Movements of Pacific Salmon in Lake Ontario in Spring and Summer: Evidence for Wide Dispersal

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ABSTRACT

To determine spring and summer movements of Pacific salmon in Lake Ontario, 16 coho (Oncorhynchus kisutch) and 7 chinook (O. tshawytscha) salmon were radiotagged and tracked in 1984. Salmon dispersed widely along shore and throughout Lake Ontario, moving as far as 33 km/d and 500 km in 4 months. Salmon generally did not occupy near shore regions after temperatures exceeded 9-10 °C, except where winds produced upwellings of cold water near shore in summer. There were no significant differences in distances moved, movement rates or average temperatures occupied by coho (4.0 ± 2.2 km/d, 0.62 ± 0.48 km/h, 9.3 ± 2.1 °C) and chinook (3.2 ± 2.7 km/d, 0.48 ± 0.04 km/h, 11.1 ± 1.9 °C). Coho moved nearer to shore and occupied surface waters (r = 0.86) more often than chinook (r = 0.47). Temperatures when salmon were last found were significantly higher for chinook (12.3 ± 2.4 °C) than for coho (9.7 ± 2.0 °C). However, averaged over species, differences between average (10.1 ± 2.1 °C) and last observed (10.7 ± 2.5 °C) temperatures were not significant. Movement and temperature data indicate that Pacific salmon in Lake Ontario use wide geographic and temperature ranges in spring and summer.

INTRODUCTION

Information about the summer locations of coho (Oncorhynchus kisutch) and chinook (O. tshawytscha) salmon in Lake Ontario is sketchy. In Lake Ontario's central basin, coho in 1981-82 appeared thinly dispersed in and below the metalimnion, generally greater than 4 km off shore (Haynes 1983). However, 91% of coho caught by anglers in the western basin in 1983 were in and above the metalimnion less than 12 m deep (Kolenosky 1983). Some chinook occupied waters in and above the metalimnion less than 4 km off shore in the central basin of Lake Ontario (Nettles et al. 1981; Olson 1984), but most were probably dispersed farther off shore (Haynes 1983). Chinook were netted from 12-23 m deep over average depths of 46 m; temperatures occupied were 14.4 ± 2.7 °C (Olson 1984) in Lake Ontario. Yet information from anglers (M. Voiland, Sea Grant Extension, SUNY Brockport; R. Penfound, St. Catharines, Ontario; both personal communications) and analysis of summer diet (Olson 1984) suggested chinook also occupied waters below the metalimnion and near bottom in summer.

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Radiotelemetry has been used successfully in the central basin of Lake Ontario to locate salmonids and to determine their environmental temperatures in fall, winter and spring (Haynes and Netles 1983; Netles 1983; Haynes 1983; Kelheer et al., in press). However, radio signals were lost, due to complete attenuation below 12 m, as fish moved to deeper, cooler habitats off shore in summer. The purpose of our study was to identify spring and summer movements and locations of Pacific salmon in Lake Ontario.

MATERIALS AND METHODS

From April 12 to June 15, 1984, 16 coho (48.5 - 76.0 cm; 1.4 - 5.0 kg) and 7 chinook (58.0 - 96.0 cm; 1.8 - 9.0 kg) salmon were captured by angling in Lake Ontario between the Niagara River and Grimsby, Ontario, Canada (Figures 1, 2). Salmon were caught in waters less than 15 m deep. Temperature-sensing radio transmitters (sensitivity 0.2 - 0.5 °C; Ross et al. 1979) were attached externally (Haynes and Netles 1983; Haynes 1983). Tagging occurred on charter boats immediately after capture. Salmon were released after regaining equilibrium and swimming ability. Total tagging and recovery time was 15-20 min.

Salmon were tracked primarily with an airplane equipped with loop receiving antennas (Winter et al. 1981; Netles 1983). A charter boat fitted with a Yagi antenna was used occasionally in the St. Catharines area. In spring we flew as far east as Sodus Bay and Port Hope less than 1.6 km off shore and returned by the same route less than 4.8 km off shore. In summer we flew parallel north-south transects at 4.8 km intervals across the western basin from 6.4 km east of the Niagara River to Hamilton (Figures 1, 2). We flew 1-3 times/wk, primarily immediately after sunrise and before sunset, and tracking time averaged 6-12 h/wk. Fish positions were determined by triangulation from landmarks along the shore of Lake Ontario (the same landmarks that permitted the pilot to fly parallel transects).

