Andrzej FURTAK, Andrzej MAJEWICZ
Sea Fisheries Institute
Department of Oceanography — Gdynia

THE HYDROLOGICAL CHARACTERISTICS OF THE SHELF WATERS IN THE GULF OF ALASKA (SUMMER 1977)

1. REGION AND METHOD OF INVESTIGATIONS

From 4th July to 3rd August 1977, hydrological and biological investigations were carried out in the shelf waters of the Gulf of Alaska under the programme of Polish-American co-operation, on board the r/v „Profesor Siedlecki". The objective of the investigations was to explore the physico-chemical and biological conditions of the marine environment, as well as the food resources and population of utilizable fish.

The hydrological investigations were carried out by the Polish team including the American oceanographer James Ingraham (NMFS Northwest and Alaska Fisheries Center, Seattle, Washington) whom we would like to thank for his co-operation.

During the cruise, measurements were carried out of the temperature, salinity and oxygen dissolved in water at 157 oceanographic stations, the majority of which were situated on 22 profiles perpendicular to the slope. They covered an area extending from Dixon Entrance to Portlock Bank (on a level with the northern part of Kodiak Island). Accordingly, almost the whole shelf of the Gulf of Alaska was explored (Fig. 1). The measurements of the hydrological elements were carried out at standard levels. The depths of the stations varied between 50 and 1500 m, the depth of the last measurement above the bottom varying. At the standard stations, water for chemical analyses was sampled by means of Nansen bottles, its temperature being measured by reversible thermometers and an MG-9 III bathothermograph. The sali-

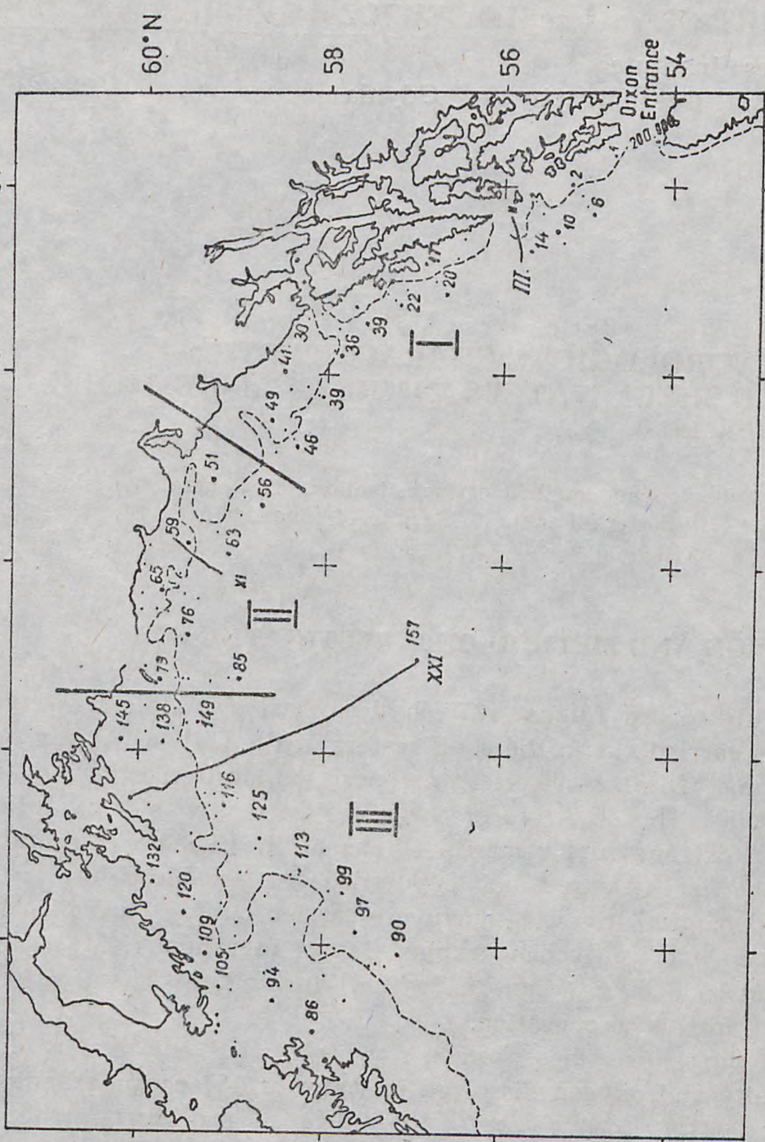


Fig. 1. Distribution of stations, profiles and separated hydrological regions in the Gulf of Alaska. July 4th — August 3rd, 1977.
Rys. 1. Rozmieszczenie stacji, profili i wydzielonych rejonów hydrologicznych w zatoce Alaska. 4 VII—3 VIII 1977 r.

nity was determined by an Autolab salinometer (model 601-M III) and the oxygen content in water by the Winkler method.

During the first leg of the cruise, vertical temperature distributions and salinity were measured at the complementary stations by STD-9060 and STD-9006 multisensor probes offerred by the American side, as the vessel's $STDO_2$-9040 probe had been sent for inspection and testing to its parent firm Bisett-Berman, San Diego.

Calculations of the values of the hydrological parameters measured and further processing of the data were carried out on board using the seagoing computer Elliot 905.

2. GENERAL HYDROLOGICAL CONDITIONS OF THE NORTH-EASTERN PACIFIC

The main factor responsible for the hydrological conditions in this area is the Subarctic Current which carries warm water masses eastward. Off the west coast of North America, on a level with Vancouver Island, the waters of this current separate. The major part of the waters flows southward along the west coast shelf of the U.S.A. in the form of the cold California Current System [6], whilst to the north of this bifurcation the hydrological situation is complicated by the superposition of the vertical and horizontal circulation of water masses and strong interaction and variability of meteorological conditions. The warm Alaska Current System is formed as a result of the interaction of these processes [2].

