

# **Determining the natal origin of angler-caught Chinook Salmon using otolith microchemistry classification algorithms**

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**Alexander C. Maguffee, Michael L. Jones, and Richard Clark**

Quantitative Fisheries Center  
Department of Natural Resources  
Michigan State University  
375 Wilson Rd, Room 100  
East Lansing, MI 48824

**Matthew S. Kornis and Charles R. Bronte**

U.S. Fish and Wildlife Service  
Great Lakes Fish Tag and Recovery Lab  
Green Bay Fish and Wildlife Conservation Office  
2661 Scott Tower Drive  
New Franken, WI 54229

## Introduction

Chinook Salmon (*Oncorhynchus tshawytscha*) were introduced to the Laurentian Great Lakes in the late 1960s to control invasive Alewife (*Alosa pseudoharengus*) while also providing anglers with recreational fishing opportunities (Kocik & Jones 1999, Tanner & Tody 2002). Since their introduction, the natural reproduction of Chinook Salmon has steadily increased (Claramunt et al. 2013), with naturally produced fish contributing more to the total population and fisheries in recent years than hatchery-reared fish in both Lake Michigan (Jonas et al. 2008, Williams 2012, Kornis et al. 2017a) and Lake Huron (Johnson et al. 2010). The increase in natural reproduction combined with ongoing stocking efforts (Claramunt et al. 2013, Tsehaye et al. 2014, Clark et al. 2016) and enhanced Sea Lamprey control is thought to have contributed in part to the predation-mediated 2004 Lake Huron Alewife collapse alongside other factors such as reduced pelagic production related to the invasion of Dreissenid mussels (Riley et al. 2008, Roseman & Riley 2009, Madenjian et al. 2015). The collapse of Alewife caused a decline in Lake Huron Chinook Salmon catch rates, growth rates (Dobiesz et al. 2005, Roseman & Riley 2009, Johnson et al. 2010), and survival (Brenden et al. 2012).

Mark-recapture studies conducted on hatchery-reared Chinook Salmon show that the majority of hatchery fish released in Lake Huron migrate to Lake Michigan (Johnson et al. 2010; Clark et al., in press). This movement is thought to be driven by greater foraging opportunities in Lake Michigan, particularly following the Lake Huron Alewife collapse (Riley et al. 2008, Roseman & Riley 2009), or by reduced survival (and therefore detection) of fish that remain in Lake Huron. Given the observed movement of hatchery-reared Chinook Salmon, it is likely that

wild fish from Lake Huron exhibit similar movement patterns. Thus, it is important to describe the natal origin of wild Chinook Salmon in Lake Michigan, especially the movement of wild fish from Lake Huron; Huron-sourced wild fish would impact the Lake Michigan forage base and predator-prey balance, which is considered by fisheries managers in developing stocking policies.

Recently, Maguffee (2017) showed that otolith microchemistry can be used to quantify the contribution of wild Lake Huron Chinook Salmon to the Lake Michigan recreational fishery. Using classification models fit to juvenile data, known-origin adults were assigned to their natal lake with 74% to 88% success, despite year class differences in otolith chemical signatures (Maguffee 2017). While classification success would likely be higher if the year classes of juvenile and adult year classes matched, the accuracy of the currently available classification models, based on 2015 and 2016 juvenile Chinook data, is sufficient to be informative when applied to open-lake Chinook Salmon harvested from the fishery.

Our goal was to determine the relative contribution of various Lake Michigan and Lake Huron regions (groups of natal streams) to the Lake Michigan recreational fishery. Samples were collected from two regions of Lake Michigan, as well as early and late in the Chinook Salmon fishing season. This allowed us to not only determine the natal origin of these individuals, but also spatial and seasonal variation in the contribution of wild fish from different areas to the fishery. We hypothesized that (1) sources of harvested fish would be similar among northern and southern ports, (2) the proportion of Lake Huron fish would be higher earlier in the season, and (3) overall, the harvest would primarily consist of fish originating from the eastern shore of Lake Michigan.