Movements were evaluated for direction and pattern, distance (km/d = total km moved/total days tracked = an estimator of seasonal movement capabilities) and rate (km/h = distance moved between successive locations less than 72 h apart/hours elapsed = an estimator of short term or daily movement capabilities). Distances and rates were compared by t-tests. Lake surface temperatures were obtained from infra-red satellite maps supplied by Environment Canada's Atmospheric Environment Service Satellite Laboratory in Downsview, Ontario. Within and between species temperatures were compared by t-tests; temperatures occupied by salmon and lake surface temperatures were compared by linear regression.

RESULTS

Transmitters were recovered from two salmon (one coho washed up on shore near Point Breeze, U.S. south shore; another was caught by an angler near St. Catharines 2.5 hr after release), leaving 21 trackable fish. Although 47% of the coho and 29% of the chinook were not found again after their releases (primarily because airplane maintenance delays prevented tracking some fish for periods of 8 and 20 d in April and May), 53% of the coho and 71% of the chinook were tracked moving within 6.4 km of shore. Permanent movements out of tracking range by these fish were not particularly rapid ( 28 d ave.; Table 1) and daily tracking results were similar: only a fraction of tagged fish were found on each flight, but often one or more different fish each flight. In other words, individual salmon moved in and out of tracking range along the same tracking routes over periods of days, weeks or months.
Table 1. Mean (± SD) distances moved (km) and temperatures (°C) occupied by Pacific salmon from April through July, 1984. Statistical comparisons are by t-test.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Coho (n = 8)</th>
<th>P</th>
<th>Chinook (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days Tracked</td>
<td>23.0 ± 13.6</td>
<td>&gt;0.1</td>
<td>32.4 ± 15.1</td>
</tr>
<tr>
<td>Total Km Moved</td>
<td>90.6 ± 97.1</td>
<td>&gt;0.5</td>
<td>84.5 ± 54.4</td>
</tr>
<tr>
<td>Km/d</td>
<td>4.0 ± 2.2</td>
<td>&gt;0.4</td>
<td>3.2 ± 2.7</td>
</tr>
<tr>
<td>Km/h</td>
<td>0.62 ± 0.48</td>
<td>&gt;0.5</td>
<td>0.48 ± 0.44</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Coho (n = 7)</th>
<th>P</th>
<th>Chinook (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>9.3 ± 2.1</td>
<td>&lt;0.05</td>
<td>11.1 ± 1.9</td>
</tr>
<tr>
<td>P</td>
<td>&gt; 0.5</td>
<td>&gt; 0.2</td>
<td></td>
</tr>
<tr>
<td>Last Observed</td>
<td>9.7 ± 2.0</td>
<td>&lt;0.05</td>
<td>12.3 ± 2.4</td>
</tr>
</tbody>
</table>

Salmon were tracked for great distances in the lake through mid-July, before disappearing until September (Figures 1, 2). Individual fish moved up to 33.4 km in a single 24 hr period and up to 315 km in 47 days (Figure 1: 200). Differences in movement between coho and chinook were not significant (Table 1). Weight was not a significant factor influencing movement distances (p > 0.25), but correlations were moderate to high (r = 0.38 for coho; r = -0.61 for chinook), suggesting larger chinook tended to disappear faster than smaller ones.

Most coho and chinook moved east (Table 2) after release. We observed most chinook moving in only one direction before they disappeared for the summer (e.g., Figure 2: 830). Some coho also displayed this pattern (e.g., Figure 1: 290), but the majority eventually reversed direction and headed west; some changed direction a third time (e.g., Figure 1: 100) before disappearing for the summer. Two chinook (Figure 2: 400, 450) and two coho (Figure 1: 200, 480) were found after they moved to the north shore. Salmon also moved east past Rochester and Port Hope on the south and north shores, respectively (Figure 1: 200, 290; Figure 2: 400, 830). Regardless of date, salmon were located only within 6.4 km of shore, the maximum antenna range when flying 4.8 km off shore.

