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PRELIMINARY REPORT ON THE BERING STRAIT SCHEME

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Prepared under a special services contract for the Northern Co-ordination and Research Centre, Department of Northern Affairs and National Resources.

> M. J. Dunbar, McGill University, Montreal, March, 1960.

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INTRODUCTION

Matthew Fontaine Maury's "Physical Geography of the Sea", an oceanographic classic published in 1855, opens with the following resounding paragraph:

"There is a river in the ocean. In the severest droughts it never fails, and in the mightiest floods it never overflows. Its banks and its bottoms are of cold water, while its current is of warm. The Gulf of Mexico is its fountain, and its mouth is in the Arctic Seas. It is the Gulf Stream. There is in the world no other such majestic flow of waters. Its current is more rapid than the Mississippi or the Amazon, and its volume more than a thousand times greater".

This expresses in dramatic form the great length and the great volume of the Gulf Stream system, and it is that system of currents that is involved in the scheme proposed by the U.S.S.R. The volume and transport of the Gulf Stream at its root, in the Strait of Florida, is actually about 600 times that of the Amazon in flood; and the flow of Atlantic water which enters the North Polar Sea (Arctic Sea) is approximately 400 times that of the St. Lawrence River as it enters the Gulf.

The idea that it might be feasible and advantageous to build a dam across Bering Strait was first suggested in the last decade of the last century, in the belief that this would stop ice-laden Arctic water from passing through the Strait into the Bering Sea and thus ameliorate the climate of the North Pacific. In point of fact, very little, if any, Arctic water passes southward into the Bering Sea, but this was not known at the time. The scheme was brought up again in recent years, since World War II, by the U.S.S.R., this time as an officially supported plan. It was given considerable publicity; the Financial Post (Toronto), for instance, published a front page story on March 3rd, 1956, combining it with another Russian plan to deflect the Ob! and the Yenisey rivers so that they no longer flowed into the Arctic Sea. The plan at that time was to pump Pacific (Bering Sea) water northward across the dam into the Arctic Sea, with the intention of increasing the amount of heat in the latter. The plan in this original form was again described in "Coronet" magazine in June, 1959, in an article already considerably out of date since the Russian plan had by that time been reversed, to pump Arctic water south into the Bering Sea.

To pump Bering Sea water northward over such a dam would in fact be of doubtful value and not very intelligent. There is already a not inconsiderable flow of Bering Sea water northward through the Strait, which would be stopped by the dam; secondly, the water of the Bering Sea itself is not greatly warmer than that of the Arctic Sea; and thirdly, such a northward flow would be in competition, as it were, with the far greater and far warmer Atlantic inflow at the opposite side of the Arctic Basin. The plan in this form has already been discussed by the present writer, and I do not intend to spend more time on it here.

I must emphasize at this point that this cannot be more than a preliminary and tentative estimate of the Bering Strait scheme. One man cannot command fluency in all the sciences and specializations involved. For a full appreciation of the possible and probable effects of the plan, especially in adequate quantitative terms, many experts and a considerable amount of time will be needed.

THE PRESENT PATTERN OF MARINE CIRCULATION

The general circulation of the upper water of the Atlantic Drift-Arctic Sea system is shown in Fig. 1. Atlantic water enters the Oceanic system north of Scotland. (The "Arctic Ocean" in the wider sense is usually taken to include the Greenland and Norwegian Seas, the Barents Sea, and Baffin Bay; the southern limit is thus the submarine ridge extending from East Greenland, through Iceland, to Scotland. I am using the term "Arctic Sea" to apply to the central basin alone). This Atlantic water crossing the Wyville-Thompson Ridge has a temperature of about 8°C. on the average, and is enormously important in modifying the climate of northwestern Europe. Since the present scheme is intended to bring Atlantic water to the surface in the Arctic Sea itself, it would be well to keep in mind the present contrast between the climates of northern Norway and Ellesmere Island.

