Thermal Mark Technology for Inseason Fisheries Management: A Case Study

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ABSTRACT: Effective management of wild and hatchery salmon stocks in Alaska requires rapid and accurate determination of each component in commercial mixed stock catches. Marking 100% of the hatchery fish with thermally induced bands on their otoliths can potentially reduce uncertainty in the management of mixed stock fisheries, this premise being the subject of our investigation. In 1992 and 1993, adult hatchery pink salmon *Oncorhynchus gorbuscha* that had been thermally marked by prescribed water temperature manipulation in Gastineau Hatchery passed through commercial fisheries on their return to this Southeast Alaska hatchery. In 1993 we processed otoliths that had been collected from the fisheries in 1992. We also applied an inseason recovery plan to process otoliths from the 1993 run; from a random sample of 400 heads collected from each of 5 commercial and 3 experimental fisheries, 100–150 otoliths were subsampled and examined within 24 h to provide managers with inseason estimates of composition. Later, additional otoliths were processed to increase precision around the estimates and to develop quality control criteria. A total of 3,870 heads from the 1993 fisheries were collected, from which 952 otoliths were processed inseason and 1,359 postseason. The final precision, based on the 95% confidence intervals, fell within ±2% of the point estimate for each fishery. The accuracy of detecting marked otoliths was determined by planting 17 known marked otoliths into samples processed for the inseason estimate. All planted otoliths were correctly identified. Personnel were trained to process and read otoliths as part of this project. Their progress was evaluated through samples containing both known marked and known unmarked otoliths and by determining between-reader agreement. The results confirmed the importance of training and indicated that, when learning to detect thermal mark patterns, individual skill development varies. We found thermal mark recovery in this study to be a timely and cost-effective tool for managing mixed stock fisheries.

INTRODUCTION

Management of Pacific salmon fisheries containing commingled wild and hatchery stocks has received considerable attention with respect to the likelihood and consequences of overharvesting wild stocks (e.g., Wright 1993). The concern arises because salmon production from hatcheries can make assessment of wild stock abundance difficult and reduce management effectiveness in controlling harvests to meet escapement needs (Wilbur and Frohne 1989). By state statute (AS 160.5730), Alaska's managers are directed to achieve sustained yield of wild stocks and, secondarily, sustained yield of hatchery fish. Managers are able to adjust the location and duration of openings during the fishing season, but in the absence of accurate and timely information on stock composition, achieving optimal harvests of either hatchery or wild components is difficult.

One mixed stock commercial fishery for pink salmon *Oncorhynchus gorbuscha* in Southeast Alaska occurs along the western shore of Admiralty Island between Point Marsden and Funter Bay, an area known as the Hawk Inlet Shore (Figure 1). After entering Icy Straits, adult pink salmon returning to the inside waters of northern Southeast Alaska pass through this area before turning north to Lynn Canal and Stephens Passage or south to Chatham Strait. Because of the

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abundance of stocks, the Hawk Inlet Shore can be a productive fishery.

Pink salmon returning to Gastineau Hatchery, a private nonprofit salmon hatchery operated by Douglas Island Pink and Chum, Inc. (DIPAC) in Juneau, also pass through the Hawk Inlet Shore. This run is believed to peak in that area during the month of July (DIPAC-TRC 1990), which is temporally similar to the local wild stocks. Purse seine openings on Hawk Inlet Shore target harvestable surpluses of north-migrating wild stocks in July. Commingled hatchery pink salmon complicated assessment of the abundance of wild stocks. Reliable inseason estimates of hatchery abundance have not been feasible, in part, because management decisions on timing and location of openings must be made within a short time frame. Previous studies have shown no difference in fish length or weight between DIPAC pink salmon and the commingled wild stocks (Ingledue 1989), so other means (e.g., tags and marks) are necessary for hatchery-wild stock discrimination.

Coded wire tags, combined with adipose fin clips to visually indicate a tagged fish, have been the primary tool used to identify hatchery stocks. The problem with this method is that, due to the volume of the releases, 100% marking of all releases has been impracticable and prohibitively costly. In addition, the small size of pink and chum *O. keta* salmon makes coded wire tags particularly difficult to apply. As a consequence, uncertainty surrounding contribution estimates becomes a function of the estimated proportion tagged and the estimated proportion of the run examined for adipose fin clips. Tag-induced mortality and tag shedding further complicate the estimates (Clark and Bernard 1987). A marking system that provides 100% identification greatly simplifies the basis for determining

