). Recently, the U.S. Congress has mandated evaluation of hatchery projects constructed under the Salmon and Steelhead Conservation and Enhancement Act of 1980 (Public Law 96-561) and the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (Public Law 96-501) (Northwest Power Planning Council 1984; Salmon and Steelhead Advisory Commission 1984). The success of a public hatchery should be measured by its contribution to the fisheries, not by the number of returning adults; returns to a hatchery do not necessarily reflect its contribution to the fisheries (Paulik 1963). This paper reviews sampling design for studies of stock contributions to the Pacific coast fisheries of North America.

Experimental Design

A contribution study consists of (1) specifying objectives, (2) selecting a method to determine fishery contributions, (3) designing statistical analysis, (4) determining numbers of fish to mark, (5) organizing the marking operation, (6) collecting release and recovery data, and (7) conducting the analysis. This report deals specifically with phases (5) and (6).

The experimental methods used in a contribution study depend on the experimental objectives. Some objectives for studies of hatchery contributions to fisheries are to determine when and where a group of fish contributes, to estimate the contribution of a group of fish to a specific fishery, and to estimate total fishery contribution of a group of fish (Pacific Marine Fisheries Commission 1984).

Two methods have been used to determine the fishery contribution of a hatchery's salmonids. In the first method, the estimated catch of marked fish is multiplied by the ratio of total release to marked release to estimate contribution. This method has seven assumptions (Rounsefell and Everhart 1953; Bevan 1959; Worlund et al. 1969; Pacific Marine Fisheries Commission 1984): (1) fish to be marked are representatively sampled and receive the same treatment as unmarked fish before and after marking, (2) marked fish are identifiable throughout their lives, (3) marked and unmarked fish have the same growth and survival rates and maturity schedules, (4) marked and unmarked fish have the same distribution and vulnerability to catch, (5) the probability of a fish being sampled is independent of whether the fish is marked or unmarked, (6) all marked fish in the sample are recognized, correctly identified, and reported, and (7) the mark is not duplicated for any other study.

Assumption (1) is concerned with the hatchery life of the fish and is important because the catch of marked fish is to be extrapolated to total contribution. The remainder of the assumptions are concerned with the life of the fish after they leave the hatchery. Assumptions (3) and (4) are necessary for expansion of marked catch to total fishery contribution. Assumptions (5) through (7) are concerned with fishery sampling. Inherent in assumption (5) is that marked fish do not travel in clumps separate from unmarked fish. Thus recovery of a marked fish does not make a recovery of another mark more likely.

In the second method, the estimated total numbers of marked fish caught in the fisheries are multiplied by the ratio of total return to marked return to estimate the contribution of a hatchery. The seven assumptions previously mentioned also underlie this method. Three additional assumptions are necessary: (8) unmarked fish from sources other than the release facility of interest do not occur at the return facility or their occurrence is estimated and adjustments are made, (9) marked and unmarked fish do not stray differently from the return group of interest, and (10) marks are not lost between harvest and return (Pacific Marine Fisheries Commission 1984). The second method requires information on numbers of marked and unmarked fish that return for the group of interest and on numbers of unmarked fish that stray to the return site (if straying occurs).

Method two is initially attractive because it avoids the hatchery release statistics required for method one, which can be difficult to obtain (see the section on "Marked and Unmarked Releases"). However, required terminal return statistics may be equally or more difficult to obtain (see "Sampling Marked Fish"). Return statistics are affected by release of all or a portion of the production of a hatchery away from the rearing site, straying of returning fish, inability to recover all fish returning to a facility, and by intense fishing or by migration obstacles (such as hydroelectric dams) below a return facility. Consequently, this paper is confined to the assumptions, data needs, and procedures for method one.

Sampling and Marking Prior to Release

To reduce the impact of handling and marking stress on a hatchery population, the time required for marking, and the cost, only a sample of fish from a hatchery population is marked.

Obtaining Fish for Marking

Marked fish should represent the entire population at a facility because catches of marked fish will be expanded to estimate the fishery contribution of that facility. To ensure likeness of marked and unmarked fish, a random sample from all rearing environments at a hatchery should be removed for marking. The sample must be proportional to the numbers of fish in each rearing environment, unless different marks are used for each environment. (For example, remove a 5% sample rather than 5,000 fish from each hatchery pond.) Even if all rearing environments physically appear to be the same, it would not be advisable to randomly select one or more rearing areas (raceways, for instance) to represent the hatchery population. Factors such as time of egg take, hatching, fish ponding, disease history, food conversion, size of fish, water flow patterns, rearing density, and predation likely will differ among rearing environments. Effects of these differences on fish survival and catch are unknown.

A method for randomly sampling fish from each rearing area at a hatchery must be employed. It should give each fish an equal and known chance of being selected for marking. A method commonly used is to dip one or more netfulls of fish from each rearing environment. This is usually achieved with the fish crowded into a small area. This method, however, is likely to be nonrandom, so the relationship between marked and unmarked fish will be unknown (Bevan 1959). Hewitt and Burrows (1948) examined the dip-net method and found that the smaller sockeye salmon in a population were obtained in the first haul of fish; the fish also were stratified in the net, the bigger individuals being on top. Bias caused by this method consistently resulted in overestimates of population size. The sample size had to include at least 38% of all the fish before there was no statistically significant difference between the estimated and actual population sizes.

Work by D. Buchanan (Oregon Department of Fish and Wildlife, personal communication) also has shown the potential for nonrandom sampling with the dip-net technique. However, Buchanan believes that tight crowding of salmon, proper mixing, and several replicate samples can yield a representative sample with a dip net. Repeatability among rearing environments at a hatchery or between hatcheries, particularly if sampling personnel differ between hatcheries, could prove to be a major problem for this more rigorous dip-net technique.

Another problem with the dip-net method is that it does not subject all fish at a hatchery to the same handling. If sampling fish with a dip net affects the survival of the fish netted, a survival bias will be introduced between the marked and unmarked fish.

A more statistically sound method to ensure that each fish has an equal chance to be selected for marking is systematic sampling. This can be accomplished by crowding the fish in the rearing environment, then netting all the fish from the crowded area to another area. If, for example, a 5% sample is desired for marking, every twentieth net of fish can be set aside. If the entire population is sampled in this manner, and the number of times fish are set aside for marking is large, the assurance of obtaining a representative sample is improved over the dip-net method. The ultimate systematic sample would be the removal of every twentieth fish in the sampling process, but this would be too time-consuming and too stressful to the fish.

A systematic dip-net sampling technique may be not applicable in all situations, and it subjects the fish to considerable handling. Because of this, fishery scientists and engineers have attempted to develop mechanical sampling devices for randomly sampling populations. Hewitt and Burrows (1948) described such a device. It consisted of a circular frame divided into four equal sections with a net hung from each section. Three nets were open at the bottom and the fourth was closed. The frame was placed in a tub of water, fish were added, and when the frame was lifted, the closed pocket retained sample of fish.