The inflowing Atlantic water very soon becomes involved with Arctic water. East of Iceland there is a turbulent area where mixing takes place to a certain extent, and west of Spitsbergen the Atlantic water meets the Arctic Front proper. At this point the difference in density between the Atlantic and Arctic water manifests itself, and the Atlantic water sinks beneath the Arctic water. The Atlantic water is considerably denser by virtue of its much higher salinity and in spite of its higher temperature; it has a salinity of over 35 o/oo (parts per thousand) and a temperature, at the Spitsbergen level, of about 4°C., whereas the outflowing Arctic water has temperatures below 0°C. and salinities of about 32.5 o/oo. The Atlantic water sinks to form a thick layer about 500 metres thick between the depths of 200 and 700 metres; this layer is traceable apparently throughout the Arctic Sea, although at considerable distances from the Spitsbergen point of entry it has cooled to temperatures of the order of 0.5° to 1.0°C. Above this Atlantic layer is the Arctic or North Polar water, ice-laden and cold, and





below it is the mass of the deep water of the Polar Basin; this latter is again cold, but fairly saline, and does not concern us here.

From the opposite side of the Basin, water enters through Bering Strait, at a volume level between about 1/3 and 1/4 that of the Atlantic inflow. The density of this water is close to that of the Arctic surface water, being about 32 o/oo salinity and close to 0°C. in temperature, and it stays on the surface for the most part, influencing the southern part of the Chukchi Sea and the coastal waters of northern Alaska and the Mackenzie area.

There is, finally, a runoff from the land, and an excess precipitation over evaporation, which complete the

sources of water flowing into the Arctic Sea.

There are only two important outflowing currents of cold Arctic water — the East Greenland Current and the Canadian or Baffin Island Current. The former is the larger, flowing down the East Greenland coast, rounding Cape Farewell, and flowing north again up the West Greenland coast as a mixed current (mixed with Atlantic water from the Irminger Current, which peels off southwest of Iceland from the Atlantic Drift (Gulf Stream) and turns west toward southeast Greenland, as shown in Fig. 1). The Canadian Current collects water from Smith, Jones and Lancaster Sounds and flows southward along the east coast of Baffin Island. At the level of Hudson Strait it is joined by water from West Greenland and Hudson Bay and continues southward as the Labrador Current.

There is a small polar contribution to the south through Fury and Hecla Strait, which joins forces with the Hudson Bay outflow through Hudson Strait. Its volume is not significant in the present discussion.

We are considering here the probable effects of pumping water south out of the Arctic Sea into the Pacific, thereby increasing the rate of inflow from the Atlantic side. Since the extent of these effects must be largely a function of the quantity of water that can be pumped, we must introduce at this point some approximate arithmetic and examine the present water circulation quantitatively. The transport of the currents varies seasonally and from year to year, and there are differences of opinion among those who have made the necessary measurements in the field, but neither the variations nor the differences in measured transport are significant enough to affect an argument as general as that presented here. The following figures are compiled from various recent sources.

Inflow northwest of Scotland	3.0 m	illion	m	sec	
Inflow through Bering Strait	1.0	Ħ		R :	
Freshwater addition (rivers, excess precipitation)	0.25		•	N	
Total inflow and freshwater addition	4.25	n	11	, n i	1
Outflow in East Greenland	1#17 (s. 1) 1	an in	s art	sulfice y	13
Current	2.90	n		11	
Outflow in Canadian Current	1.35		Ħ		
	1.25	n			

The inflow through Bering Strait is controversial, or at least highly variable. Measurements have varied between 0.3 million cubic metres per second to 1.0, the figure given here, as average for the twelve months.

VERTICAL STABILITY

The amount of heat contained in the Atlantic layer of water, beneath the Arctic layer, is very large (see below), but it is prevented from affecting the atmosphere above by the presence of the Arctic layer and by the stability of the whole system. There is at present no possibility of vertical exchange to an extent that would allow the Atlantic water to reach the surface in the Arctic Sea. At the same time, the Arctic layer itself is formed to a very large extent from Atlantic water, obviously. This somewhat paradoxical situation is explained by two important facts: (1) the fresh water from the land is an important ingredient in the Arctic water; this reduces the salinity considerably, hence the density of the Arctic water, encouraging stability and (2) the melting of ice each summer also reduces salinity of the upper layer.