Table 2. Movement directions of coho (n = 8 initially; n = 7 subsequently) and chinook (n = 5) in Lake Ontario from April through July, 1984

<table>
<thead>
<tr>
<th>Direction Sequence</th>
<th>Coho</th>
<th>Chinook</th>
</tr>
</thead>
<tbody>
<tr>
<td>Along Shore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Direction</td>
<td>75% East</td>
<td>60% East</td>
</tr>
<tr>
<td></td>
<td>25% West</td>
<td>20% West</td>
</tr>
<tr>
<td></td>
<td>20% North</td>
<td>20% North</td>
</tr>
<tr>
<td>Second Direction</td>
<td>57% West</td>
<td>20% North</td>
</tr>
<tr>
<td>Third Direction</td>
<td>14% East</td>
<td></td>
</tr>
<tr>
<td></td>
<td>29% North</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Locations and temperatures at the depth of swimming of representative coho salmon in Lake Ontario, April through September, 1984. △ = location of capture, tagging and release; ____ = fish found on successive tracking attempts; ---- = fish not found on successive tracking attempts. Distances of tracking lines from the map shoreline do not represent actual salmon distances from shore.
Figure 2. Locations and temperatures of representative chinook salmon in Lake Ontario, April through September, 1984. See Figure 1 caption for legend.
Salmon occupied and were last observed near shore at a wide range of temperatures between 6-15 C. Differences in average and last observed temperatures were not significant for coho or chinook (Table 1), indicating that salmon occupied wide ranges of temperature through mid-July. Although chinook appeared to occupy warmer waters than coho, statistical differences between species (Table 1) for average temperatures occupied (t = 2.20; p > 0.05) and for last temperature observed (t = 2.69; p < 0.05) were marginal (for n = 5, t0.05 = 2.57). There was no significant difference (p > 0.3) between tagging dates for coho (May 9 ± 10 days) and chinook (May 15 ± 17 days), so seasonal warming of the lake did not account for differences in temperatures recorded for coho and chinook.

Water temperatures relayed from transmitters were compared with lake surface temperatures mapped by satellite. Within the variability of combined satellite and transmitter temperature recording precision (1-2 C), temperatures transmitted from fish were generally equivalent to the satellite-indicated temperatures closest to shore (100% for coho; 91% for chinook). Salmon temperatures equivalent to near shore isotherm values meant a fish was very close to shore and surface in the warmest lake water; temperatures below the isotherm range meant fish were in cooler water below the surface or off shore. There was a significant linear relationship between temperatures transmitted from fish (x) and surface temperatures closest to shore (y) for coho (y = 1.06x + 1.04; p < 0.001), but not for chinook (y = 0.70x + 1.59; p > 0.1). Correlation coefficients were high for coho (r = 0.86) and moderate for chinook (r = 0.47). In other words, coho, when found, were generally in warm surface waters or near shore; the relationship for chinook was unclear (perhaps due to small sample size; n = 12 vs. n = 21).

Only three salmon (Figure 1: 200; Figure 2: 400, 450) were located after June 4 when surface temperatures near shore had exceeded 9-10 C. The appearances of salmon on the north shore from June 19 - July 23 were associated with north winds and cold water upwelling.

No salmon were found after mid-July until early September. Chinook 450 (Figure 2) was tracked entering the Niagara River (its original capture location) on September 7 and coho 200 was caught in the Salmon River, NY on September 14 (Figure 1, Location 7). These fish swam minimum distances of 130 and 500 km, respectively. Despite sufficient transmitter life (150-180 d) for most fish, no other salmon were found through the end of October by airplane tracking around the perimeter of Lake Ontario and up major tributaries.

