CURRENTS IN SOUTHEASTERN BERING SEA

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ABSTRACT

During an investigation of the tidal and average currents in southeastern Bering Sea, carried out in June 1957, the currents were observed at four anchor stations by means of an Ekman current meter. Dextrally rotating tidal currents occurred on the two offshore stations, and greatly compressed rotary tidal currents varying in direction of rotation occurred on the two inshore stations. The flow of the average current indicated a counterclockwise circulation.

These currents may affect the movement of king crabs in the planktonic stage.

TABLE OF CONTENTS

INTRODUCTION

The movements and physical characteristics of the water in the king crab fishery of southeastern Bering Sea (Figure 1), were investigated in June, 1957, to determine the tidal and average currents in an effort to assess the possible effects they may have on the king crab, *Paralithodes camtschatica* (Tilesius). This investigation was undertaken as part of the program of the King Crab Investigation of the United States Fish and Wildlife Service. The results contribute primarily to the knowledge of the currents observed in southeastern Bering Sea and also to the determination of the effects of the currents on the king crab in the planktonic stage. Future investigations will attempt to relate the water movement to other stages in the life cycle of the crab.

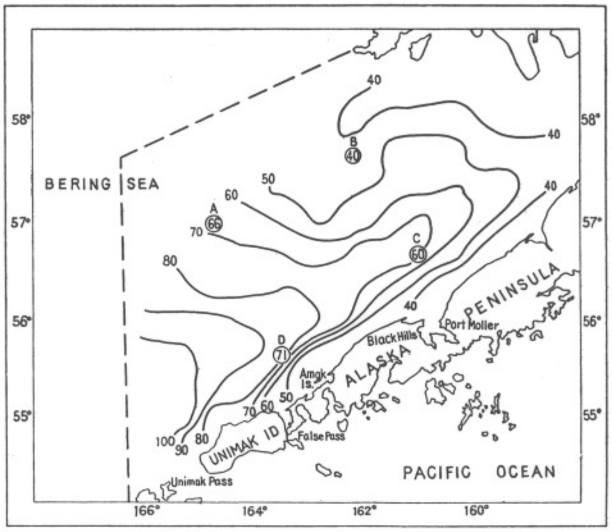

FIGURE 1. Southeastern Bering Sea (within dashed lines) showing current stations and their depths along with the depth contours for the king crab fishery area. Depths given in meters.

The area under investigation is triangular in shape, with an apex in the Bristol Bay region. The land adds freshwater runoff through many streams, among the largest being the Ugashik, Egegik, Naknek, Kvichak and Nushagak Rivers, all of which empty into the Bristol Bay region. The bottom topography is one of gradually increasing depth from Bristol Bay toward the southwest (Figure 1).

The positions of the four current stations are shown in Figure 1. The maximum depths at the sampling stations A, B, C and D are 66, 40, 60 and 71 meters, respectively.

Previous current studies covering part of the same area (surrounding and between stations C and D) were made by scientific personnel aboard the Japanese king crab mothership, *Tokei-maru*, during the crabbing seasons of 1955 and 1956 (International North Pacific Fisheries Commission, 1957). The 1955 data show that the tidal current flowed west-southwest during the ebb-tide hours and east-northeast during the

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flood-tide hours. In 1956, this general pattern sometimes became obscure. The recorded tidal current velocities did not exceed 1.5 knots in either year.

Past studies contributing to the knowledge of water circulation in and around southeastern Bering Sea include those by the U.S. Coast Guard (1936), Thompson and Van Cleve (1936), and the several mapping, tide, and current surveys made by the U.S. Coast and Geodetic Survey for the Tide and Current Tables for the Pacific Coast of North America.

Dr. Richard H. Fleming and Dr. Maurice Rattray of the Department of Oceanography, University of Washington, generously helped plan the study. Thomas S. Austin, James W. McGary, and Gunter R. Seckel of the U. S. Fish and Wildlife Service, Pacific Oceanic Fishery Investigations, also reviewed the manuscript and made many useful suggestions.