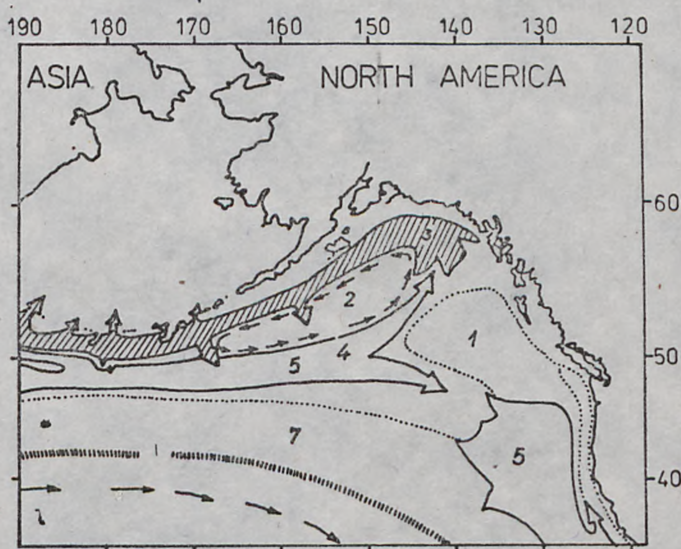


Fig. 2. General system of sea currents in south-eastern Pacific.
1 — Dilute Domain, 2 — Ridge Domain, 3 — Alaska Current System, 4 — Alaska Gyre, 5 — Subarctic Current System, 6 — California Current System, 7 — Transition Domain, 8 — Subarctic Boundary. — After Favorite et al., 1976.

Rys. 2. Ogólny system prądów morskich w północno-wschodnim Pacyfiku.
1 — strefa rozcieńczenia, 2 — strefa wynoszenia, 3 — Prąd Alaski, 4 — Wir Alaski, 5 — Prąd Subarktyczny, 6 — Prąd Kalifornijski, 7 — strefa przepływu, 8 — granica rejonu subarktycznego. — Według Favorite'a i in., 1976.

Recent oceanographic investigations have shown that the dominant hydrological phenomena in the Gulf of Alaska are: The Alaska Gyre, a divergence region referred to as the Ridge Domain and the peripheral inflow of waters of the Alaska Current System. As an outcome of seasonal climatic variations in summer, fresh waters from the melting ice flow from the coast into the bifurcation region of the Subarctic Current producing low salinity at the surface, referred to as the Dilute Domain [2] (Fig. 2).

Along the continental slope, at depths of 200—300 m, a continuous, northerly movement of waters occurs which is called the California Undercurrent [2, 5, 6]. The presence of this undercurrent causes two water masses of subarctic and equatorial origin to mix along the Western Coast of the U.S.A. from California to the Gulf of Alaska [5, 8].

Ingraham, Bakun and Favorite distinguish 4 basic types of vertical circulation of water in this area caused by tangent pressure of the wind (the Ekmàn transport) in the coastal zone. There is the transport to and from the coast, as well as upwelling and downwelling in the pelagic and bottom layers. In the two extreme cases a circular movement of water is observed (A, D). The mechanism of producing these types of circulation (A, B, C, D) is shown in Fig. 3.

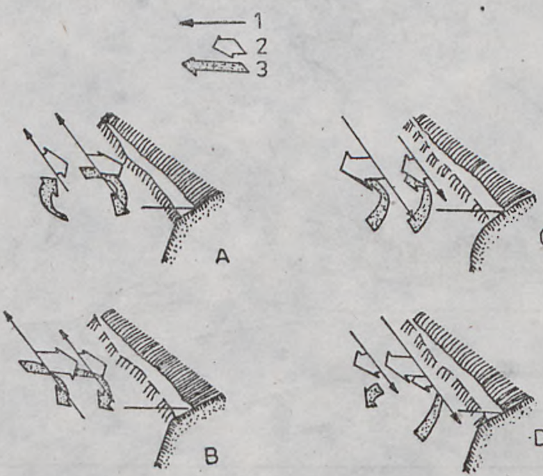


Fig. 3. Types of the forced upwelling of water in the shelf zone of the Gulf of Alaska.
1 — Wind Stress Vector, 2 — Ekman Transport Vector, 3 — Upwelling — Downwelling Vector. — After J. Ingraham et al., 1976.

Rys. 3. Typy wymuszonej cyrkulacji pionowej wody w strefie szelfowej zatoki Alaska.
1 — składowa prędkości wiatru, 2 — składowa transportu Ekmana, 3 — kierunek cyrkulacji wody. — Według J. Ingrahama i in., 1976 r.

During investigation of the south-eastern region of the Gulf of Alaska, the occurrence of clear-cut circulation of type A and poorly-pronounced circulation of type D were found [1, 2, 4].

