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# Descriptive Hydrography of Shelikof Strait, Gulf of Alaska, during the Spring Spawning Time of Walleye Pollock, *Theragra chalcogramma*, in the Early 1980's.

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# 명태(*Theragra chalcogramma*)의 산란장, 알라스카만 쉘리코프 해협의 1980년대 초반의 해황에 관한 연구

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To delineate water properties and current patterns in the spawning area of walleye pollock, hydrographic cast and current meter data collected in Shelikof Strait, Gulf of Alaska, were analysed. Three water masses are identified in Shelikof Strait. A small amount of cold and dilute water (<3℃ and <31.5‰) originates from the lower Cook Inlet and flows southwestward close to the Alaska Peninsula coast. One branch of Alaska Coastal Current which enters the strait from the northeast comprises the main body of the upper and middle layers of the strait, and flows toward the southwest.

Estimation of geostrophic baroclinic currents reveals that comparatively fast flow exists in the surface over the deepest portion of the strait, and most water exits through the southwestern entrance between Semidi and Chirikof Is. On the other hand, a relatively slow-moving warm and saline (>5℃ and >32‰) water mass from the continental slope area which intrudes into Shelikof Strait over the bottom of the southwestern entrance flows northeasterly, and occupies the bottom layer in Shelikof Strait.

알라스카만 명태 산란장에서의 해수의 성질과 해류의 흐름을 규명하기 위하여, 쉘리코프 해협에서의 CTD 조사 결과와 해류계 자료가 분석되었다. 쉘리코프해협에서는 3개의 수괴가 구분되었다. 첫번째 수괴는 Cook 내만으로부터 유래된 적은 양의 차갑고 염분이 낮은(<3℃, <31.5‰) 표층수로서 알라스카 반도 해안에 바짝 붙어서 남서쪽을 향하여 흐르고 있다. 두번째의 수괴는 알라스카 해안류 (ACC)의 가지로서 해협의 북동쪽 입구로 들어와 남서쪽을 향해 흐르며, 해협내에서는 중층과 표층의 대부분을 차지하고 있다. 해협의 가장 깊은 골의 상부층에 가장 빠른 흐름이 존재하며, 그들은 Semidi섬과 Chirikof섬 사이의 남서쪽 계곡을 통하여 해협에서 빠져나간다. 세번째의 수괴는 비교적 느리고, 따뜻하고 염분이 높은 (<5℃, 32‰) 대륙사면으로부터 남서쪽 입구의 저층을 통하여 해협으로 들어온 저층수인데 이들은 북동쪽을 향해 흐르며 해협 저층의 대부분을 차지한다.

## INTRODUCTION

Walleye pollock, *Theragra chalcogramma*, is distributed in the rim of the north Pacific along the coastal areas of Asia and north America. From a fishery standpoint, walleye pollock is the most productive single species in the Gulf of Alaska as well as in the world. Annual landing of walleye pollock from the north Pacific consists of almost 5% of world's total fish catch (Kim, 1990), and the total Gulf of Alaska groundfish catch by foreign trawl fisheries during 1977-1981 was about 66% walleye pollock (Alton and Deriso, 1983).

The importance of the early life history of fish as well as the interaction between organisms and their abiotic environment has increased rapidly in the last decade to explain recruitment processes/ stock variability of fisheries (Wooster et al., 1983). Since Shelikof Strait was found in 1980 to be the major spawning ground of walleye pollock in the Gulf of Alaska, several investigators have become interested in using this strait as a 'laboratory' for examining recruitment processes of walleye pollock. This interest stimulated to establish a cooperative research program, Fisheries Oceanography Coordinated Investigations (FOCI), between the Alaska Fisheries Science Center (AFSC) and Pacific Marine Environmental Laboratory (PMEL) of U.S. National Oceanic and Atmospheric Administration (NOAA) to study recruitment mechanisms of important fishery stocks in relation to the biotic and abiotic environments associated with their reproductive patterns.

Walleye pollock concentrate for spawning along the deep trough in the central strait, and peak spawning occurs from late March to early April (Kimand Nunnallee, 1990). Due to low specific gravity of newly spawned eggs, young eggs move upward until their specific gravities balance with those of the surrounding sea water (Kendall and Kim, 1989). As the eggs develop, they sink back toward the bottom due to increased specific gravity for a while, and finally rise toward the surface of ocean again during the very late stage of eggs. Therefore, physical environments such as sea water temperature, salinity, current direction and velocity could effect on the determination of spawning time and place as well as the distribution of eggs and larvae.

Several authors (Mysak et al., 1981; Schumacher and Reed, 1980; Schumacher et al., 1978) have already analysed current and CTD data collected in 1977 and 1978. Because the data sets used for their papers were obtained from only a small part of strait and prior to main spawning time of walleye pollock, more detailed information was needed for understanding the physical environment of the spawning population. In this paper, the physical properties of Shelikof Strait sea water are described to understand the relationship between the oceanographic environment and spawning walleye pollock.

