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# Recoveries of Thermally Marked Maturing Pink Salmon in the Gulf of Alaska in the Summer of 1998

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*Abstract.*— We detected otolith thermal marks induced by Alaskan hatcheries to determine the ocean distribution and migration of Alaskan pink salmon (*Oncorhynchus gorbuscha*) in the Gulf of Alaska. Twenty-nine thermally marked pink salmon were found among 383 maturing fish (1996 brood year class) caught along two offshore transects (145°W and 165°W) during June and July 1998. Along the 145°W transect, 25 thermally marked fish from three Prince William Sound hatcheries (PWS, southcentral Alaska) were found (8.1%, n=307 fish), and their origins were Armin F. Koernig Hatchery (AFK, n=8 fish), Cannery Creek Hatchery (CCH, n=9 fish), and Wally H. Noerenberg Hatchery (WHN, n=8 fish). Along the 165°W transect, four thermally marked fish were found (5.3%, n=76 fish), and their origins were AFK (n=1 fish), CCH (n=2 fish), and WHN (n=1 fish). PWS hatchery fish were more abundant in northern waters than in southern waters along both transects, which corresponded to the direction of their homeward migration. Observed differences in distribution of male and female PWS hatchery fish may be caused by sexual differences in the timing of homeward migrations. The recovery of four thermally marked PWS hatchery fish in the Gulf of Alaska (47-50°N, 165°W) is a southwestward extension of the known ocean range of maturing southcentral Alaskan pink salmon in summer.

**Key words** : otolith thermal marking, pink salmon, hatchery stocks, distribution, Gulf of Alaska

## Introduction

Mass marking of hatchery salmon (*Oncorhynchus* spp.) using otolith thermal marks has become increasingly popular technique for inshore fisheries management in Alaska (Hagen et al. 1995; Geiger and Munk 1998). Thermal marks are also an effective tool for stock identification in high-seas and coastal waters (Farley and Munk 1997; Ignell et al. 1997; Farley et al. 1999; Urawa et al. 1999). Salmon otoliths are thermally marked by exposing fish to alternating (relatively lower and higher) temperatures (Volk et al. 1990), whereby a "thermal ring" (dark ring) is induced by exposure to the lower temperature (Munk et al. 1993). Different thermal

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marks are made by varying the number and spacing of thermal rings. For brood-year 1996 stocks, about 490 million pink salmon (*O. gorbuscha*) were thermally marked and released from southcentral and southeastern Alaskan hatcheries. About 99% of thermally marked fish were released from Prince William Sound (PWS) hatcheries in southcentral Alaska, where all hatchery pink salmon were thermally marked (McNair 1998; Munk and Geiger 1998). To investigate the ocean distribution of PWS hatchery fish, we detected thermally marked otoliths from maturing pink salmon caught in the Gulf of Alaska in the summer of 1998.

## Materials and Methods

*Releases of thermally marked fish*

For brood-year 1996 stocks, thermally marked pink salmon were released from four PWS hatcheries: Solomon Gulch Hatchery (SGH, n=188.86 million fish), Cannery Creek Hatchery (CCH, n=136.84 million fish), Wally H. Noerenberg Hatchery (WHN, n=106.44 million fish), and Armin F. Koernig Hatchery (AFK, n=51.56 million fish). In addition, about 5.90 million pink salmon with thermal marks were released from Gastineau Hatchery (southeastern Alaska, Table 1; McNair 1998; Munk and Geiger 1998).

*Fish samples*

A total of 813 maturing pink salmon were caught by gillnets (non-selective varied research mesh, traditional commercial mesh, and experimental mesh) in two offshore transects (145°W and 165°W) by the T/S *Oshoro maru* in the Gulf of Alaska during June and July 1998 (Walker et al. 1998). Fork length (mm), body weight (g), sex, and gonad weight (g) were recorded and sagittal otoliths were collected from 383 fish. Scales were also collected for age determination.

