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MMS 95-0053

APPLICATION OF REMOTE METHODS OF LARGE CETACEAN TRACKING: BOWHEAD WHALES

FINAL REPORT - JUNE 1995

Prepared by: Bruce R. Mate and Gregory K. Krutzikowsky
Hatfield Marine Science Center
Oregon State University
Newport, Oregon 97365

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<u>Contracting Officer's Technical Representatives</u>

Jerome Montague, Jerry Imm, Cleve Cowles, Judy Wilson, and Warren Horowitz

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EXECUTIVE SUMMARY

Following a tag and attachment development phase, this project resulted in the successful tagging and tracking of two species: North Atlantic right whales in 1989 - 1991 (Mate, et al. 1992; Mate and Nieukirk, 1993) and bowhead whales in 1992. This report covers the tagging and monitoring of 12 bowhead whales in the western Arctic with satellite-monitored Argos radio tags in late August/early September 1992. Locations and sensor data were obtained through the Argos Data Collection and Location Service (ADCLS). The tags transmitted according to a pre-set transmission schedule and only when at the surface. The tags summarized data on dive durations, dive depths, and time spent at the surface/underwater for eight periods each day.

Two tag types were used: duration/depth (n = 10), which transmitted each time the whale surfaced and duration-only tags (n = 2), which restricted transmissions to two 100-min windows per day. Two or more messages were necessary in a 10-min orbit to achieve a location. Location accuracy increased with reception of additional transmissions. We received transmissions from all 12 tags, but useful locations were obtained from only eight whales. Three tags with poor attachment or placement provided the least amount of data. One was heard from only five times, but provided the longest documented tag attachment (49 days). Only six tags (depth/duration) reported battery voltage in their utility status message. Five of these reported low voltage toward the end of their operation suggesting that they quit due to battery exhaustion from frequent transmissions (every surfacing) in a very cold environment. The number of messages sent by each tag varied from 524 to 8164 ($\bar{x}$ = 3180) at the time of their last status message.

From the original 553 locations of eight whales, only 70% met editing criteria. These data summarized 111 days of tracking and 9633 km of trackline with mean speeds of individual animals ranging from an average of 1.0 km/h to 6.2 km/h.

Whale 10824 provided 203 locations during 34 days. It moved 4053 km through Canadian, U.S., and Russian waters. The whale spent a prolonged time near Herschel Island and Demarcation Bay. Had fewer locations been received, the migration route would still be apparent and the tag would have had a longer operational life and perhaps revealed more of the animal's wintering habitat. However, some of the detailed movements would have been lost and swim speeds would have been underestimated.

Sensor data from 11 whales were received during 1 - 34 days. The number of summary periods of information available for the three data types (duration, depth, time at depth) varied between whales. The latter two categories have never before been collected for bowhead whales. We received 566 periods of dive duration information, 477 periods of dive depth information, and 482 periods of time-at-depth data. For individual animals, the number of summary periods of data varied from 1 - 223.

Of the 42,332 dive durations recorded for nine animals, most (77.3%) were $\leq$ 1 min whereas only 1.4% were > 19 min. The longest recorded dive was 62 - 64 min. Five other tags recorded dives of $\geq$ 61 min in one or more summary periods. The longest dive for the other three tagged whales returning duration data, were 33 - 35 min, 44 - 46 min, and 55 - 57 min. The longest dive was < 33 min in 506 (89.4%) of the 566 summary periods recorded. The mean surfacing rate for individuals ranged from 18.2 to 47.0 surfacings/h.

Mean blow rates, calculated from dives/h, ranged from 0.3 to 0.8 blows/min and were significantly different among animals.

Most of the animals' time (61%) was spent in the upper 16 m of the water column and < 2% was spent deeper than 97 m. Water depths corresponding to satellite-acquired locations ranged from < 50 m (63.7%) to > 500 m (6.4%), with 85% of the depths < 100 m. The maximum depth of each of 32,629 dives was measured for seven whales in 466 summary periods. Of these dives, 80.6% were < 16 m. Dives deeper than 48 m often occurred in bouts. The deepest dive per summary period was reported for 468 summary periods by nine whales. The deepest recorded dive was between 440 and 455 m, the second deepest was between 344 and 359 m. Several animals spent more than half of some summary periods at depths greater than 49 m. One animal averaged 70.6% of its time at depths greater than 97 m during five consecutive summary periods (17 h). Another animal spent 62% of one 3-h period deeper than 201 m.

The mean percentage of time spent under water by the nine animals ranged from 91.6% to 96.0%. Surfacings were usually < 1 min. The longest surfacing was between 13.5 and 14.4 min (n = 562 summary periods); however 99.1% of surfacings were < 3.5 min. Based on our sensor data, the percentage of time animals were "potentially" visible from the air was comparable to previous observational studies of bowhead surfacing and dive behavior, but individual ranges exceeded literature values. The sensor information revealed characteristics of diving depths and durations that can affect aerial or shipboard surveys affecting population estimates due to regionally different behaviors.

Changes in the dive behavior of whale 10824 were observed when, on 20 September, between Harrison Bay and Pt. Barrow, it moved into areas where ice covered 90+% of the surface. Thereafter, the tag reported significantly fewer but longer dives, the mean percentage of time exposed to the air was significantly greater, the longest surfacings during periods were significantly longer, and much more time was spent deeper than 48 m. These differences likely reflect behavioral responses to heavy ice conditions. This whale may have made deeper, longer dives under the ice and longer surfacings in small open pools, or polynyas, between the ice. It may also reflect some bias in heavy ice situations where the tag may not always clear the water surface to acknowledge a surfacing. For example, this tag recorded 25 summary periods where the longest dive exceeded 61 min, 23 (92%) of which occurred in 90+% ice cover. Although such long "dives" may actually occur in heavy ice, it is possible the animal broke ice to breathe and the tag did not come out of the water to register a surfacing.

None of the dive behavior variables we examined from each of the tags showed consistent diel patterns. It is likely the dive information reflected more about the animal's prey preferences and available water depths than a limitation to the animal's diving capability. We have no information that would indicate that 500 m is a limitation of the animal's diving ability.

This study provides the first data on route and rate of movement for the fall bowhead migration from Canada to Russia. These data indicate areas of importance to bowhead whales in the Beaufort Sea and suggest that the heavy ice front may be the principle migratory cue for navigating across the Chukchi Sea. The changes in dive durations, depths and surface times seen in various ice conditions or regions would affect the sighting of whales during surveys and thus influence population estimates. Although 12 whales of similar size were tagged within one week in a 40 km^2 area, considerable variability in their subsequent movement, behavior and distribution indicate that the population does not migrate "en masse."

Future studies will benefit from improved attachments, smaller transmitters, shorter repetition rates, and a reduced duty cycle to obtain longer duration tracks.

INTRODUCTION

The bowhead whale (Balaena mysticetus) has been hunted for subsistence by indigenous people for at least 2000 years along the Arctic coasts of Russia, U.S., and Canada (Stoker and Krupnik, 1993). Before the start of commercial hunting in 1848, the Bering Sea population of bowhead whales was probably between 10,400 and 23,000 (Woodby and Botkin, 1993). By the time the commercial hunt ended in 1914 the population was severely depleted with over 20,000 bowheads killed (Bockstoce and Botkin, 1983) and an estimated 3000 remaining (Woodby and Botkin, 1993). The species remains endangered but IWC estimates of the Bering Sea stock have risen from 4417 (IWC, 1986) to 7500 (IWC, 1992). This difference represents improved estimation techniques, primarily acoustic data used to extrapolate ice counts (Clark and Ellison, 1988; 1989), more than population growth (Zeh et al., 1993). Population growth during the 1980s has been estimated at 3% per year (Zeh et al., 1991). Current harvesting is managed by the Alaska Eskimo Whaling Commission (AEWC) by taking strike and harvest quotas determined by the International Whaling Commission (IWC) and dividing them between different villages.

Information on seasonal movements of Bering Sea bowheads is incomplete. During spring, part of the population is known to migrate north through the Bering Strait along the northwest Alaska coast in the Chukchi Sea and then east into the Beaufort Sea for the summer. Observations in Russia suggest that part of the population also over-summers there (Bessonov et al., 1990). It is not yet clear if this is a distinct stock but it seems likely. The wintering area of bowheads that summer in the Beaufort Sea is unknown but must be south of the Bering Strait due to ice. Some observations of bowheads in winter months have been made in persistent polynyas south of St. Lawrence Island (Brueggeman et al., 1987) and in the Sea of Okhotsk just west of the Kamchatka Peninsula (Bogosloyska et al., 1982).

Recent studies of isotopic ratios found in western Arctic zooplankton (Saupe et al., 1989) coupled with studies of the isotopic ratio found in bowhead baleen raise questions about how important the Beaufort Sea is as a feeding area (Schell et al., 1987; 1989a; 1989b; Schell and Saupe, 1993). Nevertheless, bowheads have been observed feeding in the Beaufort Sea (Würsig et al., 1985; Ljungblad et al., 1986; Richardson and Finley, 1989). Furthermore, gut samples from bowheads killed in the Beaufort Sea during late summer and fall indicate these animals had recently eaten (reviewed by Lowry, 1993). Thus, there is no doubt that bowheads feed in the Beaufort Sea.

The Alaska Office of the MMS Environmental Studies Program funded this study to examine the movements and dive habits of bowhead whales in the Beaufort Sea. This bowhead study followed a tag development program begun in 1989 and three field seasons (1989 - 1991) of tagging North Atlantic right whales, Eubalaena glacialis, (Mate et al., 1992; Mate and Nieukirk, 1993; Mate et al., in press) under the same contract. Both bowheads and right whales are members of the right whale family and are found in areas of proposed, or present, offshore oil and gas development. Because similar interests and concerns exist in the Canadian Beaufort Sea, this bowhead study received additional support from the Canadian Department of Indian and Northern Affairs (DINA).

Information on the historic development of the tags and attachments may be found in MMS contract reports covering the North Atlantic right whale studies in 1989 - 1990 (Mate et al., 1992) and 1991 (Mate and Nieukirk, 1993). The tags used on bowheads looked similar to those used on right whales in 1990 and 1991. However, in addition to gathering information about dive duration, 10 bowhead tags included depth sensors. These latter tags were originally designed for use on sperm whales in the Gulf of Mexico under a separate contract from the New Orleans office of MMS. This bowhead project was the first utilization of these depth sensing tags.

Understanding the dive behavior of bowhead whales has important management implications. Surfacing and respiration patterns have been studied to estimate energetic budgets (Thompson, 1987), to estimate the proportion of time animals are visible from the air (Carroll and Smithhistler, 1980; Würsig et al., 1985; Dorsey et al., 1989), to estimate correction factors for the number of animals underwater that are missed during surveys (Davis et al. 1982; Miller, 1984), and as a measure of disturbance by vessel, industrial, and seismic activity (Richardson et al., 1985; 1986; Ljungblad et al., 1988). Despite intensive study of bowhead dive behavior, almost nothing is known of the depths to which bowheads can dive, where in the water column they spend their time, and whether their dive behavior exhibits diel variation. The results reported here reveal important information about the dive habits and underwater depth preferences of bowhead whales.

OBJECTIVES

This study was the third phase of a larger project whose objectives are shown below. The results of objectives #3 and #4 are the subject of this report.

1) Develop a satellite-monitored radio tag suitable for tracking and describing the dive habits of right whales, including associated attachments, housings, sensors, and software.

2) Tag, track, and monitor habits of North Atlantic right whales in their summer feeding range.

3) Develop appropriate software and hardware changes for use on bowhead whales.

4) Tag, track, and monitor up to one dozen bowhead whales in the Canadian Beaufort Sea to describe their dive habits and movements during the open water feeding season and fall/westward migration.

METHODS

The 1992 bowhead study area was the Beaufort and Chukchi Seas of the Canadian, U.S., and Russian Arctic (Figure 1). Tags were deployed in the Canadian Beaufort in order to obtain information on bowhead whale feeding habits during the last part of the open water feeding season. This also allowed information to be collected along the entire length of the westward migration from the Canadian Beaufort past Pt. Barrow. Permits were obtained from the U.S. National Marine Fisheries Service (NMFS) authorizing tagging activities under the Marine Mammal Protection Act (MMPA) and the

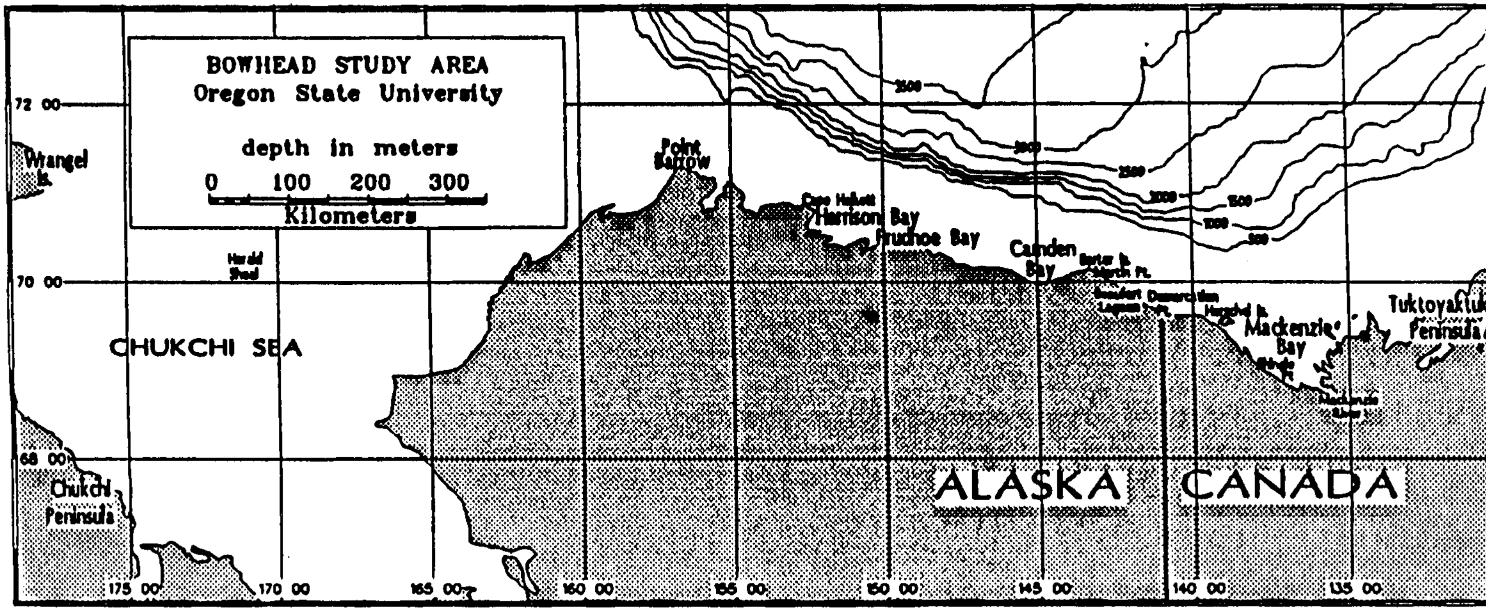

Figure 1. Study area.

Endangered Species Act (ESA) (Permit #492). A Canadian permit from the Department of Fisheries and Oceans was also obtained following a presentation to the Inuvialuit Hunting and Fishing Counsel of the Northwest Territories in Inuvik. Because the tagging took place under the Canadian permit (#11204N), the U.S. permit was never exercised. Discussions about the methodology undertaken by native hunters and proposed for this project were discussed with individual hunters from Pt. Barrow and Barter Island as well as a community meeting at St. Lawrence Island. It was the view of those who offered comment that the attachments proposed offered little consequence to bowhead whales. Tags were deployed from a 2.5 m long platform extending 45° off the starboard bow of the 13.7 m twin diesel R/V ANNIKA MARIE. The vessel departed Prudhoe Bay, Alaska on 22 August and returned on 8 September, 1992. The first three days were spent in transit to the Tuktoyuktuk Peninsula in the eastern Canadian Beaufort Sea. The abundance of bowhead whales in that area had been variable from year to year (Ljungblad et al., 1987) prior to our field work and appeared quite low west of Herschel Island (69° 25'N, 139° 00'W) during our vessel transit. As a result, we chartered a Briton Islander twin engine aircraft on 26 August and conducted a modest one-day aerial survey of the nearshore waters west of the Tuktoyuktuk Peninsula, 40 km east into Amundsen Gulf, and from the Mackenzie River west to Herschel Island. Under clear skies, with sea state $\leq$ Beaufort 2, only three whales were sighted in the peninsula and Gulf regions. Eleven whales were seen in the smaller area west of the Mackenzie River despite Beaufort 4 conditions. As a result, we concentrated our tagging efforts in the latter region.

It was difficult to keep track of whales from our vessel when they dove deeply in murky water. Diving was their usual response to even slow quartering approaches from their rear. We found it easier to keep track of animals in the shallow water near the Mackenzie River Delta (Figure 1). This may have biased our sample as we saw almost exclusively subadults in that region, but searches into deeper water farther offshore failed to identify larger animals. Whale lengths were estimated by both authors. All of the whales we encountered were juvenile/subadults ($\leq$ 13 m) (Koski et al., 1993) of unknown sex. Bowhead whales were tagged at close range ($\leq$ 8 m) in water depths $\leq$ 10 m within a 40 km^2 area near Shingle Pt., Yukon, Canada.

Tag Construction

Two types of tags were deployed: two duration tags (Argos ID #'s < 1000) and 10 duration/depth tags (Argos ID #'s > 10000). Tags consisted of a folded Telonics® (Telonics, Inc., Mesa, AZ) ST-6 asynchronous UHF radio transmitter, a controller board supplied by Telonics for duration tags or by Wildlife Computers Inc. (Redmond, WA) for duration/depth tags. All parts were (and are) available with OSU- specified software and functions. Few small batteries are able to withstand the pulsed load demand. We used eight Duracell® 2/3-A manganese dioxide batteries. The batteries were arranged in two parallel strings of four cells in series with a diode to prevent a shorted cell from draining both strings. The result was a 12-volt supply with 3400 milliamp hours capacity. Components were packaged in a stainless steel cylinder (Figure 2). Cylinders measured 189 mm long x 49 mm diameter (duration tags) or 192 mm long x 54 mm diameter

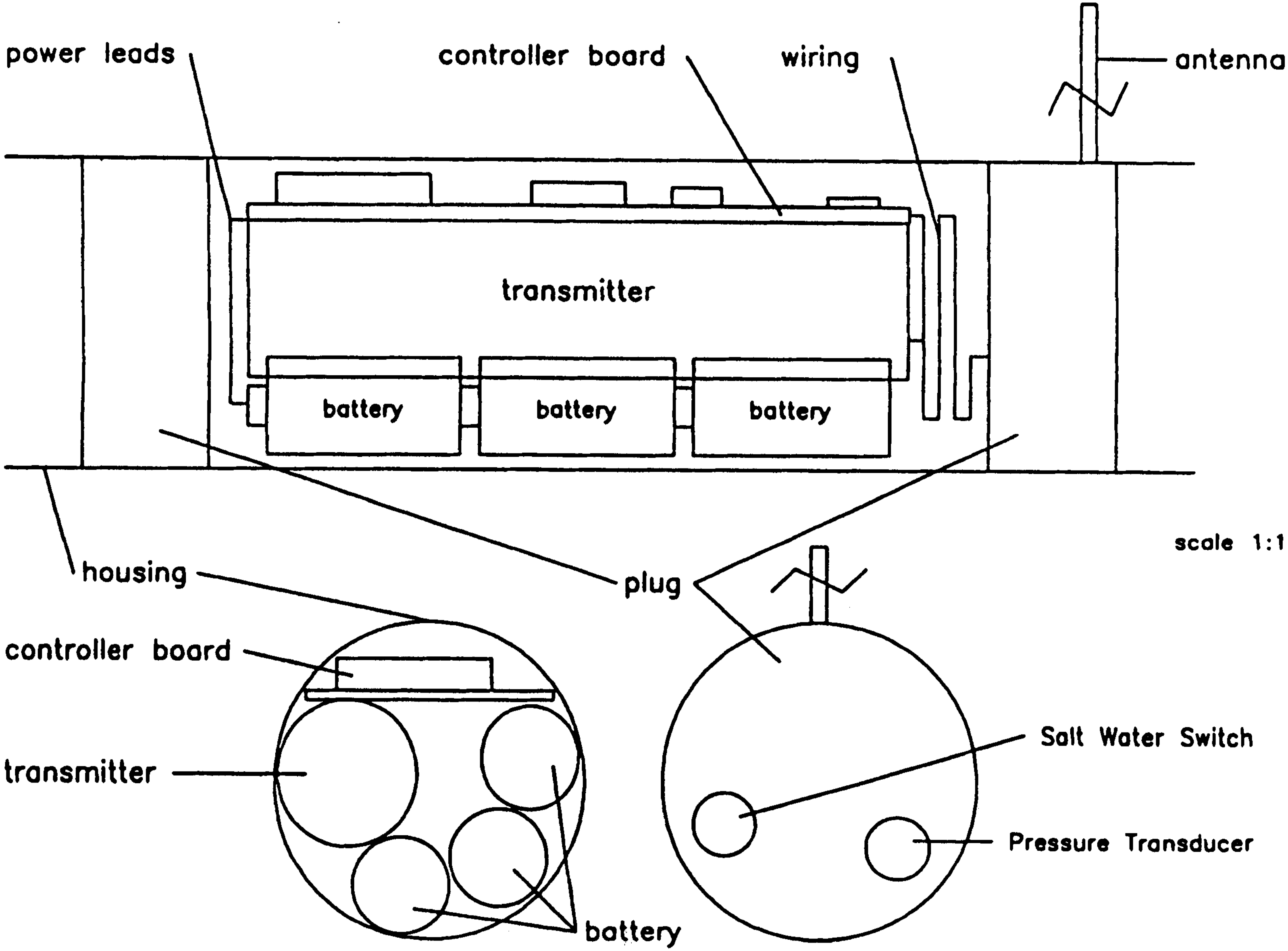

Figure 2. Schematic drawing of components: satellite-monitored duration/depth tag.

(duration/depth tags). The cylinder was potted with one to one general purpose epoxy resin (Tap Plastics, Inc., Dublin, CA) and a soft toilet-bowl sealant wax. A Delrin™ plastic plug with a rubber O-ring fitted into each end of the cylinder provided a watertight seal. Delrin™ was chosen to reduce weight, save machining time, and function as an insulator for the antenna and saltwater switch mounted on it. The antenna consisted of a 17 cm x 6 mm diameter stainless steel cable covered with plastic shrink wrap. An uncoated 5-cm section of the antenna served as a saltwater switch on duration tags. On duration/depth tags the plug with the antenna incorporated a screw head, acting as a separate saltwater switch, as well as a pressure transducer. Duration/depth tags also contained a temperature sensor in physical contact with the inside of the tag housing. A stainless steel shaft (14 cm x 6 mm diameter) was mounted through diametric holes in each end of the cylinder outside the plug (Figure 3). Two double-honed stainless steel blades at the end of each shaft facilitated penetration into the blubber, while two pairs of folding barbs behind the blades secured the tag in place. The entire tag assembly weighed 0.46 kg (duration tags) or 0.80 kg (duration/depth tags) in air.

Attachment

The tag was applied as a projectile. A modified Barnett® 68 kg (150 pound) compound crossbow was used to accurately apply tags at distances up to 8 m. An aluminum shaft with a "C"-shaped tag holder fell away after tagging (Figure 3). A bobbin-wound, 9 kg (20 pound) test line was used to recover the shaft (and the tag if it missed its mark).

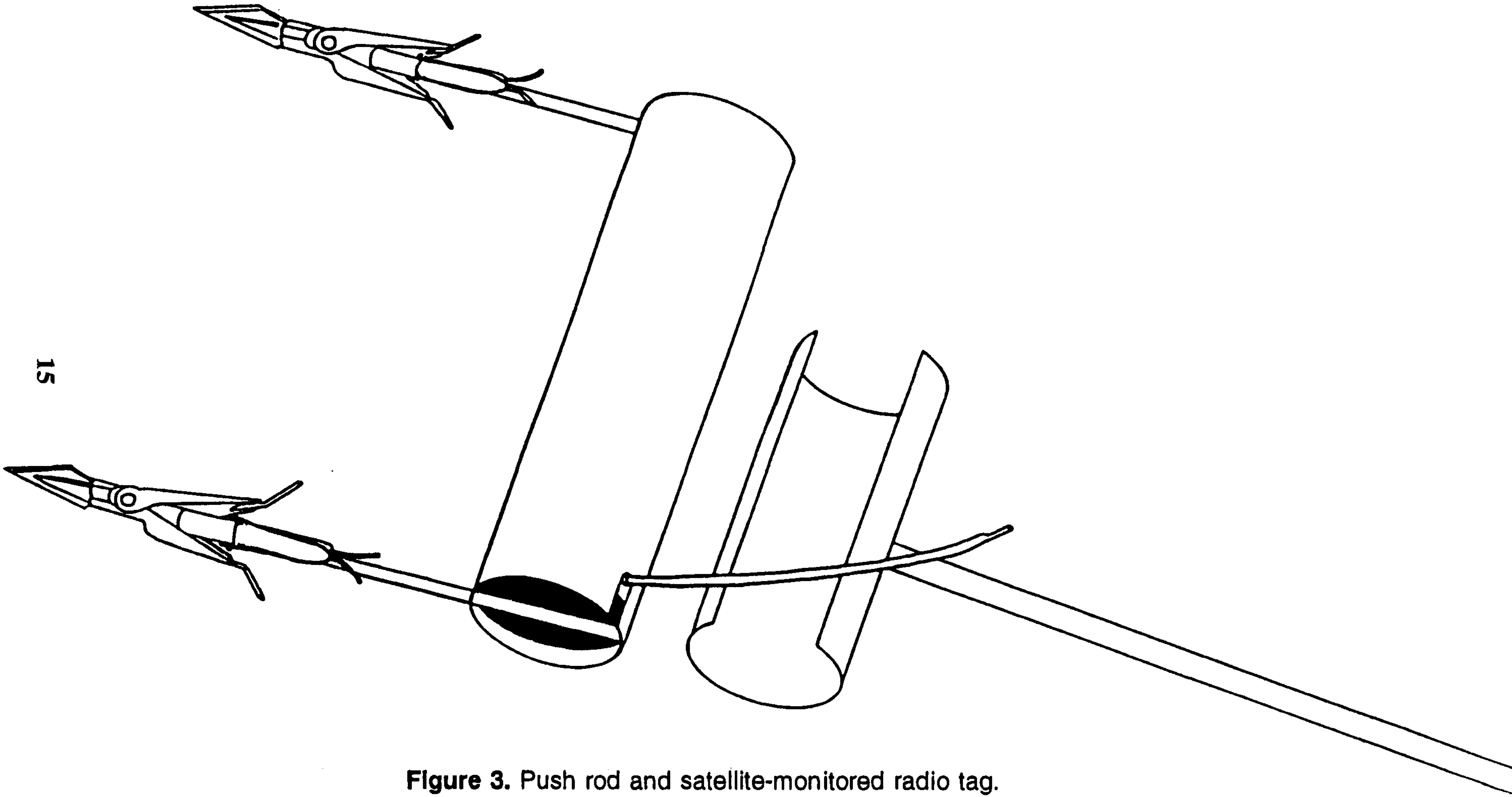

Figure 3. Push rod and satellite-monitored radio tag.
Scale of tag is one-half actual size.

The cutting action of the double-honed blades reduced resistance to penetration, allowing application with less power. One pair of barbs was in the plane of the entry blade and one pair was perpendicular. We conducted ballistic tests on bowhead blubber supplied by the North Slope Borough to determine suitable trajectory and penetration characteristics. The philosophy of the attachment mechanism was to limit penetration to the blubber layer. This was not difficult in view of the thick blubber layer found on bowhead whales during the fall when tagging was planned. The tests on excised blubber demonstrated sufficient power to deploy the tines to their full depth. In order for the barbs to fold outward, the entire tag must back out of the whale's blubber approximately 1.25 to 1.5 inches. We determined that tests on excised blubber and full carcasses of gray whales frequently produced different results owing to the thinner nature of the blubber layer and the dynamic tension on the skin, blubber, and muscle associated with the whole animal. In addition, the thin blubber layer of emaciated gray whales provided complications of ribs close to the surface of the skin. As with right whales, we anticipated that tags would back up off the body somewhat in order to laterally deploy the folding barbs. Thus, the body of the tag would not be resting against the animal's skin. In our previous experiment with right whales we saw no signs of rubbing damage to the skin from animals observed up to 58 days after tagging (16 days after tag loss).

Bowhead whales have been observed to break through ice up to 0.6 m thick in order to breathe (George et al., 1989). Observations of scarring and abrasions on the raised area around their blowholes (Albert et al., 1980; Carroll et al., 1987; Nerini et al., 1984) combined with underlying dense fibrous connective tissue up to 25 cm thick (Henry et al., 1983) suggest that bowheads use this part of the head for breaking ice. Additionally, bowheads have a depression behind the head which is frequently underwater. Therefore, we tagged animals several meters behind the "neck" as close to the mid-dorsal line as possible to assure tag exposure while surfacing and reduce tag loss while breaking ice (Figure 4).

Approaches to whales were made from the rear as whales began a surfacing sequence of respirations after a long dive. We found it advantageous to approach animals in shallow water (< 10 m) where their underwater progress could be seen from the surface as a series of eddies from the upward fluke motion or a bow wake when the animal swam more rapidly. Animals appeared most sensitive to approaches which were within 4 m of the blowhole and reacted by rapidly diving. Using such a large (and noisy) boat probably made approaches more difficult than from a smaller (quieter) boat. The best positioning, orientation, and penetration of the tag was achieved when the tag trajectory was perpendicular to the long axis of the whale. This was possible only when the boat was on a parallel course with the whale and the boat was far enough forward along the whale's length for the tagger to deliver the tag to the desired spot without shooting "forward" or to the "rear" (Figure 5).

A perpendicular trajectory results in the long axis of the tag being parallel to the whale's long axis, reducing drag to the cross-sectional surface of the tag end. Forward or rearward trajectories result in an angular tag placement relative to the forward progress of the whale and thus greater drag. Additionally, the two tines do not start into the whale's

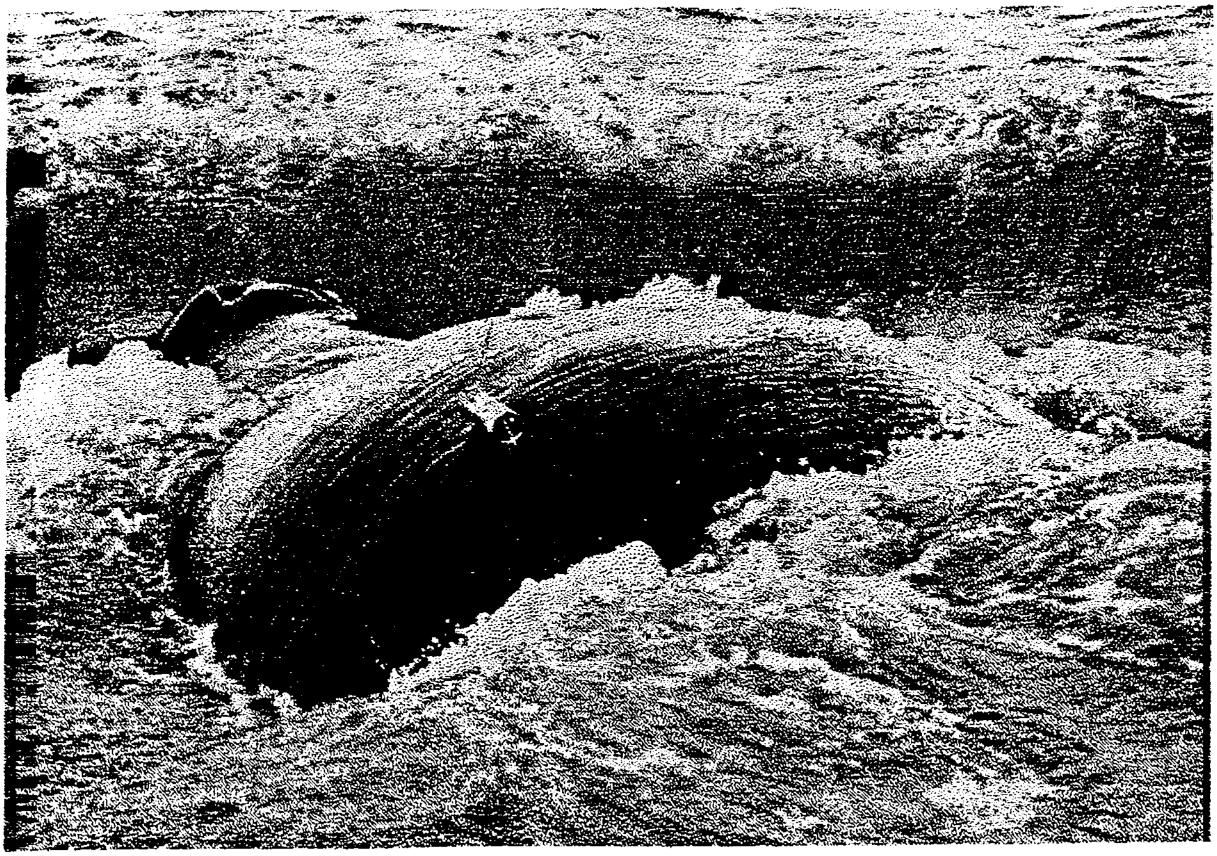

Photo: Greg Krutzikowsky

Figure 4. Ideal tag placement on bowhead whale.

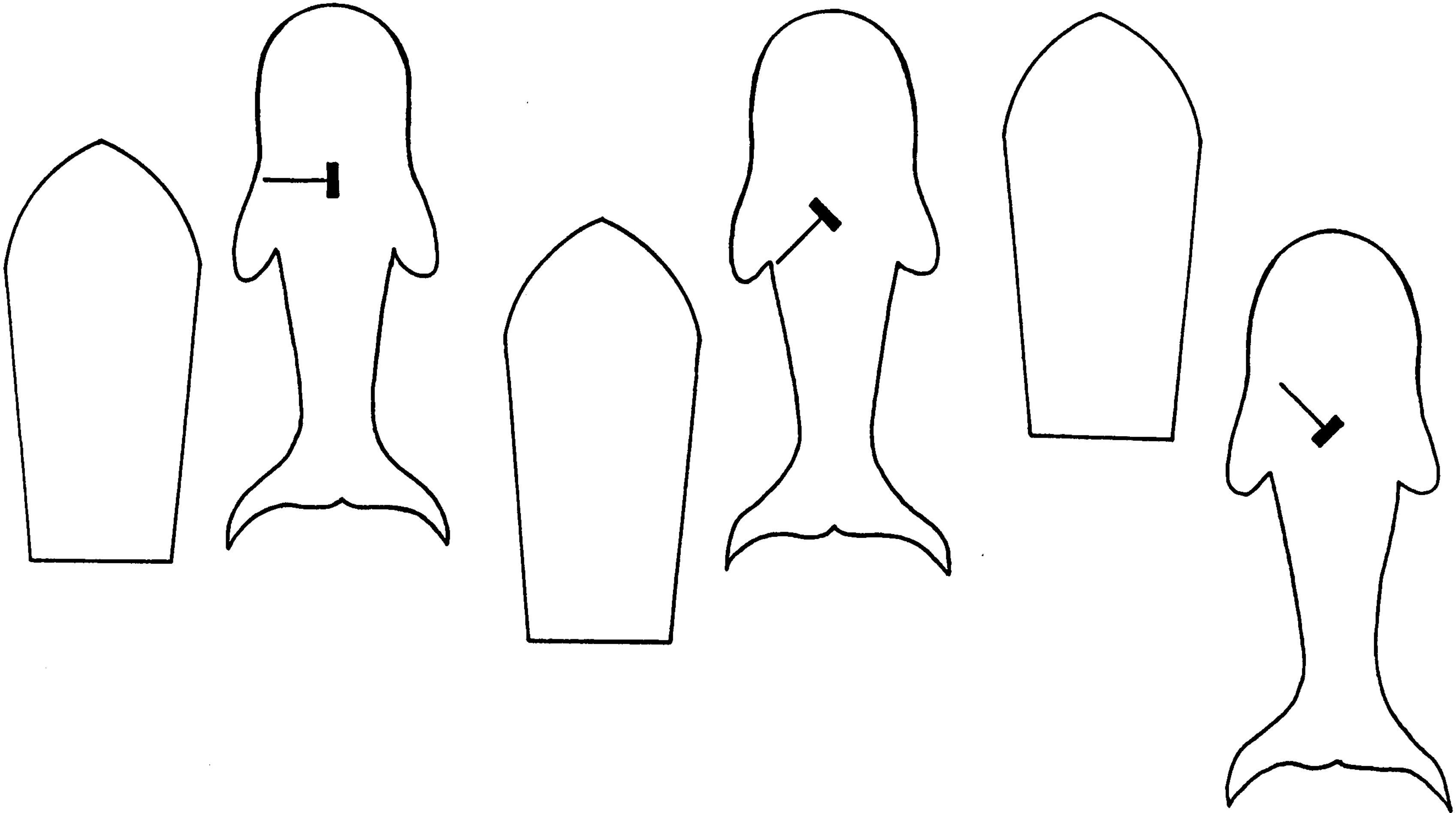

Figure 5. Boat position for best tag trajectory. Perfect position, left. Boat too far back, center. Boat too far forward, right.

skin simultaneously dissipating some of the penetration power into angular momentum changes often resulting in bent attachments which do not penetrate completely.

<u>**Sensor Data Collection and Transmission**</u>

Oregon State University specified the data to be collected, the format of transmission, and the sampling methodology. Using the right whale experiences of 1989 through 1991, we designed an efficient and compact data stream. Each tag collected sensor information during a summary period and stored 64-bit information packets for transmission at a later time. Duration tags collected one packet for each summary period (Table 1); duration/depth tags collected three packets for each summary period: 1) a duration packet; 2) a depth packet; and 3) a time-at-depth packet (Table 2). To screen for transmission errors a cyclic redundancy check (CRC) code for error detection was included with each packet (Lin, 1970; Wakerly, 1978; Mate et al., 1992). All tags were initialized based on Greenwich Mean Time (GMT) and all times and dates are reported as such. Our experimental design was to have eight 3-h summary periods beginning at 0000 GMT each day. A software error in the duration/depth tags resulted in one 1-h summary period, six 3-h summary periods, and one 5-h summary period each day (Table 3).

The saltwater switch measuring conductivity was interrogated to determine if the tag was submerged. Duration tags interrogated the saltwater switch every 0.25 s and counted time in 2 s intervals. Duration/depth tags counted time in 6 s intervals, but interrogated the saltwater switch, pressure transducer, and temperature sensor at variable

Table 1. Data Packet Structure and Transmission Scheme for Duration Tags. Each 64 bit packet contained data for one summary period. One packet was sent each transmission. Transmissions rotated through packets from the previous 4 summary periods.

Transmission Field	Unit Multiplier	# of Bits	Underflow	Overflow
packet identifier	1	2	----	----
# dives				
≤ 1 min	8 dives	6	≤ 7	≥ 504
> 1 min to 4 min	1 dive	7	----	≥ 127
> 4 min to 7 min	1 dive	6	----	≥ 63
> 7 min to 10 min	1 dive	5	----	≥ 31
>10 min to 13 min	1 dive	4	----	≥ 15
>13 min to 16 min	1 dive	4	----	≥ 15
>16 min to 19 min	1 dive	4	----	≥ 15
>19 min	1 dive	4	----	≥ 15
time underwater	1.8 min	6	< 68.4	≥ 180
longest dive	2 min	5	< 12	≥ 72
longest surfacing	1 min	5	< 1	≥ 31
error detection CRC	---	6	----	----
Total # of Bits in Packet		64		

Table 2. Data Packet Structure and Transmission Scheme for Duration/Depth Tags. All three data packets were collected each summary period. Three of the six packets from the previous two summary periods (256 bits) were sent each transmission. One packet was rotated after each transmission.

Transmission Field	Unit Multiplier	# of Bits	Underflow	Overflow
Packet #1: Dive Duration Information				
packet/period ID #	1	3	----	----
# dives				
≤ 1 min	4 dives	6	< 2	≥ 250
> 1 min to 4 min	1 dive	7	----	≥ 127
> 4 min to 7 min	1 dive	6	----	≥ 63
> 7 min to 10 min	1 dive	6	----	≥ 63
>10 min to 13 min	1 dive	5	----	≥ 31
>13 min to 16 min	1 dive	4	----	≥ 15
>16 min to 19 min	1 dive	3	----	≥ 7
>19 min to 25 min	1 dive	3	----	≥ 7
>25 min	1 dive	3	----	≥ 7
duration of longest	2 min	5	----	≥ 61
duration of deepest	1 min	5	----	≥ 31
CRC	---	6	----	----
Total Duration Packet Bits		64		

Table 2 continued.

Packet #2: Dive Depth Information

packet/period ID #	1	3		
# of dives				
≤ 16 m	2 dives	7	0	≥ 253
17 m to ≤ 32 m	2 dives	7	0	≥ 253
33 m to ≤ 48 m	1 dive	6	----	≥ 63
49 m to ≤ 96 m	1 dive	6	----	≥ 63
97 m to ≤200 m	1 dive	5	----	≥ 31
201 m to ≤400 m	1 dive	4	----	≥ 15
401 m to ≤800 m	1 dive	3	----	≥ 7
> 801 m	1 dive	3	----	≥ 7
maximum depth	16 m	7	----	≥ 1024
temperature @ depth	0.682°C	5	≤-2.808°C	≥17.280°C
CRC	----	6	----	----
Total Depth Packet Bits		64		

Packet #3: Time At Depth (TAD) Information

period/packet ID #	1	3	----	----
Time Spent				
≤ 16 m	3.6 min	6	1.7	≥ 225.0
17 m to ≤ 32 m	3.6 min	6	1.7	≥ 225.0
33 m to ≤ 48 m	3.6 min	6	1.7	≥ 225.0
49 m to ≤ 96 m	3.6 min	6	1.7	≥ 225.0
97 m to ≤ 200 m	3.6 min	5	1.7	≥ 110.8
201 m to ≤ 400 m	3.6 min	4	1.7	≥ 52.2
401 m to ≤ 800 m	3.6 min	4	1.7	≥ 53.2
> 801 m	3.6 min	3	1.7	≥ 23.4
Longest Surfacing	1 min	6	0.4	≥ 62.5
Total Surface Time	1 min	7	0.4	≥ 126.5
Error detection CRC		6		
Total Time At Depth Bits		64		

Table 3. Summary Period Times (GMT) for Duration/Depth Tags.

	Summary Periods		
PERIOD	BEGINS	ENDS	HOURS
1	02:00:00	02:59:59	1
2	03:00:00	05:59:59	3
3	06:00:00	08:59:59	3
4	09:00:00	11:59:59	3
5	12:00:00	14:59:59	3
6	15:00:00	17:59:59	3
7	18:00:00	20:59:59	3
8	21:00:00	01:59:59	5

intervals: 0.25 s while at depths < 8 m; 1 s while at depths from 8 to 32 m; 6 s while at depths > 32 m. This was done to conserve battery power during dives. Tags kept track of how much time was spent at the surface and underwater (Tables 1 and 2). To avoid counting swells and splashes as dives, dives were defined to be a submergence of the tag for at least 6 s.

Dives and surfacings were recorded in the summary period in which they ended. Each dive was registered in one of eight (duration tags, Table 1) or nine (duration/depth tags, Table 2) duration bins. The pressure transducer in the duration/depth tags measured ambient pressure and registered the equivalent depth of sea water in 8-m increments. Periodically the pressure transducer offsets were automatically reset when at the surface to correct for any drift in the sensor. Duration/depth tags registered each dive in one of eight depth bins based on the maximum depth monitored during the dive (Table 2). The temperature sensor, inside and in contact with the tag housing, measured approximate water temperature to which these tags had recently been exposed (Table 2). Underflow/overflow values were transmitted if data values fell outside the range of values allowed by the bit structure (Tables 1 and 2). For example, duration tags counted dives $\leq$ 1 min in groups of 8 up to 504 dives (Table 1). If seven or fewer dives of this duration were registered during a summary period, zero was transmitted indicating an underflow. If 504 or more dives of this duration were registered, the maximum allowed in the 6-bit field (63) was transmitted, indicating an overflow. An underflow/overflow thus established the maximum/minimum value for that transmission field.

Duration tags were programmed with a transmission duty cycle providing for transmissions during the first 100 min each 12 h. A transmission included one data packet (Table 1). Transmissions rotated through the four data packets representing 12 h of data from the previous four summary periods.

For duration/depth tags a software error caused the scheduled transmission duty cycle (2 h on/4 h off) to fail. Consequently, these tags transmitted at each surfacing > 40 s since the last transmission. Normal duration/depth tag transmissions included four of the six data packets from the two previously completed summary periods on a rotating basis (Table 2). After 15 transmissions duration/depth tags transmitted a special status packet that included total number of transmissions, battery voltage, surface water temperature, and pressure transducer offsets.

Transmissions were triggered by the tag's conductivity sensor (saltwater switch). A 400 mW signal was transmitted at 401.650 MHz for either 0.440 s (duration tags) or

0.960 s (duration/depth tags). The message identified the tag and contained 64 or 256 bits of information for the duration and duration/depth tags, respectively.

The Argos Data Collection And Location System

The Argos Data Collection and Location System (ADCLS) was used to track tagged whales during this study (Mate and Harvey, 1982). It is the only truly remote (satellite-monitoring) location system available to civilians. Argos transmitters have individual identification codes and a minimum repetition rate of 60 s. We obtained special permission to allow us to transmit as frequently as once every 40 s. Argos transmitters are located by the Doppler shift in frequency of the received signals. Service Argos calculates the locations (described in Fancy et al., 1988) and the data are retrieved with a computer and modem. In general, Argos-acquired locations were available within 3.5 h of a satellite passing overhead. We also obtained monthly backup data files from Service Argos on floppy disks.

Service Argos classifies locations of transmitters by their estimated accuracy: location class (LC) 0 to 3. A location can be calculated from as few as two transmissions, but the accuracy of such a location is unknown (LC 0). Argos estimates that at least 67% of the locations classified as LC 1, 2, 3 are within 1000 m, 350 m, and 150 m, respectively, of the true position (Table 4). In our laboratory (terrestrial) experiments and the field experience of others (Stewert et al., 1989; Harris et al., 1990; Keating et al., 1991) a lower percentage of locations met these distance criteria than are claimed by Service Argos. Most difficult to interpret are the location class 0 locations. These have no assured accuracy whatsoever. Experiments with transmitters on domestic animals in enclosures found 68% LC 0 locations were within 14.3 km (range 0.1 - 39.6 km, n = 184; Keating et al., 1991). Roof top experiments in our laboratory examined 78 LC 0 locations and found a range from < 1 km to 58 km with a mean of 8.3 km. Sixty-eight percent of locations were within 10 km. To achieve two standard deviations from the known reference point would suggest that 30 km would capture approximately 95.4% of all the LC 0 locations. Thus, the actual location of LC 0 locations cannot be well identified and should be viewed with extreme caution throughout the remainder of this report. Accuracy increases as the number of messages received and the time between the first and last message increases (Table 4).

Argos receivers are on National Oceanic and Atmospheric Administration (NOAA) sun-synchronous, polar-orbiting, TIROS-N weather satellites (Figure 6). Each of the two active satellites has four Argos receivers and is capable of monitoring up to 930 transmitters in a specific area. Because of the polar orbit, the number of orbits (passes) overhead varies by latitude. For both satellites combined, there are 28 orbits/day for latitudes greater than 75° and as few as six orbits/day along the equator (Figure 6). In the Arctic area inhabited by bowheads, an average of 24 passes were available to receive bowhead data daily. Satellites must be within a clear "line-of-sight" to transmitters to receive messages. From a fixed point on earth, the satellites move from horizon to horizon in 8 - 15 min and are within reception range of a transmitter for an average of 10 min during each pass. In 1992, Argos charged $12/day for the number of days it collected data for each transmitter.

Table 4. Accuracy and required conditions for Argos location classes.

	REQUIRED CONDITIONS	ACCURACY
CLASS 3	• At least seven minutes between first and last message of pass • At least five messages received • Very good oscillator stability • Very good geometric configuration	Location accuracy: 150 m (1 st. dev.) (Varies with sunspot activity)
CLASS 2	• At least seven minutes between first and last message during pass • At least five messages received • Good oscillator stability	Location accuracy: 350 m (1 st. dev.)
CLASS 1	• At least four minutes between first and last message of pass • At least four messages received • Reasonable oscillator stability	Location accuracy: 1 km (1 st. dev.)
CLASS 0	• At least two messages received during pass	Quality of results, to be determined by user, depends on number of messages processed.

Data Screening

Locations

Each location was plotted using CAMRIS© software on an IBM-based PC. Shorelines and depth contours were digitized into CAMRIS© from either NOAA chart #16003 or U.S. Defense Mapping Agency chart #15026. Locations were eliminated when they were either: 1) conspicuously on land (more than 5 km inland allowing for ambiguity in Argos locations nearshore), or 2) resulted in minimum speeds ≥ 25 km/h between adjacent locations. LC 0 locations were the most common locations and also the ones most likely to be deviating from actual locations. Again, the amount of error associated with LC 0 locations cannot be appropriately estimated. While at least half of our terrestrial experiments were 8.3 km or less from the true location, the other half were larger than that. The screening criteria were set up to identify those locations which were particularly inappropriate. Virtually all (98%) of the 169 locations which were edited out were LC 0 locations. We observed bowheads swimming at approximately 20 km/h for short periods and picked a figure 25% higher (25 km/h) as a safety margin for "allowable" swimming speeds. This also compensated for some of the locational errors associated with all Service Argos locations. Location edits were less likely when there were long periods of satellite time between adjacent locations. As the duration-only tags (828 and 831) transmitted only 100 min/12 h, they provided few locations and a large "acceptable" distance (based on edit criteria of allowable speeds up to 25 km/h to the next location. Thus, all of the duration tag locations were less likely to be edited than were the locations from duration depth tags (which transmitted continuously and provided more frequent locations). In fact, the edit criteria actually also proved disadvantageous to the more frequently transmitting duration-depth tags in that locations which were determined within a few hours of each other sometimes produced high swimming speeds due to a lack of accuracy in one or both locations. When applying the editing criteria, we looked at the effect of eliminating either of the locations which resulted in a high swimming speed for its "ripple effect" on adjacent speeds. Our overall intent with the editing criteria was to eliminate locations which were so erroneous as to result in unreasonable speeds. All locations and location statistics in this text are those not eliminated by the two rejection criteria unless otherwise specified.

Sensor Information

Transmissions with CRC code errors were eliminated from consideration. Remaining transmissions were condensed to summary period information and checked for logical consistency.

Summary periods where underflow/overflow values, or other logical consistency error conditions existed, were examined on an individual basis to determine if they contained any valid sensor information. Since summary period length was known, an overflow condition in a single time-at-depth bin could be recovered by subtracting the time accounted for in the other bins from the summary period length. An underflow/overflow in the duration of the longest dive or the first dive to the maximum depth determined the maximum/minimum duration for those respective dives. An overflow in the number of dives in a given bin determined the minimum number of dives in that bin.

Because duration tags reported the time submerged in increments of 1.8 min, we added half of that increment (0.9 min or 0.5% of the period) to the reported value to avoid a consistent downward bias.

For duration/depth tags, the number of dives in a period came from the duration packet, the depth packet, or both (Table 2). For periods where duration/depth tags reported both the duration packet and the depth packet, the minimum and maximum number of dives in each packet were compared to obtain the smallest possible range of

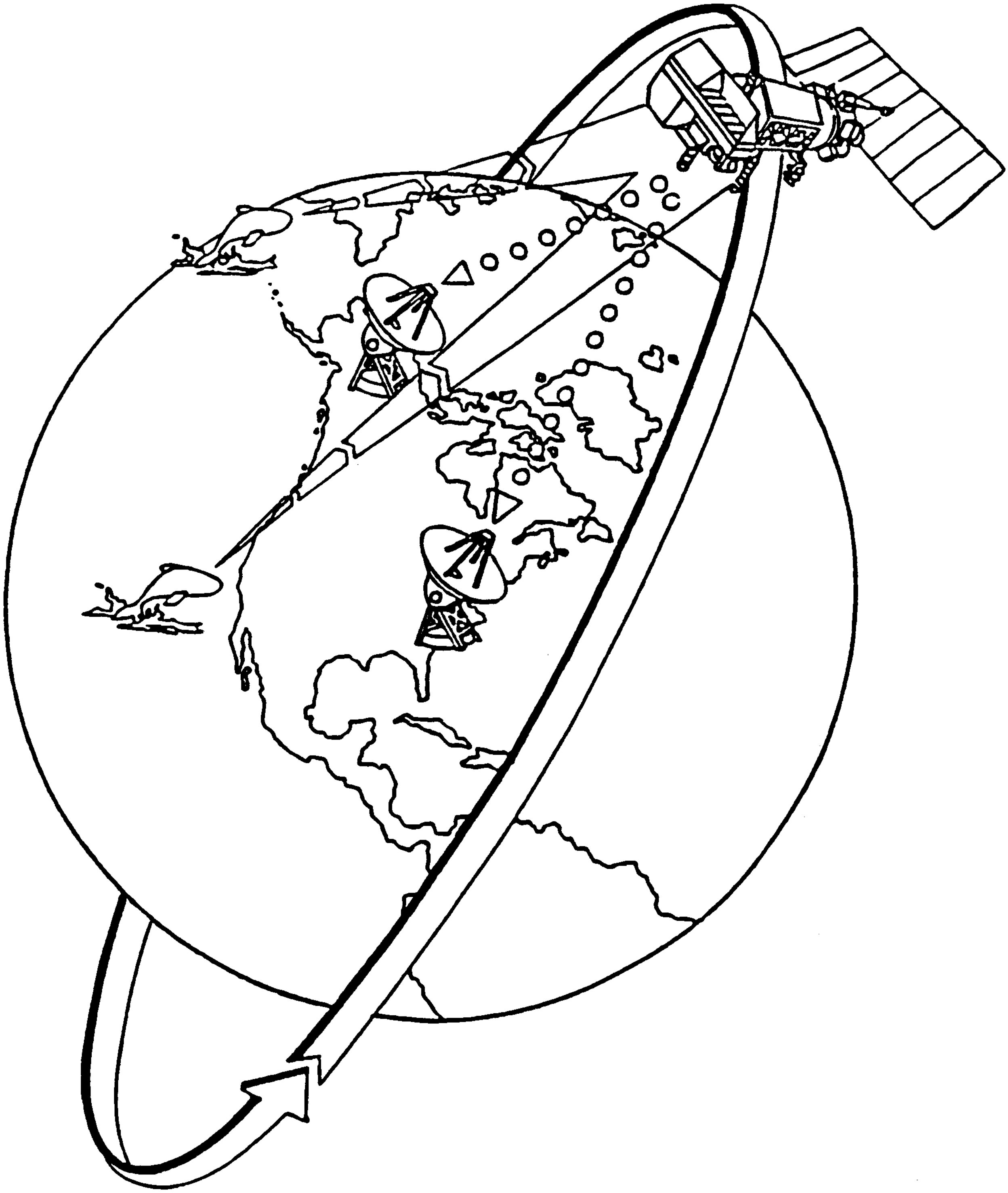

Figure 6. Representation of a NOAA TIROS-N satellite in polar orbit receiving transmissions from whales.

values. For all tags, the number of dives in the first duration bin (≤ 1 min) was taken to be the mean of the minimum and maximum number of dives possible in that bin during the period. Any uncertainty in the number of dives in the first two depth bins was spread equally between them. Thus, the final count of dives includes partial dives in some bins.

Environmental Variables

Approximate daily sunrise and sunset times (GMT) were determined based on date, Argos-determined locations for each whale, and published sunrise and sunset information (U.S. Dept. of Commerce, 1991). Summary periods were assigned one of four classifications to indicate time of day: 1) night - if they began more than an hour after local sunset and ended more than an hour before local sunrise; 2) dawn - if sunrise occurred either during the period or within an hour of the end of the period; 3) day - if they began and ended between sunrise and sunset; and 4) dusk - if sunset occurred either during the period or within an hour of when the period began. Ice cover conditions near whale locations were evaluated from daily ice analysis charts issued by Environment Canada's Ice Centre Ottawa and/or satellite images collected at the Anchorage branch of the U.S. National Weather Service.

Statistical Methods

Statistical comparisons were made with parametric tests when possible. Data were log-transformed for parametric tests where appropriate. Mean, standard deviation, and sample size are reported. When data were log transformed, geometric mean and 95%

confidence intervals are reported rather than mean and standard deviation. The conservative Tukey HSD technique was used to compare means in ANOVA tests. Differences between means are reported with 95% confidence intervals. Non-parametric tests were used to make comparisons if data included underflow/overflow values or if transformed data failed to meet the assumptions for parametric tests. Significance level for all tests was set at 0.05. Statgraphics® statistical software package was used for data analyses.

RESULTS AND DISCUSSION

PART 1: WHALE TAGS

Tagging

All shots taken resulted in tags being applied. Between 30 August and 6 September, 12 juvenile and subadult bowhead whales, ranging in size from 8 to 12 m, were tagged (Table 5). Two whales were tagged each day on five of the seven consecutive tagging days. Although we initially had trouble finding whales, we did not have trouble tagging whales once we found an advantageous circumstance in the shallow waters of the Mackenzie Delta. Experience since the bowhead tagging with blue whales and humpback whales, suggest that open water tagging of larger animals in deeper water would likely also be feasible for bowhead whales but may require a little time to develop suitable approach techniques.

Tag Attachment

Tags were applied approximately 3 m behind the blowholes near the mid-dorsal line (Figure 4). At the range whales were tagged ($\leq$ 8 m), the power of the crossbow appeared adequate. However, some tag attachments did not penetrate completely because of the angle of the application from the boat to the whale. Proper application requires a perpendicular trajectory to the target area of the whale. Attempts to tag whales farther ahead or behind the tagging platform resulted in tags not being parallel to the long axis of the whale's body (creating more hydrodynamic drag) or the tines not penetrating to their full depth (Figure 5). The first tag (10820) was poorly positioned on the side of the whale because it fell "short" of the mid-dorsal "target" due to noticeably low power from the crossbow in cold weather. We compensated for this in all subsequent tagging attempts.

Placement was judged "excellent" for five tags, "good" for four, and "poor" for three (Table 6). Three tags were placed too low on the side of the whales and failed to surface during normal surfacing sequences. The poor placement of tag 10831 was the result of a sudden roll by the whale in response to the close approach by the boat.

Transmitter Performance

Transmissions were received from all 12 tags. Locations were calculated for eight whales, and valid sensor information was received from 11 tags (Table 6). Position of the tag on the animal critically affected tag performance. Few transmissions, and consequently little or no data, were received from four tags (Table 6). Three of these tags

Table 5. Bowhead Whales Tagged in 1992.

TAG #	Approximate Animal Length (m)	WHEN TAGGED (GMT)		TAGGING LOCATION	
		Date	Time	Latitude	Longitude
10820	11-12	30 Aug	1249	69° 01'N	137° 20'W
10822	9	1 Sept	2017	69° 02'N	137° 19'W
10824	10	2 Sept	2051	69° 01'N	137° 21'W
10825	10-11	2 Sept	2330	69° 06'N	137° 25'W
10826	8	5 Sept	1929	69° 06'N	137° 05'W
10827	10	3 Sept	2049	69° 07'N	137° 06'W
10828	10	3 Sept	2129	69° 07'N	137° 02'W
10829	8-9	4 Sept	0031	69° 06'N	137° 04'W
10830	8-9	4 Sept	1806	69° 07'N	137° 06'W
10831	8-9	5 Sept	1848	69° 06'N	137° 10'W
828	8	6 Sept	0349	69° 03'N	137° 14'W
831	8.5-9.5	6 Sept	0320	69° 05'N	137° 10'W

(10820, 10829 and 10831) were positioned low on the animal's body. They probably seldom cleared the water to transmit and may not have had a clear line-of-sight to a satellite when they did. The reasons for poor performance by tag 10822 are unknown.

On the basis of battery capacity and estimated number of transmissions, we predicted a functional life of transmitters to be 30 days. Tags were monitored from 4 to 49 days after tagging (Table 6) for a total of 211 days. The best longevity was from a tag which was poorly positioned (10829) and was heard from only five times. Each contact was a single message, so no locations were ever obtained. The long battery life was likely due to the very infrequent use of power for transmissions. Of six tags with utility status messages, five reported low battery voltage which was probably the reason for loss of signals after 10 to 34 days on those whales (Table 7). Status messages revealed substantial differences between tags in the elapsed time before a significant drop in voltage. It took 10 and 11 days after tagging for tags 10827 and 10830 to drop 1.7 and 3.3 volts, whereas tag 10824 dropped 2.7 volts after 32 days. Cold temperatures and a more frequent transmission rate than originally planned likely contributed to the short battery life.

PART 2: LOCATION AND MOVEMENTS

A total of 553 Argos locations were calculated for eight whales (Table 8). Thirty percent (30%) of all locations (from 21% to 67% for individual whales) did not meet our screening criteria and were eliminated (Table 8). Most remaining locations (87%) were LC 0; 9% were LC 1; and 4% were LC 2 and LC 3 combined. Extreme caution should be exercised in the interpretation of LC 0 locations, especially those which are widely spread in time from adjacent locations. There is no assurance of the location accuracy of LC 0 locations. Those that remained met editing criteria which allowed for 25 km/h travel, which we consider a reasonable upper limit for any extended period of time. Thus, animals which had few locations per day may be most suspect. The 384 screened locations plus the tagging locations accounted for 111 days of tracking over a distance of 9565 km (Table 8). Individual whales were located from 6 to 204 times over 3 to 33 days and traveled from 70 to 4053 km. There was a significant correlation between the number of days tracked and the distance traveled ($r = 0.80$, $p = 0.016$). The number of locations per

Table 6. Tag position, transmissions, and data returns.

Tag #	Tag Position	Total Xmits	# of Days	# of Locations	Number of Summary Periods		
					Duration	Depth	TAD*
10820	poor	3	25	0	0	1	1
10822	good	9	5	0	1	1	2
10824	excellent	984	34	204	222	220	223
10825	good	140	10	18	42	44	46
10826	excellent	66	4	6	19	14	16
10827	excellent	304	12	64	78	76	78
10828	excellent	202	10	32	59	56	54
10829	poor	5	49	0	0	0	0
10830	good	211	11	43	63	65	61
10831	poor	3	10	0	0	0	1
00828	good	60	24	10	33	----	----
00831	excellent	73	17	16	49	----	----
Totals		2060	211	393	566	477	482

*Time At Depth

Table 7. Battery Strength at Last Status Message and Last Transmission Received.

Tag #	Last Status Message (days after tagging)	Volts	Last Xmit (days after tagging)
828	N/A	N/A	24
831	N/A	N/A	17
10820	NONE	-----	25
10822	NONE	-----	5
10824	32	7.23[1]	34
10825	7	8.51[*]	10
10826	2	10.18	4
10827	10	8.06[*]	12
10828	10	8.70[*]	10
10829	NONE	-----	49
10830	11	6.59[*]	11
10831	NONE	-----	10

[1,*] Battery voltage probably limited the useful life of these tags.

Table 8. Bowhead 1992 Satellite-acquired Location Information.

TAG NUMBER	ORIGINAL LOCATIONS	EDITED LOCATIONS	DAYS WITH LOCATIONS	TOTAL DISTANCE (km)	MEAN SPEED (km/h)
10824	277	203	33	4052.6	5.1
10825	38	17	8	652.3	3.4
10826	17	5	3	70.4	1.0
10827	80	63	11	1113.0	4.2
10828	42	31	8	621.6	3.2
10830	64	41	10	1429.4	5.8
828	15	9	23	619.3	1.1
831	20	15	15	1006.4	2.8
TOTAL	**553**	**384**	**111**	**9565.0**	**3.3**

Table 9. Water depth (m) at tagging and satellite-acquired locations.

Tag #	0-50	51-100	101-200	201-500	> 500	Total
10824	129	56	10	5	4	**204**
10825	16	0	0	2	0	**18**
10826	6	0	0	0	0	**6**
10827	35	20	9	0	0	**64**
10828	15	4	2	0	11	**32**
10830	30	6	0	0	6	**42**
828	10	0	0	0	0	**10**
831	14	0	1	0	1	**16**
Total	**255**	**86**	**22**	**7**	**22**	**392**

day varied from 0.4 to 6.2. There was a significant correlation between the number of locations and the distance traveled ($r = 0.97$, $p < 0.0001$). The mean speed for individual whales varied from 1.0 to 5.8 km/h ($\bar{x} = 3.3$, Table 8). Speed did not correlate well with either the number of tracking days or the number of locations (p-values > 0.05).

The movements and habitat use of the tagged whales varied considerably. Six of the eight animals moved out of Mackenzie Bay during monitoring. Most animals moved west and/or north of Herschel Island. More than half of the locations for all but one whale 46% for whale 10828) were in water < 50 m (Table 9). Overall, 87% of all locations were in water < 100 m. However, most whales did venture into deeper water. Six of eight tagged whales were located in water > 100 m deep and four of the eight were in water > 500 m deep. Movements of Individuals

Of the eight tracked whales, two (10826 and 828) limited their activities to Mackenzie Bay/Delta region. These whales had few locations/day.

- Whale 10826 was tracked for only three days between six locations (70 km) clustered within 30 km of the tagging site (Figure 7). Three locations were LC 0 and two were LC 1. Only 29% of this whale's locations survived screening criteria (Table 8), resulting in 1.7 locations/day and dramatically reducing the whale's overall distance and average speed (1.0 km/h). All locations were in water < 20 m deep and no ice was encountered by this animal.

