DEVELOPMENT AND TESTING OF TAGGING AND ATTACHMENT EQUIPMENT FOR HARBOR PORPOISES IN THE SOUTHWESTERN BAY OF FUNDY

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Abstract: During July, August and september of 1993 and 1994, we successfully employed time-depth recorders, VHF transmitters and satellite-linked transmitters in a study of the diving behavior and habitat utilization of harbor porpoises in the Gulf of Maine and Bay of Fundy. A total of 190.4 hours of diving behavior (6002 dives) was recorded by time-depth recorders placed on four porpoises. Mean dive depths were between 22 ± 23 and 41 ± 32 m. The deepest recorded dive was 226 m, the maximum depth of the study area. Satellite tags were placed on three porpoises and transmitted location data for between 2 and 21 days. The satellite telemetry data shows that porpoises are highly mobile. One animal covered most of the known summer range of the Gulf of Maine harbor porpoise population in six days. Blood chemistry values were measured for 31 porpoises. Plasma cortisol and Creatinine levels were significantly higher (p=0.0356 and 0.0174, respectively) for animals that received electronic tags than for those that only received roto-tags.

1. OBJECTIVES

This report outlines work that focused on the development of electronic telemetry equipment and appropriate attachment devices to study habitat utilization of harbor porpoises, *Phocoena phocoena*, in the Bay of Fundy. Harbor porpoises in eastern Canada are listed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), largely because of the magnitude of the incidental catches in commercial fisheries (Gaskin 1992). Recent studies indicate that perhaps 4-5% of the estimated population of 45,000 are killed in gill nets each year in the Bay of Fundy and Gulf of Maine (Anonymous 1992). Our specific objectives were to:

(1) develop a tag attachment assembly that will enable long-term transmitter deployment on free-ranging porpoises, with minimal impact on the animals,

(2) develop a satellite transmitter capable of telemetering location information over a period of at least two months,

(3) field test the saddle attachment/transmitter package on wild porpoises,

(4) evaluate the potential of satellite telemetry to provide detailed information on the long-term movements and habitat utilization of harbour porpoises,

(5) Use time/depth recorders (TDR's) to study the diving behavior of free-ranging porpoises, and

(6) assess the physiological effects of tagging on harbor porpoises.

2. OUTLINE OF WORK PERFORMED

Our field research was conducted in the Bay of Fundy, Canada during July, August and September of 1993 and 1994. We worked at the Grand Manan Whale & Seabird Research Station, located in the village of North Head, Grand Manan Island, New Brunswick. With the co-operation of local fishermen, each summer we operate a program on Grand Manan to ensure the safe release of harbor porpoises that become trapped in herring weirs (Neimanis et al. 1995). Porpoises are seined from herring weirs and placed on pads in one of our small boats, where they are measured, examined, and tagged prior to release. Blood samples are also taken from the flukes of most porpoises to assess the health and maturity status of the animals (Koopman et al. 1995).

1993 Time-Depth Recorders

This was a continuation of an investigation of porpoise diving behavior that began in 1992. Time-depth recorders (TDR's) were placed on 5 porpoises in 1993. The TDR packages were approximately 10 X 6 X 1.5 cm and weighed 118 g. Each TDR package consisted of two parts: a microprocessor-controlled Mark 5 TDR (Wildlife Computers, Woodinville, Washington), and a AI-2sp VHF radio transmitter (Holohil Systems, Woodlawn, Ontario). Both components were embedded in a low density synthetic foam. The TDR recorded depth every three seconds. The VHF transmitters operated in the range of 148-150 mHz and transmitted continuously, allowing the porpoise to be tracked and the tag to be located for retrieval after detachment.

The TDR package was attached to the dorsal fin of each porpoise. The attachment site was cleanded with 100% ethanol and a local anesthetic (Lidocaine HCl 2%, Epinephrine 1:100 000; Graham Chemical Co., Jamaica, New York) was injected prior to tag application. Two 5.0 mm diameter nylon pins embedded in the tag's epoxy housing fit through 8.0 mm diameter Teflon-covered stainless steel tubes placed through the dorsal fin. The tubes were held in place with low-grade steel nuts backed with a neoprene lined washer. The tag itself was secured with small magnesium nuts that fit into the protruding ends of the nylon pins. Galvanic action between the magnesium and steel caused the former to corrode, releasing the tag from the animal. The release time could not be precisely predicted but varied approximately with the size of the magnesium nuts. The stainless steel tubes were designed to release from the porpoise in about four weeks.

The tags were positively buoyant and floated with the VHF antenna upright. VHF transmitters had an effective surface range of 5-8 km which could be increased to almost 40 km by tracking from an airplane. Data were downloaded from the recovered TDR's to a personal computer. Six dive variables were calculated from the raw data using the computer software program Dive-Analysis version 4.0 (Wildlife Computers, Woodinville, Washington): maximum dive depth; dive duration; bottom time (time spent at greater than 85% of the maximum dive depth); descent rate; ascent rate; and interdive (surface) time. We used analysis of variance (ANOVA) to compare dive depths and dive frequencies between day and night (see Westgate et al. 1995).