METHODS

From an anchored vessel, the currents were observed at three meters, the top and bottom of the thermocline (where present), and near the bottom, every hour for 38 hours at each of four positions (anchor stations). An Ekman current meter (Ekman, 1932), recording both current velocity and direction, was used for the observations. No correction for the roll of the ship was attempted because during the observations, except at station B, the roll was usually nonexistent.

Before the beginning of the observation period at each station, a bathythermograph (BT) trace was taken to determine the thermocline depth, thereby locating the sampling depths between the surface and the bottom observed depth. (Because of isothermal conditions on station B, only three depths were observed.) The mid-depths thus found were then used throughout the sampling period, regardless of possible later changes in the thermocline depth.

In the analyses of the data for the currents involved, portions of the methods described in both the Manual of Current Observations (U.S. Coast and Geodetic Survey, 1950) and the Admiralty Manual of Tides (Doodson and Warburg, 1941) were used. Tables from the Manual of Current Observations were used to resolve the observed hourly velocities for each station into their respective north and east component velocities which include both the tidal and nontidal currents. (Negative north or east values for the components indicate a current flowing south or west, respectively.) After the component velocities were obtained, the method for obtaining mean sea level by use of multipliers was used (Doodson and Warburg, 1941, p. 111, Table 13.6) to extract the average current from the hourly components. This method has the advantage of reducing casual error which would probably be found in the hourly observations. By then subtracting the north and east components of the average current from the corresponding components of the observed current for each hourly observation, the north and east components of the tidal currents were obtained.

TIDAL CURRENTS

Observations of tidal currents occurring in southeastern Bering Sea show that both rotary and reversing movements occur, the rotary on the more offshore stations (A and B), the usual locus for this type of tidal current; and the reversing on the inshore stations (C and D). The rotation period for all stations was semi-diurnal, accompanied by cyclic variations of the current velocity, also semi-diurnal, thus showing the relationship between the currents and the tidal cycle. Figures 2 through 5 are hodographs of the tidal currents, these showing the hourly observed velocity and direction, the change in current direction between observations and the characteristic rotation occurring on each station.

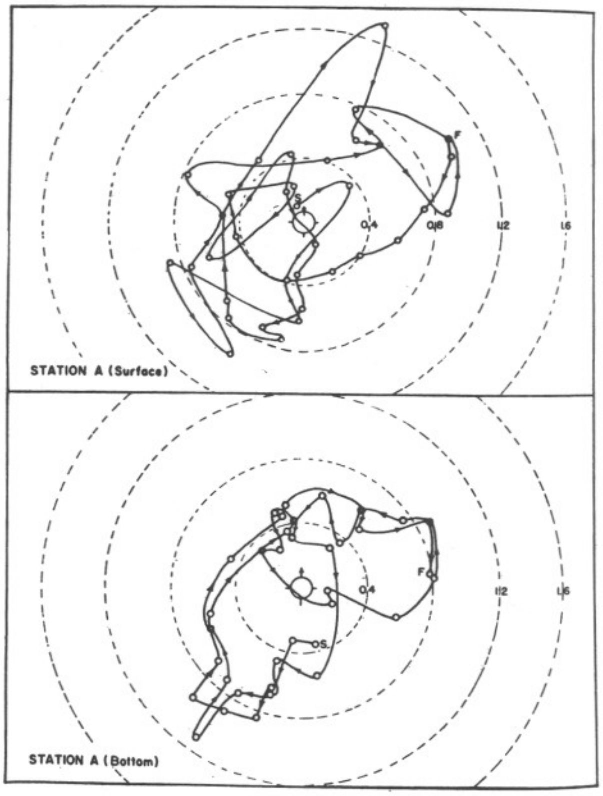

FIGURE 2. Station A hodograph of surface and bottom tidal currents.