- Whale 828 traveled at least 619 km during 23 days between the tagging site and nine LC 0 locations ($\bar{x} = 0.4$ locations/day). Sixty percent of satellite-acquired locations survived editing (Table 8) and all of these were within 185 km of the tagging site (Figure

8). Because all the locations for this animal are LC 0 locations and they are spread out over a number of days, it is impossible to substantively verify the accuracy of any of the locations. While this is true of LC 0 locations for all animals, this was the only animal to acquire < 1 edited location/day. At a mean speed of 1.1 km/h, whale 828 was the second slowest whale as it apparently moved back and forth along a northeast southwest-oriented 20 m depth contour. There were five gaps of three to five days between some of these locations. This tag type only transmitted 200 min/day and 38% of its initial locations were rejected. The last two locations were in an area with 80% ice cover and were four days apart. By the time these locations were received (late September) the migration route westward was 90+% ice-covered.

Another two of the eight whales (10827 and 10828) spent all of their time in just three areas.

• In addition to Mackenzie Bay, whale 10827 spent most of its 11 tracking days near Herschel Island (Figure 9), traveling 1113 km between the tagging and 63 satellite-acquired locations at an average speed of 4.2 km/h. This whale retained the highest percentage of locations after editing (79%) and averaged 5.7 locations per day (Table 8). The whale's locations were in water 10 to 200 m deep. Of 63 satellite-acquired locations, eight were LC 1, all the rest were LC 0. After spending several days west of Herschel Island in depths < 50 m, this animal moved east into waters with depths of 50 to 200 m at the head of Mackenzie Canyon with a short excursion back into Mackenzie Bay. The difference in water depth between the west and east side of Herschel Island make these two regions quite different. This whale was never located near any ice.

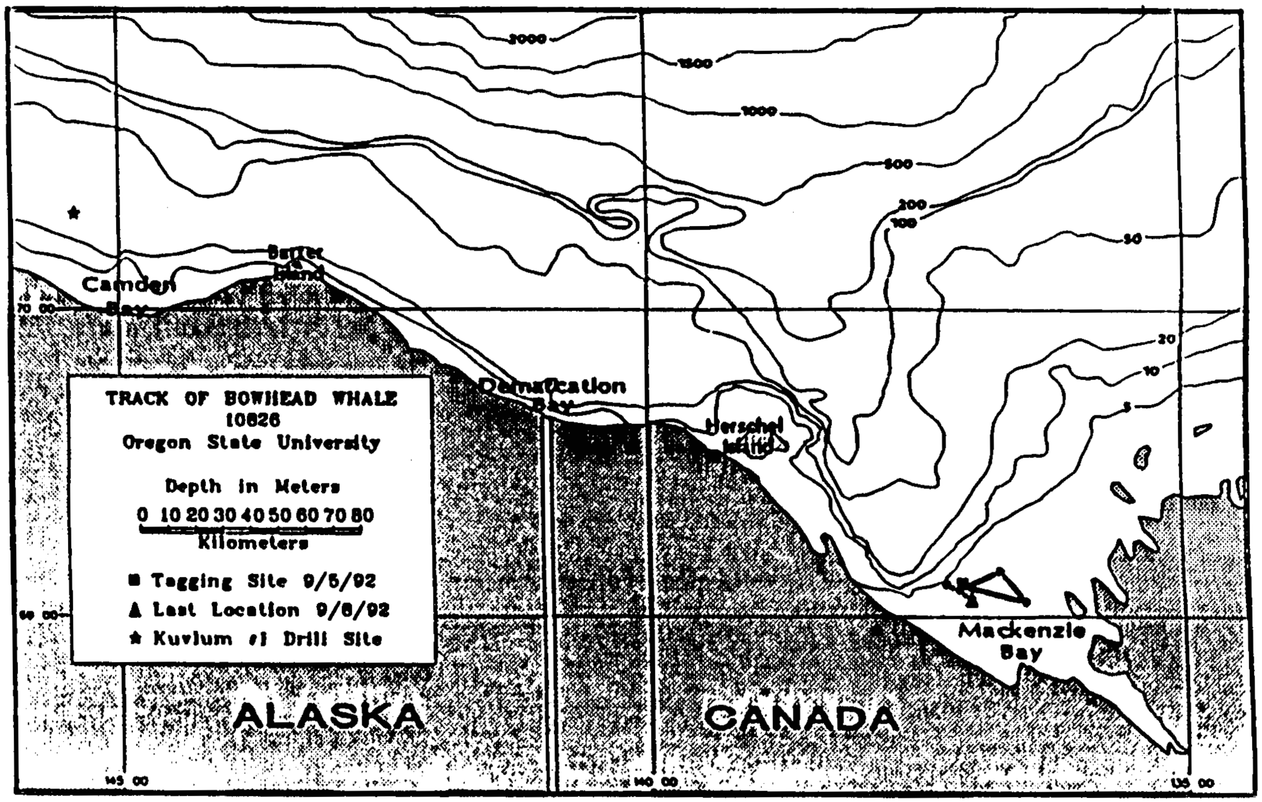

Figure 7. Track of whale 10826.

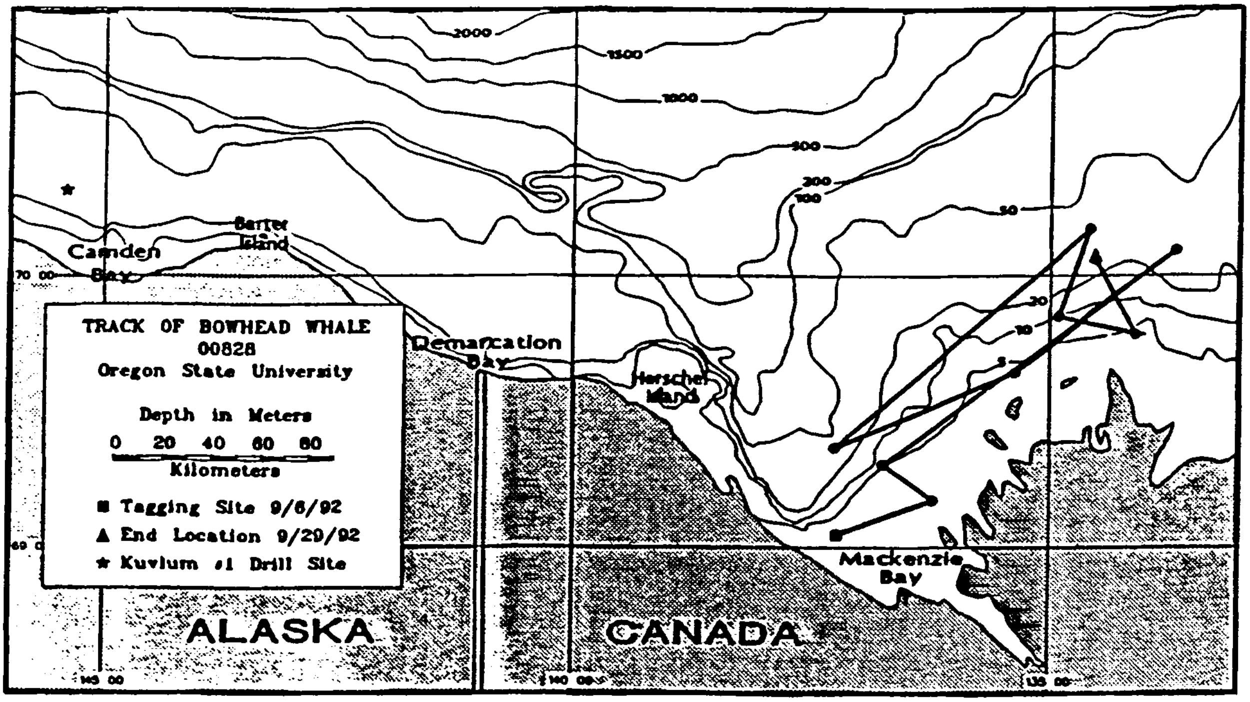

Figure 8. Track of whale 828.

• In eight days, whale 10828 moved 622 km ($\bar{x}$ = 3.2 km/h) between the tagging and 31 satellite-acquired locations ($\bar{x}$ = 3.9 locations/day) (Figure 10). Most of its locations (74%) survived editing (Table 8). With five LC 2 and four LC 1 locations, this whale had the highest percentage of non-LC 0 locations. Its time was equally divided between an area within 60 km of the tagging site in water < 50 m and traveling north along the eastern edge of the Mackenzie Canyon into the deep basin region 1000 to 1500 m deep. The second half of the track contained all of the LC 2 locations and was characterized by higher speeds, deeper water, and more frequent locations. More locations for this whale were in deep water (34% > 500 m) than any other tagged animal (Table 9). Four of the last five locations were in 10% to 50% ice. All the earlier locations were ice-free.

A westerly limit at Demarcation Bay and Barter Island characterized the movements of whale 10825 and whale 10830 respectively.

• Whale 10825 traveled 652 km ($\bar{x}$ = 3.4km/h) between the tagging and 17 satellite-acquired locations (2.1 locations/day) in eight days (Figure 11). In that short period the animal went to Herschel Island, returned to Mackenzie Bay, went northwest toward the shelf break off Demarcation Bay, then inshore to Demarcation Bay for three days before moving back offshore and east to Mackenzie Canyon into water > 300 m deep. Prior to the Canyon, all locations were < 50 m deep (89% of all locations). All locations were LC 0 and only 45% survived screening criteria (Table 8). Nonetheless, there was a big difference in the rate locations were acquired in specific areas. Nearshore by Demarcation Bay, 11 locations in 52 h ($\bar{x}$ = 5.1 locations/day) were received. During

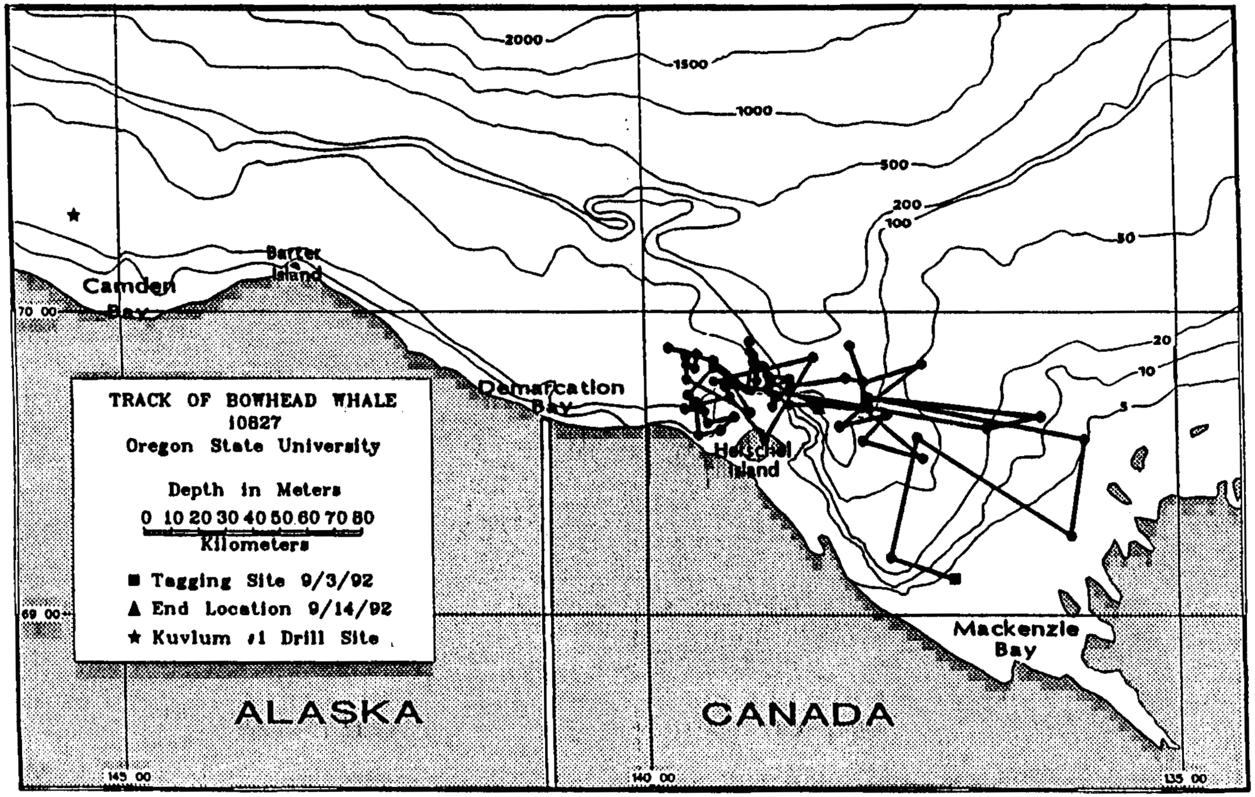

Figure 9. Track of whale 10827.

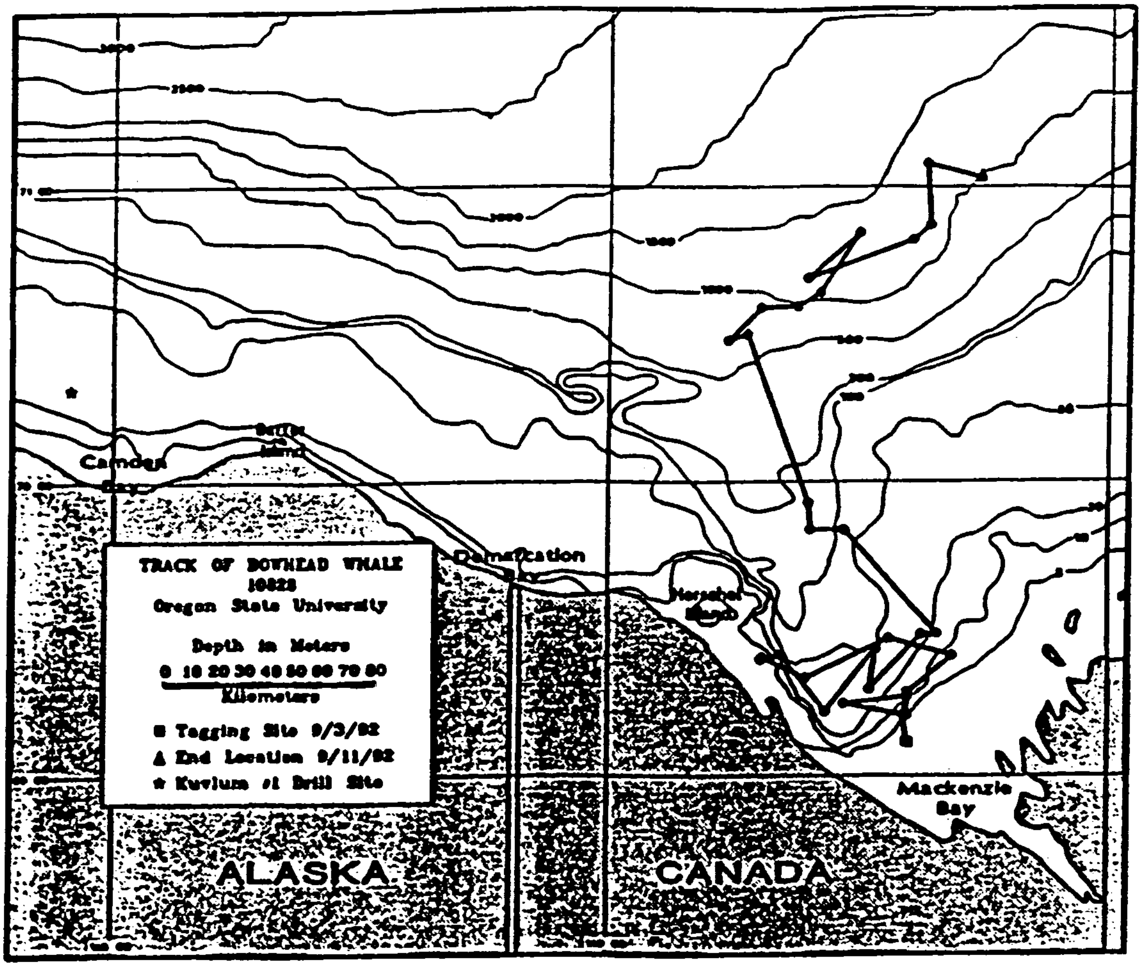

Figure 10. Track of whale 10828.

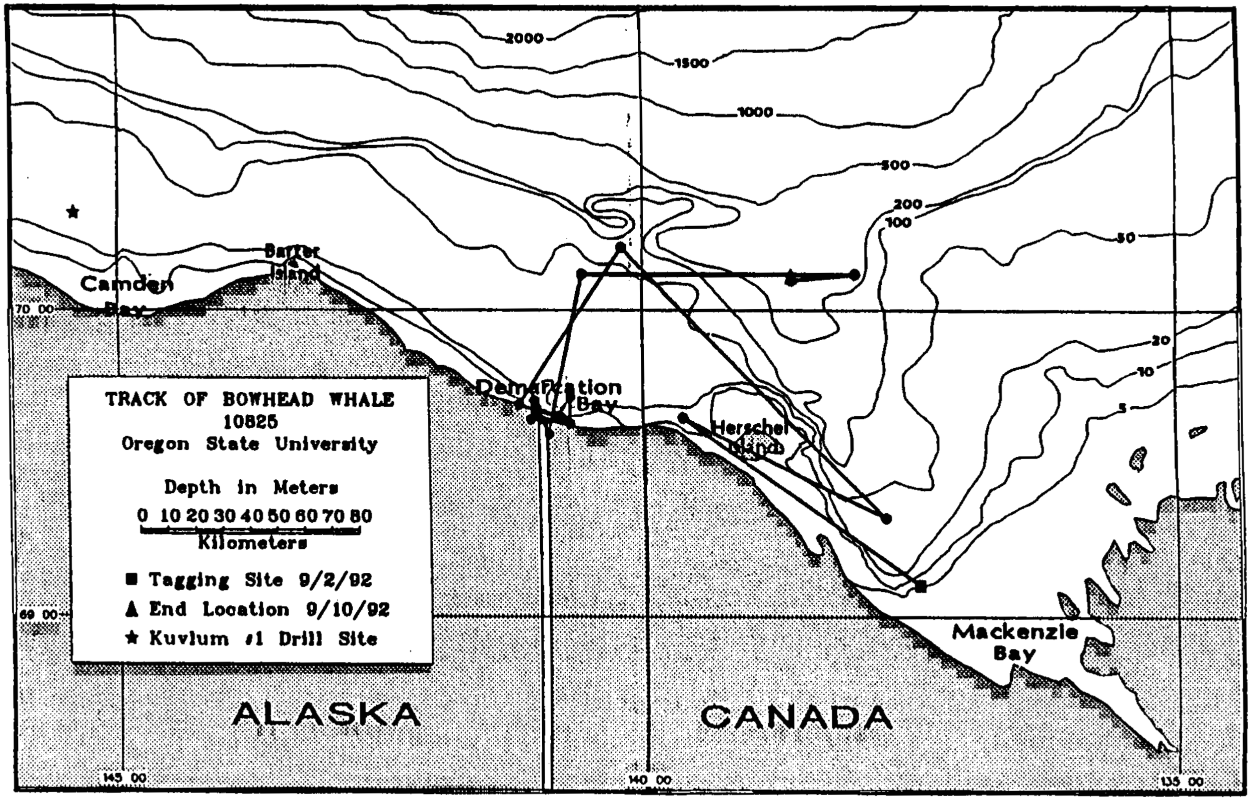

Figure 11. Track of whale 10825.

the other six days of monitoring, only one location/day was acquired. This animal was in ice-free water while it was tracked.

• Whale 10830 had the fastest mean swimming speed (6.2 km/h) and the second longest track among all whales, moving 1429 km from the taggings and 41 satellite-acquired locations ($\bar{x}$ = 4.1 locations/day) in 10 days (Figure 12). More than one-third of all locations for this animal did not meet editing criteria (Table 8). This whale visited and returned to several diverse habitats. The first two days after tagging were spent in Mackenzie Bay, followed by a one day visit to the east and west sides of Herschel Island then to deep water offshore from Demarcation Bay. Over the next six days this animal moved back to the west and east sides of Herschel Island, west to Barter Island, offshore Demarcation Bay, nearshore Demarcation Bay, and past Herschel Island to Mackenzie Bay. Finally the animal traveled north to the deep basin water (2000 m). Seventy-one percent (71%) of all locations were in water < 50 m, 14% in 50 to 100 m, and 14% in > 500 m. The areas used off Demarcation Bay included 11 m deep water very nearshore, 50 km offshore in 64 m deep water, and 100 km offshore in 586 m deep water. There were three LC 1 and three LC 2 locations, all in shallow (< 50 m) water. LC 1 locations occurred once in Mackenzie Bay one day after tagging and twice very close to shore at Demarcation Bay. The three LC 2 locations occurred within eight hours while traveling north in water 20 to 50 m deep in Mackenzie Bay eight days after tagging. As with whale 10828, contact was lost in the deep water of the Arctic basin where speeds were higher than average and ice was encountered by both whales. The last five locations were in ice cover of 50%, 20%, 40%, 70% and 40%, all on 14 September.

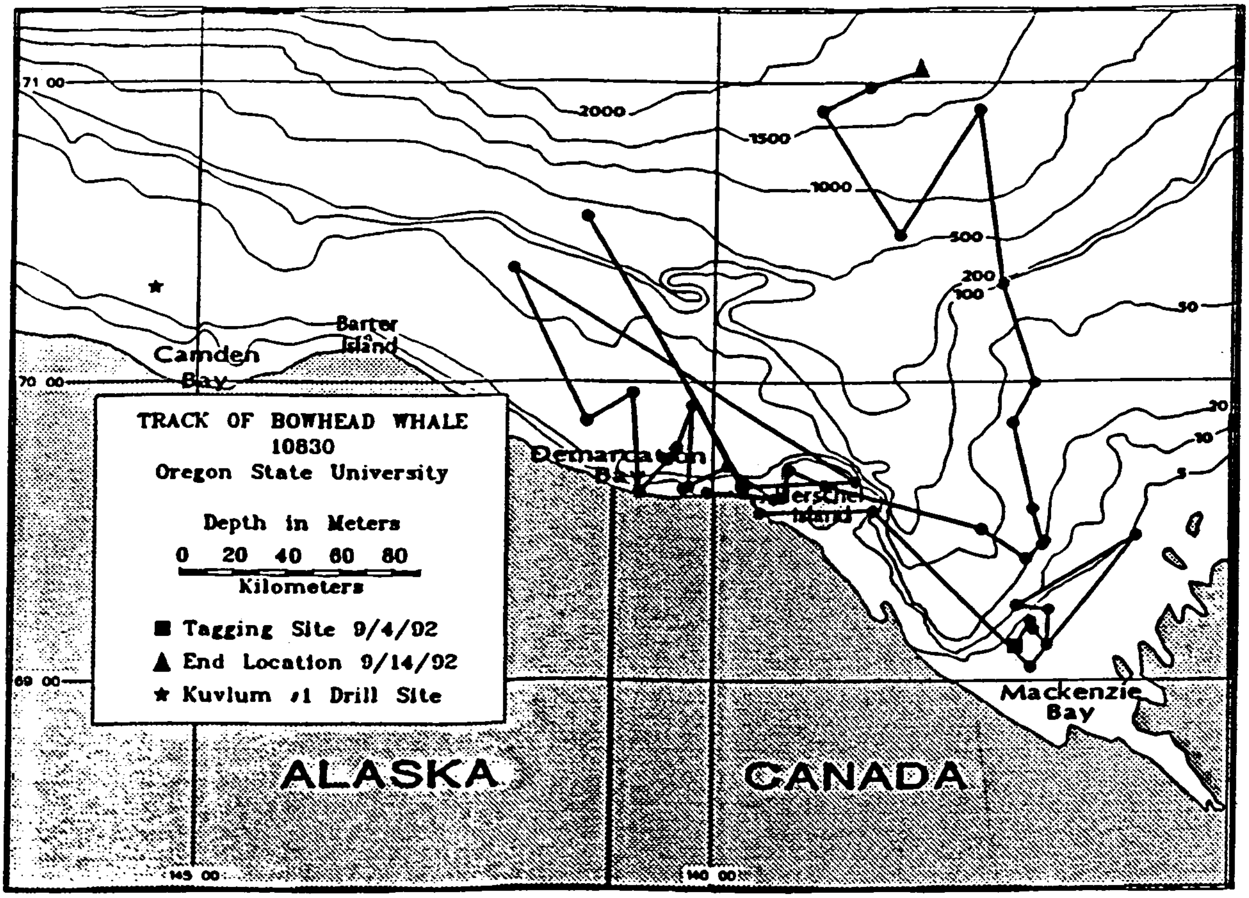

Figure 12. Track of whale 10830.

The two most westerly tracks (whales 831 and 10824) came from whales with two different tag types and very different rates of daily locations (1.0 locations/day and 6.2 locations/day respectively). This ratio reflects the proportion of time each unit transmitted daily (3.3 h vs. 24 h).

• Whale 831 traveled 1006 km (Figure 13) between the tagging site and 15 satellite-acquired locations in 15 days ($\bar{x}$ = 2.8 km/h; $\bar{x}$ = 1.0 location/day). This whale had the second lowest number of locations/day. Seventy-five percent of the original locations were retained, the best of all tags (Table 8). All of the 15 locations, were LC 0. As with whale 828, the infrequent transmission schedule of this tag provided so few locations daily that it should have made elimination of locations (based on the editing criteria of speed) difficult. In fact, 75% of LC 0 locations were retained under these circumstances, higher than for most whales (even those with a larger number of location/day). This whale either: (1) made directed long distance movements resulting in a higher mean speed than other whales with a low number of locations/day (828, 10826); or (2) the editing criteria did not detect erroneous locations and the route described here is not accurate. All LC 0 locations for this animal (and all others with very few daily locations) are more prone toward err than those that have more locations/day because the editing criteria do not provide as strong a basis for editing locations.

After three days in Mackenzie Bay, whale 831 went northwest through Mackenzie Canyon and then west (north of Herschel Island) to an area between Herschel Island and Demarcation Bay before heading offshore to water > 500 m north of Demarcation Bay. From 18 to 21 September, the whale was in 20 - 50 m water moving west across

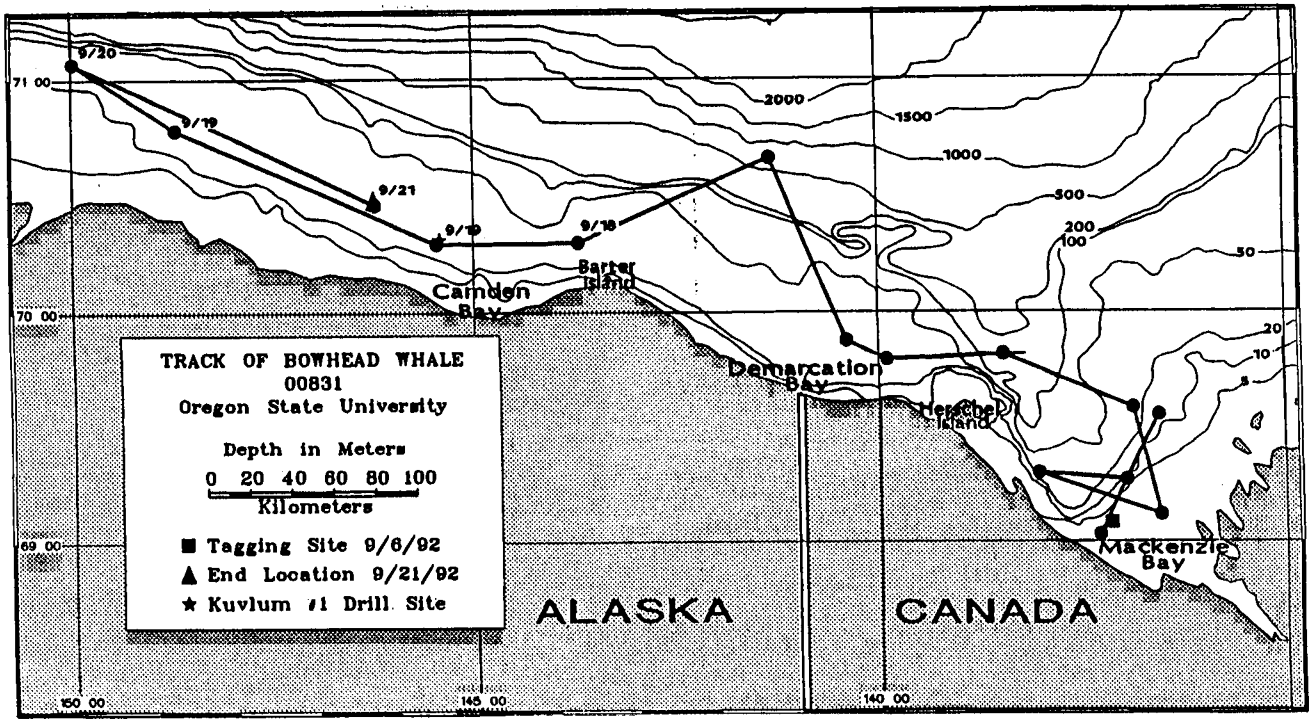

Figure 13. Track of whale 831.

Camden Bay, then northwest past Prudhoe Bay to 150°W and then reversing course back almost to Camden Bay. One LC 0 location on 19 September appears close to the site of the Kuvlum exploratory offshore drilling site, which due to heavy ice was not active (Brewer, et al., 1993). A discussion of the site's industrial activity, ice conditions, and nearby whale tracks can be found in the "Kuvlum" discussion section.

The wide separation in time between locations prior to and after the "near Kuvlum" location make it impossible to use the speed editing criteria with any real rigor to offer additional information which would be helpful in placing accuracy bounds on these locations (see Discussion: Kuvlum). The most novel aspect of this animal's movements was its eastward reversal of travel after passing Prudhoe Bay. This brings into question conventional wisdom that whales passing Camden Bay are migrating to the west and probably do not meander much or reverse course.

All locations were in water < 50 m, except for one in 200 m and one in 1000 m water. Locations during the first eight days (east of Demarcation Bay) and the Kuvlum #1 drill site were free of ice according to the Canadian ice data (see Appendix 2). However, ice observations at the site reported large first and multi-year ice floes were adjacent to, or over, the Kuvlum site (Brewster et al., 1993). With the exception of the Kuvlum drill site, ice cover from day nine until the end of tracking was 30% until the most westerly location at 150°W which was 90+% covered.

• Whale 10824 was tracked farther (4053 km) and for a longer period (33 days) than any other whale (Figure 14). Of 277 satellite-acquired locations, 203 (73%) were retained, providing 6.2 locations/day and an average speed of 5.1 km/h, the second fastest of all tagged whales (Table 8). This was the only tagged animal with locations in all water depth categories (Table 9): 63% < 50 m, 27% in 51 to 100 m, 5% in 101 to 200 m, 2% in 201 to 500 m, and 2% in > 500 m.

The first 16 days of the whale's track (Figure 15) covers a range similar to the first 13 days of whale 831. Starting nearshore, whale 10824 moved: northeast in the shallow water (< 20 m) of Mackenzie Bay; northwest to the western side of the Mackenzie Canyon; to Herschel Island's northeast shoreline; west to an area 35 km north of Demarcation Bay; northeast to the deep basin (1000 m); west to the shelf break (80 to 100 km) north of Demarcation Bay; northeast to the basin again; south to Herschel Island; west-northwest into Demarcation Bay (25 km offshore); nearshore until rounding Pt. Martin 50 km from shore; nearshore past Barter Island through the eastern half of Camden Bay at the 20 m depth contour; northwest to the shelf break about 75 km off Prudhoe Bay.

Whale 10824 then moved west to very shallow water at Cape Halkett; northwest 10 km off Pt. Barrow; generally west across the Chukchi Sea roughly between 71°N and 72°N latitude to within 30 km of Wrangell Island; then south 150 km to within 175 km of the Siberian coast. This is the first record of the detailed route and speed of migration for a bowhead from Canada to Russia. The route in the U.S. Beaufort Sea was quite similar to the highest density of bowhead sightings (Figure 16) from pooled aerial survey data from 1979 to 1989 (Moore and Reeves, 1993).

Ice was encountered by whale 10824 in several areas: 30% at its most northern Mackenzie Canyon location; 40% from Demarcation Bay to Pt. Martin; 30 to 80% in

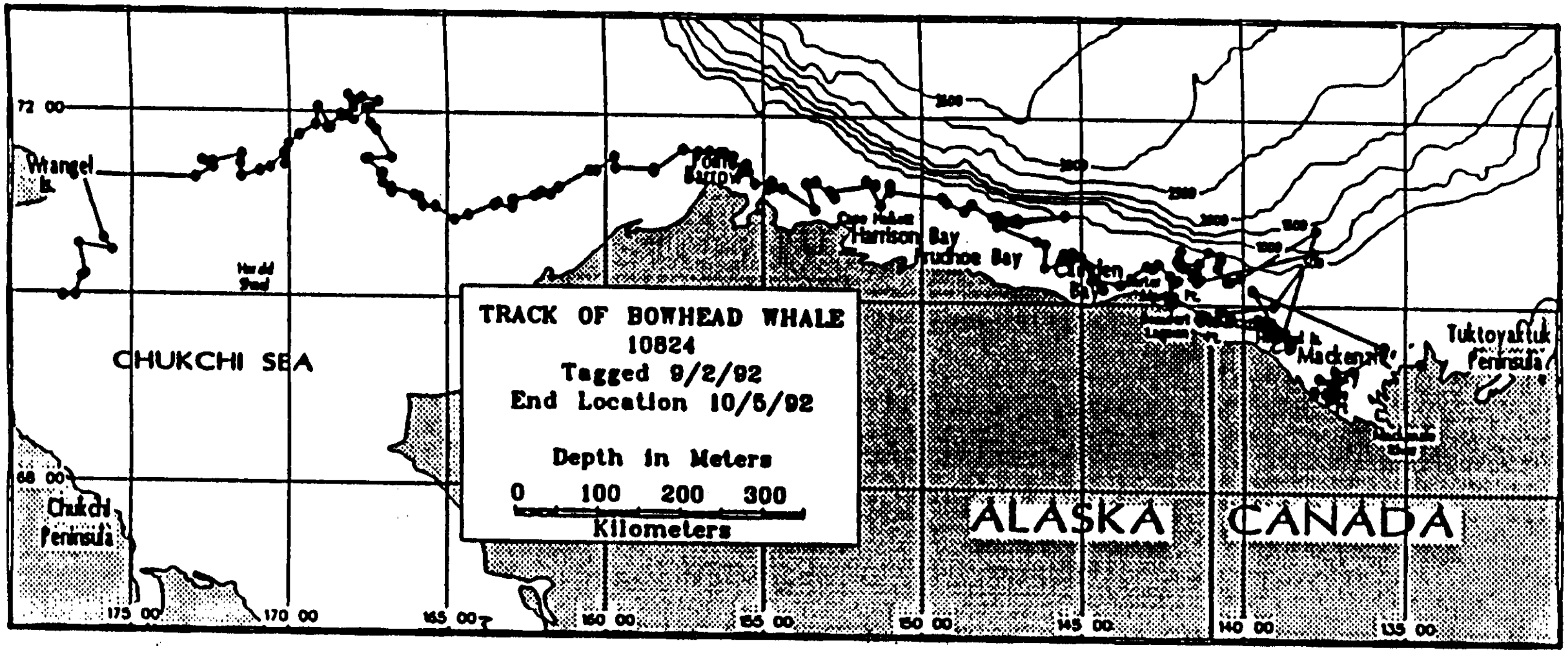

Figure 14. Track of whale 10824.

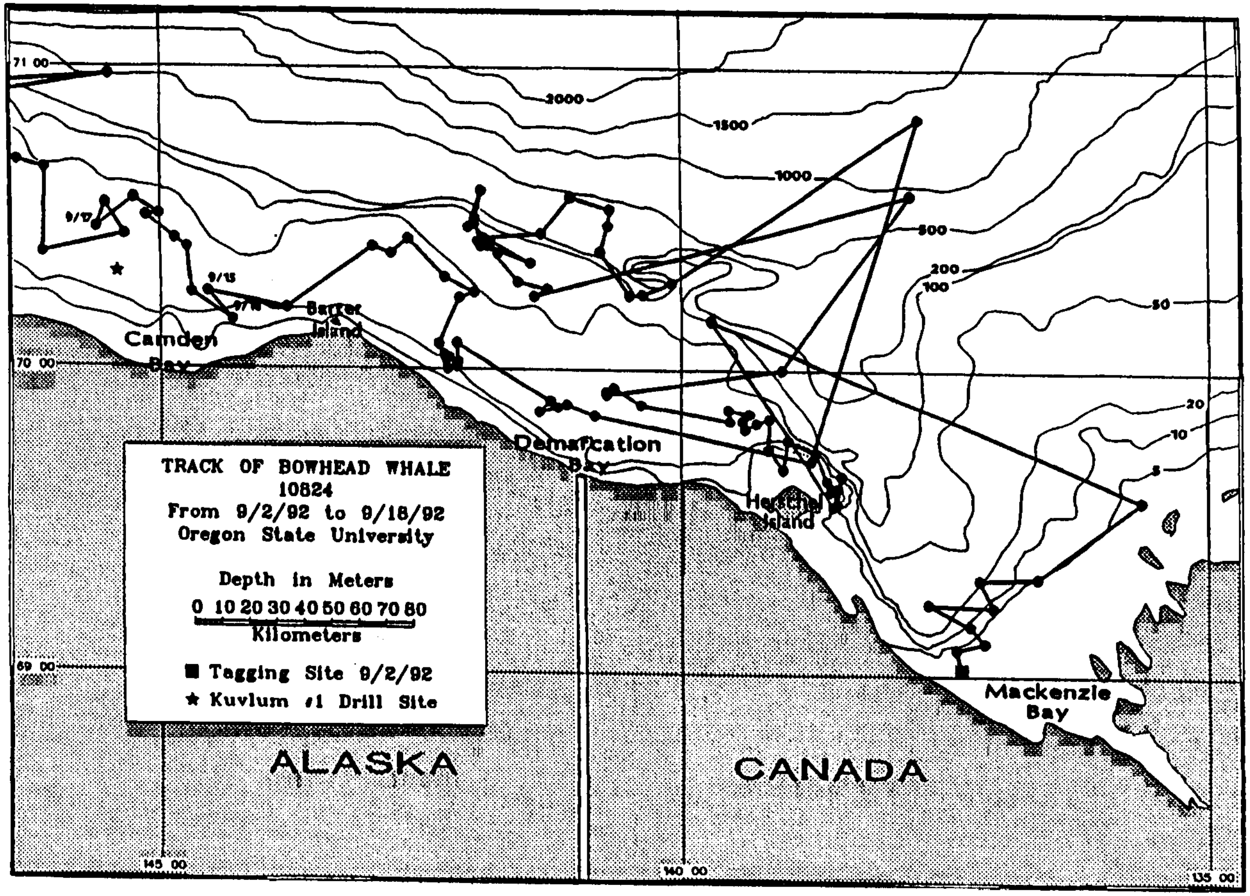

Figure 15. Track of whale 10824 from 2-18 September.

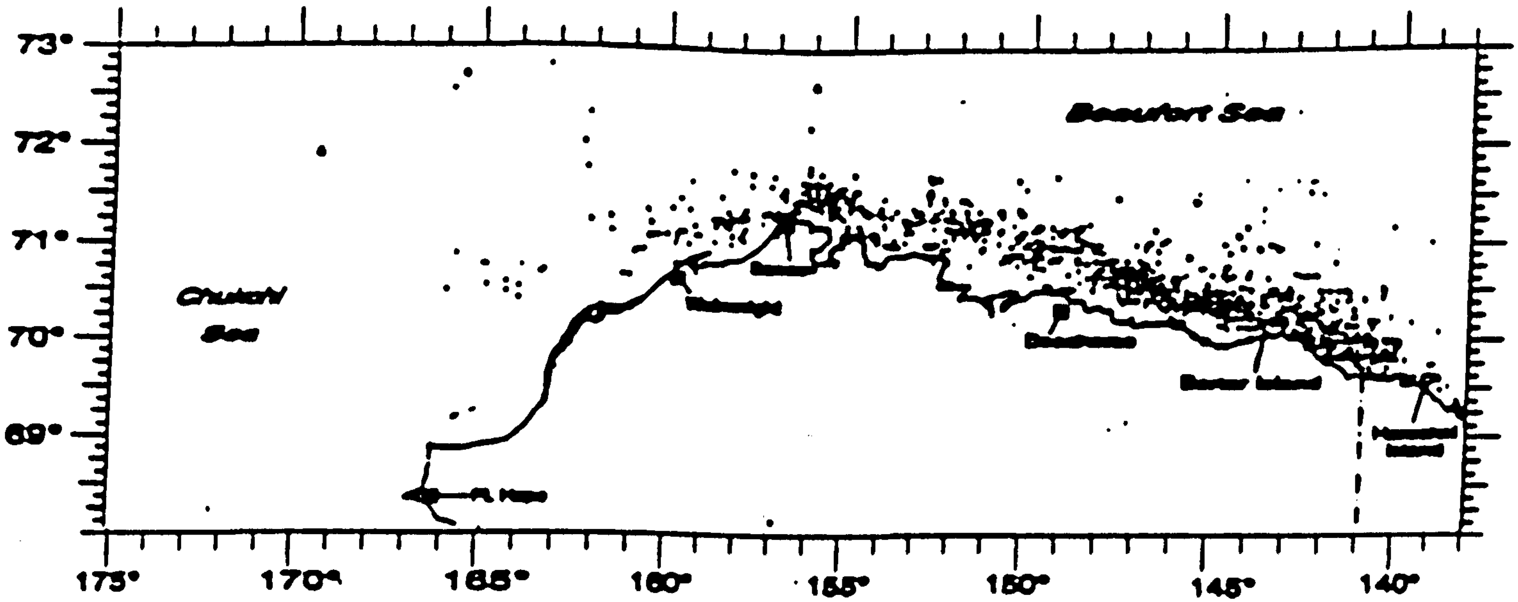

Figure 16. Cumulative fall (September and October 1979-1989) distributions for the Bering Sea bowhead stock (from Moore and Reeves, 1993).

Camden Bay; and over 90% west of 151°W. Eighteen of the 26 locations LC > 0 (69%) were obtained in the first 17 days before encountering 90+% ice. Despite the ice, good locations (LC > 0) were acquired throughout the track. We acquired TIROS-N satellite imagery of the ice in the Chukchi Sea and found whale 10824's track was along the heavy ice edge. Bowheads have a cautious surfacing behavior in ice. Where there are no conspicuous leads, the whales surface through the ice, breaking and raising the ice with the blowhole to get a breath (Figure 17). After submergence, the ice knits back together making a characteristic scar. Under these circumstances, the whale's body is not visible at the surface and the transmitter would not be exposed to transmit (or register the end of a "dive"). Thus, all locations in the Chukchi likely came while the whale was in leads or pockets of open water. The shape of the southern edge of the heavy ice across the Chukchi is determined by a northward current of warm water from the Bering Strait which splits in two. The portion near the Alaska coast keeps the nearshore waters free of ice longer into the fall. The offshore portion produces a northward intrusion of open water and slows the advance of the heavy ice front in the central Chukchi. Four of the six locations > LC 0 in the Chukchi occurred along the edge of this feature.

There were 26 locations > LC 0. Sixteen of these (62%) occurred east of 151°W in open water or light ice cover and 10 (38%) occurred west of 151°W in 90+% ice cover. Most locations > LC 0 were acquired where many locations were clustered (Figure 16) and the whale traveled at speeds < 5 km/h suggesting periods of milling or feeding behavior. Even if LC 0 locations were eliminated, the remaining higher quality locations (Figure 18) would describe the route west of Camden Bay (Figure 14) reasonably well.

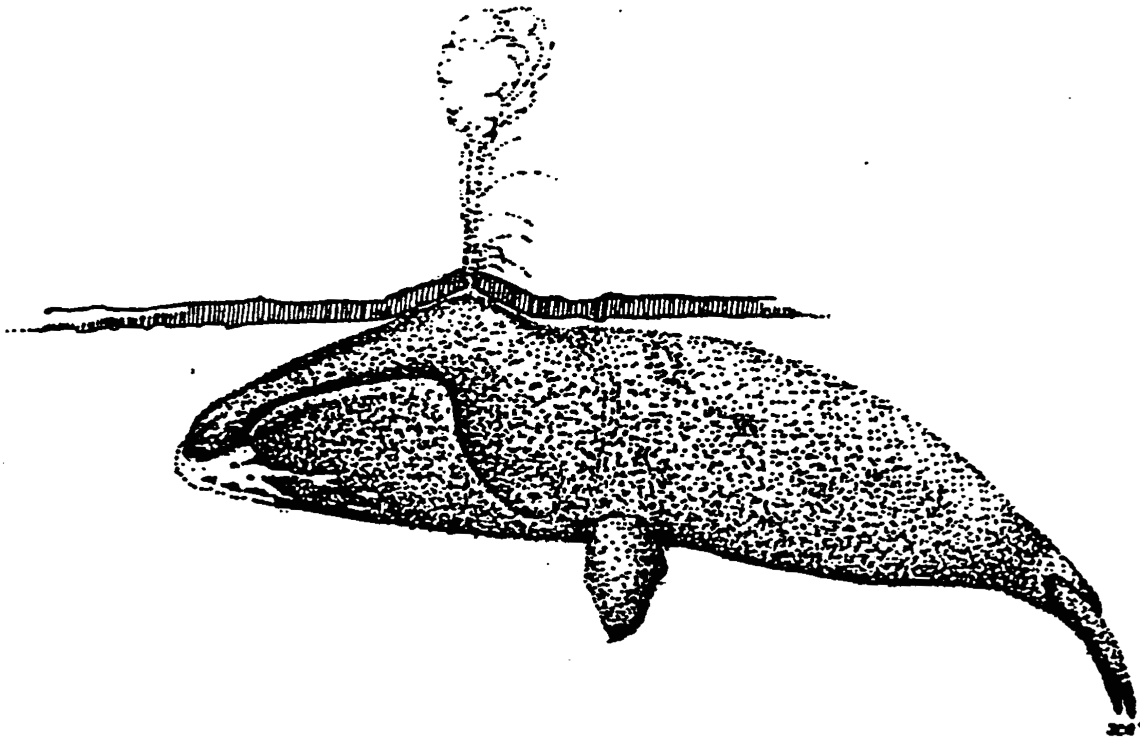

Figure 17. Schematic illustration of a bowhead whale surfacing through thin, unbroken ice. The dorsal surface of the head is highly arched with the blowholes at the apex of a high promontory, over which the ice is lifted and cracked apart for access to air (George *et al.* 1989).

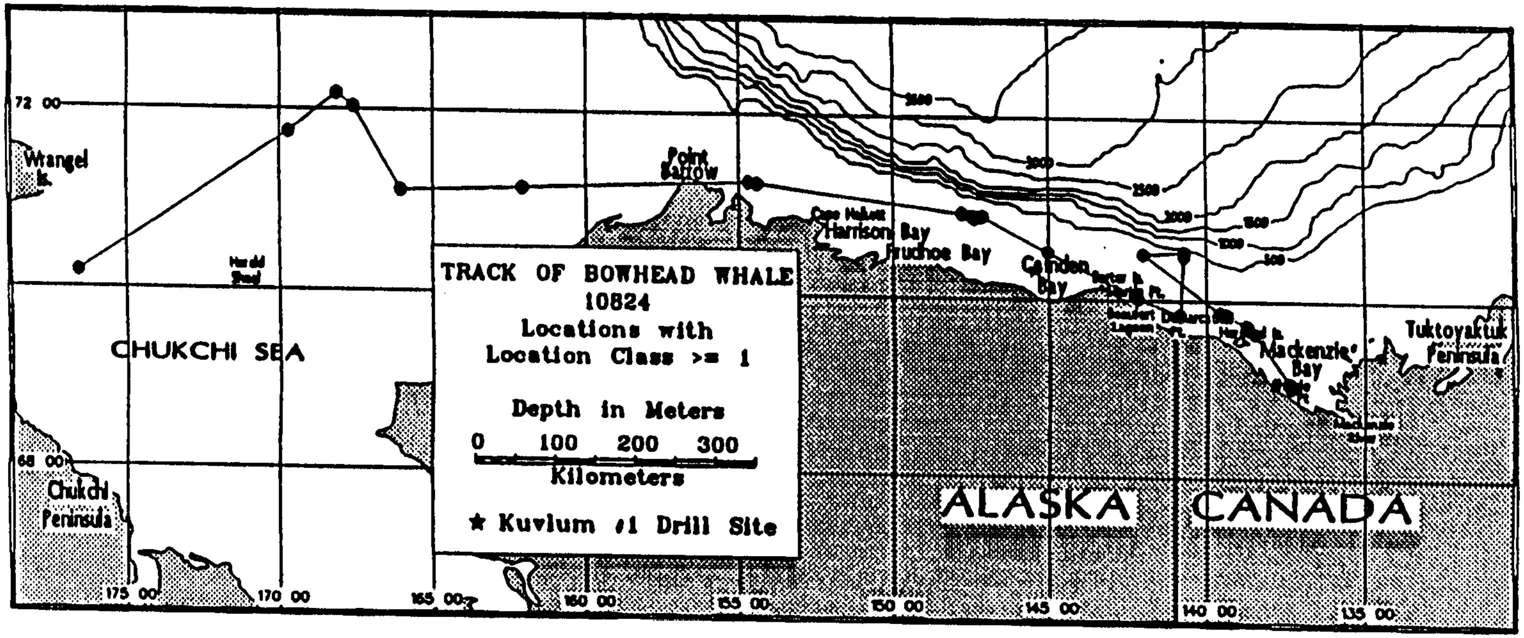

Figure 18. Track of whale 10824 using locations with Location Class > = 1.

East of Camden Bay, much of the directional change and movements would not be well represented. Using all locations west of Camden Bay the track line was more linear. Approximately equal distances were traversed by the animal east and west of longitude 145°W and revealed identical average speeds (5.2 km/h). If only a few daily locations were retained from the animal's more meandering path east of 145°W, it is likely that distances (and hence speeds) would be underestimated.

Locations

Although there may be errors in individual locations, the screening criteria we used still provided enough locations to distinguish travel routes. In this study, one-third of the LC 0 locations were eliminated in the screening process. It is important to establish suitable criteria based on what is "known" without making criteria so stringent that it would be difficult to discover unknown habits or characteristics. Deleting all LC 0 locations would eliminate all movement data for three whales (828, 831 and 10825) and reduce the distance and route information on other individual whales by as much as 78%. Thus, instead of eight whales traveling 9633 km over 111 tracking days at a mean speed of 3.4 km/h, five whales (63% less) would have covered 2766 km (71% less) in 63 days (57% less) at 1.8 km/h (53% less). For whale 10824, such an analysis would result in a 55% shorter track (1843 km) and slower average speed (2.3 km/h).

Kuvlum

The potential responses of whales moving through the Kuvlum #1 drilling site located in Camden Bay will be of interest to many people. The operational information provided here comes from Brewer et al., 1993. Operations in the area began on 11 August and testing continued until 15 October. The site is located approximately 28 km offshore of Camden Bay in 33 m deep water (70°18.956'N x 145°25.184'W). Drilling was accomplished from the CDU KULLUK, a floating drill ship displacing 19,300 tons, which positions over a drill site via multiple anchors and wires. Accompanying the KULLUK were two to three ice breakers and additional support vessels at various times. The largest of these was the 88 m long KALVIK, displacing 7100 tons and producing 23,400 hp.

Two tagged whales appeared to pass near the Kuvlum site in mid-September. The closest location of whale 10824 (Figure 15) was identified 26 km from the Kuvlum site on 17 September. On 19 September, whale 831 provided a LC 0 location within 1 km of the drill site. Several factors need to be considered in interpreting this information. Perhaps the most important operation information is that the KULLUK stopped drilling and moved off position by 16 September due to heavy ice and did not resume drilling operations until 24 September (Brewer et al., 1993). The KULLUK was forced off-station by massive floes, at least one of which became grounded to the west. Winds during the time period were basically out of the west at 31 knots and the ice tended to drift toward the southeast. During this time, up to three ice breakers were involved in ice management activities at and near the site. Most important to the overall consideration, however, is the accuracy of the whale locations and their proximity to the operations. While referring to Appendix 2 readers will be able to examine the numbers of locations, specific latitude and longitude, and location class for each of the tagged whales.

The KULLUK moved off-station on 16 September at 0330 GMT. In the 24 hours following its departure, seven locations were determined by Argos for whale 10824 (Figure 15). Only one of these (on September 16 at 1804) was not LC 0. It was, in fact, a LC 1 which was 27 km from the previous operation site of the KULLUK. That so many locations were determined in a short period of time for whale 10824 and not rejected by editing criteria suggests that the whale's true route was indeed to the north of the KULLUK site. It also adds some validity to the overall trajectory.

The same cannot be said for whale 831 (Figure 13). There was an average of 12 hours between locations identifying 831: (1) at Barter Island, (2) near the Kuvlum site in Camden Bay, and (3) the next site farther to the west. The editing criteria would only have eliminated locations which were over 300 km from the previous site (12 h x 25 km/h = 300 km). Thus, even the location 220 km west of Kuvlum that was 24 hours after the location at Barter Island, would have fallen within the 12 h range (by over 100 km) for 12 h of travel. This graphically depicts how "generous" the editing criteria are and how it is ineffective in helping to define the location of widely spaced (in time) individual locations. Thus, we have no confidence in placing accuracy bounds or limits on any of the individual points for whale 831 with the exception of three locations. One was .6 of an hour after tagging and a pair of locations on 14 September which were 1.4 hours apart. Therefore, we cannot estimate how close whale 831 came to the Kuvlum site.

It is exceedingly difficult to make any interpretation of whether acoustic activity at the site may have effected the track of whale 10824. This is not only because of the distance between the site and the whale but the presence of deeply keeled and grounded ice in the area which may have affectively isolated the animal acoustically from any sounds at the site. Additionally, high wind speeds and the grinding noise of ice floes against one another may have obliterated any industrial sounds at distances far shorter than those implied from the whale locations. Any interpretation of cause and effect relationship between apparent whale tracks and industrial noise are inappropriate in this instance. The site specific monitoring program at Kuvlum flew 31,000 km of surveys for marine mammals. None of their sightings coincide with the timing of tagged whale locations. The summary of all sightings shows a concentration of animals coinciding with the track of whale 10824.

Tagged whales in the vicinity of drilling operations can provide opportunities to determine the response of bowheads to such sounds under certain circumstances. The use of high transmitter repetition rates to provide numerous messages/orbit and thus higher quality locations would be important. Tags should also transmit frequently enough to obtain locations from many orbits and thus provide clusters of locations where additional confidence in the whales' activities could be assured. Concurrent acoustic measurements in the vicinity would be necessary to determine the levels of noise to which whales were exposed if the potential affects of acoustic stimuli on whale trajectory are to be evaluated.

Oceanography

Bowheads often occur in oceanographically complex areas in the Beaufort Sea. To interpret the movements and dive patterns of bowhead whales recorded in this study, the physical and biological oceanographic environment must be understood. This is because bowheads feed on concentrations of zooplankton (Frost and Lowry, 1984) that tend to occur in especially productive areas or along fronts characterized by strong salinity and density gradients. In the Beaufort Sea, nearshore currents tend to be driven by local winds and usually flow westward (Niebauer and Schell, 1993). Offshore, in water deeper than 50 m, there is an eastward flowing current, the Beaufort Undercurrent, that is not locally driven (Aagaard, 1984). This current, characterized by warm Bering Sea water, can advect high densities of zooplankton, particularly euphausiids, near Pt. Barrow in the fall, creating a good foraging situation for bowheads (Niebauer and Schell, 1993). Whales are sometimes observed feeding near Pt. Barrow during fall migration (Braham et al., 1984; Ljungblad et al., 1985) and have also been observed feeding under the ice in this area in spring (Carroll et al., 1987). In general, however, productivity of the Beaufort Sea is low due to the stable Arctic Surface Layer and ice that prevents wind mixing and advection of nutrients into the euphotic zone (Niebauer and Schell, 1993). Productivity is especially low in the Mackenzie River plume where the high turbidity of fresh water from the Mackenzie River limits sunlight penetration (Grainger 1975). Few bowheads were seen in the Mackenzie River plume and zooplankton sampling confirmed the low biomass there (Bradstreet and Fissel, 1986; Bradstreet et al., 1987; Thompson et al., 1986). Several processes that increase productivity or concentrate zooplankton in certain areas of the Beaufort Sea (Figure 19) have been identified (Harwood and Borstad, 1985; Thompson et al., 1986; Richardson et al., 1987): 1) an estuarine front in Mackenzie Bay/Delta region and west along the shores of King Point and Herschel Island; 2) upwelling off the Yukon coast caused by easterly winds; 3) topographic turbulence near Herschel Island and Cape Bathurst; and 4) oceanographic phenomena near the shelf break, especially near Mackenzie Canyon.

These physical factors may dramatically affect the distribution of the bowhead population. Between 1000 and 3500 bowhead whales occupy the southeast Beaufort Sea but with variable distribution and concentration from year to year (Moore and Reeves, 1993). There is some evidence to suggest that whales are further offshore and in deeper water (> 200 m) during July and early August and then move into water < 50 m in early September (Richardson et al., 1985; Richardson et al., 1987; Moore and Reeves, 1993). The number of whales inhabiting the Mackenzie River Delta region varies yearly (Moore and Reeves, 1993; Richardson et al., 1987). In general, juveniles are often found nearshore in Mackenzie Bay, near Shingle Point and King Point region (Davis et al., 1986; Richardson, 1987; Cubbage and Calamobokidis, 1987). Additional sex and age segregation may exist (Koski et al., 1993; Zeh et al., 1993), but these distributions are thought to be variable both between and within years (Davis et al., 1983). According to size distributions (Koski et al., 1993) tagged whales in this study were yearlings and sub-adults, none were considered sexually mature.

Moore and Reeves (1993) have summarized the distributions of whales in the general vicinity of the Canadian and U. S. Beaufort Sea. Their observations coincide reasonably well with the movements of tagged whales: a concentration of animals along the east Mackenzie River canyon area in late August of 1981 (Richardson et al., 1985); concentrations around Herschel Island from mid-August (1982 and 1984) to early September (1981 and 1982); along the west side of the Mackenzie canyon northwest of Herschel Island in mid-August 1982; along the Yukon coast in mid- to late August (1983) and late August or early September (1984). Concentrations in Mackenzie Bay and Demarcation Bay were found in mid- to late August 1984.

A composite of locations for all tagged whales (Figure 20) reveals very intense use of the shallow water region of the western Mackenzie River Delta, Herschel Island and Demarcation Bay (both nearshore and north at the shelf break). Five animals (831, 10824, 10825, 10827, and 10830) used the deep canyon or deep basin area north of the Mackenzie River. The latter two also used the deep water of the shelf break off Demarcation Bay. A schematic of whale movements demonstrates the relative importance of specific areas (Figure 21). Five whales spent 11 days around Herschel Island. Four whales spent 9.3 days nearshore Komakuk to Demarcation Bay. Three whales spent 4.5 days offshore from Demarcation Bay at the shelf break. Two whales spent 2.5 days nearshore between Demarcation Bay and Barter Island. There was a tendency for whales to revisit these areas. Six of eight whales (75%) changed travel direction rather than simply moving from east to west during the late summer. The two whales (10826 and 828) which never left the Mackenzie Bay/delta represent 12 of the 34 whale-days (35%) spent in that area by all whales. The time spent in these areas and revisitations lend

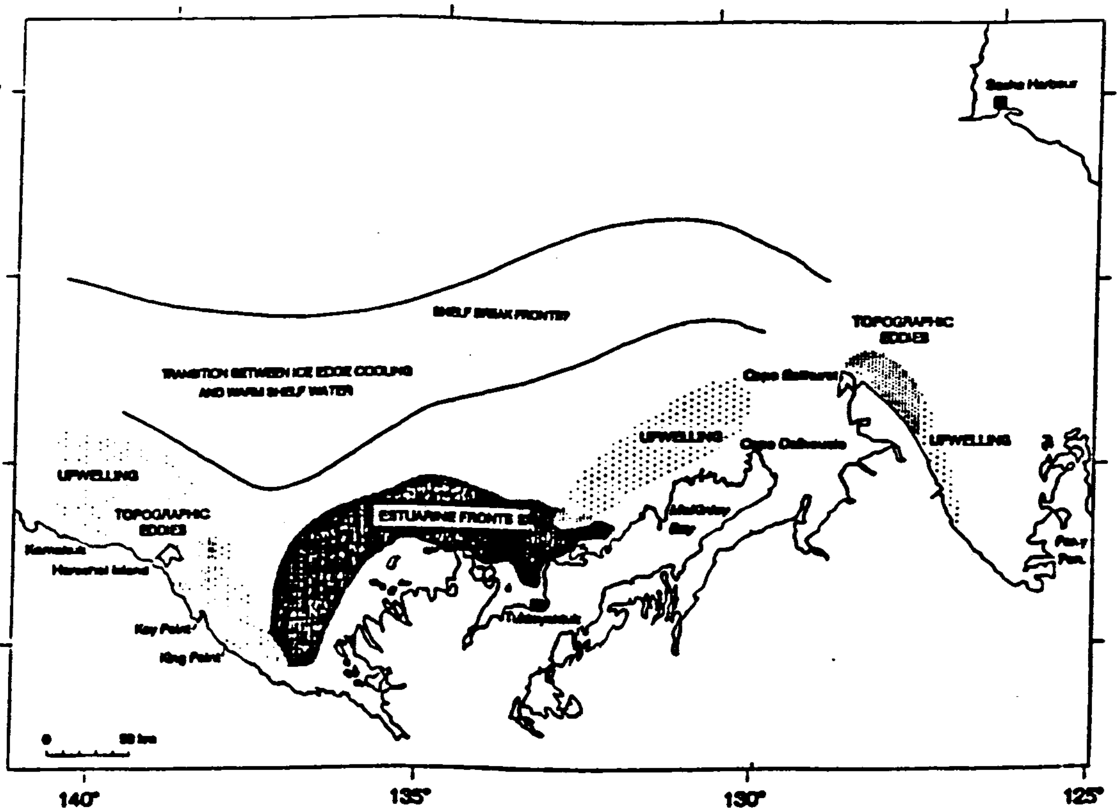

Figure 19. **Oceanographic features that likely influence bowhead distribution in the eastern Beaufort Sea in summer (from Harwood and Borstad 1985).**

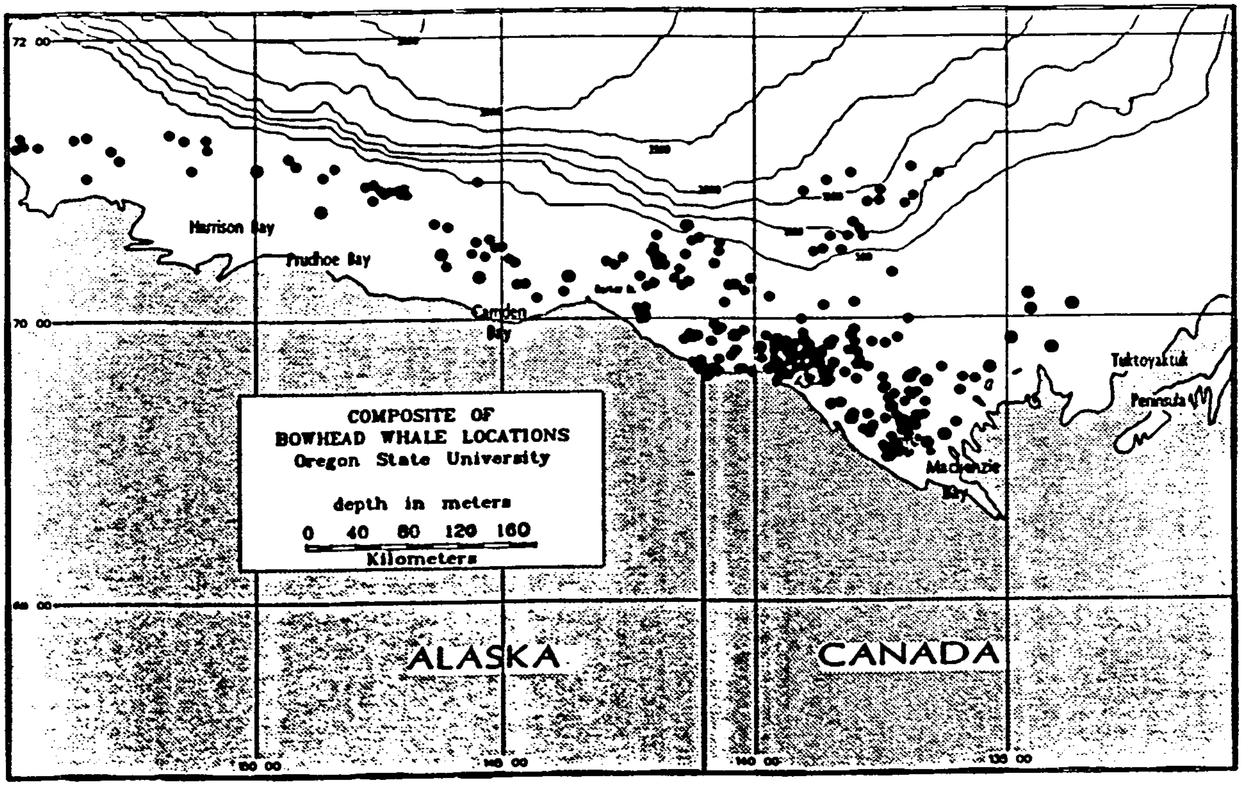

Figure 20. Composite of all locations for tagged whales east of 152° E.