The catch per unit effort (CPUE) was calculated as total catch (number of fish) per one set of non-selective varied research mesh gillnet (30 tans, 1 tan =50 m long and approximately 6 m depth; Takagi 1975; Walker et al. 1998). A gonadosomatic index (GSI) was calculated as 100 $\times$ gonad weight (g) / body weight (g) to examine maturity. Fork length, body weight, gonad weight, and GSI were compared between marked and nonmarked pink salmon using Student's t-test (equal variance) or Welch's t-test.

*Otolith Analysis*

The left sagittal otoliths were mounted on individually labeled glass slides using thermoplastic cement. If the left otolith was missing or ground through the primordia, then the right otolith was used. Otoliths were ground to expose the primordia and examined under a microscope. Thermal marks were recorded in the RBr code structure (Munk and Geiger 1998). If the same RBr code was used for a brood year class at different hatcheries, then microstructural patterns were compared with voucher specimens that were collected from the hatcheries before release. All otoliths were read independently by two readers.

## Results

Twenty-nine thermal marks were found among 383 maturing pink salmon examined (Table 2, Fig. 1). Along the 145°W transect, 25 thermally marked fish were found (8.1%, n=307 fish), and their origins were AFK (n=8 fish), CCH (n=9 fish), and WHN (n=8 fish) in PWS, southcentral Alaska. Along the 165°W transect, four thermally marked fish were found (5.3%, n=76 fish), and their origins were AFK

**Table 1.** A list of thermally marked pink salmon fry (1996 brood year class) released from Alaskan hatcheries (revised from Geiger and Munk 1998). AFK, Armin F. Koernig Hatchery; CCH, Cannery Creek Hatchery; GH, Gastineau Hatchery; SGH, Solomon Gulch Hatchery; WHN, Wally H. Noerenberg Hatchery.

| Region | Facility | Stock | Release site | Date of release | Mean body weight at release (g) | Number of releases (million) | TM ID | RBr |
|---|---|---|---|---|---|---|---|---|
| Southcentral Alaska | AFK | WHN | Sawmill Cove | 11-May-97 | 0.47 | 16.25 | AFK96early | 1:1.4+2.3 |
| Southcentral Alaska | AFK | WHN | Sawmill Cove | 27-May-97-13-Jun-97 | 1.22 | 35.31 | AFK96late | 1:1.4 |
| Southcentral Alaska | CCH | CCH | Cannery Creek | 7-May-97-26-May-97 | 0.26 | 136.84 | CCH96 | 1:1.3, 2.2 |
| | | | | | | | | 1:1.3, 2.3 |
| | | | | | | | | 1:1.4, 2.3 |
| Southcentral Alaska | SGH | SGH | SGH | 23-Apr-97, 5-May-97 | 0.39 | 188.86 | SGH96 | 1:1.6 |
| Southcentral Alaska | WHN | WHN | Lake Bay | 1-May-97 | 0.35 | 75.87 | WHN96early | 1:1.8 |
| Southcentral Alaska | WHN | WHN | Lake Bay | 7-Jun-97 | 1.51 | 30.57 | WHN96late | 1:1.8+2.3 |
| Southeast Alaska | GH | GH | Gastineau Channel | 12-May-97 | 0.55 | 5.90 | GH96 | 1:1.4 |

(n=1 fish), CCH (n=2 fish), and WHN (n=1 fish). Marked pink salmon released from southeast Alaska were not found along each transect. The CPUE of marked fish caught in research gillnets indicated that PWS hatchery fish were more abundant in the northern part of each transect than in the southern part (Fig. 2). Along the 145°W transect, PWS hatchery males were found in northern waters (55-56°N) but not in southern waters (49-52°N), although the proportions of males in nonmarked fish were 30-48% in southern waters. In contrast, PWS hatchery females were found in both northern (55-56°N) and southern (50-52°N) waters. The mean GSIs of PWS hatchery fish were lower than those of nonmarked fish except for 165°W males (Table 3, Fig. 3). In addition, the mean body sizes and gonad weights of 145°W hatchery males were smaller than those of nonmarked males (Table 3, Fig. 3).

