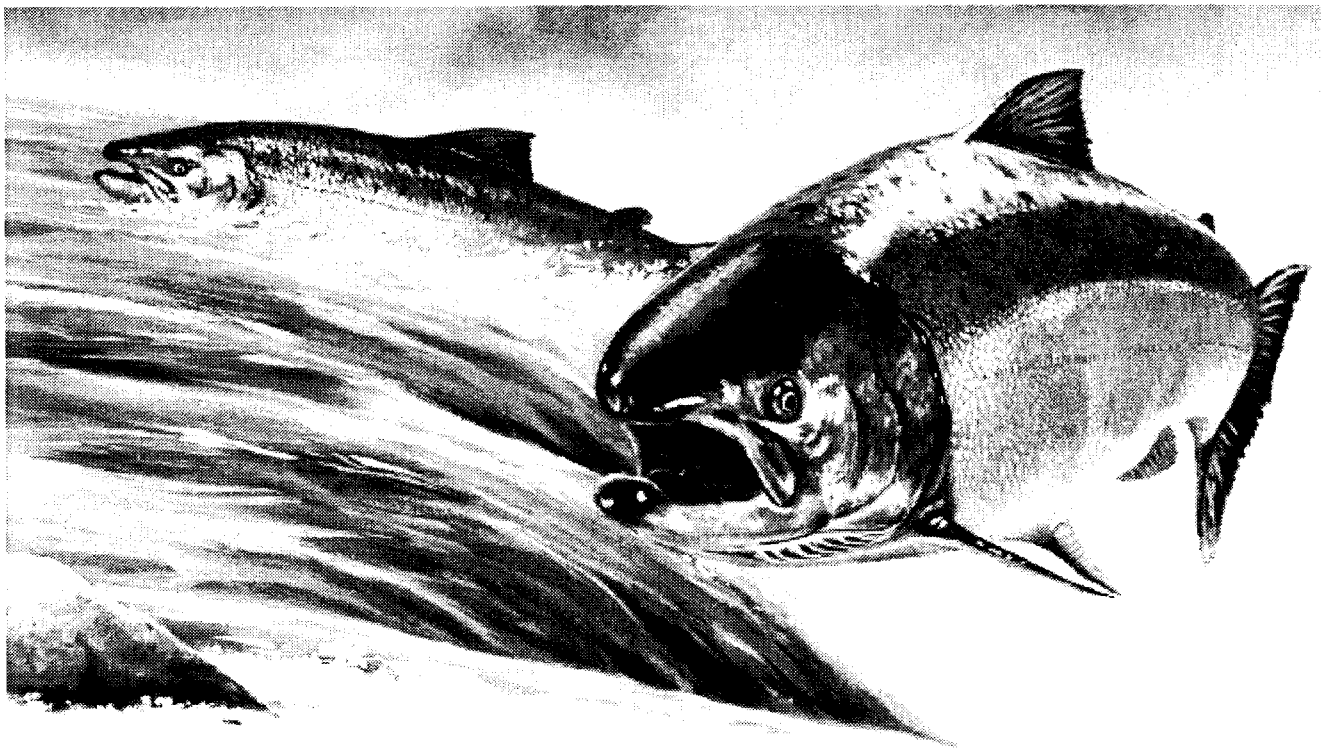
FISHERIES DIVISION
RESEARCH REPORT

Number 2013 December 21, 1994

Contributions of Hatchery and Natural Chinook Salmon to the Eastern Lake Michigan Fishery, 1992-93

Jay A. Hesse



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STATE OF MICHIGAN
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FISHERIES DIVISION

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Total Number of Copies Printed: 300
Total Cost: $1,100.93 Cost Per Copy: $3.66

CONTRIBUTION OF HATCHERY AND NATURAL CHINOOK SALMON TO THE EASTERN LAKE MICHIGAN FISHERY, 1992-1993

By

Jay A. Hesse

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife
1994

ABSTRACT

CONTRIBUTION OF HATCHERY AND NATURAL CHINOOK SALMON TO THE EASTERN LAKE MICHIGAN FISHERY, 1992-1993

By

Jay A. Hesse

All hatchery produced chinook salmon (*Oncorhynchus tshawytscha*) stocked into the Lake Michigan Basin from 1990 to 1993 were marked with various fin clips and/or an internal mark with the antibiotic oxytetracycline (OTC). As a result, individual chinook salmon could be identified as being of either hatchery or natural origin.

The chinook salmon sport harvest was sampled at three locations to determine: 1) the validity of ageing chinook salmon using vertebrae, 2) the effectiveness of OTC marking, 3) the contribution of naturally reproduced chinook salmon to the sport harvest, and 4) the regional variation of that contribution. Additional gill net samples were used to compare various sampling techniques and to examine the occurrence of bacterial kidney disease (BKD) in hatchery and natural chinook salmon.

A total of 703 and 1,374 chinook salmon were sampled from the sport fishery during 1992 and 1993, respectively. Annular bands in vertebrae were used to age samples with 97 percent accuracy. Using chinook salmon marked with fin clips and OTC, an OTC mark failure of 5 percent was established. Regional differences existed in the percentage of naturally produced age 3 chinook salmon that contributed to the sport fishery. No regional difference existed at ages 1 and 2, with about 30 percent of the sport harvest consisting of naturally produced chinook salmon. Both gill net samples and sport fishery samples exhibited the same percentage of hatchery and natural chinook salmon. BKD affected hatchery and natural chinook salmon equally.

ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Niles Kevern, for his support and guidance throughout my college education and on this graduate research project. I would also like to thank my committee members, Dr. Thomas Coon and Dr. Richard Hill, for their advice and educational example. Their never ending enthusiasm for teaching will always be an inspiration to me.

Funding sources for this research project were provided by: Michigan Sea Grant College Program, Michigan Department of Natural Resources Fisheries Division, Michigan Agricultural Experiment Station, West-Metro Chapter of Michigan Steelheaders, and the Michigan Polar-Equator Club.

A very special thanks is given to the fisherman who supplied samples and especially to the charterboat captains for their cooperation and hospitality. I thank Meryl Keller and the other MDNR personnel for their support and assistance. Robert Elliott and Jay Wesley helped immensely in the development and execution of this research project, thank you. I will never forget the friendships and support of my lab mates: Rob Elliott, Jay Wesley, Bruce Peffers, and Nan Kelly. I will always try to create my future professional relationships after this lab. I thank my entire family for their examples and support.

I have an inexpressible gratitude for my wife Linda not only for her emotional support and friendship during my graduate education, but also for her hours upon hours of free labor as a field assistant on the weekends. This research would not have been possible without her help.

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CHAPTER 1

Introduction

Introduction of exotic salmonid species into the Great Lakes was attempted numerous times between the 1870's and 1950's. Most of these introductions involved one-time stockings to various habitats in an attempt to establish self sustaining populations. Generally, these introductions were not successful due to competition from native species, lack of a proper forage base, and degraded spawning habitat (Parsons 1973). Historical reviews of the Great Lakes fish communities and management can be found in Smith (1968), Parsons (1973), Christie (1974), Carl (1980), and Keller et al. (1990).

In the late 1960's Great Lakes fishery managers started a stocking program of Pacific salmon in an attempt to produce a put and take fishery. Coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*Oncorhynchus tshawytscha*), were introduced in 1966 and 1967 respectively. These introductions were successful because of the large forage base provided by the alewife (*Alosa pseudoharengus*) which invaded the Great Lakes from the Atlantic Ocean. The presence of salmon in Lake Michigan developed one of the most spectacular sport fisheries in the world and contributed an estimated $1.4 billion annually to the Michigan economy (Robertson 1990).

Lake-wide annual stocking levels of chinook started around 700,000 during the late 1960's and increased to a peak of 7,859,000 in 1989 (Parsons 1973 and Holly

1994). Current 1993 stocking levels have decreased to 5,491,000, roughly equal to 1978 stocking levels (Holly 1994). The decision to reduce stocking levels was triggered by a decease in the average size of sport harvested salmonids (Keller et al. 1990). Around this same time (1988) disease problems in chinook salmon became apparent and were then thought to be induced by a shortage in available forage.

In an attempt to maintain a balanced predator/prey ecosystem in Lake Michigan a closer look at the interactions between forage fishes and salmonids was examined by Stewart et al. (1981), Eck and Brown (1985), Eck and Wells (1987), and Brandt et al. (1991). A computer program has been developed to simulate Lake Ontario's ecosystem dynamics (Jones et al. 1993) and a similar model is currently being developed for Lake Michigan. This model will help determine the optimal chinook salmon population size. Stewart et al. (1981) address the existence of some natural reproduction of salmonids in the Great Lakes with estimates of 10-15% of the total salmonid population coming from natural reproduction due to non-hatchery recruitment. The contribution of non-hatchery fish is not currently incorporated into Stewart et al. (1981) or Jones et al. (1993) population analysis, with the expectation that modifications can be made later when good estimates of the contribution of natural fish are available. Subsequent studies have focused mainly on estimating the available forage and make the assumption that the actual population size closely reflects stockings of salmonids (Eck and Wells 1987). However, if input of natural reproduction of chinook salmon is not taken into account, the actual population size will surpass the desired population size. Thus, estimates of lake-wide natural

reproduction input are needed to determine the actual population size and to adjust stocking levels accordingly.

Bacterial Kidney Disease (BKD) was determined to be the cause of death for high numbers of chinook salmon in Lake Michigan from 1988 to present (Nelson and Hnath 1990). BKD occurs in natural systems in low incidence (Johnson and Hnath 1991), but it is believed that intensive culture of salmon in hatcheries has increased the concentration of BKD in chinook salmon. As a result, BKD may affect hatchery chinook salmon at higher concentrations than natural chinook salmon. If this is true, offspring of natural chinook would be more desirable than prodigy from hatchery propagated chinook due to increased survival.

Shown in Figure 1, catch per effort (fish per 100 angler hours) of chinook salmon in Michigan waters of Lake Michigan has decreased since its peak in 1986 at 10.26 to a record low in 1993 of 1.80 (Rakoczy 1994). Knowledge about the proper and efficient management of the Great Lakes fishery is critical for the future success and existence of the chinook salmon fishery.

The management of the salmon fishery in the Great Lakes has been primarily controlled by the stocking of hatchery propagated smolts. Prior to the introduction of salmon into Lake Michigan, it was believed that the salmon would be unable to naturally reproduce in the tributaries (Parsons 1973). Therefore, the population would be entirely controlled and maintained by manipulating stocking levels, but as early as 1970 natural reproduction of Pacific salmon was occurring in tributaries of Lake Michigan (Rybicki 1973 and Taube 1974). Since that time studies by Carl (1982a), Seelbach (1985), Zafft (1992), and Jennings (1992) have documented

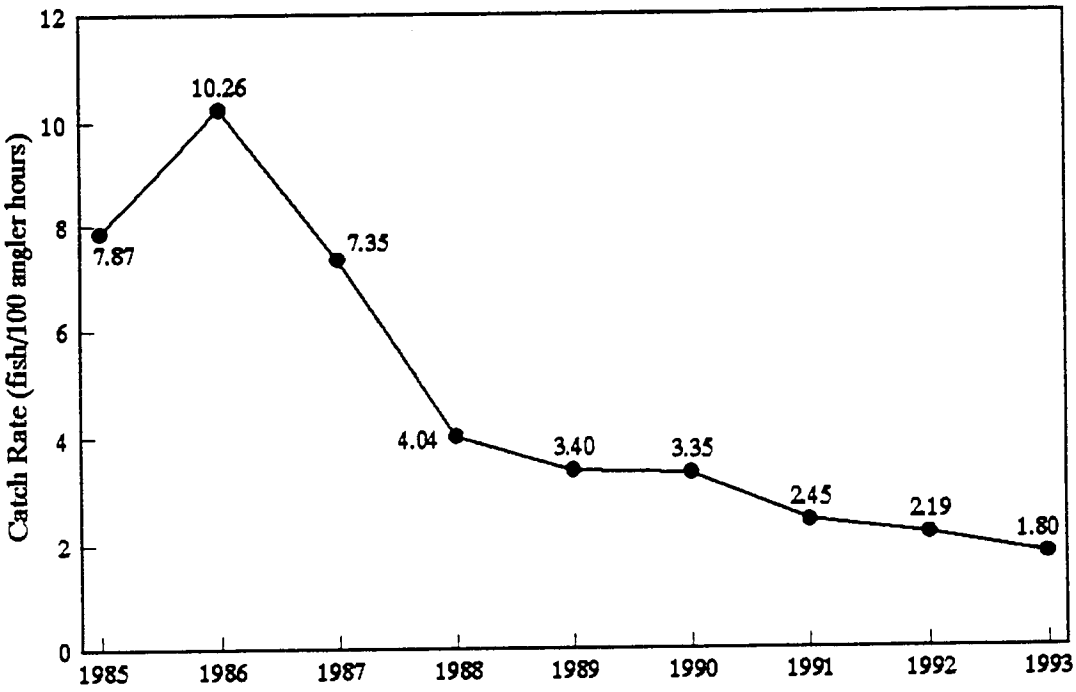

Figure 1. Catch rates of chinook salmon in Michigan waters from 1985 - 1993 (Rakoczy 1994).

chinook salmon natural reproduction in several Michigan rivers. These studies, plus Carl (1984), also contain spawning and early (river) life history descriptions of Lake Michigan chinook salmon.

Carl (1980) documented that the amount of natural reproduction is not uniform but trends vary widely from river to river due to different habitat characteristics. Zafft (1992), Jennings (1992), Seelbach (1985), and Carl (1984) also demonstrated yearly changes of natural reproductive output to occur within rivers due to variable environmental conditions. Results from these studies can be used to estimate the contribution of natural reproduction to Lake Michigan to range from 10 percent to 25 percent, but estimates are based only on initial numbers of juveniles entering the lake.

Not all tributaries and habitats have been directly evaluated for their reproductive output and, as a result, the amount of natural reproduction occurring may be underestimated. In-lake natural reproduction of chinook salmon was documented in Lake Huron by Powell and Miller (1990). They observed and verified chinook salmon spawning and presence of developing chinook salmon eggs on a shoal traditionally used by lake trout (*Salvelinus namaycush*) for reproduction.

In 1990 all of the agencies responsible for stocking chinook salmon into Lake Michigan, Michigan Department of Natural Resources (MDNR), Indiana Department of Natural Resources (IDNR), Illinois Department of Conservation (IDOC), and Wisconsin Department of Natural Resources (WDNR), began a 5 year marking program in which all hatchery produced chinook salmon were marked with fin clips and/or the antibiotic oxytetracycline (OTC). A total of 7 combinations of fin clips was used in 1990 to externally mark 29% of the chinook salmon stocked into Lake

Michigan. Similarly, 11, 9, and 7 types of fin clips were used in 1991, 1992, and 1993 to externally mark 41%, 28%, and 26%, respectively. Fish with only the adipose fin clipped also possessed a Coded-Wire Tag (CWT) in their nose (See Appendix A for specific fin clip types and numbers stocked by each agency). For these cohorts, all non-clipped and some fin clipped hatchery chinook salmon were given an internal mark of OTC. This OTC mark appears as a fluorescent ring in the vertebrae when viewed under ultraviolet light (Weber and Ridgeway 1962 and Weber and Ridgeway 1967). This extensive marking program allows for a quick and precise determination of the origin of individual chinook salmon.

With the ability to determine the number of hatchery and natural chinook salmon in every sample, a much more detailed analysis of the contribution of natural fish to the total population and to the fishery was examined in this study. Preliminary results by Elliott (1994) indicate that 50 percent (North) and 30 percent (South) of age 0 chinook salmon from Eastern Lake Michigan are from natural reproduction. This suggests a significant amount of natural reproduction. Each of the above mentioned studies only accounts for naturally produced fish in early life stages and does not answer the question of how extensively natural fish contribute to the fishery. If naturally produced chinook salmon exhibit better survival than hatchery produced chinook salmon, alternative management practices could be considered. Managing for increased natural reproduction could increase the survival of chinook salmon by reducing the effects of BKD and also reduce the hatchery costs.

Goal and Objectives

The goal of this project was to assess the contribution of hatchery and natural chinook salmon to the Eastern Lake Michigan fishery during 1992 and 1993. This could be accomplished by using the fin clips and OTC marks possessed by all hatchery chinook salmon in the 1990 - 1993 cohorts. This goal involved four objectives: 1) determining the lake-wide (Eastern Lake Michigan) contribution of naturally reproduced chinook salmon to the Lake Michigan ecosystem, but focusing on their contribution to the sport fishery, 2) determining the percentage of hatchery versus natural chinook salmon in the sport harvest at three different locations in Lake Michigan, 3) examining the relative survival rates for hatchery and natural chinook salmon while in the lake, and 4) establishing the most feasible sampling methods and procedures for future use of OTC marking in determining Great Lakes salmonid population characteristics. The third objective was tested in two ways: first, by looking at the percentage of hatchery and natural chinook salmon in the same cohort at two time intervals and second, by comparing the percentage of both hatchery and natural chinook salmon with clinical signs of BKD (high mortality factor).

Chapter 2 describes the age determination method used and its validity, chapter 3 describes the OTC detection procedure used and its validity, chapter 4 addresses the contribution of natural chinook salmon, and chapter 5 compares gill net and sport harvest sampling techniques along with the occurrence of BKD in hatchery and natural chinook salmon. Objectives 1 and 2 are addressed in chapter 4, objective 3 is covered in chapters 4 and 5, and objective 4 is covered in chapters 2 through 4.

CHAPTER TWO

An Alternative Age Determination Method for Lake Michigan Chinook Salmon Using Vertebrae

Introduction

In order to assess the population of hatchery and natural chinook salmon (*Onchorhynhus tshawytscha*) in Lake Michigan it was necessary to compile age data. Several age determination methods using different calcified structures including otoliths, dorsal spines, pectoral fin rays, opercula, subopercula, cleithra, vertebrae, and scales have been used to age fish with varying degrees of success (Menon 1950, Chilton and Bilton 1986, Sharp and Bernard 1988, Baker and Timmons 1991, Hall 1991, and Rien and Beamesderfer 1994). Historically, scales have been used to age chinook salmon from the Great Lakes. However, recent studies using known-age fish from coded wire tags have raised validity concerns of scale-age estimates. This has recently become a particular concern with regard to ageing mature chinook salmon in the Great Lakes (Dan Anson, Personal Communication).

