

***Exxon Valdez* Oil Spill
Restoration Project-Final Report**

**Assessment of Injuries and Recovery Monitoring of Prince William Sound Killer Whales
Using Photo-identification Techniques**

**Restoration Project 93042/94092
Final Report**

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Recovery Monitoring of Prince William Sound Killer Whales

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Study History: Restoration Project 93042/94092 was initiated in 1993 as a followup to Natural Resource Damage Assessment Study Marine Mammal Study Number 2 (1989-1991) to investigate injuries and monitor recovery of Prince William Sound killer whales. Two book chapters regarding the Damage Assessment phase of this project were published in 1994 (Matkin, C. O., G. M. Ellis, M. E. Dahlheim, and J. Zeh. 1994. Status of Killer Whales in Prince William Sound 1985-1992 (pp. 141-162); and Dahlheim, M. E. and C. O. Matkin. 1994. Assessment of Injuries to Prince William Sound Killer Whales (pp. 163-171). In: Marine Mammals and the *Exxon Valdez*. Academic Press. T. R. Loughlin (editor). The 1993 killer whale restoration data have not been formally published.

Abstract: Photo-identification studies of individual killer whales inhabiting Prince William Sound were collected from 1989-91 and from July to September 1993 to determine the impact of the spill on whale abundance and distribution (1989-1991) and monitor recovery (1993). Concurrent photo-identification studies were also conducted in Southeast Alaska to determine if PWS killer whales were displaced to other areas between 1989 and 1991. Despite increased effort, the number of encounters with PWS killer whales appears to be decreasing. Analysis of photographic data revealed 14 animals missing from AB pod over the three-year period. Mortality rates for AB pod ranged from 3.1% in 1988 to 19.4% in 1989, 20.7% in 1990, and 4.3% in 1991. Zero mortality occurred in 1992 and 1993. Mortality rates on the order of 20% are unprecedented for North Pacific killer whales. No new calves were born into AB pod in 1989 or 1990. There was one calf born in 1991, two born in 1992, and one born in 1993. AB pod size in 1988 was 36; in late 1993 the pod had 26 members. The cause(s) of the disappearance of 14 killer whales from AB pod is unknown. We assume, that the whales are dead from natural causes, a result of interactions with fisheries, from the spill, or a combination of these causes.

Key Words: Abundance, distribution, fisheries interactions, killer whales, mortality, *Orcinus orca*, photo-identification, Prince William Sound, recovery, reproduction, Southeast Alaska.

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EXECUTIVE SUMMARY

Photographs of individual killer whales occurring in Prince William Sound (PWS) were collected from May to September 1989-91 and from July to September 1993 to assess the impact of the *Exxon Valdez* oil spill on killer whale abundance and distribution. To account for killer whales potentially displaced from PWS to other areas, concurrent photo-identification studies were also conducted in Southeast Alaska (1989 to 1991).

Research vessels traversed an average of 17,047 km (9,205 nautical miles) in PWS between 1989 and 1991 and 5,776 km (3,119 nautical miles) in 1993. In 1989, eight resident pods (143 whales) and four transient pods (34 whales) were documented, totalling 177 animals in 89 encounters. In 1990, nine resident pods (148 whales) and four transient pods (30 whales) were identified, representing 178 animals in 80 encounters. During 1991, seven resident pods (105 whales) and two transient pods (14 whales) were identified from PWS, representing 54 encounters and 119 whales. In 1993, nine resident pods (148 whales) and two transient pods (25 whales) were identified from PWS, representing 173 whales in 41 encounters.

Photographic analysis of resident pods revealed 14 animals missing from AB pod over the three-year period (1989-1991). Despite considerable searching effort in PWS (1989-1993), in Southeast Alaska (1989-91) and research conducted by other programs throughout Alaska, the missing whales have not been observed. Given the stability of resident pods, we assume that the missing whales are dead (Bigg et al. 1990). The mortality rates for AB pod ranged from 3.1% in 1988 to 19.4% in 1989, 20.7% in 1990, and 4.3% in 1991. Zero mortality occurred in 1992 (Matkin et al. in press) and in 1993 (Dahlheim et al. 1993). The adult annual mortality rate of killer whales is usually less than 2%. Annual pod mortality rates on the order of 20% are unprecedented for North Pacific killer whales.

No new calves were born into AB pod in 1989 or 1990. There was one calf born into AB pod in 1991, two born in 1992 (Matkin et al. in press) and one born in 1993 (Dahlheim et al. 1993). AB pod size in 1988 was 36; in late 1993 the pod had 26 members.

The cause(s) of the disappearance of 14 whales from AB pod is unknown (Dahlheim and Matkin, in press). We are confident that 1) whales have not been mis-identified, 2) adequate effort was made to locate missing whales, and 3) the number of encounters was sufficient to evaluate the presence or absence of an individual whale. The current life history information available on killer whales does not support the possibility that the whales moved elsewhere. Therefore, we assume, that the whales are dead from natural causes, a result of interactions with fisheries, from the spill, or a combination of these causes.

INTRODUCTION

Killer whales, *Orcinus orca*, occur in all oceans of the world (Heyning and Dahlheim 1988). Population estimates, based on photo-identification studies, are available for three North Pacific regions: Washington State, inland waterways of British Columbia, and Prince William Sound (Bigg et al. 1987, 1990; Leatherwood et al. 1984, 1990). Recent counts for Prince William Sound include 9 resident pods (representing 205 whales) and several transient pods (representing 55 whales) totalling 260 whales (Heise et al. 1991). Another 129 whales have been documented (photo-identified) to seasonally occur in the PWS area (NMML, unpublished). Killer whales photographed in Prince William Sound have also been seen in Kodiak Island waters and in Southeast Alaskan waters.

The purpose of the 1989-1991 study was to determine the possible impact of the *Exxon Valdez* oil spill on killer whales in Prince William Sound (PWS), because on four separate occasions six different killer whale pods were observed swimming directly through oil (Harvey and Dahlheim, in press). There were no apparent attempts made by the whales to avoid the oil (Harvey and Dahlheim, in press). Impact was determined by obtaining photographs of individual killer whales in Prince William Sound from mid-May to September 1989 to 1991. Photographs were compared to an existing photographic database from 1984 to 1988 (Ellis 1984) to determine if changes occurred in whale abundance, seasonal distribution, birth and mortality rates, and continuity of habitat usage. Results of the research allowed determination of the loss (reduction in numbers; change in vital rates) to killer whale populations or extent of injury (displacement) resulting from the spill.