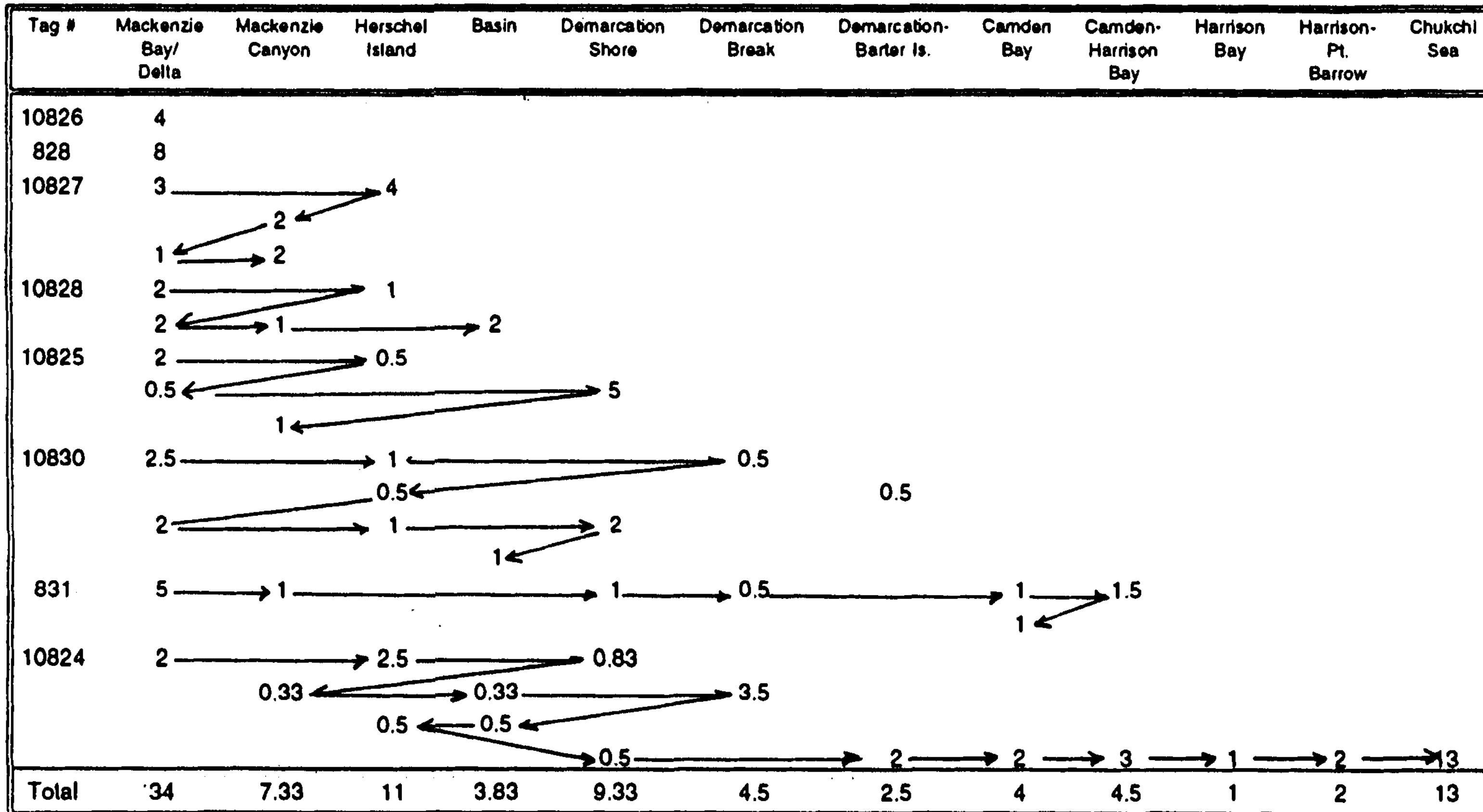

Figure 21. The number of location-days spent in an area are connected chronologically by arrows. All bowhead whales were tagged in Mackenzie Bay. Location fixes for two of the whales were all in shallow waters of Mackenzie Bay/Delta region. After traveling west, six animals moved eastward from one area to another. Five of the whales utilized Mackenzie Canyon, three went into the deep basin waters. Five whales spent time near Herschel Island. Four were located nearshore at Demarcation Point, and three were found further offshore near the shelf break. Animals 831 and 10824 were tracked farther west towards Barter Island, then off Camden Bay and on toward Harrison Bay. Only animal 10824 was tracked from Harrison Bay past Pt. Barrow and into the Chukchi Sea.

credence to the claims that these areas are used by whales as feeding or staging areas prior to the westward migration.

Despite having tagged 12 whales at one site during a one week period, we did not find consistent movements of the tagged individuals. Instead, whales moved in many different directions and into waters of different depths. This suggests that all whales do not respond to some universal cue to start their migration nor do animals found in one area move together as an integrated group. Treacy (1988) reported whales still in the eastern Canadian Beaufort on 30 October demonstrating the very late departure of some individuals. Braham et al. (1984) quote Barter Island whalers as saying juveniles migrate before adults. Nonetheless, we had quite a spread among the juvenile whales which we tagged in 1992, with whale 828 still in Mackenzie Bay/Delta region and 10824 well into the Chukchi Sea on 30 September.

Speed of travel estimates developed from other techniques are useful to compare with those obtained from satellite-monitored tags. Visual observations of bowheads have provided some information on the movement of readily identifiable individuals. A cow/calf pair were observed to move 85 km east in two weeks in August 1980 (Würsig et al., 1985). During photo-identification studies near Herschel Island in August 1982, 13 individuals were observed to move an average of 31 km in five days (Davis et al., 1983). The two longest movements recorded were 154 km in five days and 147 km in 13 days. Richardson et al. (1987) also documented movements of photo-identified bowheads in 1985/1986. Times and distances between successive resighting of individuals were generally short (2 - 24 km over periods of 2 - 11 days for seven whales in 1985, and 1 -

32 km over 1 - 14 days for four whales in 1986) but a few longer movements were documented in 1985 (66 km in 14 days and 123 km in 18 days) and 1986 (212 km in 14 days by a cow/calf pair). Comparing photos from three studies, Richardson et al. (1987) traced long distance movements of two animals from east to west in 1985, 640 km in 25 days, and 749 km in 42 days. A third animal was resighted three times and moved first west 111 km in 15 days from near King Pt. to Komakuk, then southeast, 65 km to Herschel Is. in two days and 71 km in seven days back to King Pt. In general, photo-identification efforts were confined to the coastal region and the net movement of animals was less than 100 km. Because of the limited numbers of data points for each animal, all distances in these photo-identification studies are minimums and probably dramatically underestimate the extensive movements that may have taken place during the time between sightings. Adults photographed in the main study between Shingle Pt. and Demarcation Bay area were usually photographed only once in offshore waters, whereas juveniles were often resighted multiple times over 1 to 16 days (averaging 8 days). The whales that moved great distances from the east were adults. Adults have more readily identifiable marks and react less to aircraft, so it may be easier to re-identify adults than juveniles (Davis et al., 1983; Rugh 1990). The fact that juveniles were resighted more often and over longer periods than adults suggested that adults were migrating through the area. The time between first and last sighting of juveniles were taken to be minimum residence times (Richardson et al., 1987). Similar conclusions about residency times of right whales in the Bay of Fundy proved erroneous; satellite-monitored radio tagging studies showed animals making long range movements and returning to the region

regularly (Mate and Nieukirk, in press). It is likely that the photo-identification data set was biased towards slow moving animals with restricted movements.

Conventional radio tags have been applied to bowheads on three occasions. Of two whales tagged in mid-September, 1986 near Demarcation Bay, one traveled 76 km in four days and the other traveled 46 km in two days (Richardson et al., 1987). The two whales tagged in 1988 by Wartzok et al. (1989) ranged much more widely. One stayed within an 81 km radius of its original tagging site and moved 1291 km in 17 days while feeding. A second whale began to move west traveling 550 km in six days (4.1 km/h) through ice-free water. A second segment of that animal's movements comprised 365 km during seven days in ice at an average speed of 2.7 km/h. In our study we saw very little difference in the rate of movement between "feeding area" movements and "migration" movements nor much difference between ice-free and heavy ice regions.

Four animals were tagged in 1989 (Wartzok et al., 1990). These traveled from 554 to 1347 km in a period of 18 to 36 days. Speeds averaged 1.5 to 2.5 km/h. Two animals moved west between the 20 and 100 m contour. One moved north along the 100 m contour, and one moved along the 20 m contour. All individuals crossed the U.S./Canadian border between 21 to 25 September. Our observations suggest that animals moved at a relatively uniform pace once they had passed 145°W longitude. Prior to that time it was not uncommon to see animals stay in one area for one to three days and then move up to 160 km in a single day to another region. Migrating whales moved between 80 and 150 km per day in ice-free areas. One of the whales radio tagged by

Wartzok, et al. (1990) stopped and spent time feeding just east of Pt. Barrow, Alaska, as did whale 10824 in our satellite-monitored sample.

Wartzok et al. (1989) thought the 4 km/h estimate of migration speed by Rugh (1990) was unrealistic due to feeding and resting stops. Moore and Reeves (1993) speculated that it was theoretically possible to move the 1700 km from the Canadian Beaufort to the Russian coast in 18 days at a migration speed of 4 km/h. Our study and those of Wartzok et al. (1989, 1990) show that animals do not take direct routes and pause from time to time, thus making the overall distance much longer. There may be enough differences in the migration rates of different age/sex class, individuals, or in ice condition annually to account for the observed differences.

The fall bowhead sightings from aerial surveys between 1979 and 1989 (Treacy 1990; Moore and Clarke, 1990; Figure 16) are in general agreement with the movements of the satellite-monitored animals in this study (Figure 20). The satellite-acquired information has two principle advantages: 1) they are the movements of individual animals; and 2) the route and rate of travel can be identified specifically. This was particularly important and novel through the Chukchi Sea where far offshore logistics constraints, cost, and weather have limited how much could be learned from conventional aerial and shipboard surveys in the fall. Moore and Clarke (1990) speculated that there were two travel routes west of Pt. Barrow, one north and one south of 72° N. The authors admitted that the "northerly line" was drawn without a statistical basis but it fits the track of whale 10824 reasonably well. It is extremely hard to estimate what proportion of the population may travel each of these routes as the opportunities to observe both routes are not equal. Nonetheless, whalers gave accounts of hunting animals near Herald Shoal during September/October (Bockstoce 1986) which was the same time of year that whale 10824 crossed the region. However, Miller et al. (1986) did not see whales in the Herald Shoal region in 1979 and 1980. Numerous autumn sightings at Herald and Wrangell Islands by Soviet Eskimos and a lack of whaling activity in northwest Alaska coastal villages, led Braham et al. (1984) to speculate that a northerly route was more likely for many whales. Movements south along the Chukchi Peninsula have been observed through November (Bogoslovskaya et al., 1982) and animals have been seen passing through Bering Strait from mid-October to mid-November (Bessonov et al., 1990).

It is commonly accepted that the condition of spring ice affects the spring migration timing (Gentlemen and Zeh, 1987) and effects the surfacing behavior of whales (Würsig et al., 1984). The effects of ice on the fall migration are not clear. Differences in perceived routes and behavior may be an artifact related to the difficulties of sighting and observing bowheads from the air in moderate to heavy ice (Moore and Reeves, 1993). Several studies have documented bowheads breaking ice up to 60 cm to breathe (Carroll and Smithhisler, 1980; Burns et al., 1981; George et al., 1989), but bowheads dying in the ice have also been documented (Philo et al., 1993). Many of the differences we observed in sensor data we believe are attributable to the animals' change in breathing habits in moderate to heavy ice. Many animals lost their tags shortly after encountering reasonably moderate ice but it is unknown whether ice contributed to the early loss of the tags.

One of the applications of diving data is the evaluation of correction factors for population from aerial or ship surveys. Ice-based research has demonstrated that some part of a bowhead whale is visible for 5.2% of the time, but that bowheads are visible from aircraft for a total of 11.6% of the time (Zeh et al., 1993). While these data may be applicable to open water or lead situations, they certainly do not apply to moderate to heavy ice. Indeed, conventional (non-satellite radio) telemetry techniques are most suitable to study fine details in small areas of reasonably predictable whale seasonal abundance. Satellite-monitored radio tracking may be most applicable to areas where conventional methodology is logistically difficult or where the whale's predictability in a region is so poor as to be economically unfeasible to study. For instance, with a population of 7500 whales, only 1000 to 3500 are accountable in the Canadian Beaufort. That leaves the bulk of the summering population unaccounted for (Zeh et al., 1993). Some of the likely areas are out of the normal survey range (e. g. west of Banks Island and Amundsen Gulf) and there is no information about how many animals may over-summer in the Chukchi Sea or along the Chukchi Peninsula in the east Siberian Sea (Bessonov et al., 1990; Bogoslovskaya et al., 1982). The movements of animals in these regions may be appropriate problems to study with satellite-monitored telemetry where conventional telemetry or survey data would be impossible, inefficient, or too expensive.

PART 3: DIVE AND SURFACING BEHAVIOR

Some valid sensor data were received for eleven of the twelve tagged whales (Table 9). Logical consistency checks invalidated some depth-related information in a few depth and time-at-depth packets, but the number of dives counted or the surface times were valid. Also, tags positioned low on a whale's body (10820 and 10831) probably did not break the surface on most surfacings so dive counts and surface times were not considered valid, but maximum depth and other time-at-depth information was included. Consequently, sample sizes do not always correspond to those listed in Table 9.

Period Lengths

Because duration and depth tags collected data during summary periods of 1, 3, and 5 hours, we tried to determine if the length of the summary period affected the data collected. Because 1-h and 5-h periods occurred exclusively in daylight and we wanted to eliminate time of day as a confounding variable, only 3-h periods that occurred during daylight were compared to the 1-h and 5-h periods in this analysis. Six tags returned enough data for statistical comparisons: 10824, 10825, 10826, 10827, 10828, 10830. Multiple linear regression analysis was used to compare each variable by summary period length and allow for differences among tags. Data for summary periods where the duration of the longest dive or the first dive to maximum depth overflowed ($\leq$ 61 min) were not included in this analysis (see discussion under dive duration data below).

Summary period length did not affect the number of dives per hour, the percentage of time submerged or at the surface, the log-transformed average duration of sounding dives, the duration of the first dive to the maximum depth, or the maximum depth reached for any of the six tags, p-value > 0.1 for period length coefficient and p-values > 0.05 for period length and tag interaction terms. Therefore, summary periods were treated equally in subsequent statistical comparisons of these variables.

Tags were more likely to record a longer dive when sampling over a longer time period. There was a positive relationship between increasing period length and log-transformed longest dive duration recorded during the summary period (p-value < 0.0001 on 11 and 442 df, p-value for period length coefficient $= 0.0011$). The effect of differing period lengths was similar for all tags (p-values for interaction coefficients > 0.1). Consequently, statistical comparisons of the longest dive durations were done only for summary periods of equal length.

Surfacing Rate/Blow Rate

For most of the animals, distribution of surfacing rates were approximately normal (Figure 22). Only distributions for tags 10824 and 10830 were significantly different from normal (Kilmogorov-Smimoff test, approximate p-values 0.015 and < 0.0001 respectively). The departure from normality for 10824 may be due to different behavior in areas with extensive ice cover (see section on ice cover under environmental variables). Extreme outlier values for three summary periods (Figure 22) explain the departure from normality for tag 10830. Exclusion of these three periods from the analysis below did not significantly alter the differences in mean surfacing rates among individual animals. Interestingly, these three summary periods composed one seven-hour block: periods 1-3 on 13 September. It seems this animal was engaged in distinctly different behavior during this 7-h interval than during the other 197 hours that surfacing rate was monitored. The

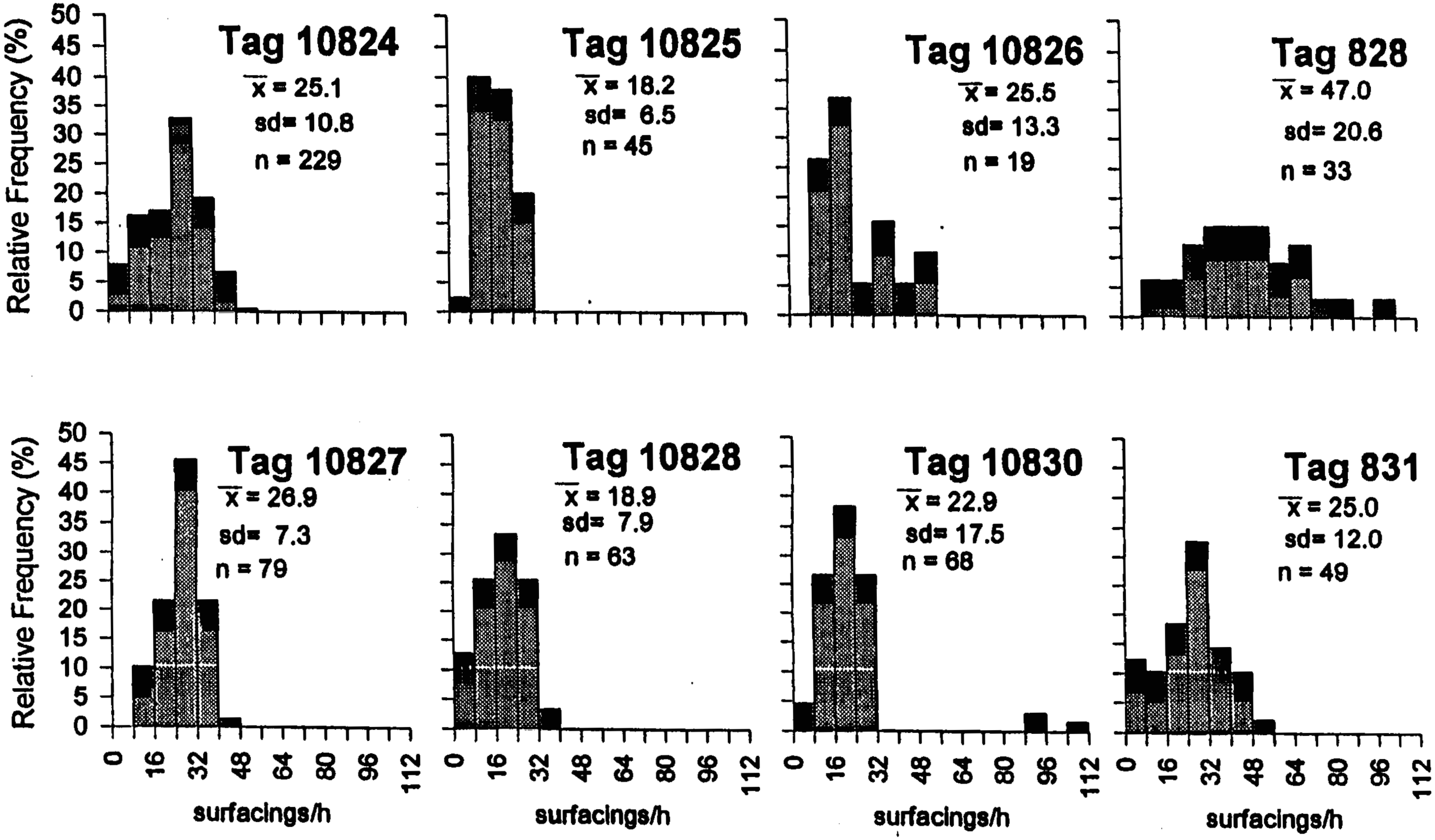

Figure 22. Frequency histograms of surfacing rates recorded by each tag. Sample size (n) is the number of summary periods.

very high surfacing rates in these periods were due to the increased number of very short ($\leq$ 1 min), shallow dives ($\leq$ 16 m). During period 1, tag 10830 recorded 110.0 surfacings/h. Overflow values returned in the $\leq$ 1 min and/or $\leq$ 16 m bins for the next two periods mean that at least 91.8 and 89.2 surfacings/h were recorded during periods 2 and 3, respectively. This surfacing activity may indicate a bout of social behavior or mating activity. Bowheads do engage in social/sexual activity in fall (Finley et al., 1986; Finley 1987; Richardson and Finley, 1989; Wartzok et al., 1989; Würsig et al., 1993), although in the Beaufort Sea this behavior was observed less frequently as fall progressed (Würsig et al., 1985). Socializing bowheads in the Beaufort Sea observed during late summer had higher mean blow rates and spent a significantly greater proportion of their time "surfacing" than nonsocializing whales (Dorsey et al., 1989). Bowhead mating activity often involves large groups of whales boisterously nudging and pushing one another. Surfacing/blow rates have not been measured for bowheads in mating aggregations because of the difficulty of identifying individuals in all the white water activity, but sexually active whales are thought to exhibit long surface times, short dive times, and high blow rates (Würsig and Clark, 1993).

The mean surfacing rate ranged from 18.2/h for tag 10825 to 47.0/h for tag 828. There were significant differences in the mean surfacing rates among the eight animals (ANOVA, $F_{7, 577} = 21.5$, approximate p-value << 0.0001). Because the assumption of equal variance was not met, the p-value is approximate, but results from a non-parametric test (Kruskal-Wallace ANOVA by ranks) confirmed the differences in surfacing rates among tagged whales. The mean for tag 828 (47.0 surfacings/h) was significantly higher than that for any other animal. Also, the two lowest mean values, 18.2 and 18.9 surfacings/h for tags 10825 and 10828 respectively, were significantly less than mean values for tags 10824 and 10827 which were 25.1 and 26.9 surfacings/h.

Mean surfacing rates are useful in calculating abundance estimates from cetacean surveys (Hiby and Hammond, 1989). Different mean surfacing rates can confound comparisons between surveys. Blow rates (blows/min) rather than surfacing rates (surfacings/h) have been published in many studies. In those observational studies, mean blow rate was calculated from the number of blows per surfacing, the duration of surfacings, and the duration of dives. Mean blow rate describes the respiratory activity of a whale over a longer time period than any of the constituent variables from which it is calculated (Würsig et al., 1984). Mean blow rate has also been used to assess energy requirements for whales (e.g. Sumich 1983; Dolphin 1987b; Thompson 1987).

While examining factors that affect surfacing and dive behavior of bowheads in the Beaufort Sea, Dorsey et al. (1989) found that comparisons of mean blow rates between species or even between studies have been confounded by the two different calculation procedures used. Method 1 divides the total number of blows during a series of surfacing-dive cycles by the total duration of those cycles (Sumich 1983; Würsig et al., 1986). Method 2 consists of calculating a blow rate for each surfacing-dive cycle and calculating a mean for the number of surfacing-dive cycles observed (Würsig et al., 1984; Dolphin 1987a, 1987b). Dorsey et al. (1989) reviewed the two methods and concluded that method 1 gives a better estimate of overall blow rate because method 2 can give biased results because each cycle is weighted equally regardless of its duration. Method 1 can be approximated by dividing the mean number of blows per surfacing by the sum of the mean durations for surfacings and dives (Dorsey et al., 1989). However, even this method is potentially biased upward because "most estimates of mean dive duration are biased downward because it is more difficult to find and recognize whales after a long dive than after a short dive" (Dorsey et al., 1989). For comparison, we calculated the overall mean blow rates of presumably undisturbed, non-calf bowhead whales in the Beaufort and Chukchi Seas from 16 sets of published mean values for number of blows per surfacing, duration of surfacing, and dive time reported in observational studies (Table 10).

Assuming that: 1) there is a blow associated with each surfacing a tag records, 2) the tag is submerged for at least 6 s between all blows, and 3) the tag clears the water at every breath, the number of surfacings counted can be used to estimate blowrate for tagged whales each summary period. Individual tags reported a great range of values across summary periods: the smallest range (0.04 - 0.51 blows/min, n = 45 periods) was reported by tag 10825; the largest range (0.08 - 1.83 blows/min, n = 68 periods) was reported by tag 10830. Mean values for individual whales ranged 0.30 - 0.78 blows/min (Table 11).

Any or all assumptions may be violated during any given summary period. If assumption 1 was violated, blow rate for the period was overestimated. If assumptions 2 or 3 were violated, blow rate for the period was underestimated. Without extensive follow up observation of tagged animals, a quantitative evaluation of bias in our sampling method is not possible. However, our sampling method was more likely to underestimate than overestimate blow rates because violations of two of the three assumptions result

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Table 10. Mean Values for Respiration and Dive Variables from Studies of Bowhead Whales in the Beaufort and Chukchi Seas.

Source:	Mean Interblow Interval (s) Visible (n)	Underwater (n)	Total (n)	Mean # of Blows per Surfacing (n)	Mean Dive Time (min) (n)	Mean Duration of Surfacing (min) (n)	Mean Blow Rate[1] (blows/min)	% Time Visible from the Air[2]
Carroll & Smithhisler, 1980.	4.7 (31)	10.6 (30)	15.5	6.57 (63)	15.8 (63)	1.62	0.38	8.9
Carroll et al., 1987. feeding			11.9 (361)	12.8 (37)	14.70 (18)	2.32 (39)	0.74	13.6
migrating 1980-1985			13.7 (140)	6.5 (76)	11.72 (156)	1.59 (19)	0.48	11.9
Dorsey et al., 1989. 1980			12.9 (915)	4.6 (70)	2.25 (25)	1.25 (99)	1.37	35.7
1981			13.0 (1113)	4.2 (194)	3.80 (80)	1.06 (248)	0.88	21.8
1982			14.9 (795)	7.4 (56)	12.08 (51)	2.05 (70)	0.52	14.5
1983			17.0 (666)	3.2 (299)	1.88 (140)	1.05 (204)	1.09	35.8
1984			11.8 (1472)	5.5 (75)	6.27 (37)	1.10 (94)	0.75	14.9
Ljungblad et al. 1986. W. Beaufort			13.1 (158)	9.2 (10)	17.93 (10)	1.82 (13)	0.47	9.2
Western Aleutian			13.0 (49)	8.5 (6)	17.80 (4)	1.81 (6)	0.43	9.2
Arctic Star			15.3 (132)	3.8 (19)	14.15 (8)	1.07 (21)	0.25	7.0
Western Polaris			14.6 (246)	8.0 (24)	16.17 (4)	1.97 (25)	0.44	10.9
Rugh & Cubbage, 1980.	6.1 (112)	11.6 (50)	17.9 (145)	----	7.5 (3)	----	----	----
Richardson et al., 1987. 1985			12.05 (480)	6.18 (17)	7.07 (5)	1.56 (36)	0.72	18.1
1986			11.24 (818)	5.08 (51)	6.32 (23)	0.99 (76)	0.69	13.5
Wartzok et al., 1990.			16.5 (388)	3.6 (52)	4.0 (22)	0.9 (52)	0.73	18.4
Zeh et al., 1993.	4.7 (1701)	7.4 (1531)	12.1	7.4 (184)	9.9 (41)	1.3 (184)	0.66	11.6
Unweighted Mean ± sd (n)	5.2±0.81 (3)	10.0±2.3 (3)	13.91 ± 2.01 (17)	6.41 ± 2.45 (18)	9.9 ± 5.49 (17)	1.48 ± 0.43 (18)	0.66±0.28 (16)	18.2±8.99 (18)
This Study: Unweighted Mean± sd (n)				4.5 ± 1.1 (6)	10.4 ± 2.4 (6)		0.44±0.15 (6)	13.3±3.22 (6)

[1] Calculated as: Mean # of Blows per Surfacing/(Mean Duration of Surfacing + Mean Dive Time).

[2] Calculated as: 100(Mean Duration of Surfacing/(Mean Duration of Surfacing + Mean Dive Time))

in underestimates of blow rates, and because studies of bowhead behavior document behaviors which violate these two assumptions, e.g., animals that do not submerge or submerge for less than 6 s between blows (Carroll and Smithhistler, 1980; Carroll et al., 1987; Dorsey et al., 1989; Ljungblad et al., 1988; Rugh and Cubbage, 1980; Richardson et al., 1987; Wartzok et al., 1990; Würsig et al., 1984; Zeh et al., 1993), and animals which only expose their blowholes or break ice to breathe (George et al., 1989).

The mean blow rate for each tagged whale fell within the range of mean blow rates calculated from observational studies, whereas the range of blow rates exhibited by tagged animals slightly exceeded the range of calculated values (Tables 10 and 11). When the potential biases of each sampling method are considered, this represents excellent agreement in values for blow rates between tagged animals and observational studies.

Dive Duration Data

Distribution of Dive Durations

Data on dive durations were reported from nine tags (Table 6). A total of 42,332 dives in 566 summary periods were reported. Overall, 77.3% of all dives recorded were 1 min or less, and 1.4% were greater than 19 min. Distribution of dives in the duration bins was highly skewed for every tag that returned data for more than one summary period, with most dives being one min or less (Figure 23). Dives $\leq$ 1 min comprised from 64.0% (tag 10826) to 82.9% (tag 828) of the total number of dives recorded for each

Table 11. Blowrate (blows/min) during summary periods.

tag #	n	min	max	quartiles		median	mode	mean	s.d.
				lower	upper				
828	33	0.19	1.73	0.54	1.02	0.75	0.75	0.78	0.34
831	49	0.08	0.85	0.28	0.55	0.44	0.29	0.42	0.20
10824	229	0.03	0.84	0.28	0.54	0.46	0.48	0.42	0.18
10825	45	0.04	0.51	0.24	0.35	0.29	0.28	0.30	0.11
10826	19	0.16	0.85	0.26	0.69	0.34	0.29	0.42	0.22
10827	79	0.15	0.73	0.37	0.52	0.46	0.48	0.45	0.12
10828	63	0.06	0.58	0.21	0.42	0.33	0.42	0.31	0.13
10830	68	0.08	1.83	0.24	0.42	0.34	0.38	0.38	0.29

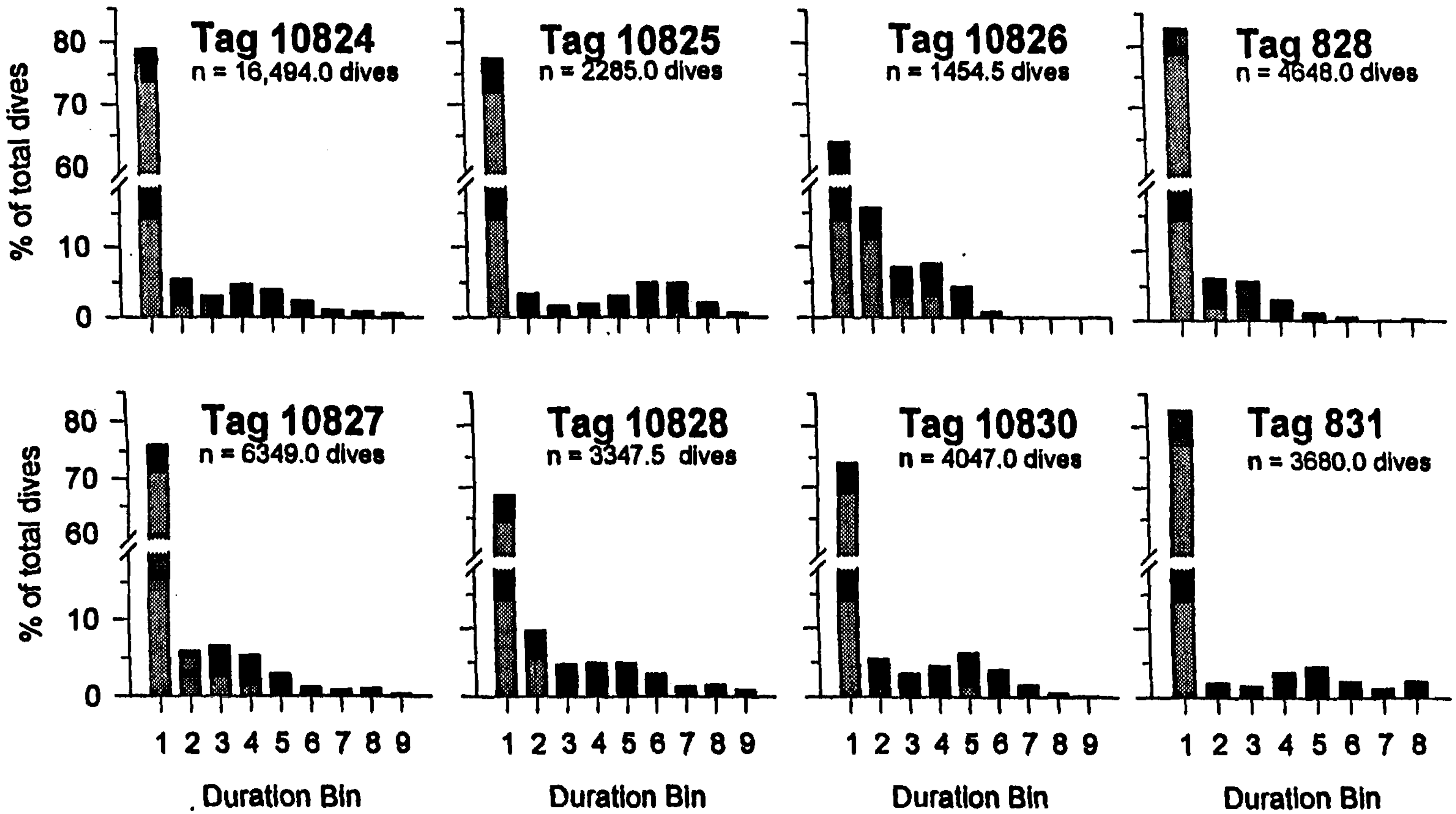

Figure 23. Distribution of dives in duration bins for bowhead whales tagged in 1992. Bins are: 1) 0-1 min; 2) 1-4 min; 3) 4-7 min; 4) 7-10 min; 5) 10-13 min; 6) 13-16 min; 7) 16-19 min; 8) 19-25 min for duration/depth tags, or > 19 min for duration tags; 9) > 25 min (duration/depth tags only).

animal. Tag 10822 reported dive duration data for only one summary period (Figure 24) in which 33.3% of the dives were ≤ 1 min.

Tags reported the duration of 9590 dives > 1 min made by nine bowheads. Five animals showed a peak in one or more of the longer duration bins: tag 10822, 4 - 7 min (Figure 24); tag 10824, 7 - 10 min (Figure 23); tags 831 and 10830, 10 - 13 min (Figure 23); and tag 10825, 13 - 19 min (Figure 23). The other four animals (828, 10826, 10827, 10828) showed a decline in number of dives in each increasing duration bin (Figure 23).

We considered dives > 1 min to be sounding dives. Tags reported the distribution of sounding dives in duration bins for each summary period. We examined when animals made sounding dives of various durations by plotting the percentage of sounding dives in each duration bin by date and summary period (Figures 25 - 32). This allowed us to get an idea of where animals were when they made mostly short or mostly long dives.

To characterize the duration of sounding dives for each period and to make statistical comparisons, we collapsed the data for each summary period into one variable, average duration of sounding dives[1]. Thirty summary periods were excluded from these analyses because the duration of the longest dive was unknown (overflow value ≥ 61 min for durations/depth tags). Summary period values for all animals combined ranged from 2.6 to 30.4 min ($\bar{x}$ = 10.5 ± 4.6 min, n = 536). Mean values across periods for individuals ranged from 6.9 ± 3.0 min (n = 19) for tag 10826 to 14.1 ± 4.6 min (n = 41) for tag 10825

[1] Σ(# dives in duration bin * mid-point of the bin)/(total # of sounding dives). For dives in the longest bin (>19 min for duration tags, >25 min for duration/depth tags) the duration of the longest dive (and the first dive to maximum depth for duration/depth tags) was known and used in the calculation. Subsequent dives in this bin were multiplied by the mid-point between the longest dive and 19 or 25 min, respectively.

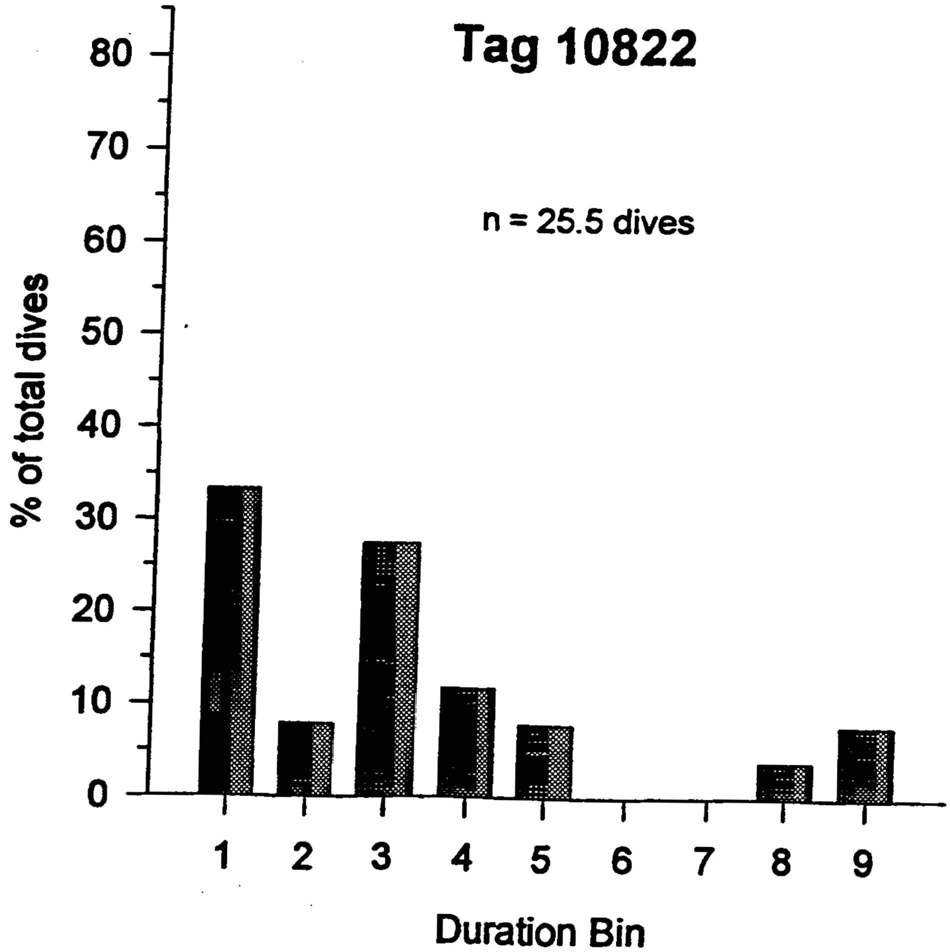

Figure 24. Distribution of dives in duration bins for tag 10822. This tag returned data for only one period. Duration bins are same as in Figure 23.

Figures 25-32. Time series plots of percentage of sounding dives in each duration bin and longest dive. Dives > 1 min were considered sounding dives. Bins are 1-4 min, 4-7 min, 7-10 min, 10-13 min, 13-16 min, 16-19 min, 19-25 min, > 25 min for duration/depth tags. Bins are the same for duration tags up to 16-19 min, then >19 min. Solid bar in bottom graph indicates valid data were received for the summary period. Small tic marks = 1 summary period. Area abbreviations show where most locations for that day were. Areas are: MB = Mackenzie Bay; MD = Mackenzie Delta; MC = Mackenzie Canyon; AB = Arctic Basin; HI = Herschel Island; MH = Mackenzie Bay and Herschel Island, ND = Nearshore Demarcation Point; OD = Offshore Demarcation Point; DB = Demarcation Point to Barter Island; CB = Camden Bay; C-CH = Camden Bay and Camden Bay to Harrison Bay; CH = Camden Bay to Harrison Bay; HB = Harrison Bay; HP = Harrison Bay to Point Barrow; and Chukchi Sea.

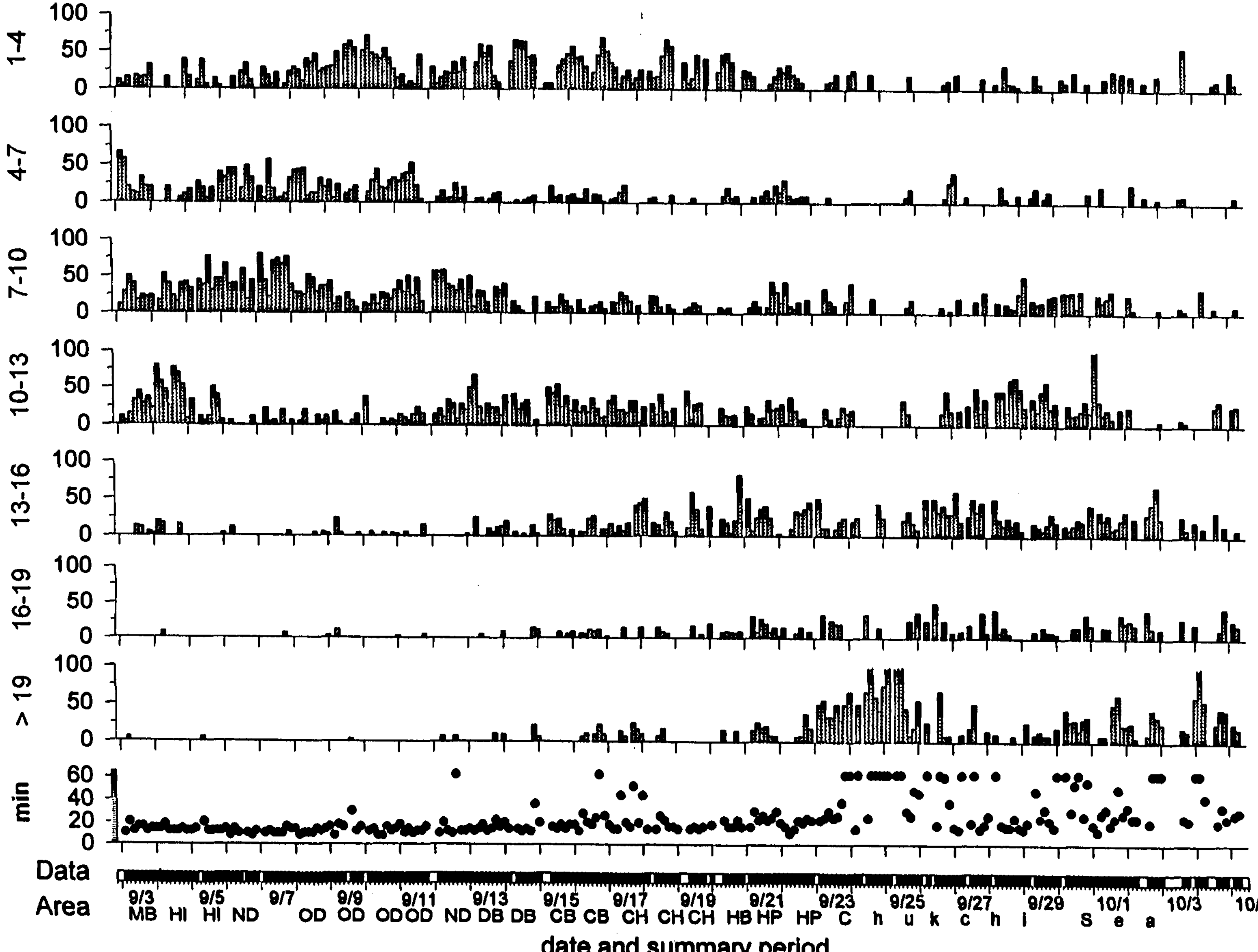

Figure 25. Percentage of sounding dives in each duration bin and longest dive by date and summary period from a bowhead whale tagged in 1992: tag 10824. Solid bar in bottom graph indicates duration data were received for the period.

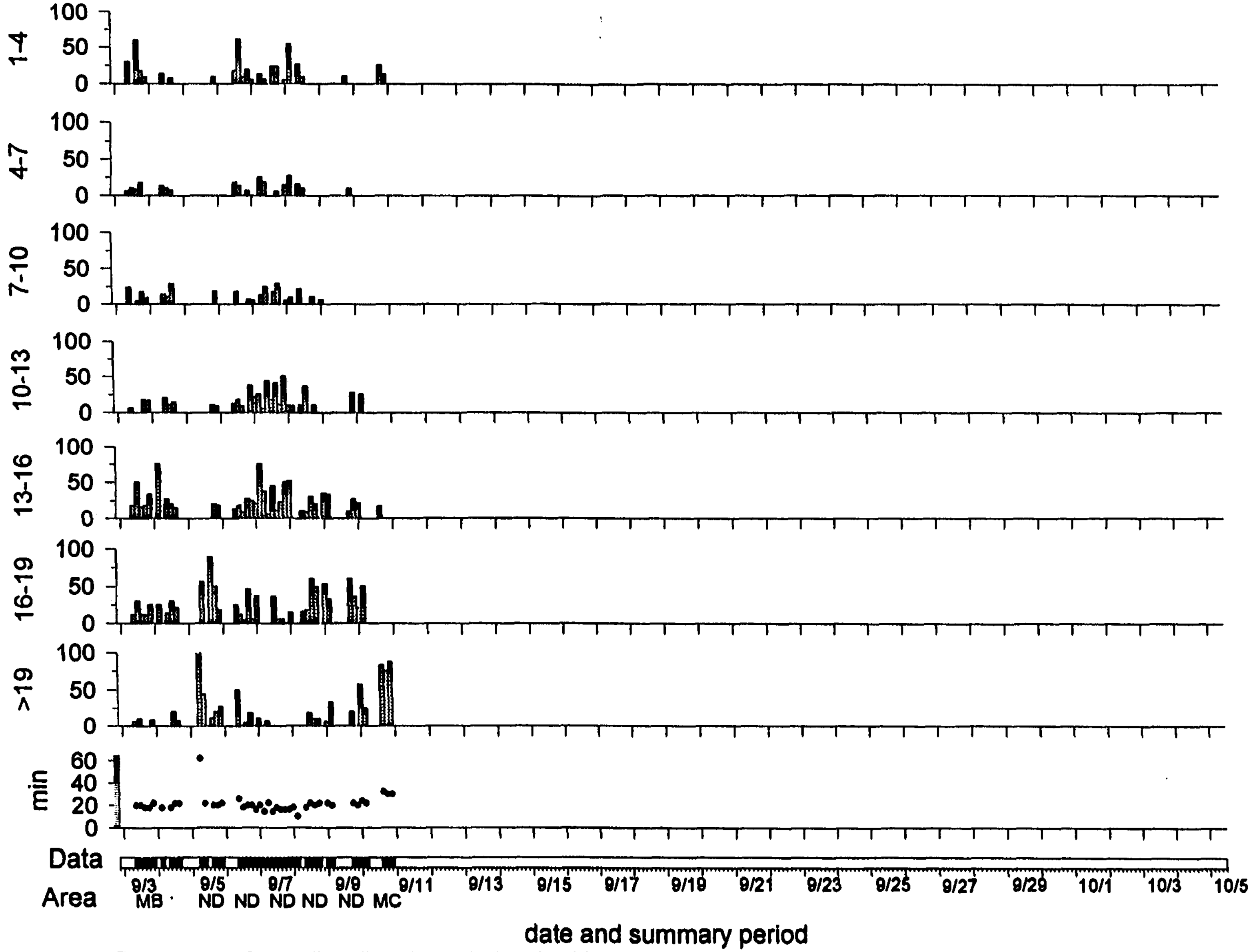

Figure 26. Percentage of sounding dives in each duration bin and longest dive by date and summary period from a bowhead whale tagged in 1992: tag 10825. Solid bar in bottom graph indicates duration data were received for the period.

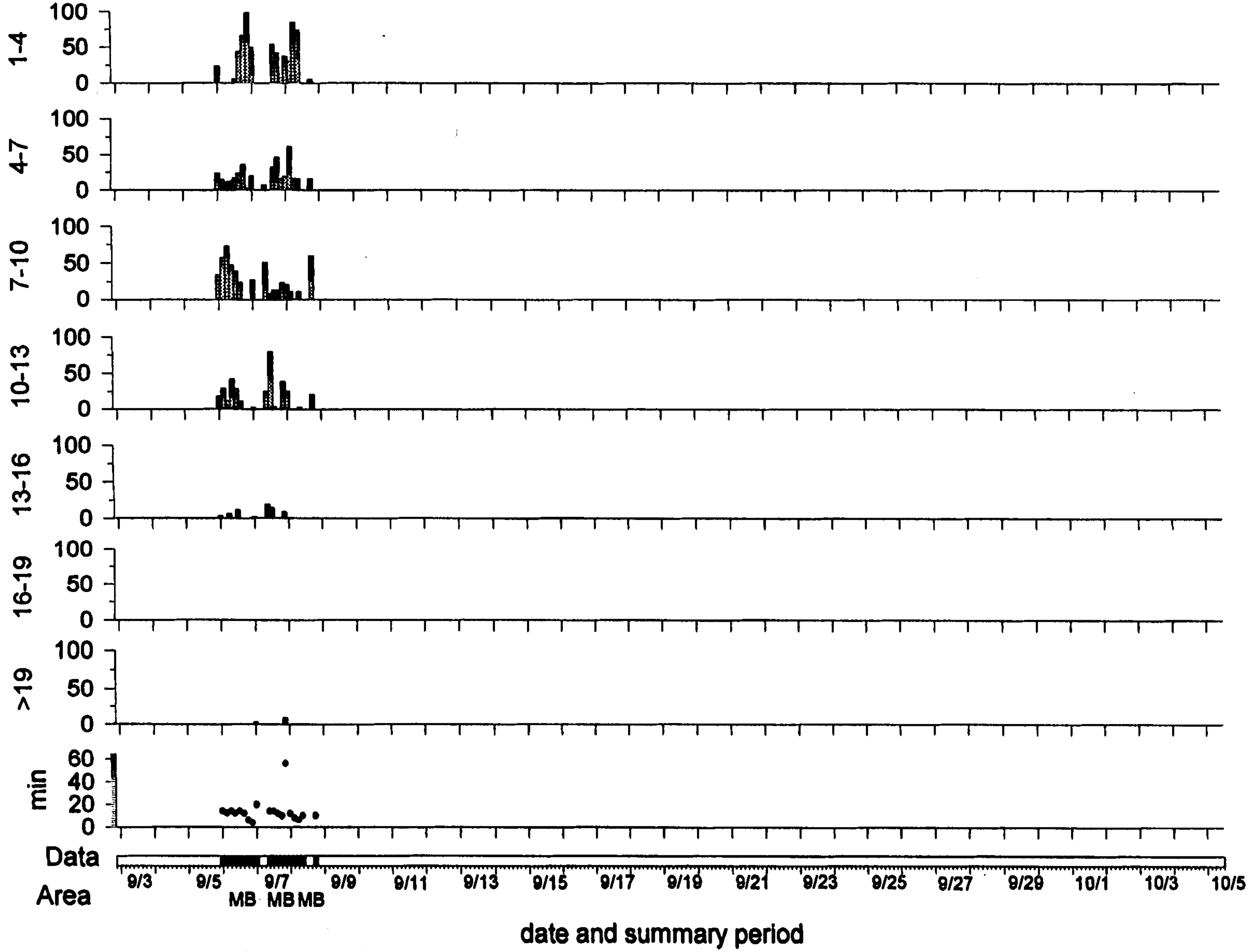

Figure 27. Percentage of sounding dives in each duration bin and longest dive by date and summary period from a bowhead whale tagged in 1992: tag 10826. Solid bar in bottom graph indicates duration data were received for the period.

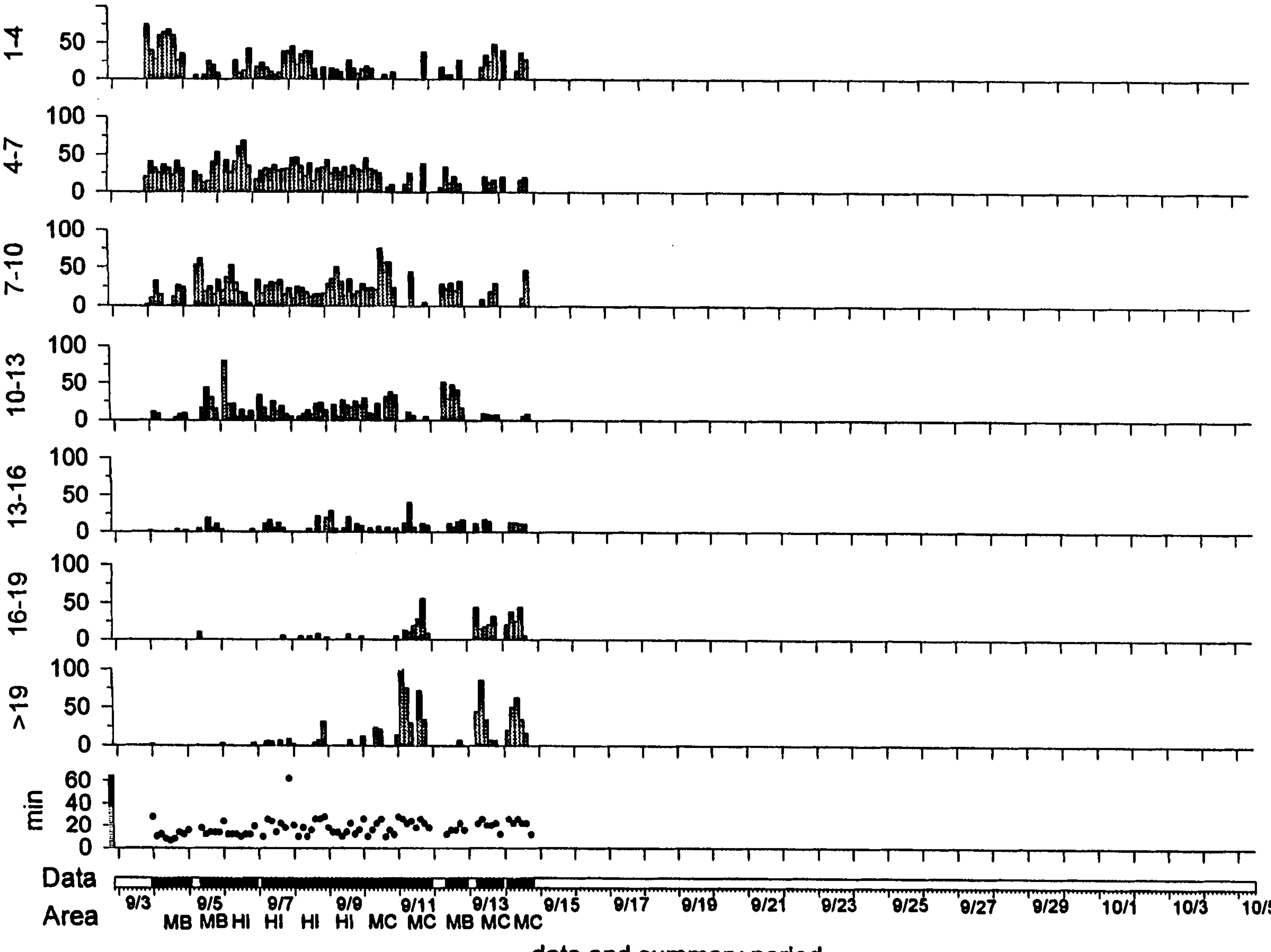

Figure 28. Percentage of sounding dives in each duration bin and longest dive by date and summary period from a bowhead whale tagged in 1992: tag 10827. Solid bar in bottom graph indicates duration data were received for the period.

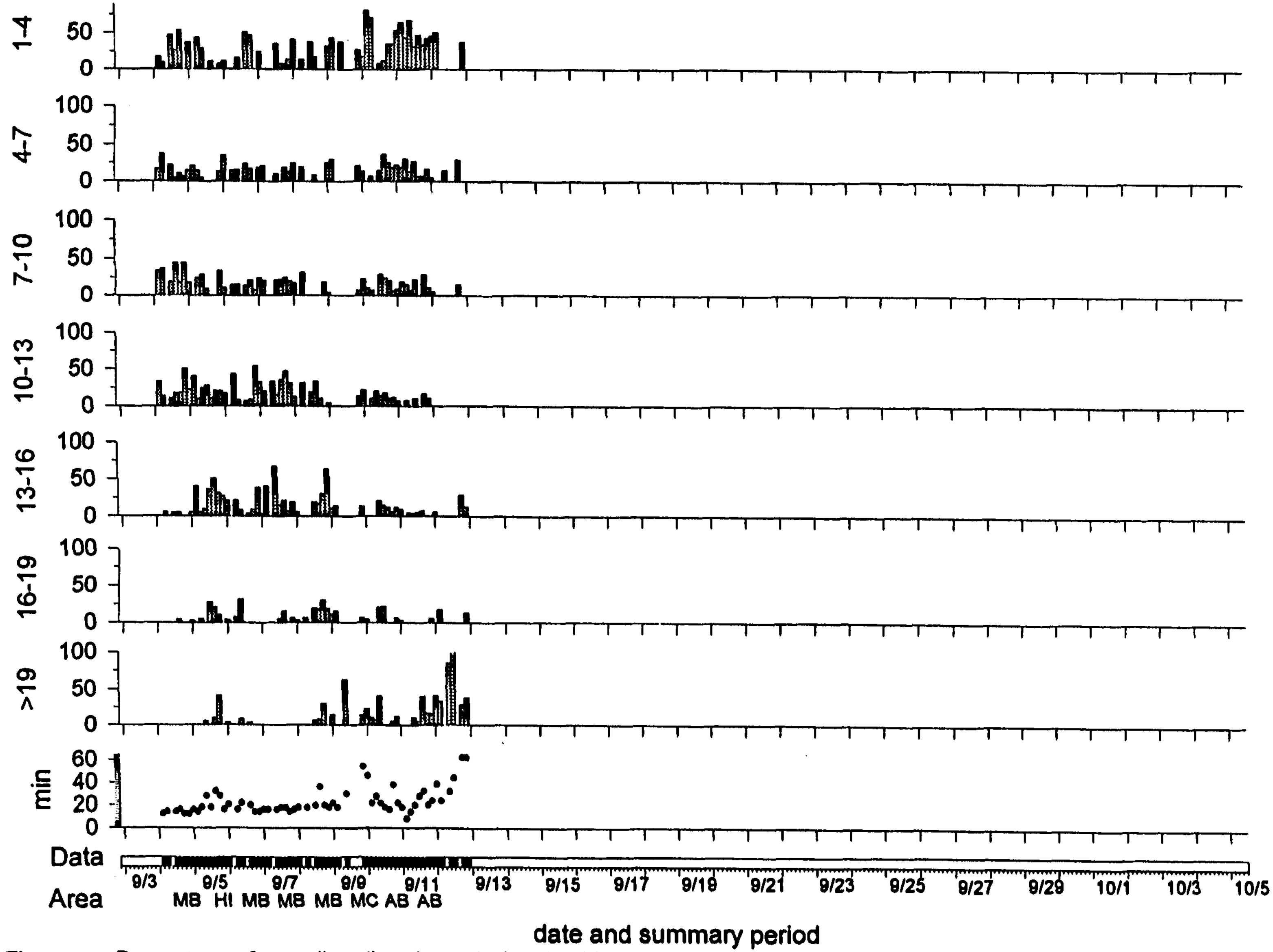

Figure 29. Percentage of sounding dives in each duration bin and longest dive by date and summary period from a bowhead whale tagged in 1992: tag 10828. Solid bar in bottom graph indicates duration data were received for the period.

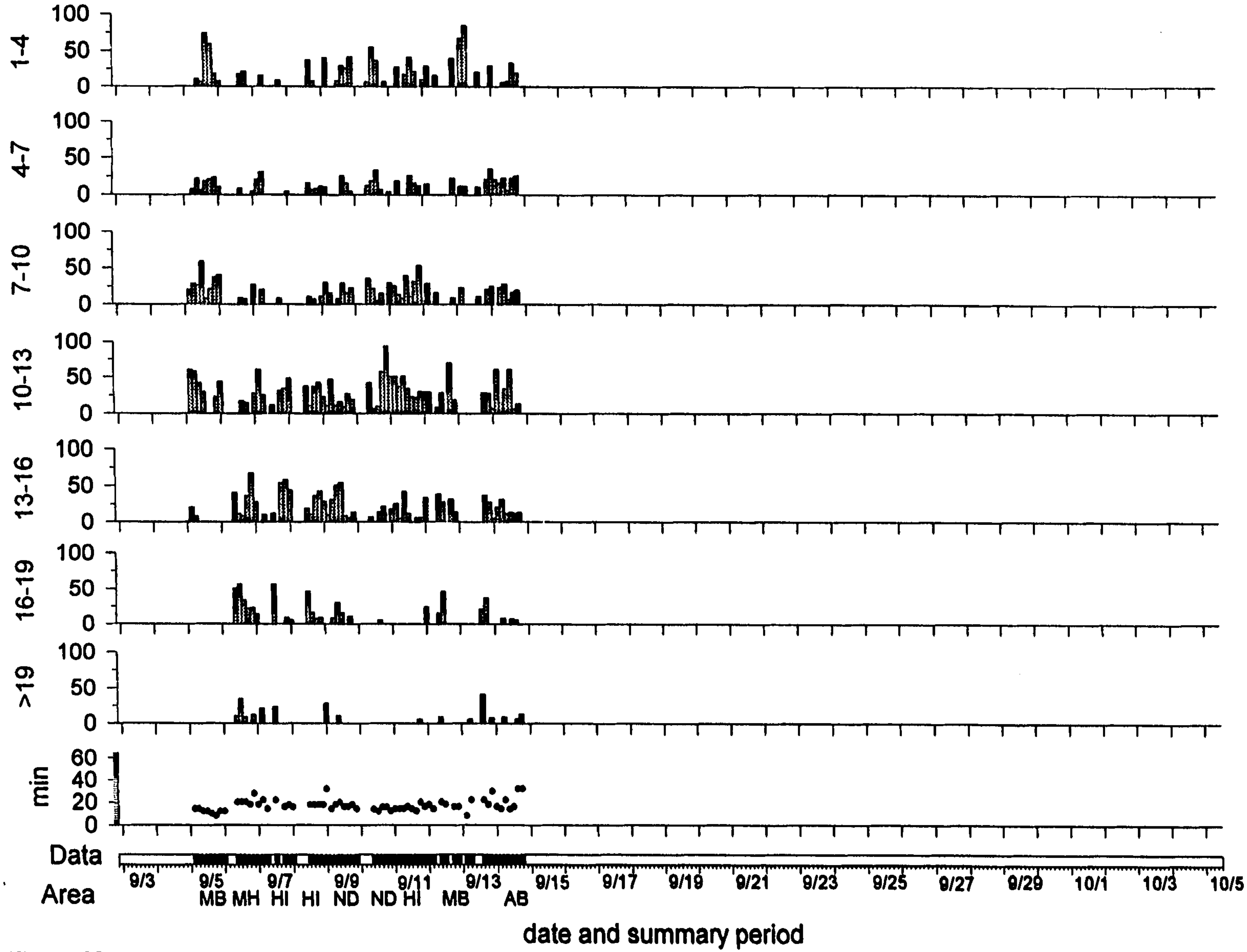

Figure 30. Percentage of sounding dives in each duration bin and longest dive by date and summary period from a bowhead whale tagged in 1992: tag 10830. Solid bar in bottom graph indicates duration data were received for the period.

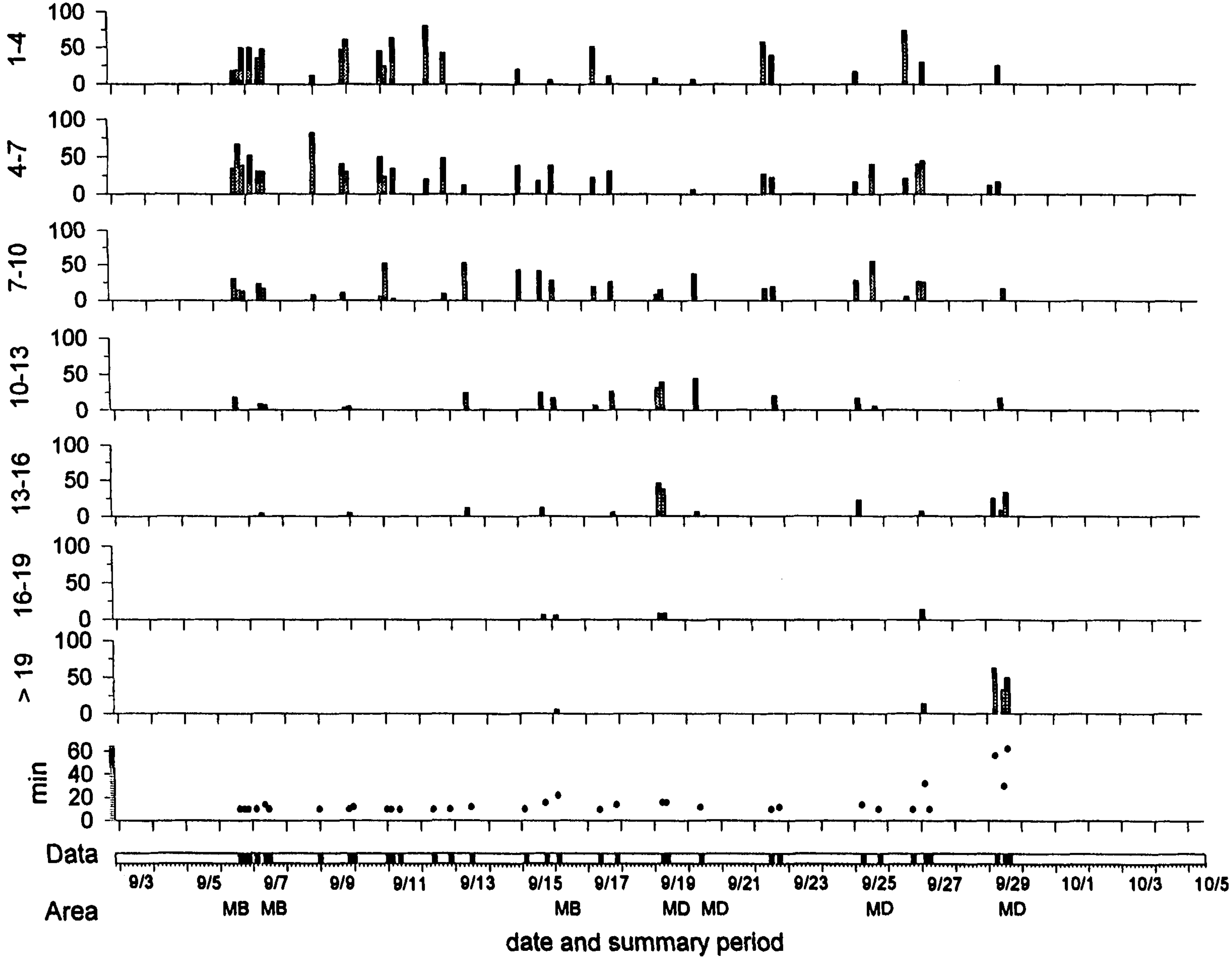

Figure 31. Percentage of sounding dives in each duration bin by date and summary period from a bowhead whale tagged in 1992: tag 828. Solid bar in bottom graph indicates duration data were received for the period.