This sampler was modified to remove a random 10% sample of fall chinook salmon for a hatchery contribution study on the Columbia River. The "10-part sampler" consisted of a circular metal frame and a cylindrical liner. The frame was divided into 10 pie-shaped sections of equal size. A net pocket with a zipper at the bottom was hung from each section. To obtain a 10% sample, the frame and liner were placed in a water-filled tub and all but one pocket were left open. Fish were then placed inside the liner. When the liner and frame were lifted, the closed pocket retained fish for marking (Wahle and Vreeland 1978).

The above sampling devices were labor intensive and they require more fish handling than do systematic dip-net techniques. Faster and less disruptive devices include one described by Jones (1965), in which fish flowed over an inclined plane, fell onto a rotating cone, and passed through a slot in the cone during each rotation. The device was reported to remove 5.1% of the fish passing down the trap, with good repeatability.

Webb and Noble (1966) described a sampler that removed a constant sample of coho and chinook salmon. The mean percent sample varied from 0.2% to 1.1%. However, the device would not sample fish longer than 16 cm.

A device used to remove a sample of sockeye salmon from spawning channels in Canada was described by Davis and Hiltz (1971). The sampler removed from 4.4% to 5.2% of the fish in tests that had a standard deviation of 0.06 to 0.85.

An incremental sampler developed in 1979 by the Washington Department of Fisheries employs two jets of water controlled by solenoids. The jets are located on either side of the throat of a Y-shaped discharge pipe. All fish from a pond are pumped to a rectangular box where excess water passes through a bar grate and fish pass into the foot of the Y. For a contribution study at a Columbia River hatchery, one jet was set to operate 95% of the time and the other jet 5% of the time. One water jet force fish down the 95% arm for 19 s. The other jet operated for 1 s, forcing fish down the 5% arm. The fish passing through the 5% arm were retained for marking (Foster 1981). The pump reduced handling but the fish still had to be crowded.

A sampler developed by the National Marine Fisheries Service in Portland, Oregon, consisted of an A-shaped inclined plane table. Fish were pumped to the narrow top of the A, passed across

a perforated plate that drained excess water, and swept off the wide lower end of the table into a return trough. The foot of the table was divided into 20 equal-width sections. To remove fish for marking, a flume was attached to the foot of the table to pass fish over the return trough. The flume was the width of one or two divisions. Thus a sample representing a desired percentage could be removed from the table for marking by altering the width and number of flumes attached to the table.

Attempts were made to examine the incremental and inclined plane samplers to determine the percentage of fish removed. However, neither sampler has been adequately tested to determine if each fish has an equal chance of being sampled or if the sample fish are representative of the population.

Accuracy of the sampling percentage may not be of great importance unless the percentage is used to determine hatchery releases. "Procedure for Coded Wire Tagging Pacific Salmonids," a manual resulting from a Pacific Marine Fisheries Commission (PMFC) workshop at Silver Falls, Oregon, in September 1981, recommended periodic testing of any sampling device to ensure that each fish has an equal chance of being sampled and that the intended percentage of fish is being removed. In one suggested procedure, a known number of fish are marked, mixed with unmarked fish, and resampled. If there is no significant difference in the proportion of marked fish within each equal portion of the sample, it may be assumed that each fish has an equal chance of being sampled. If there is no significant difference in mean lengths and weights of fish within each portion, it may be assumed that the sampler removes a representative sample of fish. Finally, the sampler may be assumed to remove the intended percentage of fish if there is no significant difference in percentage of fish removed by each section or over a number of trials, and if there is no significant difference among percentages removed by a chosen sampling section (Pacific Marine Fisheries Commission 1984).

Of the previously described samplers, the pie samplers are the most feasible to test. Because the numbers of fish placed in the samplers are small in comparison to the numbers of fish in a pond, it is possible to count, measure, and weigh the marked and unmarked fish retained by each section over several tests. The sampling characteristics of the other samplers can be influenced by the rate of fish delivery and the sample size. Foster (1981) reported that the incremental sampler operates best with a constant flow of fish and an extended sampling period, which is also true for the inclined plane sampler. Only fall chinook salmon weighing 1.8 to 6.4 g were sampled with the inclined plane sampler; how it would operate with larger or smaller fish is unknown.

The most important factor in selecting a method of obtaining fish for marking is to understand how the results will be used. If the purpose of the contribution study is to show survival and contribution trends over time, the requirement that marked fish represent the entire hatchery population may be less important than it would be for other uses of the data. In a study to compare contributions over time, the same sampling method should be used throughout. Researchers must consider which sampling method their peers or those who will be influenced by the results will accept. Sampling methods vary among agencies on the Pacific coast. Fishery scientists with the U.S. Fish and Wildlife Service and the Department of Fisheries and Oceans in British Columbia use the crowding and dip-net method. Scientists with the Washington Department of Fisheries and the National Marine Fisheries Service use a more rigorous sampling method to ensure that the marked fish represent the entire hatchery population. No studies have been conducted to determine the influence of sampling method on the estimation of hatchery contribution.

More studies of mechanical sampling devices are needed before one of them can be identified as the best method for removing a random sample of fish for marking.

Marking Organization and Timing

The success of a marking experiment depends on equipment and techniques used, timing and organization of marking, and records kept. The coded wire tag (Jefferts et al. 1963) is the marking method most frequently used for salmonid studies on the Pacific coast. Several publications and manuals contain information on equipment needs, set up, and care and maintenance of equipment for coded wire tagging of salmon and steelhead (Moberly et al. 1977; Duke 1980; Jenkinson and Bilton 1981; U.S. Fish and Wildlife Service 1985); this information will not be repeated here.

In choosing appropriate sizes of salmon and steelhead to be marked with a coded wire tag, biologists in Region 1 of the U.S. Fish and Wildlife Service (1980) recommended that fish should

be larger than 2.3 g but smaller than 15 g when tagged with a full-length coded wire tag. However, salmon fry 0.9 g and larger are routinely tagged with full-length tags in British Columbia (T. Perry, Canada Department of Fisheries and Oceans, personal communication). Yearling fish should not be tagged close to the time of smolting. The water temperature at the facility during tagging should be lower than 13°C. If the health of the fish is jeopardized, tagging should not take place. The hatchery biologist and manager make the decision about whether tagging should commence or continue (U.S. Fish and Wildlife Service 1985).

Anadromous salmonids normally are marked in spring and fall months, when water temperatures and recovery time are optimal. At some hatcheries it is difficult to match the desired water temperature, fish size, and time needed for marking and recovery. Development of the half-length wire tag (Opdycke and Zajac 1981) has helped to alleviate this situation by allowing successful tagging of small fish. Moberly et al. (1977) reported that chum salmon weighing 1.0 g could be tagged at a rate of 156 to 183 fry/h per person with the half-tag. Fish 2.5 g or larger were tagged at an average rate of 700/h. Rates as high as 1,200/h were achieved as taggers became more experienced. Opdycke and Zajac (1981) reported successful tagging of chum salmon fry that averaged 0.8 g; tag loss was 2% over 41 d of observation and negligible tagging-associated mortality occurred. No tagging rates were given. More recently, unfed chum salmon fry weighing 0.4 g were tagged at a rate of 828 fish/h (K. Crandall, Alaska Department of Fish and Game, personal communication). Thrower and Smoker (1984) tagged pink salmon fry averaging 33 mm in length and 0.25 g in weight. The tagging rate averaged 350 fish/h and approached 600/h by the end of the marking period. After 14 d, tagging-related mortality was 0.15% and tag retention was 95.7%.