Objectives for the 1989 through 1991 investigations included:

1. To count the number of killer whales in Prince William Sound.
2. To test the hypothesis that killer whale distribution within Prince William Sound and adjacent waters is similar to that reported for previous years.
3. To test the hypothesis that pre- and post-oil spill killer whale pod structure and integrity have remained the same.
4. To test the hypothesis that killer whale natality has not changed since the spill.
5. To test the hypothesis that killer whale mortality rates have not changed since the spill.

During the three-year period of damage assessment research (1989-1991), photographic analysis revealed little impact on Prince William Sound killer whale populations. However, 14 animals were noted as missing from AB pod. Studies conducted since 1991 have primarily focussed on this injured resident pod.

In 1993, photo-identification studies continued on Prince William Sound killer whales. The purpose of this study was to obtain photographs of individual whales occurring in AB pod and to document natural recovery. Multiple encounters are needed throughout the season with AB pod because the pod may temporarily fragment while foraging. Because AB pod members frequently travel with other resident pods, photographs of all whales encountered in Prince William Sound were collected. Photographs collected were compared to NMML's photographic database for the years 1989 to 1991 (summarized in Heise et al. 1991) to determine if changes continue to occur in the number of whales in AB pod, pod integrity, mortality and natality rates.

OBJECTIVES (1993 investigations)

1. Count the number and individually identify killer whales within AB pod.
2. Test the hypothesis that pre- and post-spill killer whale pod structure and integrity within AB pod have remained constant.
3. Determine killer whale reproductive rates and trends in abundance for AB pod within Prince William Sound.

METHODS

Count and Identify Killer Whales

Field Procedures - Prince William Sound.--Field seasons occurred from May to September 1989-1991. In 1989, small skiffs (< 6 m) operated from camps located on Squire Island, Hinchinbrook Island, and Perry Island (Fig. 1). The Perry Island camp was moved to Point Nowell (14 miles south of Perry Island) in mid-season. In 1990 and 1991, only one field camp was established in the southwestern region at Squire Island (off the southwest side of Knight Island). The Squire Island camp was staffed by two biologists using one small boat. In 1990 and 1991 two biologists used a live-aboard vessel for locating killer whales (replacing the 2 of 3 shore-based locations used in previous years).

Weather permitting, an average of 8 to 10 hours per day were spent conducting boat surveys searching for or photographing whales. Specific areas known for whale concentrations were emphasized. If whales were not located in known areas and opportunistic sighting reports were not available, a general search pattern was developed and implemented. Travel routes (based on information acquired prior to the spill) used by whales were surveyed.

In 1993, researchers were based out of Chenega in southwest Prince William Sound from July to September. All logistical support was provided by the Chenega Corporation. A 6.7 m (22 ft) C-Dory was used as the research vessel. The field team consisted of three people: two photographers and a boat driver.

Weather permitting, surveys in 1993 were conducted six days a week to search for and photograph killer whales. The study area was centered in areas of known killer whale concentrations (based on previous investigations), including Montague Strait and Knight Island Passage. The search pattern followed that depicted in Figure 2 although variations were made due to weather or reports of killer whales.

The 1993 search method consisted of running for 30 minutes while scanning for killer whales and then stopping for ten minutes to scan with binoculars and listen for killer whale calls using a hydrophone. This was repeated until killer whales were sighted or until the end of the day. When reports of killer whales were received from sport and commercial fishing vessels, tug boats, and State ferries, researchers broke trackline and moved to the area where whales were reported.

When encountered, killer whales were photographed and survey forms completed (Figs. 3a-c). The vessel was guided onto the whale's course and speed to approach within 30-60 meters of the whales left side. The whale's dorsal fin and saddle patch were then photographed with 35 mm camera systems (i.e., Nikon, Canon, Pentax) with motor drives

and 300 mm lens set at 1/1000th sec shutter speed, or the highest speed possible. Black and white Ilford HP5 film (ASA 400) or Fuji 1600 film was used and developed at ASA 1600. Exposed film was labeled with date, roll number, photographer's initials, location, species code, and ASA setting. A new roll of film was used for each encounter.

All exposed film was analyzed for individual identification (Fig. 4). When needed, each negative was placed under a dissection microscope for identification purposes and notes and sketches made of the dorsal fin and saddle-patch. Sub-standard photographs (not showing enough detail or improper angle/side) were not used. Photographs were then grouped by individual and each identified whale was visually compared to the photographic database available through the National Marine Mammal Laboratory. In the case of the resident whales, once an individual whale was identified, it was relatively easy to identify the pod to which it belonged. Once all photographs were examined, it was then possible to determine 1) if all members of the pod were present, 2) if pod structure/integrity was similar to previous years, and (3) if new whales (calves) were born into the pod. Any missing animals were noted.

The stability of resident pods is such that if an individual is listed as missing for at least one year, that missing whale is considered dead. No animal consistently missing from a resident group has ever returned to its pod or appeared in another pod in 20 years of research in the United States and Canada (Bigg et al. 1990). Unfortunately, due to the highly variable nature of transient pods, pod structure and mortality rates cannot be conclusively documented to assess damage.

An "encounter" was defined as the successful detection, approach and taking of identification photographs. A "sighting" was the detection and observation of whales when no photographs were obtained. Reliable and specific accounts of whales from other vessels were termed "reports". Although sightings and reports were used to select areas to be searched, all identifications used in analyses were made from photographs taken during encounters.

Daily effort logs were maintained (Figs. 3a-c). These logs permitted a quantification of the amount of time searching for whales versus photographing whales and depicts the daily vessel trackline.

Vital Rates

Calves of the year were identified by size, their mothers identified, and pod birth rates calculated. Mortality was assumed based on the absence of an identified animal from its pod for more than one year. Mortality rates were calculated for resident pods only because the database is more reliable (i.e., stability of social structure) than that collected on transient pods. Finite annual birth rates (BR) and mortality rates (MR) for each pod were calculated as follows:

$$BR = \frac{NR}{NP}$$

and,

$$MR = \frac{NM}{NP}$$

where NR = number of new calves in a pod in a given year,
NM = number of whales missing from the pod in given year, and
NP = number whales present at end of previous year.

Displacement

Aerial surveys were conducted in PWS during 1989 to locate whales on the eastern side of Prince William Sound. The thought was that if killer whales were displaced due to the spill or clean-up activities, they may have moved into the eastern sector of Prince William Sound rather than moving out of the area and not be available for counting or identification. Surveys were flown in a Cessna 180 with two observers and the pilot. Airspeed averaged 115 kts at about 300 m elevation. The survey route consisted of 23 transects connecting 24 waypoints. The waypoints were either obvious landmarks or locations preset into the Loran C. Sighting locations were obtained off the Loran C. Each survey covered approximately 328 nautical miles averaging 3.8 hrs in duration. Transect grid width was 4 miles. Survey schedules were weather dependent making sighting conditions comparable between surveys.