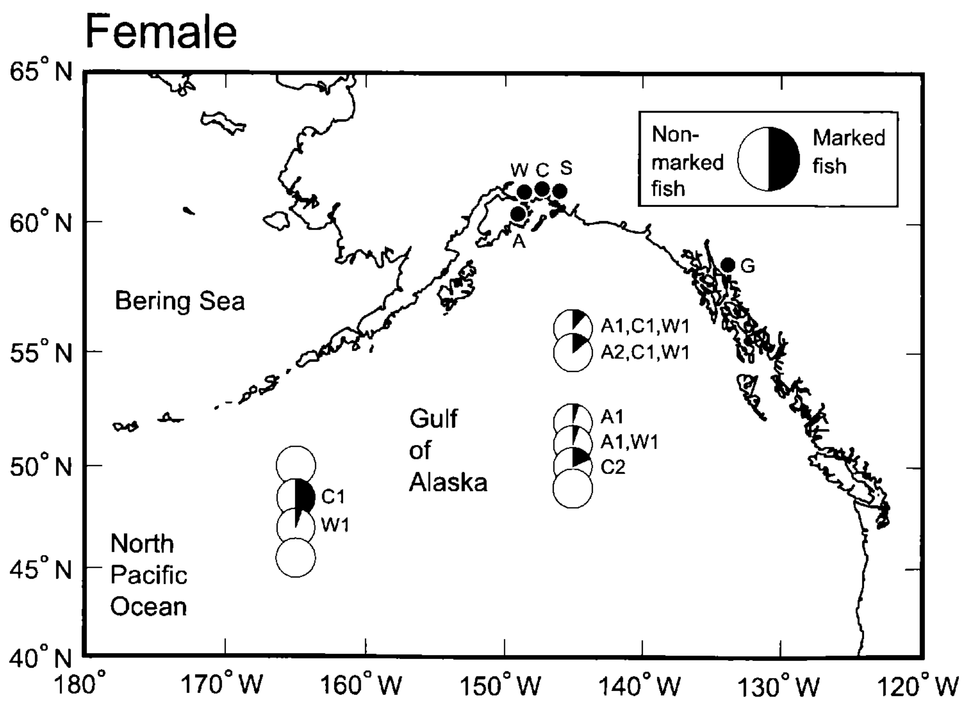
## Discussion

All thermally marked pink salmon detected in the present study were from PWS, where all pink salmon released from four hatcheries were thermally marked (McNair 1998; Munk and Geiger 1998). The CPUE of marked fish caught in research gillnets indicated that PWS hatchery fish were more abundant in the northern part of each transect than in the southern part. This corresponds to the northward direction of their homeward migrations.

A model of ocean distribution and migration patterns of pink salmon based on recoveries of tagged

**Table 2.** A list of thermally marked pink salmon recovered in the Gulf of Alaska during gillnet operations conducted by the T/S *Oshoro maru* in June and July 1998. F, female; M, male; FL, fork length; BW, body weight; GW, gonad weight; AFK, Armin F. Koernig Hatchery; CCH, Cannery Creek Hatchery; WHN, Wally H. Noerenberg Hatchery; Gear A, traditional commercial mesh; Gear C, non-selective varied research mesh.