1993-Blood Chemistry

Blood chemistry values were measured from 31 porpoises (13 females, 18 males) removed from herring weirs in 1993. Five to 50 ml of blood was drawn from the main vessels on the ventral surface of the flukes, using 21-guage Vacutainer Winged Collection sets (Becton Dickinson). All but three of the porpoises were tagged with TDR's or VHF transmitters prior to blood sampling. Glucose, cholesterol, serum osmolality, potassium, sodium, phosphorus, calcium, chloride, magnesium, total protein, hemoglobin, albumin, thyroxine, bilirubin, globulin, urea, alanine aminotransferase, aspartate aminotransferase, creatine kinase, alkaline phosphatase, cortisol, and creatinine levels were determined. ANOVA was used to compare cortisol and creatinine levels between porpoises that received electronic tags and values reported for captive porpoises and other odontocetes (see Koopman et al. 1995).

1994 Satellite Tags

In 1994 we deployed four satellite-linked tags using protocols developed during extensive field testing in 1993. The tags were attached to thin neoprene-lined polyethylene saddles with epoxy and several cable-ties. The entire assembly was attached to the dorsal fin using three 5/16" delrin or High Density Polyethylene (HDPE) pins, after the attachment site was cleaned with ethanol and treated with a local anesthetic and antibiotic. The saddles wrapped around the front of the dorsal fin and extended caudally approximately 3.5 cm; the satellite transmitter (platform transmitting terminal or PTT) was mounted on the leading edge of the saddle. The saddles, cast from the dorsal fin of a porpoise carcass, ensured that the PTT packages did not migrate backwards through the fins. The PTT antenna was a semi-rigid stub, approximately 17 cm in length. The entire PTT package, including saddle, weighed approximately 300 g.

The PTTs operate in the UHF range (401 MHz). We used Model ST-10 units, manufactured by Telonics (Mesa, Arizona) and purchased for us by the Northeast Fisheries Science Center, U.S. National Marine Fisheries Service (NMFS). The PTTs transmit to polar-orbiting NOAA weather satellites, which receive and store data before relaying it to ARGOS ground stations located in Alaska, Virginia, and France. The data are then processed and made available to users via modem or e-mail. Each PTT transmits a unique code which allows the ARGOS system to identify the tag. This identification code is followed by sensor data, to a maximum of 256 bits per transmission. To minimize the size of the transmitter packages, the only sensor used was a surface time counter, which provided a cumulative record of the amount of time the tag was above the surface. At each signal, the surface time count was transmitted twice, allowing us to compare the data to detect possible transmission errors. Each tag also incorporated a salt-water switch, which prevented the tag from transmitting when it was below the water's surface, when the signal could not reach the satellite. The salt water switch sampled every 256 microseconds; if the tag was above water, the transmission cycle was started. If the two terminals were connected by sea water, the tag remained quiescent. In addition, to further conserve battery life, we used a duty cycle in which the transmitter operated for only eight hours each day. The PTTs were powered by two 2/3 A cells which, under these operating conditions, should provide several months of battery life.

The PTTs were encased in steel cylinders to provide protection from the pressure experienced during deep dives. From our research on harbor porpoise diving behavior described above, we know that these animals can dive to the deepest portions of the Bay of Fundy (230 m), exposing the tags to considerable pressure (Westgate et al. 1995). In May, we tested two prototype housings for the PTTs in a pressure chamber at the Woods Hole Oceanographic Institution (WHOI). The housings were cycled to various depths and exposed to a maximum of 500 psi for four hours. The thin-walled housing showed minor failures in the weld that joined the end caps to the main cylinder, so we used the thicker-walled housing. This ensured that the tags would not fail because of water leakage, but added considerably to the mass of each PTT package. Each functional PTT was pressure-tested for one hour at 500 psi prior to deployment without failure.

We were able to access location and sensor data from the ARGOS system via a modem hook-up from our field station to a UNIX computer at WHOI. In addition to the estimated position of the porpoises and surface time data, the ARGOS system provided information on the quality of the estimated location. PTT positions are estimated using the Doppler effect on received frequencies. The quality of an estimated location depends on a variety of factors, including: the number of transmissions received during a satellite overpass, the time elapsed between these receptions, movement of the PTT, and the stability of the transmitter oscillator. Several categories of locations are provided: Class 1 (four messages received, position accuracy better than 1000 m), Class 0 (less than four messages received, position accuracy above 1000 m), Class A (three messages received, no estimate of accuracy), Class B (two messages received, no estimate of accuracy) and Class Z (an unvalidated location)

We also used VHF transmitters in conjunction with the PTT's to determine porpoise locations in real-time. When the tagged porpoises were within our tracking vessel's operating range, we homed in on the VHF signal to visually confirm the location given by ARGOS, assess the condition of the PTT/saddle package, assess the condition of the animal's dorsal fin, and monitor the animal's behavior. We estimated the positions of porpoises within visual range of our vessel from an on-board GPS unit.

The VHF transmitters were standard ATS Model 2 tags (Ipsanti, Minnesota). The tags measured 1.1 x 2.5 x 5.5 cm and weighed less than 15 g, tiny enough so that they could be attached to the small roto-tags (cattle ear tags) that we routinely apply to the trailing edge of the dorsal fin of all porpoises released from herring weirs. The transmitting antennae were 33 cm-long whips, covered in shrink-wrap. The VHF tags transmitted on unique frequencies in the 148 MHz range at 110 pulses per minute, without a salt water switch or duty cycle. In this configuration, the VHF tags had an expected life of more than 50 days. The VHF transmitter had an effective range of approximately 5 km at sea level, with increasing range from clifftops or from the air.