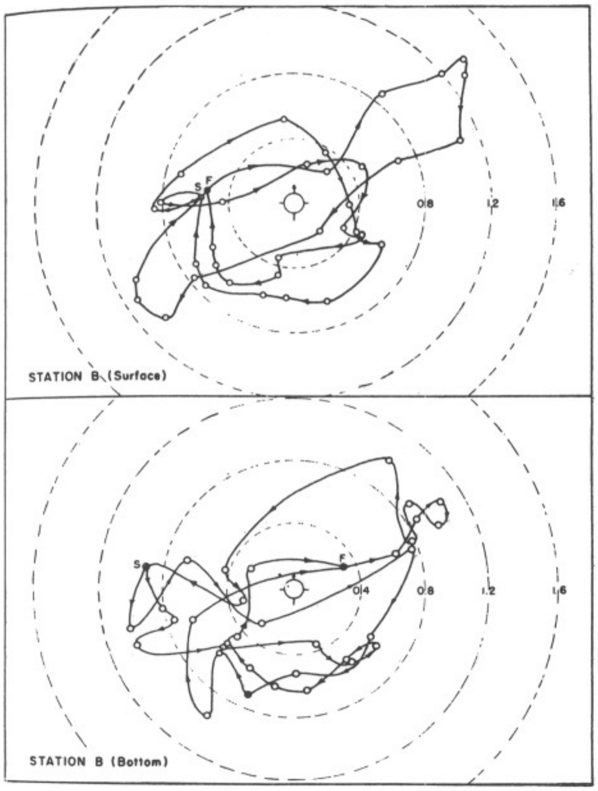

FIGURE 3. Station B hodograph of surface and bottom tidal currents.

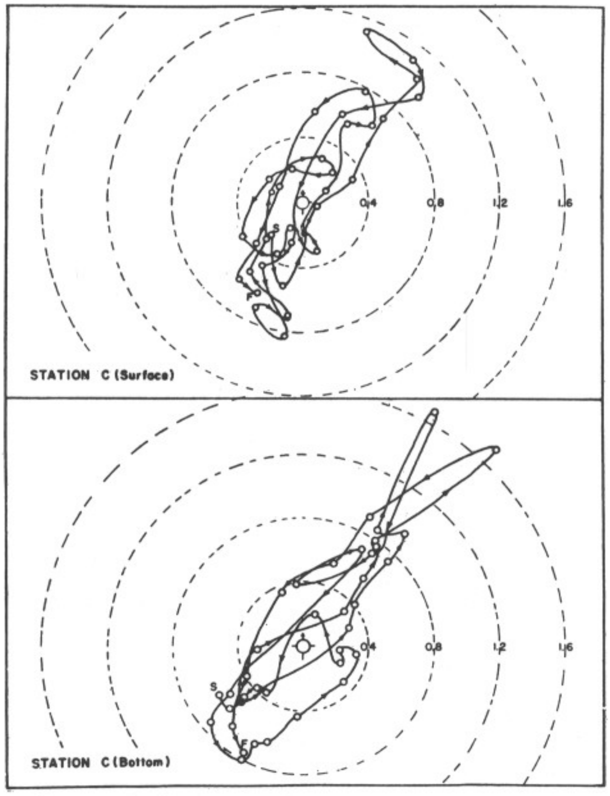

FIGURE 4. Station C hodograph of surface and bottom tidal currents.

In the northern hemisphere, the normal rotation of a rotary current is dextral, unless some other interfering force modifies the rotation. On station A, the rotation was normal at all observation depths; but on B, the direction of rotation varied with depth. Dextral deviation occurred at the surface, while at 20 meters and 40 meters the pattern was confused, both dextral and sinistral rotation occurring at each depth. This pattern is shown in Figure 3.

To determine the principal flood and ebb directions of the rotary currents, the average maximum flood and ebb currents were used, these showing, with slight individual station variation, that the flood and ebb were generally in a northeast-southwest direction at all observation depths. The directions of the flood or ebb and their variations in average velocity and direction with increased depth are shown in Table 1.