| No | Date of catch | Latitude (N) | Longitude (W) | Gear (mm) | Sex | FL (mm) | BW (g) | GW (g) | Age | RBr | Hatchery Origin |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9-Jul-98 | 51°00′ | 145°00′ | A115 | F | 502 | 1580 | 54 | 0.1 | 1:1.4+2.3 | AFK96early |
| 2 | 5-Jul-98 | 55°00′ | 145°00′ | C106 | F | 454 | 1080 | 27 | 0.1 | 1:1.4+2.3 | AFK96early |
| 3 | 4-Jul-98 | 56°00′ | 145°00′ | A121 | F | 432 | 900 | 37 | 0.1 | 1:1.4+2.3 | AFK96early |
| 4 | 4-Jul-98 | 56°00′ | 145°00′ | C082 | M | 462 | 1040 | 11 | 0.1 | 1:1.4+2.3 | AFK96early |
| 5 | 8-Jul-98 | 52°00′ | 145°00′ | C106 | F | 486 | 1480 | 48 | 0.1 | 1:1.4 | AFK96late |
| 6 | 5-Jul-98 | 55°00′ | 145°00′ | C082 | M | 447 | 1040 | 18 | 0.1 | 1:1.4 | AFK96late |
| 7 | 5-Jul-98 | 55°00′ | 145°00′ | A121 | F | 487 | 1240 | 41 | 0.1 | 1:1.4 | AFK96late |
| 8 | 4-Jul-98 | 56°00′ | 145°00′ | C106 | M | 460 | 1220 | 1 | 0.1 | 1:1.4 | AFK96late |
| 9 | 27-Jun-98 | 50°00′ | 165°00′ | C093 | M | 454 | 1240 | 29 | 0.1 | 1:14 | AFK96late |
| 10 | 10-Jul-98 | 50°00′ | 145°00′ | A115 | F | 491 | 1520 | 46 | 0.1 | 1:1.3,2.3 | CCH96 |
| 11 | 10-Jul-98 | 50°00′ | 145°00′ | A115 | F | 498 | 1400 | 56 | 0.1 | 1:1.3,2.3 | CCH96 |
| 12 | 5-Jul-98 | 55°00′ | 145°00′ | C093 | F | 472 | 1360 | 105 | 0.1 | 1:1.3,2.2 | CCH96 |
| 13 | 5-Jul-98 | 55°00′ | 145°00′ | C106 | M | 448 | 1000 | 11 | 0.1 | 1:1.3,2.3 | CCH96 |
| 14 | 5-Jul-98 | 55°00′ | 145°00′ | C072 | M | 486 | 1160 | 15 | 0.1 | 1:1.4,2.3 | CCH96 |
| 15 | 5-Jul-98 | 55°00′ | 145°00′ | C082 | M | 437 | 960 | 13 | 0.1 | 1:1.4,2.3 | CCH96 |
| 16 | 4-Jul-98 | 56°00′ | 145°00′ | A121 | F | 505 | 1540 | 49 | 0.1 | 1:1.4,2.3 | CCH96 |
| 17 | 4-Jul-98 | 56°00′ | 145°00′ | A121 | M | 481 | 1320 | 15 | 0.1 | 1:1.4,2.3 | CCH96 |
| 18 | 4-Jul-98 | 56°00′ | 145°00′ | C106 | M | 442 | 960 | 8 | 0.1 | 1:1.3,2.3 | CCH96 |
| 19 | 28-Jun-98 | 48°30′ | 165°00′ | C121 | M | 470 | 1260 | 15 | 0.1 | 1:1.3,2.3 | CCH96 |
| 20 | 28-Jun-98 | 48°30′ | 165°00′ | C093 | F | 517 | 1540 | 22 | 0.1 | 1:1.3,2.3 | CCH96 |
| 21 | 9-Jul-98 | 51°00′ | 145°00′ | C106 | F | 483 | 1280 | 32 | 0.1 | 1:1.8 | WHN96early |
| 22 | 5-Jul-98 | 55°00′ | 145°00′ | C106 | M | 467 | 1160 | 23 | 0.1 | 1:1.8 | WHN96early |
| 23 | 5-Jul-98 | 55°00′ | 145°00′ | C063 | F | 469 | 1020 | 28 | 0.1 | 1:1.8 | WHN96early |
| 24 | 5-Jul-98 | 55°00′ | 145°00′ | C082 | M | 458 | 1060 | 18 | 0.1 | 1:1.8 | WHN96early |
| 25 | 4-Jul-98 | 56°00′ | 145°00′ | C082 | M | 447 | 1020 | 21 | 0.1 | 1:1.8 | WHN96early |
| 26 | 4-Jul-98 | 56°00′ | 145°00′ | C106 | F | 518 | 1540 | 42 | 0.1 | 1:1.8 | WHN96early |
| 27 | 4-Jul-98 | 56°00′ | 145°00′ | C106 | M | 476 | 1300 | 13 | 0.1 | 1:1.8 | WHN96early |
| 28 | 4-Jul-98 | 56°00′ | 145°00′ | C106 | M | 470 | 1200 | 12 | 0.1 | 1:1.8+2.3 | WHN96late |
| 29 | 29-Jun-98 | 47°00′ | 165°00′ | A115 | F | 457 | 1060 | 25 | 0.1 | 1:1.8+2.3 | WHN96late |