## Methods

Sagittal otoliths from 306 angler-caught wild adult Chinook Salmon (ages 1 through 4) were extracted in 2014 by U.S. Fish and Wildlife Service personnel. Samples were divided into two spatial groups: fish landed in Northern Wisconsin ports (Algoma & Kewaunee;  $n = 137$ ) and fish landed in Southern Wisconsin ports (Kenosha, Milwaukee, Racine, & Port Washington;  $n = 169$ ). Samples were also defined by their date of harvest, with fish caught before August 15<sup>th</sup> representing early season harvest ( $n = 159$ ) and fish caught after August 15<sup>th</sup> representing late season harvest ( $n = 147$ ). These seasons were determined because after August 15<sup>th</sup> mature Chinook Salmon tend to return to the areas where they were stocked to spawn (Kornis et al. 2017a; Clark et al. in press) To maximize the contrast among these two temporal groups, early season samples were obtained no later than June 29<sup>th</sup>, and late season samples were obtained no earlier than August 23<sup>rd</sup>. Based on these spatial and seasonal criteria, samples were divided into four strata: northern-landed early-season fish (NE), northern-landed late-season fish (NL), southern-landed, early-season fish (SE), and southern-landed late-season fish. For each stratum, 50 otoliths were randomly selected to be analyzed for nine trace elements (Table 1).

Otoliths were analyzed as described by Maguffee (2017). In brief: all otoliths were sectioned and polished at Michigan State University, excluding any that were broken, cracked, or contained vaterite deposits (Melancon et al. 2005, Melancon et al. 2008). Chemical signatures were analyzed using a laser-ablation inductively-coupled plasma mass spectrometer at the Center for Elemental and Isotopic Analysis at Central Michigan University. The nine elements measured were: magnesium ( $^{25}\text{Mg}$ ), calcium ( $^{43}\text{Ca}$ ), manganese ( $^{55}\text{Mn}$ ), copper ( $^{65}\text{Cu}$ ),

zinc ( $^{66}\text{Zn}$ ), rubidium ( $^{85}\text{Rb}$ ), strontium ( $^{88}\text{Sr}$ ), barium ( $^{137}\text{Ba}$ ), and lead ( $^{208}\text{Pb}$ ). We were unable to reliably detect copper and lead, so these elements were removed from the data set. Calcium was not considered as a variable, but was measured so that all other elemental concentrations could be standardized by representing them as ratios to measured calcium within the otolith (Pangle et al. 2010, Marklevitz et al. 2011, Marklevitz et al. 2016). For each otolith, a transect was run from the posterior section to the anterior section across the core starting and ending at the first annulus; this was done to ensure that all data derived from stream chemistry was obtained from each otolith. To remain consistent with Maguffee (2017), the means of each element from a 400  $\mu\text{m}$  transect set 100  $\mu\text{m}$  from the primordia on the posterior side of each otolith were selected for analysis.

Maguffee (2017) developed and compared 4 classification algorithms applied to juveniles from known natal stream sources. He found that random forest algorithms with certain element combinations gave the highest classification accuracy, so we applied three juvenile-fit random forest algorithms to assign our adult fish to their natal regions: the 2015 model, a random forest algorithm using all elements with the exclusion of zinc and fit to 2015 juveniles; the 2016 model, a random forest algorithm using all elements with the exclusion of magnesium and fit to 2016 juveniles; and the combined model, a random forest algorithm using all elements and fit to 2015 and 2016 juveniles. Adult fish were assigned to four regions from Lake Michigan: Upper Peninsula (UPP), Northern Lower Peninsula (NLP), Southern Lower Peninsula (SLP), and Wisconsin (WIS); and two regions in Lake Huron: Northern Lake Huron (NLH), and Southern Georgian Bay (SGB). Because of the absence of NLH juveniles in 2015 and WIS juveniles in 2016 in our reference data set (Maguffee 2017), our adult samples for this

study could not be assigned to these regions using the individual models associated with these particular juvenile data sets. To account for the stochasticity associated with the application of machine learning algorithms such as random forests, each model was run 50 times, and median values for each region assignment were obtained.

## **Results**

The assignment of adult fish to their natal origin exhibited some variation depending on the model used, but consistent patterns were observed among all three models (Table 2). Most adult fish were assigned to the NLP and SLP regions; between 91.6% and 100% of samples were assigned to these regions across all model applications. Across all three models, few samples (between 0 and 2) were assigned to the UPP or SGB regions. Samples were not assigned to the WIS or NLH regions, regardless of the model used. No fish were assigned to either Lake Huron region using the 2016 model, but a small number of fish from the SE stratum were assigned to the SGB region using the 2015 and combined models (Table 2).