3. RESULTS

1993-TDR's

Dive data were collected from four of the five tags; one TDR (TDR-93-4) was not recovered. A total of 190.4 hours of diving behavior (6002 dives) was recorded in the 1993 field season. Duration of tag deployment ranged from 10.3 to 106.1 hours (Table 1). All porpoises swam east, into the Bay of Fundy, after they were tagged.

Mean dive depths were between 22 ± 23 (TDR-93-3) and 41 ± 32(TDR-93-5) meters (Table 2). TDR-93-2 recorded the deepest dive of 226 m. Mean dive durations were from 46 ± 32 (TDR-93-3) to 103 ± 67 (TDR-93-5) seconds (Table 2). On average, bottom time accounted for 27-39% of total dive time. Average dive frequency was 30 times per hour.

Porpoises TDR-93-2 and TDR-93-3 demonstrated diel variations in diving behavior, descending to greater depths at night (TDR-93-2, 42.5 ± 13.3 vs. 28.3 ± 12.2 m, $p = 0.0001$; TDR-93-3, 33.7 ± 11.9 vs. 17.8 ± 11.2 m, $p = 0.0001$). In addition, both animals made fewer dives during the night than during the day (TDR-93-2, 22.3 ± 6.4 vs. 31.5 ± 10.2 dives/hr, $p = 0.0001$; TDR-93-3, 28.9 ± 7.5 vs. 39.2 ± 11.4 dives/hr, $p = 0.0005$). The other porpoises were monitored for periods too short to examine diel patterns.

1993-Blood Chemistry

Sodium, phosphorus, calcium, chloride, magnesium, total protein, albumin, globulin, urea, cholesterol, serum osmolality, and alanine aminotransferase levels fell within ranges reported for captive harbor porpoises and other odontocetes (Thomson & Geraci 1986, Orlov et al. 1989, Bossart & Dierauf 1990, Kastelein & van Battum 1990, Kastelein et al. 1990). Glucose, potassium, creatine kinase, aspartate aminotransferase, hemoglobin, thyroxine, bilirubin, and alkaline phosphatase levels were generally higher than those reported for captive odontocetes (Thomson & Geraci 1986, Orlov et al. 1989, Bossart & Dierauf 1990, Kastelein & van Battum 1990, Kastelein et al. 1990). Cortisol and creatinine levels were significantly higher (p = 0.0356 and 0.0174, respectively) for porpoises fitted with electronic tags than for porpoises that only received roto-tags. The mean cortisol value was 314 ± 107 nmol/L and the mean creatinine value was 94 ± 14 μmol/L.

1994-Satellite Tags

In 1994, we tagged three porpoises with both conventional

VHF tags and PTTs and a fourth animal with a single VHF tag. Below, we outline the results from each tag deployment of 1994.

PTT-1

The first satellite-linked transmitter was deployed on a 141-cm female porpoise (PTT-1), released from Whale Cove, Grand Manan on 11 August (Table 3). This porpoise was accompanied by a 99-cm female calf that was released with the adult female. High progesterone levels in a sample of blood from this female suggest that she, like most adult females in the Bay of Fundy during the summer, was in the early stages of pregnancy. The adult female was also equipped with a small VHF tag, attached to a roto-tag positioned on the trailing edge of the dorsal fin. The calf was tagged only with a small, numbered roto-tag to facilitate later visual identification.

Satellite contact was maintained with PTT-1 for two days. During this period, we received 39 messages from the PTT during eight satellite passes (Table 4). These messages included six reliable locations (Class 0 or better) (Table 5). During this period the tagged porpoise spent approximately 5% of the time at the surface (Table 6).

We used conventional VHF telemetry to relocate and follow the female and her calf on the afternoon of 12 August near Campobello Island. In over two hours of observation, the female and calf surfaced together in a dispersed group of 5 to 10 animals in the vicinity of several schools of herring, the preferred summer prey of harbor porpoises (Recchia and Read 1989). With 35-mm still cameras and 300-mm telephoto lenses, we were able to obtain good photos of both mother and calf during this period. The tags were situated normally. We lost satellite contact with the female on 13 August, during a southwesterly gale. The VHF tag continued to function, however, and we relocated the female and calf on 15 August. From visual observations and photos taken at this time, it was clear that the attachment pins had broken and the entire saddle package had detached from the dorsal fin of the porpoise. The pins used in this deployment were made of HDPE; subsequent testing showed the pins to be considerably more brittle than originally anticipated. Based on this experience, we modified our attachment procedure and used delrin pins for the remainder of the PTT attachments.

We continued to monitor the movements of PTT-1, using shore-based and surface vessel VHF tracking until 31 August, when we permanently lost radio contact (Figure 1). During this period, it was usually possible to pick up the VHF signal from shore, although one period of several days elapsed without contact, when she may have left the area. We visually relocated the porpoise on four other occasions and each time she was accompanied by her calf. During all of our visual observations of the mother and calf, both animals were swimming normally, often accompanied by other porpoises. During this monitoring period, PTT-1 and her calf stayed in the waters to the northeast of Grand Manan, in an area where the highest concentration of harbor porpoise mortalities in gill nets have been recorded (Javitech 1994). The photos taken during these observation periods document the gradual healing process that occurred around the pin attachment sites.