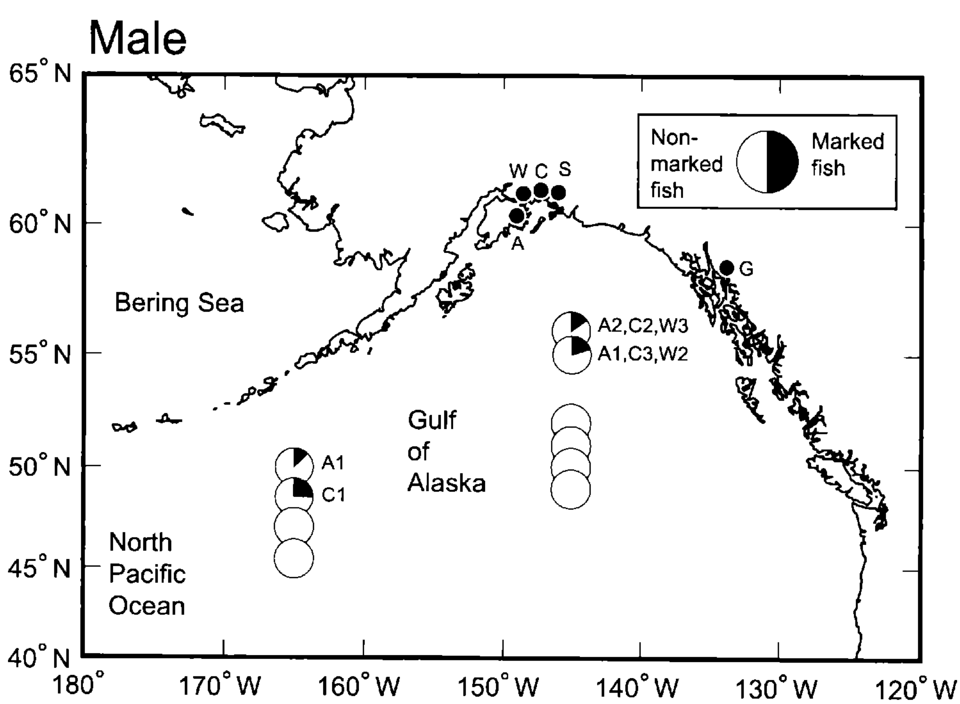




**Fig. 1.** Hatchery origins and composition of thermally marked maturing pink salmon caught along the 145°W and 165°W transects in the Gulf of Alaska in June and July 1998. Numerals indicate the number of thermally marked fish. A, Armin F. Koernig Hatchery; C, Cannery Creek Hatchery; G, Gastineau Hatchery; S, Solomon Gulch Hatchery; W, Wally H. Noerenberg Hatchery.