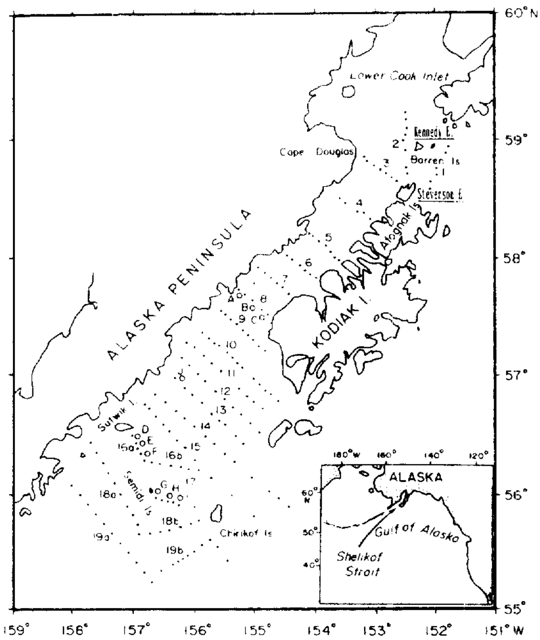


Fig. 1. The location of mooring current meter (o), CTD cast stations (·) and transects (arabic numerals) conducted in March, 1985. The letters used in mooring locations are shown in Table 2.

## GEOGRAPHY AND BATHYMETRY

The Gulf of Alaska is located in the northeastern Pacific Ocean where the permanent cyclonic Alaskan Gyre occurs (Fig. 1). High mountains range along the North American coast and a relatively broad (75 to 15 km) and deep (150 to 350 m) continental shelf forms a half-arc at the perimeter of the Gulf of Alaska. Shelikof Strait, in the northern Gulf of Alaska, is a long (about 340 km) strait between the Alaska Peninsula and several islands-Barren, Afognak, Kodiak, Trinity, Chirikof, and Semidi Is.-(Fig. 1). The northeastern tip of strait faces lower Cook Inlet and Stevenson and Kennedy Entrances. Kennedy Entrance is narrow

Table 1. U.S. research cruises in Shelikof Strait during the spawning time (March-May) of walleye pollock. 1977-1985

| Date | Research vessel | Main purpose |
|---|---|---|
| March 27, 1977 | *Discoverer* | General hydrographic survey |
| March 4-17, 1978 | *Surveyor* | General hydrographic survey |
| March 6-24, 1978 | *Discoverer* | General hydrographic survey |
| April 11-14, 1980 | *Miller Freeman* | Hydroacoustic survey |
| March 3-15, 1981 | *Miller Freeman* | Hydroacoustic survey |
| March 12-20, 1981 | *Miller Freeman* | Egg and laeval survey |
| March 24-27, 1981 | *Miller Freeman* | Egg and laeval survey |
| March 30-April 8, 1981 | *Miller Freeman* | Egg and larval survey |
| April 4-10, 1981 | *Miller Freeman* | Hydroacoustic survey |
| April 26-May 2, 1981 | *Miller Freeman* | Egg and laeval survey |
| May 20-24, 1981 | *Miller Freeman* | Egg and laeval survey |
| March 6-20, 1983 | *Miller Freeman* | Hydroacoustic survey |
| March 24-April 3, 1983 | *Chapman* | Hydroacoustic survey |
| April 6-13, 1983 | *Miller Freeman* | Hydroacoustic survey |
| May 16-28, 1983 | *Chapman* | Larval survey |
| March 3-April 7, 1984 | *Miller Freeman* | Hydroacoustic survey |
| March 20-April 8, 1984 | *Chapman* | Egg survey |
| Feb. 21-March 28, 1985 | *Miller Freeman* | Hydroacoustic survey |
| March 12-28, 1985 | *Discoverer* | General hydrographic survey |
| April 2-11, 1985 | *Miller Freeman* | Egg survey |
| May 2-11, 1985 | *Miller Freeman* | Larval survey |

(around 22 km) and deep (almost 200 m) while Stevenson Entrance is comparatively wide (around 36 km) and shallower (maximum of 120 m). The boundary with lower Cook Inlet is around 50 km wide and 150-200 m deep. The area of Shelikof Strait between the Alaska Peninsula and Afognak I. includes two deep (about 200 m) and narrow troughs having NE-SW direction. The trough on the island side is deeper than the other, and it extends north to southwest Barren Is. Shelikof Strait between the Alaska Peninsula and Kodiak I. is also narrow (about 50 km) and only one trough (around 300 m) is along the peninsula side. There is a very steep slope to coast on the peninsula side of the strait, but a relatively flat and deep topography exists toward the island with a gradual change of depths. The southwestern strait is broad (about 100 km) and the direction of trough changes slightly from NE-SW to NNE-SSW. Relatively shallow areas on either side of the central axis of the strait are broad. The western and southern boundaries of strait face two banks and a narrow valley lies between them: to the south, a shallow bank exists between Kodiak I. and Chirikof I. with depths of 30-40 m; to the west, there is a relatively deep (around 100 m) bank between Sutwik I. and Semidi I.; between two banks (i.e., between Semidi I. and Chirikof I.), there is a narrow and deep (around 200 m) valley.

## METHODS AND DATA

Few observations were made in coastal waters of the Gulf of Alaska before the Outer Continental Shelf Environmental Assessment Program (OCSEAP) started in 1974. For the Shelikof Strait region, conductivity and temperature versus depth (CTD) data have been obtained only since spring 1977. From 1977 through 1985, a total of 21 cruises by AFSC and PMEL obtained CTD data in Shelikof Strait during the spring season (Table 1). Especially, ichthyoplankton surveys in March 1985 provided much information on sea water properties (Fig. 1). US scientists collected CTD data using Plessey model 9040 systems with model 8400 data loggers. Data were recorded only during the downcast using a lowering rate of 30 m/min. Sea water samples were taken on most cruises for tempera-

Table 2. Moored current meters in Shelikof Strait. The letters used in FOX series mooring are shown in Fig. 1.