To deal with the second point first: when sea water freezes it forms a three dimensional mesh of ice enclosing pockets of brine. The brine becomes more and more concentrated as cooling of the ice continues and begins to melt the ice at the lower margins of the pockets (the heat loss is upward). In this way the brine pockets migrate downwards during the winter and leach out from the lower surface of the ice. This salt water sinks and mixes. The ice which melts in the following summer, therefore, is almost fresh and lowers the salinity of the surrounding water.

The drainage from the land, especially Siberia, is very great, about 8,000 cubic kilometres per year. If this did not exist, the salinity, at least of the upper few metres, would be raised appreciably. If in addition the surface did not freeze, the vertical stability would be greatly reduced. The present Bering Strait scheme, as publicized, is intended to remove the cold upper layer and to keep the circulation going rapidly enough to stop further winter freezing. Another Russian plan, apparently, is to divert the waters of the Ob' and Yenisey rivers southward; I mention this only in passing, because it would aid in the general objective of maintaining low vertical stability in the Arctic Sea.

MECHANICAL PHASE - DAMMING AND PUMPING

In assessing the feasibility of this engineering plan I am clearly out of my field, but a very brief examination of the quantities of water involved throws a light on the whole scheme which may perhaps relegate it to fairyland.

The building of the dam itself presumably needs only time, material, and energy. The Strait is 50 miles long and 50 metres deep. To build the dam would be a long and expensive job. but it would not be impossible. This is important, because it is possible that the damming alone would have significant and beneficial effects; this is discussed later.

Before any of the heat in the Atlantic layer in the Arctic Sea can be made available to the atmosphere, the overlying Arctic layer must be removed, together with its ice. Furthermore, once that has been done, the surface water must be drawn off in quantities sufficient to maintain the Atlantic heat supply and to prevent the surface freezing. In the following quantitative estimate, which cannot be more than approximate, I am making certain assumptions:

- 1. That the effective area to be considered is that of the Arctic Sea by itself, without the Greenland and Norwegian Seas, without the Barents Sea, and without Baffin Bay; that is to say, the water enclosed by the Siberian coast, the northern limits of Alaska and the Canadian Arctic Islands, the north coast of Greenland, Spitsbergen and Novaya Zemlya. This area is approximately 10.5 x 10^o square kilometres. Baffin Bay is on the "downstream" end of this operation and therefore any effect in the Arctic Sea will be felt in Baffin Bay, with some modification.
- 2. That the average thickness of the sea ice is 3 metres.
- 3. That the effective thickness of the Arctic water layer, in this context, is 200 metres. This is probably a considerable underestimation; negative temperatures have been observed below this depth.
- 4. That the maximum rate of flow of water which each pump could maintain efficiently is 1 metre per second. This assumption I have made after turning to expert advice at McGill University. New, atomic powered pumps of design not hitherto attempted could possibly do better.

The volume of the Arctic water to be drawn off is

 $10.5 \times 10^{12} \times 200$ cubic metres, or 2,100 x 10^{12} cubic metres.

To pump the water over the dam will encounter the problem of the ice on the surface. This is a technological matter which does not concern us here. I am assuming that the pumps are in the form of tubes pierced through the dam below ice-level, and that, for convenience of argument, each is approximately 10 metres in diameter, or a little more, so that, at the rate of 1 m/sec, the volume transport of each pump will be about

100 cubic metres per second

Such a pump, by itself, would pump 2,100 x 10^{12} cubic metres in 21 x 10^{12} seconds, or 0.67 x 10^{9} years; that is to say in

670,000 years

If one thousand such pumps could be mounted on the dam, or one every twentieth of a mile (88 yards), it would still take 670 years to pump the necessary amount of water. One million pumps, which of course would have to be staggered vertically along the dam, would do it in 8 months.