Killer whales may have been displaced out of PWS to Southeast Alaska or the Kodiak Archipelago. In 1989, three shore-based camps and one floating camp were established in Southeast Alaska from 1 June through 30 September 1989 (Fig. 5). One shore-based camp was located at Glacier Bay National Park, one out of Sitka, and the other at The Brothers (a group of islands off the southeast corner of Admiralty Island in Frederick Sound). Glacier Bay personnel surveyed the waters of Glacier Bay, Pt. Adolphus, Cross Sound and then east and south into Icy Strait. Personnel at Sitka, surveyed the Sitka Sound area. The camp at Frederick Sound was responsible for surveying Stephens Passage and Frederick Sound and included at least four researchers operating two vessels. The floating camp provided coverage in Upper Stephens Passage, Lynn Canal, Chatham Strait and the eastern side of Icy Strait. In 1990 and 1991, only one field camp was established at Glacier Bay National Park, operating each year from April to November. Similar field methods apply in Southeast Alaska as those described for PWS except that no aerial surveys were done.

A limited amount of survey effort took place off Kodiak Island. An observer was placed aboard a fisheries research vessel and collected opportunistic sightings of killer whales. The observer was instructed to collect killer whale photographs whenever possible.

RESULTS

Count and Identify Killer Whales

Between May and September 1989-91, the mean number of kilometers surveyed each year in Prince William Sound was 17,047 km (Table 1). In 1989, eight resident (143 whales) and four transient pods (34 whales) were identified, totalling 177 animals in 89 encounters. In 1990, nine resident pods (148 whales) and four transient pods (30 whales) were identified totalling 178 animals, representing 80 encounters. During the 1991 season, seven resident pods (105 whales) and two transient pods (14 whales) were identified totalling 119 animals, representing 54 encounters.

In 1989, 47 hours of aerial survey were flown covering 6,489 km. Survey effort was comparable between June and August (average 12.5 hrs/month) but declined in September (5.7 hrs). Killer whales were the most abundant cetacean seen with 90 individuals observed in 12 encounters (sightings may represent the same individuals/pods). Most sightings occurred in July (8 encounters).

In 1993, between 7 July and 3 September 1993, 5,776 km (representing 463.5 hours) were traversed while searching for or photographing killer whales. A total of 701 km (138.5 hours) were spent with whales. Nine resident pods (148 whales) and two transient pods (25 whales) were identified from Prince William Sound in 1993, representing 173 whales in 41 encounters.

Multiple encounters are needed with each pod to ensure all animals are accounted for because subpods are known to occasionally travel away from the main pod. AB pod members encountered per date by year are listed in Tables 2a-5a. These tables demonstrate the need to have multiple encounters with a pod because each animal is not always present (or potentially missed during photographic surveys). It is also important to photograph all other Prince William Sound killer whales groups because pods are known to merge. In 1989, AB pod was encountered 15 times. AB pod was associated with other pods in 14 of the 15 encounters. In 1990, 24 encounters with AB pod out of 25 included whales from other pods. In 1991, 8 encounters occurred with AB pod. On six occasions AB pod was seen with other pods. In 1993, in seven out of eight encounters, AB pod was seen associated with other PWS resident groups (Tables 2b-5b). Based on four years of seasonal data (1989-1991 and 1993) AB pod was rarely seen alone in PWS and was noted to associate with all other resident pods (Figure 6). AB pod is seen most often with AI and AN pods.

Photographic analysis of resident pods during 1989-1991 revealed that 14 whales were missing from AB pod. Although the loss of 14 whales from this pod disrupted the social structure, the subpod structure observed in 1993 appeared similar to previous years (Table 6). The 14 whales documented as missing during 1989-1992 seasons were not present in 1993.

Vital rates

Birth rates.--Two calves were observed in AE pod and one in AJ pod in 1989. In 1990, four calves were observed in AN pod, one in AE, one in AJ, and one in AK pod. In 1991, one calf was observed in AK pod and one in AN pod. Calves were not observed in

AB pod during 1989 or 1990. One calf was born in AB pod in 1991, two were born in 1992 (Matkin et al., in press), and one was born in 1993. Data are summarized in Table 7.

An annual birth rate of Prince William Sound killer whales was 3.8% combined for the period of 1984 to 1989 (all resident pods excluding AB pod). A rise in the birth rate of AB pod was documented for the years 1985-86 at 6.3%, 1986-87 at 6.4%, and 1987-88 at 15.6%; which followed an increase in mortality rates (assumed to be associated with fishery interactions).

Mortality rates.--In 1989, seven whales were missing from AB pod and one was missing from AE pod. Twenty two whales (AN 20's), representing a subpod of AN pod, did not enter Prince William Sound during 1989. This subpod was present in the area in 1990 and all individuals were accounted for. Of the seven missing whales from AB pod, two were reproductively active adult females which had calves of two and three years old, respectively. The other missing AB pod members were four juveniles of unknown sex and one adult female that had not reproduced since 1984.

In 1990, the seven whales were still missing from AB pod, plus an additional six animals. Of these six whales, one was an adult female that left behind a 3-year old calf, one was a maturing male, and four were juveniles of unknown sex (two were born in 1988 and one was born in 1986). In 1991 one additional animal (a male) was missing from AB pod. No whales were reported missing in AB pod during 1992 investigations by Matkin et al. (in press) and during 1993 investigations (Dahlheim et al. 1993).

A summary of the number of whales in each resident pod from 1984-91 and 1993 is shown in Fig. 7. AJ pod was not reported in 1984 or 1991. The reduction in AN pod in 1990-91 reflects the absence of ten whales that were subsequently photographed and given a different pod designation (AN20).

Ten whales may be missing from the AT1 pod (a transient pod). This pod was encountered ten times during the 1991 season. Three of these missing animals (AT 5, AT 7 and AT 8) were photographed behind the *Exxon Valdez* on 27 March 1989. These three whales were not seen during 1993 investigations.

A combined annual mortality rate for all Prince William Sound resident killer whale pods (excluding AB pod) was 1.8%, covering the years from 1984 to 1988 (Matkin et al., in press). Similar mortality has been noted for resident pods off British Columbia, where an annual combine rate of 2.2% (1973-88) has been documented (Olesiuk et al. 1990).

No reports of dead stranded killer whales occurred in 1989. However, in 1990 three whales stranded in PWS. In 1991, one whale was reported stranded at Cape St. Elias (just outside of PWS). In 1992, a whale was found stranded on the west side of Montague Island. Out of the five stranded whales, only one whale could be identified (AT19). None of the stranded whales were from AB pod, and no evidence of *Exxon Valdez* oil was found in or on the whales.