On stations C and D, the tidal currents were essentially reversing but with slight rotation, the amount increasing with depth to the bottom on C but remaining approximately the same at all depths on D. Because of the slight rotation, apparently no slack water occurred, as is associated with the completely reversing type of tidal current movement.

TABLE 1. Mean tidal currents for each depth and for the whole water column.

Station	Obs. Depth (m.)	Ebb		Flood	
		Vel. (kt)	Dir. °T	Vel. (kt)	Dir. °T
A	3	0.59	213	0.62	040
	11	0.65	214	0.72	065
	25	0.68	214	0.70	047
	65	0.67	220	0.51	062
	Mean	*0.65*	*215*	*0.65*	*054*
B	3	0.68	238	0.64	056
	20	0.70	235	0.74	080
	40	0.60	237	0.68	065
	Mean	*0.66*	*237*	*0.69*	*067*
C	3	0.43	196	0.55	026
	13	0.53	207	0.56	031
	18	0.50	211	0.63	032
	60	0.54	219	0.65	037
	Mean	*0.50*	*208*	*0.60*	*032*
D	3	0.42	186	0.38	027
	15	0.46	217	0.36	023
	46	0.41	215	0.42	026
	70	0.40	209	0.35	037
	Mean	*0.42*	*207*	*0.38*	*028*

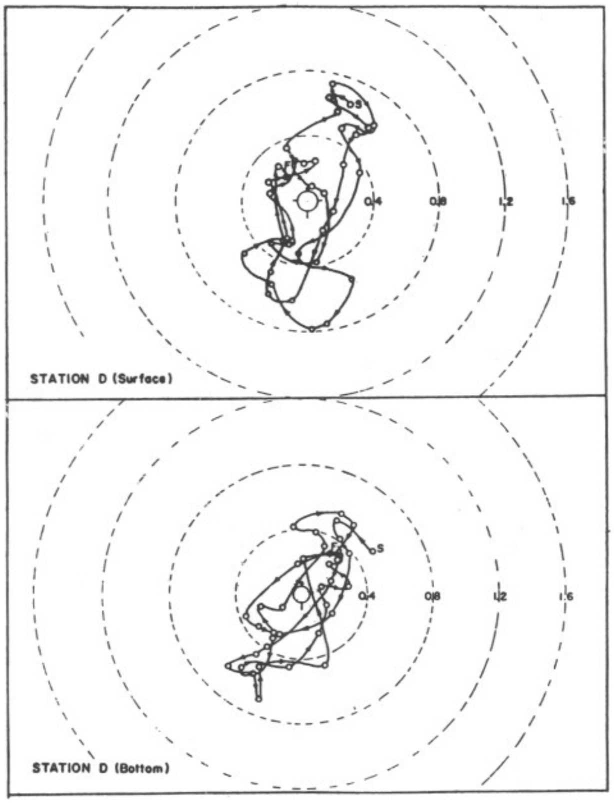

FIGURE 5. Station D hodograph of surface and bottom tidal currents.