There seems to be no information on the type or size of pumps which the Soviet Government has in mind, but their power and efficiency would have to be very considerably higher than anything available at present to make any significant difference at all in the mechanical obstacles to be overcome. Even if it were possible to increase the output by a factor of 10, which would increase the power required by a factor of about 1,000, one thousand such pumps would take 67 years to remove the Arctic water layer. This, if my figures are correct, is as much as to say that the scheme is unworkable, because in that length of time the present natural cooling of the upper layer would continue. The Arctic water layer would be thinner, but a new steady state would be established and the thousand pumps would never achieve their purpose.

This is not the conclusion implied by the U.S.S.R. Borisov writes: "Engineer Shumilin's idea is aimed writers. at invigorating the present water exchange by re-pumping 100,000 cubic kilometres of water from the Bering Sea to the Chukchi Sea". This refers to the older plan to pump the water north, but if the 100,000 cubic kilometre figure is an annual amount, which it presumably must be, it is astronomical. It corresponds to a flow of 3.18 million cubic metres per second, or the equal of the Atlantic inflow west of Spitsbergen; a little more than thirty times the flow estimated above for one thousand pumps each capable of maintaining a flow of 100 cubic metres per second. Borisov makes no other mention of the quantity of water involved, so that it must be supposed that the 100,000 cubic kilometres (per year) are now to be pumped south. There is no mention of the type of pumps proposed, nor is there any discussion of the disposal of atomic by-products.

PROBABLE EFFECTS OF PERMANENTLY REMOVING THE ARCTIC WATER LAYER

Let us suppose, nevertheless, that the removal of the Arctic layer is possible. After all, it is the initial effort that is important; once the cold layer is removed, a much lower rate of pumping will suffice to keep the surface substantially free of ice. Imagine, therefore, that the titanic operation is at the point of achieving its purpose. The Arctic water layer is now very thin, the warmer Atlantic water is about to surge over the whole surface of the Arctic Sea, the ice is still present. In this discussion I have to make certain further assumptions:

- 1. That the ice cover can be taken, for purposes of arithmetic, as complete over the area considered. This is correct within an error of something like 10-20% in summer, and within a much smaller error in winter.
- 2. That the ice, when melted by the Atlantic water, is fairly close to the melting point; that is that the Atlantic water arrives at the surface in summer, which is reasonable.
- 3. That the ice, when melted, has a low salinity of the order of 5.00 o/oo or below. Both this and the temperature of the ice affect the value of the specific heat chosen. I have chosen a value of 5.00 calories, which is probably too high. The salinity of the ice also affects the latent heat of fusion of the ice, which is here taken to be 72 calories per gram. In point of fact, the melting of the ice requires a fairly small proportion of the heat available, so that these considerations are not of first rank importance.
- 4. That the Atlantic water layer, when at the surface, has a low vertical stability, so that when cooled at the surface (by loss of heat to ice or to the atmosphere) vertical exchange of water through its whole depth (500 metres) is readily possible. This is probably correct, but it is to a certain degree dependent on the influence of the land drainage.
- 5. That the average temperature of the Atlantic layer is close to 2°C.

From these assumptions the following round figures emerge:

Area of Arctic Sea	$10.5 \times 10^6 \text{ km}^3$
Volume of ice, aver- age 3 m. thick	31.5 x 10 ¹² m ³
Mass of ice	31.5 x 10 ¹⁸ x .92 gm
	$= 29.0 \times 10^{18} \text{ gm}$

Assuming that in summer this ice is at about -2.0° C.,

Heat required to bring this ice to melting point

29 x 10^{18} x 5 g.cals. = 145 x 10^{18} g. cals.

Heat required to melt this ice

Total heat reuired to melt ice

Volume of water in Atlantic layer

Heat available in Atlantic layer assuming cooling from 2°C. to -1°C. throughout 500 metre column (and ignoring insolation)

Heat available in Atlantic layer after ice is melted (again for 3°C. drop, and ignoring solar radiation). $31.5 \times 10^{18} \times 0.92 \times 72$ gm. cals. = 2085 x 10¹⁸ gm. cals.