Sorting fish by size may improve tag placement and reduce tag loss. Sorting was found to be unnecessary if 98% of the fish fell into one of three length ranges: 50–90, 70–140, or 110–300 mm. If 10% or more of the fish fell in one of the ranges, the benefits of sorting were believed to outweigh the disadvantage of the additional handling (Duke 1980).

The success of any marking program can depend on the records kept and their accuracy. All agencies using coded wire tags have forms for recording pertinent tagging information, examples of which are illustrated in the tagging manuals previously mentioned. Obvious data to record include numbers of fish marked; location and dates of marking; species, race, stock, and brood of fish; tag code; and purpose of the marking. Other information often is kept on the method and dates of sampling of fish to be marked, holding environment for fish to be marked, size of fish marked, disease history and treatment of fish during the entire rearing period, fish condition, mortalities and water quality during marking, mark loss, and any problems occurring during marking (Duke 1980). When the coded wire tag is used, it is also recommended that a sample of wire from each roll be retained to check the tag code. Some cases of improperly labeled spools of wire have occurred. Some fish should be sacrificed and the placement and tag code should be checked to verify the records (King 1979; Duke 1980; Jenkinson and Bilton 1981).

Notes on naturally missing fins are important if fin removal is part of the mark. Marking personnel should examine and record all cases of missing fins during marking. Fins can be missing for genetic reasons or lost because of aggression by other fish, erosion from disease, or abrasion on concrete pond walls (King 1979). Normally, the adipose fin is clipped on anadromous salmonids that receive coded wire tags. Unusual numbers of fish with naturally missing adipose fins have occurred in some species at several hatcheries and in wild populations in Washington (Blankenship 1981). Unrecorded occurrences of missing fins at hatcheries could result in overestimation of the contribution, so marking supervisors must keep an accurate record of the number of fish found with naturally missing fins.

Treatment of Marked and Unmarked Fish

Handling and marking of fish could introduce bias between marked and unmarked fish. However, handling unmarked fish in the same manner as the fish during marking normally is impractical and unacceptable to hatchery personnel. Consequently, stress associated with marking must be minimized to ensure validity of the assumption of equal survival of marked and unmarked fish. To help guarantee equal treatment, marked fish should be returned to the population of unmarked fish from which they came. This creates difficulties in determining mark retention and numbers of marked fish released, but it also provides an opportunity to estimate the total population in a rearing environment.

Determining Numbers of Fish Marked

In many cases, knowing how many fish were marked is simply a matter of keeping a tally during the marking operation. When marks such as coded wire tags are internal, determining the number of fish tagged is more difficult. The wire tag injector (Northwest Marine Technology model) contains a counter that counts the number of times the injector is cycled (counter A). There are two counters in the quality control device (QCD). One counts the number of magnetized tags passing through the QCD (counter B), and the other counts the number of times the tagging cycle functioned but a tag was not detected (counter C) (Duke 1980; Jenkinson and Bilton 1981). It would seem that the number of times a tag was not detected (counter C) could be subtracted from the count in the wire tag injector (counter A) to give the count of the magnetized tags passing through the QCD (counter B). However, in practice the derived and actual numbers may differ for numerous reasons. These include stuck QCD counters, low water pressure in the QCD, electronic control box malfunction, moisture-caused shorts on the control box connector, large fish that temporarily block the exit from the QCD, fish too large for the water jet to direct to the correct QCD exit channel, a large range of fish sizes resulting in incorrect water jet pressures for the smallest or largest fish, small fish that turn sideways in the pipe entering the QCD so the tag does not become magnetized, fish tagged externally, fish caught in the QCD and washed through with another fish without being separately counted, and tag loss before fish get to the counter (Duke 1980; Jenkinson and Bilton 1981). The extent of these errors is difficult to assess. They can be minimized by proper tag placement, water pressure, QCD slope, and electronic setting (Jenkinson and Bilton 1981). Jenkinson and Bilton (1981) recommended that a separate count be maintained of any fish passed through the QCD a second time to check for the presence of a tag. Duke (1980) recommended that when counts are questionable the adjusted injector count (counter A minus counter C) be used. Despite possible counting mistakes, de Libero (1986) speculated that the incidence of counting errors is less than 0.1%. However, potential counting problems emphasize a need to estimate tag loss percentage and total tagged and untagged populations at the time of release.

Mark Retention

Marks may be lost at the hatchery or in the natural environment after release. Coded wire (and other) tags may be lost because of defective head molds, poor tagging technique (King 1979), and small fish. Bergman and Hager (1969) and Blankenship (1981) found that tag loss increased with a decrease in fish size and that tag loss was essentially complete 1 month after tagging. It is important to know the extent of tag loss so that the ratio of tagged to untagged fish can be corrected; otherwise, errors will ensue in the estimates of a hatchery's contribution to a fishery.

Duke (1980) recommended that 300 to 500 fish be randomly collected from each tag group and examined for tag loss. Of these, five from each group should be killed and their tag position checked. A minimum of 2 weeks should elapse between completion of tagging and the tag-retention check. Each fish should be examined for presence of a tag, quality of the alipose clip, and fish condition.

The U.S. Fish and Wildlife Service (1985) recommended that tag retention rate be determined at least 1 week before release. This allows fish time to recover from effects of the anesthetic used during examination. Bouck and Johnson (1979) found that fish treated with MS222 (a commonly used anesthetic) at a concentration of 100 mg/L suffered 100% mortality when transferred directly to 28‰ sea water, but only 12% mortality if 4 d elapsed before transfer.

If one were to follow the recommendations of Duke (1980) and the U.S. Fish and Wildlife Service (1985), tagging would have to be completed at least 3 weeks prior to release. Because tag loss can occur for up to 1 month, it would be advisable to complete the tagging 1 month prior to release.

The U.S. Fish and Wildlife Service (1985 suggested two ways to obtain fish for tag-retention checks. In the first, several ponds are selected for sampling, the fish are tightly crowded, and netfulls of fish are removed from all crowded areas until the desired number of marked fish is obtained. This sampling method requires the assumption that each netfull of fish is a random sample of the population. As previously mentioned, Hewitt and Burrows (1948) found this may not be true. All fish missing an adipose fin are tested for the presence of a tag. Fish with no tag are passed through the field of a powerful magnet in three different planes, then retested. This is done to ensure that the fish tested negative because they lost their tags, not because the tags lost their magnetism.