3. RESULTS OF INVESTIGATIONS

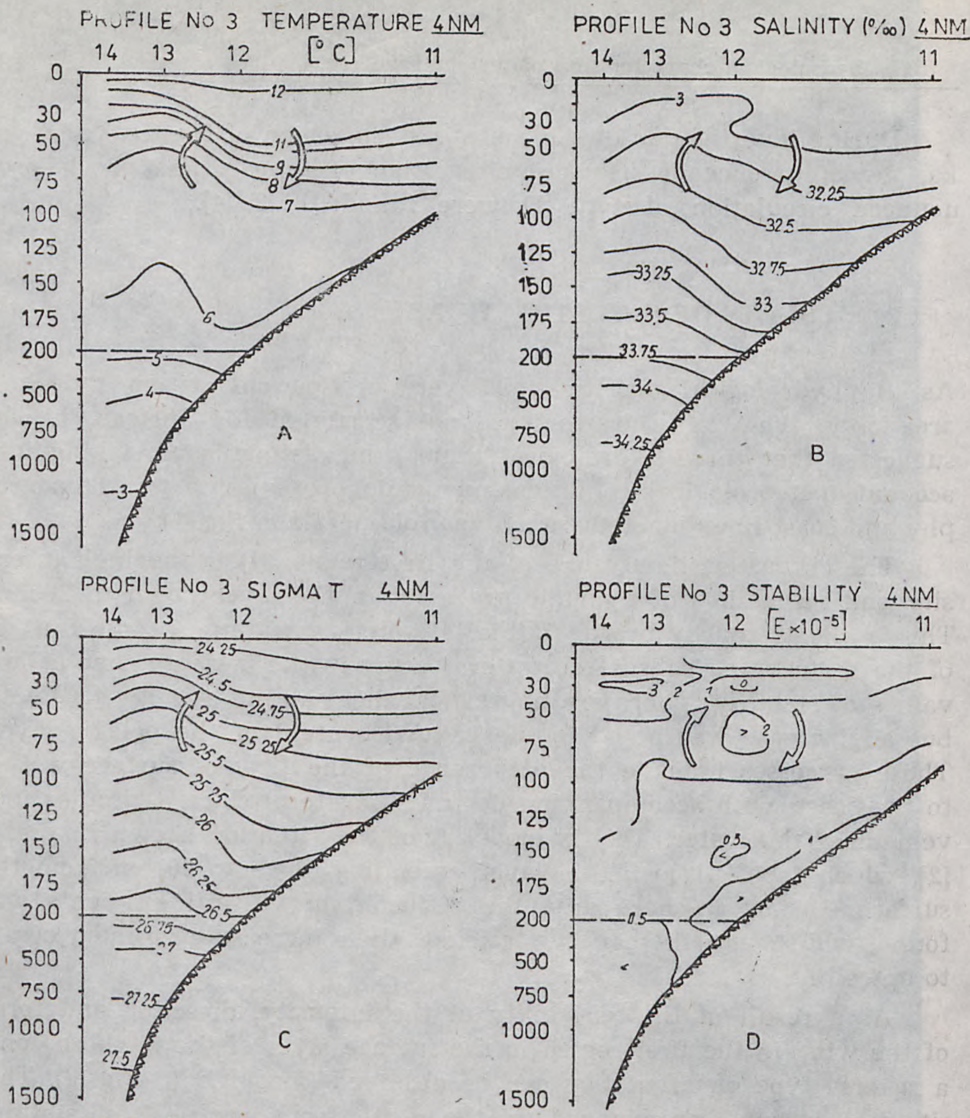
As the hydrological investigations were carried out within the shelf area only, the water masses were not accounted for. Instead, it was suggested that three hydrological regions be distinguished, taking into account meteorological conditions, dynamic processes, bottom topography and coast line (denoted with Roman numerals in Fig. 1).

The characteristic feature of the first region (I) is the high intensity and variability of dynamic processes in the layer down to 200 m. This is illustrated by profile 3 (Fig. 4) where warming up and diluting of the surface and subsurface waters occurs in the in-shore zone at low values of stability. There are no vertical thermal and salinity gradients, but an increase was noted in the oxygen content of the pelagic layer. These processes indicate the occurrence of the flow of surface waters to the coast, with accompanying downwelling to produce a circular movement of the water. This is model A of the situation shown in Fig. 3 [2], which takes place in the layer extending down to 200 m from the surface. In the in-shore area the diffusion of vertical gradients was found, whilst over the continental slope their increase was noted owing to upwelling.

As a result of the variability of the intensity, direction and force of the wind in the first region in the surface layer of the in-shore zone, a reverse type of circulation can be observed (model D in Fig. 3). This situation became pronounced to the north from profile 3 at stations No. No. 17 — 25 and appeared less distinctly. As the profiles were too short, it was not possible to observe the whole process.

Below the 200-m layer there is an increace in salinity and a decrease in oxygen content with slight decrease in temperature. This is indicative of the occurrence, in this area, of the California Undercurrent waters. On the other hand, surface waters were characterized by the absence of horizontal gradients of these hydrological elements (Fig. 5).

In the second region (II), in the surface layer, in the in-shore zone south-east of Kayak Island, there was an intense inflow of continental waters, expressed in the occurrence of sharp horizontal gradients of salinity and density (Fig. 5B and C). Thermal differences in the surface layer, caused by the inflow of cold glacial waters, are permanently sup-



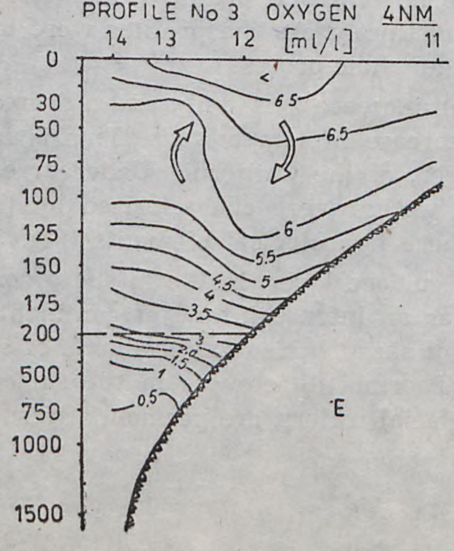


Fig. 4. Temperature of water (A), salinity (B), sigma — t (C), stability (D) and oxygen level in water (E) on profile No. 3. July 6th — July 7th, 1977.