2230 x 10¹⁸ gm. cals.

$$10.5 \times 10^{12} \times 500 \text{ m}^3$$

5250 x 10¹⁸ x 0.94 x 3 gm. cals.

 $= 14.800 \times 10^{18}$ gm. cals.

This excess heat is a minimal estimate. Solar radiation cannot be ignored, and far more important is the fact that the flow of Atlantic water into the Arctic Sea continues throughout the process of melting the ice, and after, moreover at a somewhat increased rate, according to plan. At the present rate of Atlantic inflow, and allowing for a 5.5°C. drop from the temperature at inflow to the freezing point, the heat available to the atmosphere flows infat the rate of

 $3.0 \times 10^{6} \times 10^{6} \times 5.5$ cals/sec.

= 16.5 x 10¹² cals/sec.

....

= 520 x 10^{18} cals/year: and this amount would be increased by an amount equivalent to the rate of flow which the Bering Strait pumps could maintain. If that rate were 100,000 cubic kilometres per year, as claimed by the Russian announcement, this annual inflow of heat would be doubled. This heat would warm the atmosphere above the Arctic Sea very considerably, and it would certainly be able to keep the surface free of ice. The atmospheric effects, however, involve so much more speculation and guesswork than I have had to introduce so far that prognostication would be of doubtful value.

It is taken as a general rule that of the heat in the sea available to the atmosphere, one tenth, approximately, comes off as sensible heat, warming the air, and nine tenths are used in evaporating water at the surface. At sea level pressure, one tenth of the residual heat in the Atlantic layer, after the ice is melted, $(12,570 \times 10^{17} \text{ calories})$ could raise by no less than 40°C. a layer of air covering the Arctic Sea to a height of about 12 kilometres, and the heat entering in the Atlantic water every year, if concentrated over a short period (which is impossible and of only theoretical interest), could raise a layer 2 kilometres thick by about 10°C. But what such figures mean in terms of actual climatic effect is impossible to say, beyond the obvious statement that there would be a large climatic change and that air temperatures would rise most significantly. There would also, certainly, be a great increase in atmosphere humidity.

For what it is worth, and with the repeated warning that climatic prediction of this sort is next to impossible. it might be worth quoting here a statement in Borisov's article in which he says that "the mean January temperature at the North Pole will rise by 35°C., at the New Siberian Islands by 40°C., at Point Barrow by 30°C., in the Hudson Strait by 25°-30°C., in the Bering Strait by 15°C. The mean January temperatures will even rise by 6 or 10 degrees in more southern areas, such as New York, London, Berlin. Stockholm, Moscow, and Vladivostock". And again: "The eternal frost will cease to be eternal: 70 per cent of Alaska, 60 per cent of Canada, and 47 per cent of the USSR, will become more accessible for industrial and agricultural developmentⁿ. This may well be as good a guess as any, but it would be interesting to see the reasoning and the assumptions behind the figures. In all probability the estimate that the temperature change would be greater in Siberia than on the Canadian side is correct; this is referred to again below in the discussion of changes in the marine circulation.

The <u>humidity change</u> is important. A widely held current theory of the origin of the Pleistocene ice age, the theory of Ewing and Donn, of Columbia University, supposes that the onset of the glaciation was triggered by the general warming of the Arctic Sea, in Tertiary times, to the point at which the precipitation in circumpolar lands during the winter was too great for the summer warmth to melt, resulting in a gradual accumulation of snow. The increased precipitation came, of course, from the increased evaporation from the Arctic Sea. The subsequent reduction in sea level caused a decrease in the inflow to the Arctic, according to theory; the Arctic water cooled and finally froze, thus drastically cutting down the humidity of the northern polar air and hence the precipitation. Summer melting gradually wore down the ice cover on the land, and the process was repeated. There were four separate such glaciations in the Pleistocene, and the land has only recently emerged from the last.