Displacement

The study teams in Southeast Alaska did not identify any killer whales originating from PWS during 1989. The teams collectively spent 1,011 hours in search of killer whales with a combined effort totalling 230 days of field research between early June and late September 1989. Sixty-three killer whales were photographed, principally in the Icy Strait

region. Limited photographic studies occurred in 1990 and 1991 (early June to December). No PWS killer whales were identified in Southeast Alaskan waters.

Between 8 September and 18 October 1989, marine mammal surveys were conducted off Kodiak, Alaska. Out of 399 available daylight hours, 155.5 hours were spent conducting sighting surveys. Approximately 30.7% (122.5 hrs) were lost to survey effort due to inclement weather (Beaufort 5 conditions or greater). Cetaceans composed the majority of observations. Four killer whale groups were seen, totalling 65 individuals. Bad weather precluded collection of killer whale photographs.

In Prince William Sound, areas of known resident pod concentrations and movement patterns were qualitatively compared between 1989 and 1984-1988. Since 1984, AB pod has been the most frequently encountered resident group for all months from April to September (Matkin, pers. comm.). Historically, AB pod was observed in the area south of Naked Island where herring stage before completing their spawning run in mid-April to early May. The occurrence of AB pod on the western side of PWS in early April is also well documented by blackcod fishermen. AB pod was observed in this area on 31 March 1989 but was not seen again until 27 July 1989. Sighting locations of AB pod encounters by our research teams for the years 1989-1991 and 1993 are given in Figures 8-11.

Prior to 1988, multi-resident pod aggregations were observed to occur in lower Knight Island Passage and Montague Strait in late summer and early fall (Matkin, pers. comm.). Similar multi-pod aggregations were observed in 1989-1991 and 1993. However in 1989, aggregations were short-term, lasting for only a day (Matkin, pers. comm.). The functional significance of the multi-pod aggregations is unknown but may be related to social activities or areas associated with high prey concentrations.

DISCUSSION

The overall population levels of killer whales in Prince William Sound are stable. However, the reported loss of 14 individual whales from AB pod (which numbered 36 whales in 1988) for the years 1989 through 1991 is unprecedented. The results of our 1993 investigations shows that AB pod continues to use Prince William Sound. Although fewer in number (1993 - 26 whales), the pod has remained together. The social structure (i.e., the subpod structure) also remains intact. The fourteen animals, listed as missing between 1989 and 1991, were not seen during 1993 investigations.

Several possible explanations for the missing whales were examined. The 14 missing animals could have been an artifact of the survey protocol. This possibility was evaluated by examining the potential for error in the photo-identification process and the bias in survey coverage. The number of animals present in Prince William Sound pods during summer surveys in 1989-91 was obtained through detailed examination of the photographic database of individual animals. Presence or absence of members of each pod were evaluated by comparing photographs taken during the 3-year study period to previous years. Results of the comparisons verified the absence of 14 whales in AB pod.

To evaluate whether or not a mistake was made during the identification process (for example, was a whale present but mis-identified) four researchers conducted independent analyses of the film. Analyses of the photographic data by the four researchers was

completed in a similar manner as that described for the initial examiner (detailed in the methods section of this document). Animals were recorded as being present or absent each time the pod was encountered. The results showed that earlier identifications were correct and that 14 whales were missing.

Another possible bias that could have resulted in the 14 whales not being seen and photographed was the amount of effort put forth to locate and identify the whales. The overall effort (km surveyed) conducted during 1989-1991 resulted in the greatest amount of survey effort to date for killer whales in Prince William Sound. The number of times each pod was seen in 1989, 1990, and 1991 seasons exceeded that reported for earlier studies. The amount of effort and the number of times each pod was encountered was more than adequate for locating and identifying the presence of individual animals.

The possibility that individual whales moved out of the Prince William Sound area and were not available to be photographed during these studies was also examined. Although considerable searching effort took place in Southeast Alaska during 1989-1991, the missing whales were not encountered. Photo-identification studies on killer whales have continued in Southeast Alaska under a different program (1992-1993). The missing whales have not been found in this region (Dahlheim and Waite 1993).

Unfortunately, minimal effort was expended near Kodiak Island and the waters adjacent to Prince William Sound to locate the missing whales during the 1989, 1990, and 1991 seasons. However, in 1992 and again in 1993, photo-identification studies were conducted by the National Marine Mammal Laboratory from Kodiak Island to Prince William Sound. AB pod members were not seen during these investigations (Dahlheim and Waite 1993, Dahlheim 1994).

A review of the 20-year killer whale database from British Columbia and Puget Sound, Washington, indicated that no resident killer whale consistently missing during repeated encounters had ever returned to its pod or appeared in another pod (Bigg et al. 1990). The possibility that the missing whales have moved out of the area is not supported by our knowledge of the social structure and behavior of resident killer whales. Based upon the historical life history information, it is likely that the missing resident whales are dead and have not moved off to other areas. However, a perturbation as severe as the spill and its direct impact on cetaceans has never been investigated. It is therefore possible that a major catastrophe such as the spill could have effected killer whales in ways never described before. This possibility, although highly unlikely, should not be disregarded.

The most reasonable explanation for the missing whales is that they are dead. However, the cause(s) of their death remain unclear. Natural mortality is certainly plausible, but unlikely. This species is characterized by a low birth and death rate (less than 2.2% per year; Olesiuk et al. 1990). The mortality rate for AB pod calculated for the 1989 season with the loss of seven whales was 19.4%. Six additional whales were reported missing from AB pod resulting in a 20.7% mortality rate for the 1989/90 season. In 1991, one more whale was noted as missing from AB pod (mortality rate of 4.3%). Survival rates for AB pod in 1988/89 and 1989/90 were significantly lower than survival rates calculated for AB pod in 1990/91. Survival rates of AB pod for the years 1988/89 and 1989/90 were significantly lower than those calculated for other resident pods. Mortality rates of AB pod for the 1989 and 1990 seasons are significantly higher than would be expected from natural

causes. It is unlikely that natural mortality would account for more than 1-3 animals, and not the loss of 14 whales over a 3-year period as observed.

Examination of other causes to explain the mortality of the 14 missing whales are complicated by the past history of AB pod. This pod was involved in interactions with the Prince William Sound sablefish longline fishery in the mid 1980's (Dahlheim 1988; Matkin et al. 1986; Leatherwood et al. 1990). In 1985, the National Marine Mammal Laboratory received reports of killer whales either being shot at by fishermen or by fishermen using explosives to frighten whales away from their fishing gear. Several of the animals showed evidence of bullet wounds. In 1985, three whales were reported missing. In 1986, three additional whales were missing. Between 1987 and 1988, this pod lost two more individuals. The loss of at least some of these 8 whales was attributed to shooting or the use of explosives (although never confirmed). These whales have never been seen again after the year they were first identified as missing. It is possible that all or some of the 14 whales reported missing during the 1989 through 1991 season could have been shot or died as a result of explosives being used. However, this is unlikely because 1) longline fishing was closed between the time when all whales were accounted for (September 1988) and the time when the first seven whales were first determined missing (March 1989), 2) there were no reports of shootings and, 3) no new bullet wounds have been observed on individuals of AB pod since 1986.