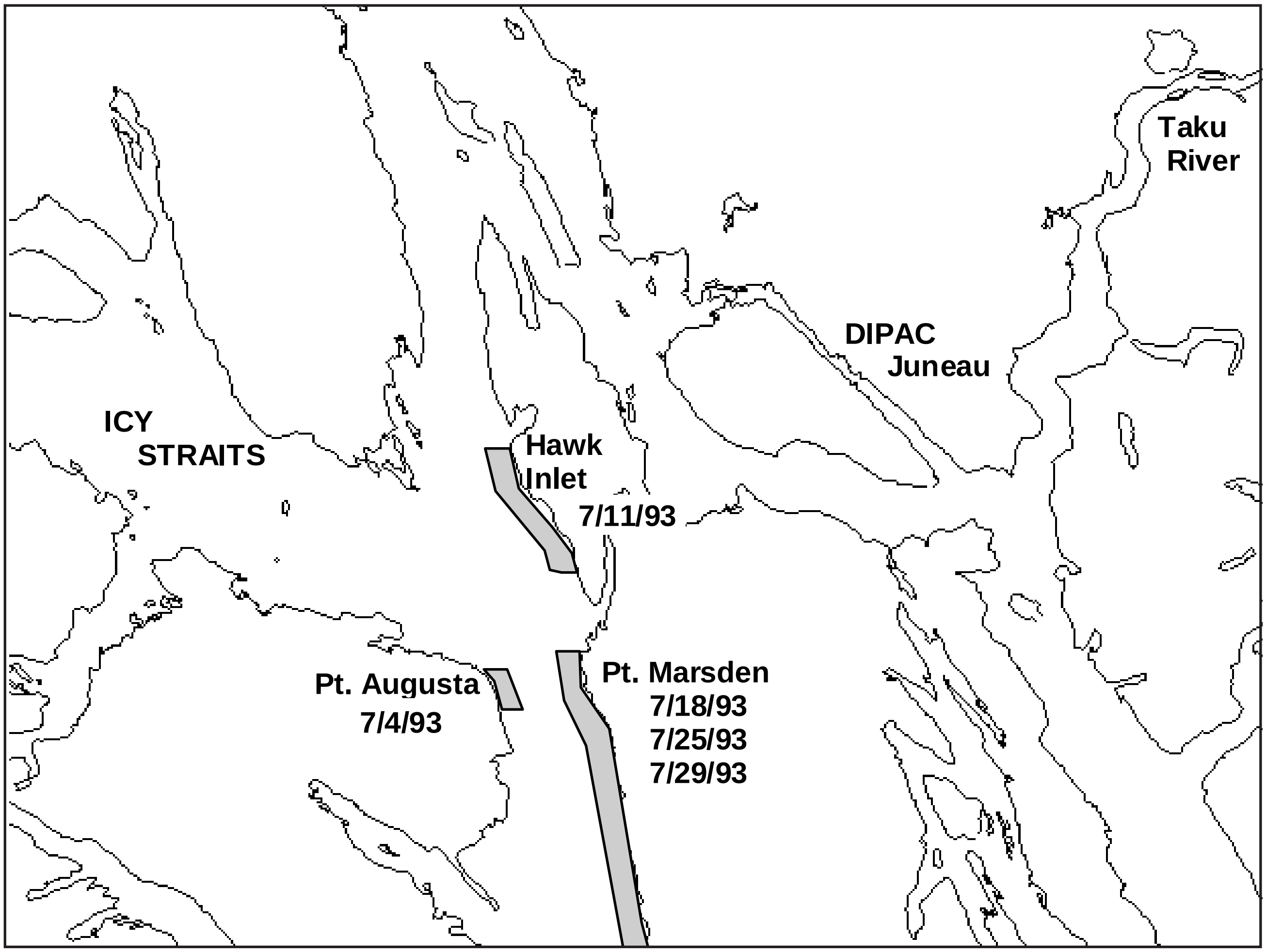

Figure 1. Dates and locations of the commercial purse seine fisheries sampled for otoliths in 1993.

contribution estimates. In particular, the sample size needed to achieve any given level of precision is unaffected by the total population size.

Brothers (1985) and Mosegaard et al. (1987) first suggested using manipulated rearing conditions to mass mark otoliths of fish. In 1990 Volk et al. (1990) described a system that marks 100% of the fish in a salmon hatchery by subjecting the fish to a sequence of planned temperature drops to induce marks in their otolith microstructures. A rapid temperature drop disrupts the process of normal otolith growth and produces an optically dark ring in the otolith. These thermal rings are similar to “check rings” observed in other fish (Campana 1983). The rings, which are induced during incubation, can be recovered from adult fish by slightly grinding the otolith and viewing its center using conventional microscopy. Varying the number and spacing of the induced rings can produce unique patterns to distinguish between similarly treated adult hatchery fish from other hatchery groups and wild stocks.

Munk et al. (1993) described the use of this method by DIPAC to successfully mark 33 million pink salmon. Thermal marks were found in all fry examined prior to release. Subsequent markings by DIPAC indicated the cost, based on the expense of heating the water, was <$0.03 per 1,000 fish. The release of thermally marked DIPAC fish also allowed the Alaska Department of Fish and Game (ADF&G) to investigate how rapidly marks could be recovered from adult otoliths and to assess potential use for inseason fisheries management.

In 1993 ADF&G and DIPAC entered a cooperative agreement. Objectives of the agreement were to (1) provide managers with timely estimates of the contribution of hatchery and wild pink salmon to mixed stock fisheries, (2) develop laboratory procedures for rapid otolith processing and establish training methods and a quality control system, and (3) describe the temporal distribution of wild and hatchery fish in the sampled fisheries. With funding and logistical support provided by DIPAC, hatchery contributions were to be determined by ADF&G from otoliths collected from the 1992 and 1993 mixed stock fisheries in Northern Chatham Strait.

DESCRIPTION OF FISHERY

Prior to statehood (1959) several fish traps were located along the Hawk Inlet Shore, and since statehood, these waters have been opened by ADF&G emergency order to the harvest of pink salmon by purse seine gear. From 1980 to 1993, purse seine catches of pink salmon in the area encompassing Hawk Inlet Shore have ranged from 0.45 million to over 3.4 million.

By regulation, purse seining along the Hawk Inlet Shore in July is managed according to a management plan for the northern Southeast Alaska purse seine fishery (Ingledue 1989): seining is allowed when a harvestable surplus of pink salmon are observed and is closed when 15,000 nontargeted sockeye salmon *O. nerka* have been harvested. Purse seine openings are determined by pink salmon abundance monitored in nearby areas. Early season fishing is delayed until early runs have shown sufficient strength. If early runs are not strong, seining is delayed until late July, when middle runs begin developing. Fishing for middle-run pink salmon begins with 15-h openings and expands if the run develops normally. Fishing continues until early September during years of large returns.

In August the Hawk Inlet Shore is managed according to pink salmon run strength in Lynn Canal and Stephens Passage. If those escapements are doing well, fishing is also allowed along the Point Marsden Shore; if escapements are poor, the area north of Point Marsden remains closed.

Pink salmon returning to the northern inside areas of Lynn Canal and Stephens Passage are conceptually managed as a single stock, although the area contains hundreds of distinct spawning populations. Aerial surveys of streams and corridor areas are conducted to help determine pink salmon run strength. Additionally, fish wheel samples from the Taku River indicate pink salmon escapements to that river (McGregor et al. 1991). Pink salmon catch per unit effort in the Stephens Passage drift gillnet fishery and in the Hawk Inlet Shore purse seine experimental fishery provide an index of run strength.

METHODS

In 1990 DIPAC thermally marked about 33 million fry (Munk 1993) and in 1991 about 51 million fry. These marked fish were recovered 2 years later in the 1992 and 1993 fisheries.

Sample Size Considerations

When determining the number of heads to collect for each fishery sampled, we considered the level of uncertainty or range of values around a point estimate that managers were willing to accept. One approach was to consider the question in terms of the risk of not