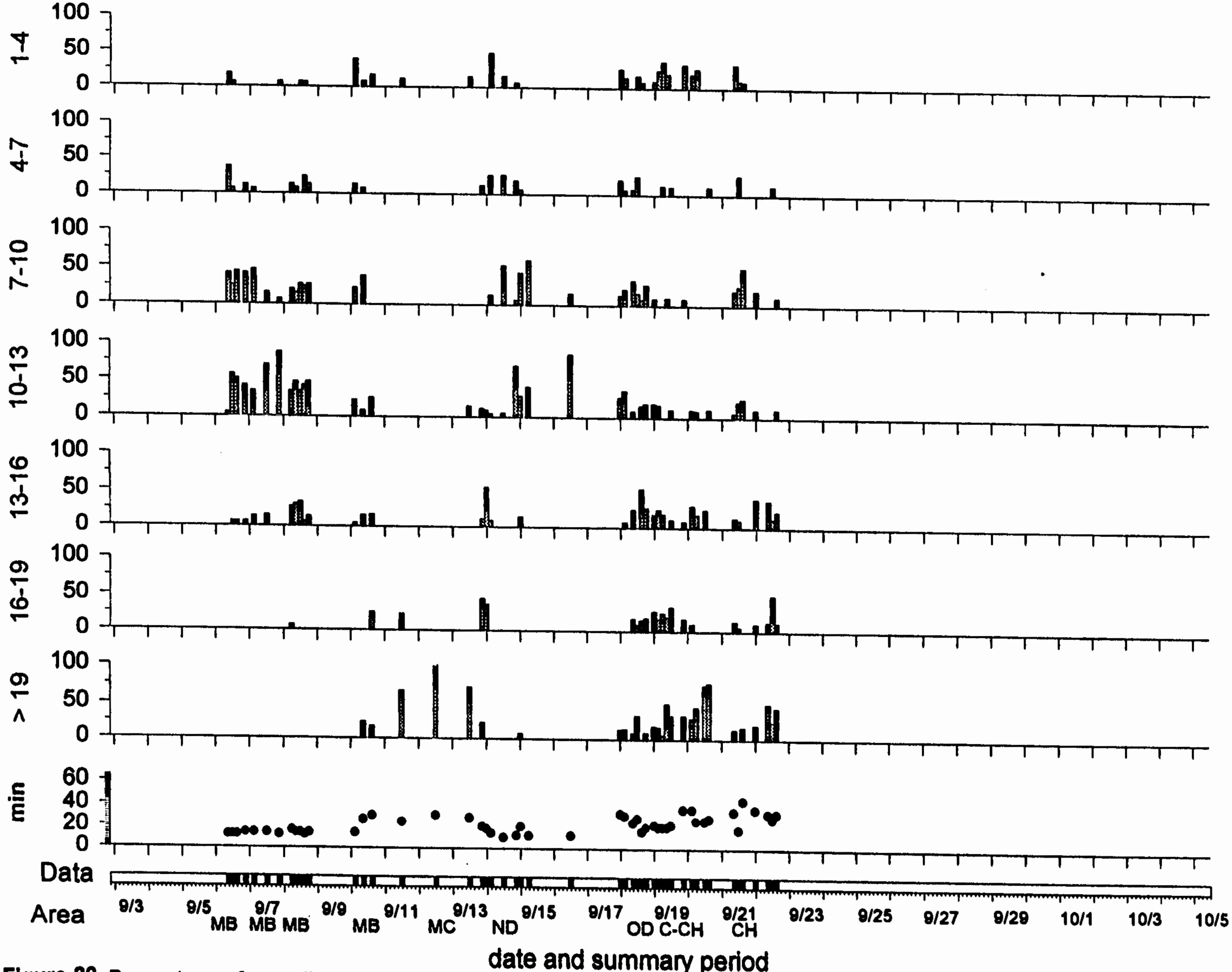

Figure 32. Percentage of sounding dives in each duration bin by date and summary period from a bowhead whale tagged in 1992: tag 831. Solid bar in bottom graph indicates duration data were received for the period.

($\bar{x}$ = 10.4 ± 2.4 min, n = 8). The average duration of sounding dives for most individuals spanned a range of 20 min or more across summary periods (Figure 33).

Data were log-transformed to make comparisons among individuals. There were significant differences among individual animals (ANOVA $F_{7, 528}$ = 14.2, p-value << 0.0001). The geometric mean of average duration of sounding dives for tag 10825 and 831 (13.3 and 12.6 min, respectively) were significantly higher than for all other tags. The geometric mean for tag 10825 was 2.1 times (95% C.I. 1.5 - 3.0 times) as long as that for tag 10826 (6.2 min); this was the greatest difference between tags. The high percentage of short dives was expected. Bowhead whales, like most cetaceans, typically make a series of short dives between breaths during a surfacing sequence followed by a longer sounding dive (Carroll and Smithhistler, 1980; Rugh and Cubbage, 1980). The mean number of blows per surfacing sequence for presumably undisturbed, non-calf bowhead whales in the Beaufort and Chukchi Seas recorded in observational studies ranged from 3.6 to 12.6 blows and the mean interblow interval ranged from 11.2 to 17.9 s (Table 10). Thus, if we consider dives ≤ 1 min recorded by the tags to be series dives in a surfacing sequence, we expect these dives to comprise 69 - 92% of all dives. Seven of the nine tags returning dive duration data fell within this range.

Two tags fell below the expected range. Tag 10822 returned only one period of dive duration data in which 33.3% of its dives were ≤ 1 min. The longest submergence in the period was ≥ 61 min. Consequently, the data returned from this tag may be suspect (see discussion of longest submergences below). During the 19 periods tag 10826 returned dive duration data, 64.0% of the 1455 dives recorded were ≤ 1 min. This tag

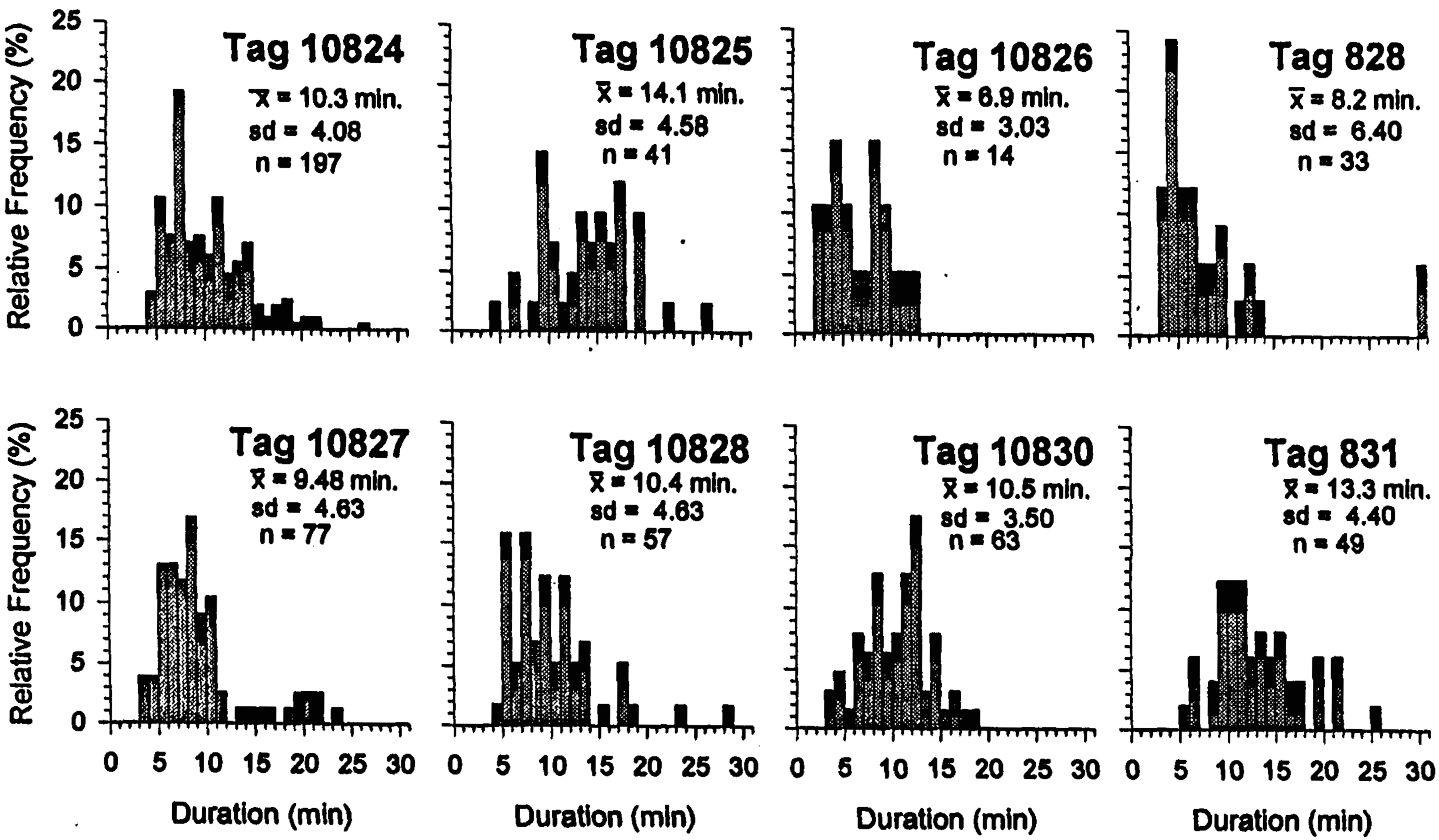

Figure 33. Frequency histogram distributions of average duration of sounding dives in summary periods for each tag. Sample size (n) is the number of summary periods.

recorded a higher percentage of 1 - 4 min dives (15.8%) than other tags (range: 2.0 - 9.6%), but seldom recorded long dives: 0.9% were $\geq$ 13 min, less than any other tag (range: 1.1 - 12.4%). Several hypotheses could explain the slightly lower than expected percentage of very short dives. First, this animal may have had a much longer interblow interval, frequently submerging for more than a min between blows. This would account for the higher percentage of 1 - 4 min dives. However, this seems unlikely because mean interblow interval values from observational studies were all less than 18 s (Table 10) and the mean interblow interval was found to be relatively constant for bowheads engaged in different activities (Würsig et al., 1984; Dorsey et al., 1989). Second, this animal may have often remained at the surface or submerged the tag for < 6 s so that no dive was recorded between blows. Bowheads have been observed blowing several times without submerging while summering in the Beaufort Sea (Würsig et al., 1984) and while feeding under ice in spring (Carroll et al., 1987). Consistent with this hypothesis, tag 10826 recorded the highest mean percentage of time at the surface for any tag (see surface time section below). If this animal was often at the surface or underwater < 6 s between blows, its mean blow rate (0.42 blows/min, the median value for all of the tagged whales) would be an underestimate. Finally, this whale may have utilized a different respiration strategy than other animals: short sounding dives, more surfacing sequences with fewer blows per surfacing sequence. The lack of long dives is consistent with this hypothesis. Of course, these are not mutually exclusive explanations. The slightly lower than expected percentage of short dives recorded by this tag could result from a combination of these behaviors.

Researchers studying bowhead surfacing and dive behavior visually (Table 10) count the short series dives as part of a "surfacing." A "dive" in those studies was judged to be a sounding dive based on either: (1) raising of the flukes or a pronounced body flexion, or (2) was a submergence greater than some specified period of time (75 s for Rugh and Cubbage, 1980; 60 s for Würsig et al., 1984; 15 s for Dorsey et al., 1989). The duration of 686 "dives" ($\overline{x}$ = 8.2 min) made by presumably undisturbed, non-calf bowheads in the Beaufort and Chukchi Seas were measured during eight published studies (Table 10). Mean dive times reported in these studies ranged from 1.88 min to 17.93 min ($\overline{x}$ = 9.9 min ± 5.49, n = 17, Table 10). Observed dive times differed significantly by year and for animals in different water depths (Würsig et al., 1984; Dorsey et al., 1989). Carroll et al. (1987) found mean dive times were significantly longer for animals feeding under ice in spring 1985 than for whales actively migrating in spring 1980-1985 and for those observed in the eastern Beaufort in summer and fall 1980-1984. Examining previously published aerial observations of surfacing and dive variables for undisturbed, non-calf bowheads in the western Arctic, Richardson et al., (1995) found mean dive times were shorter for animals socializing in shallow (≤ 50 m) water (2.65 ± 3.82 min, n = 94) than for whales feeding in deep water (11.05 ± 9.95 min, n = 43) or migrating in fall (14.56 ± 8.62 min, n = 42).

The average duration of sounding dives for individual bowhead whales tagged in this study varied greatly across summary periods. The range of values reported by most animals (Figure 33) was greater than the range of mean dive times reported in the cited studies (Table 10). This demonstrates tremendous plasticity in dive behavior. Close investigation of time series graphs of duration data (Figures 25 to 32) reveals that tagged whales sometimes made sounding dives of similar duration for many hours. For example, when animal 10825 was in Mackenzie Canyon on 10 September 81.8% of sounding dives recorded during 9 h (periods 5 - 7) were > 19 min. At the other extreme, when animal 10827 was in Mackenzie Bay on 4 September 82.6% of sounding dives recorded during 20 h (periods 3 - 8) were < 7 min. Although Würsig et al. (1984) state that "bowheads tend to make a series of dives of similar duration rather than alternating long and short dives," the extended time over which this can occur was previously unknown. There were also summary periods in which tagged bowheads made sounding dives distributed evenly across duration bins from 1 - 4 min to 19 - 25 min or bimodally distributed between short (1 - 4 min) and long (16 - 19 and 19 - 25 min) bins. We cannot tell the order in which these dives occurred, but it is probably simplistic to think that bowheads always make sounding dives of similar duration.

Longest Dive During Summary Period

The distributions of the longest dive duration during periods for duration/depth tags (when n > 1 period) which returned more than one period of data are shown in Figure 34. These distributions show all summary periods reported (1, 3, and 5 h) including those with overflow (≥ 61 min) values. The longest dive in the one period of duration data from tag 10822 was ≥ 61 min. Figure 35 shows the distribution of longest dive durations, including underflow (< 12 min) values, for duration tags.

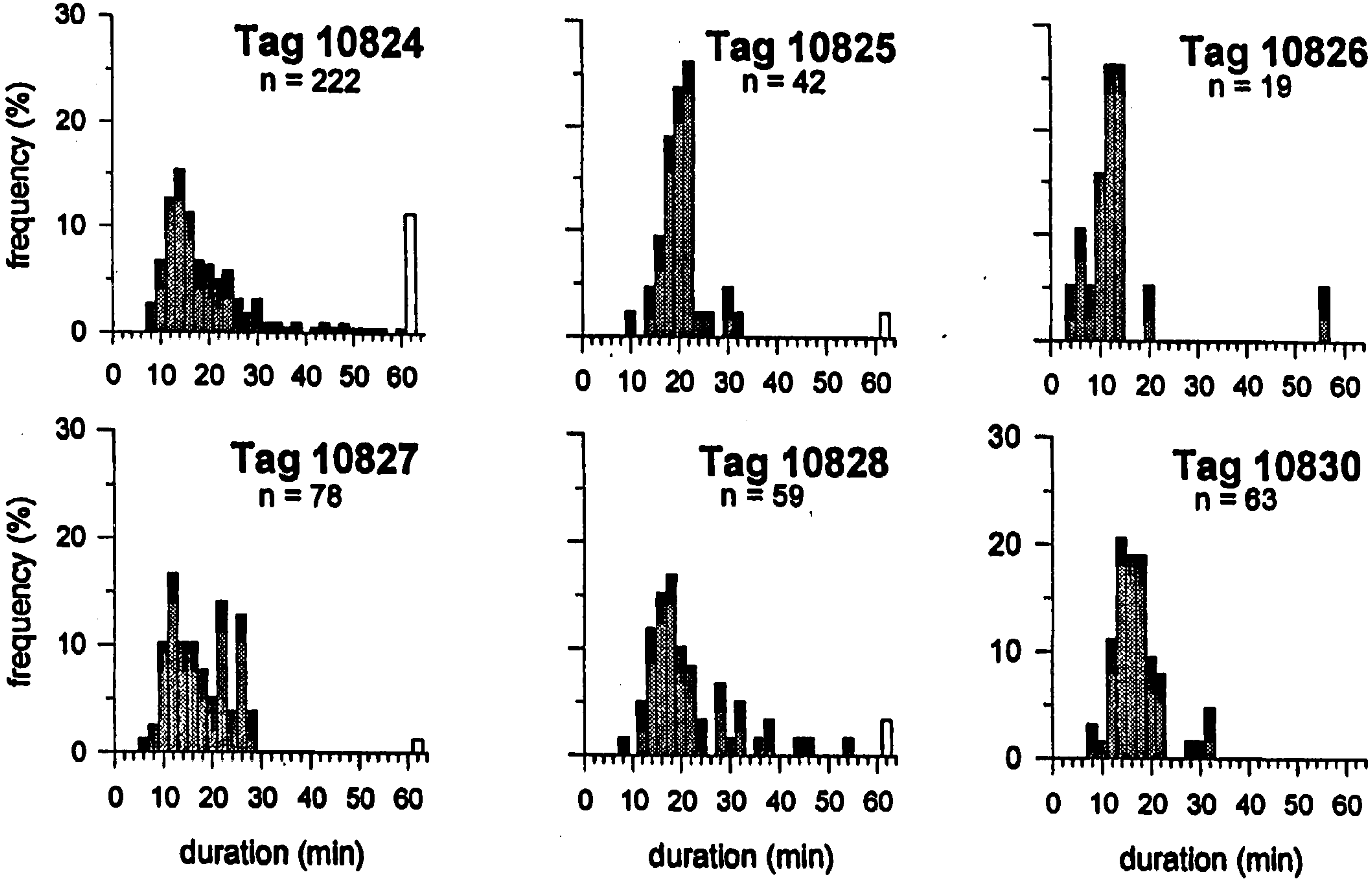

Figure 34. Frequency histogram distributions of longest dive in summary periods for duration/depth tags. All summary periods (1, 3, and 5) are shown. Bars without shading represent periods with longest dives of at least 61 minutes (overflow value). Sample size (n) is the number of periods.

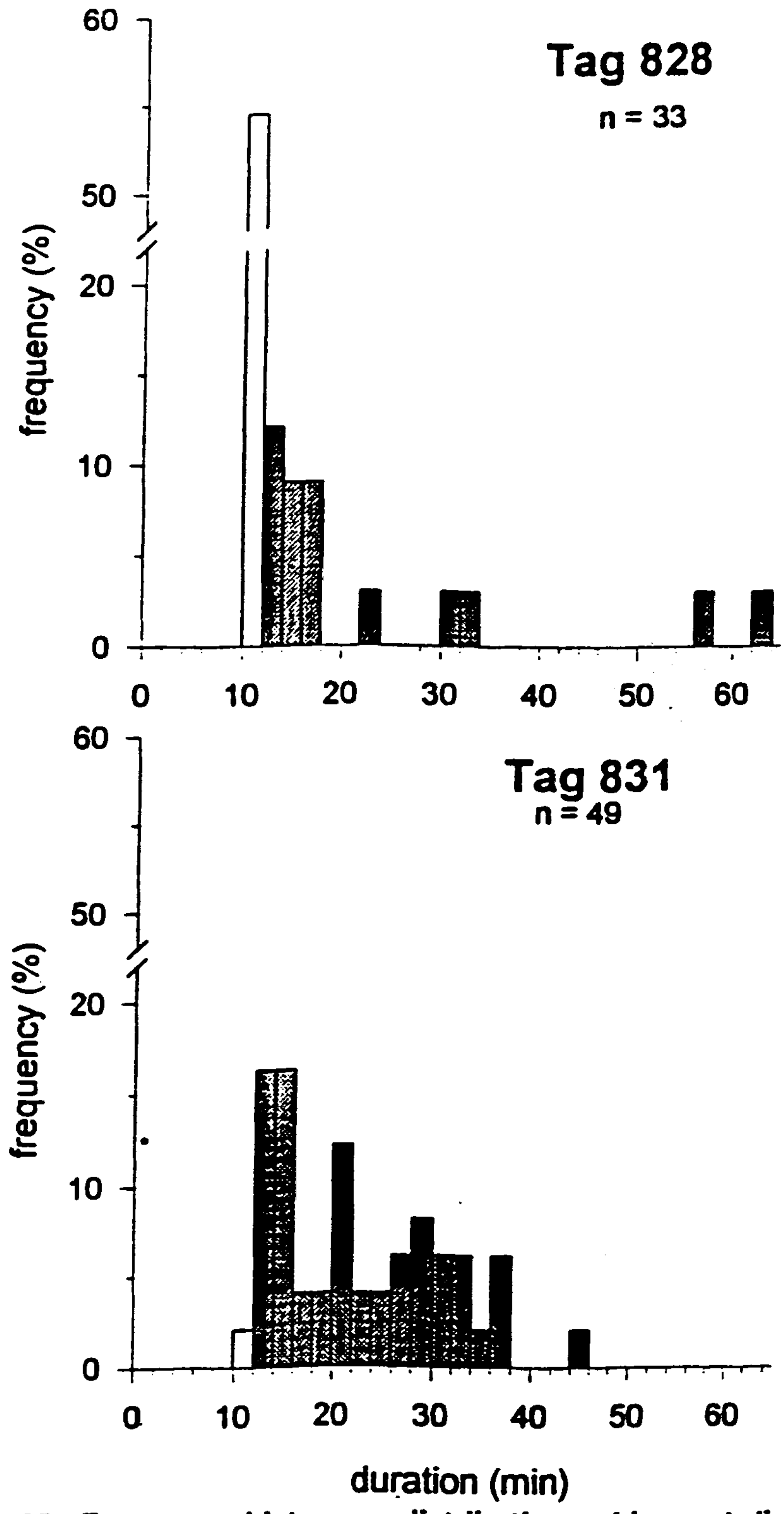

Figure 35. Frequency histogram distributions of longest dive duration in summary periods for durations tags. Unshaded bars indicate underflow values (< 12 min).

Six of the nine tags reported being submerged for at least 61 min: 828, 10822, 10824, 10825, 10827, and 10828. Unfortunately, 61 min was the overflow value for the duration/depth tags. Consequently, the duration of the longest dive is only known to be at least 61 min for 30 of the 484 summary periods (6.2%) reported by these tags. The longest dive of known duration, reported by tag 828, was between 62 and 64 min.

Few scientists have suggested that bowheads remain submerged for over an hour. Carroll and Smithhistler (1980) refer to an unpublished manuscript by Foote (1964) that claims bowhead whales can dive for up to 1.25 h if they are injured, frightened, or otherwise greatly disturbed. Some of the longest dives recorded for bowhead whales include visual observations of 26.7 (Carroll and Smithhistler, 1980) and 30.98 min (Würsig et al., 1984), and time between VHF radio tag signals of 32.3 (Wartzok et al., 1990) and 41 min (Finley and Goodyear, 1993). The investigators who used direct visual observation acknowledge their sampling methods were biased toward shorter dives due to difficulties keeping track of individual animals, especially during long dives. Wartzok et al. (1990) suggest that dive durations measured as time between received VHF radio signals may be biased upward since all signals may not be received during a surfacing sequence, but the bias should be relatively small compared to the duration of the dive. During our tagging operations we stayed with a lone bowhead whale for approximately four hours. We had good sighting conditions, winds of less than 22 km/h (12 kts) and good visibility, with the captain and three experienced observers to spot the animal when it surfaced. Most of the long sounding dives we observed were between 18 and 22 min. The longest time between sightings of this animal was approximately 40 min. Although it is possible that we missed a surfacing, we believe that the animal actually dove for that long.

Two-thirds of the tags well positioned on bowhead whales were submerged for at least 61 min in one or more summary periods, substantially longer than the longest documented dives for this species. For some animals (tags 828, 10825, and 10827) these long submergences appear to be extreme outliers, whereas for other animals (tags 10824 and 10828) they may be viewed as part of the skewed distribution of longest dives. The obvious question is whether these long submergences are real "dives" or artifacts of the sampling method.

Bowhead whales modify their surfacing and breathing patterns in response to ice cover conditions (Carroll and Smithhistler, 1980; Würsig et al., 1984). In areas where extensive ice cover exists, bowheads have been observed breathing in small pools of open water with just the blowhole exposed (George et al., 1989). Bowhead whales regularly break ice up to 20 cm thick to breathe and have been observed to break ice 60 cm thick (George et al., 1989). Tags would not break the surface when bowheads only expose their blowholes or break ice to breathe. Given these circumstances, tags would register longer and fewer dives than actually occurred. Surfacing behavior in ice cover could explain some of the very long dives recorded. To investigate this hypothesis we examined predicted ice conditions at the Argos determined locations of tagged whales.

Of the 31 periods where the duration of the longest submergence was $\geq$ 61 min, 25 (80.6%) were reported by tag 10824. Twenty-three of the 25 periods were recorded in the Chukchi Sea during late September where ice cover was predicted to be $\geq$ 90%, one period occurred on 16 September north of Camden Bay in 80% ice cover, and one period occurred on 12 September between Demarcation Point and Barter Island where ice cover was ≤ 30%. Whale 10824 probably encountered ice cover ≥ 90% from 20 September to its last transmission on 5 October. The time series plot of the longest submergences for tag 10824 (Figure 25) shows much greater variability in longest submergences and clustering of overflow values when this animal encountered ice cover ≥ 90% after 20 September. The median duration of the longest submergences for periods where this animal encountered ice cover ≥ 90% was significantly greater than for periods when the animal was in ice cover < 90% (Mann-Whitney U test, $Z = 9.63$, $df = 220$, approximate p-value << 0.0001). A time series plot of the surfacing rate for tag 10824 (Figure 36) reveals that all periods in which < 10 surfacings were reported were after the whale was in > 90% ice. Further investigation of differences in data received from this animal in heavy versus lighter ice conditions are presented in a separate section below.

Whale 828 seldom made long dives. In 55% of the summary periods ($n = 33$) the longest dive was less than 12 min (Figure 35). Only 15 (1.9%) of 797 sounding dives recorded were longer than 19 min. Eleven of these (73.3%) took place in the three summary periods received for 29 September. In only four (12.1%) of 33 summary periods was the duration of the longest dive longer than 30 min. Three of these periods occurred on 29 September when the animal was in ice cover ≥ 90%: a 56 - 58 min dive in period 2; a 30 - 32 min dive in period 4; and a 62 - 64 min dive in period 5. No location was determined during the other period with a submergence longer than 30 min. However,

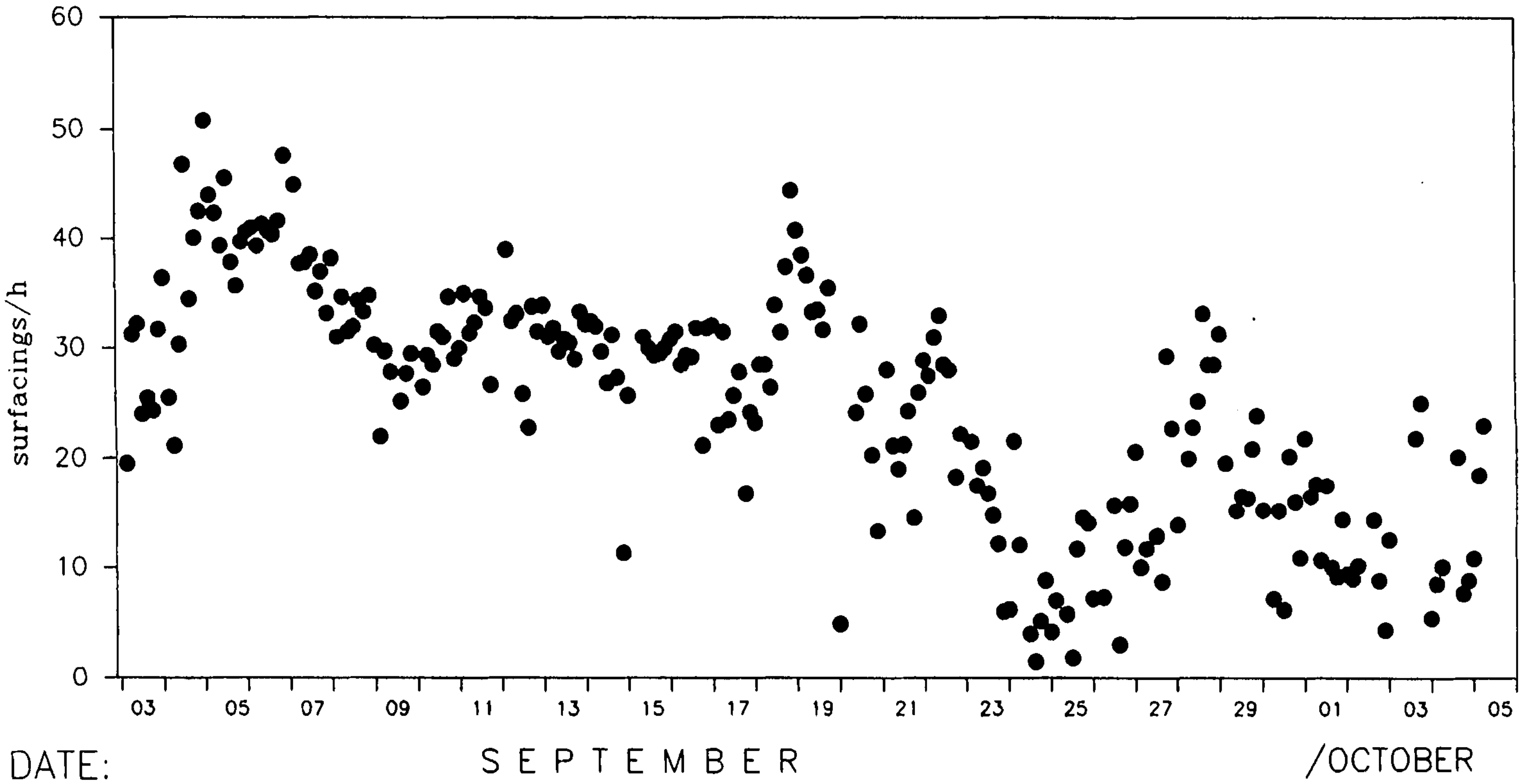

Figure 36. Surfacing rate by date and summary period for tag 10824.

locations on 25 and 29 September were both north of Richards Island < 35 km apart. Ice cover from 30% to > 90% prevailed on 27 September when this 32-34 min dive occurred.

The link between heavy ice cover and very long dives for tag 10828 was less clear. Dives of at least 61 min were reported on 12 September during the last two summary periods data were received from this tag. The last Argos location, determined more than 30 h earlier, put the animal at approximately 71° 02'N 136° 20'W, in the Canadian Basin near the ice edge.

Not all dives ≥ 61 min occurred in heavy ice conditions. Although the location of animal 10822 during the only period it returned duration data (3 September) was undetermined, it was likely in open water. Tags 10825 and 10827 each reported one period in which the duration of the longest submergence was at least 61 min while they were in open water northwest of Herschel Island on 5 and 7 September, respectively. During spring migration, Carroll and Smithhistler (1980) observed bowhead whales resting at the surface in open water exposing only their blowholes to breathe. These authors reported bowheads resting at the surface for over an hour on four occasions. Thus, it is possible that resting bowhead whales would not expose the tags to the surface for over an hour. However, these three animals first reached the maximum depth for the period (56 - 71 m for 10822, and 8 - 23 m for 10825 and 10827) during the ≥ 61 min submergence so they could not have been resting at the surface the whole time.

Overall, 91.5% of the longest submergences reported in 566 summary periods from nine tags were less than 41 min. In summary, we are unable to conclude whether or not the long submergences were real dives or artifacts of surfacing behavior, particularly in heavy ice conditions, that did not expose the tag to air.

Comparisons of Longest Dives Among Animals

Because of the different ways in which data were collected by the two tag types, statistical comparisons of the longest dives between tag types are not possible. So data were compared among tags of the same type.

For duration tags, the longest submergence during a summary period ranged from < 12 min (underflow value = 10) to between 62 and 64 min. The underflow value (10) occurred in 18 (55%) of the 33 summary periods reported for tag 828, whereas the longest dive was < 12 min in only one (2%) of 49 summary periods reported by tag 831 (Figure 33). The median of the longest dives was significantly greater for tag 831 (24-26 min) than for tag 828 (< 12 min) (Mann-Whitney U-test, df = 80, Z = 4.56, two-tailed p-value < 0.0001).

For duration/depth tags, the 30 periods where overflows occurred were not included in the calculations and analysis presented here. This biases our mean values for the longest dive duration downward for five of the six animals considered. The bias is important only if these are indeed real dives and not artifacts of surfacing behavior.

Because the longest dive recorded during a period was significantly affected by summary period length, comparisons between animals was done for periods of equal length. Data were log transformed. For 3-h periods (the largest sample sizes) there were significant differences in the geometric mean of longest dives among the six individual animals (ANOVA $F_{5, 345} = 7.03$, p-value << 0.0001, Table 12). The geometric mean of longest dives for tag 10826 was significantly less than that for all other animals. The greatest difference in geometric mean values was between animals 10828 (20.7 min, 95% CI 18.4 - 23.2 min) and 10826 (11.3 min, 95% CI 9.2 - 13.8 min). The geometric mean of longest submergences for tag 10828 was also significantly longer than that for tag 10827 (16.2 min, 95% CI 14.8 - 17.9 min). Sample sizes for some individuals were too small to make formal statistical comparisons among individuals for one and five hour periods. Nevertheless, individual animals showed similar trends for longest dive durations in one and five hour periods as in three hour periods (Table 12).

Table 12. Comparison of longest dives for duration/depth tags in 1-, 3-, and 5-hour summary periods. Statistical comparisons among tags were made using log-transformed data for 3-h periods. Sample sizes were too small to make statistical comparisons for 1-, and 5-h periods. Values given are back transformed to geometric mean. Different superscript letters indicate significant differences in longest dives among tags (ANOVA Tukey HSD 95% CI).

TAG #	GEOMETRIC MEAN DURATION OF LONGEST DIVES					
	1-hour periods		3-hour periods		5-hour periods	
	min	n	min	n	min	n
10826	9.8	2	11.3^{a}	14	15.0	3
10827	13.5	8	16.2^{b}	62	22.4	7
10830	13.8	7	16.9^{bc}	49	17.2	7
10824	13.2	24	18.1^{bc}	152	18.9	21
10825	16.2	5	20.3^{bc}	32	20.9	4
10828	15.4	7	20.7^{c}	42	22.4	8

Duration of First Dive to Maximum Depth in Summary Periods

Seven duration/depth tags reported the duration of the first dive to the maximum depth. Valid data were received for 474 summary periods. Values ranged from <1 to $\geq$ 61 min. Duration of the first dive to the maximum depth reached during the summary period was reported as 0 (meaning less than 1 min) by four tags in 21 (4.4%) of the 474 periods. Depth information was reported in 17 of these 21 periods. The deepest dive reported as 32 m or less in all 17 periods. Thus, the first dive to the maximum depth recorded during these periods was most likely one of the short series dives during a surfacing sequence. The overflow value, $\geq$ 61 min, was recorded by four tags in 17 (3.6%) of the 474 summary periods reported. Of these 17 periods, 12 (70.6%) were reported by tag 10824 in heavy ice conditions. Maximum depths reported in these 17 periods ranged from 16 to 208 m. The first dive to the maximum depth during the period was also the longest dive during the period in 120 (28.4%) of the 423 summary periods where both durations were known.

To investigate the relationship between duration and depth of the first dive to maximum depth during the summary period, a regression analysis was performed for each tag. The 38 summary periods with 0 or $\geq$ 61 min durations for the first dive to the maximum depth were not included in the following analysis. Duration significantly increased with the depth of dive for five whales, but the linear model explained less than half of the variation around the mean in all cases (Figure 37). One outlier value strongly influenced the analysis for tag 10830 (Figure 37). A significant positive relationship was still found if the outlier was excluded from the analysis (p-value = 0.03).

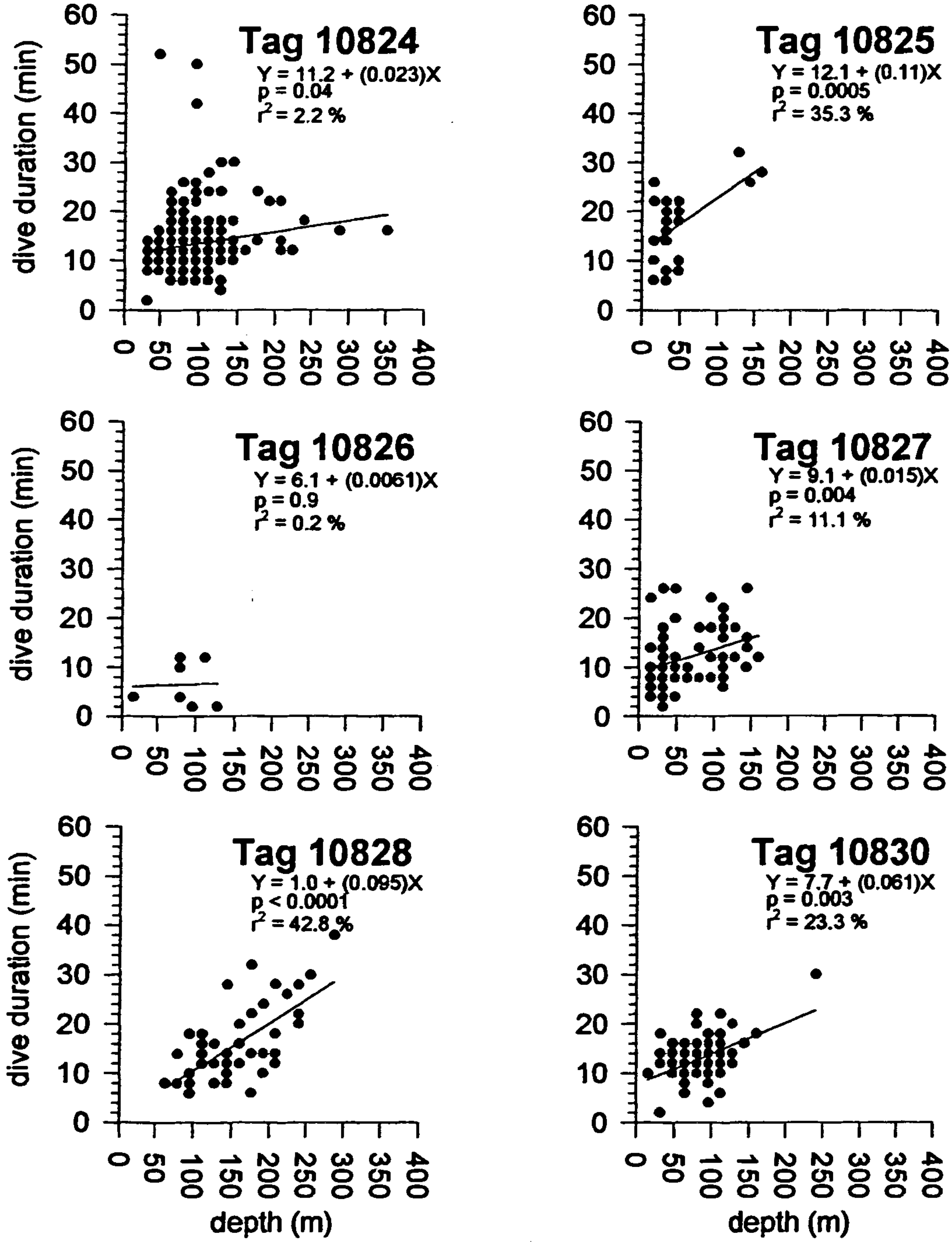

Figure 37. Regression plots of duration vs depth for the first dive to the maximum depth reached during the summary period.

A multiple linear regression model was used to investigate whether the relationship between the maximum depth and the duration of the first dive to that depth was the same for all animals. There was a positive significant relationship between the duration of the first deepest dive during a summary period and the maximum depth reached during that period even after accounting for individual animal differences (multiple linear regression, approximate p-value for maximum depth coefficient = 0.02). However, both the intercept and the slope of the regression equation were significantly different for tag 10828 (p-value for intercept coefficient = 0.0005, p-value for slope coefficient = 0.0002) than for other tags. Also, the slope of the regression equation was significantly different for tag 10825 (p-value = 0.008) than for the other tags. For both of these whales the slope of the regression equation was greater than for other whales. This multiple linear regression model was highly significant (df = 411, $p < 0.00005$) but did not explain a great deal of the variation (adjusted r^2 = 17.3%).

Kramer (1988) proposed a "theory of optimal breathing" for air breathing aquatic animals that predicts longer dive times as dive depth increases. Dive depth and dive duration are positively correlated for many air breathing aquatic animals in the wild. Examples include leatherback sea turtles, Dermochelys coriacea (Eckert et al., 1986), cormorants, Phalacrocorax sp. (Stonehouse 1967), penguins, Aptenodytes patagonicus and Pygoselis papua (Kooyman et al., 1992; Williams et al., 1992), fur seals, Callorhinus ursinus and Arctocephalus pusillus (Gentry et al., 1986; Kooyman and Gentry, 1986), California sea lions, Zalphus califomianus (Felkamp et al., 1989), beluga whales, Delphinapterus leucas (Martin and Smith, 1992), narwhals, Monodon monocerus (Martin et al., 1994), and humpback whales, Megaptera novaeanliae (Dolphin 1987a). Aerial observations of bowheads in the Beaufort Sea suggest dive times for bowheads in deep water (> 50 m) are longer than for those in shallow water (Würsig et al., 1984; Dorsey et al., 1989; Richardson et al., 1995). Our analyses suggest that although depth significantly influenced the duration of the first dive to the maximum depth during the period for tagged bowheads, it was not a good predictor of the dive's duration. Factors other than maximum depth may also strongly influence dive duration.

Dive Depth Information

Nine tags reported depth information. Three of these (tags 10820, 10822, and 10831) only reported one summary period, while the other six animals reported from 12 to 220 periods (Table 9). Only the deepest dives recorded by tags 10820 and 10831 are reported here. These two tags, positioned low on the whale's body, probably were not exposed to the air on most surfacings so dive counts recorded by these tags are likely to be inaccurate. Time series graphs (Figures 38 to 43) show the deepest dive and the percentage of dives in the period to each of the depth bins for the six tags that returned depth data for more than one summary period.

Deepest Dives

Maximum depths reached during a summary period ranged from < 8 to 455 m (Table 13). The deepest dive was < 153 m in 428 (91.5%) of the 468 summary periods reported by all nine animals. Seven tags reported dives > 100 m; three tags reported dives over 200 m (Table 13). Whale 10828 made the deepest dive recorded (between 440 and 455 m) on 9 September as it moved north along Mackenzie Canyon (69°52'N 138°10'W) to the Canadian Basin (Figure 41). Whale 10828 was the deepest diver by all measures with the minimum, maximum, mean, median, mode, and upper and lower quartiles for the deepest dive during summary periods (Table 13). The second deepest dive was recorded between 344 and 359 m by animal 10824 on 9 September while it was near the shelf break north of Demarcation Bay (Figure 37) in ice-free water.

Distribution of Dives in Depth Bins

The maximum depth of 32,629 dives by seven whales (10822, 10824, 10825, 10826, 10827, 10828, and 10830) was measured during 466 summary periods. The distribution of these dives in the depth bins was highly skewed for every animal: the majority of dives were no deeper than 16 m (Figure 44). This is not surprising since the majority of dives monitored were short (≤ 1 min), and thus probably "series dives" during surfacing sequences.

Several tagged whales (10824, 10827, 10828, 10830) showed a secondary peak in the overall number of dives to between 48 and 96 m or to between 96 and 200 m (tag 10825, Figure 44). Time series graphs of the percentage of dives to each depth bin by period (Figures 38 - 43) reveal that the higher frequency of dives to a specific depth bin resulted from bouts of repeated dives to that depth regime during relatively few of the periods monitored. For example, animal 10825 reported dive depth information for 44 summary periods, but all dives deeper than 48 m were recorded during only four periods:

3, 5, 6, and 7 on 10 September (dive depth data were not reported for period 4 this day, Figure 39). During these four periods (12 h) this animal made 25 dives deeper than 48 m: 3 to between 49 and 96 m, and 22 to between 97 and 200 m. Similarly, although tag 10827 reported dive depths for 76 periods, 194 (96.6%) of the 201 dives deeper than 48 m occurred in 29 periods from 10 to 14 September (Figure 41). Both of these animals were in the vicinity of Mackenzie Canyon when they made these deep dives.

Dive depths partially reflect available water depths. Tagged whales were often in shallow water and thus constrained from making deep dives. For example, whales 10825 and 10827 were in shallow water, near Demarcation Pt. and Herschel Island respectively, and did not make deep dives most of the time that they were monitored, but made repeated deep dives (> 97 m) when they were in the deep waters of Mackenzie Canyon (Figures 39 and 41). The three animals that were located in water > 500 m dove to over 200 m. The deepest diving whale (10828) was in deep water (> 50 m) during 14 (53.8%) of the 26 summary periods for which locations were determined (Figure 42).

However, some tags reported deeper dives than charted water depths would indicate were possible. For instance, tag 10826 recorded a dive to 128 m, but all location fixes for this whale were in shallow (< 20 m) water. In this case, sensor malfunction seems most likely. Sometimes the discrepancy may be attributed to the uncertainty associated with Argos-determined locations. Most Argos fixes obtained were of unknown

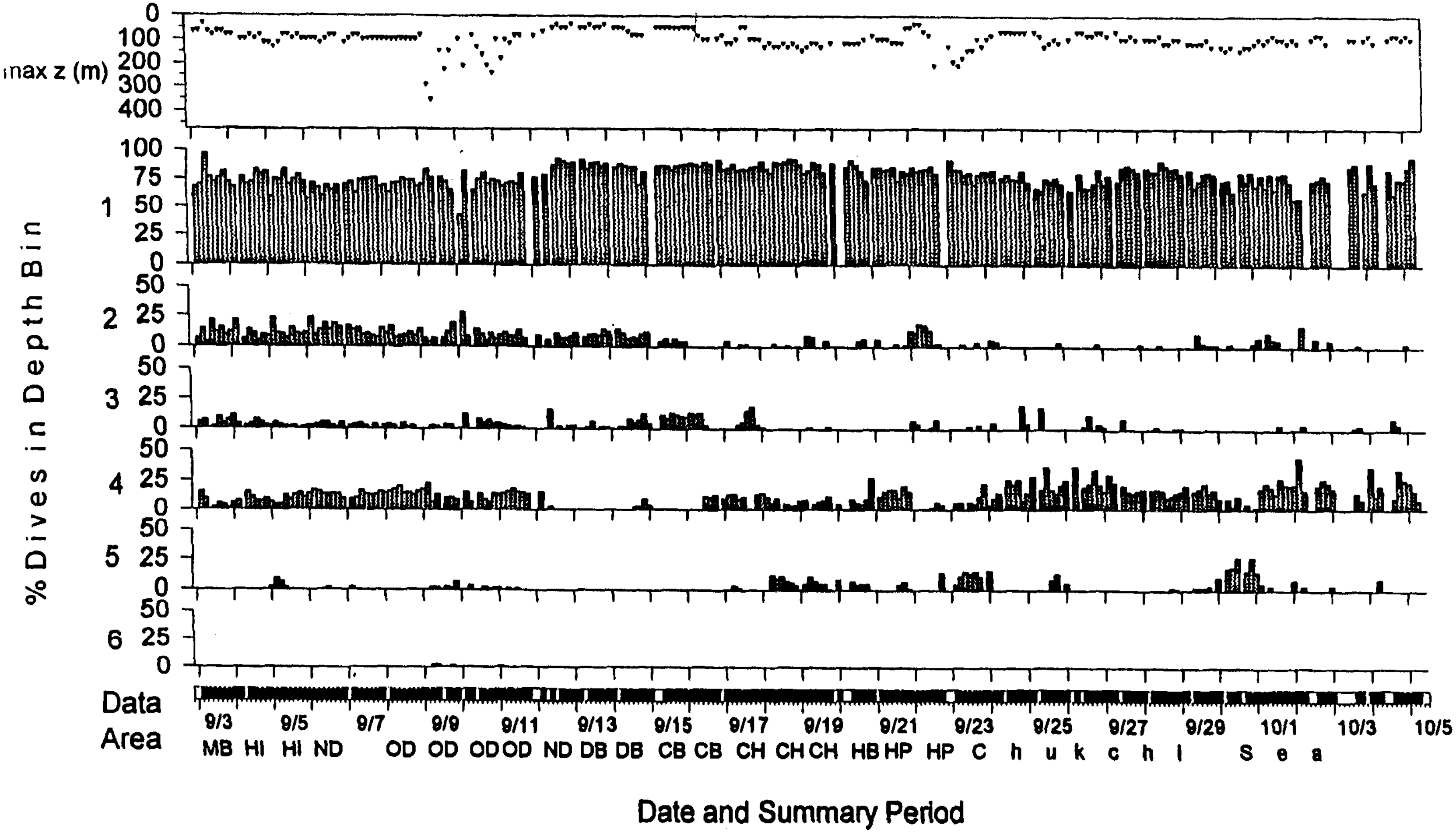

Figure 38. Time series depth information by summary period and day from a bowhead whale tagged in 1992: Tag 10824. Graphs are: Maximum depth and percentage of dives to each depth bin. Bin 1 = 0-16 m. Bin 2 = 17-32 m. Bin 3 = 33-48 m. Bin 4 = 49-96 m. Bin 5 = 97-200 m. Bin 6 = 201-400 m. Black fill in lower bar indicates valid data were received for the period. Small tic marks = 1 summary period. Areas are: MB = Mackenzie Bay; HI = Herschel Island; ND = Nearshore Demarcation Pt.; OD = Offshore Demarcation Pt.; DB = Demarcation Pt. to Barter Island; CB = Camden Bay; CH = Camden Bay to Harrison Bay; HB = Harrison Bay; HP = Harrison Bay to Pt. Barrow; and Chukchi Sea.

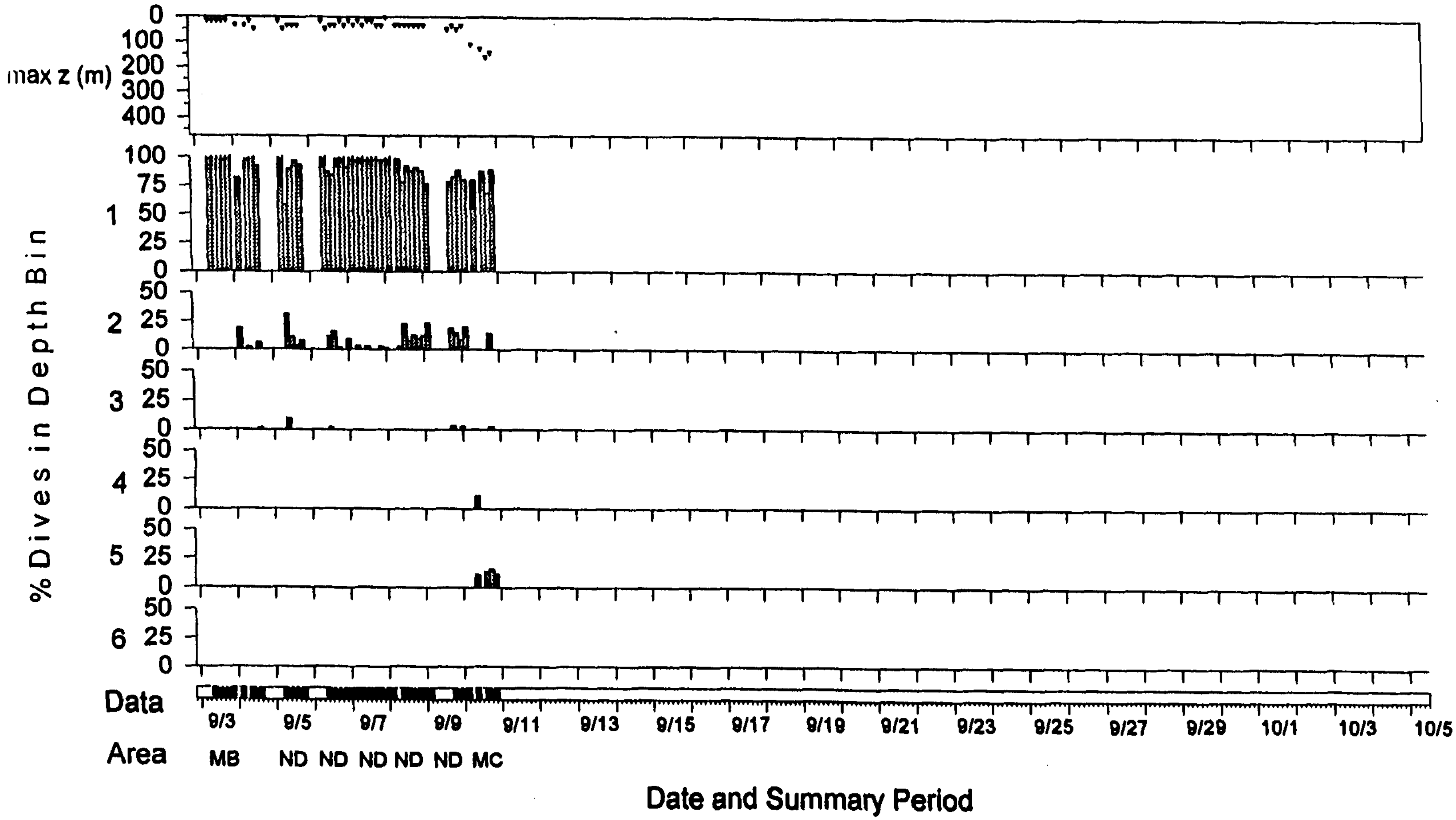

Figure 39. Time series depth information by summary period and day from a bowhead whale tagged in 1992: Tag 10825. Graphs are: Maximum depth and percentage of dives to each depth bin. Bin 1 = 0-16 m. Bin 2 = 17-32 m. Bin 3 = 33-48 m. Bin 4 = 49-96 m. Bin 5 = 97-200 m. Bin 6 = 201-400 m. Black fill in lower bar indicates valid data were received for the period. Small tic marks = 1 summary period. Areas are: MB = Mackenzie Bay; ND = Nearshore Demarcation Pt.; MB = Mackenzie Canyon.

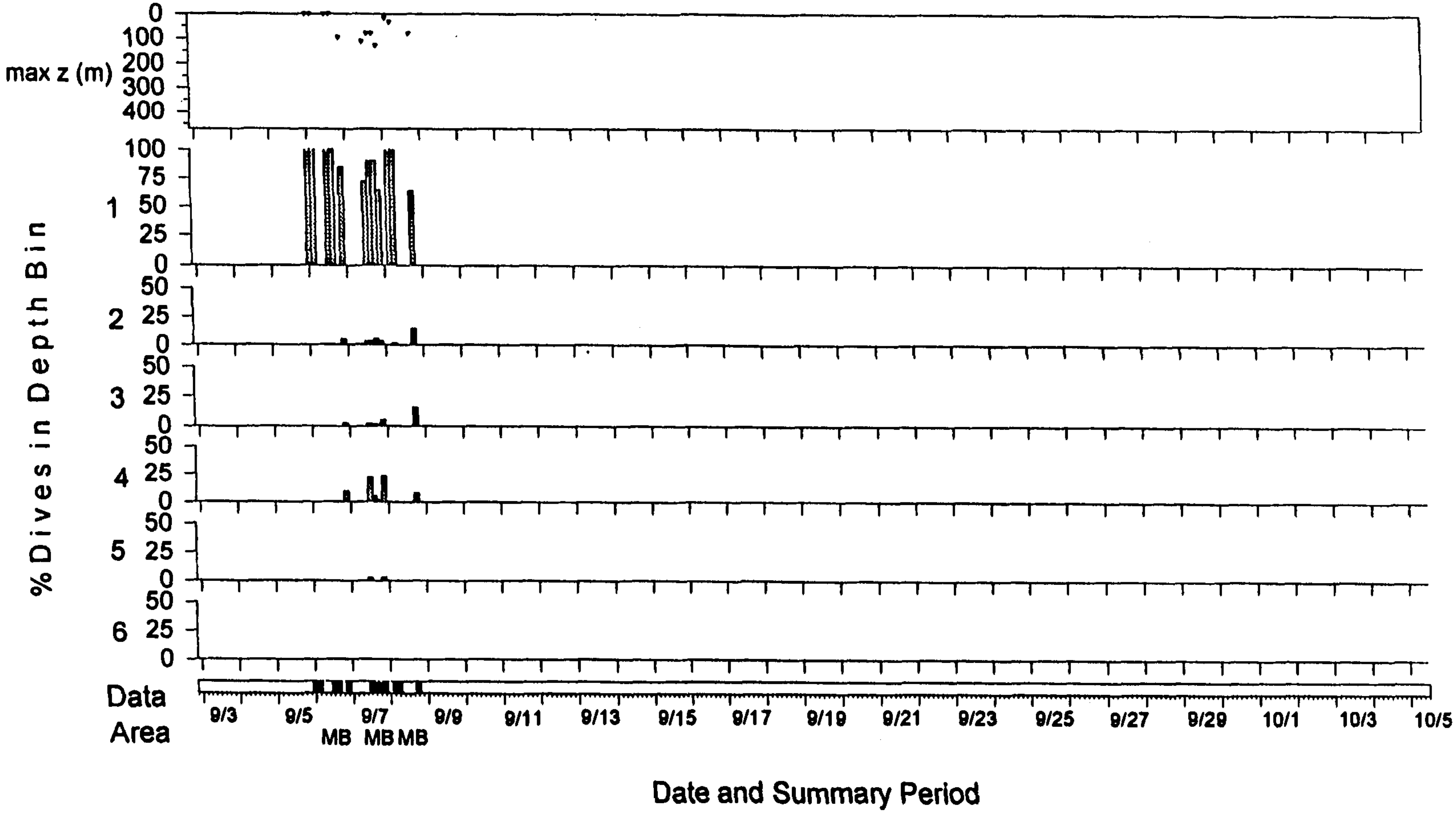

Figure 40. Time series depth information by summary period and day from a bowhead whale tagged in 1992: Tag 10826. Graphs are: Maximum depth and percentage of dives to each depth bin. Bin 1 = 0-16 m. Bin 2 = 17-32 m. Bin 3 = 33-48 m. Bin 4 = 49-96 m. Bin 5 = 97-200 m. Bin 6 = 201-400 m. Black fill in lower bar indicates valid data were received for the period. Small tic marks = 1 summary period. Area MB = Mackenzie Bay.

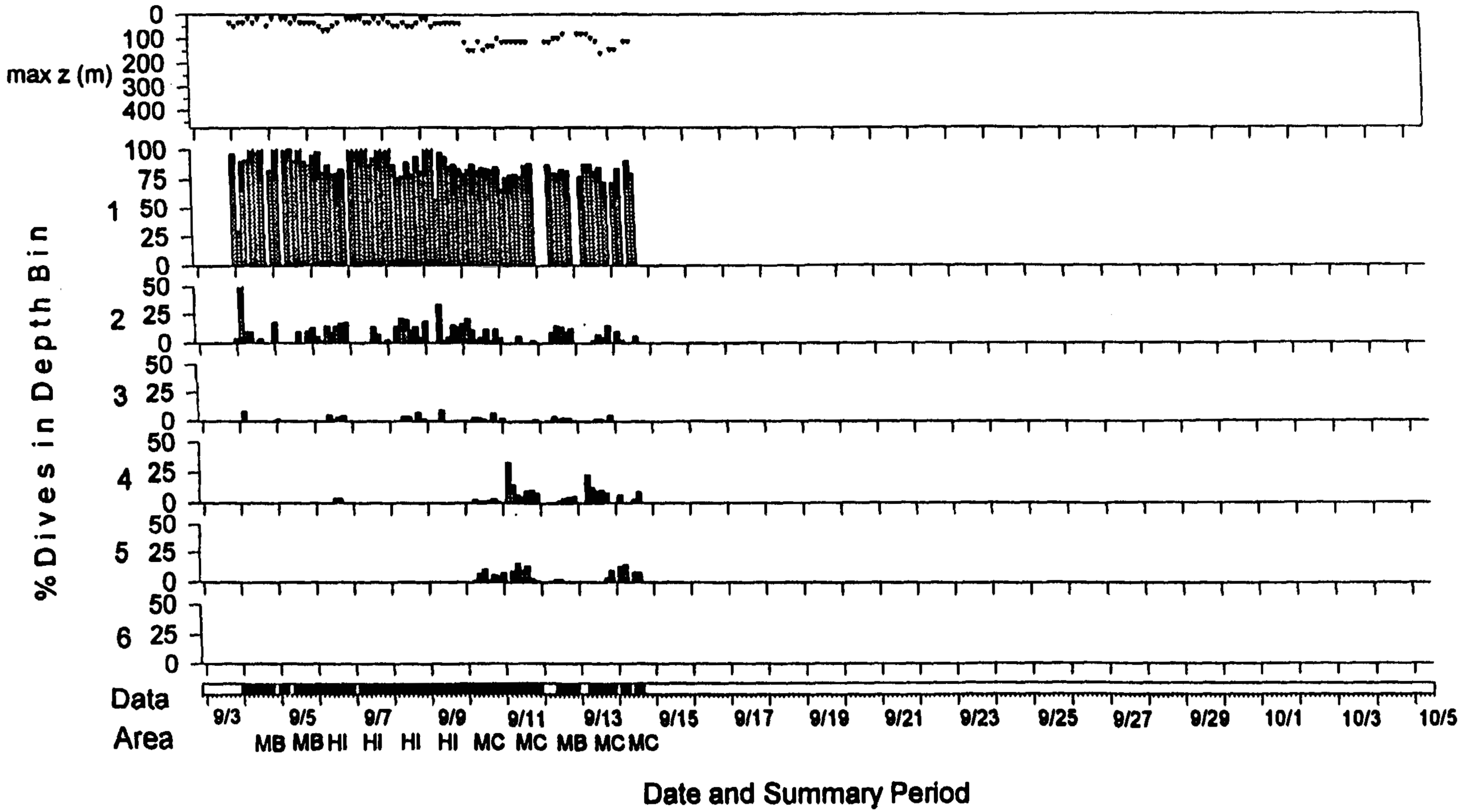

Figure 41. Time series depth information by summary period and day from a bowhead whale tagged in 1992: Tag 10827. Graphs are: Maximum depth and percentage of dives to each depth bin. Bin 1 = 0-16 m. Bin 2 = 17-32 m. Bin 3 = 33-48 m. Bin 4 = 49-96 m. Bin 5 = 97-200 m. Bin 6 = 201-400 m. Black fill in lower bar indicates valid data were received for the period. Small tic marks = 1 summary period. Areas are: MB = Mackenzie Bay; HI = Herschel Island; MC = Mackenzie Canyon.

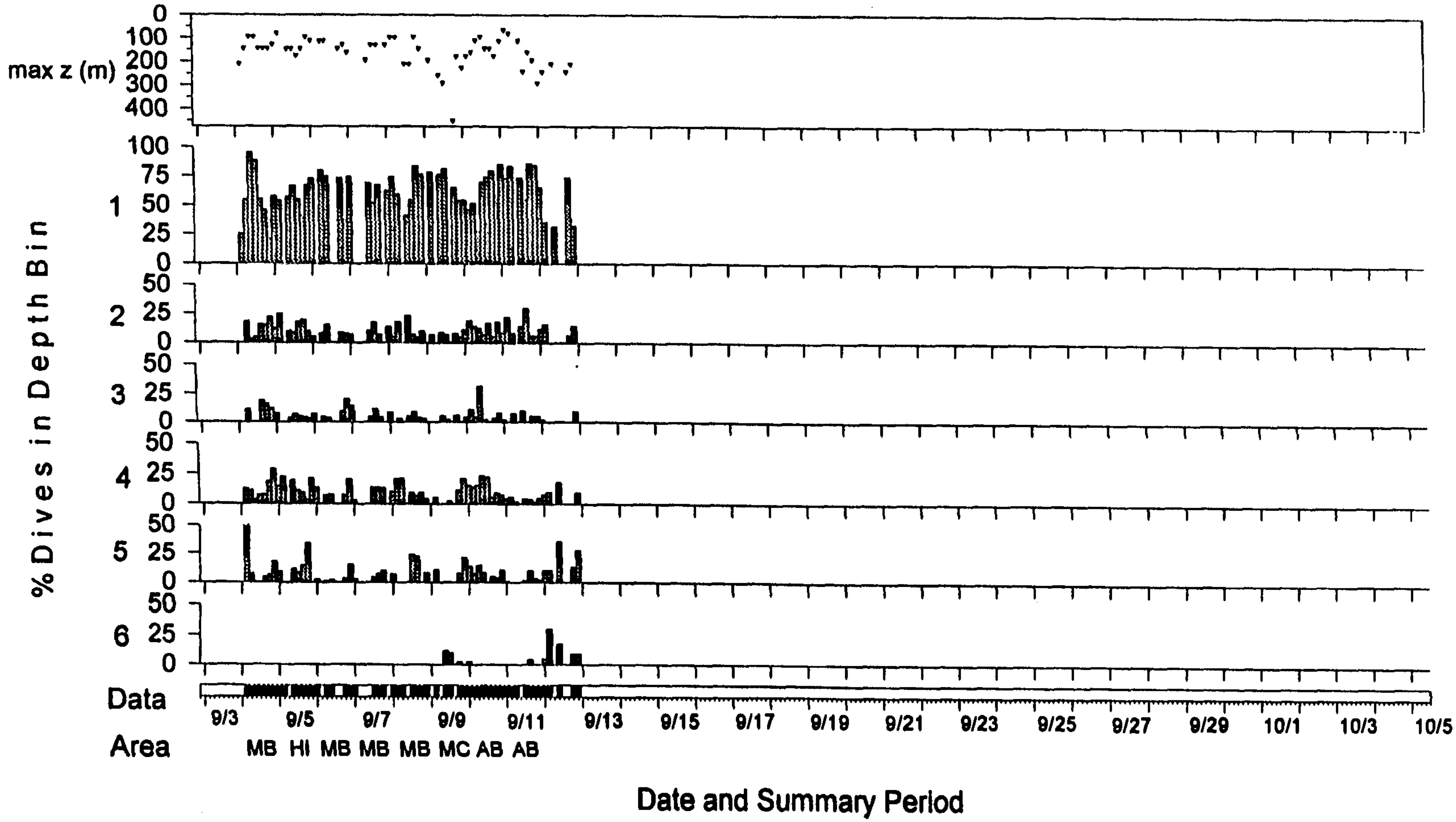

Figure 42. Time series depth information by summary period and day from a bowhead whale tagged in 1992: Tag 10828. Graphs are: Maximum depth and percentage of dives to each depth bin. Bin 1 = 0-16 m. Bin 2 = 17-32 m. Bin 3 = 33-48 m. Bin 4 = 49-96 m. Bin 5 = 97-200 m. Bin 6 = 201-400 m. Black fill in lower bar indicates valid data were received for the period. Small tic marks = 1 summary period. Areas are: MB = Mackenzie Bay; HI = Herschel Island; MC = Mackenzie Canyon; AB = Arctic Basin.