The remaining cause of death considered was the effect of the oil spill. Six different killer whale resident pods were observed swimming through oil (light sheen). The loss of the first seven animals from AB pod (if loss resulted from oil spill it occurred between 24 and 31 March 1989) could have been through direct contact with the oil, such as from inhalation of toxic volatile gases or ingestion. The loss of the six additional whales from AB pod between September 1989 and May 1990 is more difficult to explain from oil effects, but might have been associated with residual effects or from indirect effects (e.g., eating contaminated prey).

It is very possible that AB pod was in the Naked Island area when fresh oil was blown down into that area on 27 March 1989. AB pod is known to frequent the Naked Island area in early spring presumably to feed on herring and become involved with the blackcod fishery that typically opens 1 April. Although killer whale pods are seen in tightly grouped formation when resting and socializing, often when feeding or travelling they are spread out across distances of a mile or greater. It is possible that within a specific pod, some whales and not others could have come in direct contact with oil.

None of the missing whales were found stranded, although killer whales typically sink upon death (Zenkovich 1938). Five carcasses (only one whale could be identified and it was not from AB pod) were found during 1989-1992. This stranding rate is high compared to other geographical areas, and from previous stranding rates from the Prince William Sound region. However, this may simply have been an artifact of increased effort after the spill. Blubber samples and scrapings from the stomach lining from the stranded whales were analyzed for hydrocarbons. There was no indication of oil contamination in these tissues and cause of death could not be determined. Caution, however, must be used when interpreting these results because the carcasses were old when found and decomposition decreases the viability of the tissue samples for hydrocarbon analyses.

CONCLUSIONS

The cause(s) of the deaths of 14 killer whales from AB pod is unknown. There is confidence that 1) whales have not been mis-identified, 2) adequate effort was made in Prince William to locate the missing animals, and 3) the number of encounters was sufficient to evaluate the presence or absence of an individual whale. The current life history information available on killer whales precludes the possibility that the whales moved elsewhere. Therefore, we assume that the whales are dead from either, or a combination of, natural causes; a result of interactions with fisheries; or, from the *Exxon Valdez* oil spill. The highest mortality rate ever reported in the literature for North Pacific resident killer whales occurred in 1989 and 1990, coinciding with the *Exxon Valdez* oil spill. There is a strong correlation between the loss of the 14 whales and the *Exxon Valdez* oil spill, but there is no clear cause and effect relationship.

AB pod continues to use Prince William Sound each year. Although fewer in number (late 1993 count of 26 members) the pod remains together and the subpod structure remains intact. Continued research is recommended to monitor natural recovery of AB pod to pre-spill levels (36 animals) which may take 10 to 15 years.

ACKNOWLEDGEMENTS

Surveys of this magnitude could not have been completed without the help of many people. Craig Matkin was project leader during 1989, 1990 and 1991 investigations. Dave Bain was project leader during 1993 investigations. Thanks are also extended to the field crews for their many hours of effort. Judy Zeh provided the statistical analyses of the 84-92 data. We thank D. DeMaster and B. Wright for reviewing and editing various drafts of this report.

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Table 1. Summary of vessel survey effort in Prince William Sound 1989-91, and 1993.

	1989	1990	1991	1993
Inclusive dates	5/23-9/15	5/15-9/8	5/29-9/6	7/7-9/3
Number of survey days	260	247	159	59*
Days lost to weather	44	34	20	7
Kilometers surveyed	17,821	19,729	13,593	5,776
Whale encounters	89	80	54	41

*Only one survey vessel operating in 1993.

Table 2a. AB pod members encountered during the 1989 field season. An "x" signifies the presence of an individual whale on a particular day.

	2	3	4	5	8	10	11	14	16	17	19	20	22	24	25	26	27	29	32	33	35	36	38	39	40	41	42	43	44			
March 31	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
July 27		x	x	x	x	x	x				x		x		x		x		x		x	x	x		x		x		x	x		
July 30	x	x	x	x	x	x	x	x		x		x		x		x					x	x			x	x		x				
August 7	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x				
August 16	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	?	
August 20	x	x		x	x			x	x	x		x	x	x	x			x			x	x	x	x	x					x		
August 21	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
August 30	x														x			x	x	x			x	x			x					
August 31	x	x			x				x		x					x	x						x									
September 2			x			x		x	x	x	x		x																	x	x	
September 3		x	x	x		x	x	x	x			?	x	x	x	x	x			x		x		x	x		x	x		x	x	x
September 6	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x	x	x	x		x	x	x		x	x	x	x	x	x
September 7	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
September 11	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
September 14	x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x

Table 2b. Other killer whale pods present during encounters with AB pod in 1989.

March 31	AI pod, AJ pod
July 27	None
July 30	AI pod, AK pod
August 7	AI pod, AN pod
August 16	AI pod
August 20	AE pod, AI pod, AN pod
August 21	AI pod, AN pod
August 30	AN pod
August 31	AJ pod, AN pod
September 2	AI pod
September 3	AI pod, AN pod
September 6	AI pod
September 7	AI pod, AK pod
September 11	AE pod, AI pod, AK pod
September 14	AI pod

Table 3a. AB pod members encountered during the 1990 field season. An "x" signifies the presence of an individual whale on a particular day.

	2	3	4	5	10	11	14	16	17	22	24	25	26	27	29	32	33	35	38	39	40	41	43
June 1	x		x		x	x						x				?							
July 11							x	x	x		x		x					x			x	x	x
July 12	x	x	x	x	x	x						x				x	x		x	x			
July 13							x	x	x	x	x		x	x				x			x	x	x
July 16	x											x			x				x	x			
July 17		x	x	x	x	x	x	x	x	x	x		x	x				x			x	x	x
July 21	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
July 29	x	x	x	x	x	x	x							x	x	x	x		x		x	x	
August 4	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
August 6	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		
August 7	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x		
August 9	x	x	x	x		x		x	x	x		x	x		x	x	x	x	x	x			x
August 12	x	x	x	x	x	x	x	x	x			x	x	x			x	x		x	x	x	x
August 13	x		x	x		x	x		x	x	x	x			x	x	x		x	x		x	
August 14	x	x				x	x		x	x	x	x	x	x	x	x			x	x	x	x	x
August 20	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x		x	x	x	x
August 21	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x		x	x	x	x	
August 23				x	x	x	x			x	x					x	x	x			x		
August 24	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x
August 25	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
August 28	x	x		x	x	x	x		x			x		x	x	x	x	x	x	x	x		x
August 30	x	x			x		x	x	x	x	x	x	x	x	x	x	x	x		x			x
September 1			x		x	x						x			x	x	x		x	x			
September 2	x		x	x	x	x																	
September 5	x		x	x	x							x			x	x	x		x	x			

Table 3b. Other killer whale pods present during encounters with AB pod in 1990.