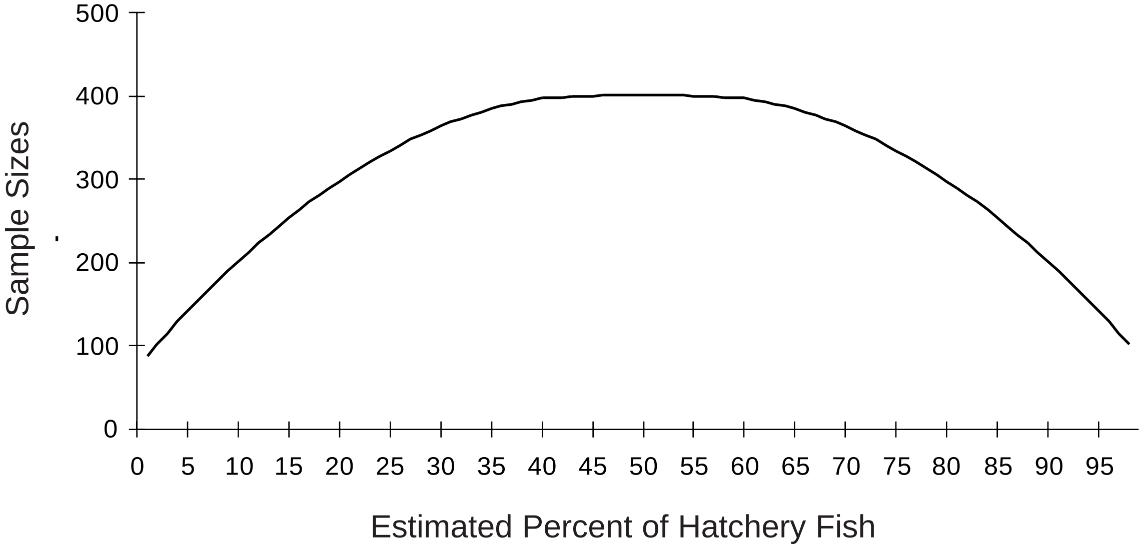

Figure 2. Sample sizes, that over the range of hatchery-fish proportions in mixed stock fisheries, are necessary to achieve a 95% confidence interval within ±5 percentage points of the estimated contribution. Calculations are based on the exact binomial method.

knowing the true abundance of wild fish and the associated costs of making an incorrect decision based on imprecise information (Wilbur and Frohne 1989; Francis 1992). However, given the pilot nature of this project, we used a common approach and the one most familiar to management: we collected enough samples to guarantee the calculated 95% confidence intervals (CI) fell within ±5 percentage points of our estimated hatchery proportion.

Working with large populations, where sampling without replacement can be ignored, the distribution of otoliths can be considered binomial: hatchery or wild stock. We used the exact method of approximating the binomial distribution to estimate sample sizes

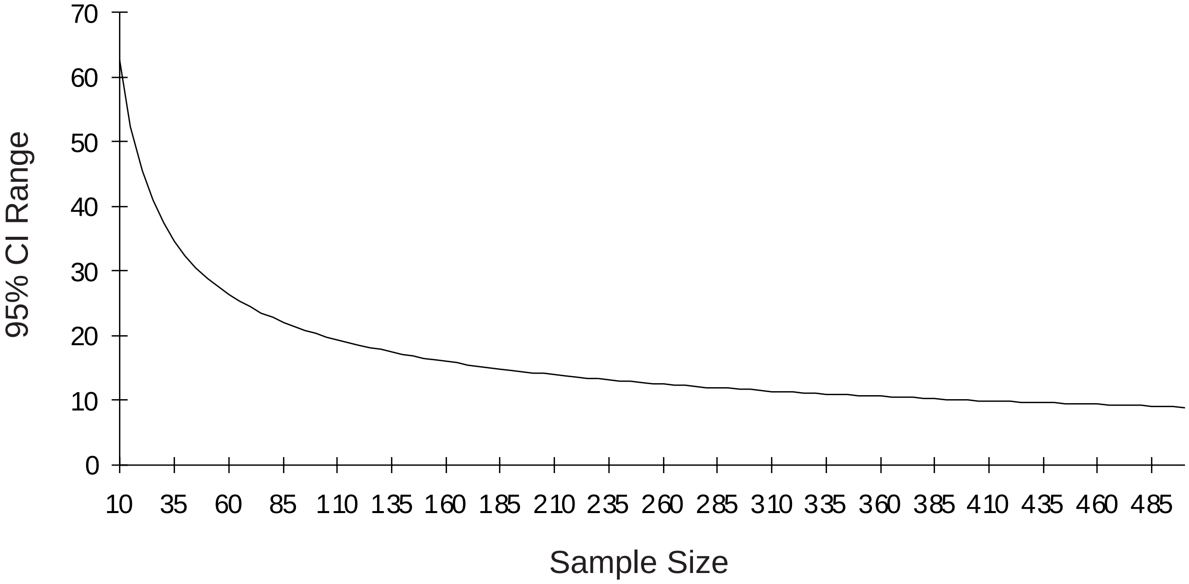

Figure 3. The 95% confidence range (upper limits minus lower limits) for a worst-case contribution of 50% hatchery fish as a function of increasing sample size.

because it is slightly more conservative than the more commonly used normal approximation (Daly 1992). The upper limit to the number of samples we needed to examine was based on the scenario offering the least amount of precision for a given sample size. For a binomial distribution, that situation occurs when a population contains 50% hatchery and 50% wild fish (Figure 2). On this basis, if the actual proportion of hatchery fish in a population was 50% and 402 fish were randomly subsampled, then over a large number of years, 95% of the point estimates would fall between 55% and 45%. Rounding to 400, this was the minimum sampling objective for each commercial opening and test fishery.

An important attribute of the binomial distribution illustrated in Figure 3 is that gain in precision (indicated by the decreasing 95% CI) flattens as sample size increases. Relative to per-unit processing cost, there is probably a point of diminishing returns. For a fishery composition of 50% hatchery fish, it would take substantially more than 400 samples at considerable cost to gain much more precision.

Because the actual proportion of hatchery fish was probably <50% and because minor reduction in precision was acceptable, we decided that processing 400 otoliths for our inseason estimates would be unnecessary, particularly due to our goal of providing a quick turnaround of information to managers.

We decided to use a 2-tier approach in our laboratory processing schedule. After the otoliths arrived, a subsample of approximately 100 was processed for our inseason estimates. If 50% were hatchery fish, a sample size of 100 would provide an approximate 95% CI around estimates within ±10 percentage points of the true proportion. The fishery managers believed this would be adequate. The number of samples was also small enough to process within a timely manner. Later, the remaining samples were processed postseason to examine the increase in precision around the initial estimates. The number processed followed Cochran's (1977) sequential scheme, although other potential methods, such as a Bayesian approach (Fuchs et al. 1993; Geiger 1994), were considered.

The Test Fishery

In 1992 and 1993 ADF&G conducted an experimental or test fishery 1 d each week during the commercial fishing season along the Hawk Inlet Shore. These test fishery operations were composed of three or four 20-min purse seine sets along a north-south gradient using chartered commercial seine vessels. The purpose was to establish an index of relative abundance and to monitor composition of hatchery and wild stocks, particularly during weeks in which no fishery was conducted.

Sampling and Processing Logistics

In 1992 ADF&G collected adult pink salmon otoliths from several commercial and test fisheries in northern Chatham Strait (Figure 1). Most of these were processed postseason in 1992, but some were processed in 1993. Several pink salmon carrying DIPAC coded wire tags were also recovered in 1992; all examined had thermal marks. These initial samples confirmed that thermal marks could be recovered from adult fish, which enabled a strategy to be developed for sampling and processing otoliths in 1993.