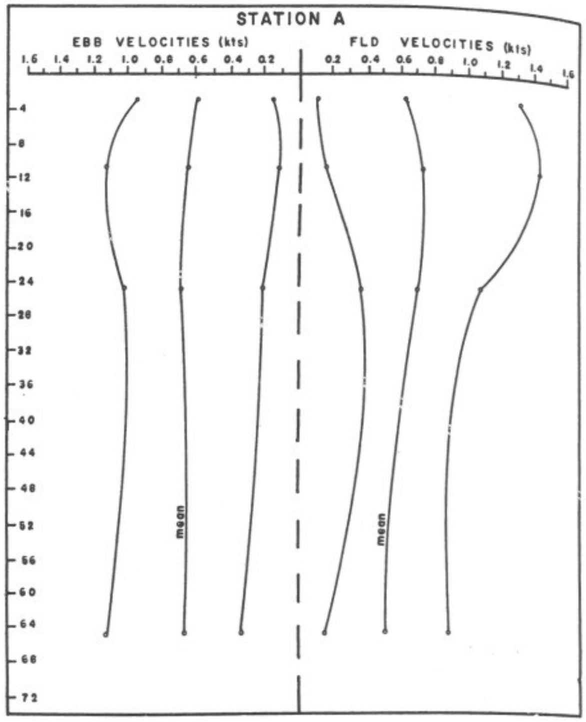

FIGURE 6. Mean velocity of the flood and ebb tidal currents observed at each depth on station A. The lines on either side of the means indicate the observed maximum and minimum tidal velocities.

The sequence of observations on C and D indicated the rotation to be both clockwise and counterclockwise. Above the thermocline on both stations the rotation was counterclockwise, while below the thermocline the rotation vacillated between clockwise and counterclockwise.

The directions of principal flood and ebb were approximately northeast and southwest, respectively. The variations of each with respect to one another and individually with respect to velocity and direction with greater depth are presented in Table 1.

The rotation period of the tidal currents is significant in that it was semi-diurnal at all observed stations and depths, thereby showing relevance to the semi-diurnal tidal cycle. From the hodographs one can see that the time required for one complete revolution was approximately 13 hours.

The velocities of the currents were less regular. Probably because of shallow depths and a smaller cross-sectional area at the inner stations (B and C), the greater velocities occurred on these two stations. The maximum, minimum, and average velocities of the tidal currents (tidal phase considered) and the variation of these with depth for the above stations as well as stations A and D are shown in Figures 6 to 9.

AVERAGE CURRENTS

In the analysis of the original observation data, the average currents were separated from the tidal currents by the method previously described. The results of the analysis indicated a counterclockwise circulation through southeastern Bering Sea (Figure 10). On the inshore stations (C and D), the average current tended to flow into southeastern Bering Sea, the flow being more definite on the inner station (C), at average velocities of 0.09 (C) and 0.05 (D) knots with directions of 072°T and 002°T, respectively. On station D, the average current varied, with depth, between north and east. Because very light winds prevailed during the observations, the probability of the currents being caused by the winds is somewhat decreased. The velocity and flow direction of the average current on stations C and D and their variation with depth are illustrated both in Table 2 and in Figure 10.

Because of strong winds during the observations on

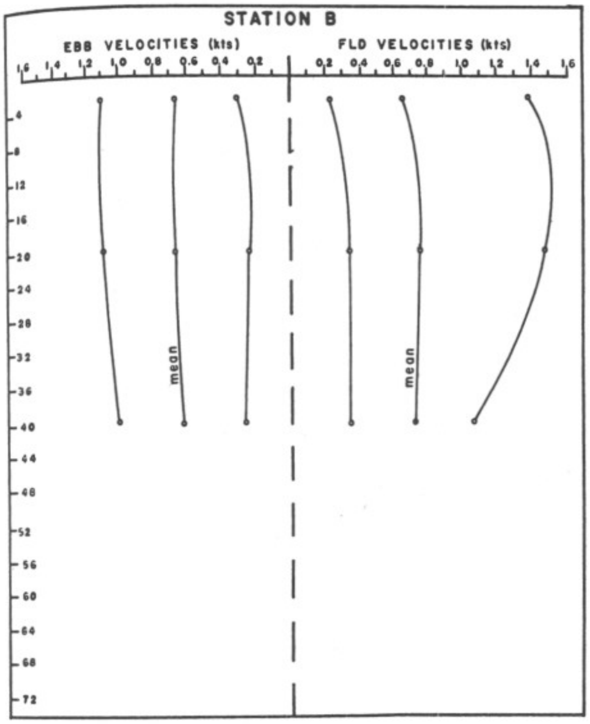

FIGURE 7. Mean velocity of the flood and ebb tidal currents observed at each depth on station B. The lines on either side of the means indicate the observed maximum and minimum tidal velocities.