Rys. 4. Temperatura wody (A). zasolenie (B), gęstość (C), stabilność (D) i zawartość tlenu w wodzie (E) na profilu nr 3. 6 VII — 7 VII 1977 r.

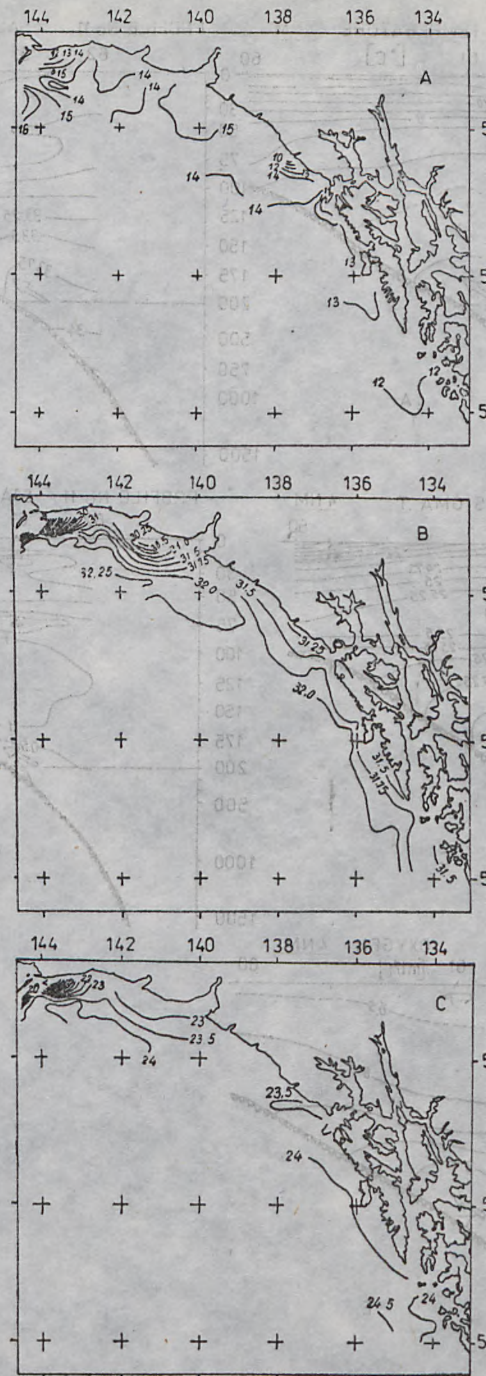


Fig. 5. Temperature of water (A), salinity (B) and sigma — t (C) on the surface of shelf waters of the eastern part of the Gulf of Alaska. July 4th — July 18th, 1977.

Rys. 5. Temperatura wody (A), zasolenie (B) i gęstość (C) na powierzchni wód szelfowych wschodniej części zatoki Alaska. 4 VII — 18 VII 1977 r.

