Fisheries Research 153 (2014) 113–122

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

# Effects of natal origin on localized distributions of Chinook salmon, *Oncorhynchus tshawytscha*, in the marine waters of Puget Sound, Washington

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ARTICLE INFO

*Article history:*
Received 29 July 2013
Received in revised form 11 January 2014
Accepted 11 January 2014
Handling Editor A.E. Punt
Available online 22 February 2014

*Keywords:*
Chinook salmon
Marine distribution
Migrations
Coded-wire tag
Puget Sound

ABSTRACT

The inland marine waters of Puget Sound, Washington, and the Strait of Georgia and associated waters of British Columbia (the Salish Sea) have long been recognized as alternative rearing habitat to the continental shelf for Chinook and coho salmon. Recent analyses have indicated that these fish (termed residents) comprise a substantial fraction of the Chinook salmon populations originating from Puget Sound rivers. However, the extent to which these resident salmon remain within their natal region or move within Puget Sound has not been studied. Analysis of two decades of coded-wire tagging data revealed several clear patterns. First, the salmon showed spatial distributions that varied systematically with area of origin. In general, they were caught in the vicinity of their origin, indicating limited net movement during several years at large; however this pattern was not universal. Second, recovery distributions were highly influenced by marine age and showed region specific spatial patterns, with the largest differences between the youngest (marine age 1) and oldest (marine age 4) individuals.


## 1. Introduction

Migratory behavior is an integral part of the life history for a wide variety of fishes including many commercially important species. Migration also connects these fishes to the ecosystems along their migratory route and can affect both exploitation and management (Morales et al., 2010). Indeed, conservation of many species depends on information regarding their migratory behavior and homing to natal sites (e.g., bluefin tuna: Rooker et al., 2008; Atlantic cod: Robichaud and Rose, 2001; Svedäng et al., 2007; Heath et al., 2008). Pacific (*Oncorhynchus* spp.) and Atlantic salmon (*Salmo salar*) have been closely studied for decades and exemplify the hierarchical scales of spatial variation and population structure. Early research determined the continent of origin of fish taken in ocean fisheries (Pacific salmon: French et al., 1976; Neave et al., 1976; Takagi et al., 1981; Atlantic salmon: Hansen and Quinn, 1998). More recent work has revealed the distributions of Pacific salmon in coastal and off-shore waters, including variation related to the species, river of origin, and population or life history type within the river (Weitkamp and Neely, 2002; Weitkamp, 2010; Sharma and Quinn, 2012).

Among the Pacific salmon species, Chinook salmon (*Oncorhynchus tshawytscha*) show particularly diverse migration patterns. Some Chinook salmon, especially males from interior river populations, mature as parr and do not migrate to sea at all (Gebhards, 1960), but otherwise the species is anadromous, though some males spend only a few months in marine waters before returning to spawn (Johnson et al., 2012). In the ocean, immature Chinook salmon are distributed along coastal waters, especially in the southern part of their range, but also in off-shore waters of the open North Pacific Ocean (Major et al., 1978; Healey, 1991). Juveniles that migrate to sea in their first year of life (ocean-type) tend to have more coastal distributions, whereas yearling smolts (stream-type) are more often found offshore (Healey, 1983). However, this distinction is not seen in all populations (Waples et al., 2004; Sharma and Quinn, 2012). The spatial distributions of populations in coastal waters also vary systematically. In general, populations originating from rivers toward the southern end of the range are found in marine waters farther south than those originating from more northerly populations. However, these distribution patterns are not explained by a simple latitudinal gradient (Nicholas and Hankin, 1989; Trudel et al., 2009; Weitkamp, 2010). The hypothesis that marine migration patterns are genetically determined has been supported by experimental evidence with Chinook salmon (Pascual and Quinn, 1994; Quinn et al., 2011) and Atlantic salmon (Kallio-Nyberg and Ikonen, 1992; Kallio-Nyberg et al., 1999).

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0165-7836/$ – see front matter © 2014 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.fishres.2014.01.008

In addition to the broad-scale differences in marine spatial distribution associated with life history type and latitude, Chinook salmon display another level of variation: the existence of "resident" salmon that remain in the protected marine waters of the Salish Sea (Puget Sound, the Strait of Georgia, and associated water bodies) and other interior waters along the coast of North America. These salmon have been known to fishermen and fisheries management agencies for decades (Haw et al., 1967; Pressey, 1953), but their patterns of behavior and the processes influencing resident behavior have seldom been investigated. These residents are a significant fraction (up to about 30% of hatchery reared fish) of all the Chinook salmon produced by rivers in Puget Sound (O'Neill and West, 2009; Chamberlin et al., 2011a), and this migration pattern affects their accessibility to fisheries within state waters and interceptions in Canadian waters (Chamberlin et al., 2011a).