Regardless of the ageing method used, Beamish and McFarlane (1983 and 1987) stress the importance of validating age determination methods over all possible ages. For an age estimation method to be useful in fisheries management it not only has to be accurate but also precise. Beamish and McFarlane (1983) define precision as the degree of agreement among readers, more simply referred to as "repeatability". The existence of coded wire tagged known-age fish provided an opportunity to

examine the validity, both accuracy and precision, of age determination methods for Lake Michigan chinook salmon. A valid age determination method using vertebrae was desirable for this project since vertebrae were already being collected and examined for the detection of oxytetracycline (OTC).

Vertebrae have been used for age determination in many species of fish. Menon (1950) provides a summary of the pre-1950 literature on ageing using bones. Fourteen of these studies, primarily on saltwater species, used vertebrae. More recently, vertebrae of channel catfish (*Ictalurus lacustris punctatus*) were used by Appelget and Smith (1951) and Sneed (1951) to determine age and growth rates. These vertebrae studies all basically used the same methods for preparing and viewing the vertebrae. The bones were boiled, soaked, and/or digested to remove flesh, then dried prior to observation through 6X magnification under reflected light. Prince et al. (1985) prepared thin cross-sections of vertebrae from Atlantic bluefin tuna (*Thunnus thynnus*) to examine internal zones used for age determination.

Kusakari (1969) provides a description of the opaque and translucent zones observed in flatfish (*Kareius bicoloratus*) vertebrae. This description is generally acceptable with the previously mentioned studies as well. The laboratory methods required to prepare samples in the manner previously published are very time consuming and, as a result, these methods did not seem conducive for examining a high number of samples. A similar pattern of opaque and translucent bands in Lake Michigan chinook salmon vertebrae was observed by this author during examination for OTC. The OTC/age detection method required very little sample preparation,

resulting in a much quicker age determination method than described in previous papers.

The objective of this chapter is to present an age determination method for Lake Michigan chinook salmon using vertebrae and test its validity by examination of known-age coded wire tagged fish.

Methods

Sample Source

Adipose fin clipped/coded wire tagged chinook salmon were sampled from the Lake Michigan sport fishery, from Michigan Department of Natural Resources (MDNR) Survey Vessel (SV) Steelhead's gill nets used for a chinook salmon-diet-study, and from the Wisconsin Department of Natural Resources (WDNR) weir harvest. Weight, length, and sex data, and scales, vertebrae, and the nose were collected. Scale samples were taken just behind the dorsal fin and above the lateral line. Scale samples were not collected from the WDNR weir fish. At least five thoracic vertebrae were collected from below the adipose fin. Noses from the coded wire tagged fish were cut off just behind the eyes. Vertebrae and noses were stored frozen until lab examination.

Laboratory preparation

The known-age from coded wire tags was provided by either the MDNR or WDNR, and the estimated age from vertebrae samples was determined by myself without prior knowledge of the coded wire tag results. The age estimate from vertebrae was obtained by completely cleaning flesh and cartilage from one vertebra

with a scalpel (# 4 round tip scalpel blades work best). It is important to remove the cartilage ring which separates vertebrae. Samples were viewed within 1 or 2 hours of cleaning to prevent drying. The vertebra was placed on end, center hole vertical, on a black background and covered with several drops of glycerin. The bone was then viewed in a dark room through a dissecting microscope, with a magnification of 15 to 50 (using 10X occulars), under reflected **ultraviolet** light (365nm). The light used in this study had an intensity of approximately 11,000 microwatts per square centimeter at six inches (distance from bulb to bone). Magnification was adjusted to allow the entire bone to be in the field of view.

Vertebrae description

The observable annular patterns are similar to those described by Kusakari (1969) in flatfish with an alternate pattern of translucent (dark, absorptive zones) and opaque (white, reflective zones) bands (Figure 2). The focus of the centrum is dark with the first white band being formed at age 1 during the second summer in the lake. The white bands are the annuli being formed during the summer months of July and August. This corresponds with formation of annuli in scales (Dan Anson, personal communication). A second dark band starts to appear during the fall (September). Each successive dark band becomes thinner. This pattern continues until the chinook salmon reaches maturity (Figure 3). In weir harvest samples, the final band is white, formed prior to return to river for spawning. The appearance of 1 to 3 "accessory checks," thin white rings, within the first dark area is common in age 0 and in some age 1 chinook salmon. These accessory checks are much thinner than the annular bands and are not visible in age 2 and older chinook salmon.

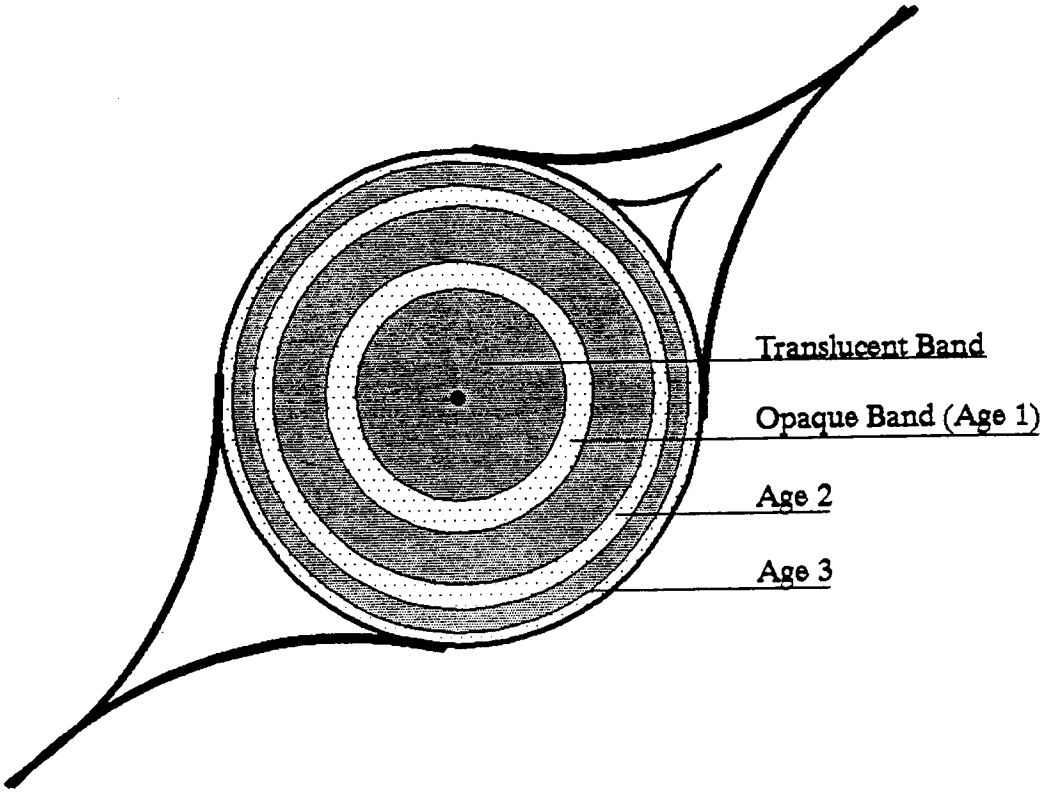

Figure 2. Diagram of translucent and opaque annular bands in vertebrae of Lake Michigan chinook salmon.

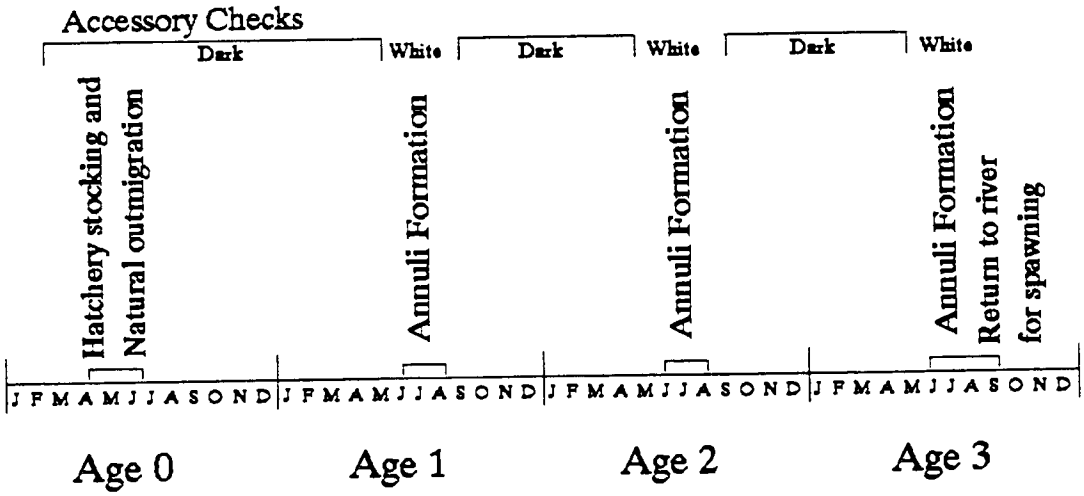

Figure 3. Timing and pattern of annuli formation in vertebrae of Lake Michigan chinook salmon.

On several trials multiple vertebrae from one fish were examined. All vertebrae exhibited the same annuli patterns. The last 4-5 caudal vertebrae were not readable due to fusing and the inability toseparate individual bones. The thoracic vertebrae were the easiest to clean and read, while the pleural vertebrae located just behind the head were the most difficult.

Test for accuracy of vertebrae age estimates

A comparison of known-age to vertebral-age estimates was done on each age class for both lake-caught and river-harvested mature samples. Bonferroni chi-square contingency tables were used to test for differences in ageing accuracy between age groups and ordinary chi-square tables were used to test for differences between locations (Gill 1978). Both tests were done at a level of confidence of 95% (alpha of 0.05). Samples where estimated age deviated from the known-age were examined to determine if any consistent bias of age estimates existed. Chi square statistics were used to determine if misaged estimates differed from the non-biased 50% ratio. Coded wire tag data were not known by the vertebrae reader at time of examination.

Test for precision of vertebrae age estimates

A sample of 100 vertebrae was aged independently by 3 readers and the age estimates compared to examine the repeatability among readers. Indices of average percent error (APE), coefficient of variation (V), and index of precision (D) were determined using methods described by Beamish and Fournier (1981) and Chang (1982). The APE consists of obtaining an average age for each fish (X_j), either from multiple readings by one reader or by readings from multiple readers (R). These

averages are used to establish an average error in aging each fish as follows:

$$\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij}-X_j|}{X_j}.$$

An average of all error rates multiplied by 100 gives the index of APE. The V is the standard deviation divided by the mean for each sample, then averaged for all samples and expressed as a percentage. D is obtained by dividing V by the square root of the number of times each sample is aged.

Results

A total of 197 chinook salmon possessing coded wire tags was sampled during 1992 and 1993 from Lake Michigan; 149 of these samples came from the sport fishery and 48 from gill nets. The coded wire tag results indicated that 152, 37, and 8 of the samples were age 1, age 2, and age 3, respectively. An additional 168 (72 age 1, 74 age 2, and 22 age 3) coded wire tagged chinook were sampled from the WDNR weir harvest (Table 1).

Accuracy

Of the lake-caught samples four age 1, four age 2, and one age 3 fish were misaged, while one age 1, one age 2, zero age 3 weir harvested fish were misaged (Table 1). Shown in Table 2, the accuracy of the vertebral ageing method did not differ at the 0.05 level between any of the age classes and the method was equally accurate for samples collected in the lake and at harvest weirs. A total of 365 coded wire tagged chinook salmon were aged using the vertebral method with 11 (3%) being incorrectly aged. Table 3 shows that three of the misaged samples were underaged

Table 1. Coded wire tag and vertebral age determination results for chinook salmon sampled from Lake Michigan and harvest weirs.

Lake Caught (Sport Caught '92–'93 and SV Steelhead '93)	Sample Size	# Correct	% Correct	# Misaged	% Error
AGE 1	152	148	97.4	4	2.6
AGE 2	37	33	89.2	4	10.8
AGE 3	8	7	87.5	1	12.5
Weir Harvest (Wisconsin '93)					
AGE 1	72	71	98.6	1	1.4
AGE 2	74	73	98.6	1	1.4
AGE 3	22	22	100.0	0	0.0
Combined Total	365	354	97.0	11	3.0

Table 2. Chi–square values for comparison of vertebral age determination accuracy.

	Lake Caught	Weir Harvested	Between Locations
Age 1 vs. Age 2[a]	4.91	0.00	
Age 2 vs. Age 3[a]	0.02	0.30	
Age 1 vs. Age 3[a]	2.44	0.31	
All Ages Combined[b]			3.54

[a] $X^2_{B,0.05,m=3,v=1} = 5.731$
[b] $X^2_{0.05,1} = 3.84$

Table 3. Difference in estimated ages between fish aged from vertebrae and from Coded Wire Tag (CWT).

CWT age	Vertebrae age	Number of times age of Vert<CWT	Number of times age of Vert>CWT	Difference in age (yr) of Vertebrae from CWT
1	2		5	+1
2	1	2		−1
2	3		3	+1
3	2	1		−1
Total		3	8	

and eight of the samples were overaged. This distribution is not statistically different ($p < 0.05$) from that of an expected 50% ratio.

Precision

Of 100 fish aged independently by three individuals, only 8 samples showed discrepancies in estimated age between readers (Table 4). The resulting index of APE was 2.17%, V was 2.81%, and D was 1.63%.

Discussion

Communication of the age of anadromous fishes is often accomplished with a decimal system (Godfrey et al. 1968, Seelbach and Beyerle 1984, Chilton and Bilton 1986), with the first digit being years spent in freshwater (stream) and the second digit representing years in saltwater (ocean or lake). This system is necessary when examining growth rates since most growth occurs during lake residency (Seelbach and Beyerle 1984). Seelbach (1985) and Zafft (1992) documented age 0.0 and 1.0 naturally reproduced chinook smolts out-migrating from the Little Manistee and Pere Marquette Rivers, respectively. The contribution of natural age 1.0 chinook salmon tends to vary annually due to environmental conditions. Zafft (1992) estimated that approximately 14% and 6% of the natural out-migrating chinook salmon were age 1.0 in 1989 and 1990, respectively.

For this paper I have not used this type of age expression for the following reasons. First, only hatchery fish were used to validate the vertebral ageing method and it is not known if hatchery fish express the same out-migration patterns as natural chinook and a fairly low percentage of natural chinook salmon out-migrate at age 1.0.

Table 4. List of estimated vertebral ages and associated APE*, V*, and D* (Beamish and Fournier 1981 and Chang 1982) from 3 readers for 100 chinook salmon

	Reader					
(n)	1	2	3	APE	V	D
(54)	1	1	1	0	0	0
(34)	2	2	2	0	0	0
(4)	3	3	3	0	0	0
(1)	1	1	2	0.3333	0.4330	0.25
(1)	2	2	1	0.2666	0.3464	0.20
(1)	3	2	3	0.1666	0.2165	0.13
(1)	2	1	2	0.2666	0.3464	0.20
(1)	2	1	2	0.2666	0.3464	0.20
(1)	2	2	1	0.2666	0.3464	0.20
(1)	2	1	2	0.2666	0.3464	0.20
(1)	1	2	1	0.3333	0.4330	0.25
	Average Percentage			2.17	2.81	1.63

* APE = Average Percent Error
* V = Coefficient of Variation
* D = Index of Precision

Second, coded wire tags only express known-age in total years and do not convey any information on amount of time spent in the river system. Third, vertebrae did not possess obvious annular patterns that would allow for early life history determination. Finally, only the total age of fish, which allowed for placement into cohorts, was needed for the OTC marking project.

The importance of validating an age determination method for each species at all possible ages is discussed by Beamish and McFarlane (1983). My research demonstrates that age 1, 2, and 3 Lake Michigan chinook salmon can be accurately aged with vertebrae. I have estimated 5 chinook salmon to be age 4 by their vertebrae. Because no coded wire tagged age 4 chinook salmon existed in Lake Michigan during the study period, I have not been able to prove the accuracy of vertebral ageing on age 4 chinook salmon. However age 4 chinook salmon make up a very small portion of the population. I encourage the continued collection of vertebrae from coded wire tagged chinook salmon to check the accuracy of vertebral age determination on age 4 chinook salmon.

The accuracy of vertebral age determination is not affected by the age of the fish, as there were no statistical differences between any of the age classes. This is not surprising since age determination accuracy problems are most often associated with time of slow growth, such as the later years in long-lived fishes (Beamish and McFarlane 1983). Slow growth is not a problem with chinook salmon which are fast growing during their entire 3-4 year lake life cycle.

Problems associated with scale adsorption when ageing river harvested mature chinook salmon by scales (Dan Anson, Personal Communication) were not apparent

when using vertebrae. The vertebral age estimates from river-harvested mature chinook salmon were just as accurate as those made from lake-collected samples. Since there were no accuracy differences between age classes or between lake-caught and mature weir-harvested samples, all samples were combined resulting in one estimate of vertebral age determination error to be 3%.

Errors in estimated vertebral ages were made by both under- and over-estimating true age. By examining the total number of under- and over-estimated samples, no consistent bias was detectable. However, Richards et al. (1992) state "we cannot assume that observed age is an unbiased estimate of true age because observed ages must fall within the life span of the species. For example, due to truncation in the age distribution, mean assigned age will overestimate true age for the youngest fish and underestimate true age for the oldest fish." In this study, both age 0 and age 4 fish do occur in the population and the possibilities did exist for age 1 fish to be underestimated as age 0 and likewise, age 3 fish could be overestimated as age 4 fish. However, all errors of age 1 fish were overestimated and all errors of age 3 fish were underestimated, but the low number of misaged samples limited the detection of any significant trends.

Richards et al. (1992) address how to incorporate ageing error estimates into population analysis. I have not included this type of correction into subsequent population analysis, as accuracy was good and age data were used in conjunction with other data for individual samples. It will be assumed that the limited ageing errors have random and unbiased effects on subsequent data analysis.

Testing precision of an age determination method does not have to be done on known-age fish, as it is a measure of repeatability and does not convey anything about accuracy. The 100 samples used to test vertebral ageing precision were randomly selected and included age 1 through age 3 chinook salmon that were of both hatchery and natural origin. This was done to mimic typical samples taken from Lake Michigan waters. The resulting 2.17% APE and 2.81% V indicate that the vertebral age determination method has a high degree of precision. As APE and V decrease, the repeatability increases (Beamish and Fournier 1981 and Chang 1982). The D expresses that an average of 1.63 % of the error is contributed by each sample. The actual amount of error contributed by individual samples is expressed by D values for each sample. These indices can be used to compare the precision of vertebral ageing to other methods such as scale ageing.