| Mooring Name | Location Latitude | Longitude | Duration | Meter depth (m) |
|---|---|---|---|---|
| K1 | 57.74 | 154.73 | Oct. 1976 - Mar. 1977 | 100 |
| K2 | 58.62 | 153.08 | Oct. 1976 - Mar. 1977 | 20 |
| | | | | 100 |
| K12A | 55.99 | 156.30 | Oct. 1977 - Mar. 1978 | 18 |
| | | | | 205 |
| C10 | 58.50 | 153.19 | Oct. 1977 - Mar. 1978 | 20 |
| | | | | 65 |
| K13A | 56.34 | 156.84 | Oct. 1977 - Mar. 1978 | 102 |
| K13B | 56.40 | 156.82 | Oct. 1977 - Mar. 1978 | 111 |
| | | | May. 1978 - Oct. 1978 | 28 |
| C10B | 58.50 | 153.20 | May. 1978 - Oct. 1978 | 25 |
| | | | | 70 |
| | | | | 165 |
| FOX8401 | 57.74 | 154.73 | Aug. 1984 - Jan. 1985 | 26 |
| (A) | | | | 56 |
| | | | | 106 |
| | | | | 165 |
| | | | | 240 |
| FOX8402 | 57.60 | 155.01 | Aug. 1984 - Jan. 1985 | 26 |
| (B) | | | | 56 |
| | | | | 106 |
| | | | | 165 |
| | | | | 220 |
| FOX8403 | 57.51 | 154.77 | Aug. 1984 - Jan. 1985 | 26 |
| (C) | | | | 56 |
| | | | | 106 |
| | | | | 165 |
| | | | | 220 |
| FOX8404 | 56.45 | 156.98 | Aug. 1984 - July 1985 | 26 |
| (D) | | | | 56 |
| FOX8405 | 56.35 | 156.90 | Aug. 1984 - July 1985 | 26 |
| (E) | | | | 56 |
| | | | | 106 |
| FOX8406 | 56.28 | 156.82 | Aug. 1984 - July 1985 | 26 |
| (F) | | | | 56 |
| | | | | 75 |
| FOX8407 | 55.95 | 156.60 | Aug. 1984 - July 1985 | 26 |
| (G) | | | | 56 |
| | | | | 106 |
| | | | | 185 |
| FOX8408 | 55.94 | 156.36 | Aug. 1984 - July 1985 | 26 |
| (H) | | | | 56 |
| | | | | 121 |
| | | | | 205 |
| FOX8409 | 55.91 | 156.15 | Aug. 1984 - July 1985 | 26 |
| (I) | | | Aug. 1984 - July 1985 | 56 |
| | | | | 121 |
| | | | | 168 |
| FOX8510A | 57.01 | 156.17 | Jan. 1985 - July 1985 | 26 |
| (J) | | | | 105 |

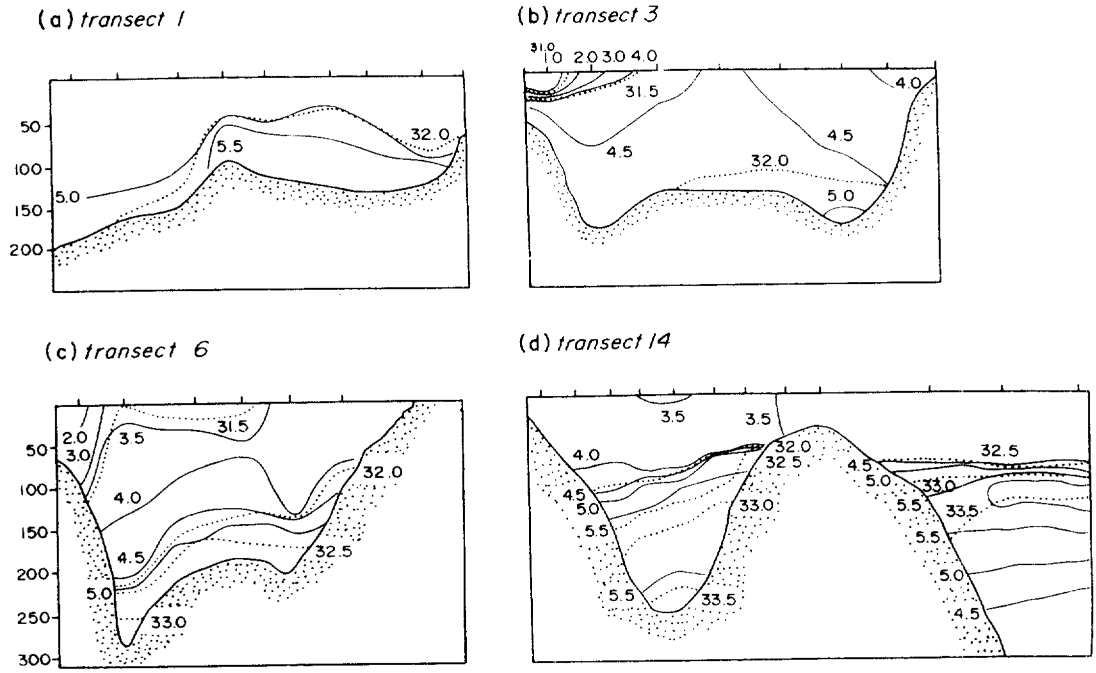


Fig. 2. Vertical sections of temperature (℃, ——) and salinity (‰, ······) along and across Shelikof Strait in March. 1985: (a) transect 1, (b) transect 3, (c) transect 6, and (d) transect 14. Kodiak Island end of the transects to the right. Sampling stations are indicated by tics on horizontal axes.

ture and salinity calibration.