The 1993 commercial fisheries at Point Augusta, the Hawk Inlet Shore, and the Point Marsden Shore (Figure 1) were sampled from July 1 to August 10. Sampling procedures in 1993 were similar to those in 1992. A port sampler collected 400 pink salmon heads at the processing plant after each opening. The collections were distributed throughout the unloading process and represented multiple vessels. Fish were selected without apparent bias. Radio communication with observers on the fishing grounds and interviews with vessel skippers and crews ensured that catches from other areas were not sampled. The same sampling criteria were applied to test-fishing operations; after each seine set the catch was placed on deck and a sample of 100 to 150 pink salmon were selected. The remaining fish were then counted into the hold, and the heads of the selected fish were removed. Each collection of heads was tracked by its set number.

Fish heads from the commercial catch and test fisheries were immediately transported by air to Gastineau Hatchery in Juneau, where a crew of 3–4 dissected the otoliths and mounted them onto glass slides. Fish heads were generally split between the eyes, and the left and right sagittal otoliths were dissected and placed in 1 cell of a 96-cell tray. If the dissector was unable to recover the left sagittae, an orange bead was placed in the cell; if the right sagittae could not be recovered, a yellow bead was placed in the cell. Pertinent otolith dissection information, including the total number of sets (pairs) of otoliths successfully dissected, was recorded.

After the first 100 otolith pairs were removed, part of the crew started to prepare the otoliths for inseason processing, while the rest of the crew members continued dissecting the remaining otoliths for postseason processing. To clean the otoliths of blood and other tissue, we placed them in a 0.5% chlorine solution until they appeared white (approximately 10 min). Several rinses were then performed beginning with a dechlorinating solution followed by tap water. We carefully decanted otoliths after every rinse, and a 90% ethanol solution was finally added to each cell (later this was allowed to evaporate).

Left sagittal otoliths from each pair were mounted sulcus-side-up on individually labeled glass slides using thermoplastic cement. If the left sagittae was missing from the cell, then the right sagittae was mounted and labeled accordingly. Pertinent specimen mounting information was recorded on the sample invoice. The dissection of all otoliths and mounting of those otoliths used for inseason processing was typically completed by 2200 hours on the day they were sampled.

Slide boxes containing mounted slides, storage trays of otoliths, and a copy of each sample invoice were then transported to the ADF&G otolith laboratory by 0800 hours the following morning. The inseason samples, initially 100 specimens per strata and an additional 150 specimens later in the season, were manually ground using 1,200-grit abrasive paper and 3-μm lapping film. Grinding removed the overlying layers of otolith material and exposed the otolith microstructure formed during the first winter of growth. This was examined for the 5-ring thermal mark identifying the DIPAC 1991 brood year (Figure 4). Mark disposition for each specimen was recorded. Those specimens identified as DIPAC fish were reconfirmed prior to tabulating the results.

When the initial batch of samples was completed, the information on the mark-to-unmarked ratio and the associated 95% CIs were provided to the fishery managers. Typically, inseason processing and mark deter-

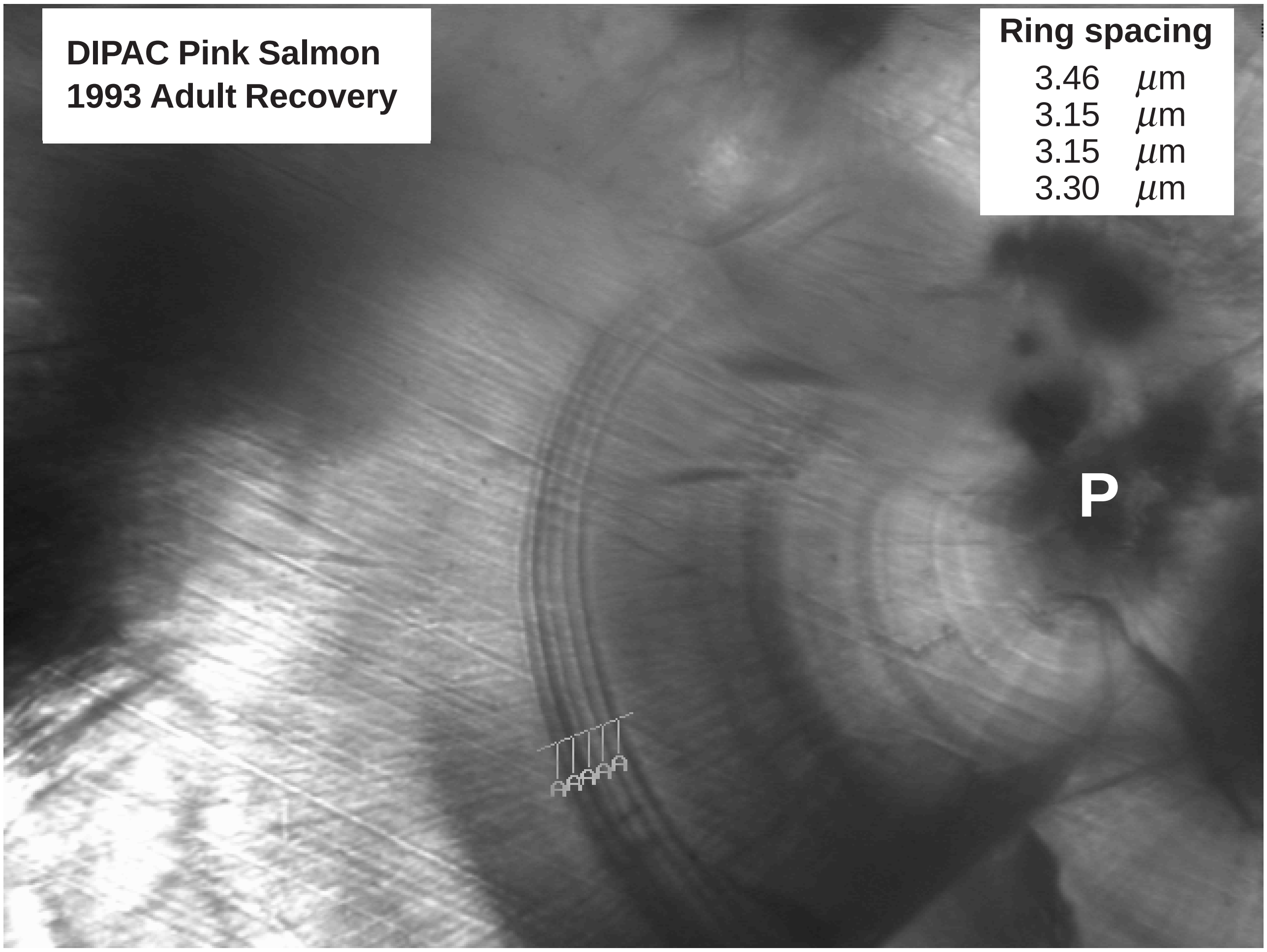

Figure 4. Digital image of an adult pink salmon otolith showing the 5-ring pattern (indicated by the letter *A*) characteristic of the DIPAC 1991 thermal mark. The distance (microns) between the thermal rings displayed from top to bottom corresponds to the inner to outermost rings. The letter *P* identifies the location of a primordia that is used as a reference point for locating the thermal rings (250x).

mination was completed by 1200 hours on the same day the samples were received in the laboratory.