PTT-2

We deployed the second satellite-linked transmitter on a 145-cm male porpoise at Fish Head, Grand Manan on 17 August, 1994 (Table 3). In this attachment, we used 5/6" delrin pins rather than the HDPE pins used with PTT-1. This porpoise also received a small VHF transmitter on a roto-tag mount.

We maintained satellite contact with PTT-2 for over six days (Table 3), during which time we received 98 messages during 26 satellite passes (Table 4). These data included 14 Class 0 or 1 locations (Table 5). During the period of satellite contact with PTT-2, the porpoise spent approximately 5% of the time at the water's surface, similar to the results obtained from PTT-1 (Table 6). Due to the great distance traveled by this porpoise (see below), we were not able to relocate the animal to monitor the attachment or ascertain the reason for loss of satellite contact with the PTT. We received excellent positional data from this porpoise until we lost contact on 24 August; the position estimated for the last day of contact was a Class 1 location.

PTT-2 quickly moved out of range of our VHF tracking system, traveling overnight to the southwestern Nova Scotia shoreline (Figure 2). The porpoise then made a straight-line movement across the mouth of the Bay of Fundy to the central coast of Maine, then continued southwest into the western Gulf of Maine. PTT-2 generally traveled along the 50-fathom contour (Figure 2), where gill net fishing activity is concentrated. This animal covered most of the known summer range of the Gulf of Maine harbor porpoise population in less than one week.

PTT-3

The third porpoise to receive a PTT was another large male, released on 24 August from Fish Head, Grand Manan (Table 3). Based on the animal's size and testosterone levels in a blood sample, this porpoise was likely both physically and sexually mature.

We maintained satellite contact with this porpoise for a total of 21 days (Table 3). The quality and frequency of satellite uplinks changed radically during the course of this deployment, however, when a severe gale occurred on 05 September. For three days after the storm, we received no uplinks from the porpoise, but we reacquired contact on 08 September. We then received intermittent signals of poor quality until 13 September, when we permanently lost contact with the PTT. We believe that this change in signal reception was most likely caused by a shift in the position of the PTT package on the saddle. One or more of the cable-ties used to attach the transmitter to the saddle may have broken during the gale, causing the transmitter to drop down along the flank of the porpoise, thus preventing efficient transmission of the signal. This explanation is supported by the difference in surface time noted before and after 05 September (Table 6). Before the gale, the amount of time that PTT-3 was at the surface was very similar to that recorded from PTTs 1 and 2. After the gale, the amount of recorded surface time was greatly reduced, because the transmitter may not have been clearing the water on every surfacing. Unfortunately, weather conditions during this period prevented us from relocating the porpoise and determining the condition of the tag or package attachment.

From 24 August until 01 September, PTT-3 remained in the waters to the north and east of Grand Manan (Figure 3), often in areas of intensive gill net fishing activity, where many harbor porpoises are known to be killed (Javitech 1994). The porpoise was visually located on 28 August in a large group of 10-20 actively feeding porpoises east of Grand Manan. At that time, the transmitter package was intact and showed no signs of migration or damage. During the next several days the porpoise moved further east into the Bay of Fundy, away from the area where gill net fishing activity generally occurs. The signals received after 05 September were not of sufficient quality to estimate positions with any accuracy, although from the available data it appears that he moved south of Grand Manan after the gale.

<u>VHF-1</u>

On 31 August, we attempted to deploy a fourth PTT on a 148-cm mature male porpoise, captured near Fish Head, Grand Manan. Unfortunately, the saddle package did not fit tightly on the dorsal fin of this extremely large porpoise and we were unable to attach the tag. We did, however, attach a small VHF tag to this animal with the standard roto-tag attachment. We received signals from this porpoise from shore-tracking stations during the first two days after release, but then lost contact until 10 September, when signals were heard for a single day. Contact was then lost again until 21 September, when strong signals were received from northeastern Grand Manan. Contact was permanently lost on 23 September. We interpret this intermittent contact as movement of the porpoise in and out of our VHF tracking range in the waters around Grand Manan.

4. DISCUSSION

1993-TDR's

This study is the first successful deployment and recovery of a TDR on a cetacean and the first significant collection of data on the diving behavior of harbor porpoises. The buoyant TDR/VHF system proved extremely successful, allowing tags to be recovered up to 17 days after deployment.

These porpoises frequently made deep dives and two dived to the bottom of the deepest parts of the Bay of Fundy. Therefore, it is unlikely that the maximum depth recorded (226 m) reflects the maximum diving capability of this species. Harbor porpoises are capable of diving to the deepest depths at which groundfish gillnets are set in the Bay of Fundy. These data support the conclusions of Read and Gaskin (1988) that porpoises are at risk of entanglement when the nets are on the bottom, and not just when they are being hauled or set.

Results of this work have recently been published by Westgate et al. (1995).