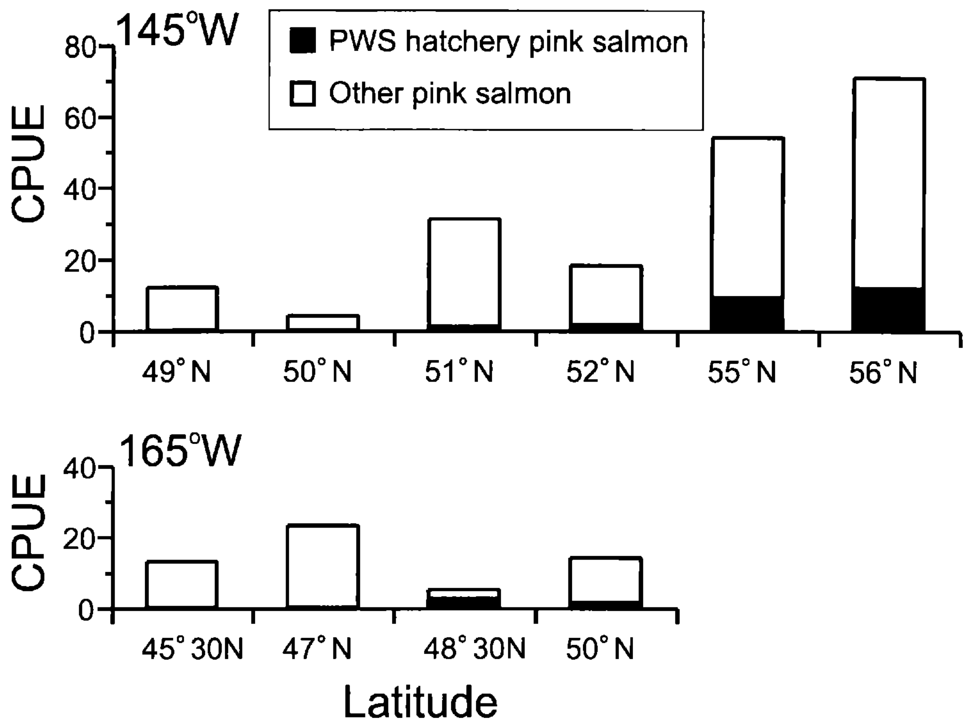



**Fig. 2.** Catch per unit effort (CPUE) of thermally marked pink salmon, which were Prince William Sound (PWS) hatchery origin caught along the 145°W (upper) and 165°W (lower) transects in the Gulf of Alaska in June and July 1998. The CPUE values are based on the catch (number of fish) per one set of research mesh gillnets (30 tans).

**Table 3.** A comparison of body and gonad measurements between maturing thermally marked Prince William Sound (PWS) hatchery pink salmon and nonmarked pink salmon caught along the 145°W and 165°W transects in the Gulf of Alaska in June and July 1998. Values are given as the mean ± SD. Numbers in parentheses are sample sizes. FL, fork length (mm); BW, body weight (g); GW, gonad weight (g); GSI, gonadosomatic index = 100 × gonad weight (g)/body weight (g).

| Sex | Measurement | PWS hatchery stocks | Other stocks | Probability |
|---|---|---|---|---|
| **145°W transect** | | | | |
| Female | FL | 483±24 (12) | 485±25 (155) | $p=0.84$ |
| | BW | 1328±227 (12) | 1443±302 (155) | $p=0.20$ |
| | GW | 47±21 (12) | 82±37 (155) | $p<0.001$ |
| | GSI | 3.54±1.41 (12) | 5.56±2.05 (155) | $p<0.01$ |
| Male | FL | 460±16 (13) | 495±35 (126) | $p<0.001$ |
| | BW | 1111±123 (13) | 1575±408 (126) | $p<0.001$ |
| | GW | 14±6 (13) | 41±29 (126) | $p<0.001$ |
| | GSI | 1.26±0.53 (13) | 2.50±1.43 (126) | $p<0.001$ |
| **165°W transect** | | | | |
| Female | FL | 487±42 (2) | 465±33 (46) | $p=0.35$ |
| | BW | 1300±339 (2) | 1244±273 (46) | $p=0.70$ |
| | GW | 24±2 (2) | 65±31 (46) | $p=0.07$ |
| | GSI | 1.89±0.66 (2) | 5.28±1.99 (46) | $p<0.05$ |
| Male | FL | 462±11 (2) | 474±40 (26) | $p=0.67$ |
| | BW | 1250±14 (2) | 1271±304 (26) | $p=0.93$ |
| | GW | 22±10 (2) | 37±28 (26) | $p=0.47$ |
| | GSI | 1.76±0.81 (2) | 2.74±1.95 (26) | $p=0.49$ |