Training and Quality Control

After receiving instruction on how to recover thermal marks, 2 technicians processed the 1993 collection and a third processed the remaining 1992 samples. Initially, the technicians were taught to dissect, prepare, and process otoliths from voucher specimens (i.e., representative samples of pink salmon fry obtained from the hatchery and preserved in alcohol before their scheduled release into the ocean). These voucher specimens became the standard or definitive mark pattern by which the technicians identified marks. Because fry developmental stages can vary during imposition of thermal marks, the mark locations and ring spacing may vary among individuals of a mark group. The technicians took measurements from a central primordia (Figure 4) of the voucher otolith to the first ring of the mark and measured the width of the mark. These measurements were used to help identify the marks in adult fish. Video prints of selected vouchers showing the range of mark variation were displayed on large poster boards to provide quick-reference visual aids to assist with difficult patterns.

Technicians were also trained to process adult otoliths. Being careful not to grind through the core, surplus mounted otoliths were ground down to optimally elucidate the primordial core by alternately grinding and viewing until several primordia became distinct. The technicians learned to reduce processing time by controlling the pressure exerted during grinding and by becoming familiar with variations in otolith patterns and shapes.

After approximately 4 weeks of training, the technicians began to examine samples containing a mixture of marked and unmarked otoliths. They were instructed to classify the otoliths as marked, unmarked, or unknown. The unknown category was used to identify problematic otoliths that were then openly compared and discussed amongst the technicians and the supervisor before a final determination was made.

After gaining some familiarity with thermal patterns, otolith readers (technicians) A and B began to process the 1993 postseason samples. They were formally tested on their ability to identify wild and hatchery fish by processing samples in which 17 known marked and 47 known unmarked otoliths were planted into samples from the commercial catches. The known marked fish were obtained from the first returns to the hatchery, and their identity was further validated through otolith examination. The known unmarked samples were obtained from commercial fisheries in southern Southeast Alaska, where the chances of collecting a DIPAC fish were negligible.

The laboratory supervisor, otolith reader C, reviewed the determinations made by readers A and B and also provided inseason estimates of contribution. Reader C's determinations were evaluated by planting 17 known marked otoliths into samples shipped to the laboratory for inseason processing.

Between-reader comparisons were also performed in which readers A and B exchanged samples they had processed and made independent determinations on each otolith. Three comparisons were conducted: reader A reexamined a sample of otoliths processed by reader B (trial 1) and reader B reexamined 2 samples of otoliths processed by reader A (trials 2 and 3). The readers identified the otoliths as marked, unmarked, or uncertain. The uncertain category was allowed because it was used routinely to flag otoliths that needed more evaluation. These data were later used to evaluate options for measuring statistically tractable levels of agreement and reliability using Cohen's Kappa statistic (Fleiss 1981).

RESULTS

Sampling and Processing

An important objective of the project was to evaluate the feasibility of using otolith thermal mark recovery to meet inseason management needs for hatchery-fish proportions in the catch. Rapid processing of heads and otoliths was critical; we experienced little difficulty satisfying the planned sampling and processing requirements. The 2-tiered processing schedule worked well, and by the end of the project we had gained valuable experience on how to efficiently schedule resources. The average dissection rate was approximately 75 heads per hour per individual, the average mounting rate was 35 otoliths per hour per individual, and the processing and initial mark-determination rates were 60 otoliths per hour per individual. ADF&G was able to provide managers with inseason estimates of hatchery contribution within 24 h of a test fishery or from the time commercial fishers delivered their catches to processing plants.

1992 Fishery

In 1992 ADF&G gathered otoliths from 2 test fisheries and from 4 of the 5 commercial fisheries along the Hawk Inlet and Point Marsden Shores. Pink salmon

Table 1. Number of adult pink salmon caught in 4 commercial (CF) and 2 test (TF) fisheries in 1992, the number of otoliths processed, the point estimates, and estimates of precision.

							Percent DIPAC Returns	
Date	Location		Pink Caught	Otoliths Processed	Number marked	Point Estimate	95% CI upper	95% CI lower
7/10/92	Hawk Inlet	TF	1,148	385	5	1.3	3.0	0.4
7/19/92	Pt. Augusta	CF	7,434	102	7	6.9	13.6	2.8
7/20/92	Hawk Inlet	TF	4,980	382	44	11.5	15.2	8.5
7/23/92	Hawk-Marsden	CF	218,873	95	12	12.6	21.0	6.7
7/26/92	Hawk-Marsden	CF	246,311	100	12	12.0	20.0	6.4
8/3/92	Hawk-Marsden	CF	200,088	100	8	8.0	15.1	3.5
	TOTAL			1,164	88	7.6		

counts from the fish wheel on the Taku River, used as a relative index of escapement, indicated the pink salmon return to the inside waters was average. Technicians processed 1,164 otoliths from the 1992 samples (Table 1). The results showed that DIPAC had contributed 7.6% of the run (Figure 5) and contributions were highest between July 20 and 26.

1993 Fishery

All commercial purse seine openings in the study area were sampled in 1993: 1 opening at Point Augusta, 1 along the Hawk Inlet Shore, and 3 on the Point Marsden Shore. In addition, weekly test fishing was conducted for 3 weeks along the Hawk Inlet Shore (Figure 1). Early season test fishing and aerial assessments along the Hawk Inlet Shore indicated a strong early run for the inside waters. That run never materialized, and resulting pink salmon escapements to the inside waters of northern Southeast Alaska from upper Lynn Canal to lower Stephens Passage were extremely weak. The index of run strength from the ADF&G fish wheel on the Taku River had the lowest pink salmon count recorded since it was established in 1984. Aerial escapement counts in Stephens Passage and Lynn Canal were also below average. This depressed run contrasted with high catches in Chatham Strait and strong escapements along the inside of Chichagof Island and the western shore of Admiralty Island (ADF&G 1993).