In 1981, Soviet Pacific Research Institute of Fisheries and Oceanography (TINRO) scientists also collected water temperatures and salinity data during their ichthyoplankton surveys in the Gulf of Alaska. Details of ship schedule and area covered are in Fadeev and Borets (1981). Sea water property data were obtained through hydrographic casts at standard depths (0, 10, 20, 30, 50, 75, 100, 150, 200, 250, 300, 400, 500, and 600 m). Because the Soviets did not use standard sea water for salinity calibration, only temperature data are presented in this paper.

Current data were collected using Aanderaa model RCM-4 current meters on taut wire moorings in and around Shelikof Strait. Among 50 current meter records at selected depths in 17 mooring stations (Table 2), 21 records include information from March through May (i.e., the adult spawning season and drifting period of eggs and larvae). Raw data were filtered to remove high-frequency noise so that over 99% of the amplitude was passed at periods greater than 5 hours, 50% at 2.86 hours and less than 0.5% at 2 hours. This time series data include direction and speed of currents, temperature, pressure, and salinity. The resulting series was then passed through a second, low-pass filter to remove most of the tidal energy. The second filter passed more than 99% of the amplitude at periods over 55 hours, 50% at 35 hours and less 0.5% at 25 hours. All US data collected were stored and analysed in Rapid Retrieval Data Display (R2D2) (Pearson, 1981) in PMEL's computer system.

## RESULTS AND DISCUSSION

As shown in Fig. 2a, the bottom water mass near Stevenson Entrance was warmer, saltier, and denser than that of Kennedy Entrance. In the strait, the surface water along the peninsula side is colder and less saline than that on island side because the discharge from lower Cook Inlet is added to the coastal current close to the peninsula

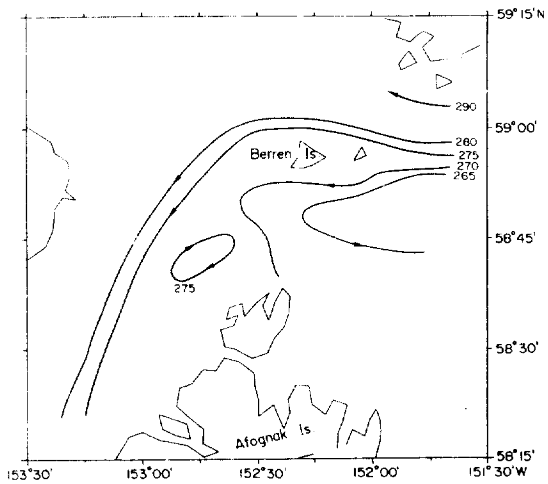


Fig. 3. Geopotential topography (0/100 dbar, in dynamic meter) observed near Kennedy and Stevenson Entrance during March, 1985.

(Fig. 2b). The waters in Kennedy Entrance, near northwest Barren Is., and in the middle part of the strait appear to have nearly the same physical properties (i.e., <5℃, <32‰, and less stratification) so that they can be distinguished from other waters nearby. Further evidence that they are the same water masses can be obtained by examining the 0/100 dbar geopotential topographic contour. The 0.275 and 0.280 dynamic meter contours continue from Kennedy Entrance to Shelikof Strait via north Barren Is. while 0.270 and 0.265 isolines in Stevenson Entrance do not extend into Shelikof Strait (Fig. 3). Therefore it can be said, as pointed out by Schumacher and Reed (1980) and Muench et al. (1978), that the coastal flow enters Shelikof Strait through Kennedy Entrance and turns south near Cape Douglas in lower Cook Inlet. Based on such information, we are able to identify three groups of different water masses and their flow patterns in northeastern end of the strait: 1) a small amount of water along the west side of the strait originated from land runoff through lower Cook Inlet which formed the surface layer (to about 50 m deep) with strong thermal and salt stratification (e.g., at one CTD station with depth of 76 m, $\Delta T = 4.08$℃, $\Delta S = 0.88$‰); 2) The waters below the surface layer on the west side of the strait occupies the biggest portion of water volume in this area, and originate from the Alaska Coastal Current (ACC) via Kennedy Entrance; 3) a small amount of warm (>5℃) and saline (>32‰) water exists in the bottom trough near the west of Stevenson Entrance (Fig. 2b). Furthermore, some evidence from the temperature and salinity contours (not shown) at 100 m depth suggests that this bottom water mass does not intrude from Stevenson Entrance but extends from the bottom layer of the strait proper along the deep trough.

The strait proper has similar characteristics to the northeastern end in terms of water mass structure (Fig. 2c). In general, cold and dilute surface water along the peninsula forms the wave-like structure which was explained by Mysak et al. (1981), as it travels down-strait (Fig. 4a). This downstream-traveling wave is probably related to fluctuations of flow with time scales of a few days. Warm (>5℃) and saline (>32‰) water always occupied the deep strait (deeper than 150 m) between the Alaska Peninsula and Kodiak Island. Temperature distribution at 150 m (Fig. 4b) suggest that the warm and saline bottom layer water comes from the continental slope area via the southwestern valley of the strait (see below). As shown in the northeastern end, water properties in the middle layer of this region (including the surface layer on the Kodiak Island side) are nearly the same as those found in Kennedy Entrance, which indicates that the source of this water mass is the ACC. Below the surface layer, the isotherms and isohalines at depth show an inclination in transects across the strait. This may result from the input of freshwater to the west side of the strait which causes the isolines to be deepened along the west side of the strait. Another possible explanation comes from the origin of the bottom water inflow. If we regard this strait as a large estuarine system with outflow of the upper layer and inflow below defined as in Pickard and Emery (1982), there would be a semipermanent reversal of current direction in the bottom layer. As shown in Fig. 4b, warm bottom water enters the strait over the southwestern side and was observed in the southern part of the trough and also in the bottom layer on the Kodiak Island side. The inflow phenome-