June 1	None
July 11	AD pod, AN pod
July 12	AI pod, AJ pod, AN pod
July 13	AN pod
July 16	AN pod
July 17	AI pod
July 21	AD pod, AI pod, AK pod, AN pod
July 29	AE pod, AI pod, AJ pod, AN pod, AX pod
August 4	AE pod, AI pod, AN pod
August 6	AI pod
August 7	AI pod, AJ pod, AN pod
August 9	AJ pod, AN pod
August 12	AI pod, AN pod
August 13	AI pod, AN pod
August 14	AE pod, AI pod, AJ pod
August 20	AI pod, AN pod
August 21	AI pod, AJ pod, AN pod
August 23	AE pod, AI pod, AN pod
August 24	AD pod, AI pod, AN pod
August 25	AI pod, AN pod
August 28	AE pod, AI pod, AN pod
August 30	AE pod, AI pod, AJ pod, AK pod, AN pod
September 1	AK pod
September 2	AD pod, AJ pod, AN pod
September 5	AE pod, AJ pod, AK pod, AN pod

Table 4a. AB pod members encountered during the 1991 field season. An "x" signifies the presence of an individual whale on a particular day.

	2	3	4	5	10	11	14	16	17	22	24	25	26	27	32	33	35	38	39	40	41	43	45
June 22		x					x	x	x	x	x		x	x			x			x	x	x	x
July 22	x	x					x	x		x	x	x		x	x	x		x	x	x	x		x
July 28		x					x	x	x	x	x		x	x			x			x	x	x	x
August 5			x	x		x																	
August 7				x		x																	
August 27		x	x		x		x	x						x						x			x
September 9	x	x	x	x			x	x	x		x	x		x	x	x	x	x	x				x
September 11	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 4b. Other killer whale pods present during encounters with AB pod in 1991.

June 22	None
July 22	AN pod
July 28	AD pod, AI pod, AN pod
August 5	AD pod, AI pod, AN pod
August 7	AI pod, AJ pod, AK pod, AN pod
August 27	AD pod, AK pod, AN pod
September 9	None
September 11	AI pod, AN pod

Table 5a. AB pod members encountered during the 1993 field season. An "x" signifies the presence of an individual whale on a particular day.

	2	3	4	5	10	11	14	16	17	22	24	25	26	27	32	33	35	38	39	40	41	43	45	46	47	48	
July 10				x			x	x		x	x	x	x	x				x	x				x	x		x	
July 12		x	x	x	x	x	x	x	x	x	x		x	x			x			x	x	x	x				x
July 23	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
July 24			x	x	x	x																					
August 22		x	x	x	x	x	x				x									x							
August 26	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
August 27	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x			x
September 3	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x

Table 5b. Other killer whale pods present during encounters with AB pod in 1993.

July 10	AN pod, AJ pod
July 12	None
July 23	AN pod, AD pod
July 24	AN pod, AK pod
August 22	AE pod, AI pod, AJ pod, AK pod, AN pod
August 26	AN1 and AN5
August 27	AN1 and AN5
September 3	AE pod, AN1 and AN5

Table 6. Subpod structure in AB pod.*

Group 1 -- AB4, AB5, AB10, AB11
Group 2 -- AB2, AB25, AB39, AB46, AB32, AB38, AB47, AB33
Group 3 -- AB14, AB24, AB40, AB22**
Group 4 -- AB17, AB35, AB43, AB22**
Group 5 -- AB3, AB41
Group 6 -- AB16, AB45
Group 7 -- AB26, AB27, AB48

*Membership of subpod structure constructed by Dave Ellifrit and Janice Waite.

**AB22 associates with both groups.

Table 7. Identification numbers of killer whales births (b) and deaths (d) in Prince William Sound resident pods, 1988-93. [] = number of whales in the pod in fall 1988.

Pod	88/89		89/90		90/91		91/92		92/93	
	d	b	d	b	d	b	d	b	d	b
AB [36]	13		8	29		45		46		48
	18		19					47		
	21		20							
	23		36							
	30		42							
	31		44							
	37									
AK [8]				10						
AE [12]	12	16		18						
AJ[27]		29		30			9			
AN [39]	2			41		45				
				42						
				43						
				44						