An alternative method for collecting marked fish has been used by the Washington Department of Fisheries, the Oregon Department of Fish and Wildlife, and the U.S. Fish and Wildlife Service. A sample of newly tagged fish is periodically collected from all tagging personnel. The fish are checked with a tag detector to verify that each fish contains a tag. This check is done to detect tagging-machine or tag-placement problems. Fish without tags are counted and left in the sample. The sample fish are held separately from other fish in the population, either in hatchery troughs or floating net pens. After an appropriate amount of time, sample fish are examined for tag retention. There are several advantages to this method. First, overall fish handling prior to release is reduced. Second, the tagged sample can easily be retained after release of the other fish; thus, if the tagging was completed less than 2–4 weeks before release, the tagged sample could be held for the recommended time to obtain the most accurate estimate of tag retention. Also, when an emergency or early release is made, the separately held sample remains available for tag-retention examination. Finally, separate holding allows an assessment of the number of fish that receive a tag but do not receive a recognizable adipose clip. This is important if the number of fish tagged minus those that die or lose the tag is used as the number of tagged fish released. If some fish are tagged but do not receive a recognizable adipose clip, the fish cannot be identified as tagged in the fishery or return samples. Thus, the tagged and unclipped fish should be added to the untagged population in calculations of the tagged to untagged ratio at release.

It is also possible that the separately held fish in the tag-retention sample are not representative of the entire tagged population. This could occur if growth and activity of the sample fish differed from those of the other tagged fish in ways that affected tag loss. These possibilities have not been examined.

To determine the appropriate number of fish to examine for tag and mark retention, decisions must be made concerning the maximum tag loss expected and the desired precision for the tag-loss estimate. In recent years, tagging programs at salmonid hatcheries on the Pacific coast of North America generally have had tag losses of between 5 and 10% (Johnson 1987).

If sampling is done without replacement, the hypergeometric distribution best describes the distribution of the estimated proportions of untagged fish obtained from a population whose fish were at one time all tagged (Chapman 1951). Use of the normal approximation to the hypergeometric distribution allows a closed formula to be used for simple calculations with various levels of tag or mark loss and estimates of precision. D. D. Worlund (National Marine Fisheries Service, personal communication) developed an equation that yields the number of fish to examine for tag retention, given a maximum tag-loss rate, the total population tagged, and a desired precision of the tag-loss estimate. If

N = number of fish tagged prior to any loss,
M = actual number of fish without tags in the population,
P = M/N = proportion of tag loss in the population,
n = number of fish sampled from the population,
m = number of fish in the sample without tags, and
k = precision as 1/2 the absolute confidence interval width.

an equation for determining the number of fish to sample to obtain a desired precision can be developed from the expected proportion of the tag loss with the formula

$$E(\hat{P}) = P = M/N .$$

In Cochran (1977), theorem (3.2) states the variance of $\hat{P}$ (the estimated proportion of tag loss) is

$$V(\hat{P}) = \left[\frac{P(1-P)}{n}\right]\left[\frac{(N-n)}{N-1}\right].$$

To restrict the precision of the difference between the actual and estimated values of tag loss to some probability, n should be chosen large enough that

$$\text{Prob}\,[-k \le |\hat{P} - P| \le k] \ge (1-\alpha);$$

k is small (≤ 0.1) and $(1-\alpha)$ is large (≥ 0.95). Let $Z_{\alpha/2}$ represent the area under a standard normal distribution curve lying outside of $-Z_{\alpha/2}$ and $Z_{\alpha/2}$. Then

$$k^2/V(\hat{P}) = Z^2{}_{\alpha/2},$$

and

TABLE 1.—Numbers of fish to examine for tag retention to be 95% confident that the true value of tag loss is within ±0.01 or ±0.02 of the estimated value.

Tagged population	Tolerance = ±0.01 for expected tag loss of				Tolerance = ±0.02 for expected tag loss of			
	0.05	0.10	0.15	0.20	0.05	0.10	0.15	0.20
20,000	1,673	2,948	3,935	4,702	447	829	1,154	1,428
40,000	1,746	3,183	4,364	5,328	452	847	1,189	1,480
60,000	1,771	3,270	4,529	5,576	453	853	1,201	1,499
80,000	1,785	3,315	4,616	5,709	454	856	1,207	1,508
100,000	1,793	3,342	4,670	5,791	455	857	1,210	1,514
150,000	1,803	3,380	4,744	5,905	455	860	1,215	1,522
200,000	1,809	3,398	4,781	5,964	456	861	1,218	1,525

$$\frac{k^2 n(N-1)}{P(1-P)(N-n)} = Z^2_{\alpha/2}.$$

Through algebraic manipulation, the above equation becomes

$$n = \{[k^2/Z^2_{\alpha/2}P(1-P)][(N-1)/N] + (1/N)\}^{-1}.$$

An examination of data in Johnson (1987) reveals that tag loss is normally less than 20% and in many cases less than 5%. Using the above equation, I calculated the numbers of fish to sample given four different expected maximum tag-loss levels and the desire to be 95% confident that the true tag loss is within ±0.01 or ±0.02 of the estimated value (Table 1). For example, if the estimated tag loss were 0.05, the 95% confidence interval would be 0.04–0.06 or 0.03–0.07, depending on the desired precision.

The U.S. Fish and Wildlife Service (1985) recommended the following formula for determining the numbers of fish to examine for tag loss:

$$n = [1.96/rq][(1-q)/q];$$

q is the estimated tag-retention rate and r is some percentage of the rate. For this equation, a binomial distribution is assumed for the proportion of tagged fish based on a sample from a population whose fish were at one time all tagged. The precision does not fix the width of the confidence interval. The smaller the tag-retention rate, the smaller the confidence interval. For example the 95% confidence interval for a tag retention of 0.95 is 0.9005–0.9995. For a tag retention of 0.85, the 95% confidence interval is 0.8075–0.8925. Because of this difference in precision, the suggested numbers of fish to sample are less than those listed in Table 1.

As can be seen from the sample sizes in Table 1, if the expected tag loss is 0.05 or less, the true tag loss will be within ±0.02 of the estimated value with a sample size of 500 fish (as recommended by Idaho Department of Fish and Game). It is also clear, if one samples about 2,000 fish, that the true tag loss will be within 0.02 of the estimated value for normally expected tag losses (5–20%).

Marked and Unmarked Releases

One of the most critical elements of a hatchery contribution study is to determine how many marked and unmarked fish are released. This is critical because to expand the catch of marked fish to the total release, one must know the marked to unmarked ratio at release. It is assumed that the survival and distribution of the marked and unmarked fish is the same after release.

The ideal method for determining marked and unmarked releases is an exact count. Hand counting is too time-consuming and detrimental to fish health, but machine counting of fish carrying coded wire tags is presently being tested by several fishery agencies on the Pacific coast of North America. Fish counters manufactured by Northwest Marine Technology, Inc., and by Smith Root, Inc., have been tested at Washington Department of Fisheries and Washington Department of Game hatcheries to count chinook and coho salmon and steelhead at release. The counter records both coded-wire-tagged and untagged releases. The error rate is less than 5% when the fish are not forced through the counter, but it increases when fish are forced through (Appleby and Schneider 1983). At present, the counter appears to be useful for species that are volitionally released (coho or spring chinook salmon). However, the counter technology is not sufficiently advanced to give 5% accuracy for species normally released en masse (fall chinook, pink, and chum salmon). Thus, with some species, other forms of sampling at or near the time of release may be required.