**DISCUSSION**

Based on intermittent tracking success (i.e., find a fish one week, lose it for one or more weeks, find it again far away along the same tracking routes) and the similarities of average and last observed temperatures for coho and chinook, it appears that Pacific salmon utilize wide geographic and temperature regions of Lake Ontario in the spring and summer. They apparently move back and forth between near shore and off shore areas in spring or they engage in substantial vertical movements (deeper than transmitter range) near shore. Our inability to fly farther than 5 km off shore before June (when pontoons were placed on the airplane) precluded determining whether off shore movements, vertical movements near shore, or both accounted for intermittent tracking success in the spring. Pacific salmon do not spend as high a percentage of their time close to shore in the spring as do rainbow and brown trout (Nettles 1983; Wenger 1982; Haynes 1983).
In April and May roughly two thirds of tagged salmon moved long distances east and north in the lake, before disappearing in May and June, but coho reversed direction near shore more often than chinook. Other salmon disappeared from near shore areas rapidly, as reported anatomically for previous studies by Haynes (1983). Other than initial eastward movement, probably in response to prevailing eastward flowing surface currents (Jenkins 1980; Wenger 1982), there was no apparent pattern to salmon movements; individual salmon disappeared at widely varying locations, times and temperatures. As summer advanced, salmon moved off shore permanently to deeper, cooler regions (Lichorat 1982; Nettles et al. 1981; Haynes 1983; Olson 1984), except where upwelling created appropriate thermal conditions near shore. The generally higher temperatures observed for chinook vs. coho corresponds with the relatively high temperature preferences reported for Lake Ontario chinook (Nettles et al. 1981; Olson 1984) in summer.

Failure to locate radiotagged salmon after mid-July probably resulted from an unavoidable physical constraint (depth attenuation) imposed by salmon temperature and depth preferences combined with wide dispersal (often into the central basin of Lake Ontario that was not searched by air in summer). Although tracking by airplane maximizes signal reception range, radio signals are impossible to detect below 12 m and difficult to detect below 8 m in Lake Ontario (Haynes, unpublished data). In summer, preferred salmon temperatures (10-14°C) are located at depths of 6.4-16.2 m in western Lake Ontario, with preferred temperatures located deepest on the southern shore and in the central basin (Eckert 1983; Boyce and Robertson 1984). In 1984, chinook salmon caught by anglers were well off shore at depths greater than 12 m; coho were much less abundant in 1984 vs. 1983, but were caught at depths less than 12 m in both years (Savice 1984; Kolosnicky 1983). Netting studies in Lake Michigan (cf. Royce et al. 1968; Dunn 1969; Godfrey et al. 1975).

Implications for the Lake Ontario Fishery

The ideal salmon fishing situation hoped for by salmon anglers is that chinook or coho form one or several large aggregations that move in predictable patterns. If, as existing evidence suggests, salmon are widely dispersed vertically and horizontally in summer, their behavioral ecology poses serious problems for anglers and fishery managers attempting to establish a summer fishery. Lake Ontario has a surface area of 1.94 million ha and an average depth of 85 m, into which ap-
proximately 4 million Pacific salmon (U.S. and Canadian) are stocked each year. Assuming 50% annual survival (a liberal estimate given the 1.5 yr in the lake), and recruitment to the fishery after 1 yr in the first year), then a reasonable estimate of the catchable stock in Lake Ontario is about 3.5 million salmon. If salmon are widely (evenly) dispersed, then an angler would expect to find 1.6 desirable salmon/ surface ha or 0.02 salmon/ha-m. Even if all salmon are aggregated around evenly spaced bait fish aggregations (e.g., 2000), an angler would still have to search 972 ha to find any salmon.

The reason that salmon and trout fishing (and radiotracking) is successful in the spring (Nettles 1983; Haynes 1983; Werger 1982) is that many (most?) salmonids are concentrated in a narrow, shallow, warm water band close to shore. Brown and lake trout remain oriented to habitat structure relatively close to shore all summer (Nettles 1983; Olson 1984), so fishing remains good for those species. As Pacific salmon and rainbow/steelhead trout disperse to the open lake (Haynes 1983), an inevitable dilution effect takes place and fishing (also radio tracking) becomes more difficult. Therefore, it will be more difficult to develop a consistently successful Pacific salmon fishery in summer for Lake Ontario.

ACKNOWLEDGMENTS

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LITERATURE CITED