If this theory is correct, the freeing of the Arctic Sea from ice and the warming of its surface must be looked upon as a probable start of another glaciation. And since the Pleistocene glaciation in Siberia was a very small affair compared to the enormous deposition of snow in Canada and western Europe, it must be assumed that these latter regions would again bear the weight of the glaciation. Such a growth of ice, of course, would take many centuries to develop, but locally the snow accumulation might be a nuisance within a comparatively short time.

The climate of Canada would be expected to become wetter and altogether less pleasant, especially in the north. It would be milder; the present climate of Newfoundland and the Labrador would expand northward. The winters would be stormier than at present. The effects on agriculture are doubtful; over much of the northern margin of agricultural land at present the limiting factor seems to be not temperature but absence of soil, and acidity. The rate of soil formation would not be affected to any appreciable extent by the envisaged climatic change.

It is also difficult to predict the fate of the fauna of the land. Of the two large arctic herbivores, Caribou and Musk-ox, I would be inclined to bet on the Musk-ox as the less upset by the change, but a great deal depends here on the behaviour of the snow; both species would be badly hit by deep snow, and similarly by raw wet winters instead of cold dry winters. The southern Canadian fauna would presumably extend its range northward.

Change in <u>sea level</u> would probably be quite unimportant, short of the onset of glaciation. The melting of the sea ice cover on the Arctic Sea would not change sea level significantly at all, since the ice is at present floating in the water anyway. Nor would there be much likelihood of a rise in sea level resulting from the melting of the Greenland Ice-cap. The Greenland Ice-cap would most probably either remain the same size or increase in extent owing to increased precipitation. Any tendency for snow to collect in Canada and in Eurasia would reduce the sea level, but the process would be extremely slow. All that might be expected, therefore, would be a slight and very gradual lowering of sea level. In the long term and pessimistic view, sea level would fall as glaciation continued.

EFFECTS ON MARINE CLIMATE AND MARINE RESOURCES

Still with the supposition that the Bering Strait scheme is possible mechanically, we may examine the probable effects in the sea itself. By "marine climate" I mean the subsurface climate, in the hydrosphere as opposed to the atmosphere. Fig. 2 shows the approximate present circulation pattern of the Atlantic layer between 200 and 700 metres below the surface in the Arctic Sea, from the work of the U.S. "Project Skijump". The division into two circulations, in opposite directions, may possibly be the effect of the ridge which crosses the Polar Basin from the New Siberian Islands to Ellesmere Island, although that ridge (Lomonosov Ridge) does not come up quite to the level of the Atlantic layer. If the Atlantic inflow were increased by the amount looked for by the Russians, it is very probable that the flow would force itself closer to the New Siberian Islands and probably right into the Siberian coast itself, because the effect upon it of the geostrophic force (Coriolis force) would be much greater. The Coriolis force has the effect of thrusting moving bodies to the right of their courses in the northern hemisphere. It is maximal at the poles and is proportional to the velocity of the moving body.

The probability is, therefore, that the new, post-Bering dam pattern of circulation (which would have Atlantic water at the surface) would be a single anticlockwise gyre, with outlets through the Canadian arctic islands and along the East Greenland coast, as at present.

It is at once apparent that the benefits of the Atlantic water at the surface, and of ice-free waters for navigation probably the whole year round, would make themselves felt first and most strongly on the Russian side. This fact stands out in some relief against the flat background of speculation which is inevitable in this sort of game. By the time the current had carried the water as far round as Bering Strait, it would have cooled. The extent of cooling cannot be accurately estimated because it depends upon the heat given up to the atmosphere, and that is not readily predictable. Let us imagine that the Atlantic layer has now a depth of 700 metres and that it is readily rendered vertically unstable. If we allow the current a velocity between one-quarter and one-fifth knot, any given particle of water would take up to 500 days to reach Bering Strait from Spitsbergen. The drop in surface temperature, allowing for heating during the summer, could be supposed to be about 2°C., and by the time the water reached Ellesmere Island and North Greenland it might drop another degree, perhaps more. These figures are guesses, because so much depends on the behaviour of the atmosphere. The water, then, flowing out of the