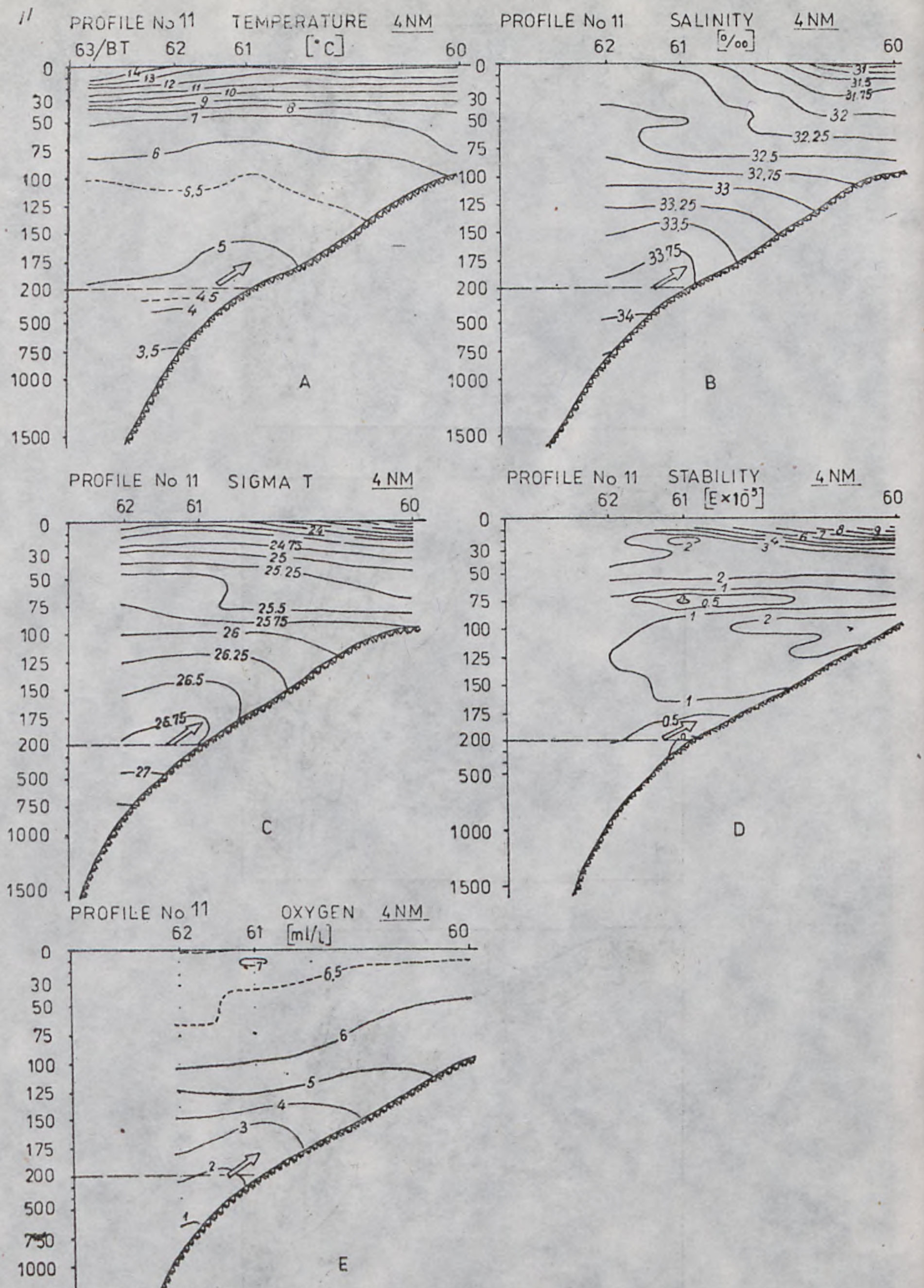


Fig. 6. Temperature of water (A), salinity (B), sigma — t (C), stability (D) and oxygen level in water (E) on profile No. 11. July 15th, 1977.

Rys. 6. Temperatura wody (A), zasolenie (B), gęstość (C), stabilność (D) i zawartość tlenu w wodzie (E) na profilu nr 11. 15 VII 1977 r.

pressed by the warming up of the sea surface (from warmer air masses and insolation during the summer months), to give a high thermal homogeneity over a large area (Fig. 5A).

Owing to the dynamic inflow of the waters to the continental slope, the pelagic waters have lower temperatures and higher salinity. This process is most distinct on profile 11 (Fig. 6). In the case of oxygen, some irregularity is noticeable, which consists in an enhanced oxygen level in the 30—250-m layer, as compared with the first region.

Region III is situated in the north-western part of the Gulf of Alaska. Owing to the considerable breadth of the shelf (167 km) and tidal currents, there is an intense mixing of bottom waters in the most shallow parts of the bank. This is indicated by even temperatures and low water stability, as well as the vertical position of salinity and density iso--lines (Figs. 7—9).

In the northern area of the region in the in-shore zone, there is a distinct inflow of fresh waters. This is indicated by sharply pronounced horizontal and vertical gradients of salinity, density and stability. On the outher side of the shelf, at stations No. No. 153 and 154, characteristic deflection of iso-lines occurred, indicating the appearance of the warm Alaska Current waters. Further out towards the open ocean, at stations No. 156 and 157 over the whole water body, rising of all iso-lines of the elements to the surface is discernible in this region (the Ridge Domain) [2, 3].

On the profile 21, the depth of the mixing layer is differentiated, amounting to about 10 m in the in-shore zone, 15 m over the slope and 20 m in the open ocean. The thermocline was most distinet beyond the shelf, whilst above it a drop in the gradient was noted, this being dependent on the predominance of tidal currents in the shallowest parts of the shelf and ascending movements beyond it.

In Fig. 10 two T — S curves are shown. The dashed curve was plotted on the basis of the mean results of many years' investigations carried out in the region of Montague Island in a square 2^0x2^0 [5]. The continuous line represents our own investigations carried out in July, 1977. By comparison of the two curves it was ascertained that in July 1977 the hydrological conditions differred from the mean. In the layer down to 125 m from the surface the water in the square considered was warmer and more saline. The greatest differentiation in the salinity occurred in the 20-m surface layer owing to smaller than usual amounts of fresh waters flowing in summer into the Gulf of Alaska. In July 1977, the characteristic thermal minimum at a depth of 100 m was absent and the inflection point on the T — S curve appeared at a depth of 150 m. These findings together with personal communications are indicative of the un-