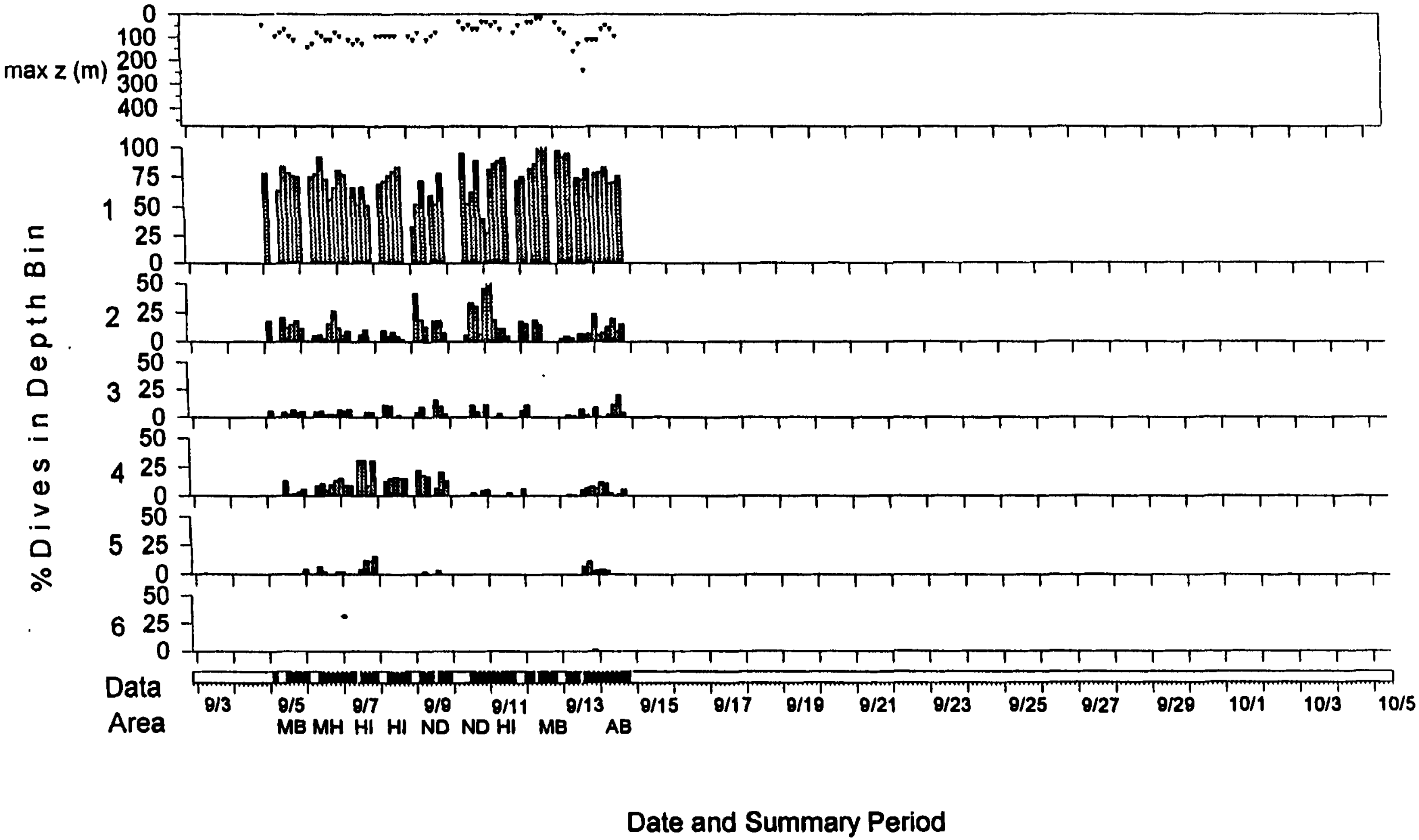

Figure 43. Time series depth information by summary period and day from a bowhead whale tagged in 1992: Tag 10830. Graphs are: Maximum depth and percentage of dives to each depth bin. Bin 1 = 0-16 m. Bin 2 = 17-32 m. Bin 3 = 33-48 m. Bin 4 = 49-96 m. Bin 5 = 97-200 m. Bin 6 = 201-400 m. Black fill in lower bar indicates valid data were received for the period. Small tic marks = 1 summary period. Areas are: MB = Mackenzie Bay; MH = Mackenzie Bay and Herschel Island; HI = Herschel Island; ND = Nearshore Demarcation Pt.; AB = Arctic Basin.

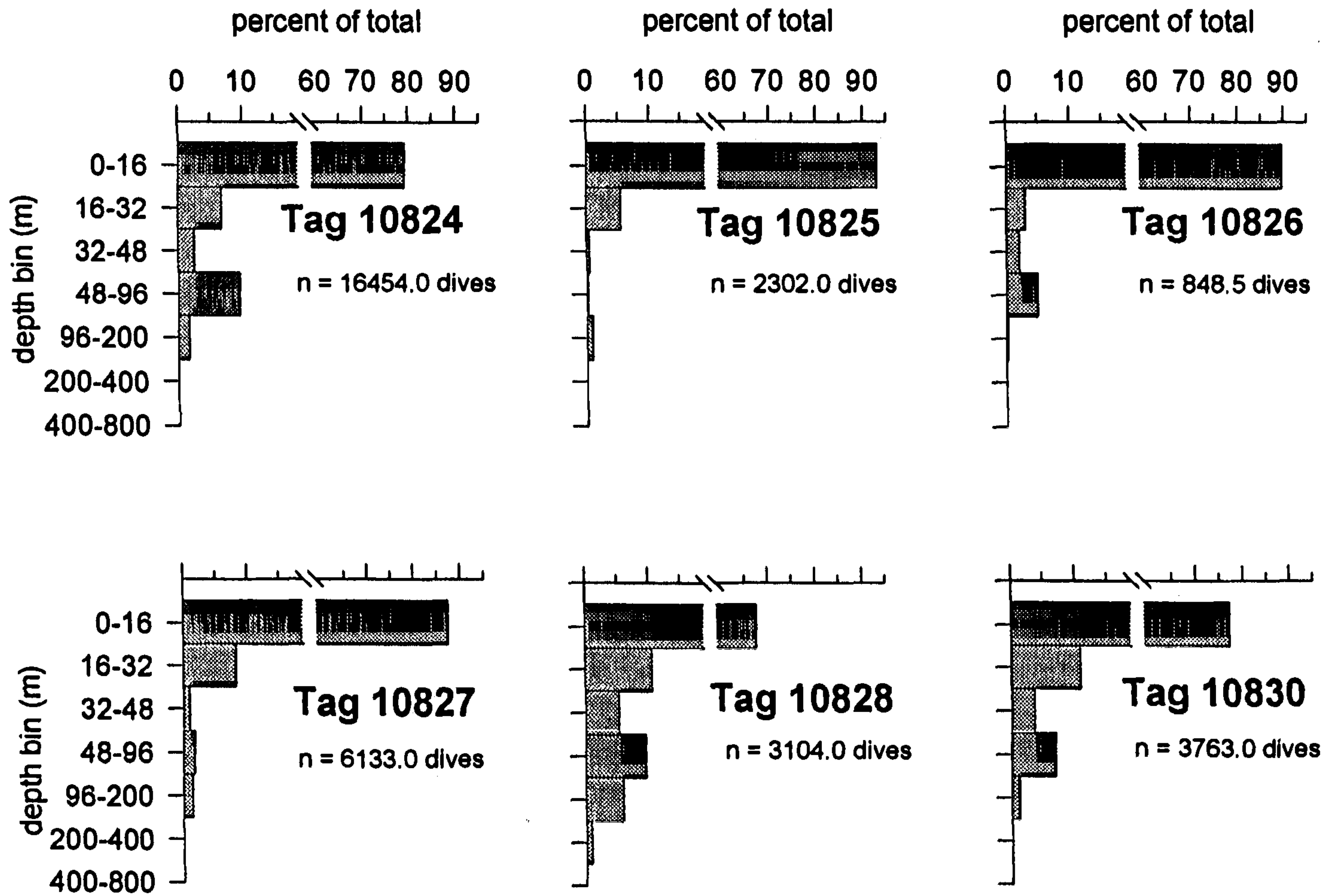

Figure 44. Percentage of dives to each depth bin for bowhead whales tagged with duration/depth tags in 1992. Only tags which reported data for more than one summary period are shown.

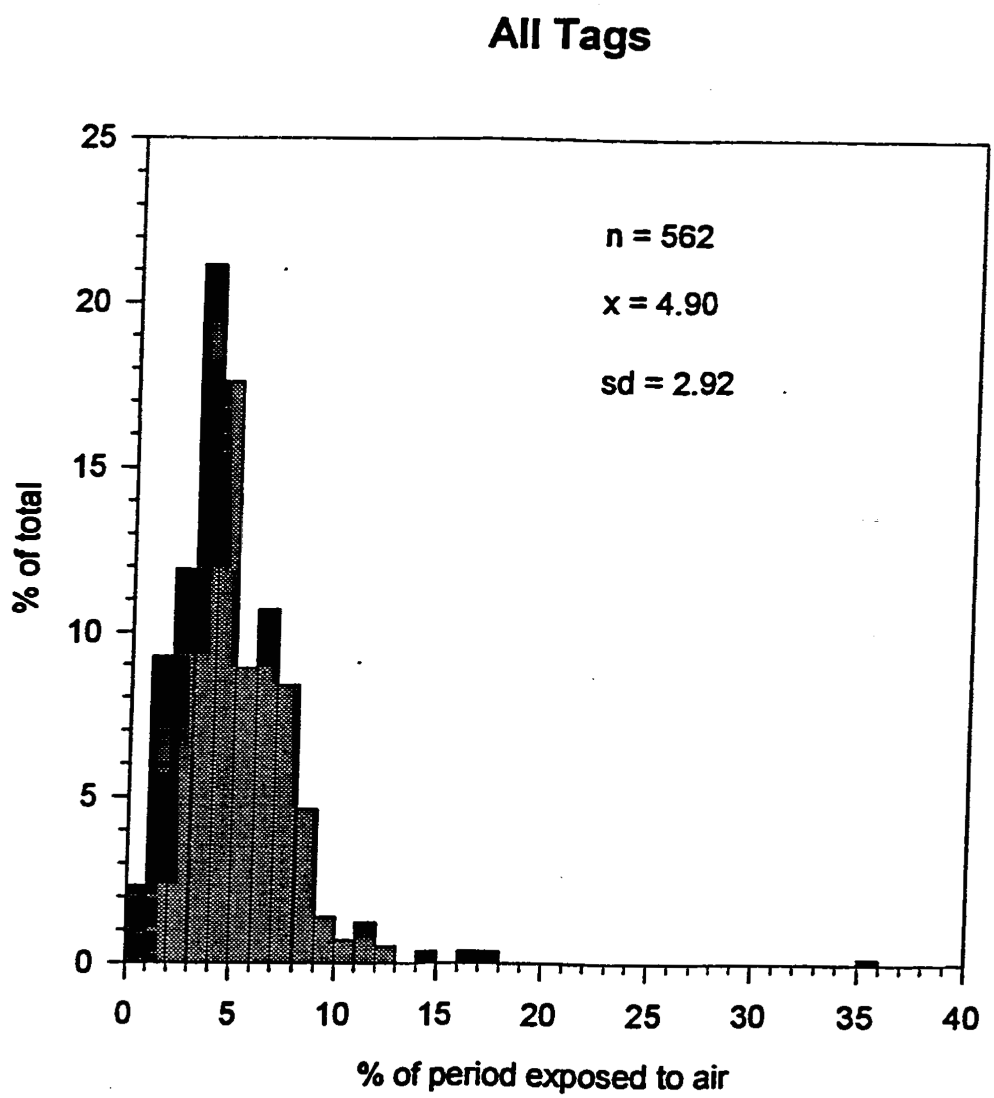

Figure 45. Percent of period tags were exposed to air. Sample size (n) is number of summary periods.

Table 13. Deepest dive during summary periods for duration/depth tags.

tag #	n	min	max	quartiles		median	mode	mean	s.d.
				lower	upper				
10820	1	160	160	-----	-----	-----	-----	-----	-----
10822	1	64	64	-----	-----	-----	-----	-----	-----
10824	220	32	352	80	112	96	96	97	41.1
10825	44	0	160	16	32	32	32	38	33.6
10826	12	0	128	0	88	56	0	52	48.8
10827	76	16	160	32	112	48	32	63	43.4
10828	55	64	448	112	192	144	144	160	66.1
10830	58	16	240	64	112	88	96	84	39.5
10831	1	32	32	-----	-----	-----	-----	-----	-----

accuracy (LC 0). Also, location fixes represent one instant in a summary period up to five hours long. Nevertheless, the discrepancy between some recorded dive depths and charted water depths are difficult to reconcile. For example, tag 10824 reported dives between 136 and 151 m in the Chukchi Sea where charted water depths do not exceed about 90 m. We cannot independently verify if there are water depths in this region which exceed the charted values. It is much more likely that the tags reported depths greater than were achieved. However, status messages received from six tags (10824, 10825, 10826, 10827, 10828, and 10830) indicated that pressure transducers were functioning properly.

There is little information in the literature on depths to which bowhead whales are capable of diving. In the western Arctic bowheads have been observed surfacing with mud streaming from their mouths in water up to 40 m deep (Richardson et al., 1995). In the eastern Arctic near Isabella Bay, Baffin Island, bowheads have been observed feeding in troughs 200 m deep where the highest concentrations of copepods were at depths > 100 m (Finley 1987; 1990). Our data indicates that bowheads are capable of diving to these depths and beyond.

Surface Time and Time Underwater

Total Surface Time During Summary Period

Two tags (10820 and 10831) reported time spent at the surface information for only one summary period each. Both tags were placed low on the animal's body and probably didn't come out of the water on most normal surfacings. Both tags recorded

< 30 s total surface time during the one 3-h period each reported. These two tags are not considered in the following analysis.

Nine tags reported total surface time in more than one period. Overall, tags were exposed to the surface between 0 and 35.6% of a summary period (n = 562 periods, Figure 45). In 96.5% of the summary periods reported, tags were exposed to the air < 10% of the period or the equivalent of 6 min/h. Tag 10824 reported < 30 s total surface time during four 1-h summary periods. No dives were recorded in these periods which confirms that the tag was not exposed to the air (did not surface) during these periods. All four of these periods were in the Chukchi Sea where heavy ice cover (> 90%) existed suggesting the whale may have been breathing in the manner described by George et al. (1989). Mean values for percent of summary period at the surface for individual whales ranged from 4.0% ± 2.04 (sd, n = 223) for tag 10824 to 8.4% ± 11.0 (sd, n = 2) for tag 10822. The unweighted mean for all nine animals was 5.8% ± 1.34 (sd, n = 9) of a summary period or 3.5 min/h exposed at the surface.

Because tag 10822 returned data for only two summary periods, it was not considered in the statistical comparison of individuals. There were significant differences in the percent of a summary period at the surface among the remaining eight individual animals (Kruskal-Wallace ANOVA by rank, p << 0.0001). Multiple comparisons between individual animals (α =0.05, Bonferroni method, Hettmansperger, 1984) revealed two groups: three animals with the lowest surface times and five animals with the highest

Table 14. Percentage of summary period tags were exposed to air. Tags with different superscript letters were significantly different from one another (α = 0.05, Bonferroni method for multiple comparisons for Kruskall-Wallace ANOVA by ranks). Tags are listed in order of their rank. Mean, median, and mode are given for convenience.

Tag #	n	mean	median	mode
10824[a]	223	4.0	3.7	3.3
10827[a]	78	4.7	3.9	3.9
10828[ab]	16	4.8	4.4	5.0
828[c]	33	5.7	5.5	5.5
831[c]	49	5.6	5.5	5.5
10830[c]	61	6.1	6.1	3.3
10825[c]	46	5.9	6.4	7.2
10826[bc]	16	7.3	6.4	5.6

surface times (Table 14). The surface times for tags 10828 and 10826 were not found to be significantly different, likely due to low power of the test with such small sample sizes for these tags.

Longest Surface Durations

Although the resolution was different, both types of tag recorded the longest duration at the surface for each summary period. Whales rarely exposed the tags to the air for very long. Neither duration tag was exposed to the surface for even 3 min (Figure 46) at one time. Four duration/depth tags (10824, 10825, 10827, and 10828) were exposed to the air 3.5 min or longer (Figure 47). This occurred in only five (0.89%) of the

562 summary periods reported by nine tags. These surfacings were approximately 14, 8, 5, 4 and 4 min long.

The distribution of longest surfacings appears quite different for the two tag types (Figures 46 and 47). The median of longest surfacings for every duration/depth tag was between 0.5 and 1.4 min and most of the longest surfacings for five of these tags fell in this range (Figure 47). The median and mode for both duration tags was < 1 min, very few periods had longer surfacings (Figure 46). The apparent difference between tag types may be due to the way they reported data. Duration/depth tags rounded up at every 0.5 min, thus only surfacings < 0.5 min were reported as 0, whereas duration tags reported 0 if surfacings were < 1 min. The longest surfacing was < 1.5 min in 75.16% of the 479 periods reported by seven duration/depth tags. However, in heavy ice conditions tag 10824 reported a higher mean percentage of surface time than for periods with less ice (see section on ice). If summary periods when 10824 was in heavy ice are excluded, the two tag types were very similar: 81.2% of the longest surfacings for duration/depth tags (n = 377 periods) were < 1.5 min and 80.7% were < 1.0 min for duration tags (n = 82 periods).

Few published reports for bowhead whale surface time are comparable to what our tags collected. As migrating bowheads passed Pt. Barrow in the spring, some exposed part of the body was visible to ice-based observers for 3.1% (Carroll and Smithhistler, 1980) and 5.2% (Zeh et al., 1993) of the time. Means for time visible above water during each roll in a surfacing sequence during spring migration were 4.7 s (Carroll and Smithhistler, 1980; Zeh et al., 1993) and 6.1 s (Rugh and Cubbage, 1980) with the greatest range (1.2 to 38.1 s) and sample size (n = 1701) given by Zeh et al. (1993). Tags would not be exposed to the air the entire time that "some body part was visible" so it might be expected that tags would record less overall time at the surface and few of the longest surfacings would be > 0.5 min. However, bowheads in the cited studies were actively migrating whereas tagged whales were monitored during late summer when they may be more prone to remain at the surface between blows if they are not actively traveling (Würsig et al., 1984). In view of this, the large proportion of periods reported by duration\depth tags with longest surfacings between 0.5 to 1.4 min (44.47%) seems reasonable, as do the overall percentages of surface time reported by all tags. On the other hand, bowheads have been reported to rest at the surface for over an hour (Carroll and Smithhistler, 1980). Either tagged whales did not rest at the surface for that long or the whale's posture did not constantly expose the tag to the air.

Abundance estimates of cetaceans from surveys depend on the probability of detecting animals (Hiby and Hammond, 1989). The proportion of time that whales are potentially visible is important in figuring the probability of sighting an animal (Leatherwood et al., 1982; Zeh et al., 1993) and has been used to calculate correction factors for bowheads missed during surveys (Davis et al., 1982; Richardson et al., 1987). Because of the advantages of aerial surveys, the motivation to develop unbiased estimators of abundance for this technique has been strong (Hiby and Hammond, 1989). Many observational studies (Carroll and Smithhistler, 1980; Dorsey et al., 1989; Richardson et al., 1987; Würsig et al., 1984; Zeh et al., 1993) report the proportion of time bowheads were potentially visible from the air. Like mean blow rates, the methods

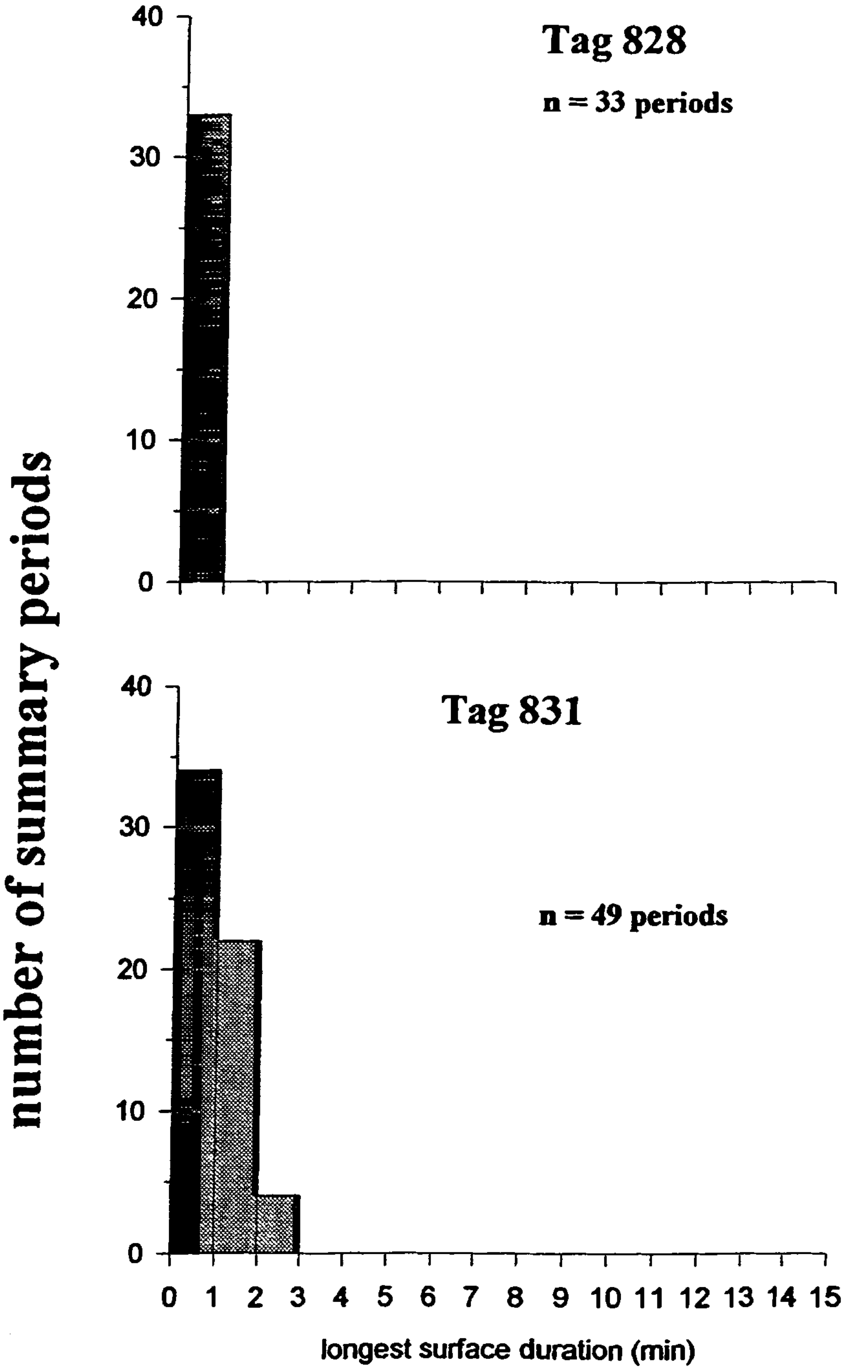

Figure 46. Longest surfacing during summary periods for duration tags.

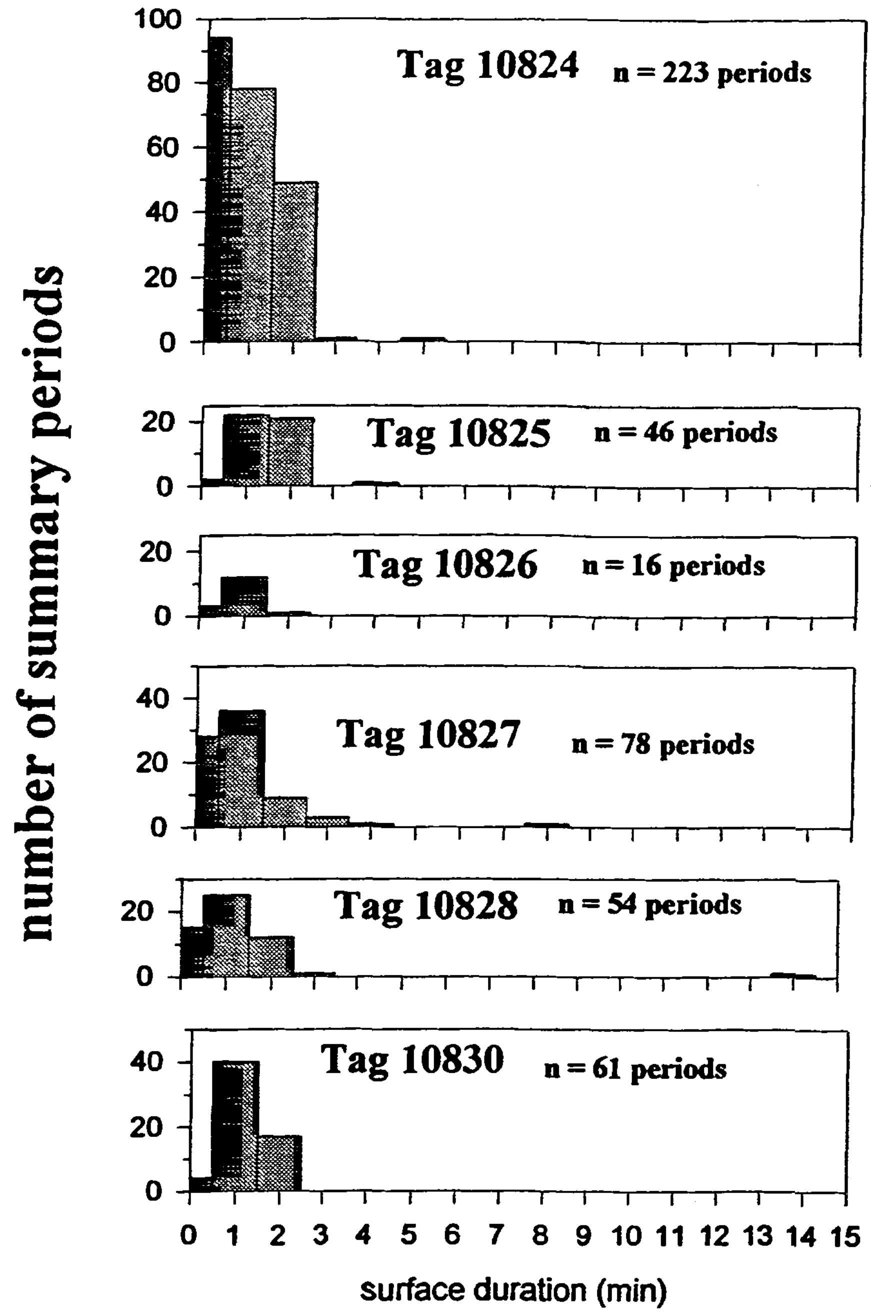

Figure 47. Longest surfacing in period for duration\depth tags. The first histogram bin is half the size of other bins and represents surfacings < 0.5 min.

of calculation have varied. We used the method recommended by Dorsey et al. (1989) to recalculate the percentage of time bowheads were potentially visible from the air for observational studies:

% time visible from the air = 100*[mean duration of surfacing/(mean duration of surfacing + mean dive time)].

Values ranged from 8.9 - 35.8% ($\bar{x}$ = 16.2 ± 8.99%, n = 16, Table 10). Although these values do not represent the proportion of time individual animals were visible from the air, they may be indicative of the visibility of bowheads at the time and place of the studies.

For comparison purposes we calculated the proportion of summary periods tagged animals were potentially visible from the air by assuming dives of one min or less to be interblow intervals during a surfacing sequence. The calculation was as follows:

% time visible from air = 100*[(total surface time + dur1 * interblow interval)/period length]

Dives one min or less, "dur1," were assigned the mean underwater interval (10.0 s) between blows in a surfacing sequence measured in three ice-based observational studies (Table 10). Although 10.0 s may be an underestimate because tags would likely be underwater while some whale body parts were still visible to ice-based observers, the difference would be small. Based on these calculations, tagged animals were potentially visible from the air between 0.9 and 42.1% of a summary period (n = 539 periods for eight animals). Mean percent of summary period visible from the air for individuals ranged from 8.5 - 16.4% ($\bar{x}$ = 11.1 ± 2.4%, n = 8, Table 15).

All the calculations above assume whales to be visible from the air between serial dives during a surfacing sequence, but not before or after a sounding dive. In the field, the depth to which whales dive and environmental conditions such as water turbidity, sea state, ice cover, and light are likely to affect the percentage of time that animals are actually visible from the air.

Time at Depth Information

Nine duration/depth tags reported time at depth (TAD) data for a total of 482 summary periods (Table 6). Depth information for nine summary periods (1 for 10826, 1 for 10828, and 9 for 10830) were eliminated in screening. Neither of the tags positioned low on the whale's body (10820 and 10831) registered any time exposed to air (Figure 48), but if allowances are made for surfacings, the time spent at depths should be valid. Animals spent most of their time between the surface and 16 m (Figures 48). Overall, 61% of the time accounted for by all animals was spent between the surface and 16 m, 32% of the time was spent between 17 and 96 m, while less than 2% was spent at depths > 96 m.

But the overall picture doesn't tell the whole story. Time series plots of time at depth profiles for tags with n > 2 periods (Figures 49 to 54) reveal that several animals frequently spent substantial portions of summary periods in one of the deeper depth bins. Four animals (10824, 10825, 10827, and 10828) spent more than half of some periods at depths > 48 meters.

During periods 4 through 8 (17 h) on 10 September, tag 10825 spent an average of 70.6% (sd = 5.6, n = 5, range 61 - 78%) of each period between 96 and 200 m (Figure 50). Dive depth information was reported only for the middle three of these five periods where the maximum depths reached were: 128, 160, and 144 meters. This animal was

Table 15. Percentage of time tagged bowheads were potentially visible from the air during summary periods.

tag	n	min	max	quartiles		median	mode	mean	s.d.
				lower	upper				
828	33	6.0	34.3	12.4	19.1	16.1	11.2	16.4	5.9
831	49	7.3	17.6	9.0	12.4	11.2	11.2	11.3	2.4
10824	214	0.9	15.5	8.0	11.4	9.7	9.0	9.5	3.0
10825	40	1.2	14.6	9.1	11.4	10.4	11.2	10.0	2.3
10826	15	4.1	28.1	8.5	14.6	13.2	11.7	12.5	5.8
10827	78	4.7	41.4	8.2	11.1	9.6	10.9	10.2	4.4
10828	51	1.3	18.5	6.9	9.9	8.8	8.5	8.5	3.6
10830	59	5.7	42.1	8.7	10.8	10.0	9.1	10.7	5.2

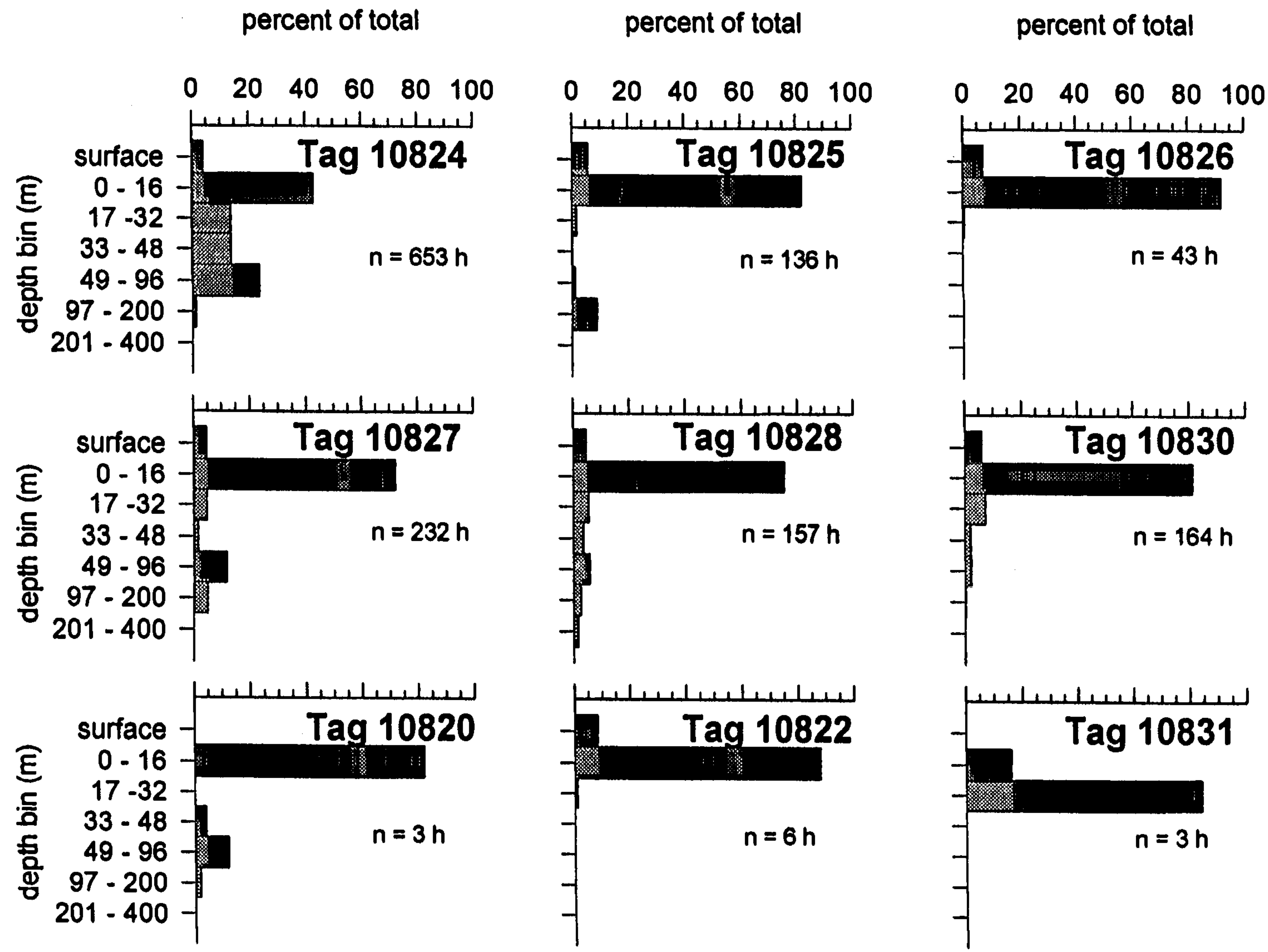

Figure 48. Percentage of time in each depth bin for bowhead whales tagged with duration/depth tags in 1992.

Figures 49 to 54. Time series plots of percent time spent in each depth bin. Bins are: 0 = tag exposed to air; 1 = 0-16 m; 2 = 17-32 m; 3 = 33-48 m; 4 = 49-96 m; 5 = 97-200 m; 6 = 200-400 m. Solid bar in bottom graph indicates valid data were received for the summary period. Small tic marks = 1 summary period. Area abbreviations show where most locations for that day were. Areas are: MB = Mackenzie Bay; MC = Mackenzie Canyon; AB = Arctic Basin; HI = Herschel Island; MH = Mackenzie Bay and Herschel Island, ND = Nearshore Demarcation Point; OD = Offshore Demarcation Point; DB = Demarcation Point to Barter Island; CB = Camden Bay; CH = Camden Bay to Harrison Bay; HB = Harrison Bay; HP = Harrison Bay to Point Barrow; and Chukchi Sea.

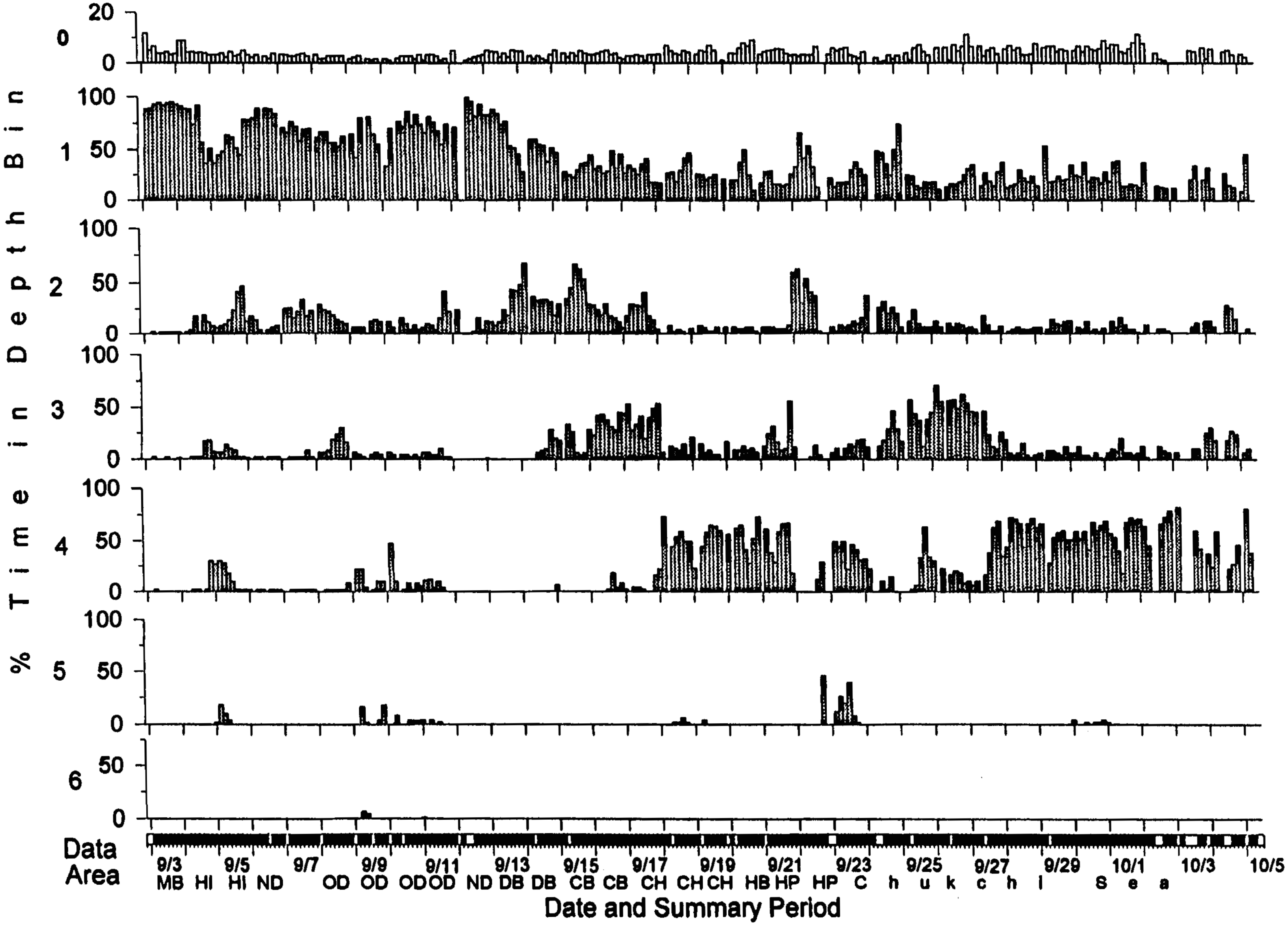

Figure 49. Percent time in depth bins by summary period and day from a bowhead whale tagged in 1992: Tag 10824.

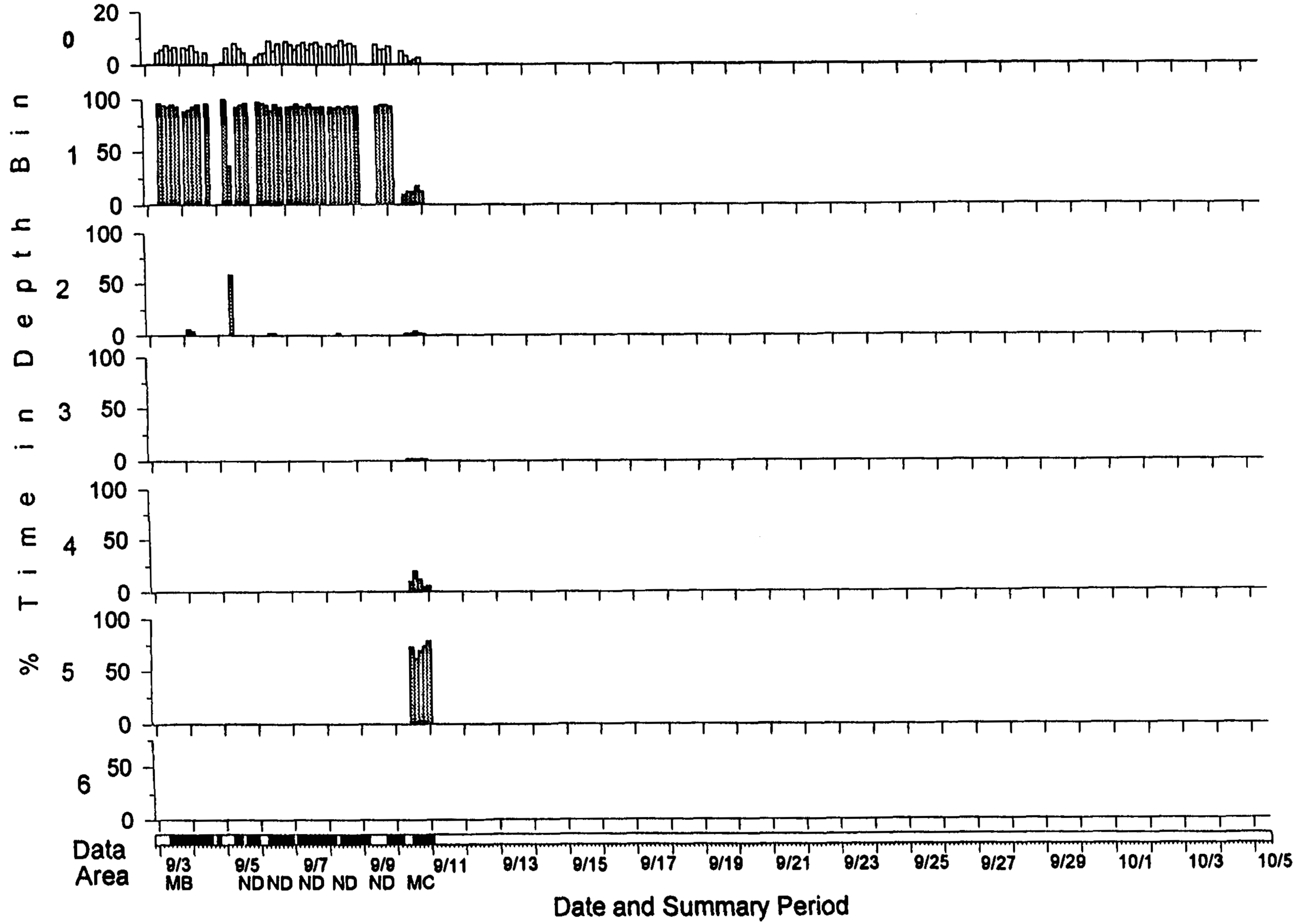

Figure 50. Percent time in depth bins by summary period and day from a bowhead whale tagged in 1992: Tag 10825.

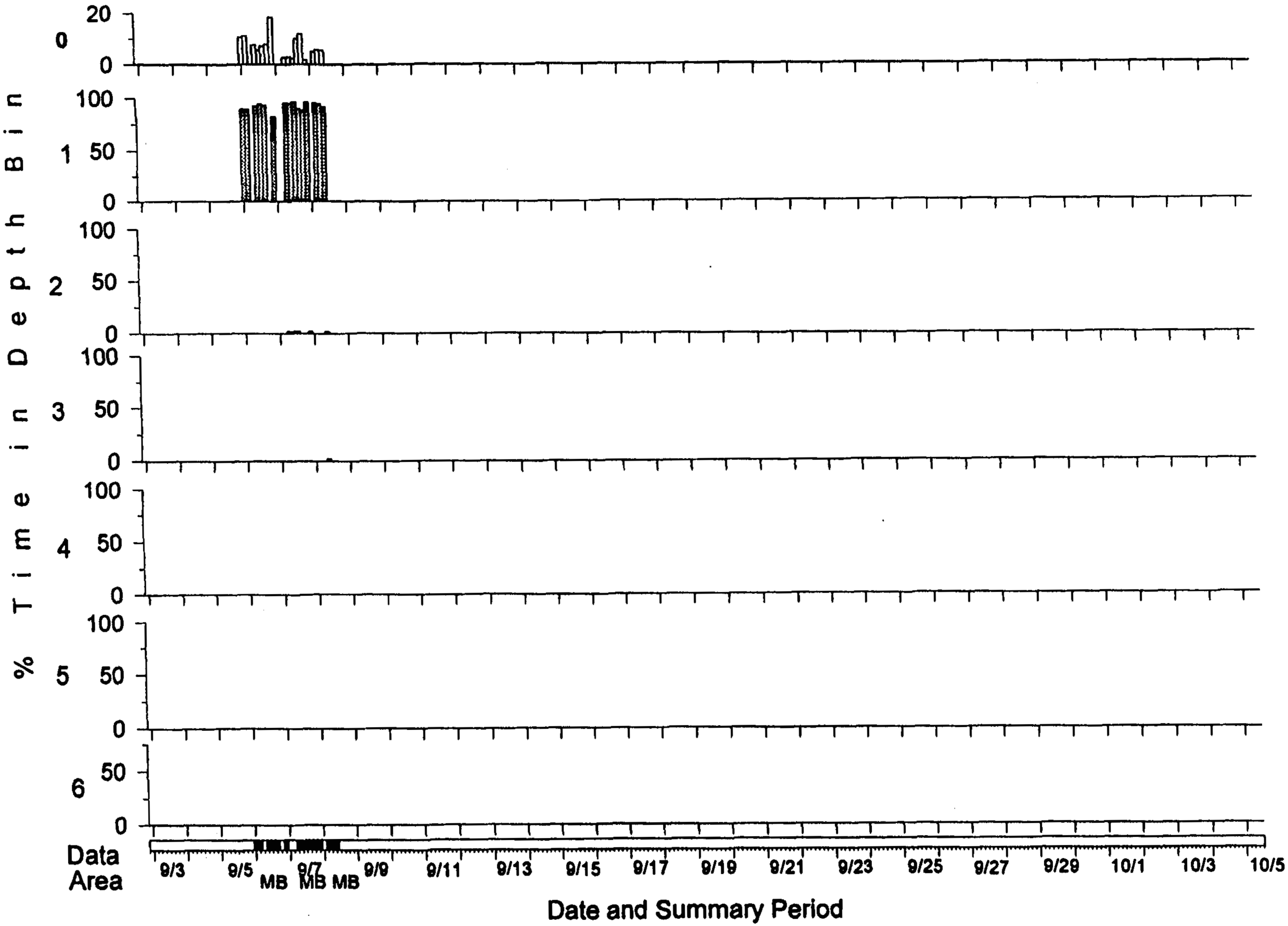

Figure 51. Percent time in depth bins by summary period and day from a bowhead whale tagged in 1992: Tag 10826.

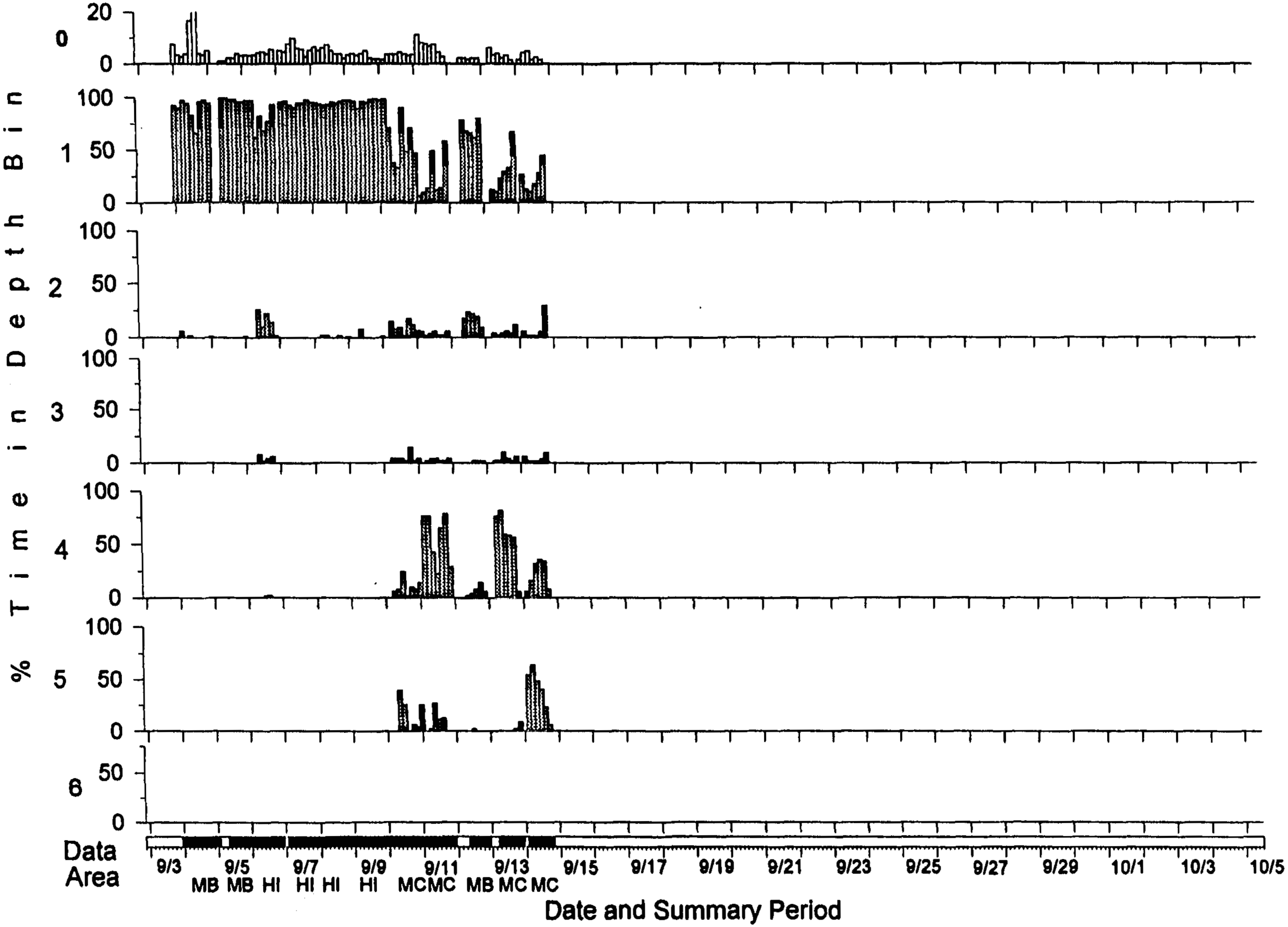

Figure 52. Percent time in depth bins by summary period and day from a bowhead whale tagged in 1992: Tag 10827.

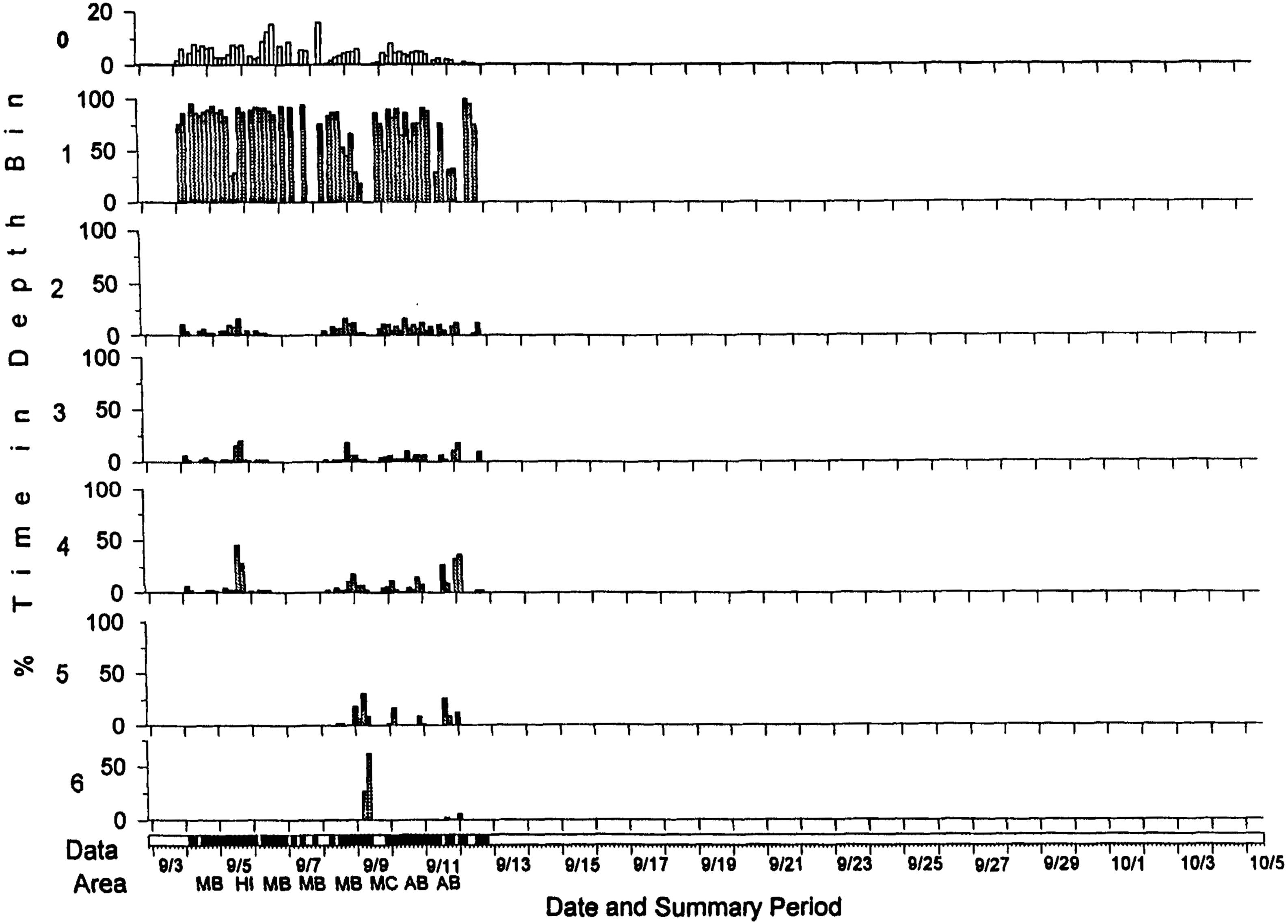

Figure 53. Percent time in depth bins by summary period and day from a bowhead whale tagged in 1992: Tag 10828.

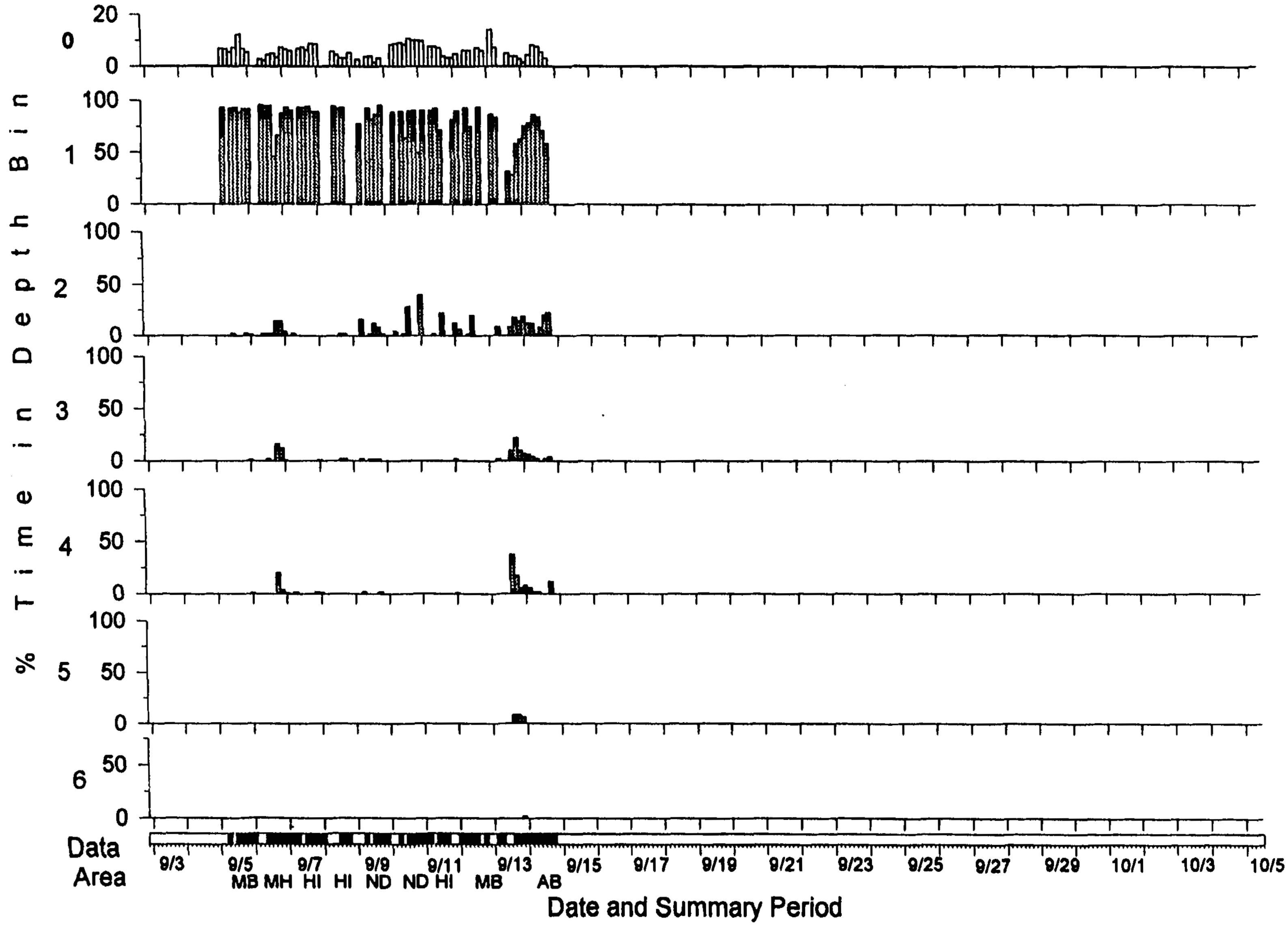

Figure 54. Percent time in depth bins by summary period and day from a bowhead whale tagged in 1992: Tag 10830.

likely in the region of Mackenzie Canyon during these five periods which were the last received from this tag.

Whale 10827 also entered Mackenzie Canyon area on 10 September and subsequently spent a great proportion of its time between 48 and 200 meters during three extended bouts (Figure 52). For 16 h from period 1 through period 6 on 11 September, a mean of 69% (sd = 15.8, n = 6, range 34 to 78%), of each period was spent deeper than 48 m. For 15 h, periods 2 through 6 on 13 September, a mean of 66% (sd = 10.0, n = 5, range 58 to 81%) of each period was spent deeper than 48 m. Again for 13 h on14 September, during periods 1 through 5, a mean of 70.6% (sd = 9.6, n = 6, range 58 to 80%) of each period was spent deeper than 48 m. Maximum depths recorded during these periods ranged from 80 to 160 m.

Although tag 10828 recorded the deepest dives, it only spent substantial time at depths > 48 m on a few occasions (Figure 53). The first occurred on 5 September. This tag recorded 46% and 28% of periods 5 and 6, respectively, between 49 and 96 m. During these periods the animal probably traversed the southern end of Mackenzie Canyon. For 6 h on 9 September, whale 10828 spent most of periods 2 and 3 deeper than 96 meters. During period 2 its time was split nearly equally between the 97-200 m bin (30%) and the 201-400 m bin (26%). During period 3, however, 62% of its time was spent in the 201-400 m bin and only 8% in the 97-200 m bin. The deepest dive in this period was between 248 m and 263 m. This animal may have continued to spend substantial time at these depths, but no time-at-depth data were received for the next three periods (4 - 6). This was especially unfortunate because the deepest dive (440 -

455 m) was recorded by this tag in period 6 of this day. No locations for this animal were received on 9 September. The last location on 8 September, obtained at 2330, put the animal near the 200 m contour on the eastern side of Mackenzie Canyon and the next location, obtained at 1230 on 10 September, put the animal about 67 km NNW near the 1000 m contour in the Canadian basin. On 11 September this tag recorded 52% and 49% of periods 5 and 8, respectively, deeper than 48 m. The last locations for this animal, received earlier that day, put it in deep water (> 1000 m) in the Canadian basin.

Like other animals, periods where certain depth regimes were favored by animal 10824 occurred in bouts (Figure 49). Beginning 18 September, as this animal moved westward from Prudhoe Bay, a major shift in behavior seems to have occurred: the animal spent less time near the surface and more time deeper than 48 m. Before 18 September, 83.7% of the time accounted for in 108 periods was spent in the upper 48 m whereas from 18 September on, only 39.6% of its time in 115 periods was spent in the upper 48 m. More than half of its time was spent at depths > 48 m in 59 (26.5%) of the 223 summary periods reporting time at depth information. Of these 59 periods, 50 (84.7%) occurred after 20 September when whale 10824 encountered heavy ice conditions.

This is the first detailed information about where bowhead whales spend their time in the water column. Animals favored certain depth regimes for extended periods. Feeding is believed to be the predominant activity for bowhead whales summering in the Beaufort Sea (Würsig et al., 1985). Bowheads feed primarily on zooplankton, especially copepods, euphausiids, and mysids (reviewed by Lowry, 1993). Bowheads likely spend time in the water column where their prey is often found or abundant. Griffiths et al. (1987) found zooplankton distributions in the Beaufort Sea to be patchy, both vertically and horizontally, with patches usually only 5 - 10 m thick and often extending several kilometers in the horizontal plane. Typically they found the thickest layer of zooplankton was either mid-water or near the bottom. Zooplankton samples collected near feeding bowhead whales have yielded higher prey biomass than samples taken elsewhere (Griffiths and Buchanan, 1982; Bradstreet and Fissel, 1986; Bradstreet et al., 1987; Griffiths et al., 1987; Wartzok et al., 1990).

Unfortunately, these studies provide very little information on zooplankton distribution deeper than 50 m in this region. In late summer, Calanus hyperboreous and C. glacialis, two species of copepod which are important prey for bowheads in the Beaufort Sea (Lowry and Burns, 1980; Lowry and Frost, 1984; Lowry 1993) make seasonal ontogenetic vertical migrations to deeper water (> 50 m) to overwinter, although when and to what depths they descend may vary with geographic location (Conover 1988; Dawson 1978; Geinrikh et al., 1980; Hirche 1991; Kosobokova 1982; Longhurst et al., 1984; Maclellan 1967; Prygunkova 1968; Pertsova 1971 cited in Arashkevich and Kosobokova, 1988). C. hyperboreous and C. glacialis that have descended to deeper water in summer have substantially greater lipid content than those near the surface (Head and Harris, 1985; Kosobokova 1990) and would be a high caloric food source for bowheads. Although we can offer no direct proof, we suspect that animals 10825, 10827, and 10828 were feeding in the water column or near the bottom on dense zooplankton patches, probably calanoid copepods, during the periods where most of their time was spent below 48 m.

Animal 10824 spent most of its time deeper than 48 m while moving through areas with heavy ice conditions near Pt. Barrow and in the Chukchi Sea. It has been suggested that the Chukchi Sea may be an important feeding area for bowheads in fall (Schell and Saupe, 1993). The Anadyr Current brings nutrient-rich water and a biological assemblage of bowhead prey species through the Bering Straight into the southern part of the Chukchi Sea along the Alaskan and Siberian coasts (Springer et al., 1989). It is unknown if areas of concentrated productivity extend north to this whale's track line. The time spent at depth could represent feeding on zooplankton at or near the bottom. From the time of tagging on 2 September until the last location on 18 September (384.8 h) this animal moved 12° west (from 135°38'W to 147°36'W) sometimes backtracking and moving east (Figure 14). However, examination of location data suggests that migration rather than feeding was the dominant activity after 18 September. From 19 September to 5 October, this whale moved 29°48' consistently westward from 147°22'W to 177°10'W in 392.3 h. The whale first encountered ice covering more than half the water's surface on 15 September. Location fixes for the next four days put this animal in water with 30 - 80% ice cover. From 20 September to 5 October, the whale was probably in $\geq$ 90% ice cover. Implications of time at depth data for this animal are discussed in the section on ice below.

Environmental Variables

Light

Sunrise and sunset time varied with animal location and date. To examine whether light significantly affected any of the variables we classified summary periods into three groups: day, night, and twilight which included both dawn and dusk periods. During most of the time bowheads were monitored, two summary periods per day were dark (periods 3 and 4), two were twilight (periods 2 and 5), and four were light (periods 6, 7, 8, and 1). Only the three animals (828, 831, and 10824) monitored after mid-September varied from this pattern. Fewer periods per day were clarified as light as the days got progressively shorter.

No significant differences in mean blow rates, percent time at the surface or underwater, log transformed duration of the longest dive, log transformed duration of the first dive to the maximum depth, or the maximum depth reached during the period were found between day, night or twilight periods for any of the animals (ANOVA p-values > 0.05).

For most animals, we found no significant differences in the log transformed average duration of sounding dives between day, night, or twilight periods (ANOVA p-values > 0.05). However, average sounding dive duration did differ significantly with light level for two tags: 828 (ANOVA $F_{2,30} = 7.14$, p-value = 0.003) and 10830 (ANOVA $F_{2,60} = 4.30$, p-value = 0.018).