1993-Blood Chemistry

Changes in blood cortisol and creatinine levels have been associated with the cetacean stress response (Thomson and Geraci 1986, Bossart & Dierauf 1990). We found no published data on cortisol levels for captive harbor porpoises. However, cortisol concentrations in all our porpoises (range 116-549 nmol/L) were higher than the mean normal concentration of 90 nmol/L for captive *Tursiops truncatus* (Orlov et al. 1989, Copland & Needham 1992). Cortisol and creatinine levels were highest in porpoises fitted with electronic tags.

Removing a harbor porpoise from a weir appears to cause the animal some degree of stress. The extended handling time required to fit a porpoise with an electronic tag presumably increases this level, but as several blood constituents are already elevated as a result of entrapment, the additional stress might be manifested only as further elevations in cortisol concentrations. At the present time, we are unable to determine which factors were responsible for the elevated plasma cortisol and creatinine levels (i.e., time spent out of water, degree of physical manipulation, or tag attachment).

With recent advances and miniaturization of radio and microcomputer technologies, it has become possible to deploy a wide variety of electronic telemetry and data logging devices on small cetaceans. It is unclear what proximate and long-term effects these procedures have on the animals. This is the first study attempting to investigate the direct physiological response of odontocetes to the tagging process. Further investigation is needed to determine which factors lead to increased stress. In 1994 we began collecting data to answer these outstanding questions. We have been taking serial blood samples before and after tagging. In addition, we have been collecting serial blood samples from porpoises that do not receive electronic tags.

The blood chemistry analysis described here has been published by Koopman et al. (1995).

1994-Satellite Tags

The long-distance movement of PTT-2 demonstrated the extreme mobility of these porpoises, something that we have long suspected, but were not able to document because of the limitations of conventional VHF telemetry (Read and Gaskin 1985). The mobility of PTT-2, a large mature male, makes it extremely unlikely that any significant sub-population structure exists in the Gulf of Maine and Bay of Fundy harbor porpoise population. We see no compelling reason to treat the Gulf of Maine population of harbor porpoises as anything other than a single management stock, for which a unified and coherent conservation strategy should be employed in both the U.S. and Canada.

The surface time data recorded from each porpoise was very consistent, indicating that harbor porpoises spend approximately 5% of the time with their dorsal fins above the water's surface (Table 6). This information may be useful to researchers attepting to correct for submerged animals while conducting line transect surveys of harbor porpoise abundance.

This work represents the first time that a satellite-linked transmitter has been successfully deployed on a harbor porpoise. The problems with attachment methods and data acquisition were not trivial and we learned a tremendous amount regarding the best methods of attachment, duty cycling and data acquisition; we hope to use these lessons in the future, to achieve longer deployments on a larger number of porpoises. We were very satisfied with our unusual double-tag approach, using both a VHF and satellite-linked tag on the same porpoise. This allowed us to determine the fate of the first PTT and monitor the porpoise for a considerable period after the tag was shed. Very little is known about the fate of electronic tags on small cetaceans; these findings will be very useful in our future efforts and, hopefully, also to those of other researchers.

The results of our satellite telemetry work in 1994 were described in a working paper submitted to the Small Cetacean Subcommittee of the International Whaling Commission at its annual meeting in Dublin in 1995 (Westgate & Read 1995a). This work was continued during the 1995 field season under further ONR support (ONR N00014-94-1-1189). We deployed six PTT's in 1995. The longest deployment was 212 days (the longest satellite telemetry track for any cetacean species), while two other tags transmitted for over 65 days (Westgate & Read 1995b). We will continue our study of the movements and habitat utilization of harbor porpoises in the Bay of Fundy using satellite telemetry in 1996. Our intent is to collect a sufficient data base on the movements and habitat use patterns of these animals to allow managers to make effective decisions about the management options, such as the use of time-area closures, to reduce porpoise mortality in bottom-set gill nets. Management actions need to be taken that will conserve this population of harbor porpoises without placing an undue burden on a fishing industry that is already facing severe restrictions to relieve pressure on over-exploited fish stocks.

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Table 1. Summary of harbor porpoises that were fitted with time-depth recorders in 1993.

ID	Sex	Length (cm)	Estimated Mass (kg)	Date of Deployment	Duration of Deployment (h)
TDR-1	F	138	48.5	07 Aug	10.3
TDR-2	F	161	70	29 Aug	106.1
TDR-3	M	130	38.9	07 Sep	54
TDR-5	F	134	38.9	26 Sep	20

Table 2. Summary of dive records of four harbour porpoises obtained from time-depth recorders in 1993. Number of dives includes includes dives tha were 2 M or greater.

ID	No. of Recorded Dives	Max. Depth (M)	Mean Depth +/-SD (M)	Max. Duration (s)	Mean Duration +/-SD (s)
TDR-1	381	131	26+/-29	264	64+/-65
TDR-2	2888	226	31+/-39	321	70+/-59
TDR-3	1883	207	22+/-23	231	46+/-32
TDR-5	469	136	41+/-32	222	103+/-67

Table 3. Summary of harbor porpoises tagged with satellite and radio transmitters on Grand Manan Island, New Brunswick during 1994.

ID	Sex	Length (cm)	Mass (kg)	Date of Release	Duration of Contact (days) VHF	Satellite
PTT-1	F	141	NE	11 Aug	20	2
PTT-2	M	145	NE	17 Aug	1	6
PTT-3	M	140	46	24 Aug	7	21
VHF-1	M	148	50	31 Aug	23	N/A

Table 4. Summary of data obtained from harbor porpoises tagged with satellite and radio transmitters on Grand Manan Island, New Brunswick during 1994. Designations of (A) and (B) for PTT-3 refer to periods before and after tag malfunction, respectively. See text for further explanation.