## **Discussion**

Our analyses demonstrated that otolith microchemistry can be used to assign adult Chinook Salmon collected in the fishery to their natal regional origin. Most adult fish were assigned to Lower Peninsula streams in Lake Michigan; these results are consistent with previous estimates of high wild smolt production in these streams (Carl 1982). Somewhat surprisingly, no fish were assigned to the WIS region. While natural reproduction is substantially lower in Wisconsin streams, we expected that a few wild Wisconsin origin fish would have been

included in our samples, especially during the late season when fish are staging to spawn. Natural reproduction in Wisconsin streams may be lower than previously expected, or our failure to classify any adult fish to the WIS region may be due to misclassification error.

Using the 2015 and combined models, a few adult fish were assigned to the SGB region, while no fish were assigned to the NLH region. The absence of wild fish assigned to NLH is consistent with recent data showing only 22% to 26% of fish captured there were wild (Kornis et al. 2017b), likely because most Chinook Salmon stocking in Lake Huron occurs in the northern basin (Great Lakes Fish Stocking Database, USFWS/GLFC 2016). The absence of SGB fish later in the season is consistent with the hypothesis that wild Lake Huron fish utilize Lake Michigan for greater foraging opportunities, but that maturing fish return to Lake Huron in the late summer to spawn. However, these results are also surprising given that stocked Chinook Salmon from Lake Huron make up a larger proportion of the catch in northern Wisconsin (23% of stocked fish) than in southern Wisconsin (13 – 15%; Kornis et al. unpublished data). Although the estimated frequency of Lake Huron origin Chinook Salmon in this dataset was small (2-4% in the SE sample) this could still represent a substantial number of fish in the overall predator population.

The accuracy of our results may have been lower than would be possible because of a mis-match in year classes between the model-generating data and the application data. Otolith samples were obtained from fish landed in the Wisconsin recreational fishery in 2014, and were between 1 and 4 years of age. Therefore, these fish do not match the year class of the juvenile fish used to fit the classification models. Maguffee (2017) showed that classification accuracy declined when the year class of the test fish does not match that of the fish used to generate

the classification model. This research demonstrates the potential for otolith microchemistry to identify the natal origin of wild adult Chinook Salmon and to quantify the inter-basin movement between lakes Michigan and Huron. Due to the effects of inter-annual otolith microchemistry variation on classification accuracy, future work should focus on adults from the same year class as juvenile samples to improve classification accuracy. We recommend the collection of adult samples from spawning tributaries in 2018. Because the majority of adult samples collected in the streams are age 2 or 3, these would match the year class of our reference juvenile data, and we would expect to see an improvement in assignment accuracy.

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## Figures and Tables

Table 1. Stratum names, descriptions, and number of samples successfully analyzed from each strata

<b>Abbreviated Stratum Name</b>	<b>Description</b>	<b>Number of Samples</b>
NE	Northern-landed early-season fish	43
NL	Northern-landed late-season fish	49
SE	Southern-landed early-season fish	48
SL	Southern-landed late-season fish	45

Table 2. Median values over fifty replicates for each model used to assign fish from each stratum. Numbers may not sum to sample sizes from Table 1 due to rounding.

<b>Model Used</b>	<b>Region</b>					
<b>Stratum Name</b>	<b>UPP</b>	<b>NLP</b>	<b>SLP</b>	<b>WIS</b>	<b>NLH</b>	<b>SGB</b>
2015 Model						
NE	0	34	8	0	-	0
NL	2	46	1	0	-	0
SE	2	42	2	0	-	2
SL	1	44	0	0	-	0
2016 Model						
NE	0	14	29	-	0	0
NL	0	19	30	-	0	0
SE	0	18	30	-	0	0
SL	0	7	38	-	0	0
Combined Model						
NE	0	22	21	0	0	0
NL	2	23	24	0	0	0
SE	2	22	23	0	0	1
SL	2	23	20.5	0	0	0