Although day and night periods did not differ significantly for tag 828, the geometric mean of the average duration of sounding dives during twilight periods (12.3 min, 95%

CI 9.1 to 16.8 min, n = 7) was about twice as long as day (5.6 min, 95% CI 4.6 to 6.9 min, n = 16) or night periods (6.4 min, 95% CI 4.9 to 8.3 min, n = 10). This difference was likely influenced by heavy ice cover ($\geq$ 90%) during two twilight periods. These two periods contained 8 (53.3%) of the 15 sounding dives > 19 min recorded by this tag, with the longest dives being 56 - 58 min and 62 - 64 min. These long dives may be artifacts of surfacing behavior without exposing the tag in heavy ice conditions (see section on longest dives). The average duration of sounding dives calculated for these periods (30.4 min) were extreme outliers in the distribution. If these two summary periods were excluded from the analysis, twilight periods still recorded longer average duration of sounding dives (geometric mean = 8.6 min, 95% CI 6.3 to 8.0 min, n = 5) than day or night periods, but the differences were not significant (ANOVA $F_{2, 28}$ = 2.33, p-value = 0.12).

For tag 10830 the significant difference was between night and twilight summary periods. Average sounding dive duration was 1.5 times longer (95% CI 1.1 - 2.0 times longer) for night periods (geometric mean = 11.7 min, 95% CI = 10.1 - 13.7 min, n = 16) than for twilight periods (geometric mean = 8.0 min, 95% CI = 6.8 - 9.4, n = 14). Daylight summary periods had intermediate average sounding dive durations (geometric mean = 10.0 min, 95% CI 9.0 - 11.1, n = 33) and did not differ significantly from either night or twilight periods.

For many air breathing nekton species, diel changes in dive behavior have been linked to diel vertical migration of their prey. Examples include leatherback sea turtles, Dermochelys coriacea (Eckert et al., 1989), king and gentoo penguins, Aptenodytes patagonicus and Pygoselis papua (Kooyman et al., 1992; Williams et al., 1992), Antarctic fur seals, Arctocephalus gazella (Croxall et al., 1985), and California sealions, Zalophus californianus (Feldkamp et al., 1989). In the Great South Channel between Cape Cod and Georges Bank in 1988, right whales (Eubalaena glacialis), which are closely related to bowheads, made longer dives during the day when copepods migrated near the bottom and shorter dives at night when copepods were near the surface; but in 1989, when copepods did not vertically migrate, no such difference in dive duration was found (Winn et al., 1995). Vertical distribution of the bowhead's zooplankton prey in Arctic waters is tied more to season than time of day with diel vertical migration absent or weak for most species (Bogorov 1946; Kosobokova 1978; Longhurst et al., 1984; Sameoto 1984). Thus, the general lack of diel differences in behavior recorded by tagged bowheads is not surprising. The longer sounding dives at night for tag 10830 are somewhat of an enigma.

Heavy Ice Conditions

Only whale 10824 provided a large enough sample size to make statistical comparisons of variables in different ice conditions. Unfortunately, the effect of ice cannot readily be separated from changes in behavior that may be related to migration. From 20 September until the last transmissions received on 5 October, Argos locations indicate animal 10824 was in waters where ice covered 90% or more of the surface. We compared data for periods when ice cover was 90% or more (heavy ice) with data for periods when ice cover was < 90%. Sensor data recorded dramatic and significant differences in the behavior of this animal in heavy ice conditions.

The median percentage of time spent at the surface was significantly greater for periods with heavy ice than for periods with less ice (Mann-Whitney U test, $Z = 5.34$, two tailed p-value << 0.0001, df = 221). Also, the median of longest surfacings during heavy ice periods was significantly longer than for lighter ice periods (Mann-Whitney U test, $Z = 10.27$, two-tailed p-value << 0.0001, df = 221). Although this tag recorded longer surfacings and more time at the surface in heavy ice conditions, the mean percentage of time visible from the air in periods with heavy ice (10.9%) was significantly less (Student's t-test, $t = 5.0$, two-tailed p-value << 0.0001, df = 189) than periods with light ice conditions (13.1%).

There was a significant difference between the mean surfacing rate (mean blow rate) recorded by tag 10824 between heavy ice cover ($\geq$ 90%) versus light ice cover (< 90%) (Students t-test, $t= 16.2$ on 227 df, two-tailed p-value <<0.0001). On average, 15.8 fewer surfacings/h (95% CI 13.8 to 17.8) were recorded when ice cover was heavy than the mean of 32.1 surfacings/h when ice cover was light. Most of the difference was in the number of very short dives ($\leq$ 1 min) recorded. After 20 September when ice cover was heavy, on average, tag 10824 recorded half the number of short dives per hour ($\bar{x} = 12.7 \pm 6.9$/h, n = 122 summary periods) that were recorded for periods before 20 September when ice cover was light ($\bar{x} = 25.4 \pm 6.9$/h, n = 100 summary periods). This difference was significant (Students t-test, $t = 13.7$ on 220 df, two-tailed p-value << 0.0001). Although the mean rate (#/hr) of short dives was significantly less for periods with heavy ice conditions, the overall proportion of short dives declined only slightly: 79.5% of 11,621.5 dives recorded in duration bins (n = 122 summary periods) were $\leq$ min when ice cover was < 90% versus 77.6% of 4872.5 dives (n=100 summary periods) when ice cover was ≥ 90%. This suggests that the animal was making longer dives with fewer surfacing sequences and the average number of "series dives" per surfacing sequence declined slightly.

Every measure of dive duration recorded by this tag showed substantial differences suggesting that this animal made longer sounding dives when ice cover was ≥ 90%. There were significant differences in the median dive rate (#/hr) for every duration bin (Mann- Whitney U test, Z = -7.8, -6.6, -8.7, -4.3, 5.2, 6.5, 6.9, 7.3 on 220 df for the number of dives/h 1 - 4 min, 4 - 7 min, 7 - 10 min, 10 - 13 min, 13 - 16 min, 16 - 19 min, 19-25 min, and > 25 min respectively, two-tailed p-values << 0.0001 in all cases). Dives over 13 min were more frequent in heavy ice conditions; dives up to 13 min were more frequent in lighter ice conditions. The difference in the overall distribution of dive durations before 20 September when ice cover was < 90% and in ice cover ≥ 90% from 20 September until 5 October can be clearly seen (Figure 55). The geometric mean for average duration of sounding dives in summary periods from 20 September - 5 October (13.2 min) was 1.7 times longer (95% C.I. 1.6 - 1.9 times) than for periods before 20 September (7.7 min). The difference was significant (Student's t-test, t = 13.1, df = 195, two-tailed p-value << 0.0001). Twenty-three (92%) of 25 periods where the duration of the longest dive was ≥ 61 min (overflow value) occurred when ice covered at least 90% of the surface. The median duration of the longest dives was significantly longer in heavy ice conditions than in lighter ice for all period lengths (Mann-Whitney U test, Z = 3.71, 8.53, and 2.95, df 24, 168 and, 24 for 1, 3, and 5-h periods respectively, two-tailed p-values <0.0005). Even if summary periods with overflow values are excluded, the means of log transformed data on the duration of the longest dives were significantly longer in periods with heavy ice than in periods with lighter ice (Students-t tests, $t = 4.60$, 8.95, and 1.75 on 22, 150, and 19 df, one-tailed p-values < 0.0001, 0.0001, and 0.05, respectively). For 3-h periods (the largest sample size) the geometric mean of these dives when ice cover was ≥ 90% (24.7 min) was 1.7 times longer (95% CI 1.5 to 1.9 times) than in lighter ice (14.7 min).

There were also differences in where this animal spent its time in the water column in heavy ice conditions. Because of the skewed distributions and unequal variances for data in the other bins, only the difference in percent time in the first bin (the upper 16 m) could be quantified with parametric comparison. The geometric mean percentage of time spent in the upper 16 m (53%) was 2.4 times greater (95% CI 2.1 to 2.7 times) for periods before 20 September when ice cover was < 90% than for periods when ice cover was ≥ 90% (geometric mean = 22%). This difference was significant (Student's t-test, $t = 13.97$, df = 221, two-tailed p-value << 0.0001). The differences in percent time spent in the other three depth bins to 96 m were also significant (Mann-Whitney U test, $Z = -3.63$, 4.7, and 8.9 on 221 df for % time 17 - 32 m, 33 - 48 m, and 49 - 96 m respectively, p-values << 0.0001). This animal spent less time in the two shallow bins (the upper 32 m) and more time in the next two deeper bins (from 33 to 96 m) in heavy ice conditions (Figure 56).

Statistics cannot establish cause and effect in this study, but data returned from this animal in heavy ice cover (≥ 90%) were significantly different than when less ice was present. The tag recorded fewer and longer dives, more time exposed to the air in fewer surfacings, increased duration of longest surfacings, less time in the upper part of the water column, and calculations suggest the animal would have been visible from the air for less time when it was in heavy ice from 20 September on. These data suggest the animal's strategy for moving through areas of heavy ice: long dives to the deeper portion of the water column (possibly near the bottom) and longer surface times when open water was found. The four 1-h periods where the tag did not break the surface coupled with the 23 very long "dives" ($\geq$ 61 min) recorded in heavy ice conditions suggest this animal may have regularly broken ice to breathe. Time at depth information for periods with no surfacings hint that diving behavior still occurred. Although this whale spent most of its time at greater depths (probably near the bottom) in these periods ($\overline{x}$ = 71.8 ± 9.8% > 32 m, n=4) it still spent some time in the upper 16 m ($\overline{x}$ = 25.8 ± 11.0%, n = 4), but spent very little time in between ($\overline{x}$ = 3.0 ± 5.2% 16-32 m, n = 4).

Most of these findings are consistent with observed behavior of bowheads in ice. The ability of bowheads to break ice to breathe is well documented (Carroll and Smithhistler, 1980; George et al., 1989). Würsig et al. (1984) noted longer dive times and more blows per surfacing for whales in ice than for those in open water. About 75% of the animals observed in ice rested quietly when at the surface. Richardson et al. (1995) reported significantly shorter dive times for bowheads migrating through areas with 65 - 90% ice cover in fall 1983 (5.5 min) than for whales migrating through areas with < 10% ice cover at the same time of year in 1985-86 (18.2 min), but noted that the 1983 dive times were probably biased downward by the difficulty of resighting animals in heavy ice

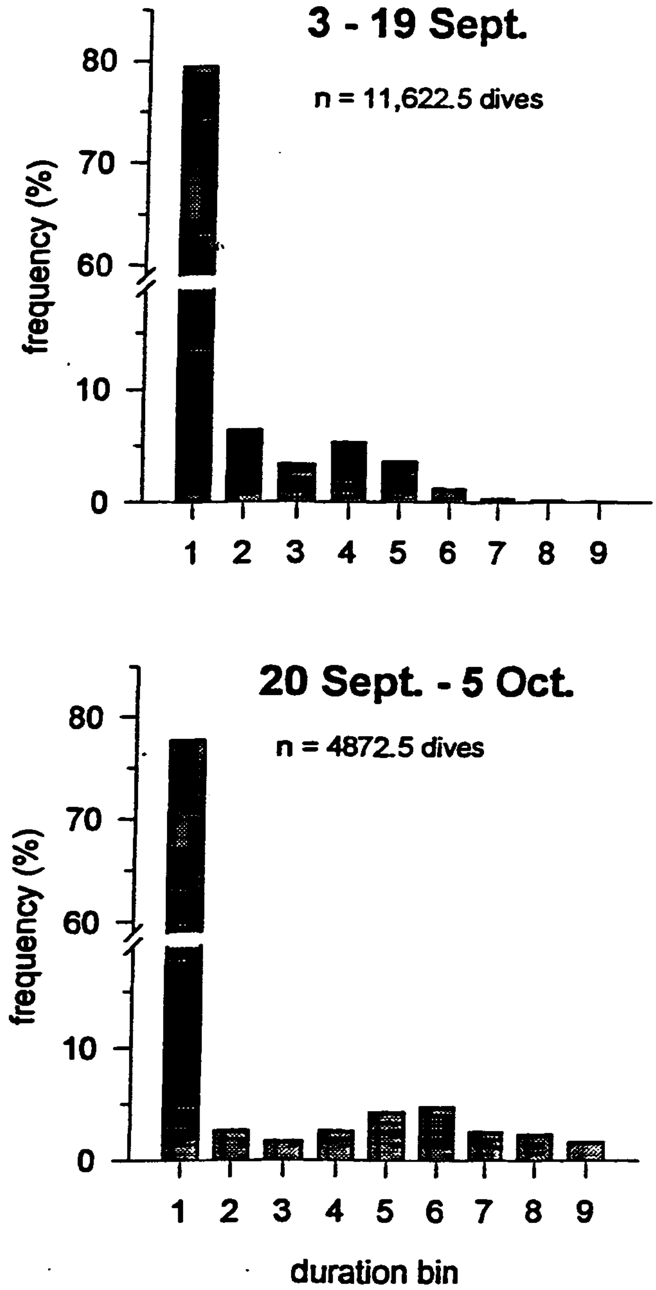

Figure 55. Frequency histogram of dive durations for whale 10824 in ice cover < 90% (3 - 19 September) and ≥ 90% (20 September to 5 October).

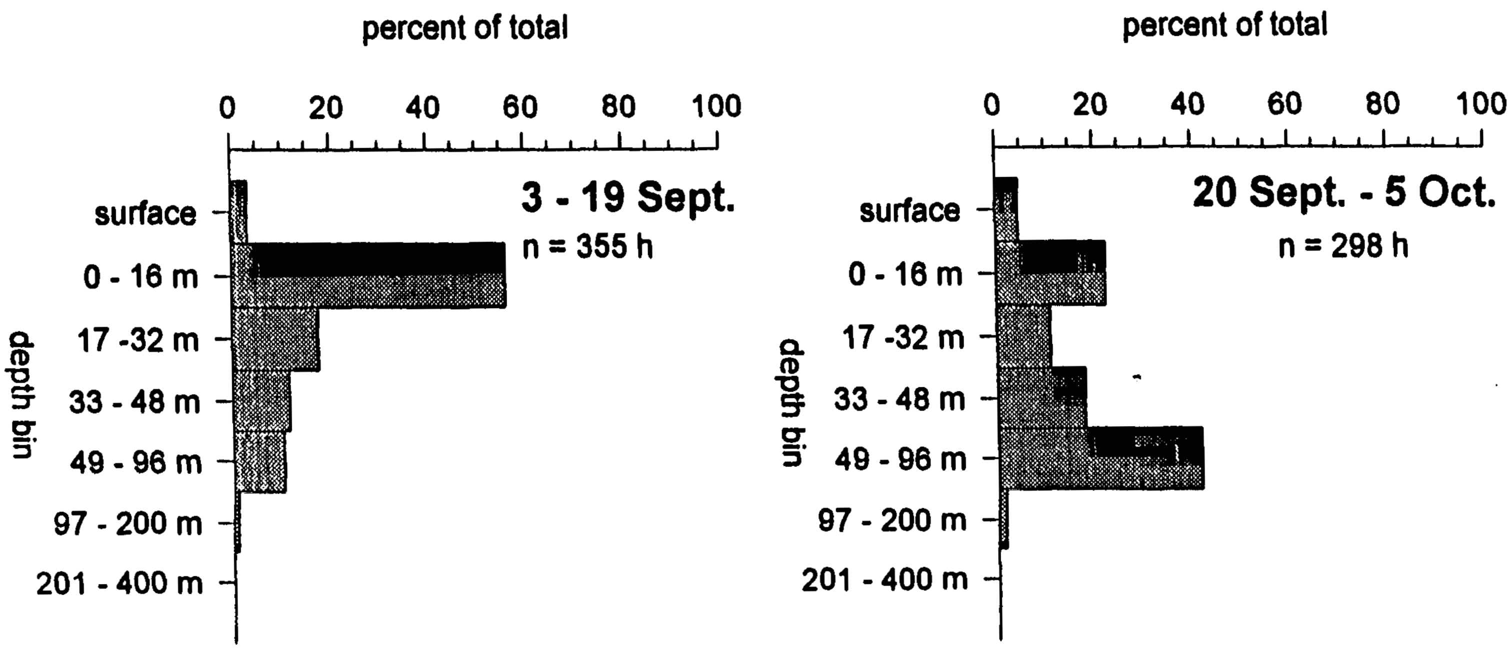

Figure 56. Percentage of time spent in depth bins during summary periods of ice cover < 90% (3 - 19 September) and ≥ 90% (20 September - 5 October).

conditions after a long dive. Tag 10824 certainly reported longer dives in heavy ice. Although the number of serial dives to breathe in a surfacing sequence decreased slightly, the increased percentage of surface time and longer duration of longest surface times in heavy ice suggest this animal may have rested quiescently at the surface between blows. Thus, the number of blows per surfacing sequence may have increased without a corresponding increase in short series dives recorded by the tag.

Perhaps the most interesting discovery about bowhead behavior while migrating through areas with heavy ice conditions was where the animal spent its time in the water column. Much less time was spent near the surface in heavy ice conditions. Although submerged swimming offers hydrodynamic advantages over swimming at the surface, animals need only submerge to about three times their body diameter to avoid surface drag effects (Hertel 1966). Bowheads would not have to exceed depths of our shallowest bin (16 m) for hydrodynamic considerations. However, traveling at greater depths could help the animals avoid the deep keels of multi-year ice. Ice floes can have deep keels reaching to 50 m below the surface (LaBelle et al., 1983). It is interesting to speculate on how bowheads navigate through areas of heavy ice. Bowheads migrating under a frozen lead where the water was 30 m deep avoided an area of deep-keeled multi-year ice and left bottom sediments in and around the hummocks created where they broke 14 - 18 cm newly formed ice to breathe (George et al., 1989). Traveling at greater depths may allow bowheads to travel more directly through areas with deep keeled ice. Ellison et al., (1987) suggested that bowheads could use the differential surface reverberations of their calls (at distances of 1 to 2 km) to discriminate between areas of rough bottomed, deep keeled, multi-year ice versus open water or smooth bottomed, young ice, thin enough to break though to breathe. The authors assumed 10 m deep ice keels and a sound source at 15 m, but they noted that the acoustic path of propagation of sound in the Arctic might allow bowheads in deep water to "see" beyond immediate obstructions if sounds were broadcast below the horizontal. Perhaps by vocalizing at greater depths and projecting their calls horizontally or slightly, upward bowheads can get a "picture" of ice conditions at greater distances.

SUGGESTED RESEARCH

This first satellite-monitored radio tracking of bowhead whales went very well and produced many notable findings. Seasonal and individual variability in response to environmental circumstances are important aspects of understanding natural bowhead behavior and the possible affects of human activities. Thus, larger sample sizes, under various conditions, may be the most important recommendation for future research.

Improvements in tag attachments will be helpful. The electronics of tags are now reasonably reliable and getting smaller. Because drag is probably a major contributing factor to tag loss, reducing tag size will be helpful. When tags are small enough to be implantable, longer operation may be expected. An external antenna will still be needed so controlling infection at the transcutaneous site will be important. Battery life for tag performance in this study was a limiting factor and is a special problem in cold Arctic temperatures. Battery capability is related to size and thus places limits on reducing tag size. Battery technologies are unlikely to change dramatically in the near future. The use of rechargeable systems is possible but has some limitations. Rechargeable batteries have low energy density (i.e. they are larger for the same power capacity than the single-use types). Longer battery life can be achieved through less frequent transmission and would likely have increased the duration of data in this study. More recent versions of satellite-monitored radio tags used on whales by Oregon State University have used duty cycles as low as 17% to achieve daily locations with reliability (Mate, in prep). This may be particularly important in cold Arctic water where battery performance is dramatically reduced and could also be important to provide adequate recovery time if rechargeable power systems are employed.

There are several candidate regions and times of year where future bowhead whale tagging would help answer specific questions about seasonal distributions and abundances.

- Tags applied off Pt. Barrow during the spring migration could help resolve questions about their continued migration and summer distribution into the Beaufort and Chukchi Seas. Tags surviving through the summer could provide information about the movements in areas far from shore which might be important for feeding but difficult to reach for tagging.

- Tagging bowhead whales in the late summer or early fall in Canada could provide more information about feeding habits and range, as well as movement west through proposed oil and gas lease areas in both Canadian and U.S. waters.

- Tagging near Pt. Barrow in the fall could: 1) determine the routes animals use to move west across the Chukchi Sea and south through the Bering Strait, 2) further resolve the relationship between bowheads and ice, and 3) possibly identify the overwintering area(s) for portions of this population. Tag survival in heavy ice conditions will remain a concern as long as tags are "external" but the results of this study show tag life was more related to battery depletion than tag loss.

● Applying tags in open water wintering areas may be quite difficult due to limited available light and the logistics of operating in difficult to reach polynyas, but would be worthwhile.

● Tags applied along the Russian Chukchi coast could examine summer habitat in that region as well as southward migration through the Bering Strait and the wintering distribution of animals from that region. In areas like the Sea of Okhotsk, where oil and gas development is under way, tagged bowheads would provide some of the first baseline data for that region.

● Reduce tag size to be implantable. Even with an implantable transmitter, it will still be necessary to have an external antenna. A transcutaneous antenna will wick sea water unless a good seal is achieved to increase the probability of encapsulation and total healing which are desirable for long-term attachment. Transcutaneous sealing technologies have been developed for humans and may prove useful to extend implantable tag longevity.

● The dive behavior of tagged bowheads suggests several areas where zooplankton sampling at depths below 50 m in late summer and early fall would be worthwhile. Mackenzie Canyon, the shelf break, and the Chukchi Sea were the sites of long, deep dives. Depth stratified zooplankton sampling throughout the water column in these areas would help resolve their importance as critical feeding areas.

- A coordinated effort would be valuable to measure the noise levels in areas of industrial activity when tagged whales move through. Some measurements of this type could be monitored from acoustic sensors (developed by Cornell University and Oregon State University) incorporated into the tag itself. If not collected from the tag, it would be necessary to plan how opportunistic acoustic data collection could be arranged on short notice or routinely.

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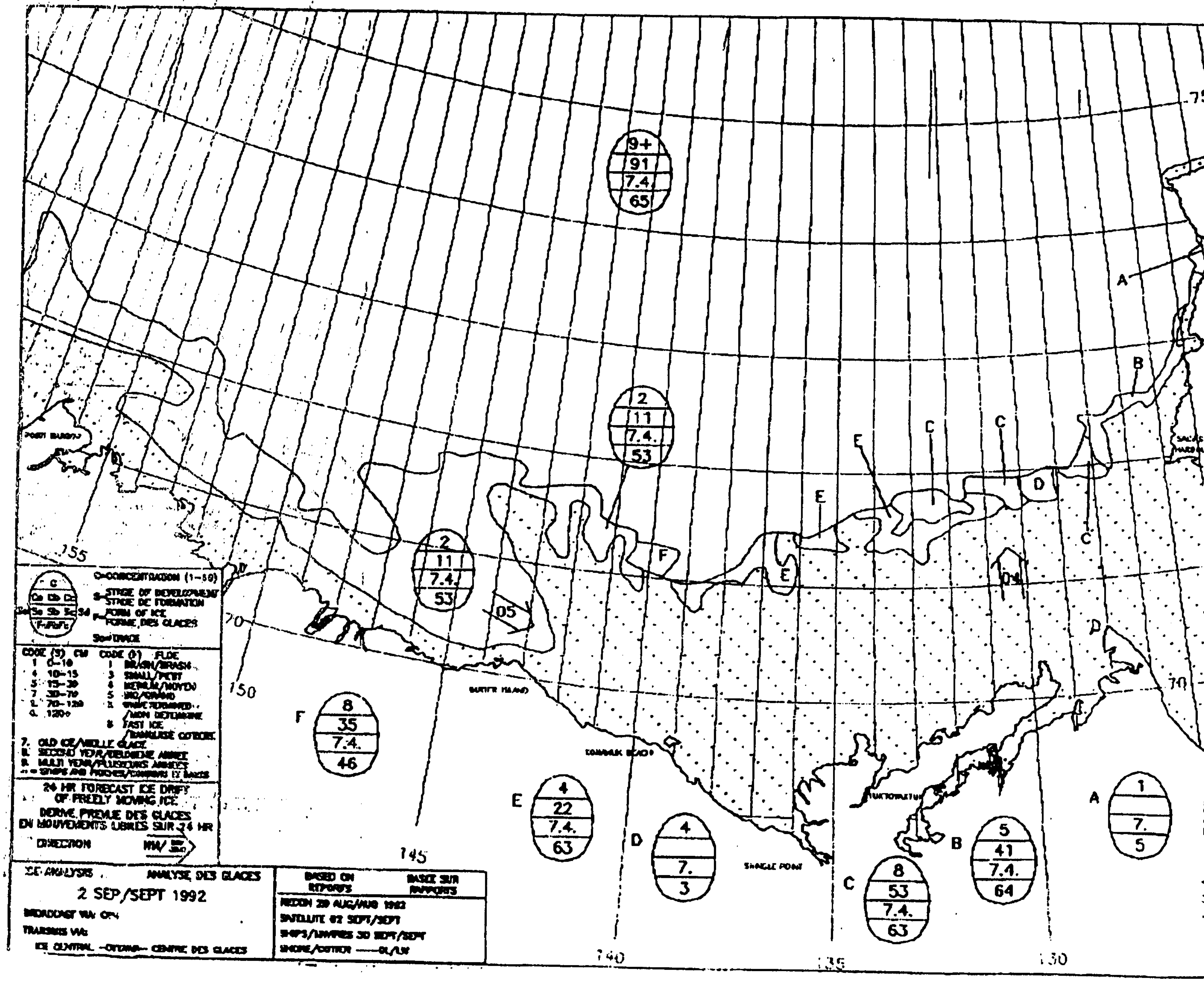
APPENDIX "1"

CANADIAN COAST GUARD ICE PREDICTIONS



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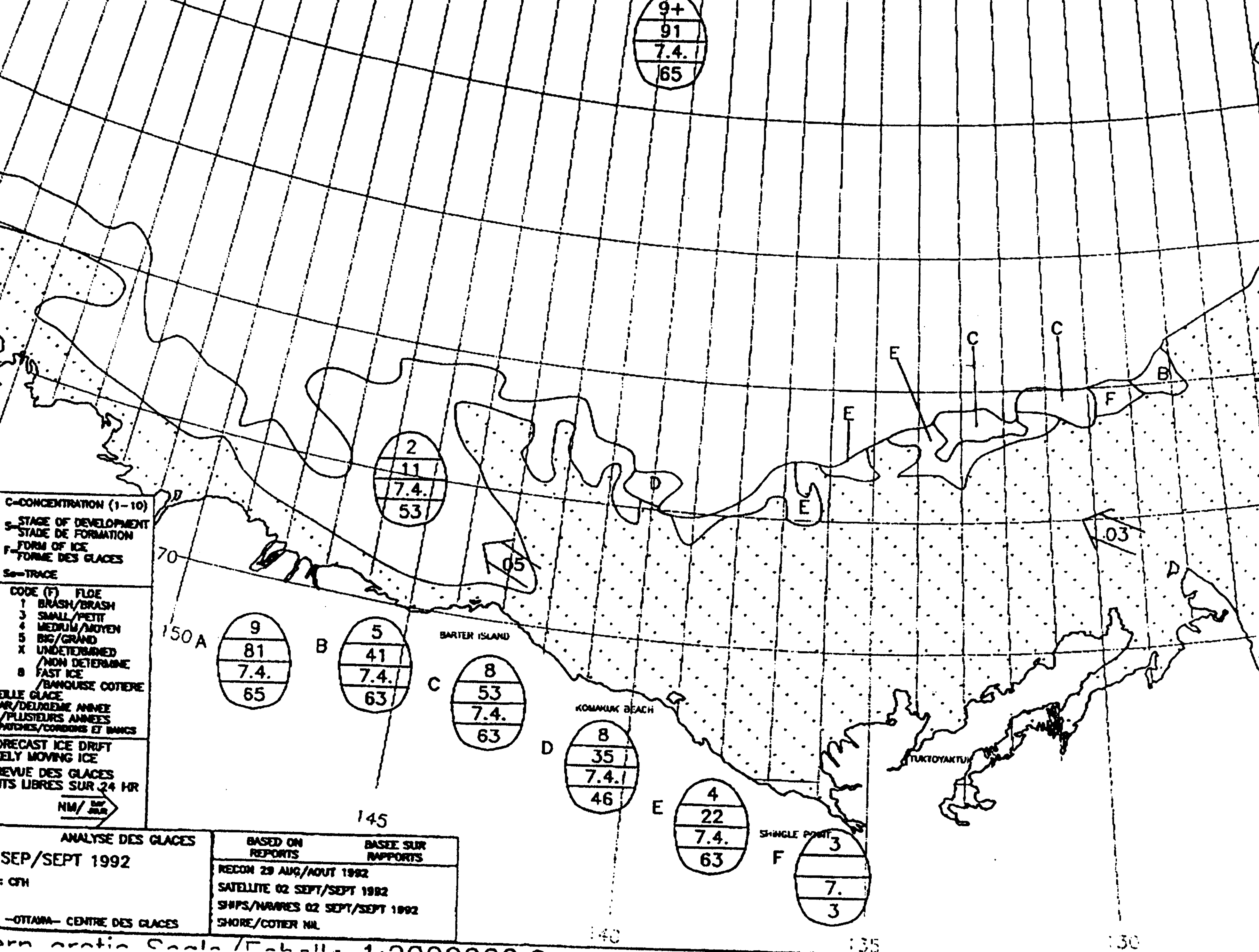

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C=CONCENTRATION (1-10)
S=STAGE OF DEVELOPMENT
STADE DE FORMATION
F=FORM OF ICE
FORME DES GLACES
CODE (F) FLOE
1 BRASH/BRASH
3 SMALL/PETIT
4 MEDIUM/MOYEN
5 BIG/GRAND
X UNDETERMINED
/NON DETERMINE
8 FAST ICE
/BANQUISE COTIERE
ORECAST ICE DRIFT
EVUE DES GLACES
NM/
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150
A
9
81
7.4.
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B
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41
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63
BARTER ISLAND
C
8
53
7.4.
63
KOMAKUK BEACH
D
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35
7.4.
46
E
4
22
7.4.
63
SHINGLE POINT
F
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7.
3
TUKTOYAKTUK
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140
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130
ANALYSE DES GLACES
SEP/SEPT 1992
CFH
-OTTAWA- CENTRE DES GLACES
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON 29 AUG/AOUT 1992
SATELLITE 02 SEPT/SEPT 1992
SHIPS/NAVIRES 02 SEPT/SEPT 1992
SHORE/COTIER NIL

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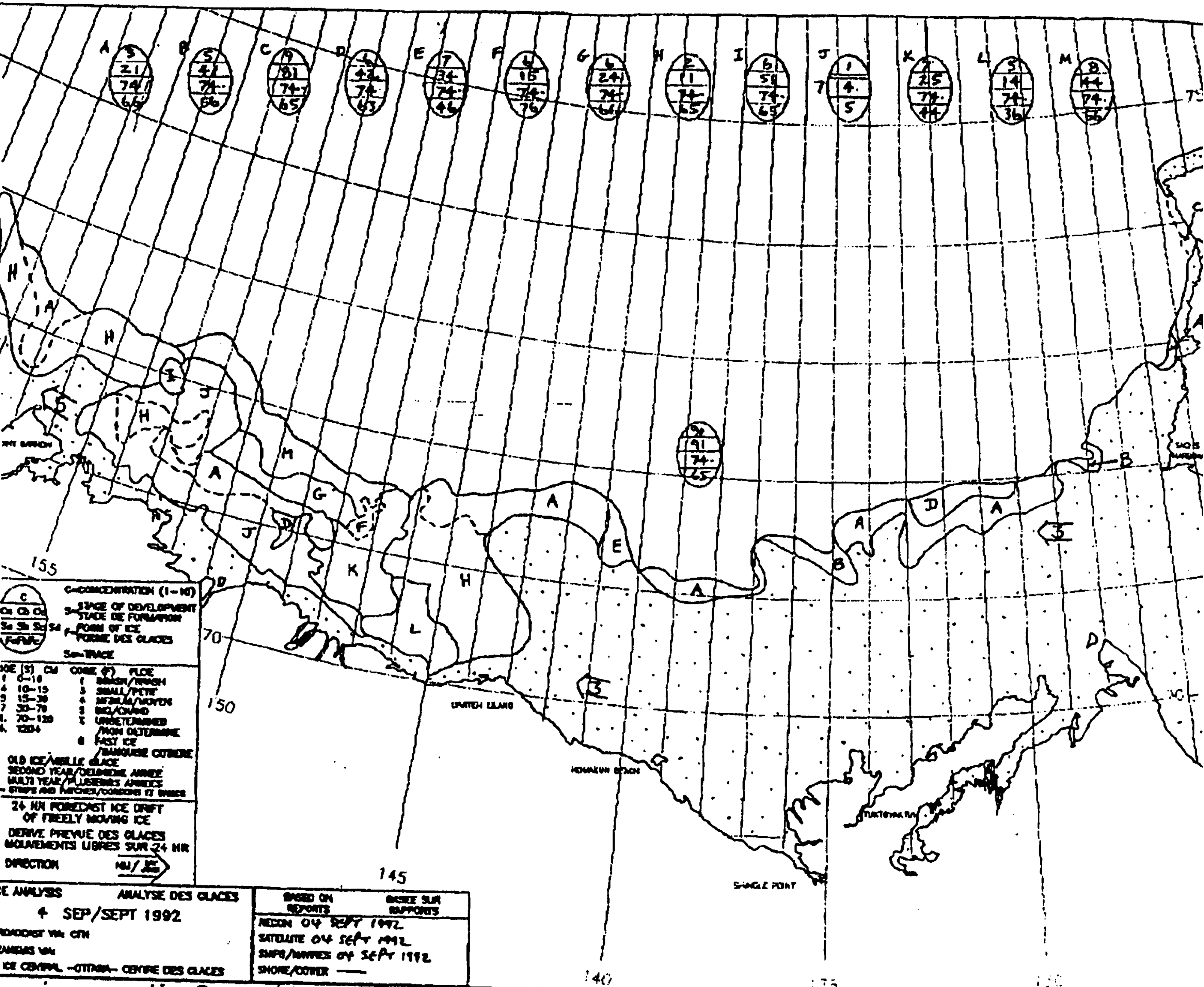

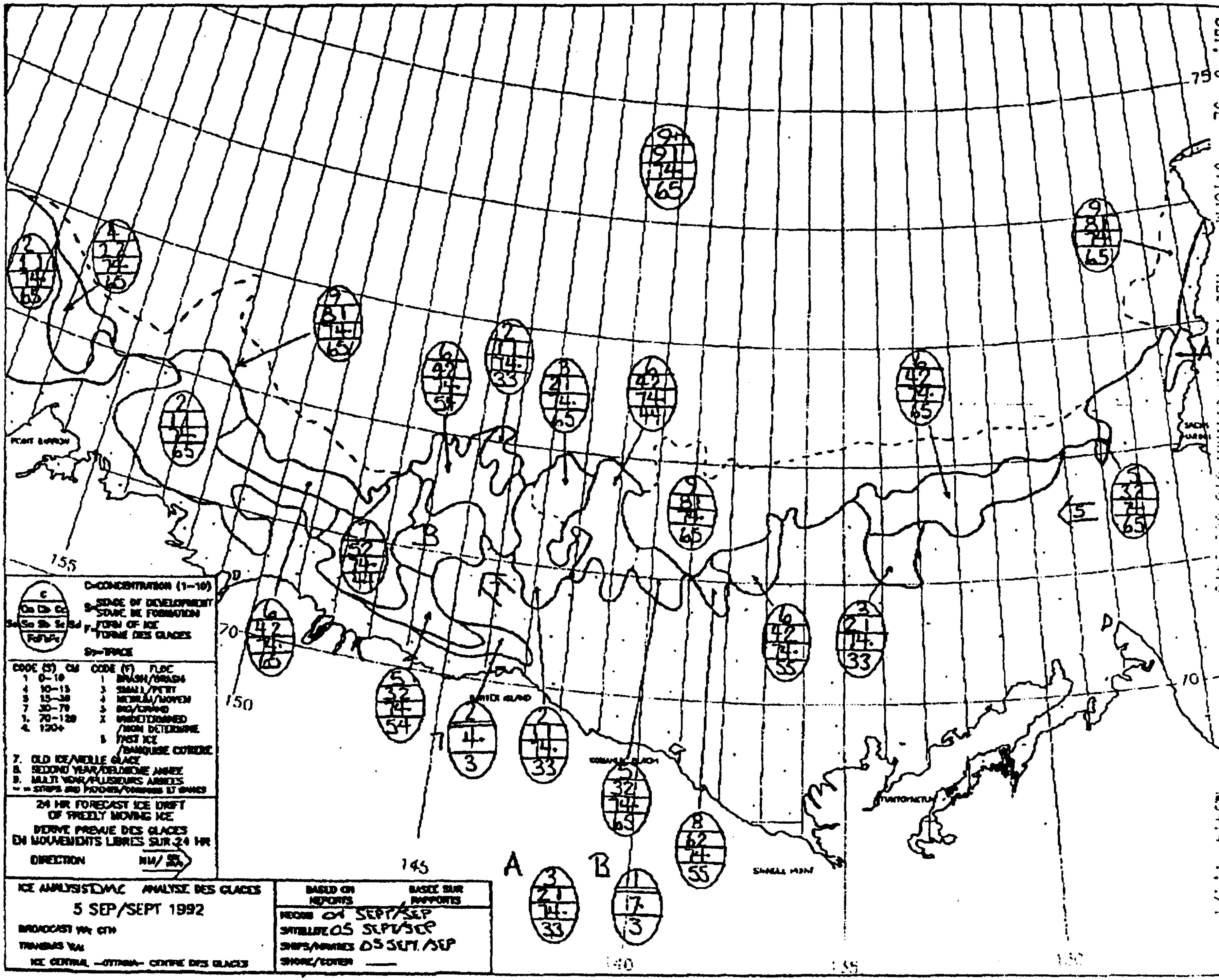
C=CONCENTRATION (1–10)
S=STAGE OF DEVELOPMENT
STADE DE FORMATION
F=FORM OF ICE
FORME DES GLACES
Tr=TRACE
CODE (S) CM
CODE (F) FLOE
1 BRASH/BRASH
7. OLD ICE/VIEILLE GLACE
8. SECOND YEAR/DEUXIEME ANNEE
9. MULTI YEAR/PLUSIEURS ANNEES
24 HR FORECAST ICE DRIFT
OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES
EN MOUVEMENTS LIBRES SUR 24 HR
DIRECTION
ICE ANALYSIS/DMC ANALYSE DES GLACES
5 SEP/SEPT 1992
BROADCAST VIA
TRANSMIS VIA
ICE CENTRAL –OTTAWA– CENTRE DES GLACES
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON 04 SEPT/SEP
SATELLITE 05 SEPT/SEP
SHIPS/NAVIRES 05 SEPT/SEP
SHORE/COTIER
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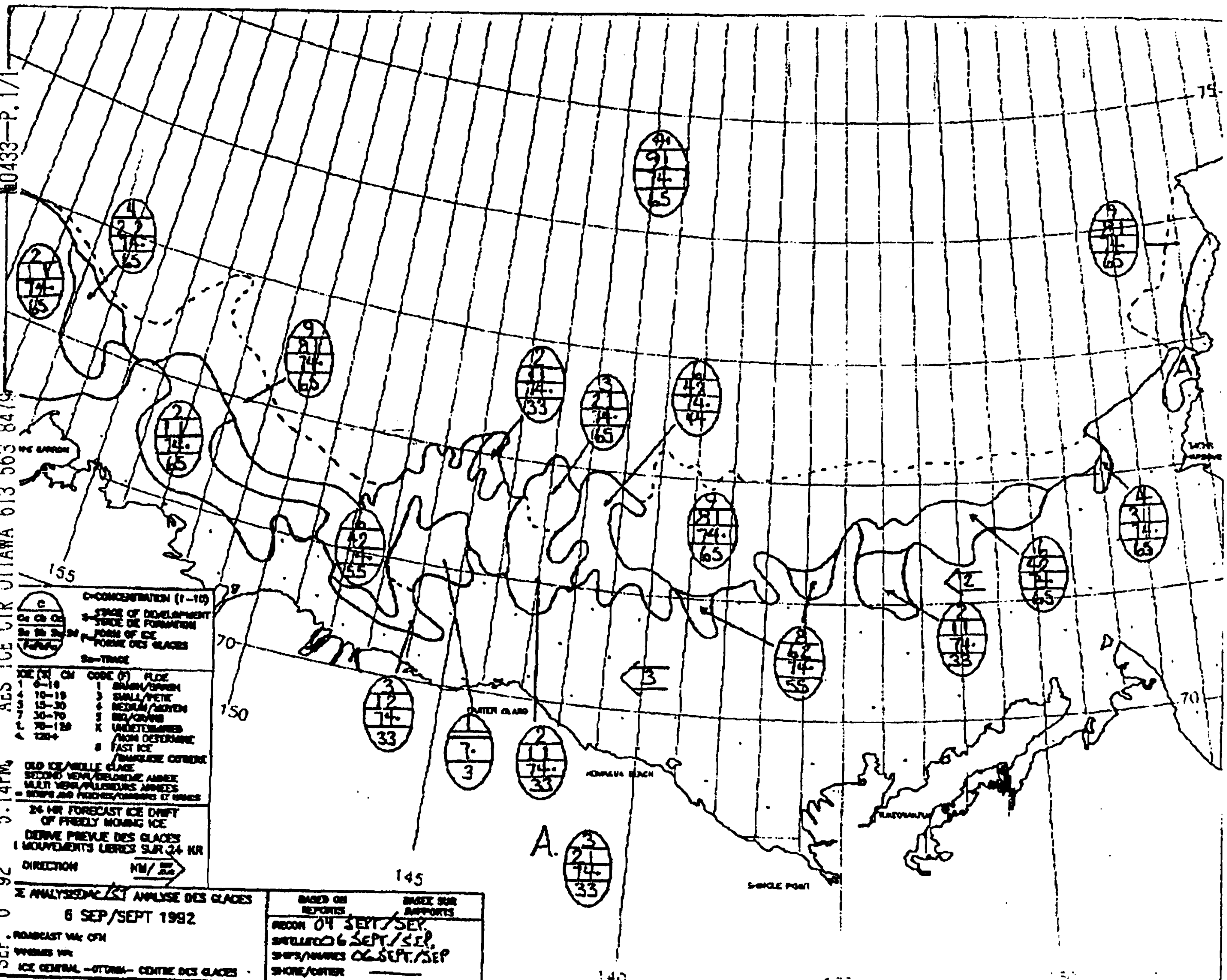

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F=FORM OF ICE / FORME DES GLACES
Sc=TRACE
24 HR FORECAST ICE DRIFT OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES I MOUVEMENTS LIBRES SUR 24 HR
DIRECTION
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ICE ANALYSIS/ANALYSE DES GLACES
6 SEP/SEPT 1992
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON 04 SEPT/SEP
SATELLITE 06 SEPT/SEP
SHIPS/NAVIRES 06 SEPT/SEP
SHORE/COTIER
ICE CENTRAL -OTTAWA- CENTRE DES GLACES
HONEAVA BEACH
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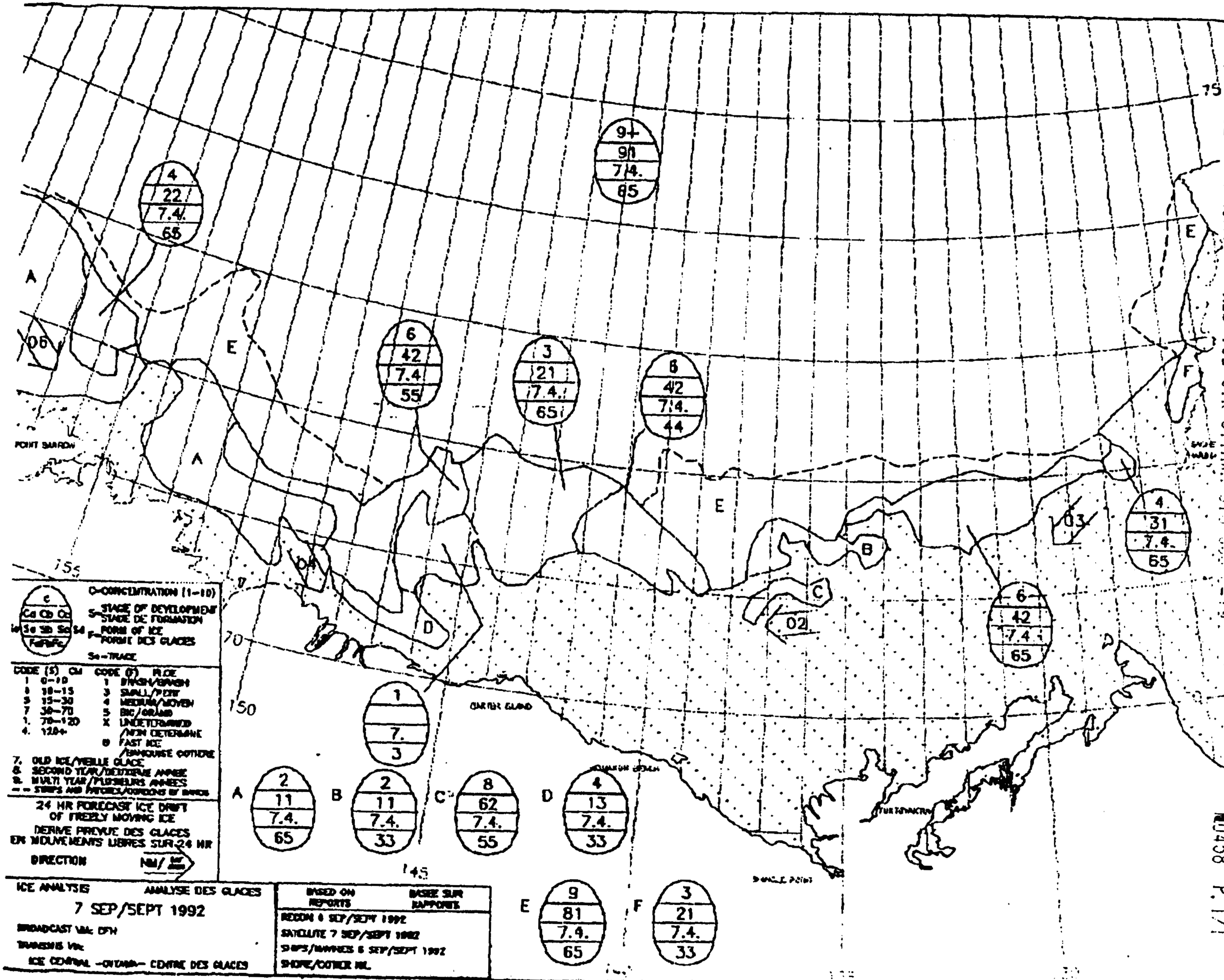

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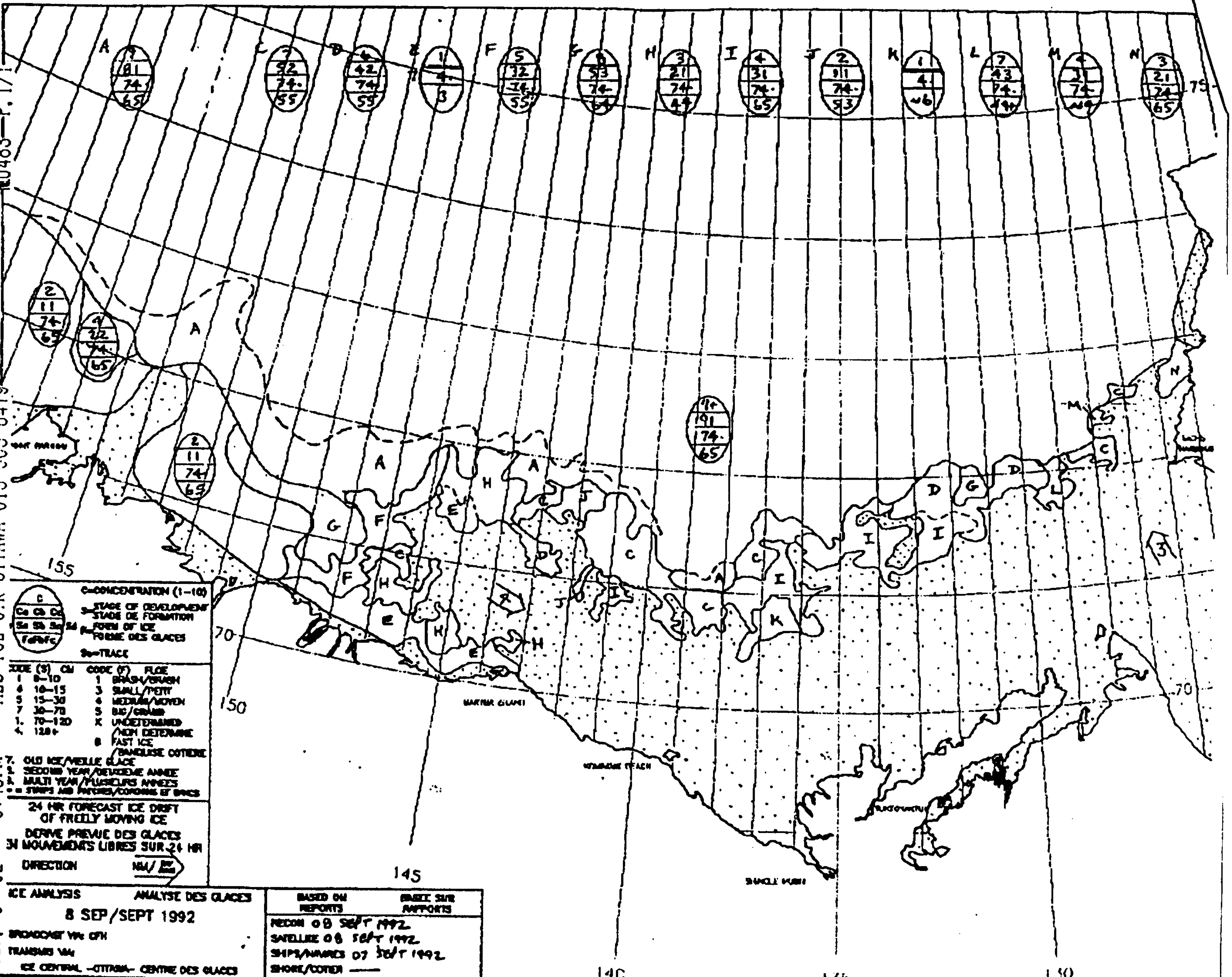

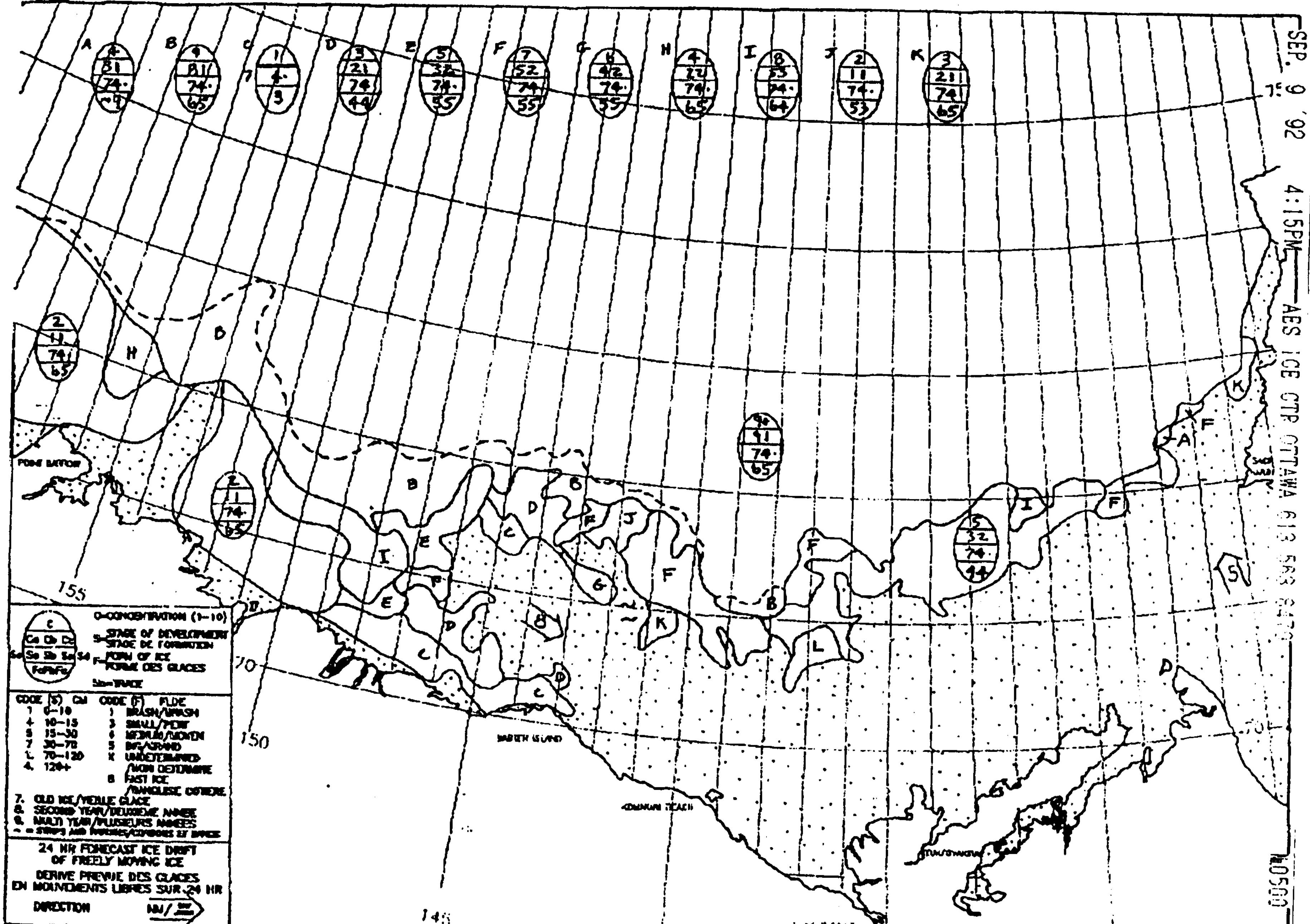

ICE ANALYSIS ANALYSE DES GLACES

9 SEP/SEPT 1992

BROADCAST VIA: CTH

TRANSMIS VIA:

ICE CENTRAL -OTTAWA- CENTRE DES GLACES

BASED ON REPORTS	BASEE SUR RAPPORTS
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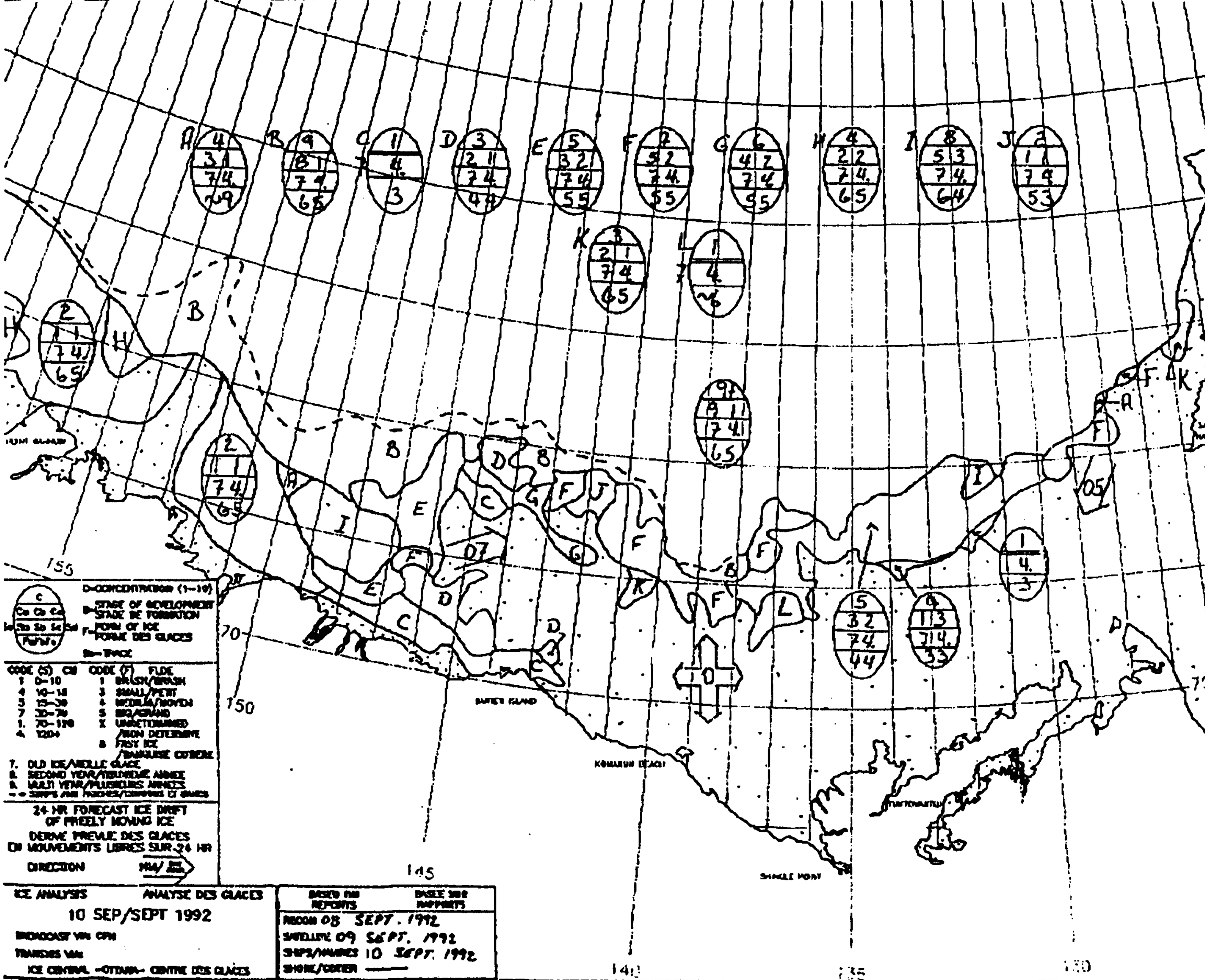
SHIPS/NAVIRES 9 SEPT 1992	
SHORE/COTIER ——	



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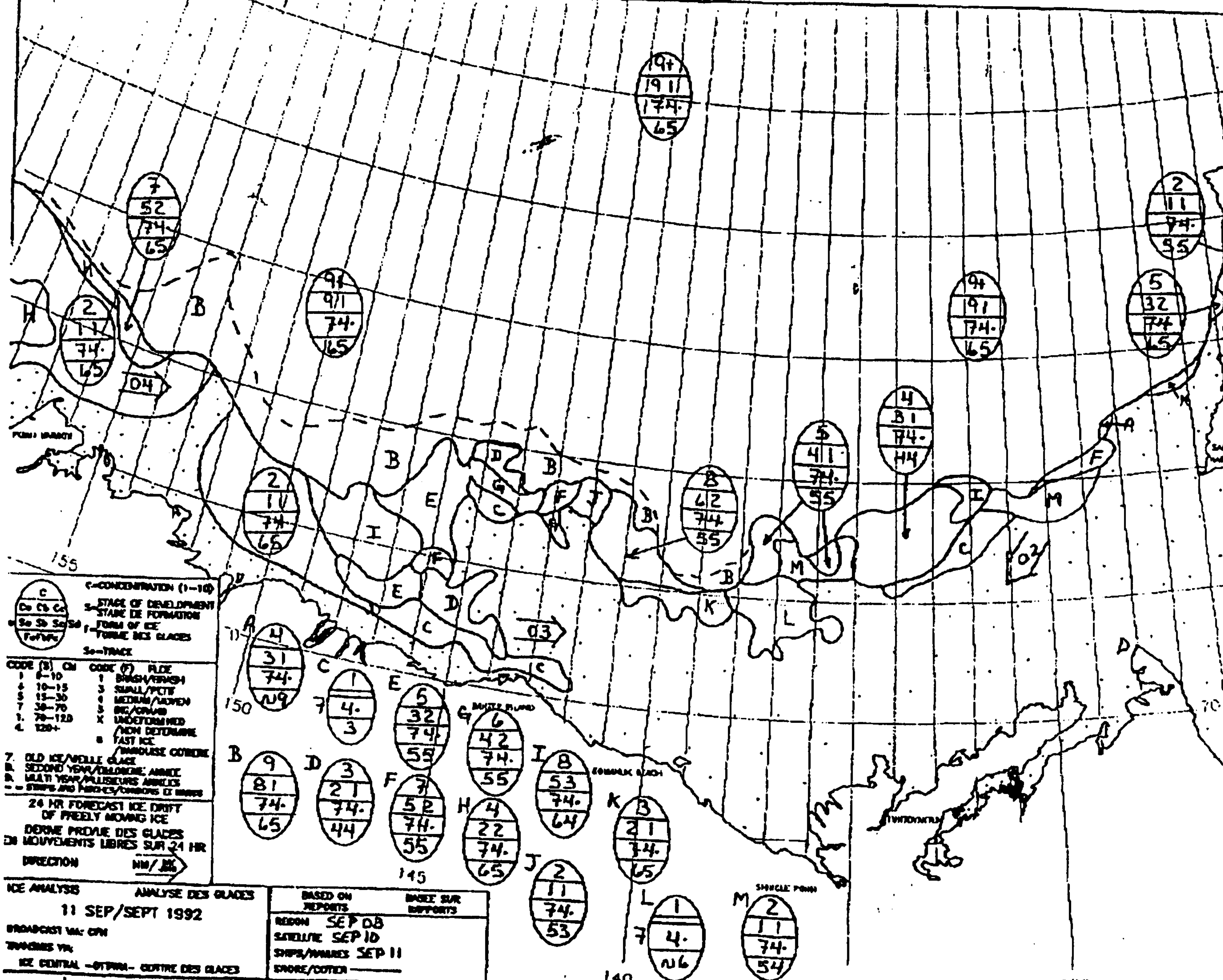

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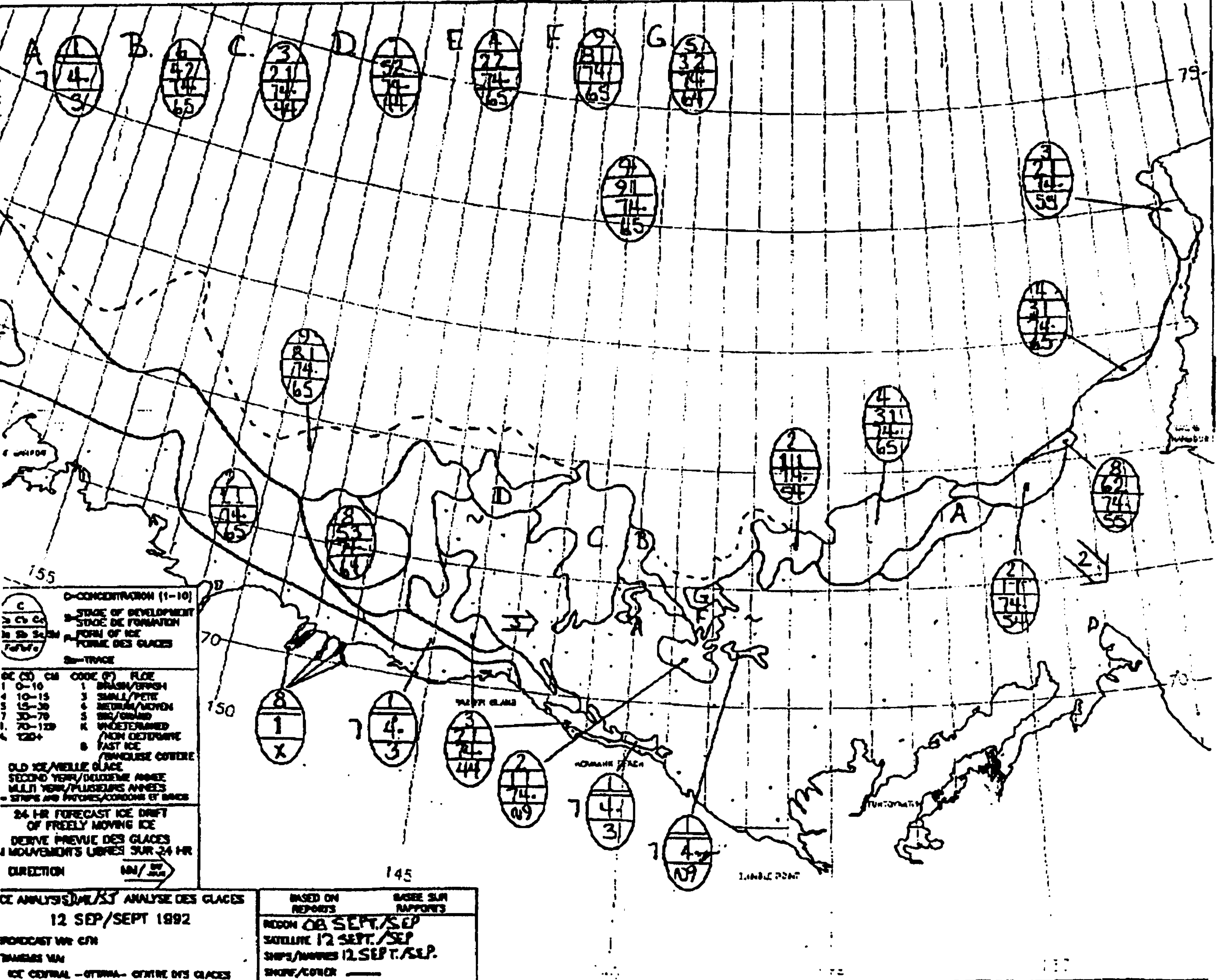