ID	Duration of Contact (d)	Number of Messages Received	Number of Satellite Passes	Mean No. Messages Per Pass	Proportion Error-Free Messages
PTT-1	2	39	8	4.9+/-2	1
PTT-2	6.3	98	26	3.8+/-2	0.92
PTT-3 (A)	12.1	186	49	3.8+/-1.8	0.81
PTT-3 (A)	9	17	11	1.5+/-0.8	0.35

Table 5. Summary of location data received from harbor porpoises tagged with satellite-linked transmitters on Grand Manan Island, New Brunswick during 1994. Designations of (A) and (B) for PTT-3 refer to periods before and after tag malfunction, respectively. See text for further explanation.

ID	Total No. Satellite Passes	No. of Positions Calculated in Each Position Class 1	0	A	B	Z
PTT-1	8	0	6	0	2	0
PTT-2	26	2	12	5	2	5
PTT-3 (A)	49	3	23	8	6	9
PTT-3 (A)	11	0	0	1	1	9

Table 6. Summary of surface time data received from harbor porpoises tagged with satellite-linked transmitters on Grand Manan Island, New Brunswick during 1994. Designations of (A) and (B) for PTT-3 refer to periods before and after tag malfunctions, respectively. See text for further explanation.

	Surface Counter			Total	Percentage
ID	Start	End	Elapsed Time (s)	Surface Time (d)	of Time at Surface
PTT-1	9276	17374	8292	1.96	4.9
PTT-2	3330	28282	25551	6.01	4.92
PTT-3 (A)	1761	43282	42518	11.02	4.46
PTT-3 (A)	43282	63404	21099	8.99	2.65

Figure Captions

Figure 1. Movements of harbor porpoise PTT-1, as determined by satellite and VHF telemetry between the release point on 11 August 1994 (8/11) and the final contact on 28 August (8/28). Only one position for each day is indicated. Points between 8/11 and 8/13 were obtained by satellite positions, all others were obtained using VHF telemetry with subsequent visual confirmation.

Figure 2. Movements of harbor porpoise PTT-2, as determined by satellite telemetry between the release point on 17 August (8/17) and the final contact on 23 August (8/23). Only one position for each day is indicated. All positions were obtained by satellite telemetry.

Figure 3. Movements of harbor porpoise PTT-3, as determined by satellite and VHF telemetry between the release point on 24 August (8/24) and the final contact on 04 September (9/04). Only one position for each day is indicated. All positions were obtained by satellite telemetry. The position shown for 8/26 was confirmed with VHF telemetry and visual contact.