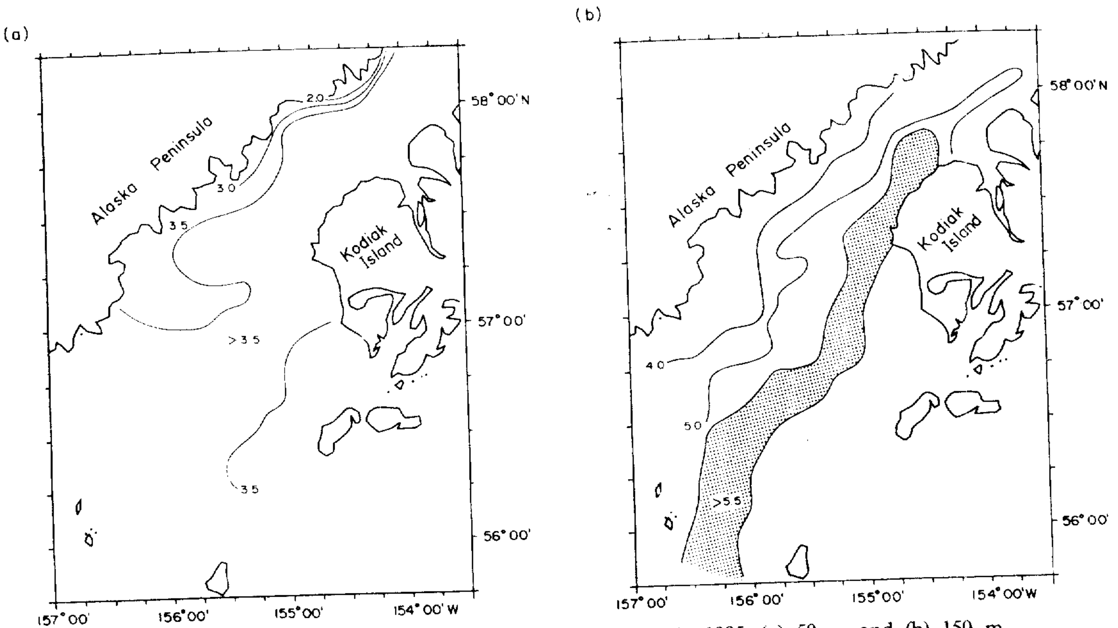


Fig. 4. Temperature (℃) in Shelikof Strait during March, 1985. (a) 50 m and (b) 150 m.

non might be related to the earth's rotation. The effect of Coriolis force results in a horizontal salinity gradient (freshwater on the left facing upstream in broad estuaries of the northern hemisphere), and the inflow at the bottom layer tends to hug the right side of the estuary (Knauss, 1978). Some evidence for estuarinelike flow is shown in current meter data from moorings A, B, C, G, H and I. For example, current records near the Kodiak coast (mooring C) during fall through winter 1984 showed a northeastward flow, and more dense water compared to that on peninsula side (mooring A) (Table 3). The current records in the valley area (moorings G, H and I) will be discussed later in this paper.

In the southwestern part of the strait, relatively

Table 3. Monthly means of; (1) Vel=current velocity (cm/sec), (2) Dir=direction (degree), (3) Temp=water temperature (℃), (4) Sal=salinity (‰), and (5) Sig-t=density (sigma-t) observed from moored meters during August 1984-July 1985.

| | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mooring A | | | | | | | | | | | | |
| 165 m | | | | | | | | | | | | |
| Vel | | 1.70 | 8.30 | 6.40 | 8.20 | 16.20 | | | | | | |
| Dir | | 210.70 | 219.70 | 218.20 | 218.90 | 220.10 | | | | | | |
| Temp | | 5.48 | 6.44 | 7.07 | 6.98 | 6.18 | | | | | | |
| Sal | | 32.70 | 32.49 | 32.37 | 31.87 | 31.27 | | | | | | |
| Sig-t | | 25.82 | 25.54 | 25.36 | 24.98 | 24.61 | | | | | | |
| Mooring C | | | | | | | | | | | | |
| 165 m | | | | | | | | | | | | |
| Vel | | 1.90 | 5.40 | 5.50 | 8.20 | 9.00 | | | | | | |
| Dir | | 22.00 | 43.50 | 37.10 | 42.10 | 51.30 | | | | | | |
| Temp | | 5.47 | 5.53 | 5.64 | 5.71 | 5.87 | | | | | | |
| Sal | | 32.84 | 32.92 | 32.92 | 32.99 | 32.73 | | | | | | |
| Sig-t | | 25.93 | 25.99 | 25.98 | 26.03 | 25.80 | | | | | | |

Table 3. Countinued.

| | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mooring G | | | | | | | | | | | | |
| 185 m | | | | | | | | | | | | |
| Vel | 11.70 | 2.70 | 3.80 | 3.20 | 5.10 | 14.50 | 6.10 | 3.50 | 3.00 | 5.30 | 0.90 | 9.20 |
| Dir | 35.80 | 81.70 | 39.20 | 190.10 | 40.20 | 192.80 | 47.20 | 40.30 | 17.40 | 39.00 | 145.00 | 39.80 |
| Temp | 5.51 2 | 5.50 | 5.55 | 6.02 | 6.07 | 6.28 | 5.81 | 5.39 | 5.04 | 5.14 | 4.61 | 5.29 |
| Sal | 33.41 | 32.78 | 32.85 | 32.67 | 32.82 | 31.69 | 32.40 | 32.57 | 32.61 | 32.80 | 31.97 | 32.31 |
| Sig-t | 26.38 | 25.88 | 25.93 | 25.74 | 25.84 | 24.93 | 25.55 | 25.73 | 25.80 | 25.94 | 25.34 | 25.53 |
| Mooring G | | | | | | | | | | | | |
| 205 m | | | | | | | | | | | | |
| Vel | 3.30 | 4.60 | 6.40 | 0.10 | 7.80 | 13.20 | 6.50 | 7.30 | 4.90 | 8.40 | 6.50 | 12.30 |
| Dir | 10.50 | 67.50 | 71.10 | 282.40 | 60.20 | 204.30 | 74.40 | 51.40 | 154.80 | 80.40 | 71.70 | 67.00 |
| Temp | 5.43 | 5.41 | 5.39 | 5.54 | 5.45 | 5.78 | 5.80 | 5.40 | 5.28 | 5.22 | 5.16 | 5.40 |
| Sal | 33.63 | 33.48 | 33.45 | 33.41 | 33.53 | 33.10 | 33.20 | 33.48 | 33.40 | 33.45 | 33.31 | 33.48 |
| Sig-t | 26.56 | 26.44 | 26.42 | 26.38 | 26.48 | 26.10 | 26.18 | 26.45 | 26.40 | 26.44 | 26.34 | 26.45 |

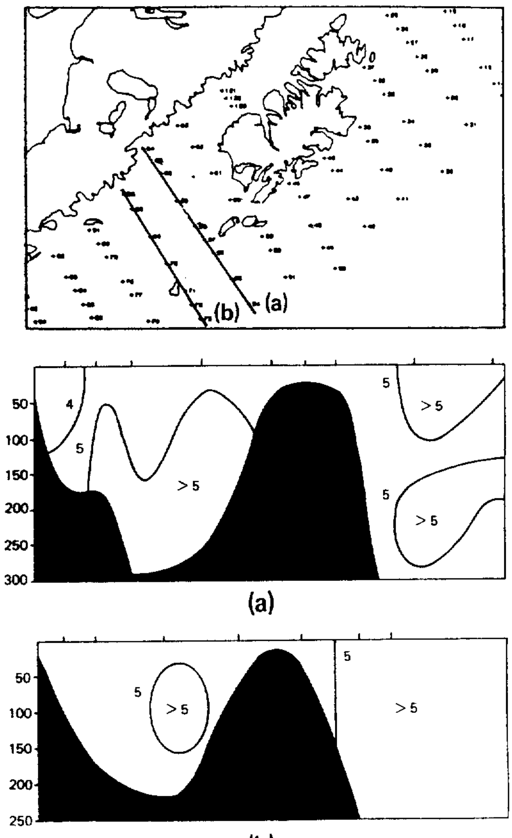


Fig. 5. Temperature (℃) profiles in the southwestern Shelikof Strait taken by U.S.S.R. R/V Shantar, March 1981. Alaska Peninsula end of transects to the left. Sampling stations are indicated by tics on horizontal axes.

large amounts of warm and saline water occupied the bottom layer, and surface cold water along peninsula side was not conspicuous (Fig. 2d). The flow pattern might be changed due to the irregular bathymetry and the broaden width of the strait. It is not clear whether the water properties are influenced by oceanic water through banks in southern boundary or not. However, transect 14 (Fig. 2d) and a transect from the 1981 Soviet data (Fig. 5) show a distinct discontinuity of water temperature between the strait and slope area. Also, both figures show a warm water mass in the south trough, which is thought to be evidence of bottom inflow. In the coastal area (e.g., mooring J) during March, current is directed generally southwestward with reduced speed.

Several islands, banks and valley in the southwestern end of the strait affect the current and transport patterns. Because the bank between Sutwik and Semidi Islands is shallow (maximum of 130 m), most outbound surface water flows southward through the valley area between Semidi and Chirikof Islands. This is illustrated by the 0/100 dbar geopotential topography (Fig. 6). As shown in Fig. 4b, the temperature distribution at 150 m shows the connection of water masses between the bottom layer of the strait and the continental slope. The water mass which had a temperature above 5.5℃ continued from the southwestern strait

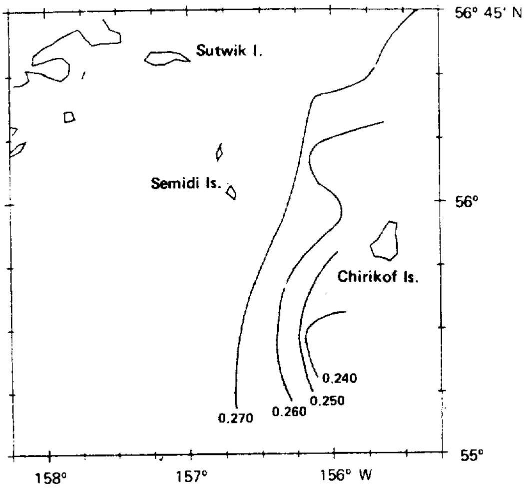


Fig. 6. Geopotential topography (0/100 dbar, in dynamic meter) observed near the valley area during March, 1985.