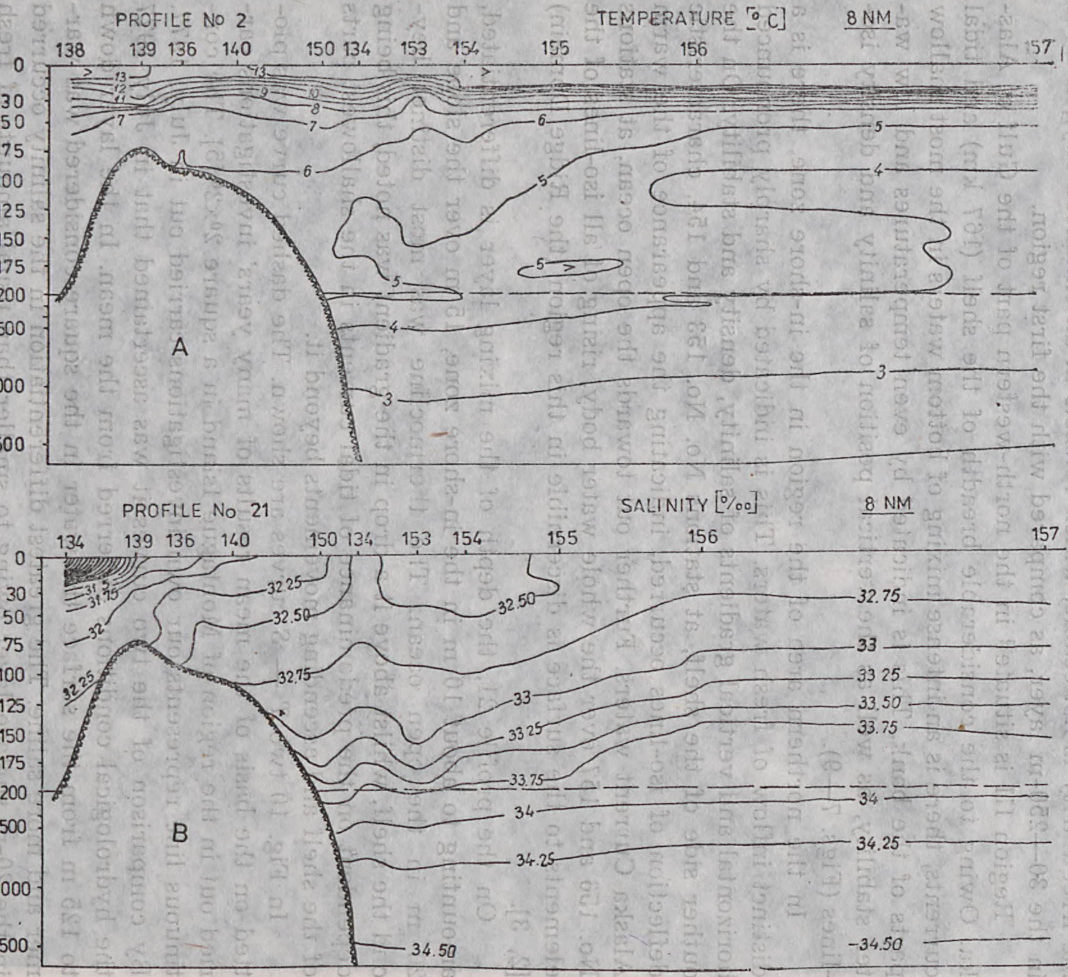


Fig. 7. Temperature of water (A) and salinity (B) on profile No. 21. July 30th — August 3rd, 1977.
Rys. 7. Temperatura wody (A) i zasolenie (B) na profilu nr 21. 30 VII — 3 VIII 1977 r.