Because the number of fish marked is recorded at the time of marking, this number minus any mortalities of marked fish prior to release could be used as the release number. There are two problems inherent in this procedure: collecting all dead fish and determining how many of them are marked.

It may be very difficult to collect all fish that die before the release date, particularly if several weeks elapse between marking and release. Dead fish normally collect on pond drain screens, but some may sink directly to the bottom, and some may never appear because of predation. Determining predatory losses can be difficult or impossible; collection and examination of dead fish may be nearly as difficult. The routine at a hatchery may be to collect dead fish daily when several hundred fish are dying per day but only once every second or third day if daily mortalities are 50 or fewer. The longer the time before collection, the greater the chance of losing dead fish to predators or deterioration. If predator problems were nonexistent or minimal, pond bottoms remained clean, and water remained clear enough to see all dead fish, daily collections might yield a reasonably accurate number. However, such ideal conditions are rare.

Dead fish must be examined for tags. Because dead fish deteriorate rapidly, they must be examined soon after they are collected or the fish must be preserved. Fish may be frozen or placed in a preserving solution. Fish must be frozen individually—a block of frozen fingerling salmonids quickly turns into a fish slurry when thawed. Freezing fish individually is time-consuming and takes considerable space. Preserving solutions may be noxious to work with and must be kept away from production facilities.

One might assume that the absence of an adipose fin indicates the dead fish was tagged, but the adipose fin is the first external part of a fingerling salmonid to deteriorate after death. Thus, every fish missing an adipose fin must be passed through a tag detector. Fish that test negative must then be passed through a magnet and rechecked to control for any tags that lost magnetism. When the number of marked fish that died before release has been determined, it can be subtracted from the initial number marked to determine the number of marked fish released.

To expand the catch of marked fish from a hatchery to the total catch of fish, one must know the total release. Records are normally kept of the numbers of fish on station during rearing and at release. These numbers are based on (1) samples taken periodically through the rearing period, (2) subtraction of deaths in ponds from the original counted egg take or the numbers of fish placed in the ponds, (3) application of some standard mortality rate, or (4) a combination of (1)–(3). In the past, these methods have led to overestimates of release numbers (Worlund et al. 1969; de Libero 1986).

A reasonably accurate estimate of total population can be obtained when appropriate sampling procedures are followed. That is, fish in all hatchery rearing environments are weighed, a random sample is removed to estimate fish per kilogram, and the total population is estimated by multiplying the total weight of fish by the estimated fish per kilogram. Subtraction of deaths in ponds is fraught with the previously mentioned problems. The application of a standard mortality rate to estimate the total population is probably the least accurate method to estimate populations because it cannot account for unexpected survival or mortality. Thus a researcher must know the method used to estimate populations before accepting total release figures from hatchery records.

A more accurate method for determining releases requires that all fish be handled very near the time of release. This procedure was used to estimate releases of chinook and coho salmon for contribution studies at Columbia River hatcheries (Worlund et al. 1969; Wahle et al. 1974). The entire population of chinook and coho salmon at each hatchery was sampled with the 10-part sampler. The numbers of marked and unmarked fish retained by the closed pocket were counted. These counts were then divided by the estimated proportion of fish retained in the pocket. The sampler was tested to determine the variance of the proportion of fish retained. This allowed calculation of variances for the number of marked and unmarked fish released. Other sampling devices or procedures (such as those suggested for removing fish for marking) could be used to remove a random sample of fish for examination. However, the device or procedure must be calibrated if an estimate of variance is desired.

Methods developed to estimate populations of animals in the wild could be applied to hatchery fish. To use these methods, either marking or subsequent sampling must be random. If the marked fish are randomly distributed in the population sampled, the subsequent sampling does not have to be random (Ricker 1948; Schaefer 1951). Five assumptions apply to any population estimate based on marking and recapture: (1) the marked fish randomly mix with unmarked fish, (2)

the sampling method is not selective for marked or unmarked fish, (3) the marked and unmarked fish suffer equal mortality, (4) the mark is not lost, and (5) all marks are recognizable when fish are recaptured (Ricker 1948; Fredin 1950). These assumptions are difficult to test and are not always reasonable (Chapman 1955).

If a mark–recapture method is used to estimate hatchery populations, the Petersen method is more appropriate for a study designed to determine the contribution of hatchery fish. Multiple marking and recapture methods described by DeLury (1951) and Ricker (1975) require more handling and tagging of fish, in addition to what is done to estimate the hatchery contribution. Because marking was done randomly to ensure that marked fish represent the total population, subsequent sampling to estimate hatchery populations need not be random, provided one is willing to accept the assumption that marking does not alter the behavior of the fish in a manner that affects the probability of recapture. A dip net could be used to grab-sample an appropriate number of fish for an estimate of any desired precision. This technique has been used routinely since the mid 1970s at salmon hatcheries in British Columbia to obtain estimates of the tagged-to-untagged ratios and the total population sizes (T. Perry, Canada Department of Fisheries and Oceans, personal communication).

All of the previously mentioned five assumptions must be well satisfied if the Petersen technique is to yield an accurate population estimate. If a month or more has elapsed between marking and Petersen sampling, it could be difficult to determine the number of marked fish in the population. Even if resampling occurs within a month of marking, the actual number of marked fish may be difficult to ascertain for the reasons previously mentioned. In addition, fish are not fed during marking, and the stress of handling and marking may reduce their food consumption after marking. This could cause the marked fish to be smaller than the unmarked fish. This difference in size likely would not be made up if the time between marking and release were a month or less. The smaller size of the marked fish could result in a nonrandom mix of marked and unmarked fish because of the selectivity of larger fish for the more favorable habitats in ponds (Senn et al. 1984). Also, size difference could result in selectivity for tagged fish in sampling (Hewitt and Burrows 1948). It is probably also unreasonable to assume that marked and unmarked fish undergo the same rate of mortality, considering the additional handling stress incurred by the marked fish.

If one is unwilling to accept the validity of the assumptions concerning random mixing of marked and unmarked fish, then random sampling at the time of release is required. If the number of marked fish present in the population at the time of sampling cannot be accurately determined, then a Petersen estimate of the total population is not useful.

In summary, although it is desirable to minimize the handling of fish just before release, it is also necessary to obtain an accurate release estimate. Not sampling fish at release increases the chance of inaccurate release estimates. The greater the probability of error in release estimates, the less useful the contribution estimates. In short, to ensure that the funds and time expended for a hatchery contribution study are well spent, it is necessary to obtain the best possible estimate of the number of marked and unmarked fish released. With some species of salmonids, this estimate may be obtained with an electronic counter. With other species, it may be necessary to weigh the entire population at the hatchery and randomly sample to obtain release estimates. In some cases, as when fish are released from large ponds, it may be impossible to obtain an electronic count or to weight the release population, and a Petersen estimate may be the only alternative. It would be best to apply a new mark to a sample of fish a week or so before release, and resample just prior to release. A granule spray dye or a partial clip of the caudal lobe or ventral fin might provide an acceptable mark. However, given all the problems with the Petersen technique, an equally accurate release estimate might be obtained with an electronic counter at the pond outlet, even for mass releases. If electronic counters continue to improve, they may provide the best release estimates for all situations.