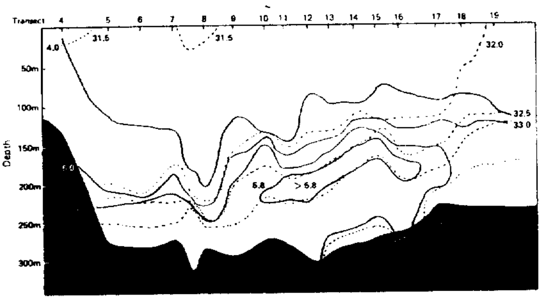


Fig. 7. Temperature (℃, ······) and salinity (‰, ——) profiles along Shelikof Strait at the deepest part of each transect in March, 1985.

to the slope area through the valley. The monthly means of current speed and direction from current meters in the valley area show semi-permanent inflow in the bottom layer (e.g., 185 m of mooring G and 205 m of mooring H), which confirm that at times Shelikof Strait has a two layered flow system-outflow in the upper layer and inflow below.

The isotherms and isohalines along the strait (the deepest station in each transect was chosen) shown in Fig. 7 indicate that the warm and saline water which entered via the southwestern valley (Transect 17), occupied the bottom layer of the strait, and isotherms and isohalines tended to deepen continuously to the deepest station of strait.

Table 4. Baroclinic transport and velocity along Shelikof Strait during March, 1985. Calculation for transport and surface velocity is based on 100 m (Transects 1-4) and 150 m (Transects 5-19) depths of no motion

| Transect Name | Total transport (10,000 m$^3$/sec) | Width of Strait (km) | Transport in unit distance | Mean speed (cm/sec) |
|---|---|---|---|---|
| 1 | 2.66 | 55.6 | 0.48 | 1.9 |
| 2 | 4.16 | 58.5 | 0.71 | 2.0 |
| 3 | 7.17 | 39.2 | 1.83 | 5.0 |
| 4 | 10.82 | 36.0 | 3.01 | 6.4 |
| 5 | 15.44 | 39.5 | 3.91 | 7.0 |
| 6 | 16.45 | 36.0 | 4.57 | 6.6 |
| 7 | 16.05 | 46.0 | 3.49 | 4.4 |
| 8 | 34.05 | 43.7 | 7.79 | 8.8 |
| 9 | 34.32 | 59.5 | 5.77 | 8.5 |
| 10 | 11.22 | 75.5 | 1.49 | 1.7 |
| 11 | 17.12 | 86.5 | 1.98 | 3.5 |
| 12 | 25.70 | 80.0 | 3.21 | 3.3 |
| 13 | 20.71 | 79.5 | 2.61 | 3.0 |
| 14 | 15.87 | 88.0 | 1.80 | 1.8 |
| 15 | 23.40 | 93.0 | 2.52 | 2.3 |
| 16a | 0.71 | | | 0.9 |
| 16b | 35.44 | 47.6 | 7.45 | 8.7 |
| 17 | 26.86 | 40.5 | 6.63 | 5.3 |
| 18a | 2.45 | | | 0.5 |
| 18b | 39.29 | 50.0 | 7.86 | 7.8 |
| 19a | 1.35 | | | 0.9 |
| 19b | 15.43 | 61.0 | 2.53 | 6.5 |

Fig. 7 also shows that the water structure both in the northeastern tip (Transects 4-6) and just outside of the valley (Transects 18-19) are less stratified than that in the central area (Transects 7-17). A very warm core of water existed at about 200 m in the southwestern strait (Transects 10-16) where the width of strait is greatest.

Geostrophic transport and geostrophic speed were derived from waterproperty observations (Table 4 and Fig. 8). The calculation is based on the assumption of two-layered flow, i.e., southwestward flow between the surface and 150 m, and reversed flow below 150 m. Therefore a depth of no motion of 150 m was assumed at most stations except at the northern tip where 100 m depth of no motion was applied because of shallow topography A large amount of water with relatively high geostrophic speed (e.g., transport and speed are 0.14 Sv. and 11.0 cm/sec, respectively; 1 Sv$=10^6$ m$^3$/sec)

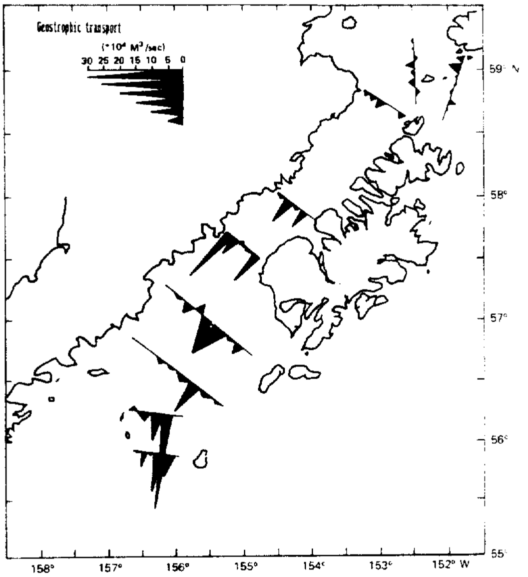

Fig. 8. Baroclinic transport (0-150 m) in Shelikof Strait during March, 1985.

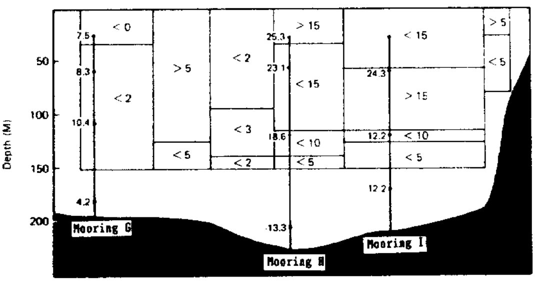

Fig. 9. Estimates of baroclinic speed (0/150 db) and observed speed from mooring current meters in March, 1985. In order to remove tidal effect, the mooring current data (three days before and after CTD cast data) were 35-hour filtered and resampled at 6-hourly intervals. Unit is cm/sec.

entered the strait via Kennedy Entrance and north Barren Is., while a very small amount was transported into the strait via Stevenson Entrance. The geostrophic transport and velocity generally are highest in the surface layer along the deepest part of each transect. The flow direction changed from NE-SW to N-S to the east of Sutwik Is. and increased velocity and transport near the valley area. Velocities were high in the northeastern strait (Transects 4-9), and the southwestern end (Transects 16-19). In the southwestern strait (Transects 10-15), velocities rapidly decreased and/or reverse-directed currents were found. Large transport, roughly speaking, was shown in the boundary between the northeastern and the southwestern parts of the strait (Transects 8-9) and the southwestern end (Transects 16-18), while small transports were in the northeastern tip, and bank areas in the southwest.