Having determined that vertebral age determination of Lake Michigan chinook salmon is a valid procedure does not imply that all studies of this population should use the vertebral ageing method to estimate age. There are advantages and disadvantages of vertebral age determination when compared to the traditional scale ageing method. The primary advantage of vertebral ageing arises when used in conjunction with OTC studies. In this manner, both field and laboratory time is saved by being able to use one structure and method to determine both the presence or absence of OTC and estimate age. A second advantage deals with the ability to estimate age on mature fish after they have returned to rivers for spawning. In this situation, erosion of the annuli on scales occurs as the scales are reabsorbed making ageing by scales difficult, while the structure and appearance of vertebrae remains

constant. Distinguishing vertebral annuli may also involve less guess work, as annuli are broad bands, whereas identification of scale annuli involves recognition of slight changes in circuli patterns. Both methods require some training; however, less experience seems needed to become proficient at vertebral age determination.

Vertebral age determination also has disadvantages. 1) The use of vertebrae necessitates sacrificing the fish: unlike scale ageing from which fish can be released after sample collection. 2) Information on growth rates and early life history can only be obtained from scales and not from vertebrae. This type of information may be obtainable from vertebrae with further examination of internal zonation; however, increased laboratory preparation would likely be required. 3) Vertebrae must be stored frozen until time of lab examination and multiple readings require repetition of the entire lab process. Scales on the other hand can be stored in thin envelopes and multiple readings can be made from a single prepared slide.

As Chilton and Bilton (1986) discuss, the use of combinations of multiple structures for ageing can reduce improper management of fish stocks. Whatever age determination method or methods are used, periodic checks of the methods' validity should be applied (Beamish and McFarlane 1987). Depending on the desired data, vertebrae represent a valid alternative for ageing Lake Michigan chinook salmon.

CHAPTER THREE

Oxytetracycline Detection and Quality of Marks in Lake Michigan Chinook Salmon

Introduction

The ability to mass mark various species of hatchery fish with the antibiotic oxytetracycline (OTC) has been demonstrated in several studies (Weber and Ridgeway 1962, Weber and Ridgeway 1967, Odense and Logan 1974, Koenings et al. 1983, Bilton 1986, Lorson and Mudrak 1987, Bumguardner and Colura 1991). OTC can be administered by injection, immersion, or through feeding. The most effective method depends on the species of fish being marked. Likewise, the best structure for OTC detection also varies by species.

Weber and Ridgeway (1963 and 1967), Odense and Logan (1974), and Bilton (1986) examined marking salmonids (*Oncorhynchus sp.* and/or *Salmo sp.*) with OTC. Weber and Ridgeway (1967) determined that an oral dosage of at least 250 mg of OTC per kilogram of feed at 2.0% of body weight for 4 or more consecutive days produces a consistently distinguishable and permanent (at least 3.5 years) mark. OTC is deposited in areas of osteogenesis and can be detected in scales, teeth, opercular bones, ribs, otoliths, and vertebrae shortly after feeding (Weber and Ridgeway 1963). Continued deposition of calcium on top of OTC marks and exposure to sunlight reduces the ability for long-term detection of OTC in most of these structures. Vertebrae are the best structure to use for long-term detection of OTC in chinook

salmon (*Onchorhynhus tshawytscha*) (Weber and Ridgeway 1967 and Odense and Logan 1974).

Size of the fish at time of OTC administration can affect the quality of the OTC marks. Poor marking success can occur if OTC is administered prior to the development of calcified bone structure. Once the critical size where the onset of calcification has been reached, mark quality increases as long as the dosage per body weight remains constant (Odense and Logan 1974 and Bilton 1986). Depending on the size of the fish at time of OTC administration and the total amount of OTC consumed by each fish, the quality of OTC marks will be variable.

OTC and/or fin clips were used to mark all hatchery chinook salmon being stocked into the Lake Michigan Basin, from 1990 to 1994, in an effort to distinguish natural and hatchery fish. Appendix B contains a list of the marking patterns used by each state agency. All OTC marking was done by feeding 350 mg OTC per kilogram of feed at 2.0% body weight for 5 consecutive days approximately one month prior to release (MDNR, interoffice communication). As with age determination (Beamish and McFarlane 1983), the validity/quality of the marking methods being used must be checked periodically on each population being studied. Likewise, to confidently use data obtained for studies on the contribution of hatchery and natural chinook salmon in Lake Michigan, the quality of the OTC marks must be established.

The objective of this chapter is to describe the methods used to detect the presence or absence of the OTC marks and to determine the effectiveness/validity of marking Lake Michigan hatchery chinook salmon with OTC. This objective included examining the permanency of the OTC mark over time, establishing the percentage of

known hatchery fish not showing an OTC mark (marking error rate), and examining the repeatability of OTC detection among readers.

Methods

Sample Source

Chinook salmon were sampled from the Lake Michigan sport fishery, Michigan Department of Natural Resources (MDNR) Survey Vessel (SV) Steelhead chinook salmon-diet-study gill nets, and from the Wisconsin Department of Natural Resources (WDNR) weir harvest. Weight, length, sex and fin clip data, and scales, vertebrae, and the noses from adipose fin clipped fish were collected. At least five thoracic vertebrae were collected from below the adipose fin. Exposure of vertebrae to direct sunlight was kept to a minimum and samples were stored frozen until lab examination.

Laboratory preparation

The second vertebra from each sample was removed by cutting through the cartilage rings. All flesh and cartilage were removed with a scalpel (# 4 round tip scalpel blades work best). It is important to remove the cartilage ring which separates vertebrae. Prepared samples were placed in stacked tin weighing dishes and viewed within 30 minutes of cleaning. This reduced exposure to light and prevented drying of vertebrae. Each vertebra was placed on end, center hole vertical, on a black background and covered with several drops of glycerin. The bone was then viewed in a dark room through a dissecting microscope, magnification ranging from 15 to 50 X (using 10 X oculars), under reflected **ultraviolet** light (365nm). The light used in this

study had an intensity of approximately 11,000 microwatts per square centimeter at a distance of 15 cm (distance from bulb to bone). Except for the cleaning process, these methods follow those described in Weber and Ridgeway (1963 and 1967).

The incidence and quality of OTC marks was recorded on an eight point scale. This scale was broken down into four groups of marks: no mark (0), poor marks (1-3), good marks (4-6), and a great mark (7). The samples were given a 0 rating if no OTC mark was observed or if the reader harbored any doubt about the existence of an OTC mark. Within the poor/good categories mark quality was further broken down into poor/good (minus), poor/good, and poor/good (plus) relating to the color intensity of the OTC mark. The poor category describes marks that required some degree of microscope focusing to detect mark. The poor minus rating was used when the OTC mark was only visible in one focal position and may not have exhibited yellow-green color. Good marks were detectable with the microscope slightly out of focus, and appeared as a sharply defined yellow-green line. Great marks were observable without the microscope and when viewed with the microscope appeared as a wide fuzzy line. Some of the great marks also exhibited vertical rays extending from the OTC ring towards the center hole. Multiple marks were recorded in order of formation (inner ring first).

Classification of samples into respective cohorts was accomplished by vertebral age determination, using the methods described in Chapter 2.

Mark Permanency

OTC mark permanency was examined by observing the range in quality of the OTC marks independently for the 1990 and 1991 cohorts over a two year period.

Only hatchery chinook salmon, those possessing an OTC mark and/or fin clip, were used in the study. A weighted average of mark quality was used to compare quality of marks in successive years.

Mark Retention

An OTC marking error rate was established as the percent of double marked (both OTC and fin clipped) samples not showing an OTC mark. This was accomplished by matching the OTC detection results with fin clip data. Since each state used unique fin clips, a marking error rate was established for each state. A lake-wide OTC marking error rate was determined by combining all state results into one estimate. From this lake-wide estimate of OTC marking error, the percent of non-marked hatchery chinook salmon was obtained by multiplying the lake-wide OTC marking error rate by the number of chinook salmon marked only with OTC, then dividing by the total number chinook salmon stocked. Fin clips were not known by the OTC reader at the time of examination.

Repeatability

A sample of 100 vertebrae was examined for OTC independently by 3 readers and the OTC observations compared to examine the repeatability among readers. Comparisons between readers were made with regard to 1) assigning mark quality and 2) detection of OTC mark incidence. Results were expressed as percent agreement among all three readers.

Results

Mark Permanency

A total of 271 (146 at age 2 and 125 at age 3) known hatchery chinook salmon from the 1990 cohort and a total of 462 (157 at age 1 and 305 at age 2) known hatchery chinook from the 1991 cohort were examined for OTC mark quality (Figure 4). The weighted average of mark quality, expressed on a scale of 0-7 defined earlier, for the 1990 cohort was 3.15 at age 2 and 3.0 at age 3. The weighted average mark quality for the 1991 cohort was 3.69 at age 1 and 3.62 at age 2. An additional 398 age 1 known hatchery chinook salmon from the 1992 cohort were examined and had a weighted average mark quality of 4.14 (Table 5).

Table 5. Weighted average of the quality of OTC marks for all hatchery chinook salmon in the 1990 - 1992 cohorts over time.

	Age 1	Age 2	Age 3
1990 cohort	--	3.15	3.00
1991 cohort	3.69	3.62	--
1992 cohort	4.14	--	--

Mark Retention

Table 6 shows the total number of chinook salmon sampled for each type of fin clip and the number not showing an OTC mark. Fish from Indiana and samples exhibiting non-possible fin clip patterns were excluded from subsequent analysis. A total of 57 double marked chinook salmon were sampled from the 1990 cohort, three (5.26%) of which did not exhibit a detectable OTC mark (Table 7). Likewise, 12

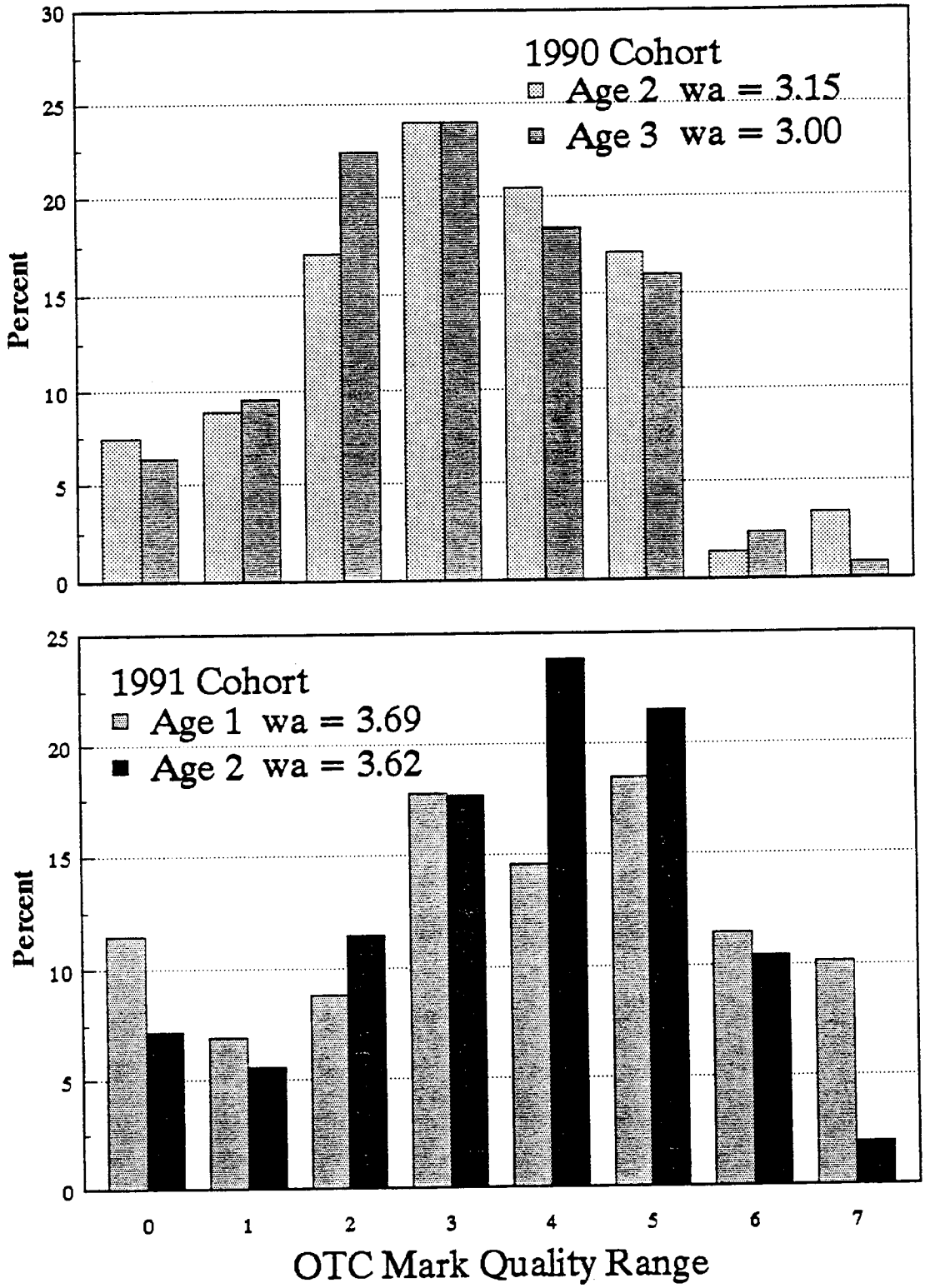

Figure 4. Range in quality and weighted average (wa) of OTC marks over a two year period for the 1990 and 1991 Cohorts. (0 = no mark, 1-3 = poor, 4-6 = good, 7 = great).

Table 6. Correlation between fin clips and OTC marks.

	1990 Cohort			1991 Cohort			1992 Cohort		
Fin Clip Used	State	Total Sample Size	# with No OTC	State	Total Sample Size	# with No OTC	State	Total Sample Size	# with No OTC
Ad – CWT	MI	21	1	MI	86	2	MI	122	5
Ad – CWT	WI	22	0	WI	75	4	WI	73	3
LV		1	1	IND[a]	15	10		6	4
RV	MI	13	2	MI	41	6		6	0
LP		2	0	IND[a]	35	21			
RP	IND[a]	10	7		4	0	ILL	4	0
AdLV		1	1	IND[a]	6	6			
AdRV				IND[a]	6	4		3	2
AdLP	IND[a]	4	3				IND[a]	5	5
AdRP	IND[a]	1	0		1	0	IND[a]	1	1
BV	IND[a]	4	3		1	0	ILL	3	0
LPRV				ILL	1	0			
RPLV				ILL	2	0			
AdBV				ILL	1	0			
D	ILL	1	0				ILL	5	2
DAd				ILL	6	0			
DRV							ILL	2	0
DLP				ILL				1	0
DRP							ILL		
RMLV							WI		
LM									

[a] Fish not marked with OTC

Table 7. Percentage of double marked chinook salmon not exhibiting an OTC mark.

State	Clip	1990 Cohort	1991 Cohort	1992 Cohort
MI	Ad	4.76	2.33	4.10
	RV	15.38	14.63	– –
WI	Ad	0.00	5.33	4.11
ILL	all clips	0.00	0.00	14.29
Cohort Total		5.26	5.66	4.76
TOTAL ACROSS COHORTS				5.22

out of 212 (5.66%) and 10 out of 210 (4.76%) double marked samples from the 1991 and 1992 cohorts, respectively, did not exhibit detectable OTC marks. Also shown in Table 7 are the percent marking errors for each state. All three non-marked samples from the 1990 cohort were Michigan stocked fish (3 of 34, 8.82%), while all Wisconsin (22) and Illinois (1) double marked fish exhibit OTC marks. Of the 1991 and 1992 respective cohort samples, 127 and 122 were Michigan clips with eight (6.29%) and five (4.10%) not showing an OTC mark, 75 and 73 were Wisconsin clips with four (5.33%) and three (4.11%) not showing an OTC mark, and 10 and 14 were Illinois clips with zero (0%) and two (14.30%) not showing an OTC mark. A total of 25 out of 479 (5.22%) double marked fish did not exhibit OTC marks.

Repeatability

Table 8 shows comparisons between samples for which discrepancies in OTC mark quality between two or more readers occurred. Forty-two of the 100 (42%) samples were assigned different OTC mark qualities by at least two readers, with four (4%) of the discrepancies disagreeing about the presence of an OTC mark. Overall, there was 96% agreement among readers in the detection of OTC marks.

Discussion

The mass marking of hatchery chinook salmon in Lake Michigan with OTC provided an opportunity to independently examine hatchery and natural chinook salmon populations. Ridgeway and Weber (1963 and 1967) demonstrated that Pacific salmon can be effectively massed marked by feeding OTC. However, prior to using this OTC data in Lake Michigan management decisions, the validity/effectiveness of

Table 8. Oxytetracycline mark quality ratings for samples which multiple readers assigned different OTC mark qualities.

Reader 1		Reader 2		Reader 3		Reader 1		Reader 2		Reader 3		
3		4		4		2	3[a]	3		3		
5		5		6		7		6		7		
6	2[a]	4		5		1		0		0		Difference
3		3		4		1		0		0		Difference
5		4		5		4		5		5		
5		6		6		3		4		3		
4		4		5		3		4		4		
4		5		4		1		1		0		Difference
2		0		0	Difference	4	4[a]	5	4[a]	4	4[a]	
6		3		2		3		4		3		
3		4		4		3		4		5		
1	3[a]	2		2		5		6		5		
2	4[a]	2	4[a]	3		4	4[a]	4	4[a]	4	5[a]	
4		4		3		4		5		4		
3		4		5		7		7		6		
7		6		7		3		3		4		
3		2		2		5		4		4		
2		1		1		2		3		3		
5		4		5		4		4		5		
3		4		4		5		5		6		
3		4		4		4	5[a]	4	5[a]	3	5[a]	

[a] Indicates the presence of a double mark (2 OTC rings). The first number is the inner ring.

this marking method for Lake Michigan chinook salmon must be established. Errors in the OTC data could result from mark deterioration over time, failure to adequately mark all hatchery chinook salmon, and poor repeatability among readers to detect OTC marks.