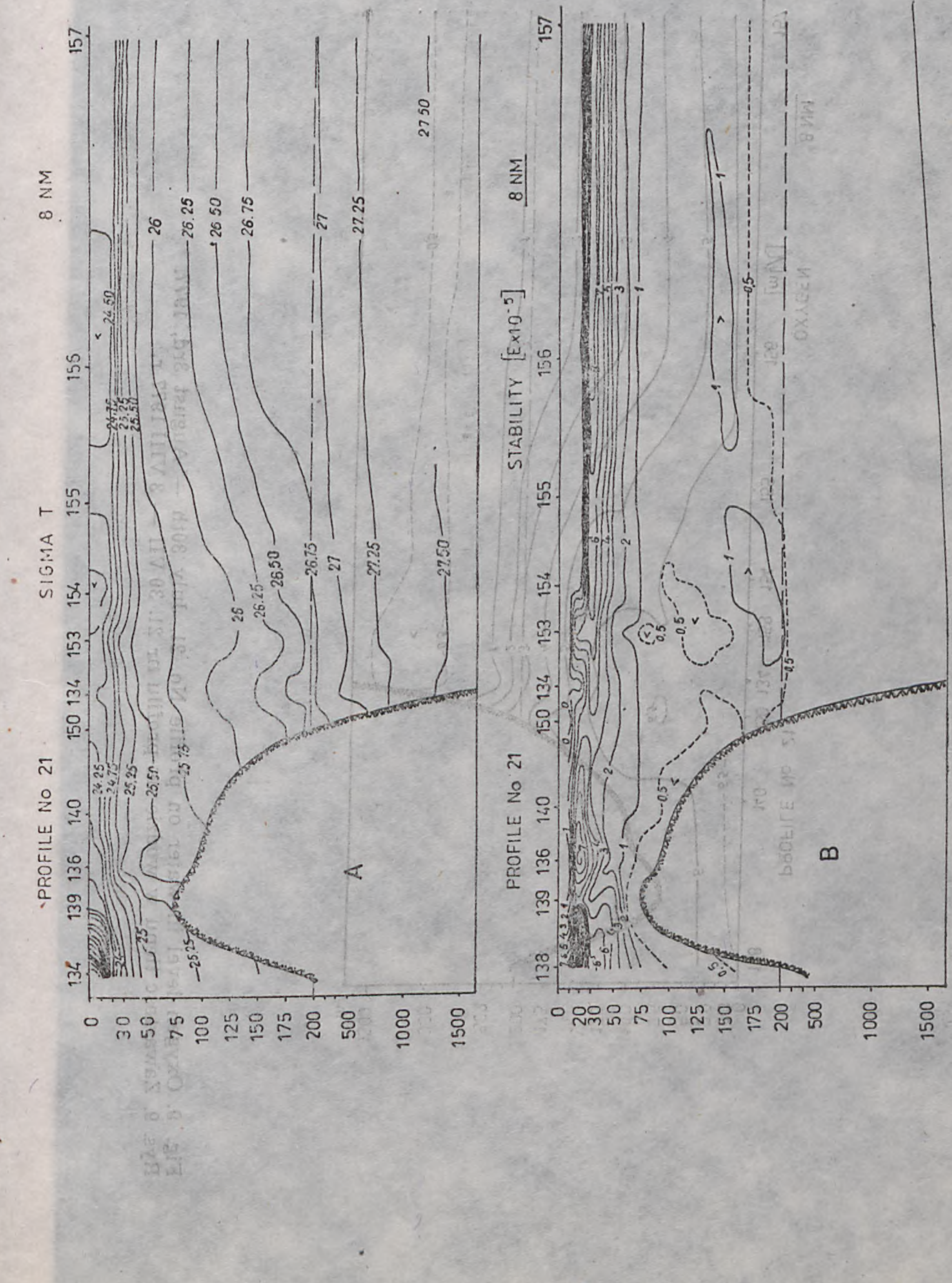


Fig. 8. Sigma — t of water (A) and stability (B) on profile 30 VII — 3 VIII 1977 r.
Rys. 8. Gęstość wody (A) i stabilność (B) na profilu nr 21 No. 21. July 30th — August 3rd, 1977.

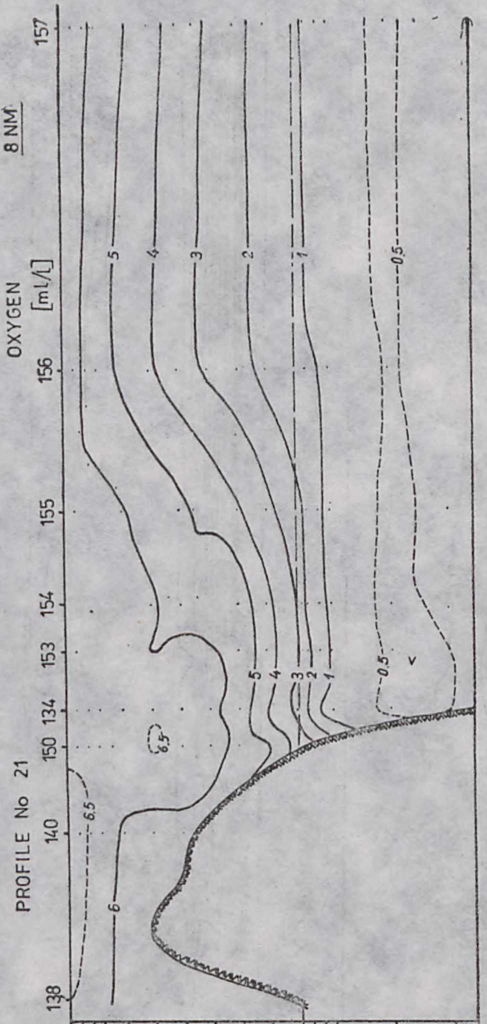


Fig. 9. Oxygen level in water on profile No. 21, July 30th — August 3rd, 1977.
Rys. 9. Zawartość tlenu w wodzie na profilu nr 21. 30 VII — 3 VIII 1977 r.

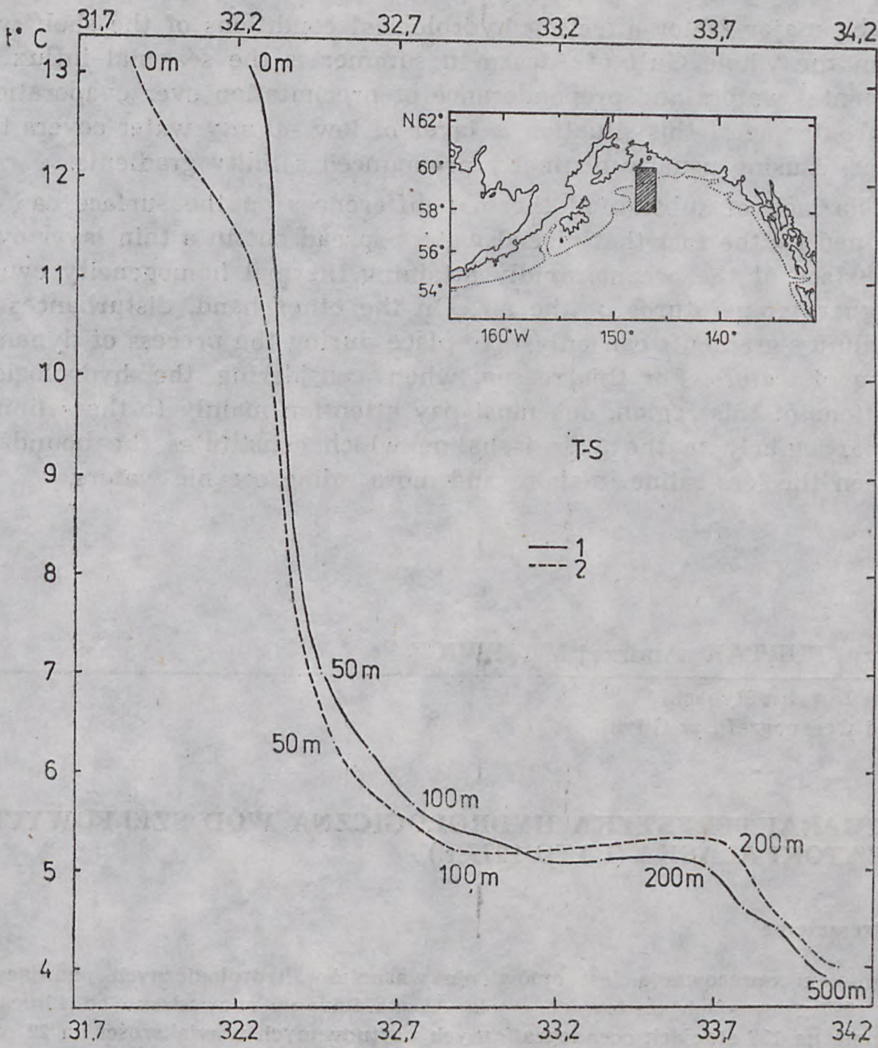


Fig. 10. T — S curves in a square 2×2° (marked in the map).
1 — r/v „Profesor Siedlecki", summer, 1977; 2 — many years' data, summer. — After J. Ingraham et al., 1976.