Figure 2

Arctic Sea might be expected to have a surface temperature approaching 0°C., still more than a degree and a half above the freezing point. In East Greenland and in Baffin Bay this outflow would meet Atlantic water coming directly from the Atlantic Drift, and therefore considerably warmer. The probability is that no ice of any significance would form between the islands or in Baffin Bay; some might be expected to appear in sheltered inlets, and in Foxe Basin and Hudson Bay. Icebergs from the Greenland coasts would continue to be calved, perhaps more rapidly than at present. But they would melt considerably more quickly.

The effects in the North Pacific would in all probability not concern Ganada at all. During the process of drawing off the cold Arctic layer, this water would flow down the west side of the Bering Sea and into the Sea of Okhotsk; it would either mix with the Bering Sea water or sink to depth.

> The upheaval in the marine animal world would be immense. The sparseness or absence of ice would hit the Ringed Seal and the Polar Bear the hardest; both of which might well be extinguished. The Bearded Seal or Squareflipper would also be distressed, but would probably adapt and survive in a smaller population number. I would certainly expect the Walrus to be comparatively undisturbed; it was distributed far to the south of its present range in the past (Jacques Cartier recorded walrus breeding on Sable Island in 1534), and it is not dependent on the presence of ice. The Harbour Seal, a boreal and subarctic species, would probably greatly increase its range and numbers. The fate of the Harp Seal is uncertain; it would certainly suffer from the shortage of ice.

Among the whales one would expect the white whale and the narwhal to retreat to island and coastal refuges, or to disappear entirely; the change might also finally extinguish the Greenland whale or Bowhead. The Finbacks, greater and lesser, would no doubt move north and increase in number, and the Sperm Whale, a cosmopolitan species, would make more use of the northern waters. There would also be expected to be a large northward spread and increase in numbers of the Blackfish (Caa'ing or Pilot Whale), and Killer Whale.

The whole of the shallow water areas of the Polar Basin, especially the Siberian shelf, would become far richer in fish species. At present, the cold Arctic water is very poor in fish; the areas of high fish production lie a little further south, in subarctic and boreal waters. With the flooding of the shelf depths with Atlantic water, they become available to Cod, Haddock, Halibut, various smaller flatfish and secondary commercial species. The Redfish would move in at greater depth, and the Herring would spread over all or most of the Arctic Sea. These species would all move farther north also in the Labrador-Baffin Bay area, and some might reach Hudson Bay.

The Atlantic Salmon, probably, would invade streams to the north of Hudson Strait on the Baffin coast; so would the Speckled Trout. The range of the Arctic Char would no doubt be reduced.

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Impressive although these changes would be qualitatively, the quantitative results would be far more so. The most significant change of all would be the enormous increase in basic production, in the development of the marine plankton. The removal of the ice cover and the decrease in vertical stability would increase the production of plant plankton (phytoplankton) by a very large factor. The Arctic Sea might in fact become one of the most productive areas in the world in terms of living resources. Again, this effect would be greatest on the Russian side. Both the temperature regime and the width of the shelf would be in its favour.

Zoogeographers would have a glorious two or three generations mapping the changes in distribution. Atlantic fauna would be constantly pumped into the Pacific.

THE EFFECTS IN LOWER LATITUDES

The scope of this report does not properly include this aspect of the matter. Here again, as in the prediction of atmospheric events following the Bering operation, we are in the realm of fantasy; it is simply not possible to predict what would happen. Obviously more Atlantic water from the Atlantic Drift would be diverted northward to the Polar Basin than flows there at present; but the increase necessary to establish a new steady state in the Arctic Sea, so that the surface remains ice free, cannot be calculated at present. The scale of the heat engine of the North Atlantic circulation is so vast, as has been indicated here, that the change in lower latitudes might well be quite small.