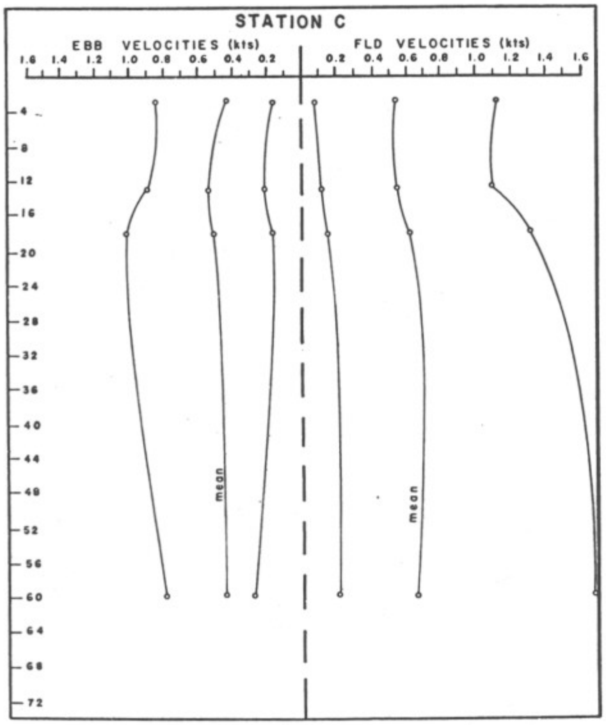

FIGURE 8. Mean velocity of the flood and ebb tidal currents observed at each depth on station C. The lines on either side of the means indicate the observed maximum and minimum tidal velocities.

station B, the offshore stations (A and B) had to be considered separately. On station A, the average current flowed essentially southwest at an average velocity of 0.05 knot and an average direction of 223°T. The variations in the current velocity and direction with respect to depth for stations A and B are also shown in Table 2.

On station B, where the wind tended to set up the average current, the wind current was effective throughout the water column. The average current flow was generally between east and southeast: the flow at the surface, 153°T; at 20 meters, 146°T; and at the bottom (40 meters), 112°T. The whole column considered, the mean flow direction of the average current was 137°T at a velocity of 0.11 knot.

To determine whether this station (B) was consistent with the counterclockwise circulation in southeastern Bering Sea, an attempt was made to remove the wind effects in order to determine the average current less the wind current. The wind current velocity was considered to be 2 per cent of the wind velocity and flowing 42° to the right of the wind (Rossby and Montgomery, 1935). Subtracting the vectors of the wind current from the observed average current results in an average current (only the surface considered) following 224°T at 0.14 knot; thus the water movement at this station is probably also consistent with the suspected counterclockwise circulation throughout southeastern Bering Sea.

DISCUSSION OF AVERAGE CURRENTS

Analysis of the data for the average currents on the stations indicated that the water movement through southeastern Bering Sea during the course of these observations was in a counterclockwise direction, that is, toward Bristol Bay along the Peninsula and away from Bristol Bay in the more northern parts of southeastern Bering Sea.

Two investigations in the vicinity of southeastern Bering Sea support the counterclockwise circulation, indicating that this type of circulation may be a continual movement throughout much of the year. Although not in southeastern Bering Sea as defined in Figure 1, the U.S. Coast Guard (1936) has shown a current flowing toward the northwest near Nunivak Island. The subsequent recovery in southeastern Bering Sea of drift bottles released south of Unimak Island (Thompson and Van Cleve, 1936) also lends