Fishery Sampling

Anadromous salmonids on the Pacific coast range from central California to central Alaska (Yonker 1963). They are captured in a variety of commercial and sport fisheries in marine and fresh water, often far from their origin. For example, chinook and coho salmon from hatcheries in the Columbia River Basin are caught in marine fisheries from Alaska to California (Wahle et al. 1974; Wahle and Vreeland 1978). This causes unique problems in sampling the fisheries for marked fish.

The major marine and freshwater sport and commercial salmonid fisheries from Alaska through California have been sampled for fin marks since 1963 (Worlund et al. 1969) and for coded wires since 1974 (Oregon Department of Fish and Wildlife 1976; Heizer and Beukema 1977). The sampling is done by the Department of Fisheries and Oceans in British Columbia and by fishery agencies in Alaska, Washington, Oregon, Idaho, and California.

The Canada Department of Fisheries and Oceans (formerly Canada Fisheries and Marine Service) began examining chinook and coho salmon for coded wire tags in 1973 in the commercial troll fishery in Georgia Strait (Heizer and Argue 1976), and has been sampling salmonids in the sport and commercial fisheries along the coast of British Columbia since 1974. Tag recovery information is available in Heizer and Beukema (1977) for 1974 and at the Pacific States Marine Fisheries Commission's Mark Processing Center for 1975 through the present.

The Oregon Department of Fish and Wildlife housed the Regional Mark Processing Center from 1970 through 1977. The Center assimilated, compiled, and distributed data on recovery of wire-tagged salmonids in U.S. coastal fisheries in Alaska, Washington, Oregon, and California (Oregon Department of Fish and Wildlife 1976, 1977a, 1977b). The Pacific States Marine Fisheries Commission assumed the duties of the center in 1977. Recovery data from 1977 onward can be retrieved on line from the Commission at 2501 S.W. First Avenue, Metro Center Suite 200, Portland, Oregon 97201. Descriptions of fishery sampling may be obtained by writing the Canada Department of Fisheries and Oceans, Mark Recovery Program, 1090 West Pender Street, Vancouver, British Columbia, V6E 2P1, and the Pacific Marine Fisheries Commission. De Libero (1986) discussed fishery sampling errors.

Sampling at the Spawning Site

In contrast to fishery sampling, routine sampling at the return sites does not always occur. Thus, plans to sample hatchery returns and adjacent streams must be developed. The plans must include sampling purposes, location, design, and data requirements.

Purpose of Sampling

Fish are sampled at return to obtain an estimate of the survival of all marked fish. This sampling gives managers a complete picture of the life cycle of marked salmonids. The sampling allows one to determine the harvest-to-return rate (catch to escapement) of marked fish. Return-site sampling also allows one to evaluate the permanence of the mark and the equality of survival of marked and unmarked fish after release. It also gives an indication of the extent to which hatchery salmonids stray.

Sampling Marked Fish

Two types of sampling occur at the spawning site—sampling for marked fish, and sampling to obtain age distributions and average fish lengths. Usually, returns are small enough so the entire population can be sampled for marks. The U.S. Fish and Wildlife Service (1980) recommended examining all returning fish for marks at the time of spawning. The normal spawning procedure is to examine the returning salmonids for maturation one to three times a week during the spawning season. Fish ready to spawn are removed and spawned. Immature and dead fish also are removed from the holding ponds. In some cases immature, and excess male fish are removed from the holding ponds before spawning begins.

Personnel should be present for the specific task of mark sampling. Hatchery personnel are normally too busy with the spawning operation to adequately examine all fish. Each fish with a mark is set aside for later examination and collection of biological data. In coded wire tag sampling, the snout of each marked fish is removed with a cut from the top of the head, behind the eyes, to the back of the mouth. The snout is placed in a plastic bag with a label that notes sampling site, date, species, length, sex, and mark quality (U.S. Fish and Wildlife Service 1980). Each fishery agency on the Pacific coast of North America has a form for recording these data.

It is also recommended that a scale sample be taken from all returning fin-clipped fish. If a fish has lost its tag, ages determined from the scales will allow the fish to be assigned to its mark group. If the fish retains its tag, which will indicate age precisely, the accuracy of scale-reading can be checked and, if necessary, corrected.

If the entire returning population is sampled, no estimates of marked returns are required. In some cases, the entire population cannot be sampled because of inefficient weirs or traps at return sites. These may allow smaller salmon to escape. In other cases, the return exceeds egg-take needs,

and the traps may be removed. Then, if a count of the total return population can be obtained, the return to the hatchery is assumed to be a random sample, and the return of marked fish can be applied to the total return to obtain an estimate of the total marked return.

Sampling Unmarked Fish

If fish from one year of marking return to a facility over more than one year, scale samples should be collected to estimate the age of returning unmarked fish. In some cases, as with returning coho salmon, the lengths of returning fish may yield a sufficiently accurate estimate of age at return. In many cases, however, a scale sample from unmarked fish is necessary. Usually, scale removal from all unmarked fish would be impractical because of the expense and time required. Simple random sampling of unmarked fish would be complex and difficult to achieve during a spawning operation that lasts over several days or weeks. However, a systematic sample could easily be drawn and accomplished with less mistakes. Another advantage of systematic sampling is that the sample can be spread more evenly through the population (Cochran 1977). A systematic sample consists of choosing a starting point and then sampling every kth fish from that starting point. The starting point can be chosen from a random number table (Schaeffer et al. 1979). The size of the kth interval will depend on the population size and on the sample size needed.

Suppose 10,000 fish are expected to return to a spawning site. Also suppose a sample of 2,000 fish is needed to estimate the age proportions at return within certain limits. To obtain 2,000 fish, one out of every five fish could be examined starting with a number (1, 2, . . ., 5) given by a random number table. If the starting number were 2, the 2nd, 7th, 12th, 17th, . . . fish spawned would be sampled. If the sampled fish was marked, the sampler could choose the next unmarked fish spawned, then continue sampling every k^{th} unmarked fish.

A systematic sample yields variances that are equal to or less than those yielded by a simple random sample, if the order of the population is random or the measurements are not related to the order of the periods within the population (Williams 1978; Scheaffer et al. 1979). Systematic sampling could lead to bias if there were periodic cycles in the population of spawned fish. For example, if only one person were spawning the fish and the spawning procedure consisted of taking eggs from two female fish and then fertilizing the eggs with one male, a systematic sample of every third fish would result in a sample of all male or all female fish.