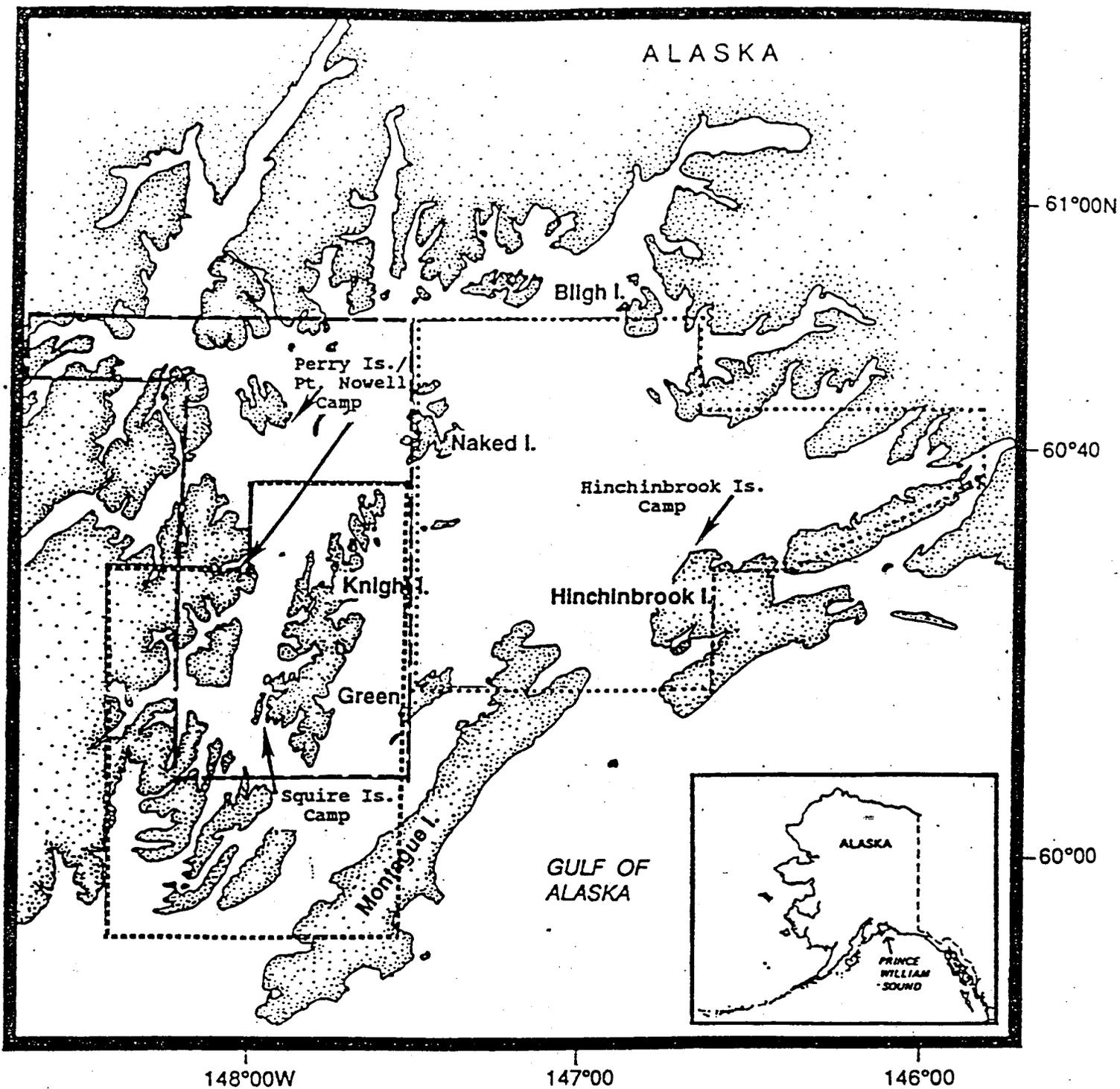


Figure 1. Approximate range covered by shore-based field stations in Prince William Sound; Perry Is./Pt. Nowell Camp (—), Squire Is. Camp (-----), and Hinchinbrook Is. Camp (.....).

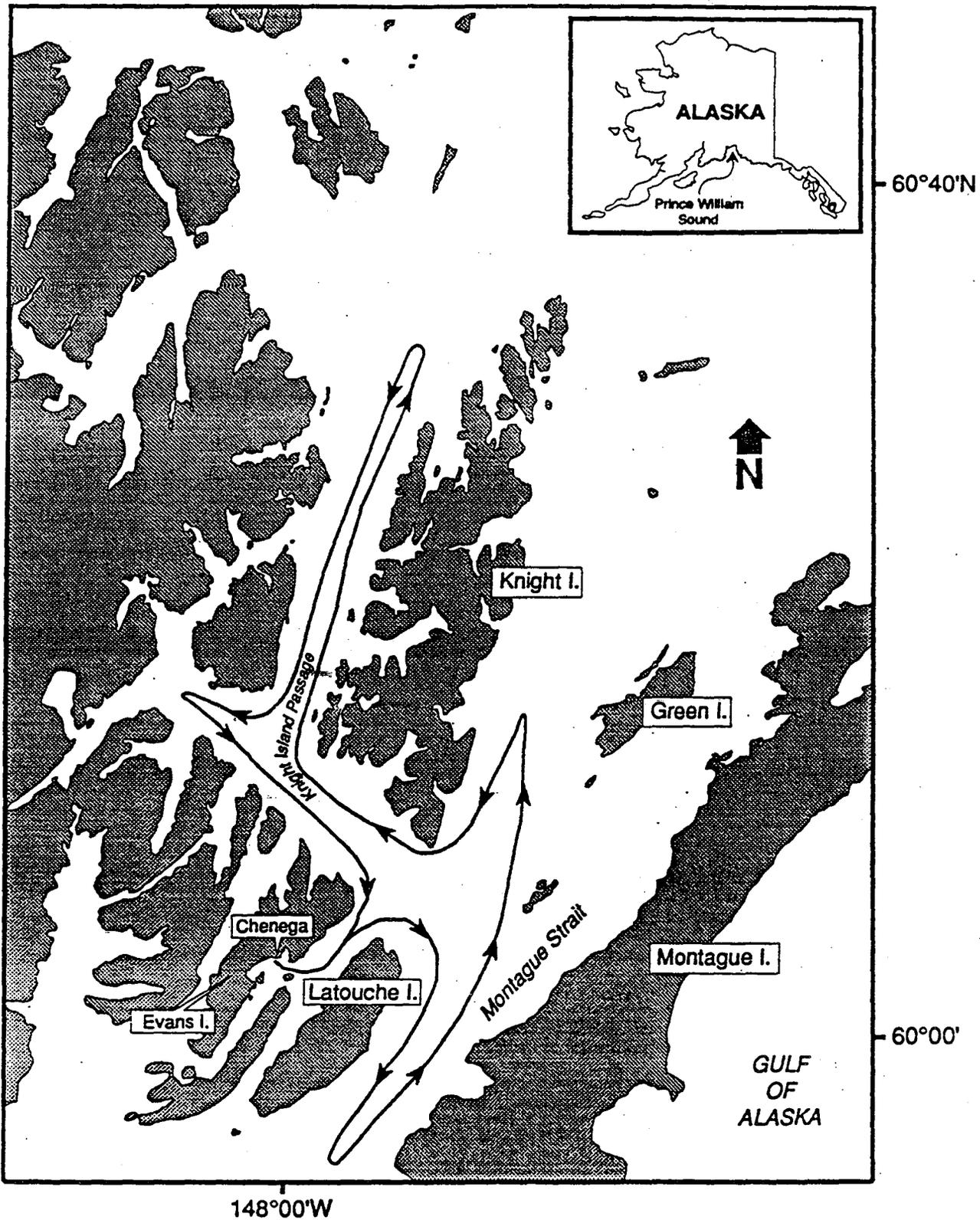


Figure 2. Daily search pattern used to locate killer whales in Prince William Sound during 1993 investigations.

DAILY RESEARCH LOG

DATE _____ PLATFORM _____

BEGIN LOCATION _____ END LOCATION _____

BEGIN TIME _____ END TIME _____

SEARCH TIME _____ TIME WITH WHALES _____ (Hrs)

TOTAL MILES SURVEYED (trackline) _____

PERSONEL _____

WEATHER & SEA STATE /TIME _____

WHALE
SIGHTINGS/TIME _____

ACTIVITIES/COMMENTS _____

Figure 3a. Daily Research Log.