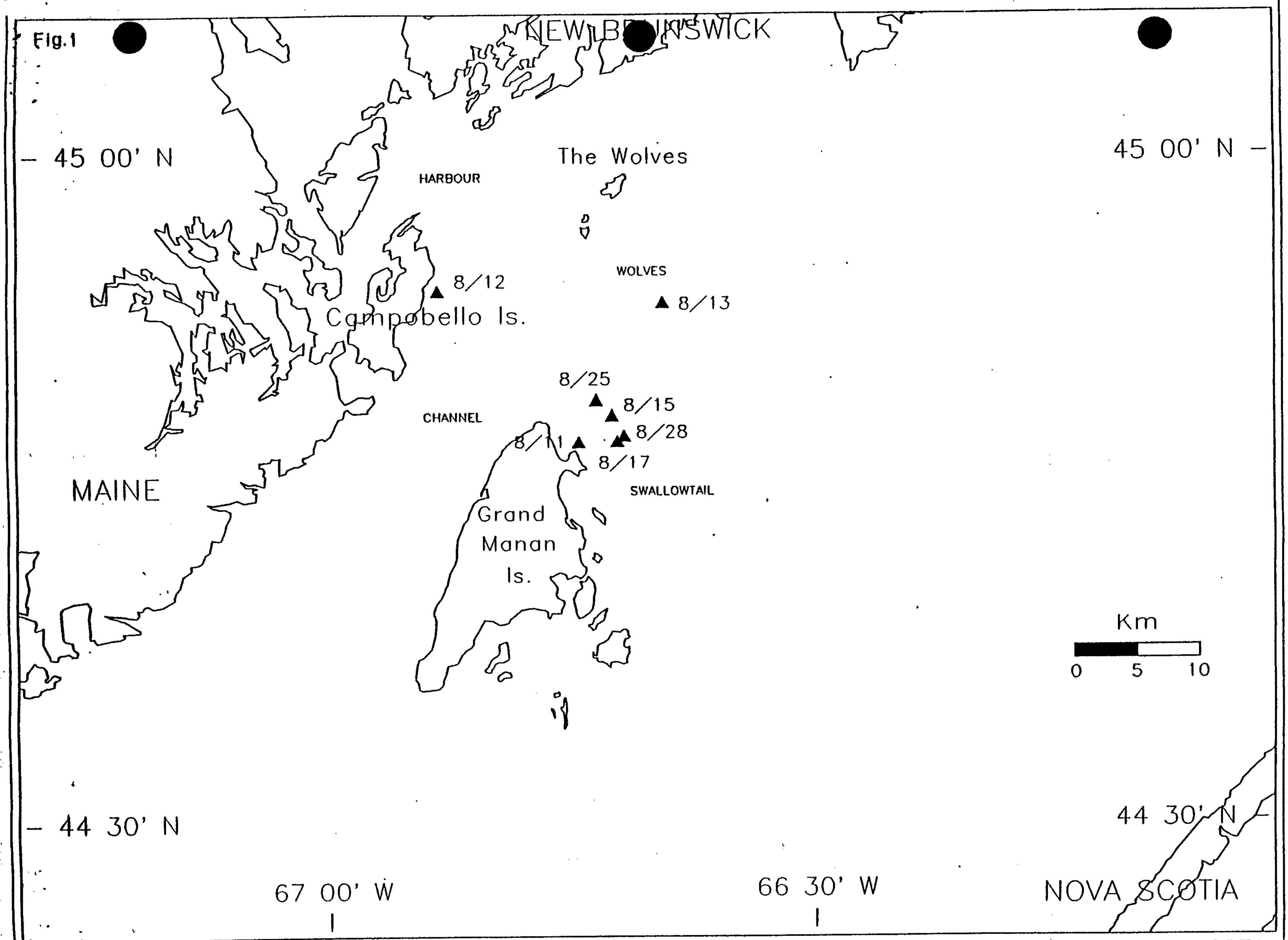
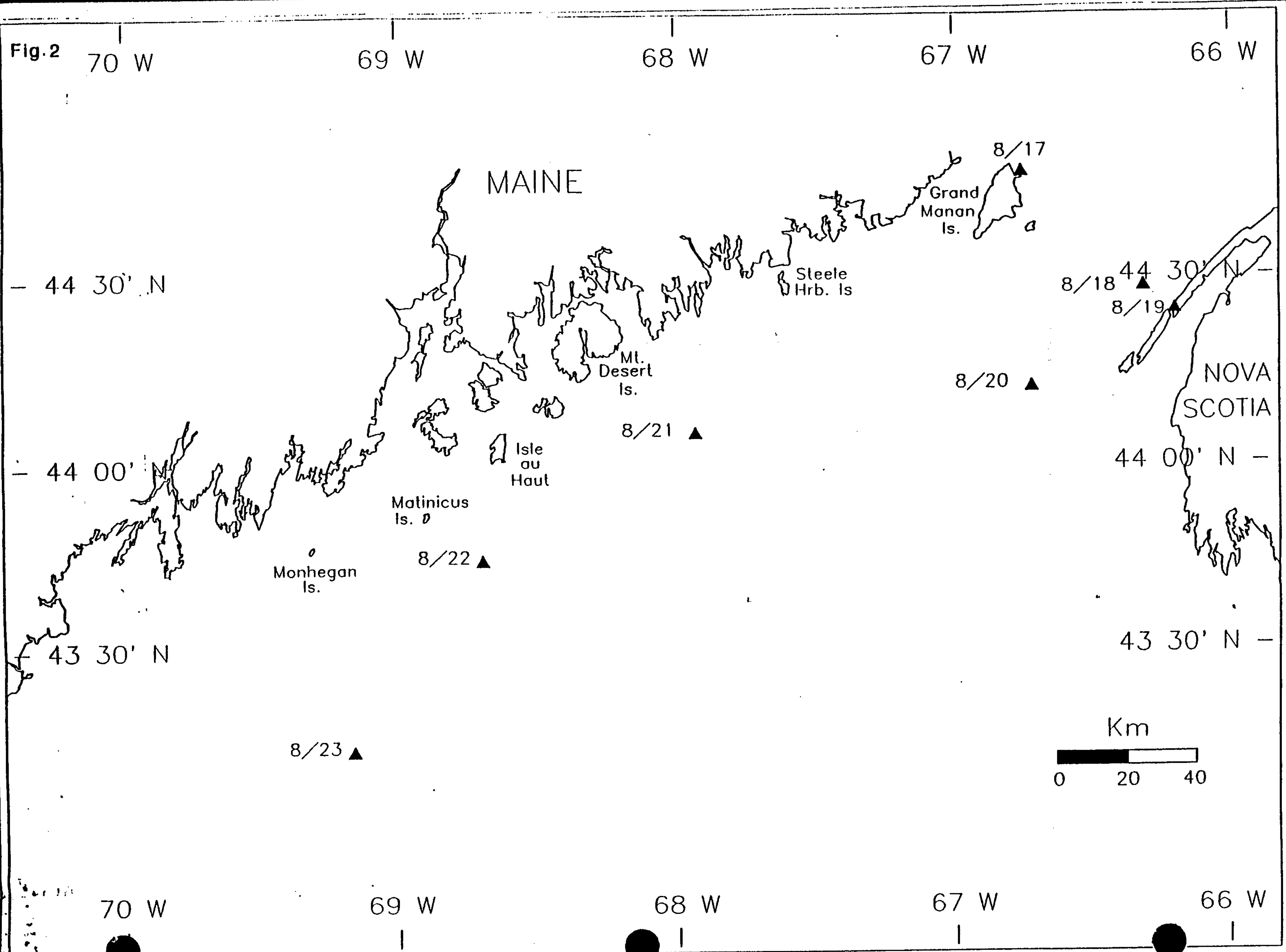