Examination of OTC mark quality over time should be done within cohorts and examined only for shifts in over-all mark quality (Figure 4). Due to the subjectivity of assigning OTC mark quality, slight changes in individual quality categories do not have any management implications. The use of a weighted average of mark quality for each cohort reflects the over-all permanency of OTC marks over time. The weighted average of OTC mark quality for the 1990 and 1991 cohorts decreased as the fish aged 1 additional year by 0.15 and 0.07, respectively. This slight decrease in mark quality does not change the overall quality rating, indicating that the OTC marks do not degrade significantly over time in terms of management implications. This is supported by Weber and Ridgeway (1967) where OTC marks were still detectable after 3.5 years. The 1993 results of OTC mark quality weighted averages across cohorts, shown in Table 5, indicate that the 1992 cohort (4.14) received higher quality OTC marks than did the 1991 (3.62) and the 1990 (3.00) cohorts.

The percentage of hatchery chinook salmon not exhibiting an OTC mark (shown with an OTC mark quality of 0 in Figure 4) does not represent a true OTC marking error rate. Rather, this is representative of both the hatchery chinook salmon that received only a fin clip and no OTC and those chinook salmon that were double marked but failed to exhibit an OTC mark.

External marking with fin clips provides a means of identifying the state of origin and establishing marking error rates. However, fin clips are not a fool-proof method of identifying fish. Both the regeneration of clipped fins and the natural loss of fins do occur, but the rates of regeneration and loss are unknown (Fry 1961). The regeneration of all fin clips on a single fish does not adversely impact this OTC mark evaluation study. However, the regeneration of a single fin on multiple fin clipped fish or the natural loss of a non-clipped fin can result in the mis-identification of a fish in terms of state and cohort of origin. The possibility of human marking error also exists with the administration of incorrect clips. This mis-identification of fish origin due to incorrect fin clips, regeneration, and natural fin loss could have effects on this study. Samples were placed into cohorts based on vertebral age estimates and it is possible that some samples were misaged.

The fact that errors do occur is evident in Table 6, as 25 samples were placed into non-possible fin clip/cohort compartments. For example, 4 samples were collected with a right pectoral (RP) clip and assigned to the 1991 cohort based on vertebral age; this was not a fin clip used for that cohort. Several possible types of error exist: 1) the samples could have been misaged as both the 1990 and 1992 cohorts used RP fin clips, 2) these samples could have been RP, left ventral (LV) fin clip fish which regenerated LV fins, and 3) the RP fin could have been clipped by mistake. These types of errors are easily detected when expressed as non-possible combinations. These samples were not used in the marking error determination.

Errors could also occur and not easily be detected if the errors mimic used fin clips. For example, Indiana marked chinook salmon with fin clips only and did not

use OTC, but 14 out of 35 left pectoral (LP) samples from the 1991 cohort exhibited an OTC mark. This existence of OTC in samples that should not have OTC marks can be explained by the regeneration of dorsal (D) fins from Illinois 1991 stocking of D, LP and OTC marked chinook salmon. An alternate explanation involves the existence of false-positive OTC marks. However, the appearance and location of OTC marks is very distinctive and uncontrolled exposure of chinook salmon to OTC is not likely. This type of non-detectable error could be responsible for some of the fin clipped samples not showing OTC if a non-hatchery chinook salmon naturally lost fin(s).

The resulting estimates of each state's OTC marking error (Table 7) can be used to monitor OTC marking effectiveness of individual states. Obtaining an adequate sample size of each type of fin clip or each state's fin clips is difficult due to low numbers marked. For example, I only sampled 1, 10, and 14 Illinois fin clip chinook salmon from the 1990, 1991, and 1992 cohorts, respectively. If an adequate sample size of each state's fin clips is obtained to provide an accurate estimate of OTC marking error for each state (not the case with this study), then it would be appropriate to adjust the lake-wide OTC marking estimate in respect to the numbers of OTC-only marked chinook salmon stocked by each state. If the sample size of each state's fin clips is small, it is more appropriate to make the assumption that all states obtained similar rates of OTC marking effectiveness and to lump all samples into one estimate. It is not possible to determine and include samples that did not take an OTC mark and regenerated fin clips with this type OTC marking evaluation. The resulting lake-wide OTC marking error estimates were similar between cohorts

3.74%, 3.32%, and 3.52%. These data agree with marking error estimates by Elliott (1994), where 2-5% of age 0 hatchery chinook salmon, sampled prior to and after stocking, did not exhibit OTC marks.

In accordance with Elliott's (1994) findings, I used an estimate of 5% OTC marking error for correcting hatchery and natural percentages. By using a slightly inflated OTC marking error rate rather than that actually observed, some correction for non-recognition of hatchery chinook salmon that regenerated fin clips may be taken into account. This also produces a conservative estimate of the contribution of naturally produced chinook salmon.

Correction of hatchery and natural estimates for 5% non-marked hatchery chinook salmon was accomplished by multiplying the number of marked (fin clip and/or OTC mark) fishby 0.05. That product is then subtracted from the number of unmarked fish and added to the number of marked fish. In this manner, the correction method does not increase hatchery and decrease natural percentages each by 5%.

The relatively poor agreement (58%) between different readers assigning OTC mark quality should not be a concern as the mark quality scale is very subjective. The discrepancies in OTC mark quality ratings were small; with the exception of one sample, ratings differed by only 1 or 2 quality categories. The important aspect of repeatability among readers is the ability to distinguish OTC marks. The 4 samples where the incidence of an OTC mark differed among readers were all rated as "poor minus" or "poor" quality marks. Experience and patience examining vertebrae will help reduce non-detection of poor quality OTC marks. Samples not showing an OTC mark could be saved and reexamined to reduce the non-detection of poor quality marks.

CHAPTER FOUR

Percentage of Hatchery and Natural Chinook Salmon in the Lake Michigan Sport Fishery

Introduction

Since the introduction of chinook salmon (*Oncorhynchus tshawytscha*) into the Great Lakes in 1967 several studies have documented the occurrence of successful natural reproduction (Rybicki 1973, Taube 1974, Carl 1980 and 1982a, Seelbach 1985, Powell and Miller 1990, Zafft 1992, and Jennings 1992). The studies by Carl (1982a), Zafft (1992), and Seelbach (1985) estimated numbers of natural smolts out-migrating from several streams in Michigan. There have been no lake-wide estimates of the contribution or comparison between hatchery and natural chinook salmon in Lake Michigan.

The identification and quantification of the hatchery and natural components of the chinook salmon population is difficult after out-migration from rivers has occurred. It is not economically feasible to externally mark the millions of the hatchery chinook salmon being stocked each year. Hankin (1982) discussed estimating escapement of hatchery and wild chinook salmon by marking a consistent proportion of the hatchery fish being stocked, from which the relative contribution of hatchery and wild fish can be estimated regardless of year and location of spawning return. By marking only a portion of the hatchery fish stocked the non-marked hatchery fish are still non-distinguishable from the natural fish, making comparisons

between hatchery and natural fish difficult. Hankin's method also requires the assumption of equal mortality/survial for hatchery and natural fish. Scale circuli patterns of West Coast chinook salmon and Great Lakes steelhead (*Oncorhynchus mykiss*) have been successfully used to distinguish hatchery and wild (natural) individuals (Sneva and Knudsen 1989 and Seelbach and Whelan 1988). However Carl (1982b) was not able to differentiate Lake Michigan hatchery and natural chinook salmon by scale patterns. In an attempt to distinguish hatchery and natural chinook salmon, all hatchery chinook salmon stocked in the Lake Michigan basin from 1990 to 1994 were marked with the antibiotic oxytetracycline (OTC) and/or fin clips.

During 1992 and 1993 I sampled Lake Michigan chinook salmon to determine the occurrence of hatchery and natural chinook salmon in the sport fishery. The objectives of this paper are to: 1) describe the contribution of hatchery and natural chinook salmon to the Lake Michigan sport fishery, and 2) examine relative survival rates for hatchery and natural chinook salmon during lake life stages.

Methods

Sampling Ports Description

Three Michigan ports were used for sample collection: Grand Haven, Ludington, and Leland (Figure 5). These ports incorporate areas that have different amounts of natural reproductive input from nearby streams and also have sport fisheries that catch high numbers of chinook salmon. Grand Haven, located in the southern part of the lake and at the mouth of the Grand River, represents an area with low natural reproductive input (Jennings 1992). Ludington, located in the central portion of the lake at the mouth of the Pere Marquette River, is in an area with high

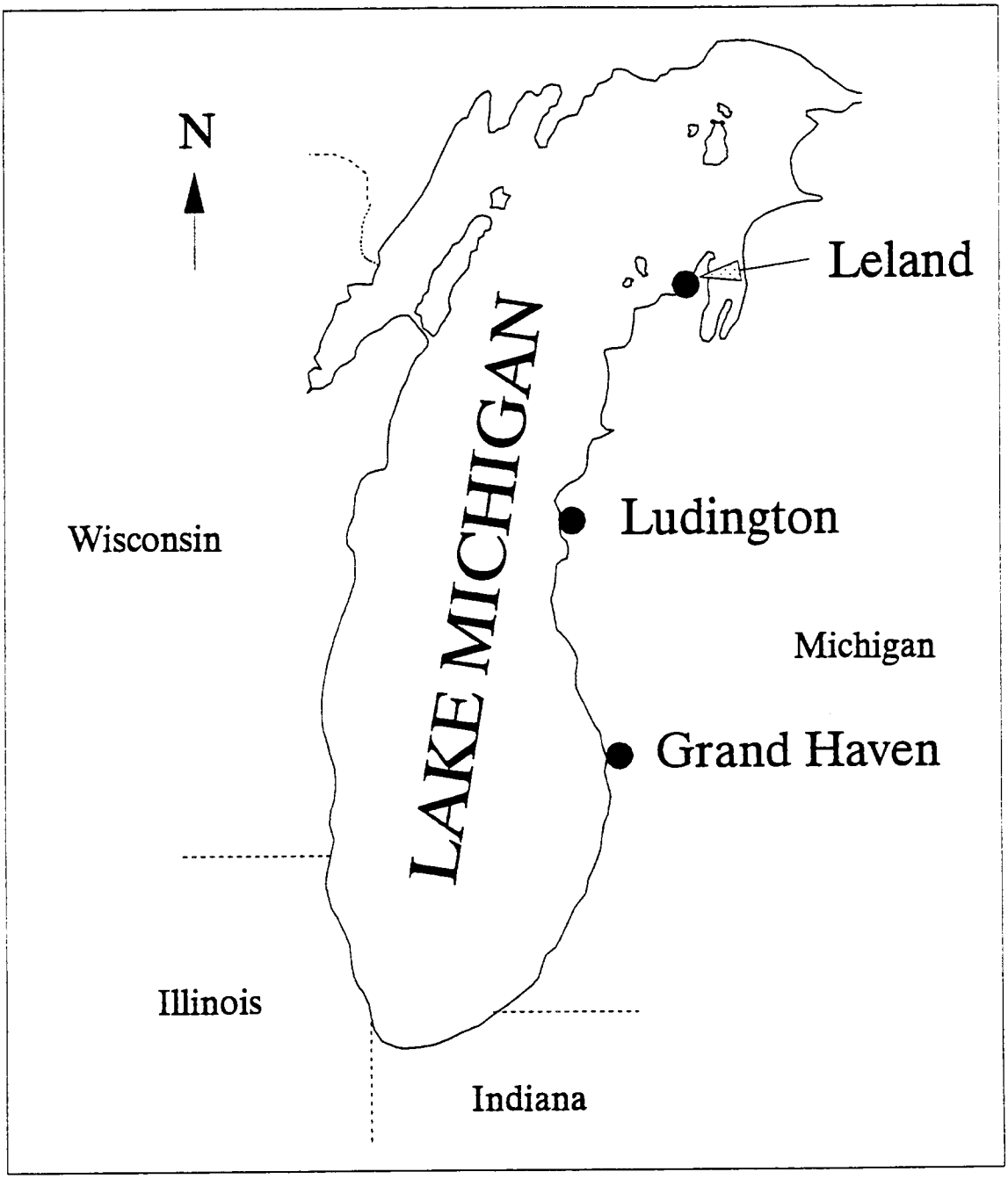

Figure 5. Lake Michigan and location of sampled ports.

natural reproductive input (Carl 1982a and Zafft 1992). Both Grand Haven and Ludington have consistently been one of the top chinook salmon catch ports in Michigan water's (Rakoczy 1992). Leland, located in the northern part of the lake, is in an area that has no major rivers and low natural reproduction potential, but has traditionally had the highest chinook salmon catch of all Lake Michigan Ports (Rakoczy 1992).

Field Methods

Samples were collected from the sport fishery, primarily at the cleaning stations where charterboat crews clean their fish (Table 9). With the permission of the captains, all observed chinook salmon were sampled. Weight, length, and fin clip data, and scales were collected prior to cleaning. Sex and maturity data, general health condition, and a section of vertebrae were collected after cleaning. The name of the captain or boat name was recorded. Weight was recorded to the nearest 1/4 pound on fish over 4 lbs and to the nearest 25 grams on fish under 4 lbs. Total length (end of pinched caudal fin) was recorded in millimeters. The incidence, including type, of fin clips was recorded. Noses from adipose fin clipped fish (containing coded wire tags) of all species were collected and delivered to the Michigan Department of Natural Resources. Scale samples were taken just posterior of the dorsal fin just above the lateral line. In 1992 scales were collected from all chinook salmon and in 1993 only from adipose fin clipped chinook salmon. Observations of health condition followed a shortened procedure of Geode (1988) with the condition of the kidney, liver, spleen, hindgut, and any gross abnormalities being noted. A section of at least 5 thoracic vertebrae, from below the adipose fin, was

removed with shears. Vertebrae samples were placed in individually labeled bags and frozen as soon as possible. Exposure of vertebrae to direct sunlight was minimized.

Table 9. Primary cleaning stations targeted for sample collection.

Grand Haven	Chinook Pier Sportfishing. 301 N. Harbor Dr.
	Bolhouse Charters. Holiday Inn M-21.
Ludington	Abrahamsons Marina. S. Washington St.
	Ray's Auto Marina. 801 S. Washington St.
Leland	Carlson's Fish Market. Leland.

In an effort to collect additional samples, during 1993, "muck buckets" (approximately 10 gallon garbage cans) were placed at the cleaning stations not being personally attended. A sign was attached reading: "Michigan State University chinook salmon research. Please place all chinook salmon carcasses in green tub. Tub is checked daily." These buckets were checked several times a day. Data including total filleted length, sex and maturity, general heath condition, and fin clips (if possible) were recorded, and a section of the vertebrae collected. It was observed that not all chinook salmon carcasses were placed in these buckets; therefore all samples collected in this fashion were distinguished on the data sheet as being not representative of the harvest.

During 1992 sampling occurred mainly on weekends whereas sampling in 1993 occurred on all days. Ports were sampled proportionately to the success of chinook salmon fishing. Grand Haven was sampled from May - September, Ludington June - September, and Leland July - August. The number and pattern of sampling days at

each port were adjusted continually in attempts to keep total sample size approximately equal between ports.

Laboratory Analysis

Age determination and detection of OTC marks were accomplished using the techniques described in chapters 2 and 3, respectively. It was determined that the vertebral ageing method misages 3% of the samples and the ageing errors occur randomly with no bias effects on subsequent data analysis. Data presented on the percentage of hatchery and natural chinook salmon have been corrected for a 5% occurrence of non-marked hatchery chinook salmon (see chapter 3).

Statistical Analysis

All tests were done individually for each cohort. Tests for seasonal variation within locations and annual variation between locations were done with chi-square contingency tables ($p < 0.05$) (Gill 1978). With the use of chi-square contingency tables it was determined that a sample size of 400 fish per cohort per port per year was needed to detect a 5% change in the percentage of hatchery and natural chinook salmon.

Results

Due to the low catch rates of chinook salmon during 1992 and 1993 the desired sample size was not obtained. In 1992 and 1993, a total of 753 and 1,374 chinook salmon were sampled, (201 and 615 from Grand Haven, 249 and 697 from Ludington, and 303 and 65 from Leland), respectively. Sampling effort was not equal for the two years, with 41 sampling days in 1992 and 83 sampling days in 1993.

Daily sample sizes ranged from 0 - 94 by cohort, with averages of 5 to 20 and modes of 1 or 2 (Appendix C). Due to the frequency of small daily sample size no statistically significant differences in the daily percentages of hatchery and natural chinook salmon were detected (Figures 6a and b). Monthly totals were compared within each location, samples were combined for each calendar month sampled, and no statistically significant differences were detected. Samples were further combined to produce one estimate of percent hatchery and natural at each port and for each cohort. Shown in Appendix D are the daily, monthly, and yearly percentages of natural chinook salmon for each cohort by port in 1992 and 1993.

Table 10 lists by port yearly total sample size, percentage of hatchery and natural, and associated standard errors of hatchery and natural chinook salmon at: ages 2 and 3 for the 1990 cohort, ages 1 and 2 for the 1991 cohort, and age 1 for the 1992 cohort. The percentages of naturally reproduced age 1 and age 2 chinook salmon in 1992 and 1993 ranged from 20-39% and were not statistically different within or between ports and cohorts (Figure 7). The 1990 cohort age 3 Ludington sample did significantly differ ($p < 0.05$) from both the 1990 cohort age 3 Grand Haven sample (Figure 7) and the 1990 cohort age 2 Ludington sample. A limited sample of six age 3 chinook salmon, from Leland in 1993, provided an uncertain estimate of 67% from natural reproduction that was not significantly different from other results.