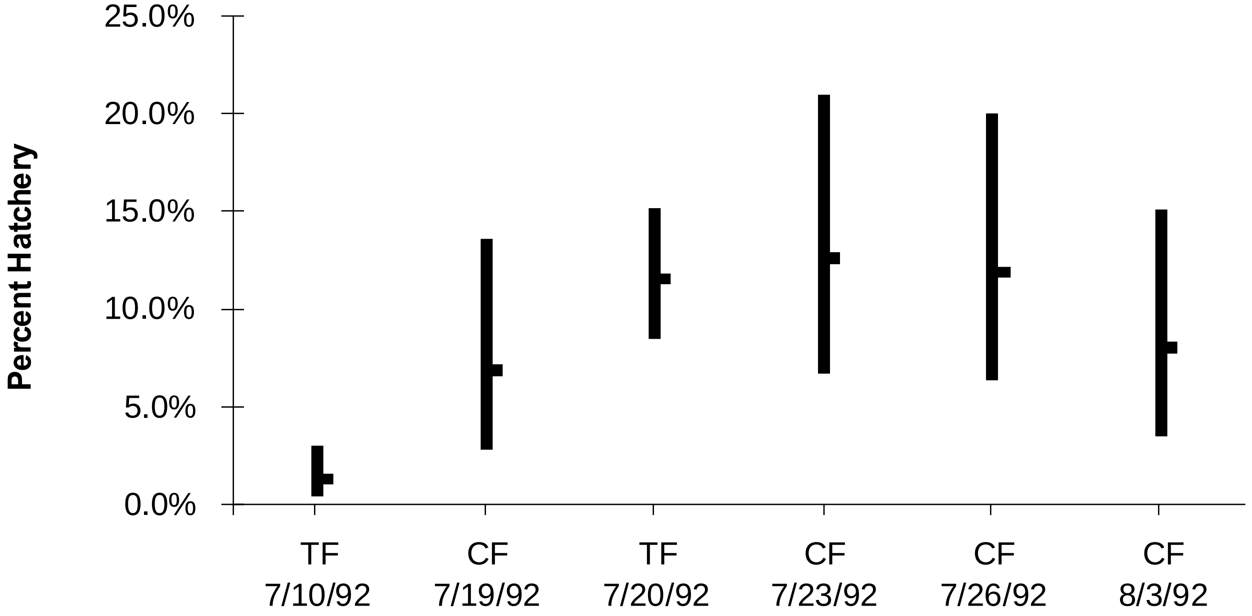

Figure 5. Point estimates and 95% confidence intervals for the estimated proportion of hatchery fish in the commercial and test fishery samples from the 1992 season.

Table 2. Number of otoliths processed to meet inseason management needs for 5 commercial fisheries (CF) and 3 test fishing (TF) operations in 1993, the number of otoliths processed, the point estimates, and estimates of precision.

							Percent DIPAC Returns	
Date	Location		Pink Caught	Otoliths Processed	Number marked	Point Estimate	95% CI upper	95% CI lower
7/4/93	Pt. Augusta	CF	11,347	99	0	0.0%	3.7%	0.0%
7/6/93	Hawk Inlet	TF	9,255	100	1	1.0%	5.4%	0.0%
7/11/93	Hawk Inlet	CF	80,471	91	1	1.1%	6.0%	0.0%
7/16/93	Hawk Inlet	TF	1,708	158	5	3.2%	7.2%	1.0%
7/18/93	S. Marsden	CF	264,053	99	0	0.0%	3.7%	0.0%
7/23/93	Hawk Inlet	TF	2,847	137	2	1.5%	5.2%	0.2%
7/25/93	S. Marsden	CF	487,592	119	2	1.7%	5.9%	0.2%
7/29/93	S. Marsden	CF	387,373	149	0	0.0%	2.4%	0.0%
	TOTAL			952	11	1.2%		

From the 952 otoliths processed to meet inseason needs, 11 thermal marks were recovered (Table 2). Based on these recoveries, DIPAC contributed 1.2% of the run in the sampled fisheries, and run percentages were highest between July 11 and 26 (Table 3).

With the inclusion of postseason otolith analyses, a grand total of 2,331 fish (Table 3) were examined; 30 of these were hatchery fish. Within each commercial opening and test fishery, no significant differences were found in the percentage of hatchery fish between the boats sampled or between the location of the purse seine sets (chi-square tests: all $P > 0.345$), so these data were pooled in Tables 2 and 3. In no fishery did the inseason estimate of contribution change significantly after processing the postseason otoliths (Figure 6). As expected, increasing the numbers simply nar-