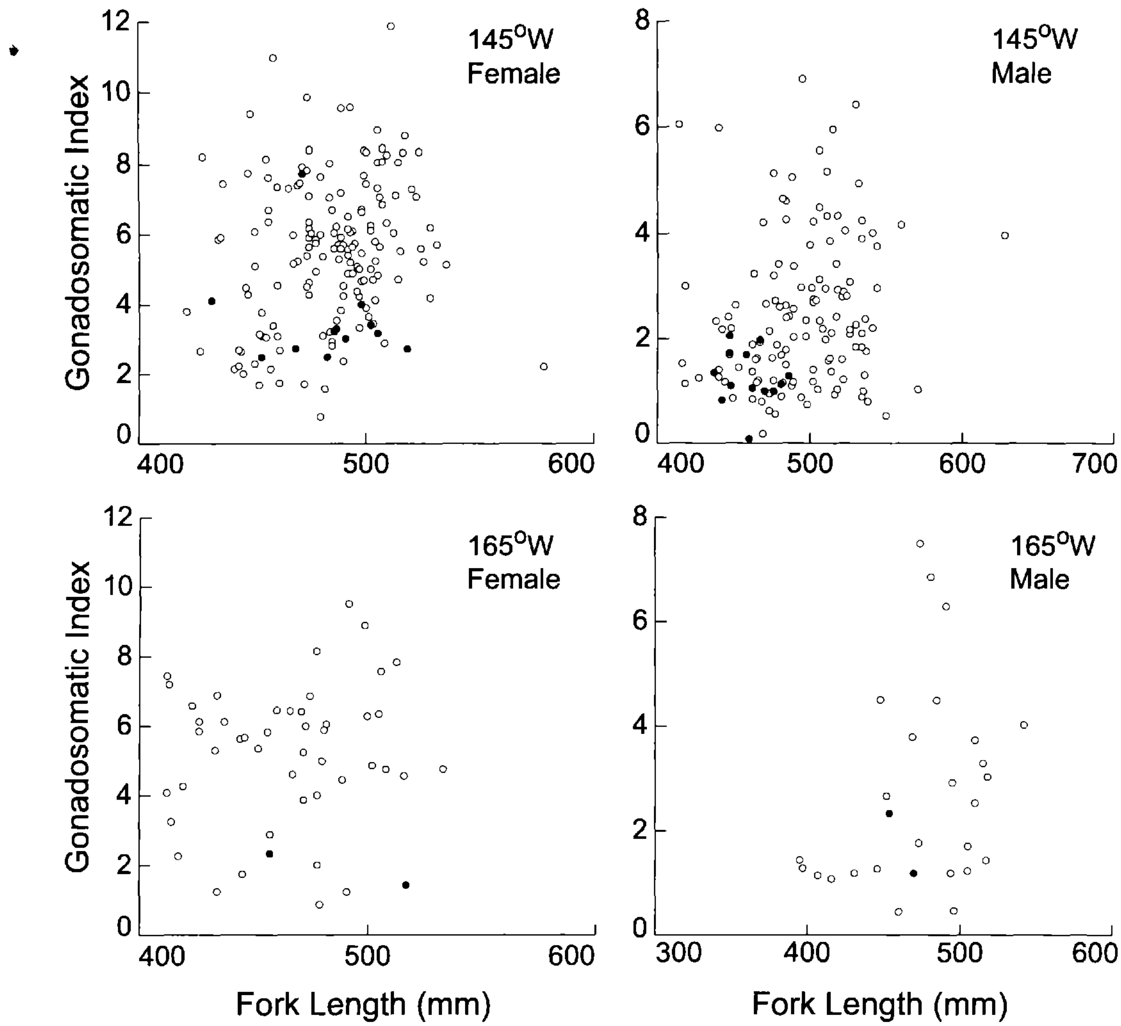



**Fig. 3.** Relationships between gonadosomatic index and fork length (mm) in maturing pink salmon caught along the 145°W and 165°W transects in the Gulf of Alaska in June and July 1998. Closed and open circles show Prince William Sound hatchery and other pink salmon, respectively.