Coded wire tagging data indicated that Chinook salmon originating from Puget Sound hatcheries have been caught year-round in Puget Sound (Chamberlin et al., 2011a). Salmon that had been feeding in waters of the coastal Pacific Ocean throughout their lives might be caught in Puget Sound in the late summer and early fall as they return to spawn. However, salmon caught in Puget Sound later in fall, when maturing salmon are already in rivers, and from winter through spring when immature salmon are still in coastal waters, can be categorized as residents (Chamberlin et al., 2011a). Analysis of these tag recoveries (Chamberlin et al., 2011a) indicated that the primary factor affecting the proportion of residents from a given cohort was the part of Puget Sound where they originated, with only minor effects of body size and date of release from hatcheries. Ultrasonic tracking of Chinook salmon released from a hatchery in Hood Canal (Fig. 1) suggested that movements during the first summer after seawater entry were localized (Chamberlin et al., 2011b). Otherwise, it is unclear how much resident salmon move within Puget Sound, and patterns of movement and residency might affect not only fishery interceptions but also uptake of chemical contaminants (O'Neill and West, 2009), transfer of contaminants (Cullon et al., 2009), and roles of salmon as predators and prey in local ecosystems.

Accordingly, the purpose of this study was to analyze coded-wire tagging data to determine patterns of distribution among resident Chinook salmon within Puget Sound. Specifically, we sought to determine whether juvenile Chinook salmon produced in each of five regions of Puget Sound tended to 1) remain in their natal region, 2) converge on some specific area or areas in Puget Sound regardless of their origin, 3) display region-specific and/or marine age-specific patterns of distribution within Puget Sound (e.g., were Hood Canal origin fish caught in central Puget Sound but central Puget Sound fish were caught in south Puget Sound?).

## 2. Materials and methods

### 2.1. Data acquisition

All data were acquired from the Regional Mark Information System coded wire tag (CWT) database (Regional Mark Information Systems Database, 1977). The database manages release and recovery information for all CWT programs along the west coast of the United States and British Columbia. Data for this particular analysis were limited to fall run hatchery-reared Chinook salmon due to the lack of CWT data available for wild populations within Puget Sound. We only included data from hatcheries that had at least 10 years of fall Chinook salmon releases within the period of interest. Hatchery-reared fall Chinook salmon were predominantly released as sub-yearlings, but some fish were released as yearlings, and these groups were also included in the analysis.

All CWT groups were assigned to one of the five release regions within Puget Sound: the Strait of Juan de Fuca, north Puget Sound, central Puget Sound, south Puget Sound, and Hood Canal (Fig. 1). Release regions were defined using the RMIS domain classifications as used by the Pacific States Marine Fisheries Commission and the Regional Mark Processing Center for Washington State (Regional Mark Information Systems Database, 1977). Each release region includes multiple releases from several hatchery locations (Table A.1) but we used only release groups that were reared and released from the watershed where the hatchery was located (i.e., cohorts that had been transported during their incubation and rearing histories were not included).

Recovery data were synthesized for all release groups as defined above. To minimize the effect of multiple gear comparisons, data were limited to tags recovered via recreational fishing, which accounted for ~90% of all recoveries in Puget Sound marine areas (Chamberlin et al., 2011a). We used the estimated number of recoveries determined by the following equation:

$$R_T = aR_o \tag{1}$$

where $R_T$ is the total estimated number of recoveries of a particular tag code in a given location, $R_o$ is the observed number of tags of a given tag code, and $a$ is an expansion factor determined by the ratio of total catch: sampled catch (Johnson, 2004). To reduce the effect of unexplained error due to the expanded recovery estimates we limited our analysis to estimates that used an expansion factor of <10 (Weitkamp, 2010). Recovery data were then aggregated according to release groups (release region × release year × age class at release) and summed by statistical catch area as designated by Washington Department of Fish and Wildlife (WDFW, Fig. 1) for a given recovery month/year. Summed data were then transformed to relative proportions of recoveries by release group among the statistical catch areas for analysis. It is important to note that a given release region (as defined above) can contain more than one statistical catch area. For our specific analysis it was important to distinguish recoveries of "resident" salmon from those returning at maturity from the ocean. We designated a recovery as "resident" if it occurred in WDFW catch areas 5–13 (Fig. 1) from 1 October to 31 May. Although it is likely that "resident" fish are caught outside the chosen window, this period excluded recoveries during months when the majority of recoveries likely reflect ocean migrants returning to Puget Sound (Chamberlin et al., 2011a). Recoveries of unique tag codes were summed by month, year, and WDFW catch area where the recovery occurred.

To analyze general distribution patterns we compared the relative proportions of fish from each release group that were recovered in each specific WDFW statistical catch areas for a given recovery month/year. However, differences in recovery distribution between months for a given release region were not significant (ANOSIM: $R = 0.041$, $p = 0.13$); therefore, we combined all months when fish were considered to be "residents" within a given year for each particular RG and analyzed distribution patterns accordingly. To assess differences in distributions associated with age-class at release and marine age, fish from a particular release region were further grouped into either sub-yearling or yearling groups based on their particular release types and by marine age at recovery, calculated as the difference between the recovery year and release year and adjusted for age class at release.

Data were limited to releases between 1973 and 1991 and recoveries between 1973 and 1993. These years were chosen due to the lack of data before 1973 and significant changes in Puget Sound fishing regulations that occurred in 1994. Prior to 1994, all areas in Puget Sound were open year-round for recreational salmon fishing. In 1994 WDFW began implementing area/month closures in Puget Sound, which made comparisons among catch areas difficult due to variable fishing effort within and among years and areas. Although a thorough analysis of fishing effort in Puget Sound between 1973 and 1993 was outside the scope of our study,