Rys. 10. Krzywe T — S otrzymane w kwadracie 2×2° (zaznaczony na mapce).
1 — statek „Profesor Siedlecki", lato 1977 r., 2 — dane wieloletnie, lato. — Według J. Ingrahama i in., 1976 r.

typical winter season preceeding the investigations. It was characterised by higher air temperatures than normal and little precipitation. The reverse situation was noted below the point of intersection of the T — S curves, where lower temperatures and salinity were noted. This was most probably due to decreased thermal activity of the Alaskan Current in the square considered.

The major factor affecting hydrological conditions of the shelf waters in the whole Gulf of Alaska in summer is the seasonal influx of continental waters and preponderance of precipitation over evaporation. As an outcome of this situation, a layer of low salinity water covers the surface, causing usually distinctly pronounced salinity gradients.

The lack of substantial thermal differences on the surface can be explained by the fact that glacial waters spread out in a thin layer over the surface of the ocean, rapidly attaining thermal homogeneity owing to higher temperatures of the air. On the other hand, disturbances in the salinity gradients can only take place during the process of dynamic mixing of waters. For this reason, when considering the hydrological conditions of this region, one must pay attention mainly to the salinity, and particularly to the 32‰ isohaline which constitutes the boundary between the less saline in-shore and more saline oceanic waters.

Andrzej FURTAK, Andrzej MAJEWICZ

Morski Instytut Rybacki
Zakład Oceanografii w Gdyni

CHARAKTERYSTYKA HYDROLOGICZNA WÓD SZELFOWYCH ZATOKI ALASKA (LATO 1977 r.)

Streszczenie

Przedmiotem opracowania jest omówienie warunków hydrologicznych panujących latem 1977 r. w wodach szelfowych zatoki Alaska. Badania prowadzono od 4 lipca do 3 sierpnia na 157 stacjach oceanograficznych usytuowanych w większości na 22 profilach prostopadłych do stoku. Na każdej stacji oznaczano temperaturę, zasolenie i zawartość tlenu w wodzie na poziomach standardowych.

Uwzględniając procesy dynamiczne, warunki meteorologiczne, ukształtowanie dna morskiego i linii brzegowej oraz procesy lokalne, takie jak np. napływ wód roztopowych do zatoki, wydzielono tu trzy rejony hydrologiczne (rys. 1). W pierwszym przeważa pionowa cyrkulacja w warstwie powierzchniowej (typ A i słabo ukształtowany typ D — rys. 3), w drugim proces wysładzania na powierzchni (napływ wód roztopowych — rys. 5 B i C) przy równoczesnym wynoszeniu wód głębnych na stok, w trzecim zaś prądy pływowe i napotkanie wód Prądu Alaski (poza szelfem na stacjach 156 i 157 — rys. 7 i 8).

Analiza porównawcza oparta na krzywych *T-S* dla wartości średnich wieloletnich wykazała, że w sezonie letnim 1977 r. wody szelfowe w północnej części zatoki Alaska, w warstwie od powierzchni do głębokości 125 m, były cieplejsze i bardziej słone (rys. 9). Świadczy to o nietypowym okresie zimowym poprzedzającym

badania, a więc o małej ilości wód słodkich (roztopowych) napływających tego lata do zatoki Alaska. Rozpatrując warunki hydrologiczne tego obszaru, należy zwrócić głównie uwagę na zasolenie powierzchniowe, a szczególnie na izohalinę 32‰ stanowiącą granicę między wodami przybrzeżnymi i oceanicznymi.

REFERENCES

1. Bakun A., *Coastal Upwelling Indices West Coast of North America, 1946—1971*, NOAA, Technical Report, NMFS — 671, Seattle, Wash., 1973.
2. Favorite F., A. J. Dodimead, K. Nasu, *Oceanography of the Subarctic Pacific Region, 1960—1971*, International North Pacific Fisheries Commission, Bulletin No. 33, Vancouver 1976.
3. Favorite F., T. Laevastu, R. R. Straty, *Oceanography of the North-eastern Pacific Ocean and Eastern Bering Sea and relations to various living marine resources*. North-West and Alaska Fisheries Center, Processed Report, Seattle, Wash., 1977.
4. Ingraham W. J., *The Geostrophic Circulation and Distribution of Water Properties off the Coasts of Vancouver and Washington, Spring and Fall 1963*, Bureau of Commercial Fisheries Biological Laboratory, Seattle, Wash., 1967.
5. Ingraham W. J., F. Favorite, A. Bakun, *Physical Oceanography of the Gulf of Alaska. Environmental Assessment of the Alaska Continental Shelf*. Final Report RU-357, NOAA, Seattle, Wash., 1976.
6. Sverdrup H. U., M. W. Johnson, R. H. Fleming, *The Oceans. Their Physics, Chemistry and General Biology*, New York, 1942.
7. *South-East Alaska Pilot, Dixon Entrance to Cook Inlet*. Fifth Edition, 1972.
8. Tibby R. B., *The Water Masses off the West Coast of North America*, Journal of Marine Research, Vol, IV, 1941, No. 2.