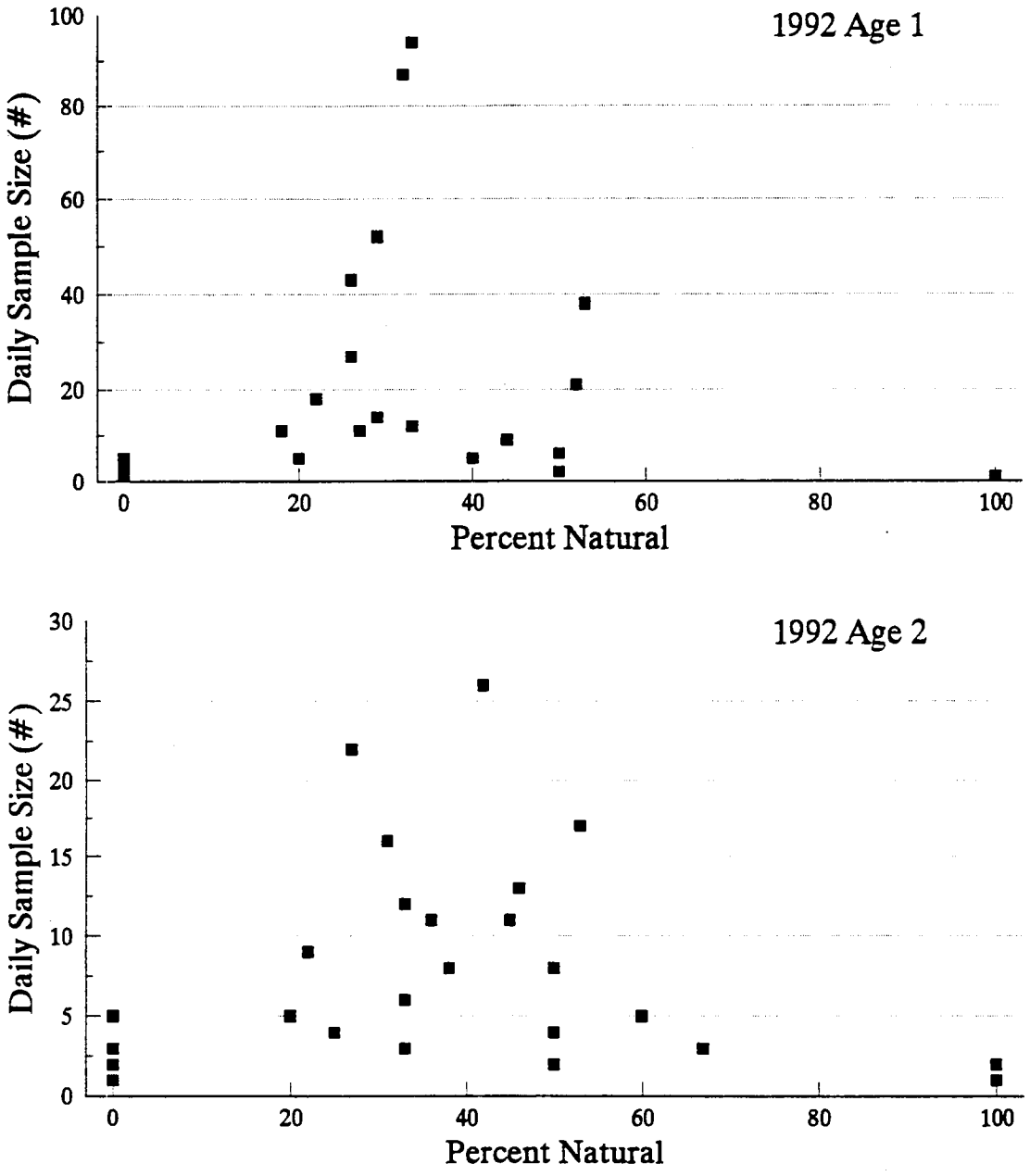

Figure 6a. Daily percentage of chinook salmon from natural reproduction with respect to sample size for all ports combined at age 1 and 2 during 1992.

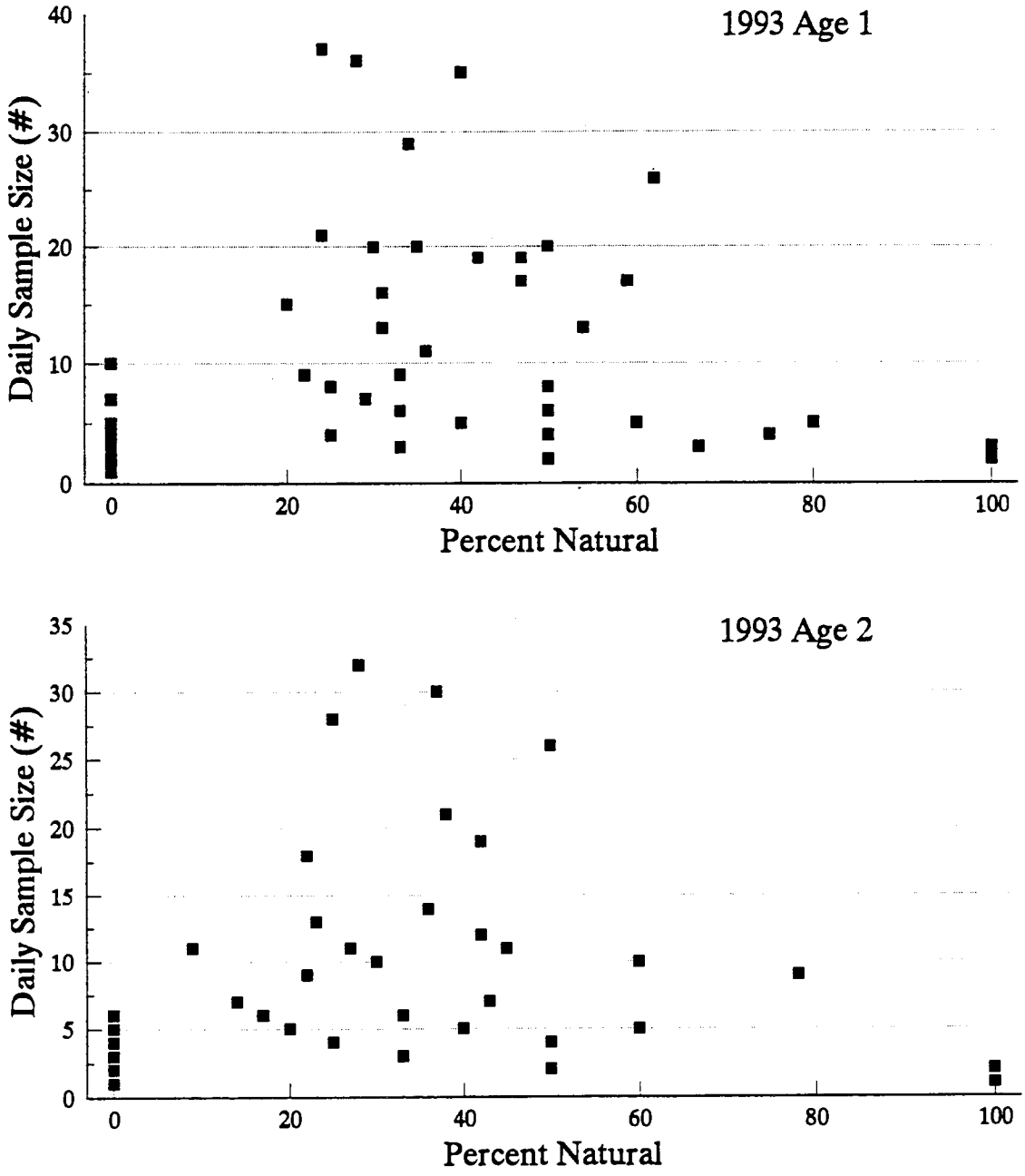

Figure 6b. Daily percentage of chinook salmon from natural reproduction with respect to sample size for all ports combined at age 1 and 2 during 1993.

Table 10. Summary of the percentage of hatchery and natural chinook salmon at Grand Haven, Ludington, and Leland during 1992 and 1993.

		1990 Cohort		1991 Cohort		1992 Cohort
		Age 2	Age 3	Age 1	Age 2	Age 1
Grand Haven	Sample Size	80	90	97	165	339
	Percent Hatchery	67	61	79	73	67
	Percent Natural	33	39	21	27	33
	Standard Error	5.2	5.1	4.1	3.5	2.6
Ludington	Sample Size	93	147	130	268	242
	Percent Hatchery	63	46	69	71	68
	Percent Natural	37	54	31	29	32
	Standard Error	5.0	4.1	4.0	2.8	3.0
Leland	Sample Size	64	6	280	22	37
	Percent Hatchery	64	33	70	68	78
	Percent Natural	36	67	30	32	22
	Standard Error	6.0	19.2	2.7	9.9	6.8

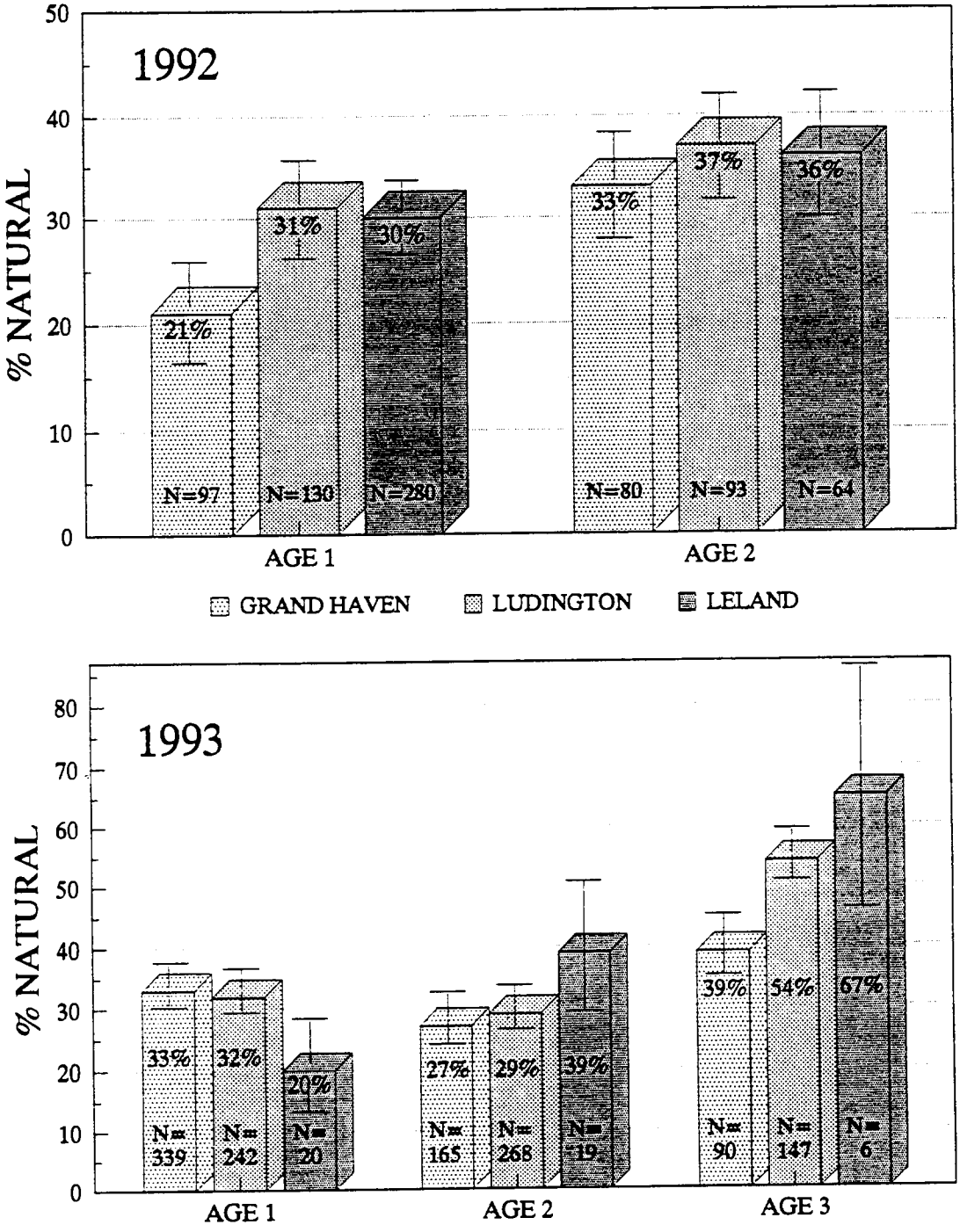

Figure 7. Percentage of naturally reproduced chinook salmon in the 1992 and 1993 sport harvest at Grand Haven, Ludington, and Leland. Error bars represent +/- 1 standard error.

Discussion

I have refered to Great Lakes naturally reproduced chinook salmon as "natural" rather than "wild". This was done for two reasons: 1) Great Lakes chinook salmon are an introduced species which has become naturalized, and 2) the methods used in this study cannot distinguish how many generations removed natural fish are from hatchery produced parents. With only 6-8 generations of chinook salmon having existed in the Great Lakes, combined with the likely continual cross mating of hatchery and naturally produced fish, none of the natural fish are very far removed from hatchery produced parents. Thus, the terminology of "natural" chinook salmon seems more appropriate than "wild" when discussing Great Lakes naturally reproduced chinook salmon.

Carl's (1982b) inability to distinguish hatchery and natural Lake Michigan chinook salmon using scales is not surprising due to the short period of time where hatchery and natural chinook experience different environmental conditions. However, Carl (1982b) did not have a sample of mature known natural chinook salmon, but rather assumed that samples from the Pere Marquette River were natural fish. Repetition of Carl's study using the scales collected during my study where both known hatchery and natural scale samples are available may prove beneficial.

Seasonal and Port Trends

Catch per effort of chinook salmon at different locations in Lake Michigan varies seasonally (Elliott 1994 and Rakoczy 1992). Chinook salmon were consistently harvested at Grand Haven from May through August, likewise in Ludington from June through August. Chinook salmon catches during June at both of these ports

were generally low. Chinook salmon have consistently contributed to the Leland sport harvest from mid-July to Late August (Rakoczy 1992).

The ability to determine daily changes in the percentage of hatchery and natural chinook salmon is limited by small daily sample sizes. As the daily sample size increased above 10, most percentages of natural chinook salmon fell within the 95% confidence interval of the yearly mean (Figures 6a and b). However, a much larger sample size was needed to produce confident estimates. The monthly proportions of hatchery and natural chinook salmon did not change over the sampling period. It was hypothesized that a change in the percentages of hatchery and natural chinook salmon during the season might occur for age 3 fish as mature fish home in on their native streams or stocking locations. This change was not apparent. The lack of change over the season combined with increased precision as sample size increases allowed for the combination of all samples within a port for each cohort. Comparisons between ports based on these combined yearly samples revealed an increased contribution of age 3 natural chinook salmon at Ludington over Grand Haven.

Cohort Trends

Elliott (1994) used the OTC/fin clip marks to estimate that at age 0, 36% (south) and 56% (north) of the 1990 cohort and 26% (south) and 44% (north) of the 1991 cohort were from natural reproduction, and at age 1, 18% (south) and 35% (north) of the 1990 cohort were from natural reproduction. Elliott's south samples were collected from St. Joseph to Muskegon, Michigan, and the north samples were

collected from Pentwater to Leland, Michigan. These can be compared to my Grand Haven and Ludington samples, respectively.

Combining Elliott's age 0 and age 1 data with my age 2 and age 3 data for the 1990 cohort, the percentage of natural chinook salmon over an entire life cycle was available (Figure 8). For both locations the age 0 percentages are similar to the age 3 percentages; however there is a significant drop to the age 1 and age 2 percentages. This decrease in the percentage of natural fish at age 1 and 2 is probably due to mixing of fish throughout the lake. With most natural reproduction occurring in Michigan rivers, age 0 natural chinook salmon are concentrated on the Eastern side of Lake Michigan. By the time the chinook salmon are age 1, they have time to move, and the percentages of natural fish drop to 18% and 35% at age 1 and 33% and 37% at age 2. The 18% percent natural fish for the Grand Haven age 1 sample is probably artificially low due to the disproportional collection of adipose fin clipped (hatchery) by anglers (Rob Elliott, personal communication). The age 3 chinook salmon are sexually mature and are homing in on their native streams/stocking locations. As a result, the percentages of age 3 chinook salmon from natural reproduction match those observed at age 0. This same trend, although not complete, is also prevalent in the 1991 cohort at ages 0, 1, and 2 (Figure 8).

Relative Survival

If differential survival of hatchery and natural chinook salmon occurs during the lake life stages corresponding shifts in the percentage of hatchery and natural chinook salmon should be apparent. Due to the migration and mixing trends over the life cycle of a cohort, annual differential survival could not be determined. However,

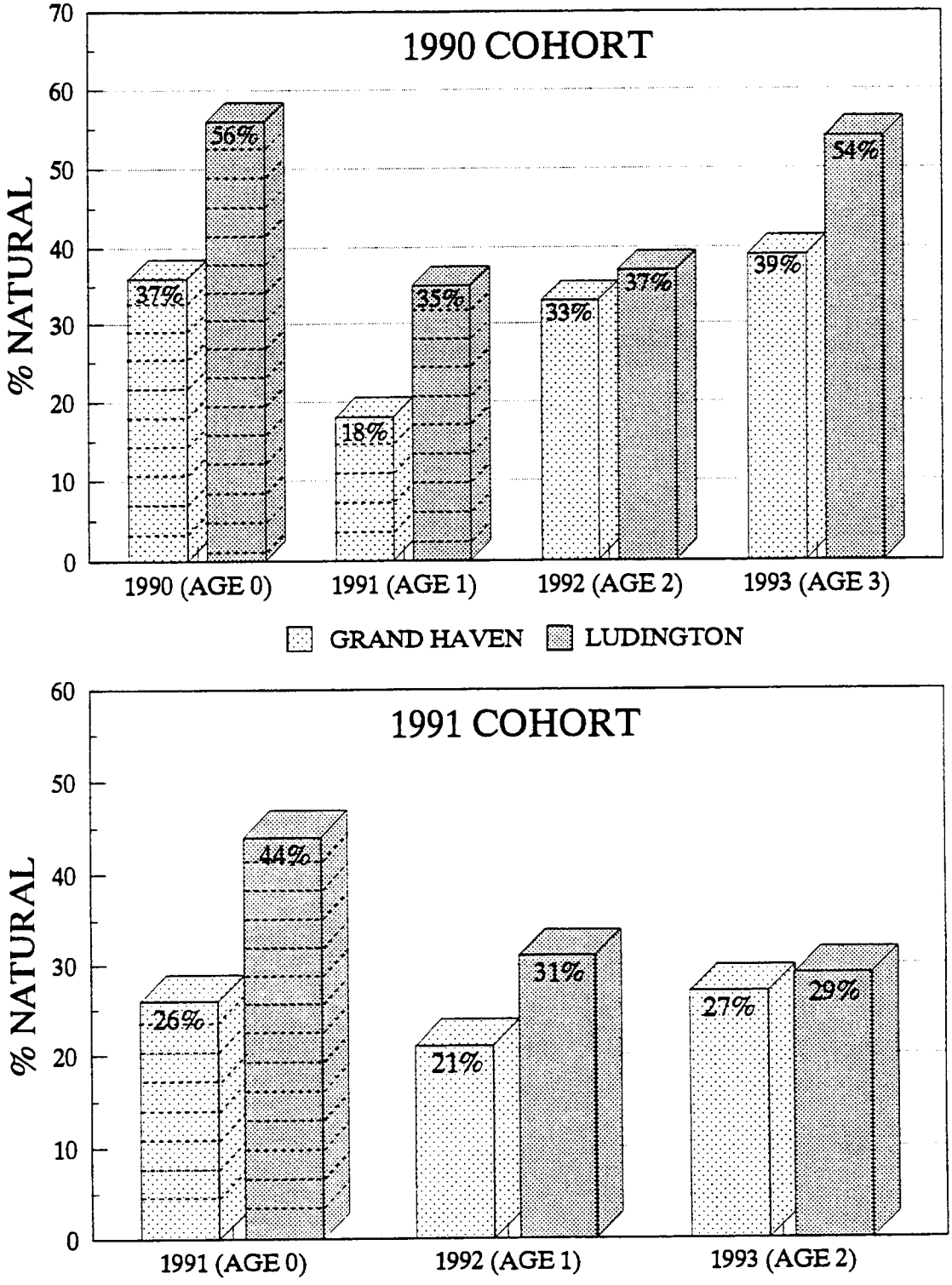

Figure 8. Yearly percentages of naturally reproduced chinook salmon in the 1990 and 1991 cohorts at Grand Haven and Ludington. Bars with dashed lines represent data from Elliott (1994).

differential survival over a cohort's entire lake life cycle was examined by comparison of age 0 and age 3 percentages of hatchery and natural chinook salmon. With the age 0 natural percentages (37% and 56%) not being significantly different than the age 3 natural percentages (39% and 54%) for the 1990 cohort at both Grand Haven and Ludington, it appears that no differential survival between hatchery and natural chinook salmon occurs during the lake life stages.