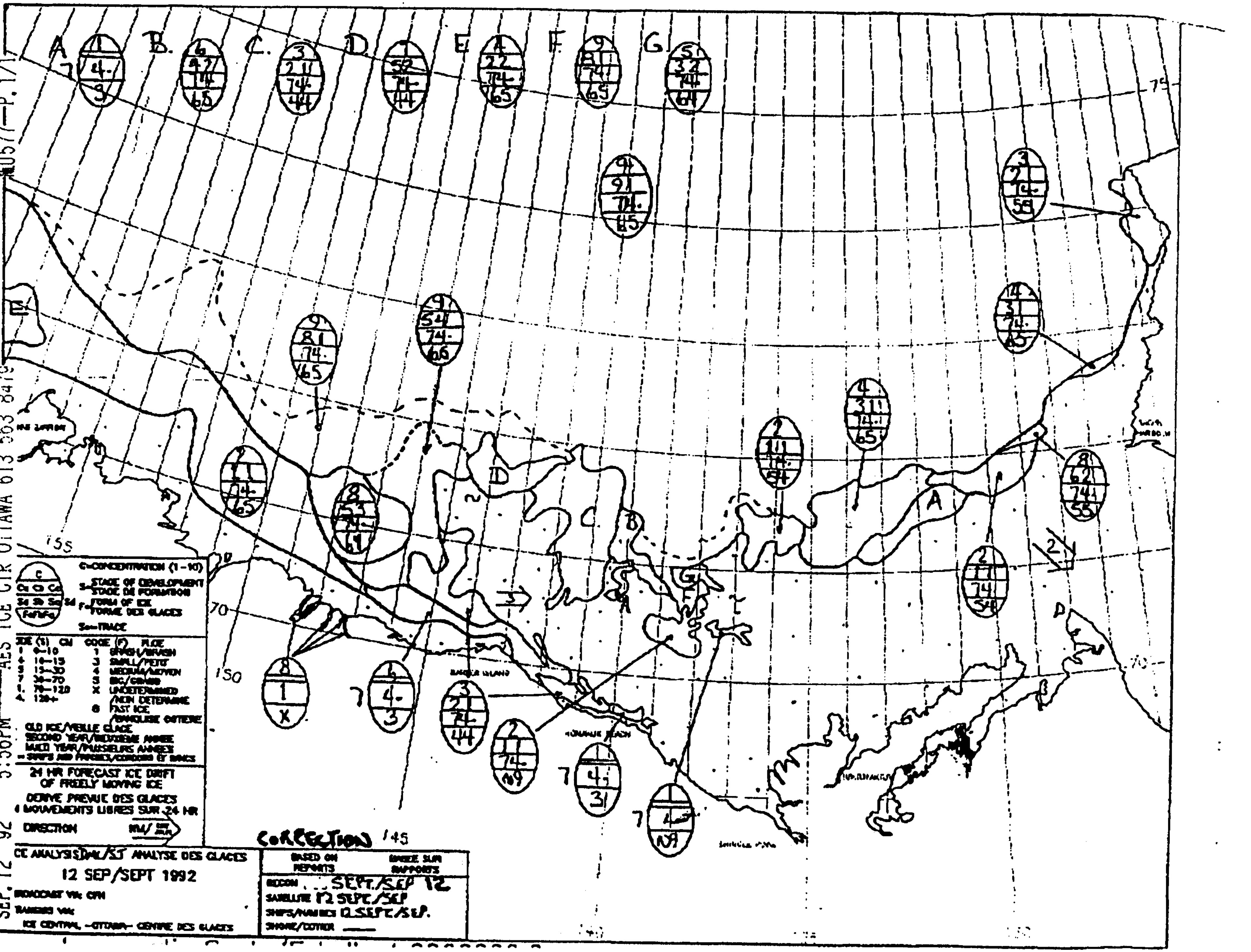
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S-STAGE OF DEVELOPMENT
STADE DE FORMATION
F-FORM OF ICE
FORME DES GLACES
Tr-TRACE
24 HR FORECAST ICE DRIFT
OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES
A MOUVEMENTS LIBRES SUR 24 HR
DIRECTION
CORRECTION
ICE ANALYSIS DAL/ST ANALYSE DES GLACES
12 SEP/SEPT 1992
ICE CENTRAL -OTTAWA- CENTRE DES GLACES
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON ... SEPT./SEP 12
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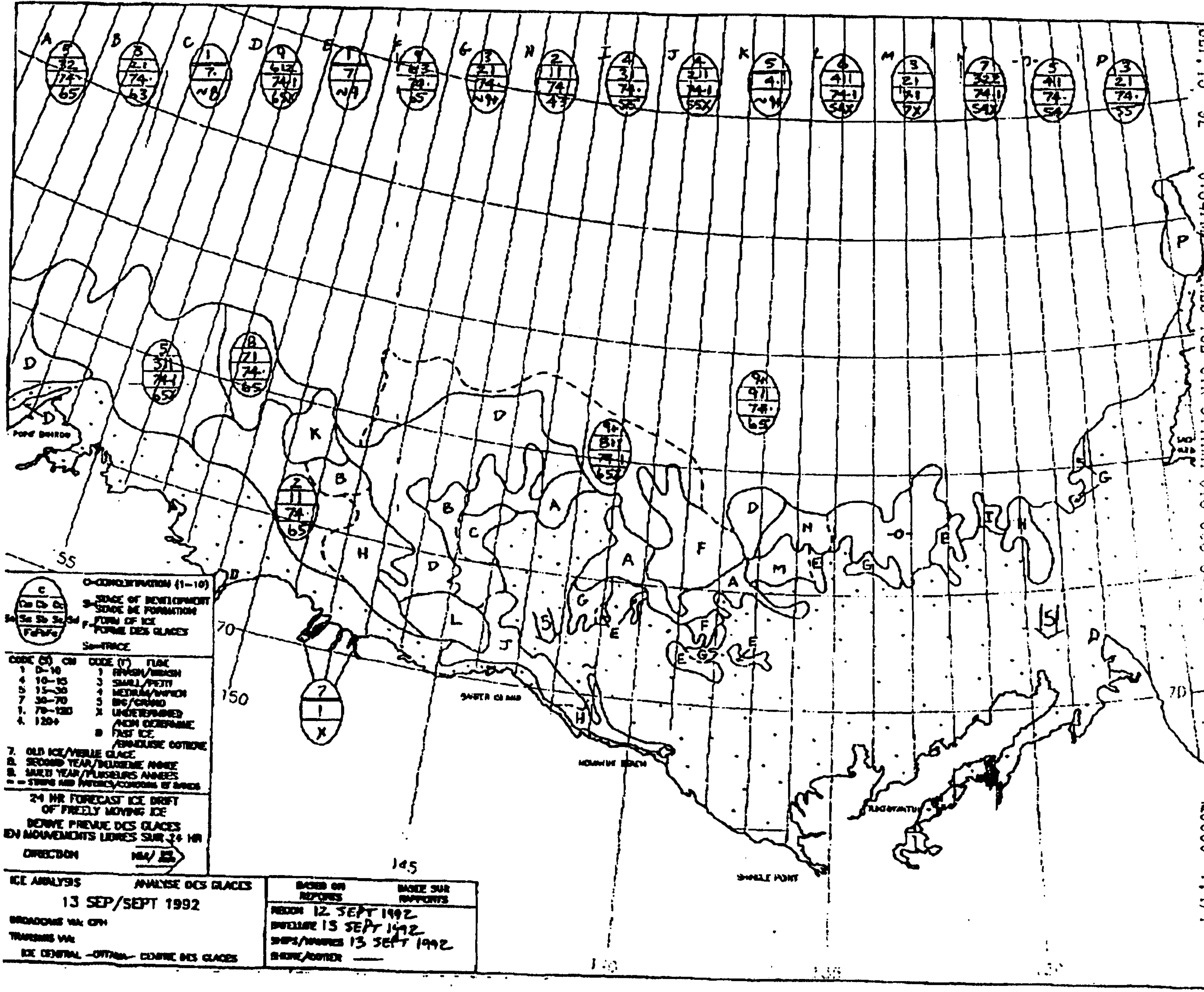
SHIPS/NAVIRES 12 SEPT./SEP.
SHORE/COTIER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F-FORM OF ICE
FORME DES GLACES
S=TRACE
CODE (S) CM
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4 10-15
5 15-30
7 30-70
1. 70-120
4. 120+
CODE (F) FLOE
1 BRASH/BROKEN
3 SMALL/PETIT
4 MEDIUM/MOYEN
5 BIG/GRAND
X UNDETERMINED
/NON DETERMINE
8 FAST ICE
/BANQUISE COTIERE
7. OLD ICE/VIEILLE GLACE
8. SECOND YEAR/DEUXIEME ANNEE
9. MULTI YEAR/PLUSIEURS ANNEES
24 HR FORECAST ICE DRIFT
OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES
EN MOUVEMENTS LIBRES SUR 24 HR
DIRECTION
ICE ANALYSIS
ANALYSE DES GLACES
13 SEP/SEPT 1992
TRANSMIS VIA
ICE CENTRAL -OTTAWA- CENTRE DES GLACES
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON 12 SEPT 1992
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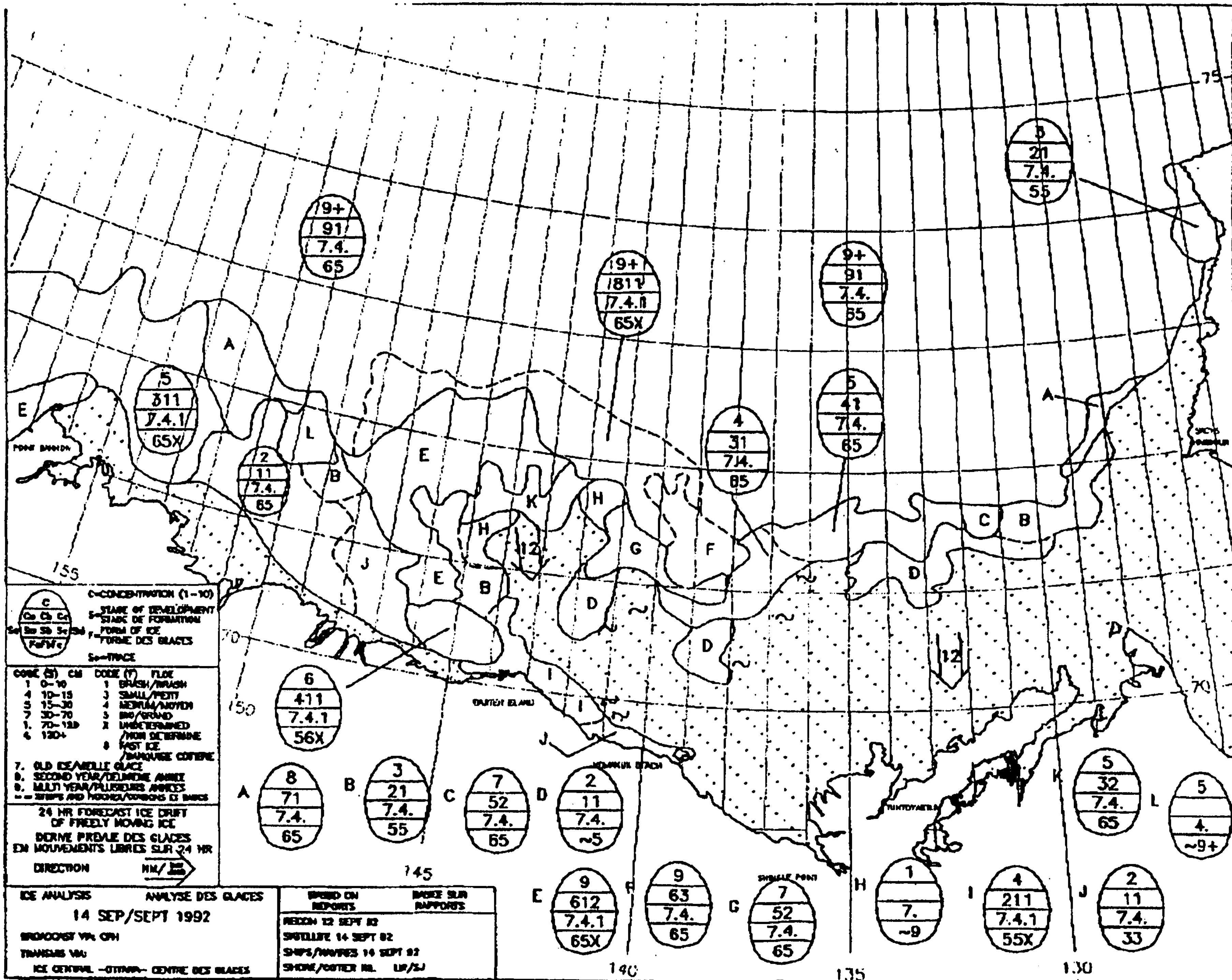

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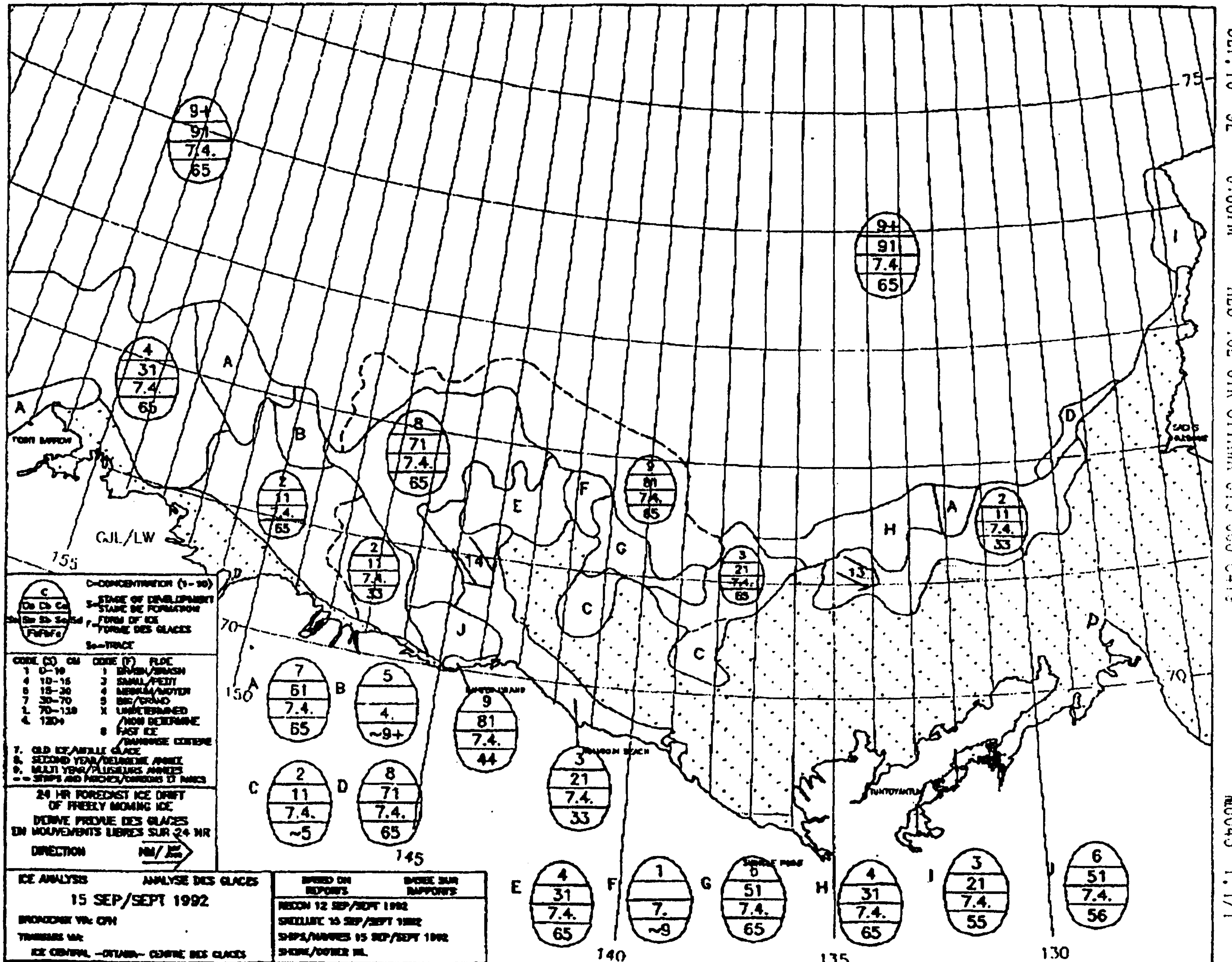
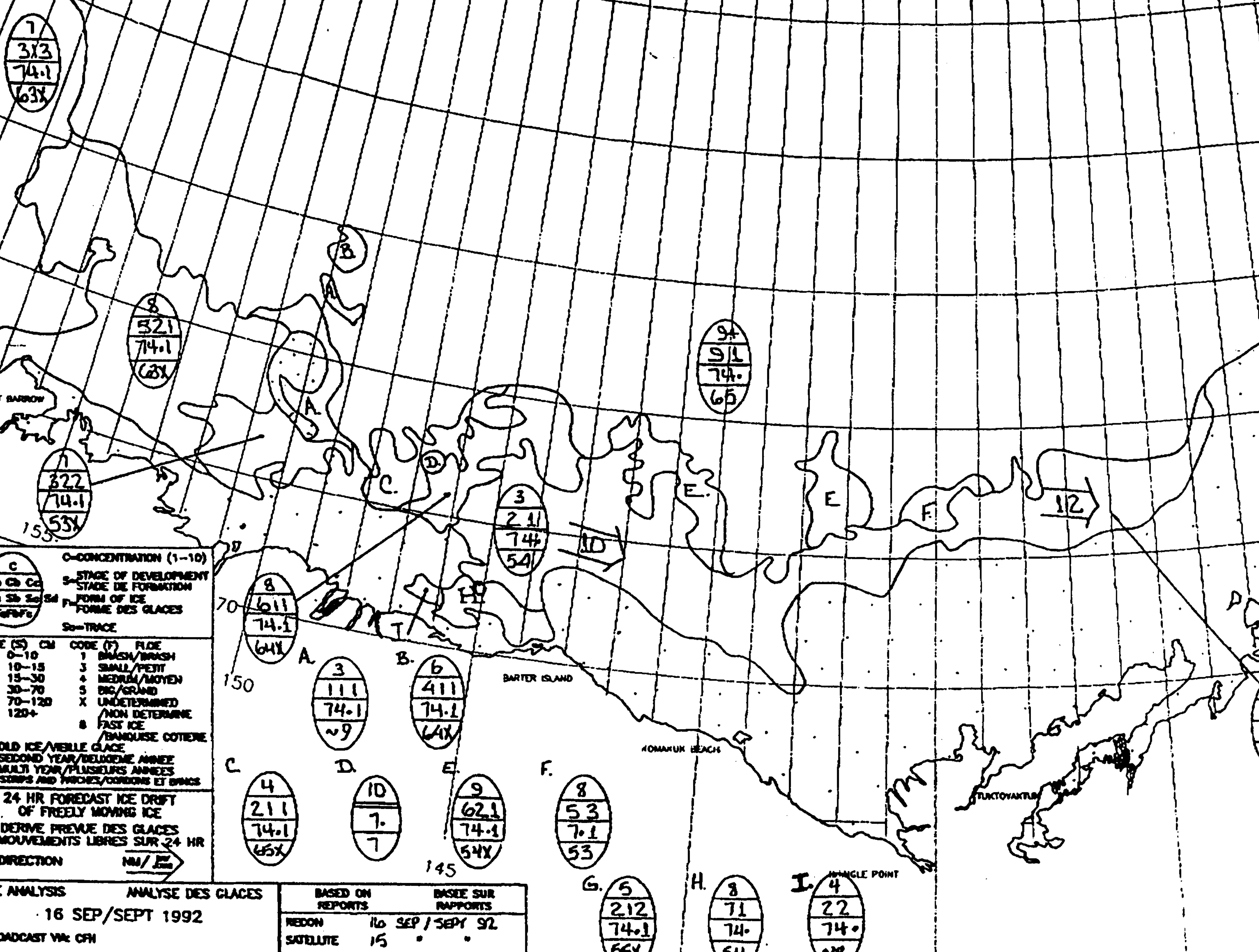
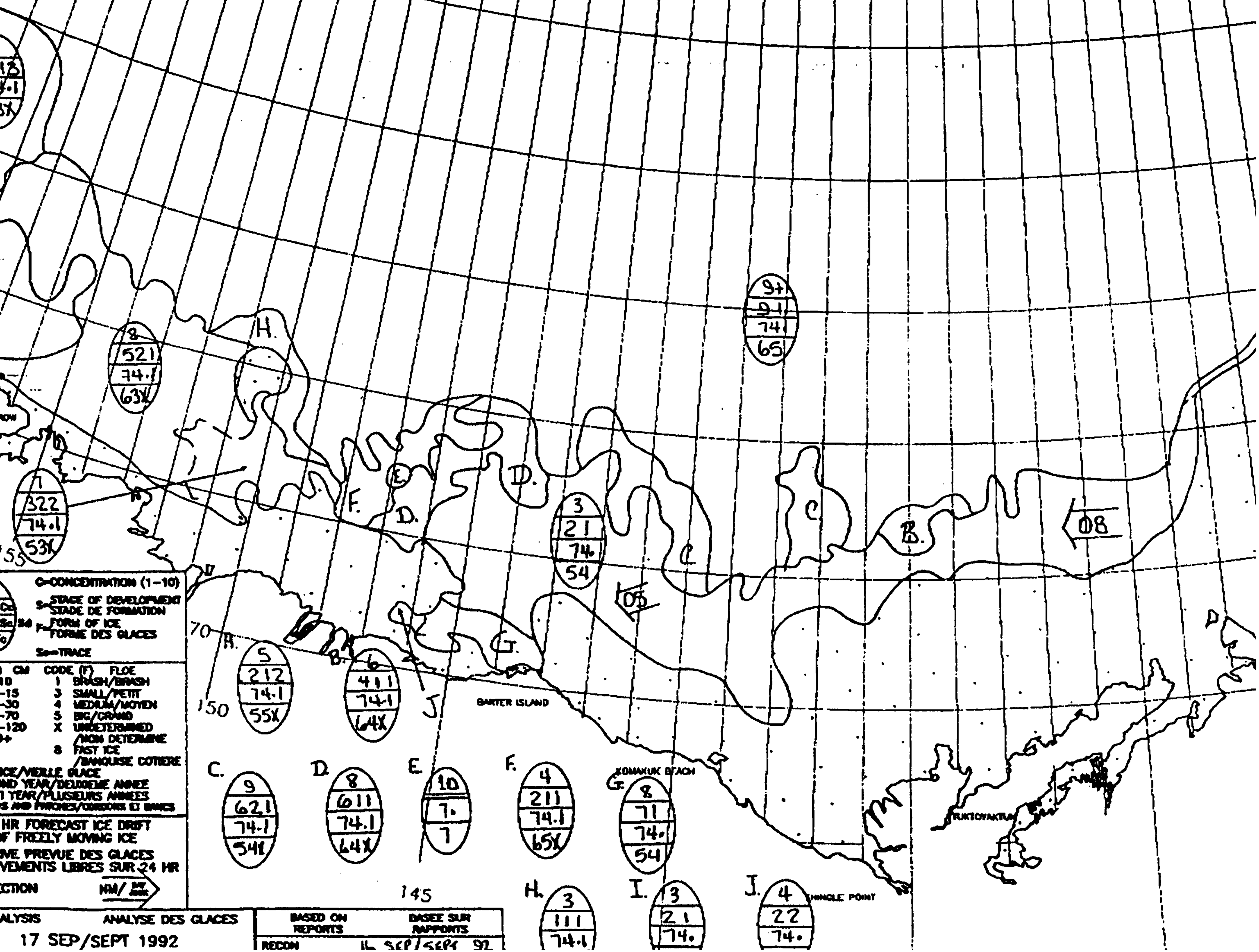
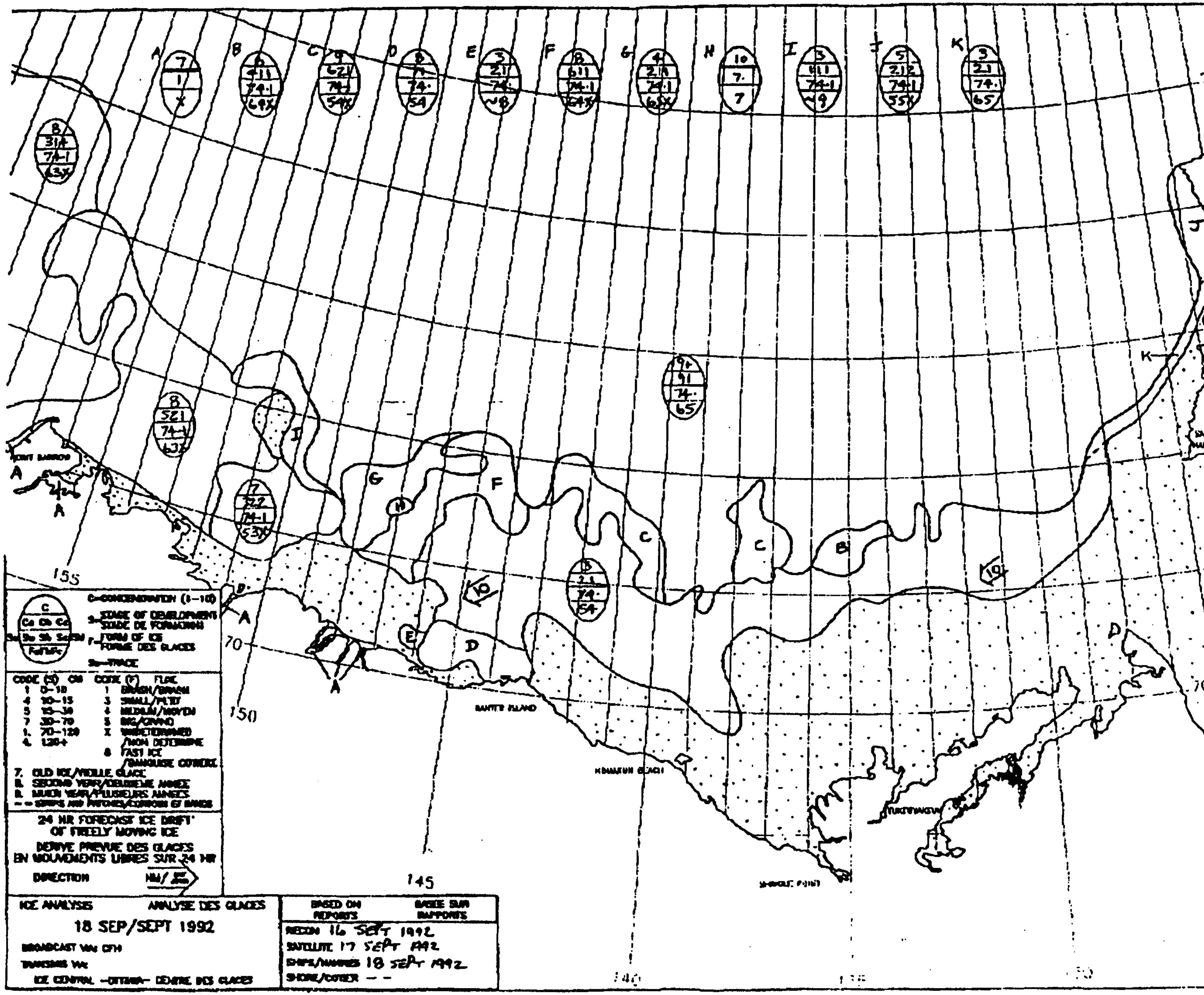




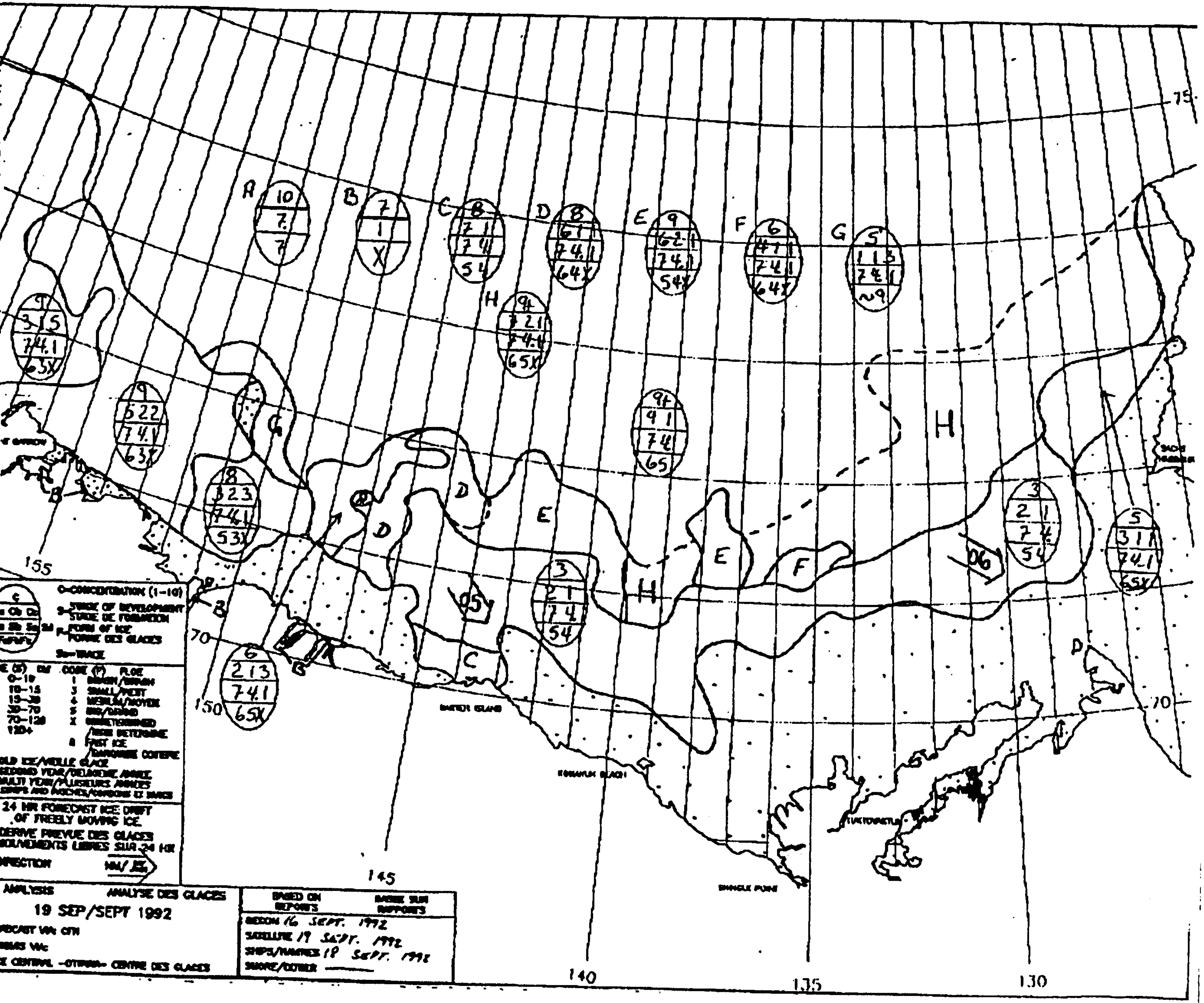
T BARROW
BARTER ISLAND
KOMAKUK BEACH
TUKTOYAKTUK
NGLE POINT
153
150
145
70
C=CONCENTRATION (1-10)
S=STAGE OF DEVELOPMENT
STADE DE FORMATION
F=FORM OF ICE
FORME DES GLACES
Sa=TRACE
CODE (F) FLOE
0-10 1 BRASH/BRASH
10-15 3 SMALL/PETIT
15-30 4 MEDIUM/MOYEN
30-70 5 BIG/GRAND
70-120 X UNDETERMINED
120+ /NON DETERMINE
8 FAST ICE
/BANQUISE COTIERE
OLD ICE/VIEILLE GLACE
SECOND YEAR/DEUXIEME ANNEE
MULTI YEAR/PLUSIEURS ANNEES
STRIPS AND PATCHES/CORDONS ET BANCS
24 HR FORECAST ICE DRIFT
OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES
MOUVEMENTS LIBRES SUR 24 HR
DIRECTION
ANALYSIS
ANALYSE DES GLACES
16 SEP/SEPT 1992
BASED ON REPORTS
BASEE SUR RAPPORTS
REDON 16 SEP / SEPT 92
SATELLITE 15
OADCAST VIA: CFH

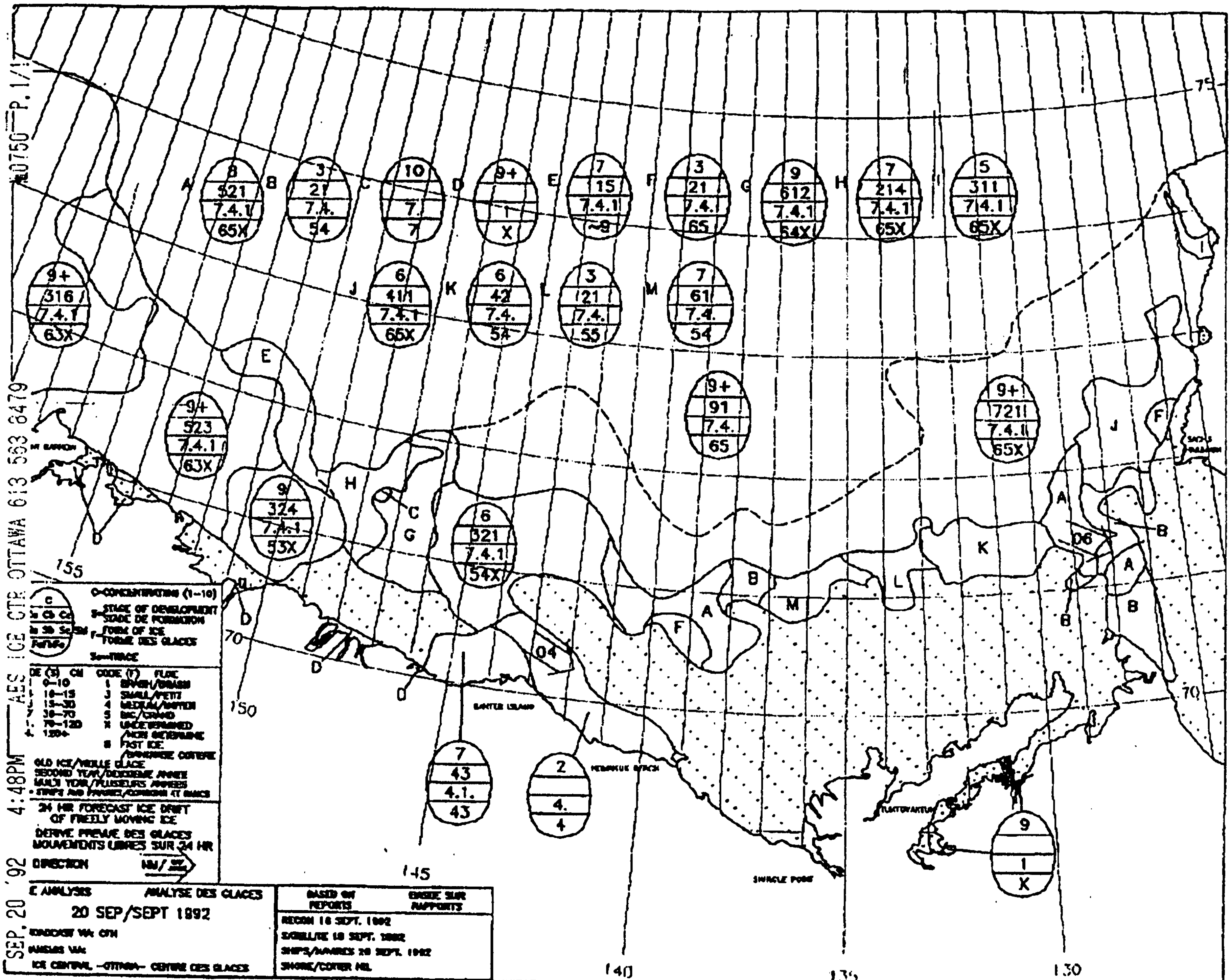

C=CONCENTRATION (1-10)
S=STAGE OF DEVELOPMENT
STADE DE FORMATION
F=FORM OF ICE
FORME DES GLACES
S=TRACE
CODE (F) FLOE
1 BRASH/BRASH
3 SMALL/PETIT
4 MEDIUM/MOYEN
5 BIG/GRAND
X UNDETERMINED
/NON DETERMINE
8 FAST ICE
/BANQUISE COTIERE
HR FORECAST ICE DRIFT
OF FREELY MOVING ICE
VE PREVUE DES GLACES
VEMENTS LIBRES SUR 24 HR
ANALYSE DES GLACES
17 SEP/SEPT 1992
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON
16 SEP/SEPT 92
BARTER ISLAND
KOMAKUK BEACH
TUKTOYAKTUK
SHINGLE POINT
70
150
145
155
08
05

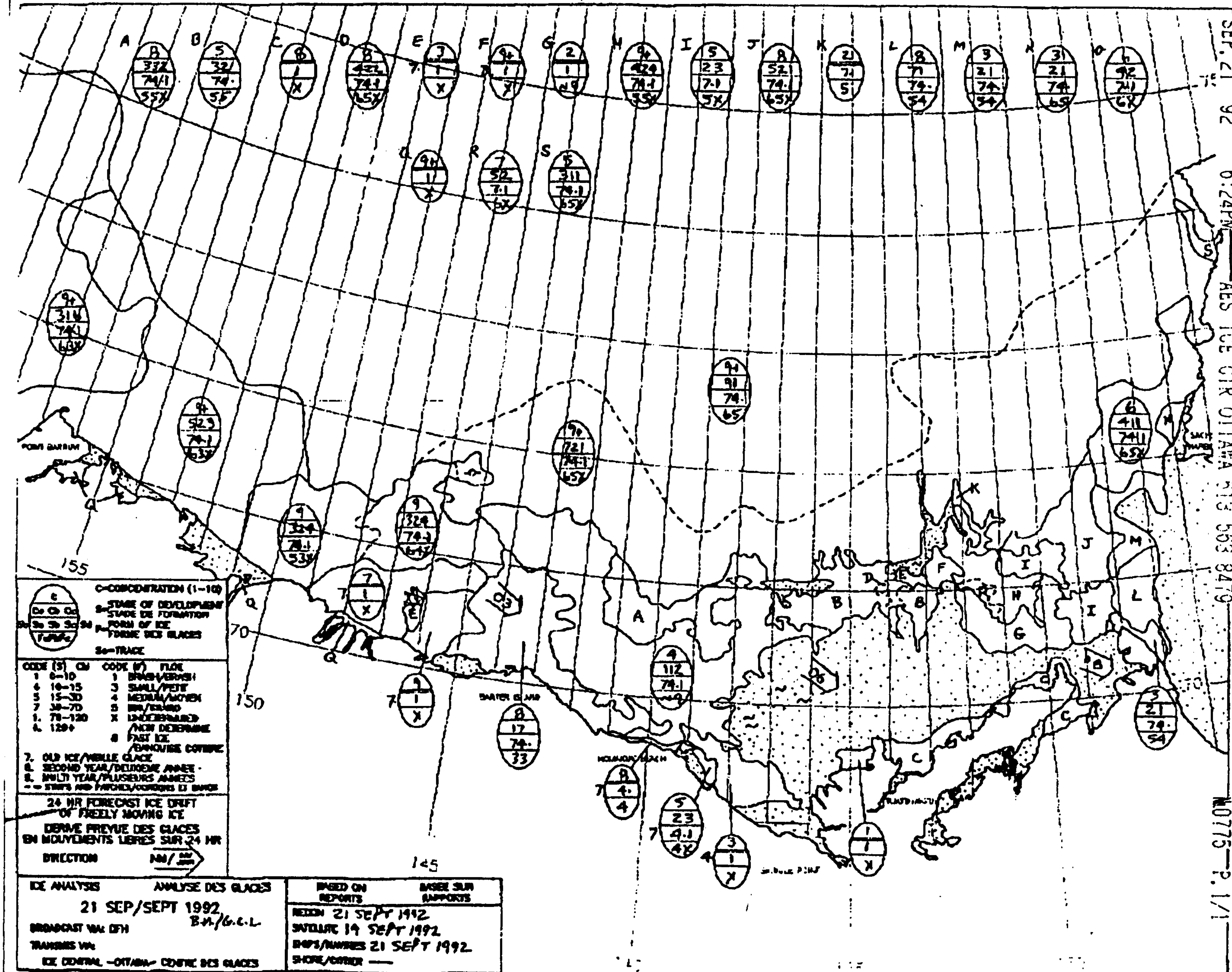


SEP.18 '92 6:17PM —AES ICE CTR OTTAWA 613 563 8479— No.0715 P.1/1

SEP 19 '92 2:25PM AES ICE CTR OTTAWA 613 563 8479 NO726 P.1/1

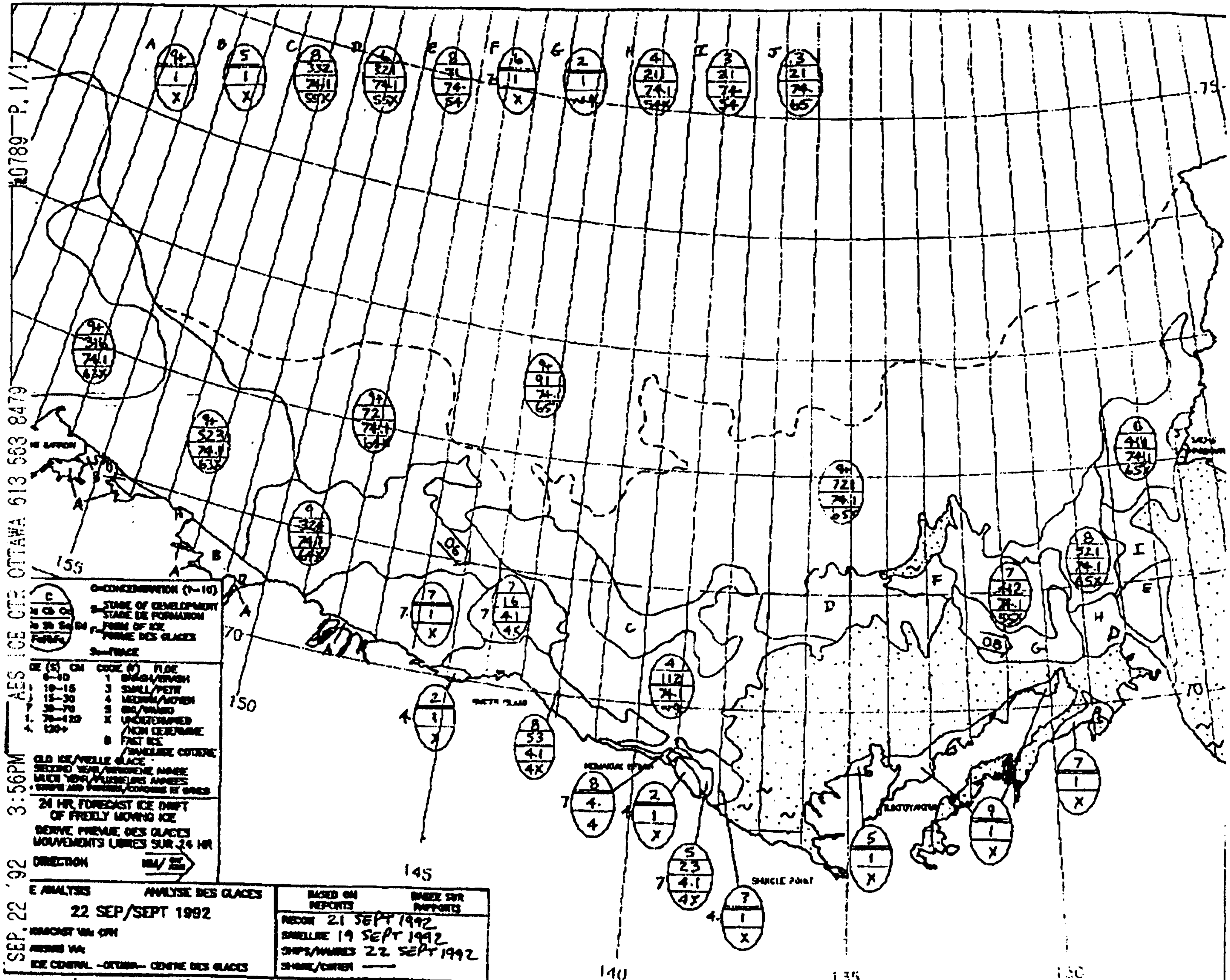



SEP. 20 '92 4:48PM AES ICE CTR OTTAWA 613 563 6479 #0750 P.1/1
E ANALYSIS ANALYSE DES GLACES
20 SEP/SEPT 1992
ICE CENTRAL -OTTAWA- CENTRE DES GLACES
BASED ON REPORTS / BASEE SUR RAPPORTS
RECON 18 SEPT. 1992
SATELLITE 18 SEPT. 1992
SHIPS/NAVIRES 20 SEPT. 1992
SHORE/COTIER NIL
C-CONCENTRATION (1-10)
S-STAGE OF DEVELOPMENT / STADE DE FORMATION
F-FORM OF ICE / FORME DES GLACES
24 HR FORECAST ICE DRIFT OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES MOUVEMENTS LIBRES SUR 24 HR
DIRECTION
OLD ICE/VIEILLE GLACE
SECOND YEAR/DEUXIEME ANNEE
FAST ICE
BARTER ISLAND
SHINGLE POINT
TUKTOYAKTUK
SACHS HARBOUR
PT BARROW
75
70
155
150
145
140
135
130

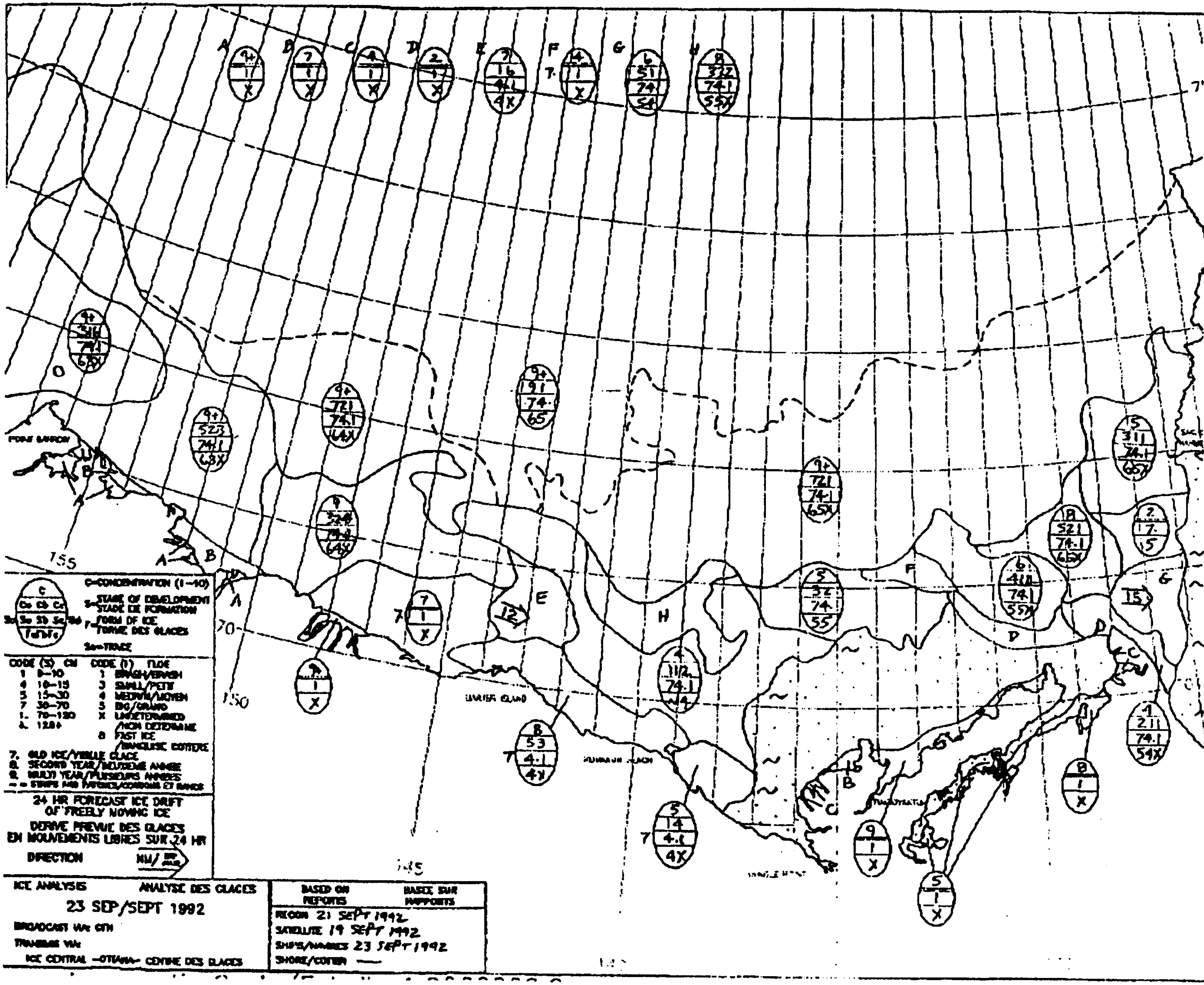


SEP 21 '92 6:24PM AES ICE CTR OTTAWA 613 563 8479 P.1/1

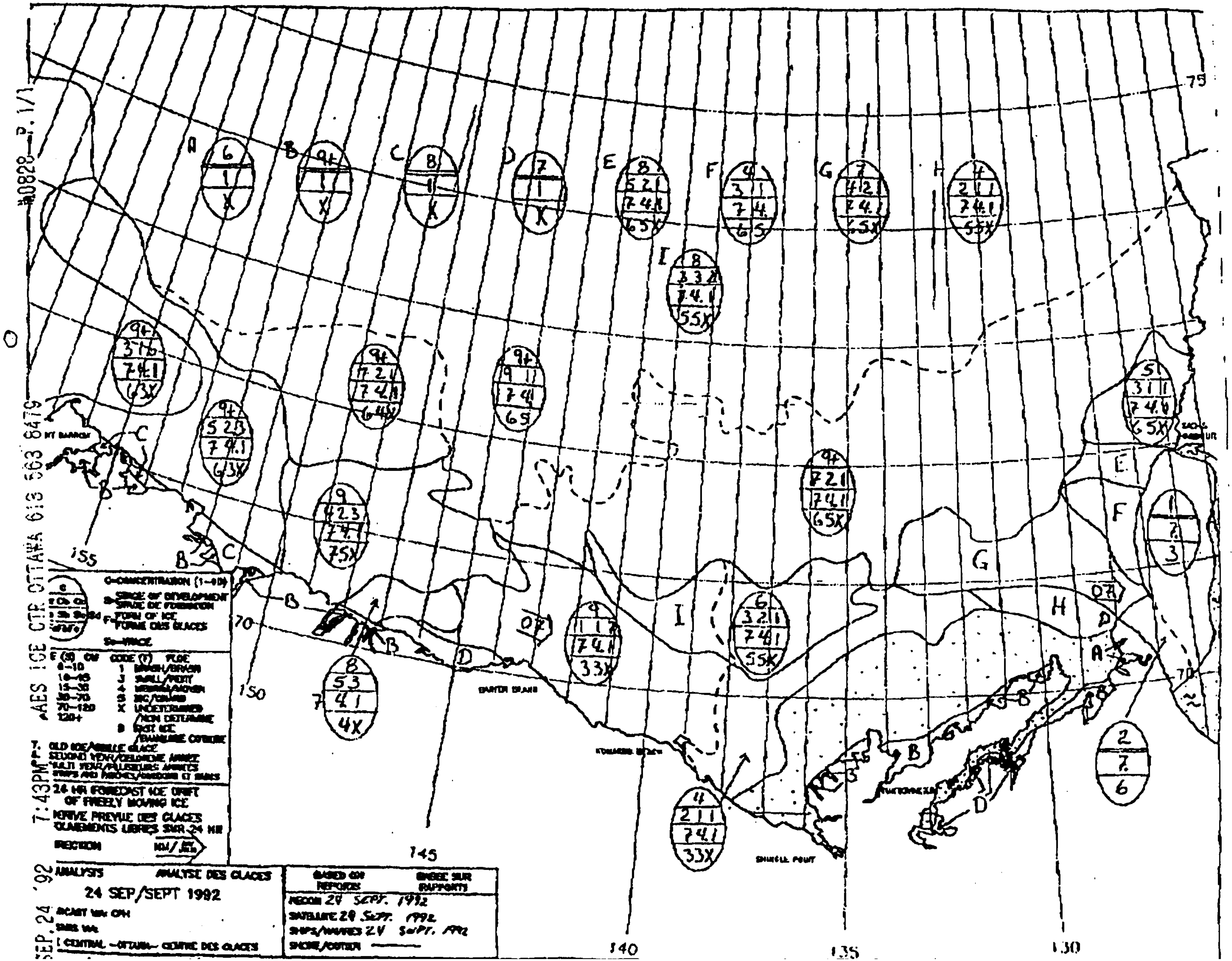
SEP 22 '92 3:56PM AES ICE CTR OTTAWA 613 563 8479 No.0789 P.1/1



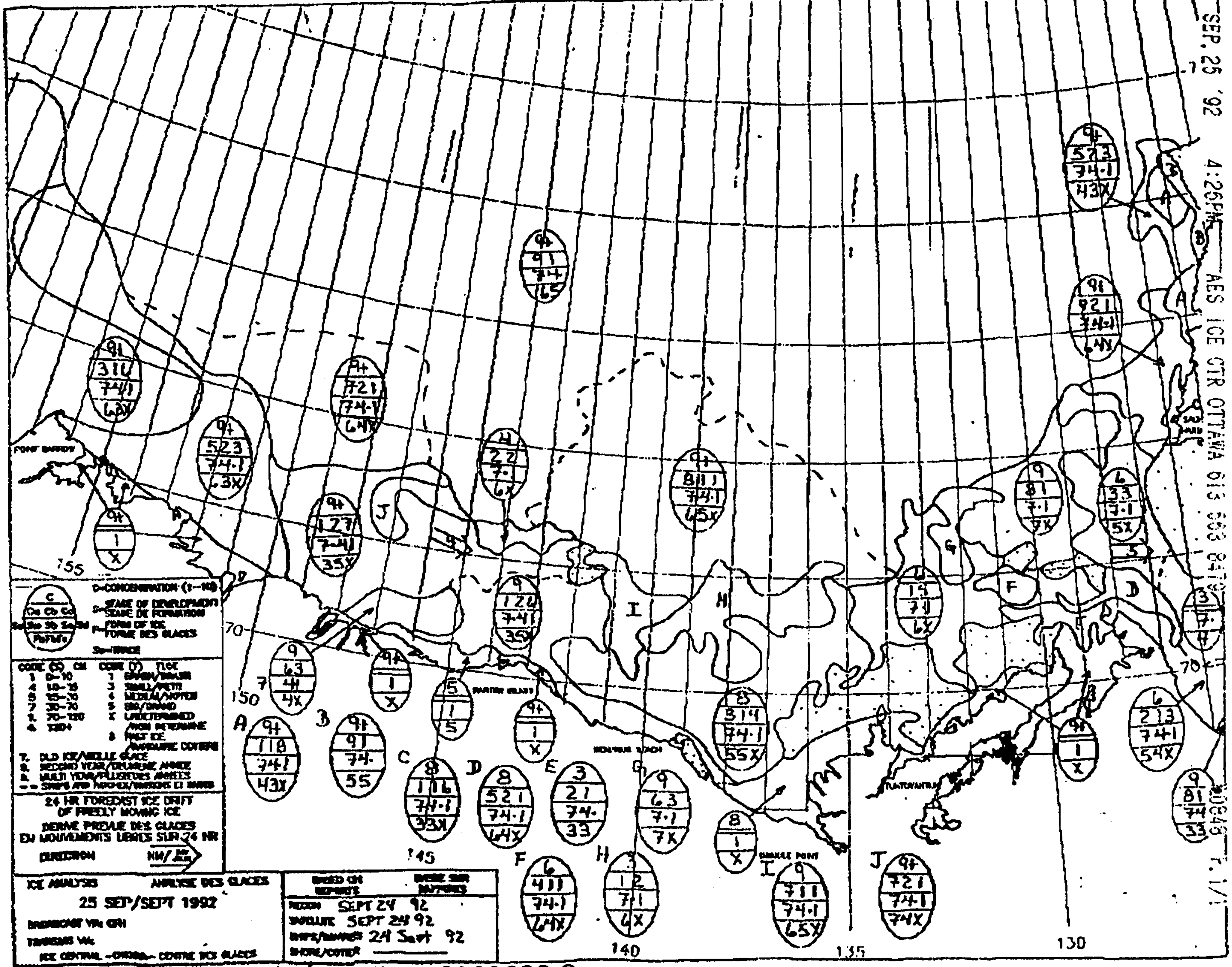
SEP. 23 '92 4:23PM AES ICE CTR OTTAWA



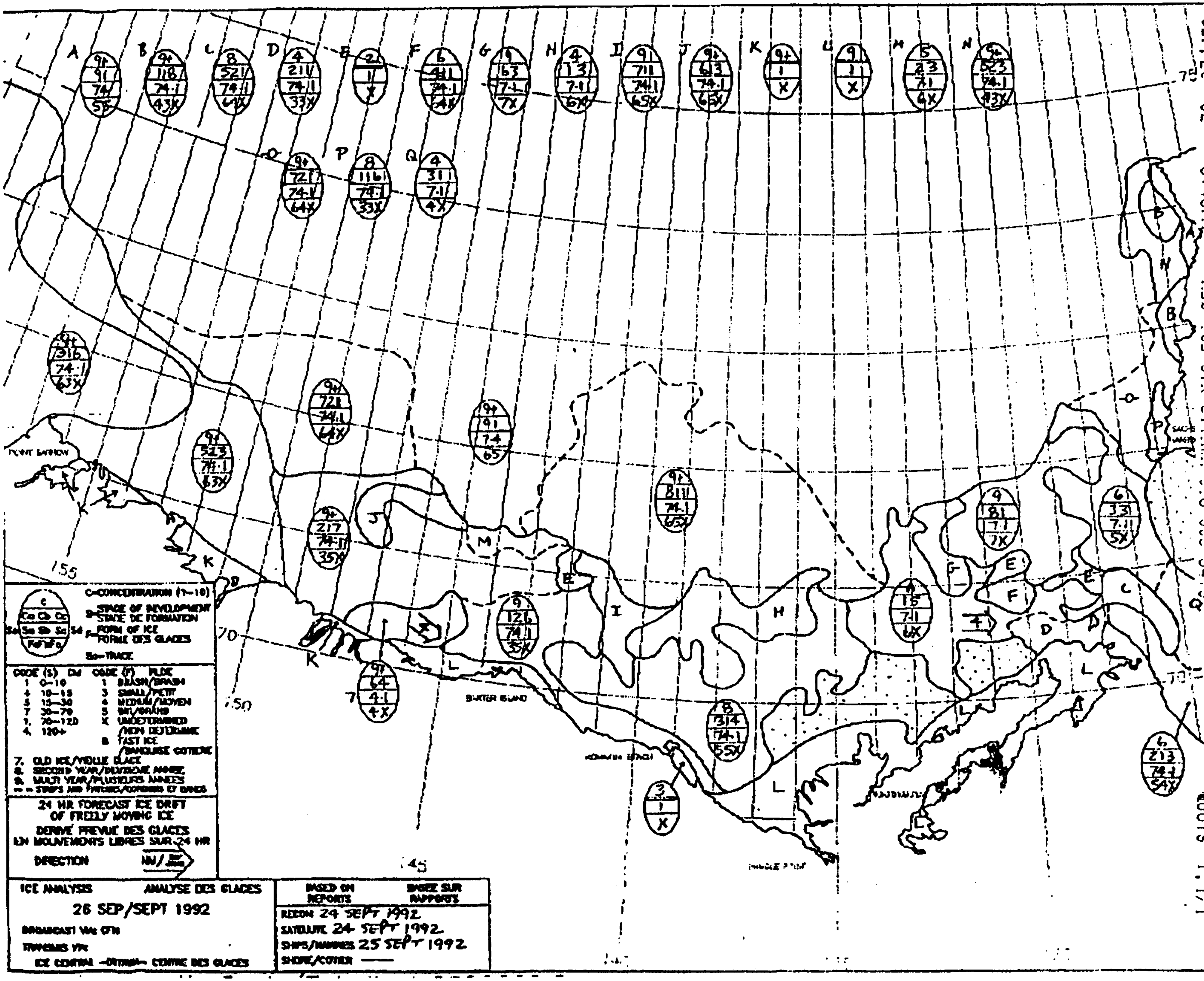
P. 1/1

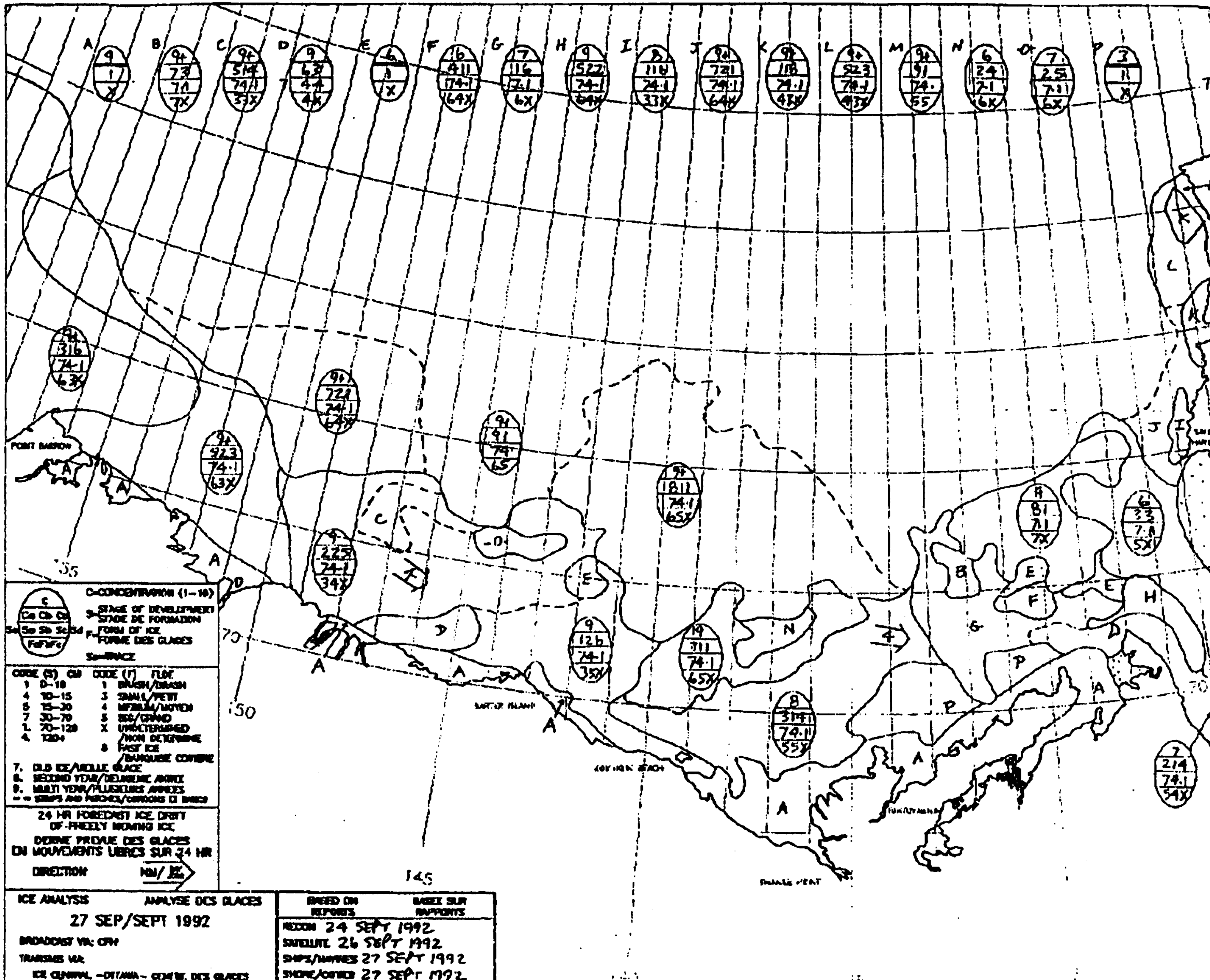


SEP. 24 '92 7:43PM
AES ICE CTR OTTAWA 613 563 8479
#0828 P.1/1
ANALYSIS ANALYSE DES GLACES
24 SEP/SEPT 1992
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON 24 SEPT. 1992
SATELLITE 24 SEPT. 1992
SHIPS/NAVIRES 24 SEPT. 1992
SHORE/COTIER
C-CONCENTRATION (1-10)
S-STAGE OF DEVELOPMENT
STADE DE FORMATION
F-FORM OF ICE
FORME DES GLACES
24 HR FORECAST ICE DRIFT OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES
DIRECTION
BARTER ISLAND
SHINGLE POINT
PT BARROW
75
70
155
150
145
140
135
130