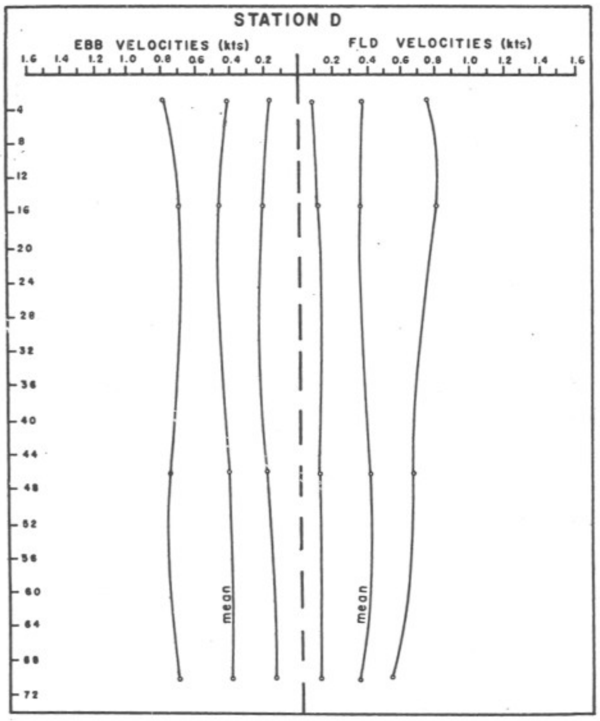

FIGURE 9. Mean velocity of the flood and ebb tidal currents observed at each depth on station D. The lines on either side of the means indicate the observed maximum and minimum tidal velocities.

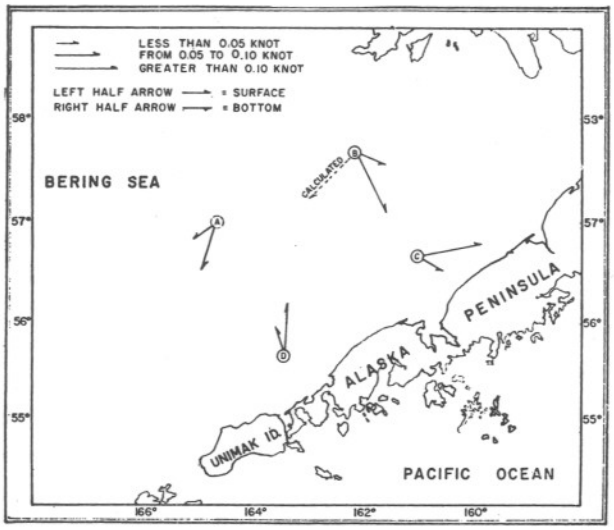

FIGURE 10. Average current vectors for surface and bottom observations. The station B calculated vector is the average current after removal of the wind driven current.

support to the counterclockwise circulation.

The forces fundamental to the above circulation have not been determined because of the lack of sufficient data. The possible forces which may support or contribute to the support of this circulation are (1) the addition of fresh water from streams of the surrounding land, (2) the buildup by winds of a hydraulic head of water along the coasts which upon relaxation would set up temporary currents, and (3) the addition of water to the region from the North Pacific through Unimak Pass as indicated by the before-mentioned drift bottle releases and subsequent recoveries.

TABLE 2. Average current velocity and direction (station B numbers in parentheses are calculated).

Station	Obs. Depth (m.)	Velocity (kt)	Direction °T
A	3	0.08	200
	11	0.03	218
	25	0.07	236
	65	0.02	236
	Mean	*0.05*	*223*
B	3	0.25 (0.14)	153 (224)
	20	0.02	146
	40	0.04	112
	Mean	*0.11*	*137*
C	3	0.11	078
	13	0.11	046
	18	0.11	046
	60	0.04	119
	Mean	*0.09*	*072*
D	3	0.05	003
	15	0.05	326
	46	0.06	056
	70	0.03	344
	Mean	*0.05*	*002*

EFFECTS OF CURRENTS ON THE KING CRAB LARVAE

One of the major effects of the currents would be upon the larvae during the zoea stages of the king crab, when the larvae are planktonic. If we assume that the findings of Marukawa (1933) are valid concerning king crab in the natural environment, the organisms spend approximately 60 days as zoea larvae, of which 5 days are spent in the upper water layers before the larvae migrate to the water layers immediately above the bottom, where the remainder of the time as zoea larvae is spent. The glaucothoeal larvae, formed from the zoea larvae, exist approximately 20 days, this period being spent resting on the bottom or swimming in the water immediately above the bottom.