Further examination for the possibility of differential survival was accomplished by examination and determination of the origin of chinook salmon showing clinical signs of bacterial kidney disease and will be discussed in chapter 5.

Natural Contribution

By examining a cohort over an entire life cycle it became clear that sampling at one point in time is not sufficient to answer all questions. If a single estimate of the lake-wide contribution of naturally reproduced chinook salmon is desired it should be obtained by sampling the age 1 and age 2 fish. The data collected in this project were only collected from the Eastern side of Lake Michigan. As a result it requires some extension of the data to estimate lake-wide contribution. It is acceptable to estimate that 35% of the 1990 cohort, 29% of the 1991 cohort, and 32% of the 1992 cohort are contributed by natural reproduction to the Eastern Lake Michigan sport fishery. These reduced estimates from the estimates at age 0 and age 3 indicate the immigration of hatchery chinook salmon and/or the emigration of natural chinook salmon at age 1 and age 2. Making the assumption that hatchery and natural chinook exhibit the same in-lake behavior, it may be reasonable to extend the estimate of the contribution of natural chinook salmon to Eastern Lake Michigan to the entire lake.

With significant differences occurring in the percentages of age 3 natural chinook salmon between ports it is not appropriate to use age 3 fish for lake-wide estimates. Rather these samples can be used to estimate the regional contribution of natural chinook salmon. Either the age 0 or age 3 year classes can be used to estimate regional contribution of natural chinook salmon. However, age 3 fish must be used if samples are collected though the sport harvest. Only the 1990 cohort has been sampled at age 3, with 54% of the Ludington area and 39% of the Grand Haven area age 3 sport harvest of chinook salmon being contributed from natural reproduction.

Using the premise that survival of hatchery and natural chinook is not different throughout the entire life cycle and the premise that estimates of natural reproduction at age 1 and age 2 from the Eastern portion of Lake Michigan are applicable to the entire lake, estimates of the number of naturally produced chinook salmon entering the lake can be made. Estimates are obtained by multiplying the number of hatchery chinook stocked by the percentage of natural fish estimated in the lake population, then dividing by the percentage of hatchery fish in the lake population. The resulting estimate represents the number of stocked equivalent natural fish entering the Lake Michigan ecosystem. Using this technique, approximately 3,838,500 and 2,549,800 natural chinook salmon entered Lake Michigan in 1990 and 1991 respectively.

These estimates of natural reproduction far exceed the estimates for the streams in the lower peninsula of Michigan made by Carl (1982). This could represent a significant contribution of natural chinook salmon from other streams. However, it should be kept in mind that the current Lake Michigan chinook

population is very different than that it was even 5 years ago. As a result, my estimates of the contribution of natural reproduction during 1990-1993 should not be assumed to be constant or applicable for the entire time of existence of chinook salmon in the Great Lakes. My estimates do represent a current significant contribution of natural chinook salmon to the Lake Michigan ecosystem. Future Great Lakes fisheries management strategies should account for and include the contribution of natural chinook salmon in the decision making process.

CHAPTER FIVE

Occurrence of Bacterial Kidney Disease and Comparison of Sampling Techniques Using Hatchery and Natural Chinook Salmon

Introduction

The examination of many population characteristics of Lake Michigan hatchery and natural chinook salmon is possible with the existence of an extensive OTC/fin clip marking program from 1990 through 1994. In addition to samples collected for examination of the percentage of natural reproduction discussed earlier in chapter four, chinook salmon were being collected by the Michigan Department of Natural Resources as part of a diet-study. This study used gill nets as the sampling method and allowed for several additional aspects of Lake Michigan hatchery and natural chinook salmon population characteristics to be examined without additional field sampling. The gill net sampling permitted a comparison of sampling methods (gill net and sport harvest) and determination of the origin of chinook salmon exhibiting clinical signs of Bacterial Kidney Disease (BKD).

Gill nets have been extensively used as an efficient and relatively non-biased method of sampling fishery resources (Nielsen and Johnson 1983). However, depending on the type of data desired other sampling techniques maybe more appropriate. Comparison of similar data sets collected with different types of sampling techniques provides an opportunity to examine assumptions regarding the representitivness of various sampling techniques.

Bacterial Kidney Disease (BKD) was determined to be the cause of death for high numbers of chinook salmon in Lake Michigan from 1988 to present (Nelson and Hnath 1990). BKD occurs in natural systems in low concentrations (Johnson and Hnath 1991), but is believed that intensive culture of salmon in hatcheries has increased the incidence of BKD in chinook salmon. As a result, BKD may affect hatchery chinook salmon at higher rates than natural salmon.

The objectives of this paper are to briefly compare the percentage of hatchery and natural chinook salmon: 1) estimated by gill nets and the sport fishery, and 2) showing clinical signs of BKD.

Methods

Sample Source

Samples were collected from the sport fishery at Ludington and Pentwater and from gill nets set off of Pentwater. The location of sport fishery fishing effort is highly variable, but generally occurs between Little Point Sable, to the south, and Big Point Sable, to the north, covering approximately 40 km of shore line. Gill net sampling, conducted by the Michigan Department of Natural Resources Survey Vessel (SV) Steelhead, occurred at various distances off shore in the Pentwater vicinity, within the area targeted by the sport fishery. Due to the highly mobile and migratory patterns of chinook salmon it was assumed that both collection methods had equal probability of encountering the same groups of chinook salmon.

Field Methods

Chinook salmon from the sport fishery and gill nets were sampled for weight, length, sex and maturity, and general health condition; also fin clip data, scales, and vertebrae were collected. At least five thoracic vertebrae were collected from below the adipose fin. Observations of health condition followed a modified procedure of Geode (1988) with the condition of the kidney, liver, spleen, hindgut, and any gross abnormalities being noted.

Laboratory Methods

Procedures for age determination and the detection of OTC marks followed those described in chapter 2 and chapter 3.

Results

A total of 117 clinically sick chinook salmon was collected in the MDNR gill nets. No significant differences existed in the percentage of hatchery and natural fish between the total gill net sample and the clinically sick gill net sample. Comparison between the percentage of hatchery and natural chinook salmon with clinical signs of BKD shows the only significant difference occurs in the 1991 cohort at age 1 (Table 11). The proportion of sick to heathy chinook salmon increased within each cohort over time; the 1992 cohort (age 0 to age 1) increased from 0 to 12 percent, the 1991 cohort (age 1 to age 2) increased from 6 to 33 percent, and the 1990 cohort (age 2 to age 3) increased from 18 to 33 percent.

A total of 223 and 657 chinook salmon were sampled from the Ludington/Pentwater sport harvest in 1992 and 1993 respectively. Similarly, 214 and 547 chinook salmon were collected in the Pentwater area by gill nets. Table 11 lists

Table 11. Percentages of hatchery and natural chinook salmon from the 1992 and 1993 Ludington area sport harvest, Michigan Department of Natural Resources (MDNR) chinook salmon diet study gill nets, and clinically sick chinook salmon sampled in diet study gill nets.[1]

		1990 Cohort		1991 Cohort		1992 Cohort	
		Age 2	Age 3	Age 1	Age 2	Age 0	Age 1
Sport Harvest							
	Sample Size	93	147	130	268	--	242
	% Hatchery	63	46	69	71		68
	% Natural	37	54	31	29		32
	Standard Error	5.0	4.1	4.0	2.8		3.0
Gill Net							
Total	Sample Size	67 [a]	15	124 [a]	123	23	409
	% Hatchery	43	47	68	72	83	66
	% Natural	57	53	32	28	17	34
	Standard Error	6.1	12.9	4.2	4.1	7.9	2.3
Clinically Sick	Sample Size	12 [a]	5	8 [a]	41	0	51
	% Hatchery	42	40	100	71		78
	% Natural	58	60	0	29		22
	Standard Error	14.2	21.9	0.0	4.1		5.8
Percentage Hatchery with BKD (# of sick hatchery divided by total # hatchery)		17	29	10	33	0	15
Percentage Natural with BKD (# of sick natural divided by total # natural)		18	38	0	34	0	8

[1] Percentages have been adjusted to account for a 5% occurrence of unmarked hatchery chinook salmon.

[a] Samples were examined by MDNR Charlevoix personel.

for each sampling technique the number of samples in each cohort, the respective percentages of hatchery and natural, and standard errors. Estimates of the contribution of natural chinook salmon by the two sampling techniques are nearly identical with no significant differences existing in the percentage of hatchery and natural chinook salmon between the two sampling techniques, except for the 1990 cohort at age 2.

Discussion

Chinook salmon sampled from the sport fishery exhibited a low incidence of clinical signs of BKD. This was probably due to the reduced feeding activity of fish with advanced stages of BKD. Contrary to the sport fishery sample the "non-biased" gill sample of chinook salmon exhibited a high incidence of BKD. Only the samples collected by gill nets were used to examine the occurrence of BKD in hatchery and natural chinook salmon. The apparent difference in the rate of occurrence in BKD between sport caught and gill net samples raises the question of the representativeness of the sport fishery sample.

With the observed difference in the occurrence of BKD positive samples collected in gill nets and in the sport fishery it is appropriate to first discuss the effects of BKD on hatchery and natural chinook salmon prior to discussing the comparison of sampling methods. The occurrence of BKD causing bacteria, *Reni salmonarium* (R.S.), in chinook salmon is not equal to the rate occurrence of clinical signs of BKD. Fish can harbor R.S. and not show clinical signs of BKD (Johnson and Hnath 1991). However, it was assumed that the rate of clinical signs of BKD reflects the rate of occurrence of R.S. for both hatchery and natural chinook salmon.

Hatchery chinook salmon may exhibit a slightly higher occurrence rate of BKD at age 0 and 1 in comparison to naturally produced chinook salmon. However, the difference is small and probably not significant in terms of management decisions. At age 2 and 3 both hatchery and natural chinook salmon exhibit the same levels of BKD occurrence. Although the occurrence of BKD is equal between hatchery and natural chinook salmon, it appears that the rate of occurrence increased over the life cycle of the fish with over 30 percent of the age 3 samples showing clinical signs of BKD. With respect to objective 4, to determine if survival rates of hatchery and natural chinook differ, it appears that the significant mortality factor in BKD does not affect the survival of hatchery and natural chinook salmon differently.

Since there is not a difference in the occurrence of BKD between hatchery and natural chinook salmon the selection of healthy fish by the sport fishery should not affect the subsequent comparison of sampling techniques. All but one of the cohort/age groups sampled by both sampling methods exhibited the same composition of hatchery and natural chinook salmon. The age 2 - 1990 cohort showed the only discrepancy with 37 percent of the sport harvest and 57 percent of the gill net sample being from natural reproduction. The OTC determination on this gill net sample was done by MDNR personnel and could have included some age 3 - 1989 cohort samples which were not marked with OTC, resulting in an inflated estimated of the contribution of natural chinook salmon.

Depending on the type of samples and data needed for specific research projects, it can be beneficial to utilize the sport harvest as a practical sample collection method.

CHAPTER SIX

Summary

Natural reproduction of chinook salmon in the Great Lakes basin has been documented by several studies since the introduction of chinook salmon in 1967. These studies concentrated on estimating the production of natural chinook in individual streams. Estimates of the lake-wide contribution of natural chinook salmon to Lake Michigan was not possible due to the inability to distinguish natural chinook salmon from unmarked hatchery chinook salmon after outmigration from streams. Starting in 1990 and continuing through 1993 an extensive hatchery chinook salmon marking program using external marks of fin clips and/or internal marks with oxytetracycline (OTC) has provided the opportunity to examine the lake-wide contribution of natural chinook salmon to the Lake Michigan ecosystem.

Successful completion of this study required: 1) all samples to be aged with a high degree of accuracy, 2) a standard method for the detection of OTC marks be established along with a detection failure rate of those OTC marks, and 3) an adequate sample size of chinook salmon be obtained from Grand Haven, Ludington, and Leland, Michigan.

Age was determined by counting annular bands appearing on the vertebrae. The validity of this vertebral ageing method was determined by comparing known ages from fish marked with coded wire tags to age estimates made from the

corresponding vertebrae. A sample of 197 tagged chinook salmon were age with 97% accuracy.

The existence of double marked (fin clipped and OTC fed) chinook salmon enabled the calculation of an OTC marking/detection failure rate of 5 percent. By rating the quality of the OTC marks observed and comparing the quality of those marks over time in the same cohort, it was concluded that once an OTC mark is administered the quality of that mark does not decrease over time.

The sampling of chinook salmon at three ports for two years allowed for 3 age classes and 3 cohorts to be examined. It can generally be concluded that at ages 1 and 2 the fish are randomly mixed within the lake, with approximately 30 percent of the chinook salmon sport catch being from natural reproduction at all three ports. The percentage of naturally reproduced age 3 chinook salmon differed between ports, from 39 percent in the Grand Haven area to 54 percent in the Ludington area. This difference may represent the differences in contribution of natural fish between river systems.

APPENDIX A

Table 12. Summary of Lake Michigan hatchery chinook salmon marking, 1990 – 1993 stockings, numbers of fish in each category.

	Mark Type	1990	1991	1992	1993
Michigan	RV/OTC	604,809	499,554	0	0
	Ad/OTC	698,596	1,014,261	917,993	828,766
	OTC	2,239,769	1,803,440	2,497,433	2,278,261
	nm	96,582			
	Total	3,639,756	3,317,255	3,415,426	3,107,027
Indiana	BV	153,590			
	LV		148,267		
	RP	288,234			
	LP		353,837		
	AdRV		95,181		83,770
	AdLV		97,066		82,372
	AdLP	93,688		60,888	
	AdRP	94,744		112,890	
	OTC			330,453	292,464
	Total	630,256	694,351	504,231	458,606
Illinois	D	102,200		52,819	
	DLP/OTC		51,500		
	DRP/OTC			50,996	
	RP/OTC			51,221	
	DRV/OTC			100,499	
	BV/OTC			39,240	
	AdBV/OTC		51,000		49,873
	RPLV/OTC		50,041		52,343
	LPRV/OTC		75,817		50,517
	AdD/OTC		76,500		49,044
	OTC	377,200	191,480	57,894	162,420
	Total	479,400	496,338	352,669	364,197
Wisconsin	Ad/OTC	25,100	65,761	69,265	233,886
	RMLV			166,989	
	OTC	2,354,211	1,668,857	1,286,885	1,327,234
	Total	2,379,311	1,734,618	1,523,139	1,561,120
GRAND TOTAL		7,128,723	6,242,562	5,795,465	5,490,950
OTC Only		5,067,762	3,663,777	4,172,665	4,059,179
%clipped		28.9	41.3	28.0	26.1

APPENDIX B

Table 13. Summary of fin clips used by state and year.

Fin Clip	1990	1991	1992	1993
Ad	MI/WI	MI/WI	MI/WI	MI
LV		IND		
RV	MI	MI		
LP		IND		
RP	IND		ILL	
AdLV		IND		IND
AdRV		IND		IND
AdLP	IND		IND	
AdRP	IND		IND	
BV	IND		ILL	
LPRV		ILL		ILL
RPLV		ILL		ILL
AdBV		ILL		ILL
D	ILL		ILL	
DAd		ILL		ILL
DRV			ILL	
DLP		ILL		
DRP			ILL	
RMLV			WI	
LM				

APPENDIX C

Table 14a. Summary of the 1992 age 1 and age 2 daily samples for each port. Percentages have not been corrected for 5% occurrence of unmarked hatchery chinook salmon.