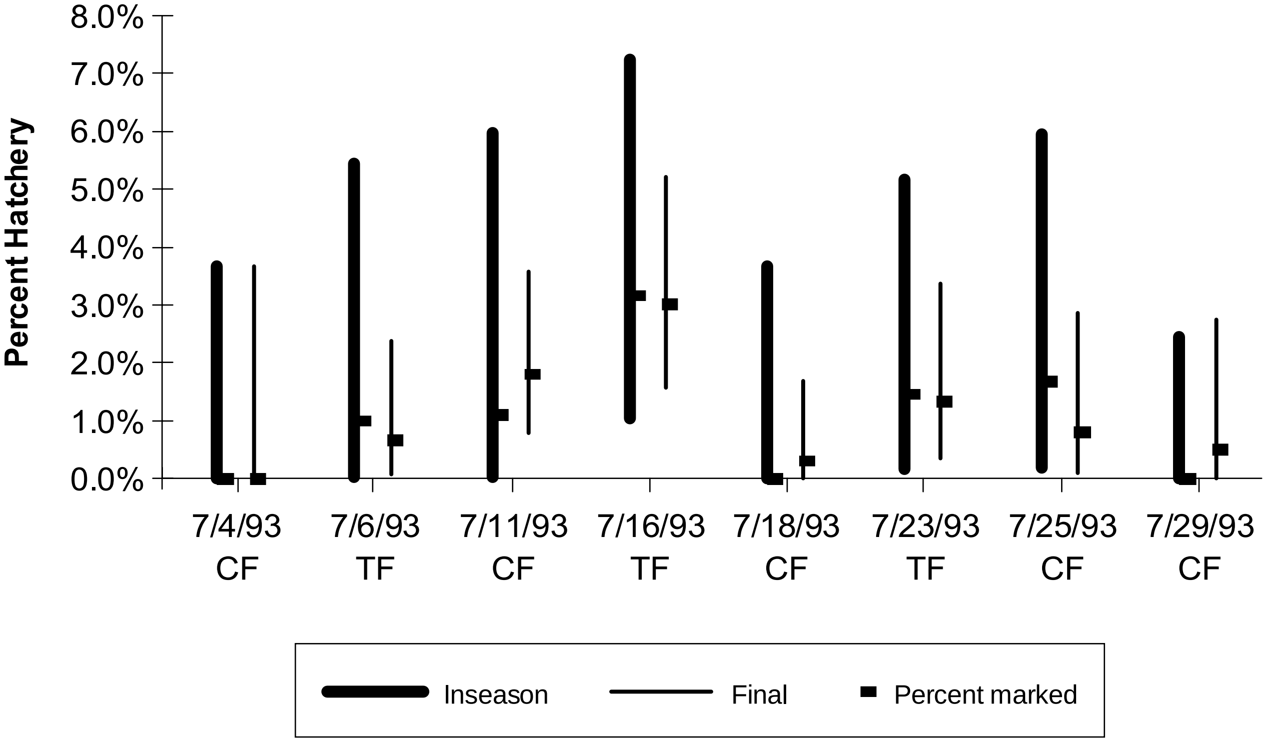

Figure 6. Comparison of point estimates and 95% confidence intervals for the estimated proportion of hatchery fish in the 1993 samples. The thick bar displays inseason results (952 otoliths) and the thin bar displays final results, which includes both inseason and postseason samples (2,331 otoliths).

Table 3. Number of otoliths processed at the completion of the project from 5 commercial (CF) and 3 test (TF) fisheries sampled in 1993, the number of otoliths processed, the point estimates and estimates of precision. The number of otoliths processed includes those used for the inseason estimates and those processed later to increase precision for each of the fisheries.

							Percent DIPAC Returns	
Date	Location		Pink Caught	Otoliths Processed	Number marked	Point Estimate	95% CI upper	95% CI lower
7/4/93	Pt. Augusta	CF	11,347	119	0	0.0	3.7	0.0
7/6/93	Hawk Inlet	TF	9,255	300	2	0.7	2.4	0.1
7/11/93	Hawk Inlet	CF	80,471	436	8	1.8	3.6	0.8
7/16/93	Hawk Inlet	TF	1,708	398	12	3.0	5.2	1.6
7/18/93	Marsden S.	CF	264,053	328	1	0.3	1.7	0.0
7/23/93	Hawk Inlet	TF	2,847	300	4	1.3	3.4	0.4
7/25/93	Marsden S.	CF	487,592	250	2	0.8	2.9	0.1
7/29/93	Marsden S.	CF	387,373	200	1	0.5	2.8	0.0
	TOTAL			2,331	30	1.3		

rowed the confidence bounds around the estimates. The final precision, based on the 95% CIs, fell within ±2 percentage points of the point estimate for each fishery.

Because the proportion of hatchery fish was low in 1993, the prerequisite of reading enough otoliths to achieve 95% confidence within ±5 percentage points of the estimate was met with the number of inseason otoliths processed. However, postseason otolith processing helped build confidence in the methodology used and provided further opportunities to confirm each technician's ability to distinguish thermal marks.

Training and Quality Control

Planting known marked and unmarked otoliths into the 1993 mixed stock samples proved to be an effective means of monitoring a reader's accuracy in identifying the otoliths. Reader A correctly identified all known marked and unmarked fish planted in samples from the commercial catch; reader B had more difficulty, correctly identifying only 83% in a similar sized sample; reader C, the laboratory supervisor, correctly identified 100% of the known marked fish that were planted in the inseason samples (Table 4).

Other testing involved processing and exchanging samples between both trainees. Between-reader comparisons from 3 separate trials, particularly by the last trial, indicated that both readers had achieved a similar level of agreement on marked and unmarked identifications. As presented in Table 5, two measures of overall agreement were provided for each of the 3 trials: the percent agreement and a weighted measure of Kappa (Fleiss 1981).

Percent agreement is a commonly used measure of between-rater agreement. The percent agreement includes factors that could be due to chance alone, and thus, it is higher when a category being rated has a high probability of occurrence. Kappa, on the other hand, is chance-corrected. The ratings can be more directly compared across different tests, and it has an associated standard error that can be used for testing statistical significance (Fleiss 1981). Kappa is scaled to vary between 1 and -1, Kappa = 1 meaning perfect agreement, Kappa = 0 meaning no different than chance alone, and Kappa = -1 meaning perfect disagreement. The common interpretation of Kappa in the literature is that a value > 0.75 means there is excellent agreement beyond chance. Values between 0.40 and 0.75 represent fair to good agreement, and a Kappa < 0.40 represents poor agreement beyond chance (Fleiss 1981). Individual Kappas can be calculated for each category and pooled from different trials.

The weighted version of Kappa has the same properties as above, but it is adjusted by giving zero weight to disagreements over the uncertain category and full weight to disagreements over marked and unmarked. In this manner the value better reflects agreement on what is marked and unmarked and reduces the influence of the subjectively classified *uncertains*. Results from the 3 trials, the third taking place at the end of the study, show a broader range of values than percent agreement, but they confirm progressive improvement on the level of agreement between the 2 readers being trained.

DISCUSSION

Prior research findings pertaining to thermal mark recovery on a large scale were not found. This project demonstrated that recovering otolith marks rapidly and

Table 4. Numbers of known marked and unmarked otoliths planted into 1993 commercially caught samples and subsequently correctly or incorrectly identified by otolith readers A, B, and C.

Reader	Otolith Type	Number of Known Otoliths Planted	Number Correctly Identified	Percent Correctly Identified
A	Marked	10	10	100
	Unmarked	24	24	100
	Total	34	34	100
B	Marked	11	7	64
	Unmarked	25	23	92
	Total	36	30[a]	83
C	Marked	17	17	100
	Unmarked			
	Total	17	17	100

[a] Of the 6 misidentified otoliths, reader B identified 4 known marked otoliths as unmarked, 1 known unmarked otolith as marked, and 1 known unmarked as uncertain.

accurately enough to serve as an inseason tool for the management of mixed stock fisheries is feasible and may be a more effective means of identifying hatchery fish than coded wire tags, particularly when tagging costs more for a similar degree of precision.

The 2-tiered processing schedule — rapid processing to meet inseason management needs and postseason processing to increase precision around the initial estimates — worked well, and we encountered no difficulty in applying it to the fisheries during the 1993 season. Postseason processing enabled us to increase the precision of the estimates and gave us time to conduct quality control checks on the initial determinations. By making use of the inseason results, a 2-stage sampling approach can be used to identify the optimum number of otoliths to process for postseason estimates (Cochran 1977). A method described by Geiger (1994) applies a Bayesian method for allocating postseason processing effort when multiple fisheries are sampled. Inseason otolith processing to recover thermal marks, although seemingly labor-intensive, was actually quite rapid: if necessary, a reader could process over 400 otoliths per day, provided they were already affixed to glass slides. The inseason sample size of 100 was easily accommodated within the schedule and adequately satisfied management needs.