The effect of the currents on the larvae is greatest in the dispersion or concentration of the larvae, depending upon the type of current flow in their immediate environment. Should hatching occur in a region of linear currents, the zoea would be carried and dispersed by the forth and back movement of the tidal currents, with a net movement of the larvae in the direction of the steady currents. In addition, the larvae would tend to be concentrated where gyrals and eddies are formed.

Because the adult female molts very shortly after the eggs which she has been carrying hatch, we can consider the areas of molting adult females as the areas of larval hatching. In 1957, just prior to the current station observations, both molting females and females with eggs approaching the hatch were observed along the Alaska Peninsula between Amak Island and Port Moller (Figure 1), with the largest abundance near Amak Island. Because of the limited scope of the investigations of crab distribution prior to the current station observations, no other areas of molting females or females with eggs ready to hatch were located.

If we consider the relation between the average velocity of the average current along the Peninsula, 0.04 knot, and the 60-day period the king crab spends as a zoea larvae, we may estimate that the current would carry the larvae approximately 60 miles; variations that might occur would be caused by the tidal currents. In effect, the zoea larvae hatched in the vicinity of Amak Island would be carried into the vicinity of Port Moller. As a matter of observation, the only area where small crabs were located on the abovementioned cruise is in the vicinity of Black Hill, approximately 50 miles from Amak Island. Should hatching occur in other regions, which is very probable, the zoea larvae would be carried, generally, in the direction of the average current for a distance obviously depending upon the net current velocity and the time spent as planktonic larvae.

Because of the habitat of the glaucothoeal larvae, the movements of the larvae caused by the currents are practically indeterminable. About the only time the larvae of this stage would be affected by the currents would be during their periods of swimming, and then perhaps for only short periods of time.

Not only do the currents affect the distribution of the larvae within an area, but they may carry into an area larvae from king crab populations of other areas. Because of the suspected flow of water from the North Pacific into southeastern Bering Sea, by way of Unimak Pass, recruitment of larvae into the Bering Sea from king crab populations south of the Alaska Peninsula is a possibility. False Pass (Figure 1), a small pass between Unimak Island and the Alaska Peninsula, may also be a source of larval recruitment into southeastern Bering Sea.

SUMMARY

The results of current observations in southeastern Bering Sea have been determined by evaluating the characteristics of the currents at two offshore and two inshore stations. The offshore stations revealed dextrally rotating semi-diurnal tidal currents. The maximum currents of between 1.0 and 1.5 knots were flowing parallel to the coast. The minimum current was 0.1 knot, flowing approximately perpendicular to the coast.

The inshore stations showed tidal currents which were also rotary but greatly compressed from the northwest and southeast, so that the major water movement assumed an oval pattern. Here again the currents were semi-diurnal but they varied in the direction of rotation. Maximum observed currents were oriented parallel to the coast with velocities of 1.7 knots at station C and 0.8 knot at D. Minimum observed currents were approximately 0.1 knot.

The maximum observed tidal current velocities at stations A, B, and D tended to decrease with depth but to increase with depth at station C. The minimal tidal currents tended to remain the same or increase in velocity from the surface to the bottom on all stations.

The average current flowed toward Bristol Bay at the inshore stations and seaward at the offshore stations, thus setting up a counterclockwise circulation through southeastern Bering Sea. At all stations, the velocities of the average current tended to decrease with increased depth. Further investigation of the dynamics of southeastern Bering Sea is required in order to determine exactly the forces which set up and maintain the average currents of the area. The permanence of these average currents is of interest because of their importance in the distribution of the king crab larvae during the spring and summer months.

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