			Age 1			
Port	Date	Number	# Natural	# Hatchery	% Natural	% Hatchery
GH [1]	05/09/92	1	1	0	100	0
GH	05/23/92	1	1	0	100	0
GH	05/24/92	2	1	1	50	50
GH	05/25/92	2	0	2	0	100
GH	05/28/92	5	2	3	40	60
GH	05/30/92	1	0	1	0	100
GH	05/31/92	2	0	2	0	100
GH	06/21/92	2	0	2	0	100
GH	07/17/92	14	4	10	29	71
GH	07/18/92	11	2	9	18	82
GH	07/25/92	5	1	4	20	80
GH	08/01/92	1	1	0	100	0
GH	08/15/92	11	2	9	18	82
GH	08/16/92	11	2	9	18	82
GH	08/22/92	27	7	20	26	74
GH	09/12/92	1	0	1	0	100
LU [2]	06/20/92	2	1	1	50	50
LU	07/03/92	4	0	4	0	100
LU	07/04/92	5	0	5	0	100
LU	07/11/92	9	4	5	44	56
LU	07/12/92	21	11	10	52	48
LU	07/19/92	1	1	0	100	0
LU	07/23/92	2	1	1	50	50
LU	08/07/92	52	15	37	29	71
LU	08/14/92	3	0	3	0	100
LU	08/15/92	12	4	8	33	67
LU	08/17/92	6	3	3	50	50
LU	09/05/92	11	3	8	27	73
LU	09/12/92	2	1	1	50	50
LE [3]	07/26/92	18	4	14	22	78
LE	08/02/92	43	11	32	26	74
LE	08/05/92	94	31	63	33	67
LE	08/06/92	87	28	59	32	68
LE	08/23/92	38	20	18	53	47

[1] Grand Haven.
[2] Ludington.
[3] Leland.

Table 14a. Continued

Port	Date	Number	Age 2 # Natural	# Hatchery	% Natural	% Hatchery
GH	05/09/92	8	4	4	50	50
GH	05/23/92	4	1	3	25	75
GH	05/24/92	4	2	2	50	50
GH	05/25/92	5	1	4	20	80
GH	05/28/92	8	4	4	50	50
GH	05/30/92	8	4	4	50	50
GH	05/31/92	3	0	3	0	100
GH	06/28/92	2	1	1	50	50
GH	07/05/92	2	0	2	0	100
GH	07/17/92	2	2	0	100	0
GH	07/18/92	1	0	1	0	100
GH	07/25/92	5	3	2	60	40
GH	08/01/92	2	1	1	50	50
GH	08/15/92	6	2	4	33	67
GH	08/16/92	9	2	7	22	78
GH	08/22/92	5	0	5	0	100
GH	09/05/92	3	0	3	0	100
GH	09/12/92	3	2	1	67	33
LU	06/06/92	1	0	1	0	100
LU	06/27/92	1	1	0	100	0
LU	07/03/92	1	1	0	100	0
LU	07/04/92	1	1	0	100	0
LU	07/11/92	11	4	7	36	64
LU	07/12/92	13	6	7	46	54
LU	07/19/92	3	0	3	0	100
LU	07/23/92	4	2	2	50	50
LU	08/07/92	26	11	15	42	58
LU	08/14/92	16	5	11	31	69
LU	08/15/92	8	3	5	38	63
LU	08/17/92	1	1	0	100	0
LU	09/05/92	3	1	2	33	67
LU	09/12/92	4	1	3	25	75
LE	07/26/92	17	9	8	53	47
LE	08/02/92	22	6	16	27	73
LE	08/05/92	12	4	8	33	67
LE	08/06/92	11	5	6	45	55
LE	08/23/92	2	1	1	50	50

Table 14b. Summary of the 1993 age 1, 2, and 3 daily samples for each port. Percentages have not been corrected for 5% occurrence of unmarked hatchery chinook salmon.

		Age 1				
Port	Date	Number	# Natural	# Hatchery	% Natural	% Hatchery
GH[1]	05/08/93	2	0	2	0	100
GH	05/15/93	3	1	2	33	67
GH	05/16/93	5	2	3	40	60
GH	05/19/93	4	1	3	25	75
GH	05/20/93	2	1	1	50	50
GH	05/21/93	4	0	4	0	100
GH	05/22/93	20	6	14	30	70
GH	05/23/93	3	0	3	0	100
GH	05/26/93	3	1	2	33	67
GH	05/27/93	20	6	14	30	70
GH	05/28/93	2	0	2	0	100
GH	05/30/93	15	3	12	20	80
GH	06/02/93	8	2	6	25	75
GH	06/03/93	5	3	2	60	40
GH	06/04/93	4	2	2	50	50
GH	06/05/93	11	4	7	36	64
GH	06/20/93	1	0	1	0	100
GH	06/22/93	1	0	1	0	100
GH	06/27/93	2	1	1	50	50
GH	06/28/93	3	0	3	0	100
GH	07/07/93	1	0	1	0	100
GH	07/08/93	2	2	0	100	0
GH	07/09/93	1	0	1	0	100
GH	07/13/93	3	1	2	33	67
GH	07/14/93	2	0	2	0	100
GH	07/18/93	2	0	2	0	100
GH	07/19/93	1	0	1	0	100
GH	07/20/93	4	3	1	75	25
GH	07/23/93	20	10	10	50	50
GH	07/28/93	4	2	2	50	50
GH	08/01/93	5	3	2	60	40
GH	08/05/93	9	2	7	22	78
GH	08/06/93	3	1	2	33	67
GH	08/07/93	8	4	4	50	50
GH	08/13/93	8	2	6	25	75
GH	08/17/93	16	5	11	31	69
GH	08/18/93	13	4	9	31	69
GH	08/19/93	19	8	11	42	58
GH	08/20/93	7	0	7	0	100
GH	08/23/93	3	3	0	100	0
GH	08/26/93	26	16	10	62	38
GH	08/28/93	29	10	19	34	66
GH	08/29/93	35	14	21	40	60

[1] Grand Haven

Table 14b. Continued

Port	Date	Number	Age 1 continued # Natural	# Hatchery	% Natural	% Hatchery
LU [2]	05/29/93	1	0	1	0	100
LU	05/30/93	2	0	2	0	100
LU	06/03/93	5	0	5	0	100
LU	06/04/93	1	0	1	0	100
LU	06/19/93	17	10	7	59	41
LU	06/22/93	2	0	2	0	100
LU	06/23/93	1	0	1	0	100
LU	06/26/93	7	2	5	29	71
LU	07/03/93	6	2	4	33	67
LU	07/04/93	3	2	1	67	33
LU	07/10/93	6	3	3	50	50
LU	07/11/93	17	8	9	47	53
LU	07/17/93	21	5	16	24	76
LU	07/22/93	9	3	6	33	67
LU	07/28/93	5	4	1	80	20
LU	07/30/93	8	2	6	25	75
LU	07/31/93	13	7	6	54	46
LU	08/08/93	36	10	26	28	72
LU	08/12/93	19	9	10	47	53
LU	08/21/93	6	2	4	33	67
LU	08/22/93	20	7	13	35	65
LU	08/27/93	37	9	28	24	76
LE [3]	07/21/93	10	0	10	0	100
LE	07/24/93	4	2	2	50	50
LE	07/25/93	8	2	6	25	75
LE	07/31/93	3	1	2	33	67
LE	08/02/93	2	1	1	50	50
LE	08/10/93	4	1	3	25	75
LE	08/14/93	4	2	2	50	50
LE	08/15/93	1	0	1	0	100

[2] Ludington
[3] Leland

Table 14b. Continued

Port	Date	Age 2 Number	# Natural	# Hatchery	% Natural	% Hatchery
GH	05/12/93	1	1	0	100	0
GH	05/15/93	14	5	9	36	64
GH	05/16/93	10	3	7	30	70
GH	05/19/93	11	1	10	9	91
GH	05/20/93	2	0	2	0	100
GH	05/21/93	13	3	10	23	77
GH	05/22/93	10	3	7	30	70
GH	05/23/93	7	3	4	43	57
GH	05/26/93	5	1	4	20	80
GH	05/27/93	6	1	5	17	83
GH	05/28/93	1	1	0	100	0
GH	05/30/93	9	7	2	78	22
GH	06/02/93	3	0	3	0	100
GH	06/03/93	9	2	7	22	78
GH	06/04/93	5	3	2	60	40
GH	06/05/93	10	3	7	30	70
GH	06/22/93	1	0	1	0	100
GH	06/27/93	1	0	1	0	100
GH	07/13/93	1	0	1	0	100
GH	07/14/93	2	0	2	0	100
GH	07/18/93	1	0	1	0	100
GH	07/23/93	4	0	4	0	100
GH	08/05/93	2	2	0	100	0
GH	08/06/93	1	0	1	0	100
GH	08/07/93	6	1	5	17	83
GH	08/13/93	1	0	1	0	100
GH	08/18/93	7	3	4	43	57
GH	08/19/93	5	2	3	40	60
GH	08/20/93	3	0	3	0	100
GH	08/26/93	2	1	1	50	50
GH	08/28/93	4	2	2	50	50
GH	08/29/93	6	2	4	33	67
LU	05/29/93	5	0	5	0	100
LU	05/30/93	1	0	1	0	100
LU	06/03/93	3	0	3	0	100
LU	06/04/93	4	1	3	25	75
LU	06/06/93	4	1	3	25	75
LU	06/19/93	14	5	9	36	64
LU	06/22/93	4	1	3	25	75
LU	06/23/93	7	1	6	14	86
LU	07/03/93	6	0	6	0	100
LU	07/04/93	3	1	2	33	67
LU	07/10/93	10	6	4	60	40
LU	07/11/93	5	3	2	60	40

[1] Grand Haven
[2] Ludington

Table 14b. Continued

Port	Date	Number	Age 2 continued # Natural	# Hatchery	% Natural	% Hatchery
LU	07/17/93	32	9	23	28	72
LU	07/22/93	11	3	8	27	73
LU	07/28/93	12	5	7	42	58
LU	07/30/93	19	8	11	42	58
LU	07/31/93	21	8	13	38	62
LU	08/08/93	30	11	19	37	63
LU	08/12/93	18	4	14	22	78
LU	08/21/93	4	1	3	25	75
LU	08/22/93	26	13	13	50	50
LU	08/27/93	28	7	21	25	75
LE	07/21/93	11	5	6	45	55
LE	07/24/93	2	1	1	50	50
LE	07/25/93	3	1	2	33	67
LE	07/31/93	1	1	0	100	0
LE	08/02/93	1	0	1	0	100
LE	08/10/93	1	0	1	0	100
LE	08/11/93	2	0	2	0	100
LE	08/14/93	1	0	1	0	100
LE	08/15/93	1	0	1	0	100

[2] Ludington
[3] Leland

Table 14b. Continued

Port	Date	Age 3 Number	# Natural	# Hatchery	% Natural	% Hatchery
GH	05/08/93	2	0	2	0	100
GH	05/12/93	1	0	1	0	100
GH	05/15/93	18	8	10	44	56
GH	05/16/93	11	3	8	27	73
GH	05/19/93	6	5	1	83	17
GH	05/20/93	2	1	1	50	50
GH	05/21/93	5	2	3	40	60
GH	05/22/93	5	3	2	60	40
GH	05/23/93	1	1	0	100	0
GH	05/26/93	2	1	1	50	50
GH	05/27/93	2	0	2	0	100
GH	05/30/93	3	1	2	33	67
GH	06/02/93	1	0	1	0	100
GH	06/03/93	1	1	0	100	0
GH	06/05/93	1	0	1	0	100
GH	07/08/93	1	0	1	0	100
GH	07/23/93	1	0	1	0	100
GH	07/27/93	1	0	1	0	100
GH	08/05/93	1	0	1	0	100
GH	08/06/93	3	2	1	67	33
GH	08/07/93	1	1	0	100	0
GH	08/13/93	1	0	1	0	100
GH	08/17/93	2	0	2	0	100
GH	08/18/93	1	1	0	100	0
GH	08/26/93	5	4	1	80	20
GH	08/28/93	5	2	3	40	60
GH	08/29/93	7	2	5	29	71
LU	05/29/93	1	0	1	0	100
LU	06/03/93	1	1	0	100	0
LU	06/04/93	1	1	0	100	0
LU	06/06/93	1	1	0	100	0
LU	06/19/93	2	0	2	0	100
LU	06/23/93	1	0	1	0	100
LU	06/24/93	2	2	0	100	0
LU	07/03/93	7	3	4	43	57
LU	07/10/93	5	2	3	40	60
LU	07/11/93	4	2	2	50	50
LU	07/17/93	16	10	6	63	38
LU	07/22/93	9	4	5	44	56
LU	07/28/93	3	2	1	67	33
LU	07/30/93	9	3	6	33	67
LU	07/31/93	16	12	4	75	25
LU	08/08/93	18	11	7	61	39
LU	08/12/93	12	7	5	58	42
LU	08/21/93	1	0	1	0	100
LU	08/22/93	19	15	4	79	21
LU	08/27/93	19	6	13	32	68
LE	07/21/93	4	2	2	50	50
LE	07/24/93	2	2	0	100	0

APPENDIX D

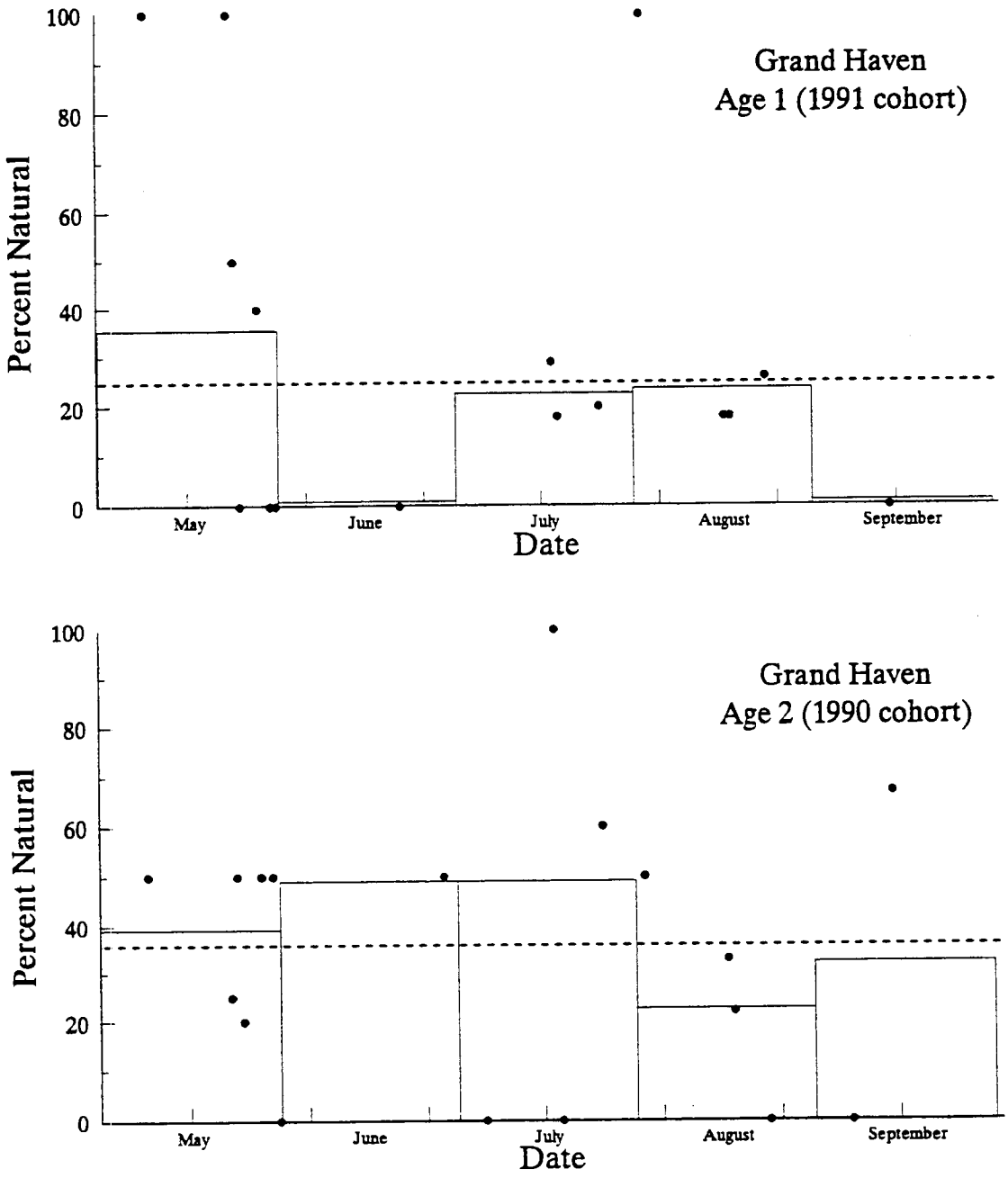

Figure 9a. Daily, monthly, and yearly percentages of age 1 and age 2 natural chinook salmon in the 1992 sport harvest at Grand Haven. Dots represent daily samples, bars represent monthly averges, and dashed line represents yearly average. Only months in which sampling occured are shown.