fish in 1956-1992 (Myers 1994, updated from Takagi et al. 1981) indicated that pink salmon originating in southwestern, central, and southeastern Alaska are not distributed south of 50°N in the vicinity of 165°W. However, we recovered four thermally marked PWS hatchery pink salmon at 47-50°N, 165°W, which is a southwestward extension of the known ocean range of maturing southcentral Alaskan pink salmon in summer.

Marked SGH fish were 39% of the total releases from four PWS hatcheries of pink salmon with good quality thermal marks (Joyce et al. 1997; Munk and Geiger 1998). During a May 1998 salmon survey along the 145°W transect, marked SGH fish were caught in northern waters (52°59'-55°03'N), and three other hatchery stocks were caught in southern waters (42°57'-46°58'N, Farley et al. 1999). In 1998, most of the three other hatchery fish indicated low GSI in July. The run-timing of SGH pink salmon is approximately 3-4 weeks earlier than that of the three other hatchery stocks. Therefore, in July SGH pink salmon may be distributed closer to the coast of PWS than other PWS hatchery stocks.

In general, the proportion of males in catches of maturing pink salmon at AFK is more than 80% during the last 10 days of July and decreases gradually to the end of August in even year stocks (Mathisen and Zheng 1994). The more northerly distribution of PWS hatchery males compared to females that we observed in offshore waters in late June to early July may be related to sexual differences in the timing of their homeward migrations.

The total number of otolith-marked Pacific salmon released into the North Pacific Ocean and adjacent seas is increasing (Munk and Geiger 1998). In Japan, mass marking of hatchery salmon with otolith thermal marks began with 1998 brood-year stocks, after US, Canadian, and Russian otolith-marking programs had already implemented. We are detecting thermal marks on chum (*O. keta*) and pink salmon otoliths collected by Japanese salmon research vessels during summer 1999 salmon surveys from a wide area of the North Pacific Ocean and Bering Sea. Continued monitoring of the distribution of hatchery stocks by detection of otolith thermal marks is important for mixed-stock management of Pacific salmon.

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## 1998年夏期にアラスカ湾で再捕された温度標識カラフトマス成魚

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アラスカ産カラフトマスの海洋分布と移動を調べるため，アラスカの孵化場で施された耳石温度標識を利用して，夏期アラスカ湾で流網により採集された個体を分析した．1998年６月から７月にかけてアラスカ湾（西経145度と165度）で採集されたカラフトマス成魚383個体のうち，29個体がプリンス・ウイリアム・サウンド地域（PWS，中央アラスカ）から放流された温度標識魚だった．西経145度定線では，307個体のうち25個体（8.1%）が標識魚であり，起源はArmin F. Koernig Hatchery（AFK，８個体），Cannery Creek Hatchery（CCH，９個体），Wally H. Noerenberg Hatchery（WHN，８個体）だった．また西経165度定線では，76個体のうち４個体（5.3%）が標識魚であり，起源はAFK（１個体），CCH（２個体），WHN（１個体）だった．両定線でPWS孵化場魚のCPUEが、母川回帰方向に相当する北方海域で高かった．PWS孵化場魚の分布に雌雄差が観察され，母川回帰時期の違いに由来することが示唆された．また，西経165度定線の沖合（北緯47-50度）においてPWS由来の標識魚が４個体再捕されたことは，中央アラスカ系カラフトマス成魚の既知の分布域を南西方向に拡張するものであった．