There is no reason to believe that periodicity occurs in a spawning operation at salmonid hatcheries. The order of spawning depends on fish ripeness. Several hatchery personnel normally spawn fish, so the mix of males and females is not periodic. In most cases, it seems safe to assume that a systematic sample will yield estimates of variance equivalent to those obtained from a simple random sample. If this cannot be assumed, one could repeatedly choose a number from a random number table and count that many fish to choose the one sampled.

It is best not to include marked fish in the age sample of unmarked fish. The age of marked fish is known. Including marked fish reduces the number of unmarked fish examined. This dilution could result in age proportion variances for unmarked fish that are larger than desired; in turn, the larger variances may make it impossible to detect the influence of marking on age of return. To obtain the desired sample of unmarked fish in the previous example, one could sample one in every four fish (rather than one in five) if it was believed that 500 marked fish would return.

The sampling operation is accomplished most efficiently with two or more samplers. One person can examine all fish spawned for marks, while the second person records all data and keeps track of the kth unmarked fish to be sampled for age determination.

The number of fish to sample to obtain an age distribution depends on the expected age of the returning fish and the desired precision of each of the age proportions. The expected age may be based on previous studies of return age at the spawning site, ages of returns to nearby spawning sites, or a reasonable guess. For example, coho salmon return in their second and third years. In the absence of information on age at return, an assumption of 50% 2-year-olds and 50% 3-year-olds could be made. This is probably an unreasonable assumption, given the general knowledge of hatchery personnel. An assumption of 25% or less 2-year-old fish and 75% or more 3-year-old fish might be more appropriate.

After an appropriate age proportion has been assumed, one must decide what precision is desired. The desired precision of a particular age proportion will proscribe the necesary sample size. For example, it would require a much smaller sample size to estimate the age proportion of 3-year-old coho salmon in the previous example to within ±10% of the expected age proportion than would be required to estimate the proportion of 2-year-old fish with the same precision (if 25% are 2-year-old fish and 75% are 3-year-old fish). If a small age proportion is to be estimated very precisely, the entire population may have to be sampled.

Because samples for scale analysis are taken without replacement, the normal approximation to the hypergeometric function best describes age distribution. The numbers of unmarked fish to examine for various possible age proportions and numbers of returns are presented in Table 2 for two different levels of precision (10 and 20% of the expected age proportion). The number to sample comes from an equation developed by Worlund (personal communications). The equation was developed in the same manner as that for the numbers of fish to sample for mark loss, except that the confidence interval around P is not fixed. In Worlund's equation,

N = number of fish returning to a hatchery,
M = number of fish of a specific age returning to the hatchery,
P = M/N proportion of fish of a specific age,
n = number of fish sampled for age, and
k = dP = precision as one-half the absolute confidence interval width.

As was the case for the mark-loss equation,

$$E(\hat{P}) = P = M/N.$$

The variance of $\hat{P}$ is described by Cochran (1977):

$$V(\hat{P}) = \left[\frac{P(1-P)}{n}\right]\left[\frac{(N-n)}{(N-1)}\right].$$

Again, n is to be chosen such that

$$\text{Prob}\,[\,|(\hat{P}-P)| \le dP] \ge (1-\alpha),$$

dP being small and $(1-\alpha)$ large. Let $Z_{\alpha/2}$ represent the area under a standard normal distribution curve lying outside of $-Z_{\alpha/2}$ and $Z_{\alpha/2}$. Then,

$$d^2P^2/V(\hat{P}) = Z^2{}_{\alpha/2}.$$

Substituting for $V(\hat{P})$,

$$\left[\frac{d^2P^2n(N-1)}{P(1-P)(N-n)}\right] = Z^2{}_{\alpha/2}.$$

Solving for n, the above equation becomes:

$$n = \left[\left(\frac{k}{Z_{\alpha/2}}\right)^2\left(\frac{P}{1-P}\right)\left(\frac{N-1}{N}\right) + \frac{1}{N}\right]^{-1}.$$

Because the confidence interval ($-dP \le P \le dP$) is not fixed, the number of fish to sample decreases as P increases. Also, the less stringent the precision, the smaller the sample size required for a given return number and age proportion.

Because the sample size for age analysis depends on the precision desired, it seems prudent to select a small age proportion, say 0.20, and a reasonable precision level, 0.10. The sample sizes suggested in Table 2 are for readable scales. Some unreadable scales will inevitably occur, so it is wise to set a sampling goal somewhat larger than the tabled values. For example, to estimate the 0.20 age proportion within ±0.1 for an expected return of 750 unmarked fish, a sample size of 504 is necessary. Removing scales from two of every three unmarked fish that are spawned would yield a sample size of 500 fish. Unreadable scales would dilute this sample and make the precision less than desired. Removing scales from three of every four unmarked fish would yield a sample size of 562 fish, which would provide some buffer for unreadable scales and other unforeseeable circumstances.

For each scale collected, data should be taken on spawning return site, sample date, species, record number, sex of fish, and fork length. These data will ensure proper organization of the information, allow application of age proportions to total population, and may aid in reading some scales. It is recommended that the age proportions be applied to total returns by sex, as determined by the spawning crew. If all fish are spawned, total return and total male and female fish are known. If the small, "jack" salmonids are not spawned, a small error in the numbers of male and female fish returning may result. Jack salmonids are almost always males, but small females may be included inadvertently with them. I believe that incorrect sexing of the returning fish causes a smaller error than that introduced by applying age proportions irrespective of sex. Application of age proportions without regard to sex may yield numbers of males and females quite different from those reported by the spawning crew, particularly if the sample size for age at return is small. Each situation should be examined carefully. The decision on how to apply age proportions will ultimately rely on the researchers' knowledge of the percentage of returns han-

TABLE 2.—Numbers of unmarked fish to examine to be 95% confident that the true age proportion is within ±0.10 or ±0.20 of the estimated value.

Hatchery return	Estimated age proportion									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
	Sample size for tolerance = ±0.01 of true age proportion									
100	99	97	96	94	92	90	88	85	83	80
500	468	437	407	377	349	321	294	268	242	217
750	680	616	558	504	455	409	366	326	289	254
1,000	880	776	685	606	536	473	417	366	320	278
1,500	1,244	1,046	888	759	652	561	484	417	358	306
5,000	2,968	2,044	1,517	1,176	937	760	624	517	429	357
7,500	3,699	2,367	1,687	1,275	999	801	652	535	442	365
10,000	4,220	2,569	1,788	1,332	1,033	823	666	545	449	370
20,000	5,348	2,948	1,963	1,427	1,090	858	689	560	459	377
30,000	5,871	3,100	2,030	1,462	1,110	870	697	565	462	379
	Sample size for tolerance = ±0.02 of true age proportion									
100	95	90	85	80	74	69	59	59	54	49
500	393	317	261	217	183	155	132	112	95	81
750	532	402	316	254	208	173	144	121	102	85
1,000	646	464	353	278	224	183	151	126	105	88
1,500	824	549	400	306	242	195	160	132	109	90
5,000	1,337	737	491	357	272	215	172	140	115	94
7,500	1,468	775	507	365	277	218	174	141	116	95
10,000	1,543	796	516	370	280	219	175	142	116	95
20,000	1,672	829	530	377	284	222	177	143	117	96
30,000	1,720	840	535	379	285	222	177	143	117	96

dled, numbers of fish spawned (sex known), thoroughness of the spawning crew, size of the jack population, and the size of the sample for age determination.