Geostrophic current speed and the observed current speed from the southern valley are shown in Fig. 9. The geostrophic speeds were lower than observed current speeds because the barotropic current is included in actual measurements and should be significant in this area during spring (Schumacher and Reed, 1980). However, these two speed values seem to have the same trend; in the eastern and central valley the speeds were high in the surface layer and reduced with depth, while the speeds of western valley were low in the surface layer and increased in middle layer.

The wind pattern is very closely related to oceanic currents. In the Gulf of Alaska, winds have different strengths and directions with respect to season and location. In general surface winds in the open ocean are roughly parallel to isobars and strong (8-11 m/sec) during the winter but weak (6-7 m/sec) during the summer (Schumacher and Wilson, 1985). Because winds flow counterclockwise around a low pressure center in the northern hemisphere, offshore winds are predominant from the south in the eastern Gulf, from the east in the north-central region, and from the west, but highly variable, near the Aleutian Is. (Brower et al., 1977). In the coastal area, however, the wind characteristics are different from those in the open sea, because wind fileds are modified by the presence of coastal mountains. Whenever geostrophic imbalances occur due to variations in sea surface temperature or small-scale radiation or latent-heat release in clouds over the open sea, a geostrophic adjustment process which returns conditions to a geostrophically balanced state occurs within about 12 hours. The geostrophic imbalance caused by a coastal mountain arc, however, cannot be adjusted in the same manner, because the wind cannot flow through the mountain barrier; within the Ro-

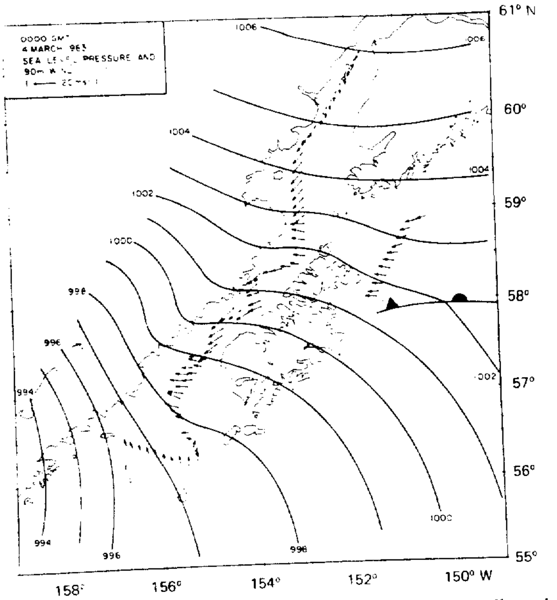


Fig. 10. Surface winds and sea level pressure collected from the NOAA WP-3D aircraft in March, 1983 (from Macklin et al., 1984).

ssby radius (e.g., a distance of 80 km of a 1500-2000 m coastal mountain range), the wind direction depends upon the direction of isobars in relation to the coastline as mentioned in Schumacher and Wilson (1985). In this case, it is difficult to predict wind strengths from geostrophically balanced pressure gradients. Northeastern Shelikof Strait has a smaller width than the Rossby radius so that winds tend to accelerate parallel to the pressure gradient when isobars are perpendicular to the Strait. Fig. 10 shows an example of this: On 4 March 1983, the wind east of Kennedy and Stevenson Entrances roughly paralleled the isobars over the open ocean. The winds in the north part of Shelikof Strait were similar in direction but speeds were accelerated somewhat. In the northeastern strait, the winds increased in magnitude toward the southwest as they accelerated down the pressure gradient. As they approached southwestern strait, they decelerated.

Because the spawning period of walleye pollock is almost the same each year in Shelikof Strait, the effects of environmental variations should be investigated to understand variations in the strength of future recruitment. There are large interannual fluctuations in physical properties and current strength. For example, during the spring 1985, the surface temperature was colder than that during the spring 1981, but the bottom temperature in 1985 was warmer than that in 1981 (Kendall and Kim, 1989). Therefore, the temperature difference between top and bottom was larger in 1985 compare to that in 1981. In 1985, salinity and sigma-t were higher through the water column in 1981. Because of the presence of cold and saline water in the upper layer in March 1985, dynamic heights in the main spawning area were lower than during 1981 (i.e., means of 0.289 and 0.275 dynamic meters in 1981 and 1985, respectively (Kim, 1987)). The Mixed Layer Depth (MLD), which was defined as the depth at which sigma-t increased by 0.03 units per meter, of the central strait during late March was greater in 1985 (mean and S.D. are of 37.4 m and 26.1 m (unpublished data)) compared to 1981 (mean and S.D. are 22.4 m and 15.2 m, respectively) due to the delay of surface warming and possibly an increased wind mixing in 1985. Also the monthly means of current speed varied year after year. For example, over the valley area, surface current speeds in 1985 in March were higher than those in February (Moorings G and H), while speed in 1978 was reduced in March compared to that in February (Mooring K12A in Kim (1987)).

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