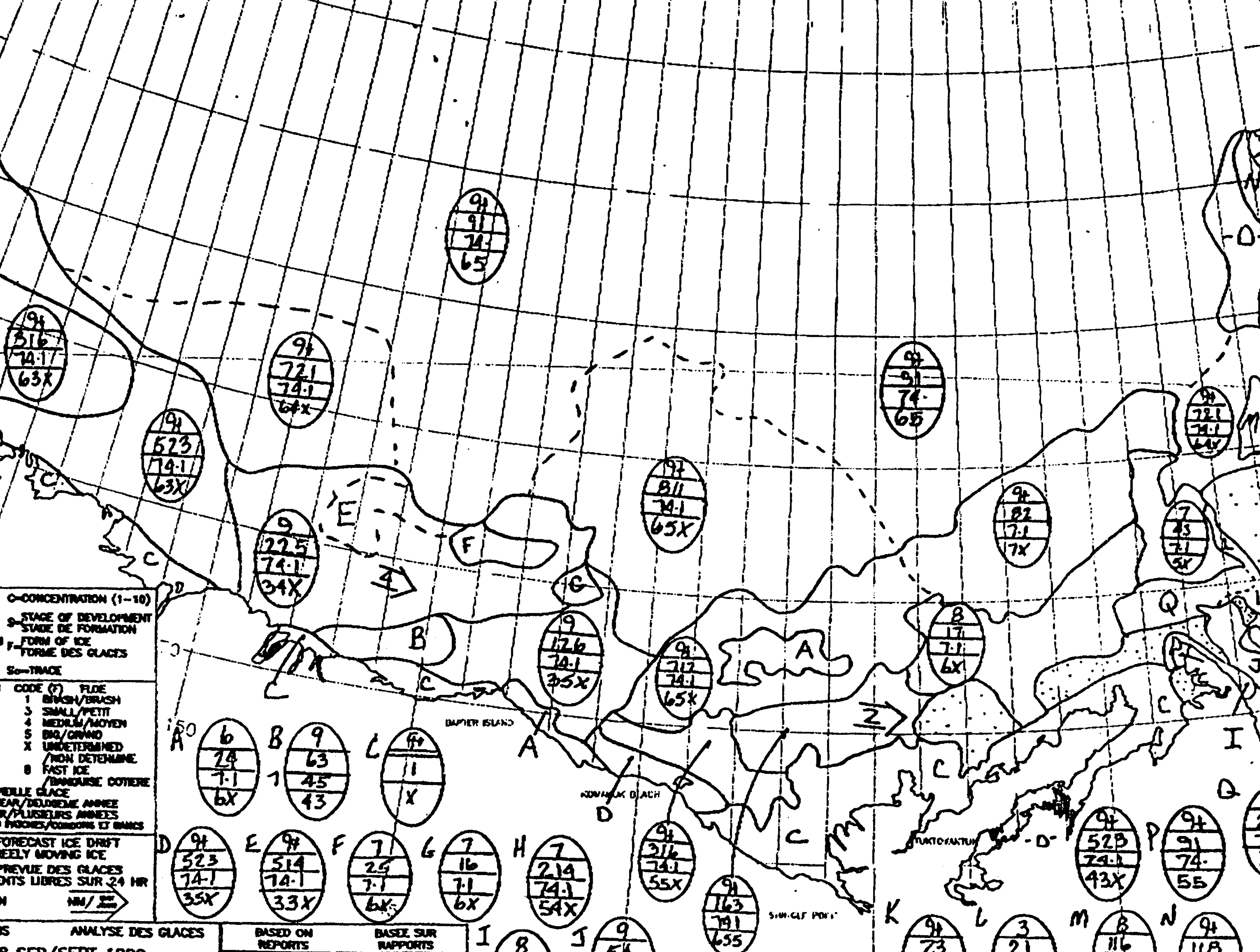


western arctic Scale/Echelle 1:2000000.0

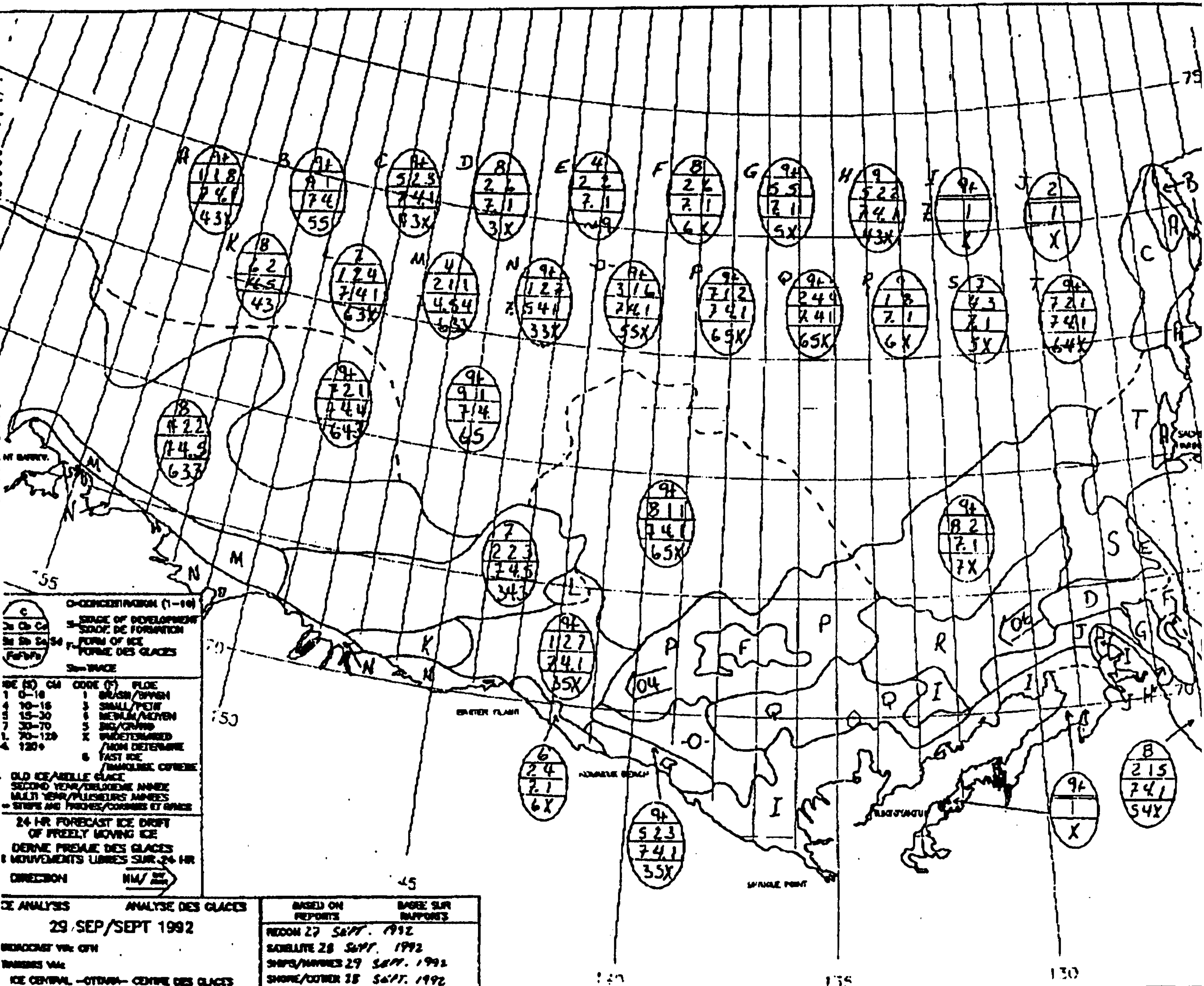

ICE ANALYSIS ANALYSE DES GLACES
26 SEP/SEPT 1992
BROADCAST VIA: CFH
TRANSMIS VIA:
ICE CENTRAL -OTTAWA- CENTRE DES GLACES
BASED ON REPORTS BASEE SUR RAPPORTS
RECON 24 SEPT 1992
SATELLITE 24 SEPT 1992
SHIPS/NAVIRES 25 SEPT 1992
SHORE/COTIER
24 HR FORECAST ICE DRIFT OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES EN MOUVEMENTS LIBRES SUR 24 HR
DIRECTION NM/
C-CONCENTRATION (1-10)
S-STAGE OF DEVELOPMENT
STADE DE FORMATION
F-FORM OF ICE
FORME DES GLACES
So-TRACE
CODE (S) CM
1 0-10
4 10-15
5 15-30
7 30-70
1. 70-120
4. 120+
CODE (F) FLOE
1 BRASH/BRASH
3 SMALL/PETIT
4 MEDIUM/MOYEN
5 BIG/GRAND
X UNDETERMINED /NON DETERMINE
8 FAST ICE /BANQUISE COTIERE
7. OLD ICE/VIEILLE GLACE
8. SECOND YEAR/DEUXIEME ANNEE
9. MULTI YEAR/PLUSIEURS ANNEES
STRIPS AND PATCHES/CORDONS ET BANCS
POINT BARROW
BARTER ISLAND
155
150
145
70
75

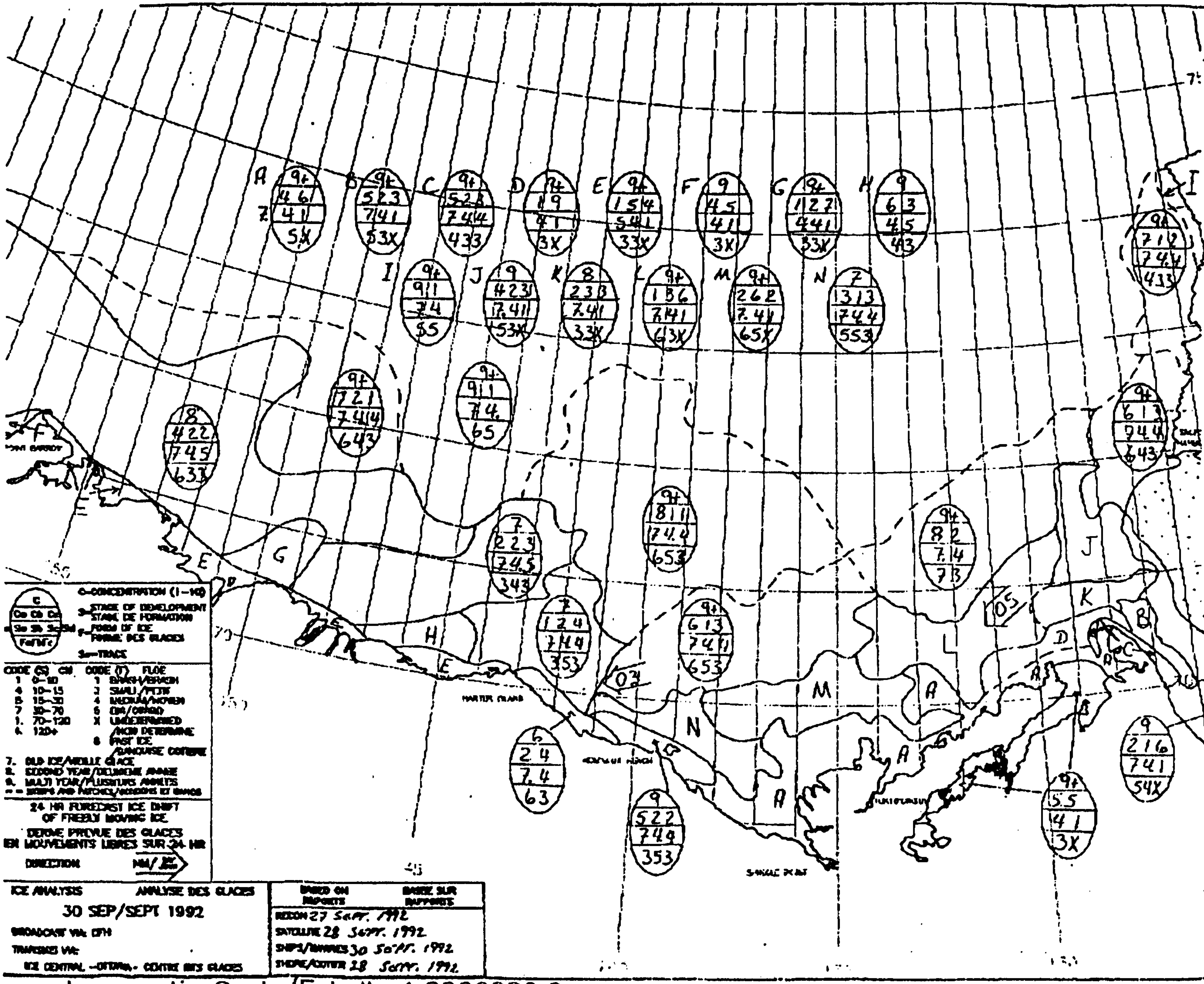


SEP. 27 '92 5:04PM AES ICE CTR OTTAWA NO895 P.1/1

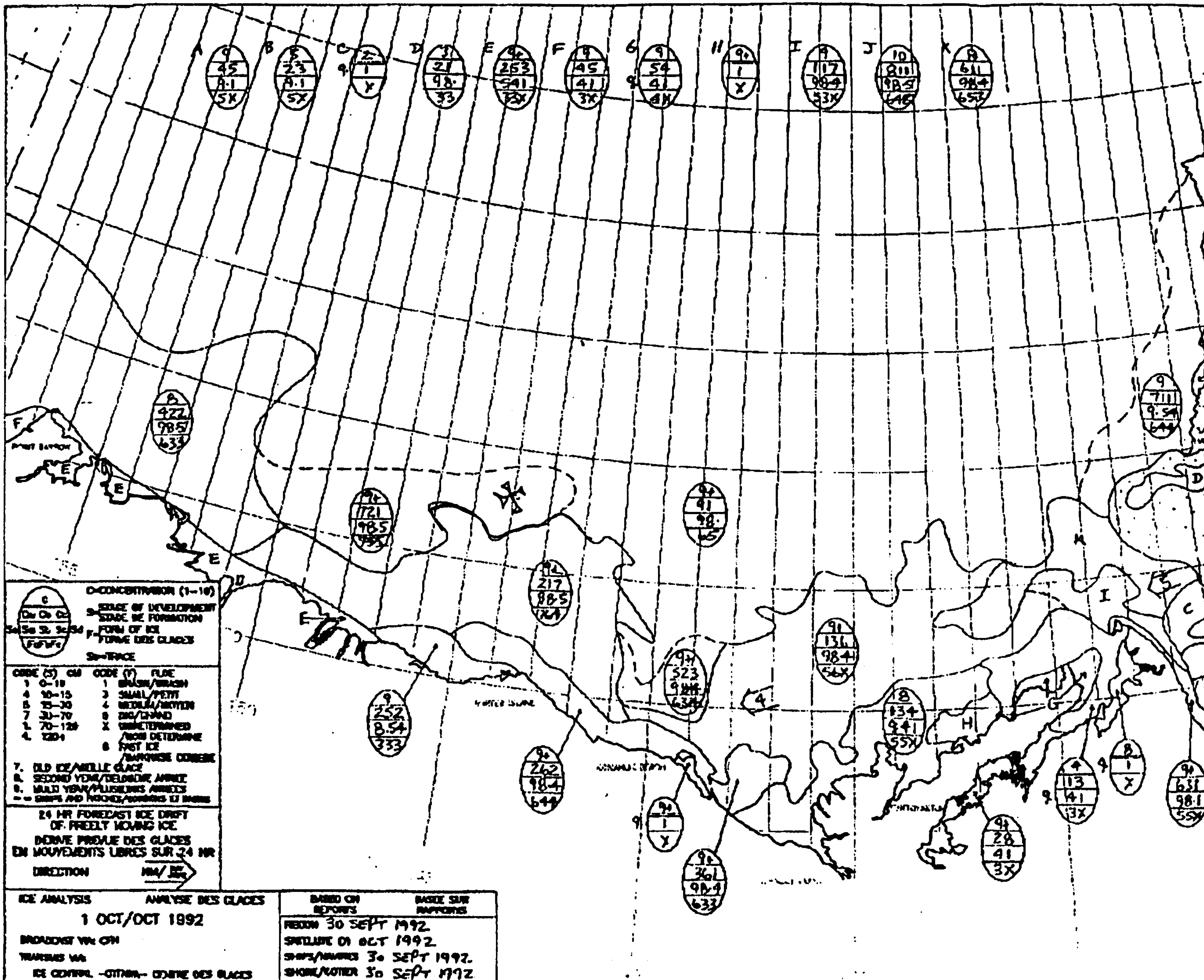

C—CONCENTRATION (1-10)
S—STAGE OF DEVELOPMENT / STADE DE FORMATION
F—FORM OF ICE / FORME DES GLACES
S—TRACE
CODE (F) FLOE
1 BRASH/BRASH
3 SMALL/PETIT
4 MEDIUM/MOYEN
5 BIG/GRAND
X UNDETERMINED /NON DETERMINE
8 FAST ICE /BANQUISE COTIERE
FORECAST ICE DRIFT
PREVUE DES GLACES
ANALYSE DES GLACES
BASED ON REPORTS
BASEE SUR RAPPORTS
TUKTOYAKTUK

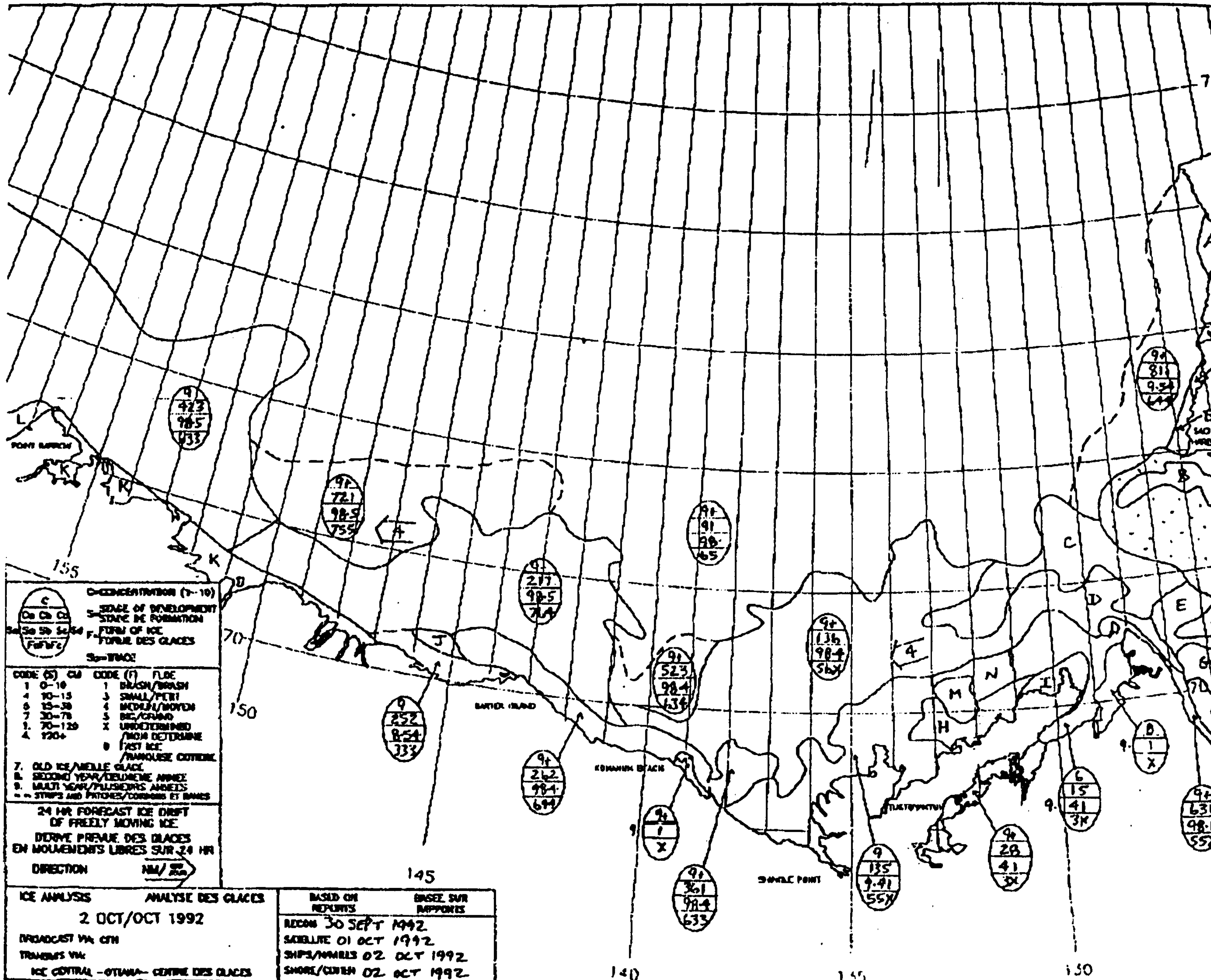
SEP. 29 '92 3:20PM AES ICE CTR OTTAWA 613 563 8479 #0930 P.1/1

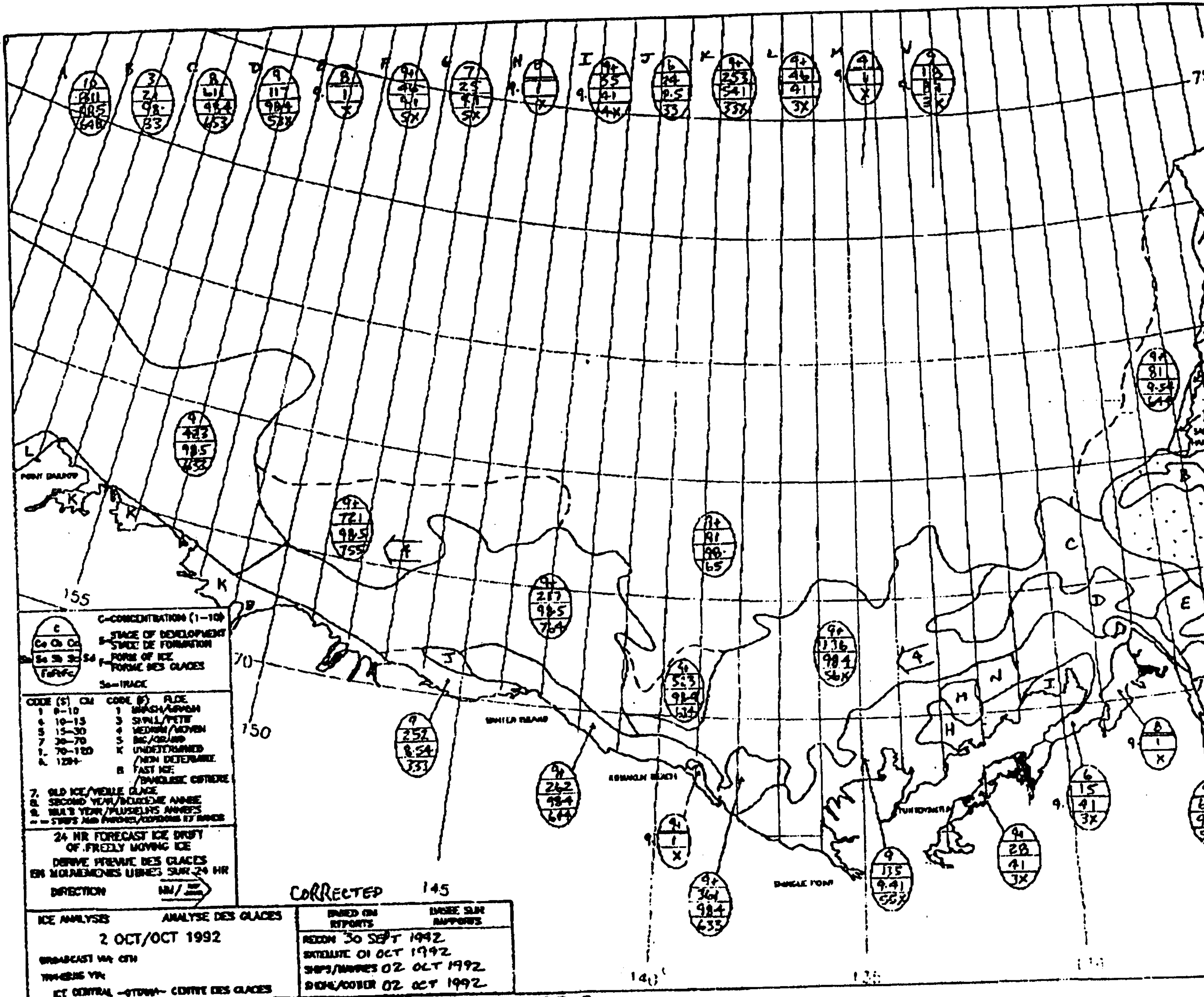




western arctic Scale/Echelle 1:2000000.0

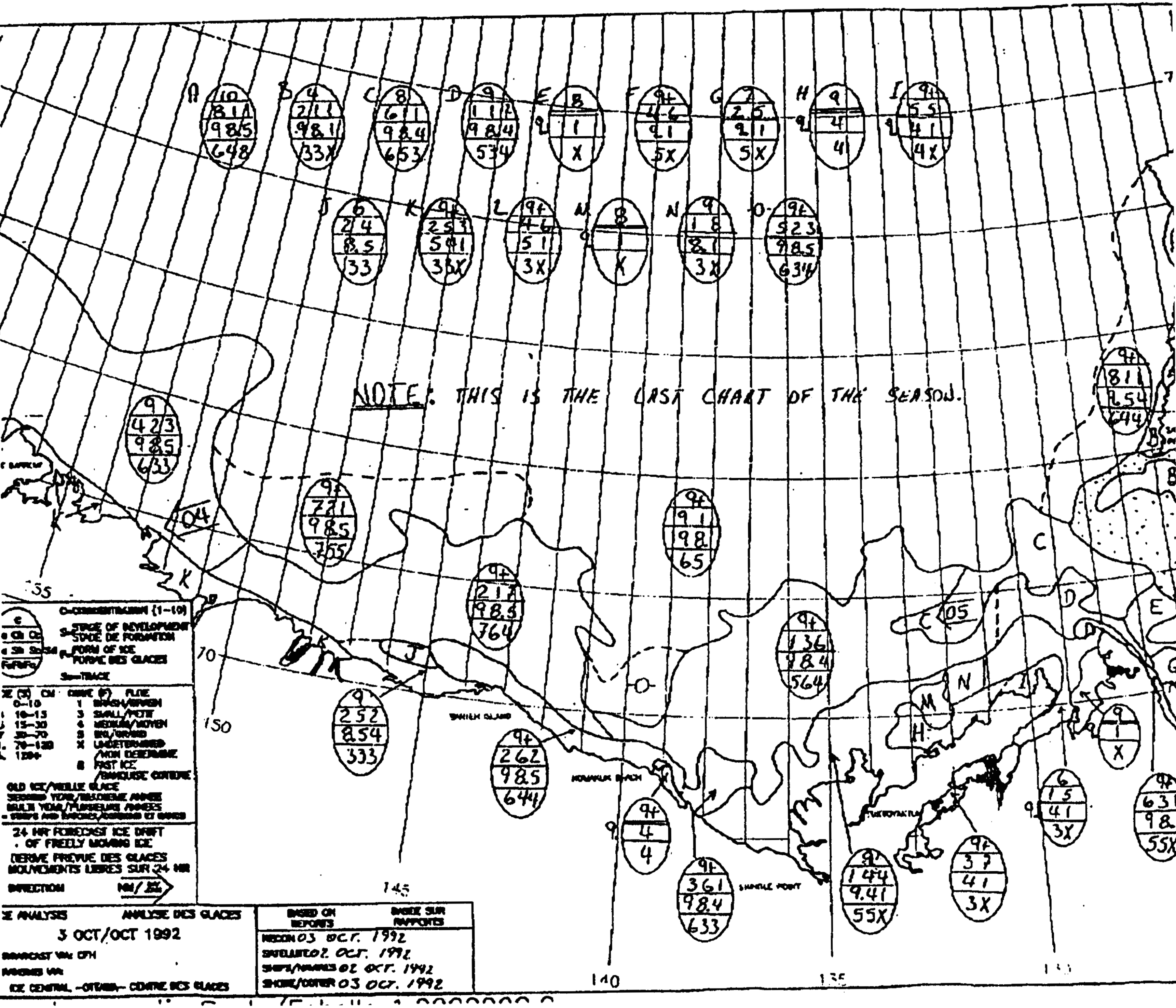

C-CONCENTRATION (1-10)
S-STAGE OF DEVELOPMENT
STADE DE FORMATION
F-FORM OF ICE
FORME DES GLACES
St-TRACE
CODE (S) CM
1 0-10
4 10-15
5 15-30
7 30-70
1. 70-120
4. 120+
CODE (F) FLOE
1 BRASH/BRASH
3 SMALL/PETIT
4 MEDIUM/MOYEN
5 BIG/GRAND
X UNDETERMINED
/NON DETERMINE
8 FAST ICE
/BANQUISE COTIERE
7. OLD ICE/VIEILLE GLACE
8. SECOND YEAR/DEUXIEME ANNEE
9. MULTI YEAR/PLUSIEURS ANNEES
24 HR FORECAST ICE DRIFT
OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES
EN MOUVEMENTS LIBRES SUR 24 HR
DIRECTION
ICE ANALYSIS
ANALYSE DES GLACES
1 OCT/OCT 1992
BROADCAST VIA: CFH
TRANSMIS VIA:
ICE CENTRAL -OTTAWA- CENTRE DES GLACES
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON 30 SEPT 1992
SATELLITE 01 OCT 1992
SHIPS/NAVIRES 30 SEPT 1992
SHORE/COTIER 30 SEPT 1992
POINT BARROW


POINT BARROW
BARTER ISLAND
SHINGLE POINT
TUKTOYAKTUK
155
150
145
140
130
70
ICE ANALYSIS ANALYSE DES GLACES
2 OCT/OCT 1992
BROADCAST VIA: CFH
ICE CENTRAL -OTTAWA- CENTRE DES GLACES
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON 30 SEPT 1992
SATELLITE 01 OCT 1992
SHIPS/NAVIRES 02 OCT 1992
SHORE/COTIER 02 OCT 1992
C=CONCENTRATION (1-10)
S=STAGE OF DEVELOPMENT STADE DE FORMATION
F=FORM OF ICE FORME DES GLACES
So=TRACE
CODE (S) CM
1 0-10
4 10-15
5 15-30
7 30-70
1. 70-120
4. 120+
CODE (F) FLOE
1 BRASH/BRASH
3 SMALL/PETIT
4 MEDIUM/MOYEN
5 BIG/GRAND
X UNDETERMINED /NON DETERMINE
8 FAST ICE /BANQUISE COTIERE
7. OLD ICE/VIEILLE GLACE
8. SECOND YEAR/DEUXIEME ANNEE
9. MULTI YEAR/PLUSIEURS ANNEES
24 HR FORECAST ICE DRIFT OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES EN MOUVEMENTS LIBRES SUR 24 HR
DIRECTION



C=CONCENTRATION (1-10)
S=STAGE OF DEVELOPMENT / STADE DE FORMATION
F=FORM OF ICE / FORME DES GLACES
CODE (S) CM
CODE (F) FLOE
1 BRASH/BRASH
3 SMALL/PETIT
4 MEDIUM/MOYEN
5 BIG/GRAND
K UNDETERMINED /NON DETERMINE
8 FAST ICE /BANQUISE COTIERE
7. OLD ICE/VIEILLE GLACE
8. SECOND YEAR/DEUXIEME ANNEE
9. MULTI YEAR/PLUSIEURS ANNEES
24 HR FORECAST ICE DRIFT OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES EN MOUVEMENTS LIBRES SUR 24 HR
DIRECTION
POINT BARROW
155
150
145
70
CORRECTED
ICE ANALYSIS
ANALYSE DES GLACES
2 OCT/OCT 1992
BROADCAST VIA: CFH
TRANSMIS VIA:
ICE CENTRAL —OTTAWA— CENTRE DES GLACES
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON 30 SEPT 1992
SATELLITE 01 OCT 1992
SHIPS/NAVIRES 02 OCT 1992
SHORE/COTIER 02 OCT 1992

OCT 3 '92 3:48PM AES ICE CTR OTTAWA 613 563 8479 No.1029 P.1/1



APPENDIX "2"

WHALE LOCATIONS

TAG #10824

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-02	20:51:00	tag	69.017N	137.350W			
1992-09-02	22:20:24	1	69.083N	137.393W	7.5	1.5	5.053
1992-09-03	00:11:45	0	69.105N	137.128W	10.8	1.9	5.813
1992-09-03	06:37:26	0	69.162N	137.263W	8.3	6.4	1.289
1992-09-03	13:34:58	0	69.232N	137.651W	17.2	7.0	2.468
1992-09-03	15:43:34	0	69.223N	137.044W	23.9	2.1	11.170
1992-09-03	20:19:31	0	69.314N	137.170W	11.3	4.6	2.448
1992-09-03	23:58:19	0	69.322N	136.623W	21.5	3.6	5.891
1992-09-04	04:34:34	0	69.572N	135.636W	47.5	4.6	10.311
1992-09-04	17:12:33	0	70.159N	139.708W	168.8	12.6	13.362
1992-09-05	01:01:47	0	69.551N	138.553W	80.7	7.8	10.322
1992-09-05	01:28:43	1	69.646N	138.472W	11.0	0.4	24.532
1992-09-05	02:38:14	0	69.558N	138.511W	9.9	1.2	8.540
1992-09-05	04:19:47	0	69.608N	138.507W	5.6	1.7	3.284
1992-09-05	05:58:03	0	69.633N	138.612W	4.9	1.6	3.005
1992-09-05	07:41:51	0	69.599N	138.582W	4.0	1.7	2.285
1992-09-05	13:35:55	1	69.724N	138.720W	14.9	5.9	2.521
1992-09-05	18:39:02	0	69.761N	138.982W	10.9	5.1	2.155
1992-09-05	19:44:06	0	69.668N	139.026W	10.5	1.1	9.657
1992-09-05	21:14:49	0	69.733N	139.164W	9.0	1.5	5.933
1992-09-05	22:01:21	0	69.833N	139.160W	11.1	0.8	14.328
1992-09-05	22:55:19	0	69.817N	139.278W	4.9	0.9	5.402
1992-09-05	23:40:06	0	69.797N	139.392W	4.9	0.7	6.571
1992-09-06	00:33:28	0	69.824N	139.415W	3.1	0.9	3.516
1992-09-06	01:15:50	2	69.848N	139.347W	3.7	0.7	5.279
1992-09-06	02:14:35	1	69.863N	139.545W	7.8	1.0	7.923
1992-09-06	07:19:24	0	69.824N	139.529W	4.4	5.1	0.861
1992-09-06	18:27:29	0	69.879N	140.382W	33.2	11.1	2.983
1992-09-06	19:14:51	0	69.937N	140.642W	11.8	0.8	14.989
1992-09-07	00:17:01	0	69.924N	140.715W	3.1	5.0	0.623
1992-09-07	01:08:02	0	69.915N	140.710W	1.0	0.9	1.198
1992-09-07	13:13:28	0	70.001N	139.038W	64.4	12.1	5.325
1992-09-07	18:16:08	0	70.586N	137.821W	79.4	5.0	15.739
1992-09-08	00:56:49	0	70.239N	141.405W	138.9	6.7	20.805
1992-09-08	02:33:57	0	70.265N	141.277W	5.6	1.6	3.463
1992-09-08	06:38:59	0	70.288N	141.560W	10.9	4.1	2.673
1992-09-08	13:01:15	0	70.411N	141.850W	17.4	6.4	2.738
1992-09-08	14:41:24	0	70.352N	141.444W	16.5	1.7	9.888
1992-09-08	16:23:39	0	70.427N	141.825W	16.5	1.7	9.665
1992-09-08	18:04:00	0	70.385N	141.759W	5.3	1.7	3.154
1992-09-08	19:45:13	0	70.436N	141.884W	7.3	1.7	4.348
1992-09-08	21:57:46	0	70.427N	141.950W	2.7	2.2	1.200
1992-09-09	01:14:38	0	70.408N	141.921W	2.4	3.3	0.723
1992-09-09	06:12:42	1	70.505N	141.976W	11.0	5.0	2.208
1992-09-09	07:53:13	0	70.592N	141.916W	9.9	1.7	5.921
1992-09-09	11:06:59	0	70.474N	142.039W	13.9	3.2	4.298
1992-09-09	21:30:57	0	70.485N	141.981W	2.5	10.4	0.238
1992-09-10	00:30:33	0	70.437N	141.894W	6.2	3.0	2.084
1992-09-10	07:34:49	0	70.453N	141.342W	20.6	7.1	2.914
1992-09-10	15:54:52	0	70.575N	141.051W	17.3	8.3	2.078

TAG #10824

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-10	19:27:37	1	70.535N	140.677W	14.5	3.5	4.098
1992-09-11	00:17:06	1	70.479N	140.693W	6.3	4.8	1.296
1992-09-11	02:09:10	0	70.393N	140.775W	10.0	1.9	5.370
1992-09-11	07:11:58	0	70.243N	140.493W	19.7	5.0	3.909
1992-09-11	12:22:54	0	70.247N	140.364W	4.9	5.2	0.939
1992-09-11	13:58:55	0	70.287N	140.085W	11.4	1.6	7.106
1992-09-11	20:40:22	0	70.832N	137.740W	105.8	6.7	15.807
1992-09-12	06:53:20	0	69.694N	138.765W	132.2	10.2	12.936
1992-09-12	18:53:14	1	69.842N	140.826W	80.9	12.0	6.741
1992-09-13	01:28:03	0	69.880N	141.096W	11.2	6.6	1.696
1992-09-13	01:36:42	0	69.871N	141.178W	3.3	0.1	22.823
1992-09-13	03:05:18	0	69.854N	141.360W	7.2	1.5	4.885
1992-09-13	03:19:34	0	69.892N	141.253W	5.9	0.2	24.725
1992-09-13	18:27:22	0	70.084N	142.152W	40.3	15.1	2.663
1992-09-13	20:10:21	0	70.024N	142.141W	6.7	1.7	3.891
1992-09-13	21:45:40	1	70.009N	142.150W	1.7	1.6	1.071
1992-09-13	23:29:56	0	70.047N	142.273W	6.3	1.7	3.622
1992-09-14	01:03:51	3	70.038N	142.226W	2.0	1.6	1.305
1992-09-14	01:27:03	0	70.029N	142.256W	1.5	0.4	3.919
1992-09-14	02:48:40	0	70.001N	142.241W	3.2	1.4	2.325
1992-09-14	07:50:07	0	70.079N	142.325W	9.2	5.0	1.838
1992-09-14	14:40:14	0	70.234N	142.124W	18.8	6.8	2.753
1992-09-14	19:45:23	0	70.253N	141.982W	5.7	5.1	1.128
1992-09-14	21:27:49	0	70.303N	142.266W	12.0	1.7	7.036
1992-09-14	23:03:12	0	70.434N	142.615W	19.5	1.6	12.288
1992-09-15	01:13:08	0	70.385N	142.780W	8.2	2.2	3.792
1992-09-15	02:50:15	0	70.409N	142.956W	7.1	1.6	4.375
1992-09-15	19:27:27	0	70.200N	143.782W	38.7	16.6	2.327
1992-09-15	22:47:38	0	70.253N	144.544W	29.2	3.3	8.765
1992-09-16	00:27:48	0	70.157N	144.308W	13.9	1.7	8.314
1992-09-16	02:03:52	0	70.249N	144.701W	18.0	1.6	11.229
1992-09-16	07:04:50	0	70.403N	144.740W	17.2	5.0	3.424
1992-09-16	11:21:43	0	70.433N	144.859W	5.5	4.3	1.295
1992-09-16	17:20:09	0	70.508N	145.137W	13.3	6.0	2.221
1992-09-16	18:04:18	1	70.515N	145.009W	4.8	0.7	6.534
1992-09-16	18:57:33	0	70.566N	145.251W	10.6	0.9	11.943
1992-09-17	01:44:07	0	70.469N	145.615W	17.3	6.8	2.548
1992-09-17	03:22:17	0	70.547N	145.525W	9.3	1.6	5.676
1992-09-17	05:05:59	0	70.446N	145.340W	13.2	1.7	7.611
1992-09-17	12:54:06	0	70.381N	146.127W	30.2	7.8	3.870
1992-09-17	19:28:46	0	70.656N	146.106W	30.6	6.6	4.647
1992-09-17	22:48:17	0	70.681N	146.375W	10.3	3.3	3.090
1992-09-18	02:12:24	0	70.849N	147.602W	48.6	3.4	14.297
1992-09-18	12:34:13	0	70.972N	145.495W	77.8	10.4	7.504
1992-09-18	15:59:45	0	70.932N	146.984W	54.2	3.4	15.815
1992-09-18	18:20:21	0	70.883N	146.942W	5.7	2.3	2.413
1992-09-18	19:26:12	0	70.891N	147.053W	4.1	1.1	3.767
1992-09-18	19:58:22	2	70.920N	147.107W	3.8	0.5	7.038
1992-09-18	21:38:31	2	70.910N	147.273W	6.1	1.7	3.674
1992-09-19	00:23:17	1	70.918N	147.443W	6.2	2.7	2.272

TAG #10824

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-19	00:56:59	3	70.897N	147.370W	3.5	0.6	6.290
1992-09-19	02:07:00	0	70.961N	147.593W	10.8	1.2	9.234
1992-09-19	02:38:43	2	70.945N	147.757W	6.2	0.5	11.742
1992-09-19	14:05:45	0	71.080N	148.403W	27.8	11.5	2.424
1992-09-19	15:52:05	0	71.018N	148.658W	11.5	1.8	6.486
1992-09-19	17:32:45	0	71.097N	149.196W	21.3	1.7	12.694
1992-09-19	18:02:19	0	71.150N	149.348W	8.0	0.5	16.302
1992-09-20	12:12:45	0	71.216N	150.982W	59.0	18.2	3.247
1992-09-20	13:59:33	0	71.289N	150.998W	8.1	1.8	4.568
1992-09-20	19:03:11	0	71.068N	151.287W	26.7	5.1	5.266
1992-09-20	22:21:19	0	71.323N	151.733W	32.5	3.3	9.850
1992-09-21	00:17:47	0	71.284N	151.437W	11.4	1.9	5.872
1992-09-21	06:56:30	0	71.210N	152.893W	52.7	6.6	7.924
1992-09-21	08:37:24	0	71.141N	152.727W	9.7	1.7	5.772
1992-09-21	12:02:09	0	71.305N	153.351W	28.8	3.4	8.443
1992-09-21	13:44:16	0	71.291N	153.628W	10.0	1.7	5.870
1992-09-21	19:01:01	0	71.016N	153.365W	32.0	5.3	6.058
1992-09-21	22:15:32	1	71.241N	154.384W	44.3	3.2	13.677
1992-09-22	01:35:31	1	71.254N	154.661W	10.0	3.3	3.000
1992-09-22	03:18:41	0	71.234N	154.833W	6.5	1.7	3.800
1992-09-22	04:54:18	0	71.308N	154.741W	8.9	1.6	5.555
1992-09-22	06:38:28	0	71.289N	155.249W	18.2	1.7	10.495
1992-09-22	10:06:32	0	71.413N	155.482W	16.1	3.5	4.635
1992-09-22	11:46:31	0	71.403N	155.693W	7.6	1.7	4.535
1992-09-22	15:11:19	0	71.486N	155.535W	10.8	3.4	3.159
1992-09-22	16:50:12	0	71.479N	155.971W	15.4	1.6	9.347
1992-09-22	18:39:09	0	71.608N	156.378W	20.3	1.8	11.157
1992-09-22	20:15:25	0	71.572N	155.955W	15.4	1.6	9.581
1992-09-23	06:14:30	0	71.608N	156.231W	10.5	10.0	1.049
1992-09-23	07:57:11	0	71.609N	156.377W	5.1	1.7	2.991
1992-09-23	13:16:12	0	71.625N	156.715W	12.0	5.3	2.252
1992-09-23	14:59:50	0	71.614N	157.067W	12.4	1.7	7.175
1992-09-23	18:13:37	0	71.640N	157.544W	17.0	3.2	5.249
1992-09-24	04:15:16	0	71.406N	158.482W	42.0	10.0	4.192
1992-09-24	05:52:41	0	71.427N	158.475W	2.3	1.6	1.445
1992-09-24	16:10:09	0	71.433N	159.696W	43.2	10.3	4.199
1992-09-24	19:31:35	0	71.556N	159.740W	13.8	3.4	4.097
1992-09-25	02:14:26	0	71.407N	160.284W	25.4	6.7	3.776
1992-09-25	04:10:53	0	71.404N	160.492W	7.4	1.9	3.801
1992-09-25	14:37:42	0	71.229N	161.476W	40.1	10.4	3.834
1992-09-25	15:51:38	0	71.172N	161.995W	19.6	1.2	15.933
1992-09-25	17:59:52	0	71.148N	161.736W	9.7	2.1	4.524
1992-09-25	19:13:20	1	71.168N	162.069W	12.2	1.2	9.927
1992-09-25	22:35:51	0	71.132N	162.235W	7.2	3.4	2.126
1992-09-26	04:02:15	0	71.081N	162.882W	24.0	5.4	4.404
1992-09-26	05:13:00	0	71.085N	162.920W	1.4	1.2	1.220
1992-09-26	05:44:57	0	71.008N	162.927W	8.6	0.5	16.072
1992-09-26	06:47:40	0	71.030N	163.495W	20.7	1.0	19.776
1992-09-26	08:30:03	0	71.053N	163.379W	4.9	1.7	2.875

TAG #10824

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-26	17:13:52	0	70.914N	164.320W	37.4	8.7	4.285
1992-09-26	19:22:00	0	70.865N	164.757W	16.8	2.1	7.868
1992-09-27	02:11:01	0	71.009N	165.362W	27.2	6.8	3.985
1992-09-27	03:04:41	0	71.016N	165.755W	14.2	0.9	15.908
1992-09-27	06:26:07	0	71.103N	165.889W	10.8	3.4	3.219
1992-09-27	08:11:51	1	71.128N	166.034W	5.9	1.8	3.352
1992-09-27	15:55:05	0	71.210N	166.772W	28.0	7.7	3.626
1992-09-27	16:49:00	0	71.158N	166.758W	5.8	0.9	6.455
1992-09-27	17:33:07	0	71.255N	167.048W	15.0	0.7	20.352
1992-09-27	18:27:45	0	71.205N	166.808W	10.2	0.9	11.226
1992-09-27	20:54:51	0	71.346N	167.102W	18.9	2.5	7.689
1992-09-27	21:48:49	0	71.355N	167.032W	2.7	0.9	2.981
1992-09-28	03:35:37	0	71.501N	167.582W	25.3	5.8	4.384
1992-09-28	04:26:22	0	71.513N	167.475W	4.0	0.8	4.729
1992-09-28	06:10:52	0	71.522N	166.763W	25.1	1.7	14.411
1992-09-28	13:57:28	0	71.810N	167.259W	36.4	7.8	4.680
1992-09-28	18:06:25	0	71.881N	167.429W	9.8	4.1	2.372
1992-09-28	22:22:02	1	72.037N	167.580W	18.1	4.3	4.248
1992-09-28	23:10:17	0	72.050N	167.434W	5.2	0.8	6.473
1992-09-29	00:06:23	0	71.917N	167.956W	23.2	0.9	24.857
1992-09-29	01:48:16	0	72.111N	167.165W	34.7	1.7	20.410
1992-09-29	03:27:07	0	72.162N	167.664W	17.9	1.6	10.881
1992-09-29	04:07:31	0	72.119N	167.967W	11.4	0.7	16.896
1992-09-29	05:11:39	0	72.139N	167.779W	6.8	1.1	6.347
1992-09-29	05:45:21	2	72.180N	168.123W	12.6	0.6	22.370
1992-09-29	12:07:58	0	72.048N	167.945W	15.9	6.4	2.489
1992-09-29	13:50:40	0	71.976N	168.367W	16.5	1.7	9.665
1992-09-29	15:28:56	0	71.966N	168.167W	7.0	1.6	4.254
1992-09-29	19:23:50	0	71.959N	168.361W	6.7	3.9	1.716
1992-09-29	20:32:59	0	71.835N	168.799W	20.5	1.2	17.751
1992-09-29	21:13:19	0	71.834N	168.696W	3.6	0.7	5.310
1992-09-29	22:44:07	0	72.052N	169.085W	27.7	1.5	18.291
1992-09-30	05:27:28	0	71.869N	169.140W	20.4	6.7	3.038
1992-09-30	07:05:17	1	71.755N	169.689W	22.9	1.6	14.028
1992-09-30	13:35:59	0	71.653N	170.007W	15.9	6.5	2.435
1992-09-30	20:24:07	0	71.436N	170.145W	24.6	6.8	3.616
1992-10-01	00:01:57	0	71.555N	170.179W	13.3	3.6	3.657
1992-10-01	02:56:29	0	71.406N	170.614W	22.6	2.9	7.762
1992-10-01	06:42:48	0	71.367N	170.925W	11.9	3.8	3.142
1992-10-01	13:25:14	0	71.309N	171.508W	21.7	6.7	3.236
1992-10-01	16:59:59	0	71.440N	171.564W	14.7	3.6	4.105
1992-10-01	18:39:52	0	71.544N	171.496W	11.8	1.7	7.089
1992-10-02	01:07:02	0	71.442N	172.550W	38.9	6.5	6.023
1992-10-02	02:52:20	0	71.471N	172.763W	8.2	1.8	4.665
1992-10-02	04:29:27	0	71.458N	172.425W	12.0	1.6	7.430
1992-10-02	06:15:13	0	71.399N	172.400W	6.6	1.8	3.753
1992-10-02	18:13:58	0	71.290N	172.982W	24.0	12.0	2.001
1992-10-03	18:07:01	0	71.311N	176.553W	127.2	23.9	5.326
1992-10-04	05:51:25	0	70.614N	175.883W	81.2	11.7	6.913

TAG #10824

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-10-04	19:21:59	0	70.479N	175.596W	18.4	13.5	1.361
1992-10-04	22:42:35	0	70.548N	176.666W	40.4	3.3	12.082
1992-10-05	00:22:24	0	70.206N	176.458W	38.8	1.7	23.314
1992-10-05	01:57:00	1	70.176N	176.573W	5.5	1.6	3.466
1992-10-05	07:02:13	0	69.974N	176.787W	23.9	5.1	4.691
1992-10-05	08:40:21	0	69.966N	177.171W	14.6	1.6	8.952

Total distance traveled = 4052.6

TAG #10825

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-02	23:30:00	tag	69.100N	137.417W			
1992-09-03	15:41:58	0	69.653N	139.622W	105.9	16.2	6.539
1992-09-03	20:19:55	0	69.323N	137.730W	82.3	4.6	17.761
1992-09-05	11:53:28	0	70.203N	140.199W	136.2	39.6	3.444
1992-09-06	13:28:45	0	69.693N	141.180W	67.9	25.6	2.653
1992-09-06	18:25:47	0	69.655N	140.818W	14.6	5.0	2.948
1992-09-06	19:22:09	0	69.716N	140.693W	8.3	0.9	8.854
1992-09-07	01:04:35	0	69.633N	140.696W	9.2	5.7	1.616
1992-09-07	06:57:48	0	69.645N	141.069W	14.5	5.9	2.460
1992-09-07	16:31:17	0	69.669N	141.023W	3.2	9.6	0.335
1992-09-07	18:12:34	0	69.706N	141.033W	4.1	1.7	2.446
1992-09-07	18:55:46	0	69.682N	141.016W	2.7	0.7	3.814
1992-09-08	01:32:04	0	69.651N	140.767W	10.2	6.6	1.546
1992-09-08	04:52:40	0	69.645N	140.974W	8.0	3.3	2.401
1992-09-08	17:58:18	0	69.598N	140.901W	5.9	13.1	0.453
1992-09-09	19:55:31	0	70.117N	140.572W	59.0	26.0	2.274
1992-09-10	04:06:13	0	70.117N	137.991W	97.5	8.2	11.925
1992-09-10	20:57:45	0	70.097N	138.586W	22.6	16.9	1.341

Total distance traveled = 652.3

TAG #10826

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-05	19:29:00	tag	69.100N	137.083W			
1992-09-06	18:22:50	0	69.049N	136.496W	24.0	22.9	1.047
1992-09-07	00:13:32	0	69.147N	136.730W	14.3	5.8	2.447
1992-09-08	00:57:14	0	69.087N	137.105W	16.3	24.7	0.658
1992-09-08	01:32:37	1	69.105N	137.228W	5.3	0.6	8.938
1992-09-08	06:33:23	1	69.058N	136.997W	10.5	5.0	2.104

Total distance traveled = 70.4

TAG # 10827

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-03	20:49:00	tag	69.117N	137.100W			
1992-09-04	08:00:51	0	69.190N	137.699W	25.0	11.2	2.236
1992-09-04	14:59:42	0	69.587N	137.443W	45.2	7.0	6.480
1992-09-04	19:59:36	0	69.264N	136.011W	66.4	5.0	13.292
1992-09-05	02:35:50	0	69.582N	135.877W	35.7	6.6	5.409
1992-09-05	13:34:37	0	69.717N	137.896W	79.4	11.0	7.235
1992-09-05	16:58:11	0	69.654N	136.286W	62.5	3.4	18.421
1992-09-06	00:35:21	0	69.618N	136.791W	19.9	7.6	2.616
1992-09-06	13:22:04	0	69.769N	139.353W	100.2	12.8	7.841
1992-09-06	15:55:10	0	69.850N	138.407W	37.4	2.6	14.648
1992-09-07	00:14:47	0	69.582N	138.880W	34.9	8.3	4.192
1992-09-07	06:53:35	0	69.721N	139.201W	19.8	6.6	2.980
1992-09-07	13:49:23	0	69.679N	139.627W	17.1	6.9	2.463
1992-09-07	20:33:39	1	69.670N	139.444W	7.1	6.7	1.059
1992-09-07	21:36:12	0	69.686N	139.502W	2.9	1.0	2.741
1992-09-07	22:16:34	0	69.635N	139.411W	6.7	0.7	9.910
1992-09-08	02:39:20	0	69.654N	139.158W	10.0	4.4	2.284
1992-09-08	06:30:52	0	69.611N	139.295W	7.1	3.9	1.849
1992-09-08	11:21:36	0	69.596N	139.502W	8.2	4.8	1.690
1992-09-08	13:00:01	0	69.700N	139.519W	11.6	1.6	7.056
1992-09-08	14:45:01	0	69.699N	139.538W	0.7	1.8	0.423
1992-09-08	15:13:45	0	69.725N	139.593W	3.6	0.5	7.481
1992-09-08	16:58:21	0	69.814N	139.351W	13.6	1.7	7.786
1992-09-08	18:05:10	0	69.740N	138.996W	15.9	1.1	14.298
1992-09-08	19:38:29	1	69.754N	139.249W	9.9	1.6	6.336
1992-09-09	00:47:07	0	69.776N	139.206W	3.0	5.1	0.574
1992-09-09	02:26:51	0	69.666N	139.014W	14.3	1.7	8.594
1992-09-09	06:09:20	1	69.776N	139.606W	25.9	3.7	6.976
1992-09-09	11:05:08	0	69.850N	139.608W	8.2	4.9	1.668
1992-09-09	12:47:49	0	69.823N	139.605W	3.0	1.7	1.755
1992-09-09	19:26:54	0	69.813N	139.528W	3.2	6.7	0.474
1992-09-09	19:52:09	0	69.860N	139.502W	5.3	0.4	12.632
1992-09-10	00:32:41	0	69.881N	139.770W	10.5	4.7	2.248
1992-09-10	02:14:32	0	69.838N	139.351W	16.7	1.7	9.854
1992-09-10	03:53:51	0	69.744N	139.030W	16.2	1.7	9.757
1992-09-10	05:51:37	1	69.857N	138.974W	12.7	2.0	6.490
1992-09-10	07:32:51	0	69.820N	138.880W	5.5	1.7	3.239
1992-09-10	12:33:22	0	69.868N	139.003W	7.1	5.0	1.421
1992-09-10	14:27:17	1	69.901N	139.010W	3.7	1.9	1.937
1992-09-10	16:08:59	0	69.834N	138.976W	7.6	1.7	4.459
1992-09-10	17:33:01	0	69.771N	138.948W	7.1	1.4	5.056
1992-09-10	17:48:35	1	69.826N	138.946W	6.1	0.3	23.552
1992-09-10	19:18:46	0	69.789N	138.844W	5.7	1.5	3.775
1992-09-10	21:13:39	0	69.777N	138.637W	8.1	1.9	4.209
1992-09-11	00:26:17	0	69.749N	138.834W	8.2	3.2	2.550
1992-09-11	02:03:24	0	69.740N	138.834W	1.0	1.6	0.618
1992-09-11	03:47:13	0	69.720N	138.747W	4.0	1.7	2.323
1992-09-11	07:11:11	0	69.693N	138.646W	4.9	3.4	1.446
1992-09-11	12:25:20	0	69.693N	138.414W	8.9	5.2	1.709
1992-09-11	15:44:48	0	69.679N	137.888W	20.3	3.3	6.121

TAG # 10827

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-11	19:00:59	0	69.888N	138.060W	24.1	3.3	7.384
1992-09-11	22:21:43	0	69.765N	137.941W	14.4	3.3	4.306
1992-09-12	01:43:24	0	69.827N	137.386W	22.4	3.4	6.659
1992-09-12	13:55:32	0	69.623N	138.171W	37.8	12.2	3.096
1992-09-12	15:22:22	0	69.662N	137.726W	17.7	1.4	12.257
1992-09-12	17:07:12	0	69.577N	137.952W	12.9	1.7	7.366
1992-09-13	01:38:57	0	69.520N	137.390W	22.7	8.5	2.664
1992-09-13	11:57:07	1	69.682N	137.953W	28.3	10.3	2.744
1992-09-13	16:51:18	0	69.770N	137.942W	9.8	4.9	1.996
1992-09-13	18:38:50	0	69.780N	138.106W	6.4	1.8	3.569
1992-09-13	23:43:33	1	69.755N	138.624W	20.1	5.1	3.957
1992-09-14	06:09:25	0	69.688N	138.802W	10.1	6.4	1.573
1992-09-14	13:30:43	0	69.768N	138.812W	8.9	7.4	1.210
1992-09-14	18:07:50	0	69.688N	138.365W	19.4	4.6	4.193

Total distance traveled = 1113.0

TAG #10828

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-03	21:29:00	tag	69.117N	137.033W			
1992-09-04	01:22:16	0	69.210N	137.070W	10.4	3.9	2.684
1992-09-04	04:39:17	0	69.270N	137.033W	6.8	3.3	2.078
1992-09-04	06:13:53	0	69.247N	137.634W	23.8	1.6	15.087
1992-09-04	12:04:18	0	69.206N	137.034W	24.1	5.8	4.123
1992-09-04	23:14:51	0	69.285N	137.031W	8.8	11.2	0.785
1992-09-05	01:25:07	0	69.409N	136.606W	21.6	2.2	9.956
1992-09-05	04:15:45	1	69.467N	137.204W	24.2	2.8	8.513
1992-09-05	16:53:59	0	69.333N	138.015W	35.0	12.6	2.772
1992-09-05	20:14:24	0	69.403N	138.429W	18.0	3.3	5.382
1992-09-06	00:35:01	1	69.396N	138.446W	1.0	4.3	0.235
1992-09-06	02:12:29	1	69.411N	138.258W	7.5	1.6	4.639
1992-09-06	09:59:15	0	69.219N	137.815W	27.5	7.8	3.538
1992-09-06	22:31:16	0	69.435N	137.329W	30.6	12.5	2.445
1992-09-07	20:28:42	0	69.295N	137.388W	15.7	22.0	0.716
1992-09-07	22:11:50	0	69.482N	136.906W	28.1	1.7	16.322
1992-09-08	00:56:53	0	69.485N	136.761W	5.7	2.8	2.056
1992-09-08	16:22:42	0	69.835N	137.636W	51.5	15.4	3.339
1992-09-08	18:34:08	0	69.838N	137.653W	0.7	2.2	0.334
1992-09-08	21:17:40	1	69.838N	137.977W	12.4	2.7	4.553
1992-09-08	23:30:14	2	69.928N	137.997W	10.0	2.2	4.540
1992-09-10	02:07:04	0	70.499N	138.598W	67.4	26.6	2.531
1992-09-10	03:55:21	0	70.479N	138.789W	7.4	1.8	4.116
1992-09-10	12:33:06	2	70.588N	138.460W	17.2	8.6	1.991
1992-09-10	14:17:20	0	70.591N	138.112W	12.9	1.7	7.400
1992-09-10	16:08:19	2	70.641N	137.891W	9.9	1.8	5.332
1992-09-10	17:40:50	0	70.843N	137.510W	26.4	1.5	17.143
1992-09-10	20:48:50	0	70.688N	138.016W	25.3	3.1	8.072
1992-09-11	00:16:10	2	70.819N	137.003W	39.9	3.5	11.533
1992-09-11	02:06:43	2	70.871N	136.838W	8.3	1.8	4.527
1992-09-11	03:53:07	0	71.080N	136.876W	23.3	1.8	13.118
1992-09-11	07:11:33	0	71.032N	136.336W	20.2	3.3	6.107

Total distance traveled = 621.6

TAG #10830

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-04	18:06:00	tag	69.117N	137.100W			
1992-09-04	18:49:57	0	69.200N	136.959W	10.8	0.7	14.711
1992-09-04	19:58:59	0	69.173N	136.924W	3.3	1.2	2.871
1992-09-05	01:28:59	0	69.120N	136.790W	7.9	5.5	1.440
1992-09-05	13:41:15	0	69.238N	136.781W	13.1	12.2	1.075
1992-09-05	20:14:13	1	69.254N	137.092W	12.4	6.5	1.889
1992-09-06	01:13:17	0	69.489N	135.928W	52.5	5.0	10.536
1992-09-06	15:01:02	0	69.047N	136.950W	63.5	13.8	4.600
1992-09-06	22:35:13	0	69.574N	138.472W	83.7	7.6	11.051
1992-09-07	02:50:35	0	69.566N	139.551W	41.9	4.3	9.835
1992-09-07	05:15:04	0	69.653N	139.698W	11.2	2.4	4.658
1992-09-07	16:36:34	0	70.553N	141.206W	115.1	11.4	10.134
1992-09-08	02:33:20	0	69.654N	139.734W	114.3	9.9	11.496
1992-09-08	13:03:27	0	69.670N	138.653W	41.8	10.5	3.979
1992-09-09	11:07:26	0	70.382N	141.901W	146.5	22.1	6.637
1992-09-09	19:27:34	0	69.869N	141.197W	62.9	8.3	7.546
1992-09-09	21:09:34	0	69.965N	140.781W	19.1	1.7	11.249
1992-09-10	12:33:40	1	69.632N	140.713W	37.1	15.4	2.408
1992-09-10	16:14:01	0	69.742N	140.445W	16.0	3.7	4.359
1992-09-10	17:55:42	0	69.783N	140.362W	5.6	1.7	3.282
1992-09-10	19:37:21	0	69.921N	140.216W	16.3	1.7	9.633
1992-09-10	22:36:02	0	69.653N	140.249W	29.8	3.0	10.008
1992-09-10	22:47:40	0	69.644N	140.303W	2.3	0.2	11.935
1992-09-11	00:12:26	0	69.722N	139.858W	19.2	1.4	13.612
1992-09-11	03:49:46	0	69.614N	139.420W	20.7	3.6	5.724
1992-09-11	05:28:00	1	69.632N	140.063W	25.0	1.6	15.244
1992-09-11	12:21:52	0	69.618N	139.343W	27.9	6.9	4.044
1992-09-11	14:06:14	0	69.708N	139.287W	10.2	1.7	5.882
1992-09-11	15:45:35	0	69.658N	138.942W	14.4	1.7	8.710
1992-09-12	01:49:10	0	69.511N	137.427W	60.9	10.1	6.058
1992-09-12	13:46:24	0	69.413N	137.004W	19.8	12.0	1.653
1992-09-12	22:06:12	2	69.472N	136.825W	9.6	8.3	1.150
1992-09-12	22:12:28	2	69.459N	136.846W	1.7	0.1	15.893
1992-09-13	01:36:07	0	69.579N	136.947W	13.9	3.4	4.095
1992-09-13	06:26:56	2	69.865N	137.139W	32.6	4.8	6.731
1992-09-13	13:41:37	0	69.998N	136.938W	16.6	7.2	2.298
1992-09-13	20:23:41	0	70.329N	137.258W	38.7	6.7	5.776
1992-09-14	01:09:16	0	70.913N	137.488W	65.4	4.8	13.749
1992-09-14	06:05:13	0	70.491N	138.239W	54.4	4.9	11.028
1992-09-14	14:42:29	0	70.908N	139.003W	54.2	8.6	6.283
1992-09-14	16:23:53	0	70.985N	138.539W	18.9	1.7	11.172
1992-09-14	19:45:38	0	71.038N	138.061W	18.3	3.4	5.430

Total distance traveled = 1429.4

TAG #00828

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-06	03:49:00	1	69.050N	137.233W			
1992-09-07	03:32:01	-1	69.178N	136.223W	42.5	23.7	1.790
1992-09-07	16:31:46	-1	69.310N	136.754W	25.5	13.0	1.965
1992-09-10	04:05:29	-1	70.095N	133.661W	147.7	59.6	2.480
1992-09-10	16:13:53	-1	69.648N	135.358W	81.7	12.1	6.731
1992-09-16	03:41:43	-1	69.373N	137.266W	80.2	131.5	0.610
1992-09-19	16:22:49	-1	70.173N	134.569W	136.5	84.7	1.612
1992-09-20	15:39:06	-1	69.854N	134.914W	37.8	23.3	1.624
1992-09-25	16:16:13	-1	69.787N	134.080W	32.8	120.6	0.272
1992-09-29	16:07:57	-1	70.061N	134.510W	34.6	95.9	0.361

Total distance traveled = 619.3

TAG #00831

date	time	location class	latitude (degrees)	longitude (degrees)	distance (km)	time (h)	speed (km/h)
1992-09-06	03:20:00	tag	69.083N	137.167W			
1992-09-06	03:58:10	0	69.030N	137.308W	8.1	0.6	12.775
1992-09-06	15:51:33	0	69.558N	136.577W	65.3	11.9	5.494
1992-09-07	03:32:07	0	69.266N	136.973W	35.9	11.7	3.078
1992-09-08	16:20:35	0	69.296N	138.050W	42.5	36.8	1.154
1992-09-09	04:24:45	0	69.116N	136.560W	62.1	12.1	5.144
1992-09-10	16:13:32	0	69.592N	136.885W	54.4	35.8	1.519
1992-09-12	15:31:58	0	69.822N	138.464W	66.0	47.3	1.395
1992-09-14	03:03:25	0	69.800N	139.892W	54.8	35.5	1.543
1992-09-14	04:26:30	0	69.880N	140.384W	20.8	1.4	15.044
1992-09-18	04:36:36	0	70.659N	141.310W	93.3	96.2	0.970
1992-09-18	15:59:44	0	70.303N	143.692W	96.9	11.4	8.508
1992-09-19	03:44:37	0	70.299N	145.457W	66.1	11.7	5.627
1992-09-19	16:22:16	0	70.778N	148.697W	131.2	12.6	10.390
1992-09-20	15:57:49	0	71.070N	149.967W	56.4	23.6	2.390
1992-09-21	15:28:20	0	70.462N	146.226W	152.7	23.5	6.494

Total distance traveled = 1006.4