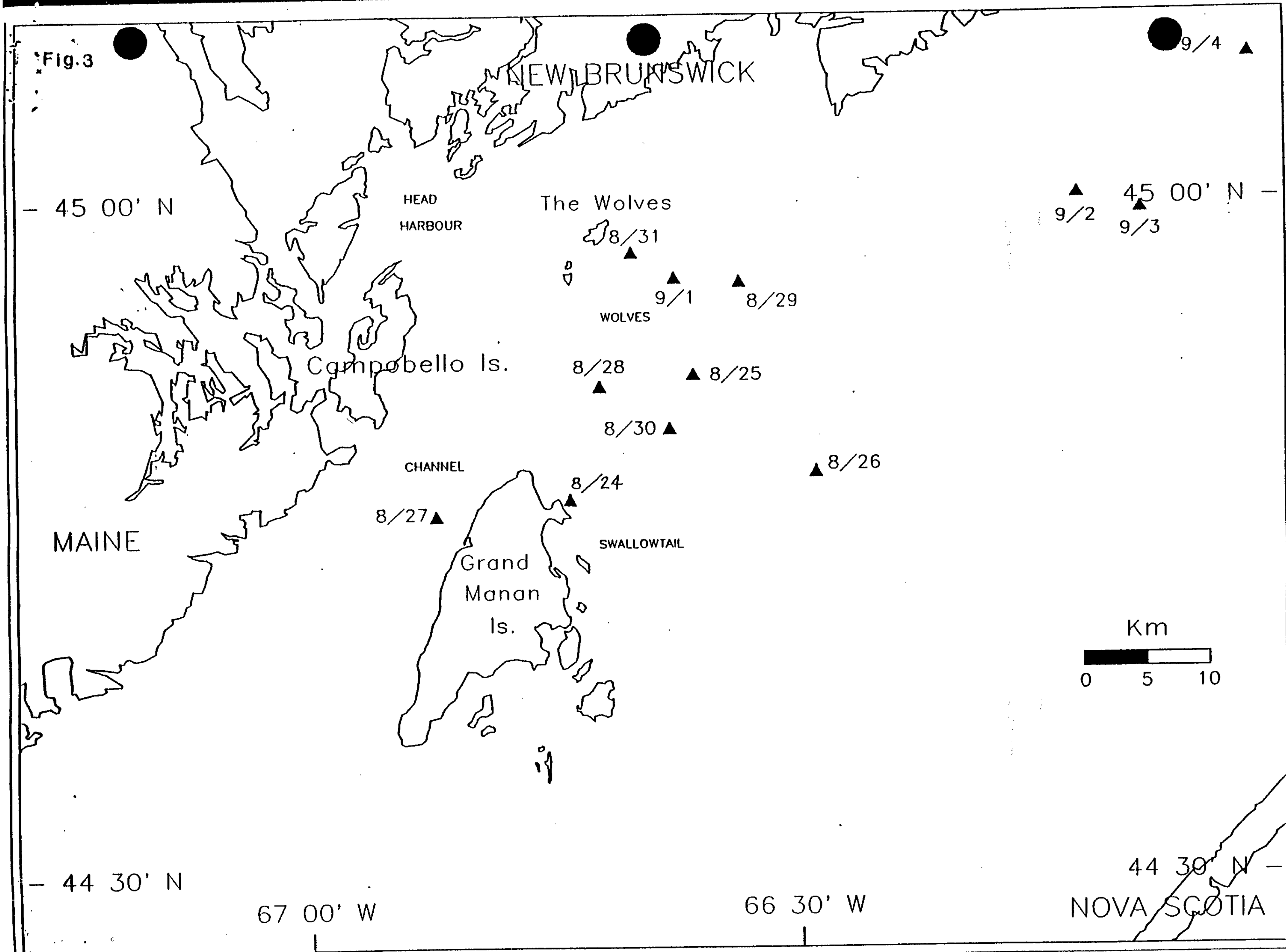
Fig.1
NEW BRUNSWICK
45 00' N
45 00' N
HARBOUR
The Wolves
WOLVES
8/12
8/13
Campobello Is.
8/25
8/15
CHANNEL
8/28
8/11
8/17
SWALLOWTAIL
MAINE
Grand
Manan
Is.
Km
0
5
10
44 30' N
44 30' N
67 00' W
66 30' W
NOVA SCOTIA

Fig.2



70 W
69 W
68 W
67 W
66 W
44 30' N
44 00' N
43 30' N
MAINE
NOVA SCOTIA
Grand Manan Is.
Steele Hrb. Is
Mt. Desert Is.
Isle au Haut
Matinicus Is.
Monhegan Is.
8/17
8/18
8/19
8/20
8/21
8/22
8/23
Km
0
20
40

Fig.3


NEW BRUNSWICK
HEAD
HARBOUR
The Wolves
45 00' N
8/31
9/1
8/29
9/2
9/3
9/4
WOLVES
Campobello Is.
8/28
8/25
8/30
8/26
CHANNEL
8/24
8/27
SWALLOWTAIL
MAINE
Grand
Manan
Is.
Km
0
5
10
44 30' N
67 00' W
66 30' W
NOVA SCOTIA