The variances of the age proportions based on actual returns and sample size may be calculated with formula (3.6) from Cochran (1977):

$$V(\hat{P}) = \left[\frac{(P)(1-P)}{n}\right]\left[\frac{(N-n)}{(N-1)}\right];$$

N is the total return of fish and n is the sample of readable scales. A confidence interval (CI) around the age proportion may be calculated by multiplying the square root of the variance by the appropriate Z value:

$$\text{CI} - \hat{P} \pm Z_{\alpha/2}\,[V(\hat{P})]^{1/2}.$$

For a 95% confidence interval, the appropriate $Z_{\alpha/2}$value is 1.96.

Sampling Adjacent Streams

Sampling of adjacent streams is important, particularly if fish are passed upstream to spawn naturally above a hatchery, or if a hatchery meets the egg-take needs before the run is complete and the ladder is then closed or the weir removed. In such cases, stream surveys are necessary to obtain complete return information. Even when all returning fish are examined, surveys of adjacent streams can be useful because they provide an indication of straying of marked fish.

Stream surveys are fraught with difficulties. It is impossible to observe all the fish in a stream or to sample all the fish found. Deteriorated carcasses complicate sampling by increasing the likelihood that regenerated scales will be collected and by hampering recognition of marked fish. For these reasons, it is important to examine all fish found for marks, to remove the snout from all fish suspected of carrying a coded wire tag, to obtain a scale sample, and to record length and sex of all fish. Sampling other hatcheries near the release sites is also recommended to check for straying of marked fish.

Application of Hatchery Return Data

Hatchery return data are useful for examining two key assumptions: (1) marked and unmarked fish have the same survival rates and maturity schedules, and (2) insignificant loss of marks occurs after release. The age proportions and sizes of fish at the spawning sites can be used to generate not only the survival and growth rates but the maturity schedules of marked and unmarked fish. A comparison of marked to unmarked ratios at return with those at release can be used to document loss of marks and differential

mortality between marked and unmarked fish. However, straying of unmarked fish from other sources may influence the comparisons. If marked to unmarked ratios do not differ significantly among the ages of return, or between release and return, the assumption of equal survival and maturity of marked and unmarked fish probably is satisfied. If significant differences occur, further investigation is needed.

Postrelease mark loss can also influence marked–unmarked ratios at return. For studies that involve coded wire tags, it is necessary to carefully examine all fish for missing adipose fins (the external indicator for the presence of a coded wire), and to record which fin-clipped fish did not contain tags. Then, returns of fin-clipped fish with no tag can be applied to the appropriate tag group by age. The assumption of insignificant mark loss after release fails if a significant difference occurs between marked and unmarked ratios at release and return.

Lowering of the marked–unmarked ratio at return relative to release indicates a higher mortality of marked fish. This can be further examined by comparing marked–unmarked ratios by age of return. If the ratio for returning jack salmon is significantly lower than the release ratio, but the jack ratio does not differ significantly from the adult ratios at return, then higher mortality of marked fish likely occurred after release but prior to the first year of return. The possible influence of straying and increased catch caused by the mark must always be considered. Straying among hatcheries on the same river system, as in the Columbia River, can be consequential (Vreeland 1989). Certain types of marks—dangler tags, for example—may create a bias for capture of marked fish because of entanglement in gill nets or other fishing gear. It is recommended that marked–unmarked ratios only be compared when straying and catch bias are believed to be nonexistent or modest.

Returns of marked fish to spawning sites can be combined with fishery recoveries to obtain a total picture of survival. Catch and return data also are useful in developing standard catch to escapement ratios.

Summary

In this analysis, I have outlined the steps necessary to determine the fishery contribution of an individual hatchery with one year of marking, and to compare this contribution with that of other hatcheries and other years. A critical assumption for hatchery contribution studies is that the marked fish are representative of the total release. To ensure that the assumption is correct, methods must be employed to obtain a random sample of fish for marking. Opinions vary as to the appropriate method for obtaining the random sample. Some believe an adequate sample may be obtained by crowding fish in all rearing areas and netting them for marking. Others believe a more rigorous procedure is required, whereby all fish are handled in some fashion and systematic samples are frequently removed. The more rigorous sampling procedure has a better statistical foundation, but a comparison of the procedures has never been made. The variance of the contribution estimates due to fishery sampling procedures and expansion methods may be large enough to mask any possible difference between contribution estimates that result from different procedures for removing fish for marking. Given the stress and potential added mortality placed on hatchery fish by a rigorous sampling procedure, it is appropriate that comparisons be made between contribution estimates from the grab-net sample and from the more rigorous procedures. Until results from this type of comparison are available, it is recommended that a rigorous sampling procedure be employed to obtain fish for marking. This will ensure that the marked fish reflect the total population.

Once the fish have been marked, fishery scientists must obtain the most accurate release statistics possible. To apply the recovery of marked fish to the entire population, one must know the numbers of marked and unmarked fish released. Determining the original number of fish marked can be troublesome, but adherence to meticulous marking procedures should yield reliable numbers of fish marked. However, determining mortality of marked fish between marking and release is fraught with difficulties. Sampling of rearing environments for marked and unmarked fish prior to release also has its difficulties, and it places additional stress on the fish. In studies with coded wire tags, electronic counters collect sound data on releases of tagged and untagged fish, provided the fish are released on their own volition. The data become less reliable when fish are forced through the counters. Given the difficulties of sampling prior to release, electronic counters are recommended to determine the numbers of tagged and untagged fish released.

It is important to determine the extent of mark loss at and after release. The marked to unmarked ratio will be used to apply marked catch to total

hatchery contribution. Undetected or unaccounted losses of marks after release will result in an underestimate of hatchery contribution. The recommended numbers of fish to examine for mark loss have ranged from 300 to 2,000; sampling approximately 2,000 fish at release allows the mark loss to be estimated within 1%, provided the mark loss is expected to be equal to or less than 5%.

It is assumed fishery sampling will occur in the fisheries of interest, otherwise a hatchery contribution study should not be undertaken. Random errors occurring during fishery sampling and expansion of the observed catch of marked fish are not addressed here, but they must be assessed if contribution estimates are to be compared among hatcheries and years.

Sampling at the return site allows age structure to be estimated, mortalities to be examined, and maturity schedules for marked and unmarked fish to be charted. All returning fish should be sampled for marks, and information should be collected as described earlier.

A systematic sample of returning unmarked fish is also recommended. The number of fish to sample depends on expected returns, the age proportion to be estimated, and precision of the estimate.

Sampling of hatcheries and streams adjacent to the return facility is also recommended to obtain an indication of straying. The assessment of all returns will allow the best estimate of catch to escapement ratios.

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