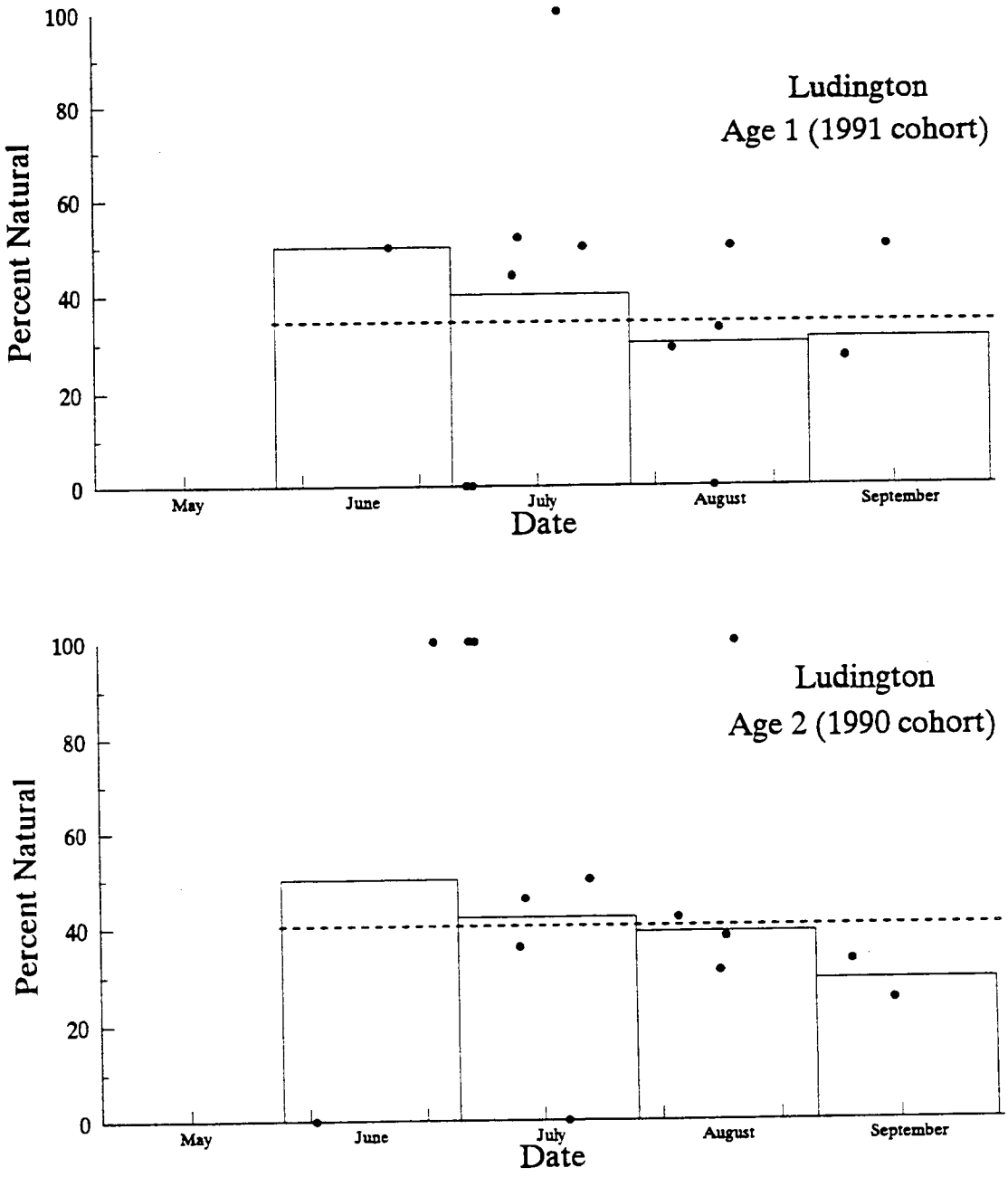

Figure 9b. Daily, monthly, and yearly percentages of age 1 and age 2 natural chinook salmon in the 1992 sport harvest at Ludington. Dots represent daily samples, bars represent monthly averges, and dashed line represents yearly average. Only months in which sampling occured are shown.

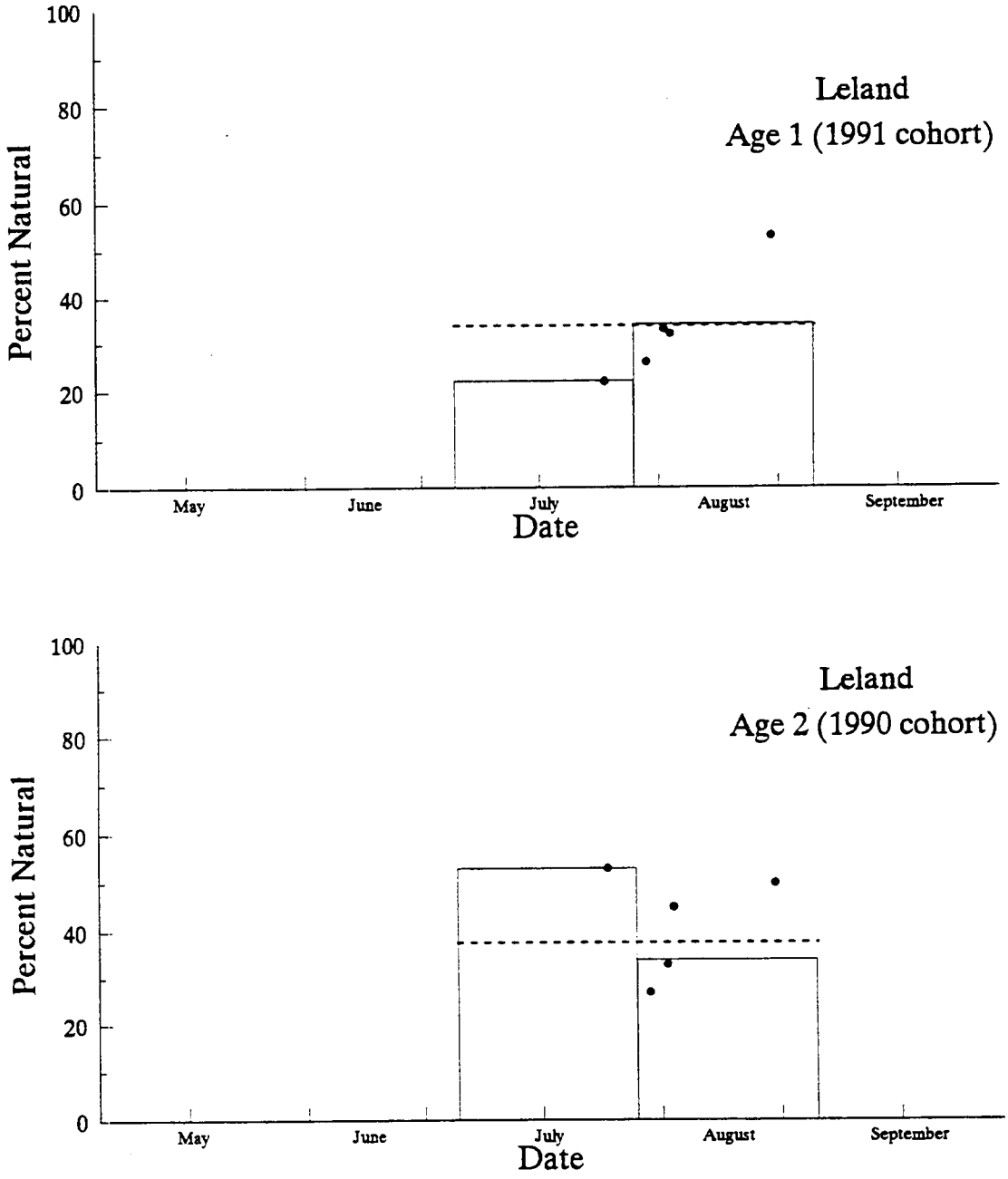

Figure 9c. Daily, monthly, and yearly percentages of age 1 and age 2 natural chinook salmon in the 1992 sport harvest at Leland. Dots represent daily samples, bars represent monthly averges, and dashed line represents yearly average. Only months in which sampling occured are shown.

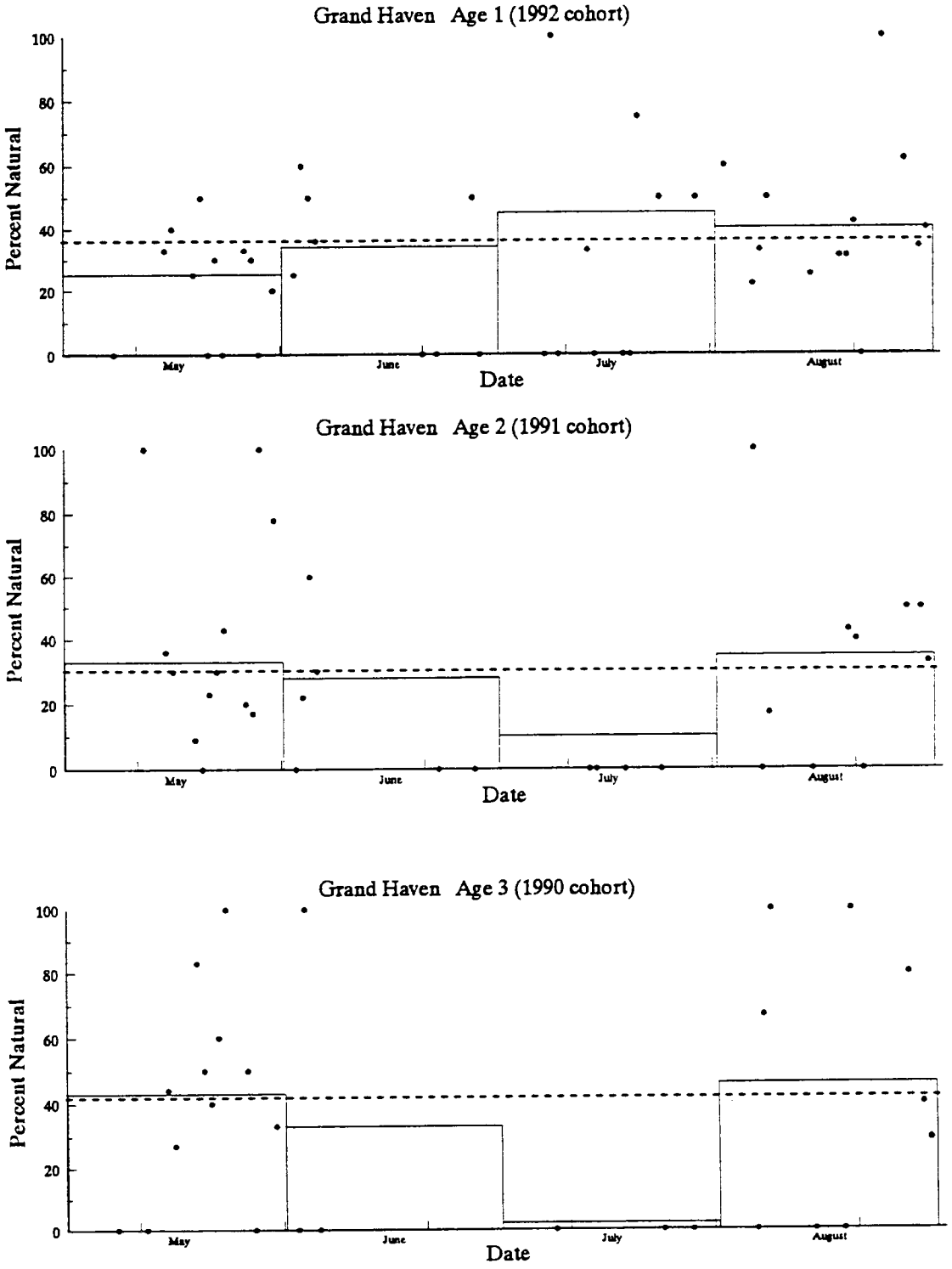

Figure 9d. Daily, monthly, and yearly percentages of age 1, 2, and 3 natural chinook salmon in the 1993 sport harvest at Grand Haven. Dots represent daily samples, bars represent monthly averges, and dashed line represents yearly average. Only months in which sampling occured are shown.

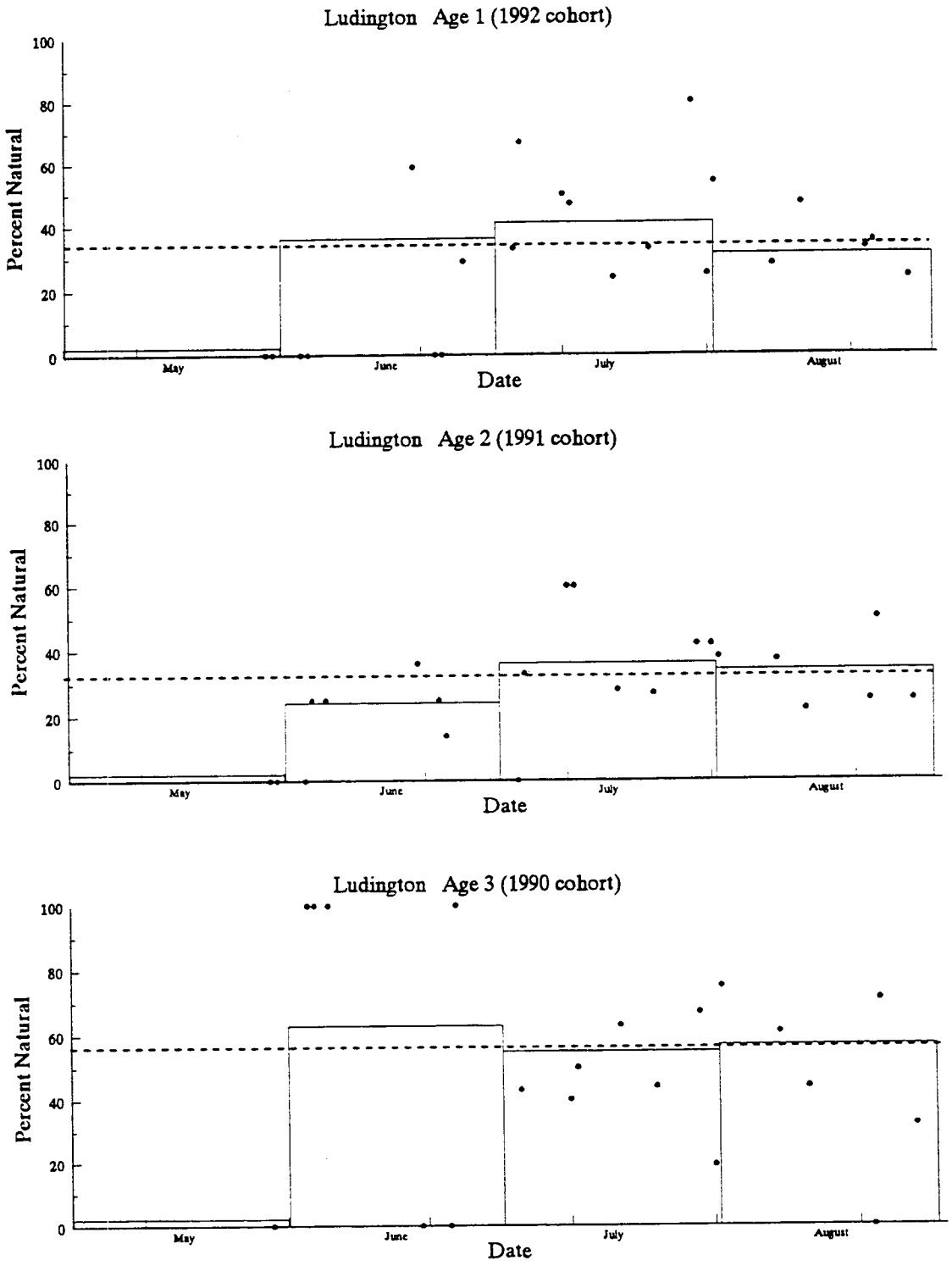

Figure 9e. Daily, monthly, and yearly percentages of age 1, 2, and 3 natural chinook salmon in the 1993 sport harvest at Ludington. Dots represent daily samples, bars represent monthly averges, and dashed line represents yearly average. Only months in which sampling occured are shown.

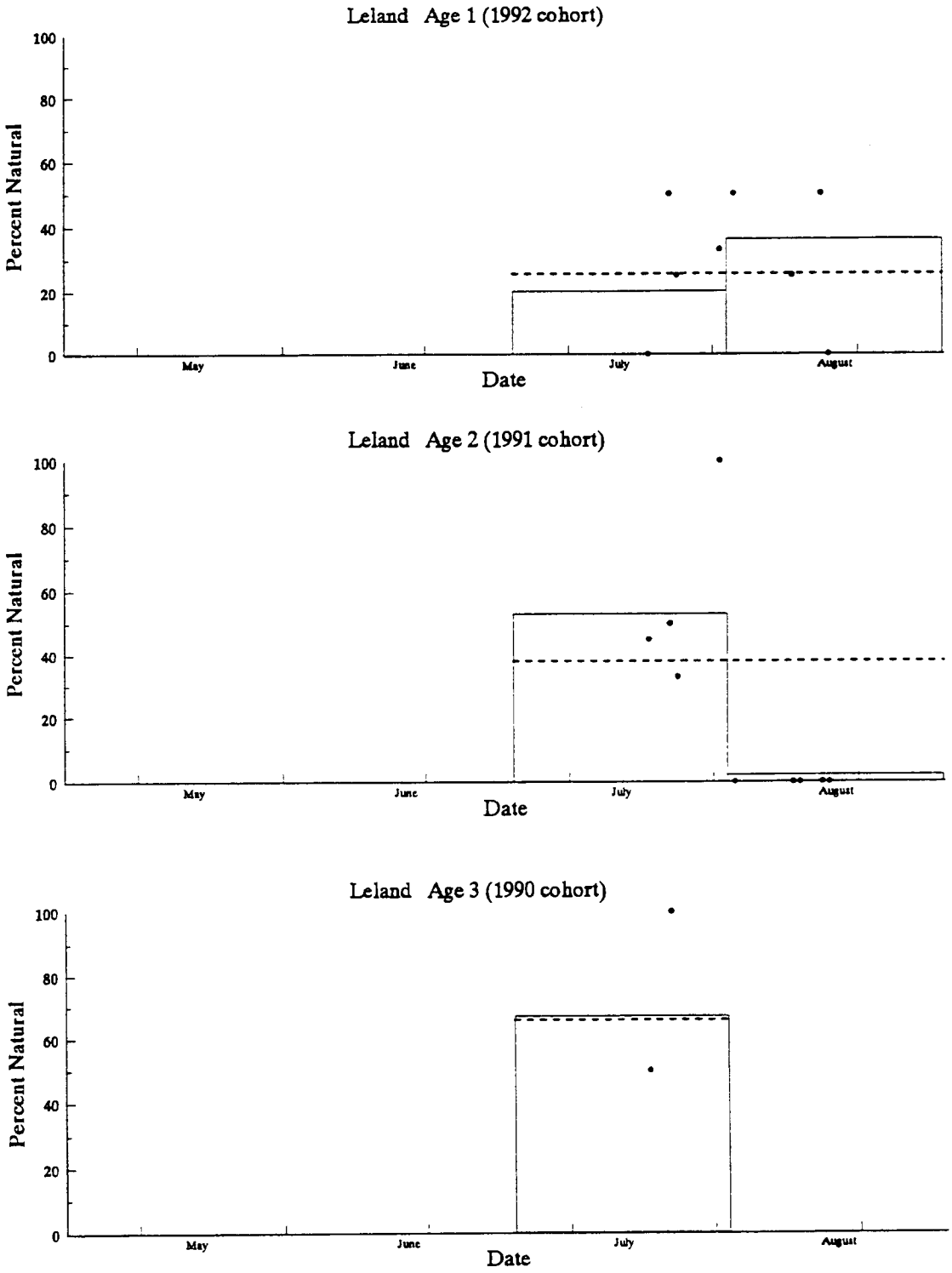

Figure 9f. Daily, monthly, and yearly percentages of age 1, 2, and 3 natural chinook salmon in the 1993 sport harvest at Leland. Dots represent daily samples, bars represent monthly averges, and dashed line represents yearly average. Only months in which sampling occured are shown.

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