On the other hand, there is one consideration that may be important. In the heat budget of the world, there is at present a net loss in the polar regions and a net gain in the tropics, so that heat constantly flows from the tropics to the high latitudes. This happens both in the water and in the air, but it has become a part of the orthodoxy of oceanography that the atmospheric movement is very largely responsible for the maintenance of the oceanic movement. If this is correct (and I have serious doubts that it is, against an overwhelming weight of opinion), then a change in the heat budget of the north polar regions as great as that we are discussing here might well reduce the flow of Atlantic water northward to a quite significant extent. If that happens, we are in difficulties at once, because everything depends on the maintenance of the Atlantic flow into the Arctic Sea. In other words, by warming the climate of the north polar regions we may be in danger of depriving ourselves of the continued means of doing it; a sort of global feed-back nemesis. How serious a consideration this is must be left for others in the future, but it certainly should not be ignored.

THE POSSIBLE EFFECT OF THE DAM ALONE WITHOUT PUMPS

The foregoing sections have dealt with the probable effects of successfully completing the Bering Strait scheme, in spite of the apparent improbability of it being mechanically possible. It would be worth while to consider what the effects might be of carrying the scheme through only as far as it appears to be mechanically possible, namely as far as the building of the dam.

The dam alone, without any pumps, would stop the Bering Sea water from entering the Arctic Sea. If we take the present Bering Sea inflow as somewhere between 0.5 and 1.0 million cubic metres per second, this means that the outflow of Arctic water is reduced by that amount. At the most liberal estimate, this would be a reduction by almost one quarter of the present maximum value of 4.25 million cubic metres per second.

This effect differs from all that has been considered up to this point in that it would be felt in the <u>North American</u> <u>sector and not in the Russian</u>. It would be felt most on the coast of Greenland and in Baffin Bay. The east coast of Greenland would no doubt still be washed by Arctic water outflow, but the proportion of Arctic water in the Arctic-Atlantic mixture which makes up the West Greenland Current, flowing northward, would be reduced from about one-third to one-quarter or rather less, and there would be a corresponding weakening in the Canadian Current down the east coast of Baffin Island. The Labrador Current would be slightly warmer. The Atlantic Cod would go farther up the west coast of Greenland and the halibut also. The cod would be more plentiful on the Labrador coast (whatever good that would do), and they might even move up to southeast Baffin Island and into the body of Ungava Bay.

At the same time the modifying effect of the <u>Pacific</u> water entering through Bering Strait, which is now felt along the north coast of Alaska and off the mouth of the Mackenzie, would be lost. The Pacific Cod and Herring, and the Starry Flounder, would disappear from that coast. This would probably be no great loss. But at all events, since the effects of the dam alone would benefit Canada and Greenland alone, there is little chance of the dam being built for this purpose, on the international scene.

CONCLUSION AND SUMMARY

1. It is very doubtful that the Bering Strait scheme is possible, on mechanical grounds. The scale of the natural circulation in the Arctic Sea is such as to dwarf anything that we can do at present.

- 2. If it were possible the effects would be farreaching. The climate of the north would be greatly changed in the direction of higher temperatures and greater precipitation; this would not necessarily be a good thing. There would be a likelihood of accumulation of snow towards a glaciation.
- 3. The important improvements would be on the Siberian side.
- 4. The most impressive change would be in the marine productivity. The Arctic Sea might become one of the most productive areas in the world.
- 5. The Bering Strait dam alone, without any attempt to pump water across or through it, would have significant effects in the Canadian Eastern Arctic and in Greenland, because the outflow of cold Arctic water from the Arctic Sea would be reduced.
- 6. If the scheme is to be taken seriously (and I think there is just enough in it to warrant taking it seriously), it should be studied by an international scientific commission, which would have to sit for many months before the complexities involved could be unravelled. Perhaps the building of a working model would be useful.
- 7. The possibility of using the tidal difference on the two sides of the dam has not been discussed here. The quantities movable by this means are probably quite small in relation to the scale involved.
- 8. It is not clear whether the Russians are putting the plan forward seriously, or as a means of testing our sense of humor.