In this study the target sample size was based on ensuring that the precision of the estimates, as measured by the 95% confidence intervals, was within a predetermined range. Target sample sizes could also be based on consideration of how the information is used to achieve management objectives, in particular assuring adequate escapement of wild salmon to the spawning grounds. Wilbur and Frohne (1989) discuss how errors in estimating hatchery contribution in a fishery translate into management actions that could allow over or underescapement of wild stocks. They show that, given the same amount of estimated contribution error, the error in achieving a target escapement goal increases as the hatchery contribution in the fishery increases. At low levels of hatchery contribution as occurred here, the danger of overharvesting wild stocks due to estimation errors is low; consequently the number of samples processed could be reduced. Conversely, when hatchery contribution is expected to be high, the number of samples necessary to estimate the wild stock contribution and minimize escapement error is greater.

The coefficient of variation, CV, is frequently used to measure precision when there is an interest in the total number of items of 1 of the categories (Cochran 1977). For a given sample size, the CV of the wild stock contribution will increase as the proportion of wild stocks in the fishery decreases. A sampling strategy to minimize errors in achieving escapement goals could be based on collecting enough otoliths to achieve a CV of wild stock contribution such that uncertainty about escapement numbers falls within the fishery manager's target levels.

To successfully use thermal marking to aid in management decisions, it is critical that samples be randomly collected or representative of the catch. Considerable care must be given to design of the sampling program, and given the complex nature of most fisheries, care must be given to ensuring that samples come from the intended area. In our study, we felt fairly confident that the sampling procedure, while not random per se, satisfied the assumptions of random sampling. There were no significant differences in hatchery composition for the boats sampled during each opening, which implied that marked fish were fairly evenly distributed in the fisheries and complemented our sampling procedure. Nevertheless, the issue still requires careful consideration; the advantages of using small sample sizes, which makes this method feasible, is tempered by the considerable weight that each specimen contributes to the results.

In that regard, identification errors would have a relatively large influence on the reliability of the contribution estimates. Therefore, the importance of effective training and a reliable quality control system cannot be overstated. Blind planting of known marked otoliths into samples during processing can definitively measure the accuracy of thermal mark recovery. In this study the otolith reader responsible for the final

Table 5. Between-reader comparisons of readers A and B for the 1993 samples. For trials 1 and 3, reader A processed the otoliths and B provided the second reading; for trial 2, reader B processed and A provided the second reading. For each trial the overall percent agreement is shown, as well as the weighted Kappa (a measure of interrater agreement on the categories marked and unmarked).

Reader A	Reader B Determinations				
Determinations	Marked	Unmarked	Uncertain	Total	Trial 1
Marked	5	2	0	7	N = 150
Unmarked	1	137	3	141	% Agreement = 95
Uncertain	1	1	0	2	Kappa = 0.65
Total	7	140	3		

Reader A	Reader B Determinations				
Determinations	Marked	Unmarked	Uncertain	Total	Trial 2
Marked	5	0	0	5	N = 118
Unmarked	0	107	5	112	% Agreement = 95
Uncertain	0	1	0	1	Kappa = 0.76
Total	5	108	5		

Reader A	Reader B Determinations				
Determinations	Marked	Unmarked	Uncertain	Total	Trial 3
Marked	4	0	2	6	N = 95
Unmarked	0	89	0	89	% Agreement = 98
Uncertain	0	0	0	0	Kappa = 0.90
Total	4	89	2		

determinations successfully identified all planted thermal marks, as did one of the trainees (reader A), indicating that results presented to managers were reasonably accurate. The other trainee (reader B) was 83% correct, indicating (1) thermal mark identification is not necessarily a simple process without error, (2) individual differences should be expected, and (3) training is not quick or easy. However, upon review, the sample of otoliths reader B processed was judged to have had more difficult patterns to decipher than those processed by reader A.

Between-reader comparisons using a summary statistic such as Kappa can also provide a measure of confidence in the reader's ability to recover marks, particularly in instances where known marked otoliths are unavailable. Kappa can also be used to monitor the training process or reveal differences in readability among marked groups. Because detection of thermal marks is visual, it is necessarily subjective, but between-reader agreement and the use of Kappa can provide an objective way to quantify the precision of readings.

Quality control begins when the marks are planted at the hatchery. Insufficient temperature changes, breakdowns in heating or cooling equipment, or premature hatching during marking can all produce thermal marks that are of poor or insufficient quality. Poorly defined thermal marks complicate otolith reading by increasing (1) uncertainty and perhaps bias in the estimates of contribution, and (2) time to process and read otoliths, which can increase costs of processing and perhaps hamper use of thermal-mark recovery for in-season management. Therefore, hatchery operators must be properly educated on thermal marking if they are to provide distinctive, easily read marks.

The voucher specimens examined in this project included those of pink salmon not expected to return until 1994 and 1995. Evaluating the appearance of the mark in advance allows mark distinctiveness and consistency within the mark group to be determined and appropriate plans to be developed. It also allows an opportunity to see if the marks are being laid down as intended. If not, adjustments to the marking schedule can be made if enhancements are needed and feasible, or if changes in subsequent mark groups are warranted.

The results of this project allowed us to determine the percentage of hatchery contribution to the Hawk Inlet Shore, Point Marsden Shore, and Point Augusta commercial fisheries in 1992 and 1993. The poor showing of hatchery returns in 1993 coincided with the poor showing of wild stocks in the same general area. If run strengths of both wild and hatchery fish were the result of early marine mortalities, then following marked fry after release to determine their association with low food supply or predators could help managers identify mortality causes and improve run forecasting.

Thermal marking can also be used to address issues associated with wild and enhanced fisheries. For example, under Annex IV of the U.S./Canada Pacific Salmon Treaty, the progenies of Canadian sockeye salmon reared at ADF&G's Snettisham Hatchery in Southeast Alaska have been thermally marked and transplanted back into Canadian lakes where the marks have been recovered from fry and smolts to evaluate success of the transplants (Pacific Salmon Commission 1994). In addition, the marks are being recovered from adult sockeye salmon that pass through the fisheries of both countries (Hagen 1993). The ability to meet treaty-specified allocation goals for these enhanced fish largely relies on the recovery of thermal marks.

Finally, thermal marks recovered from spawning grounds can also provide a cost-effective means for determining the extent that hatchery fish may stray and spawn with wild stocks. Conversely, otoliths from the hatchery can be used to determine the extent that wild stocks may stray into hatchery systems. An ongoing project to recover thermally marked DIPAC fish from the hatchery and from streams located at varying distances from the hatchery was initiated in 1992 and will provide important information about rates and variability of straying patterns.

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