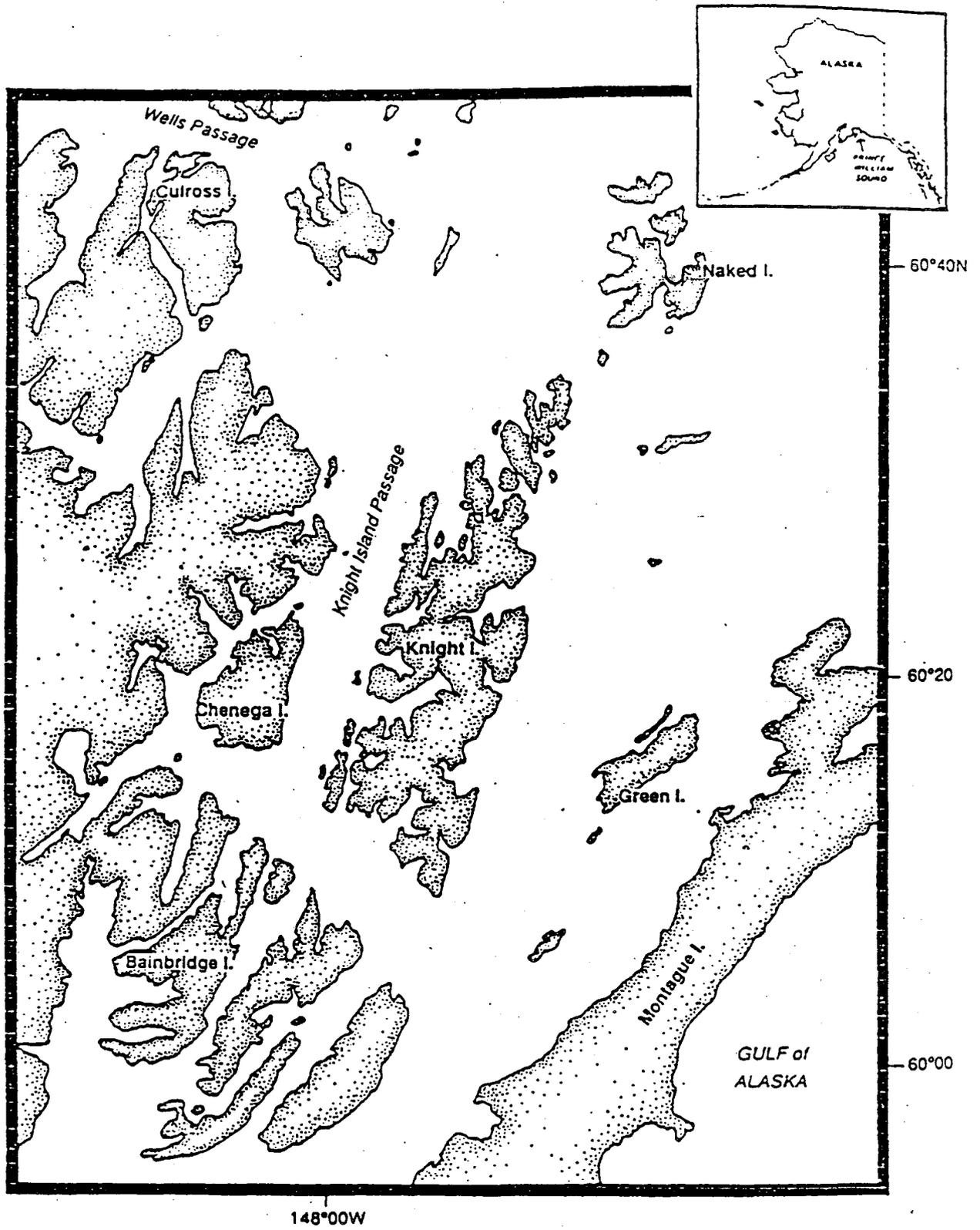


Figure 3b. Data sheet used to record vessel trackline when following killer whales during photo-graphic surveys.

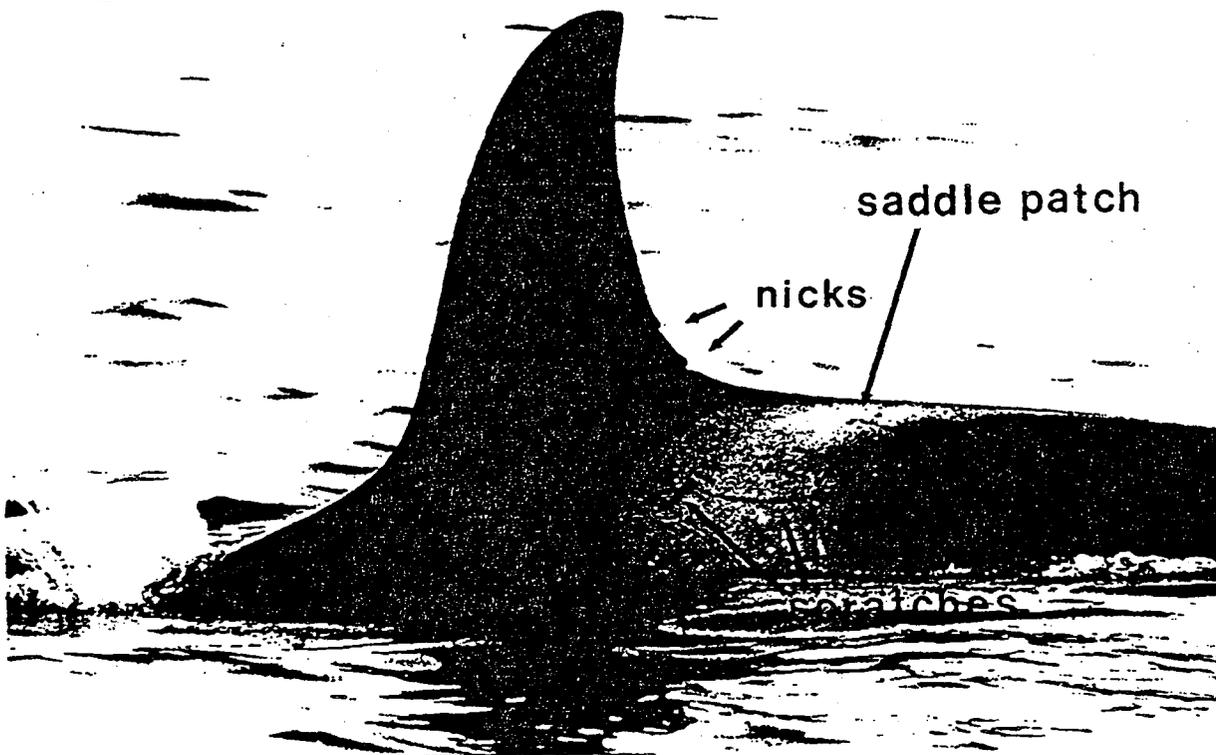
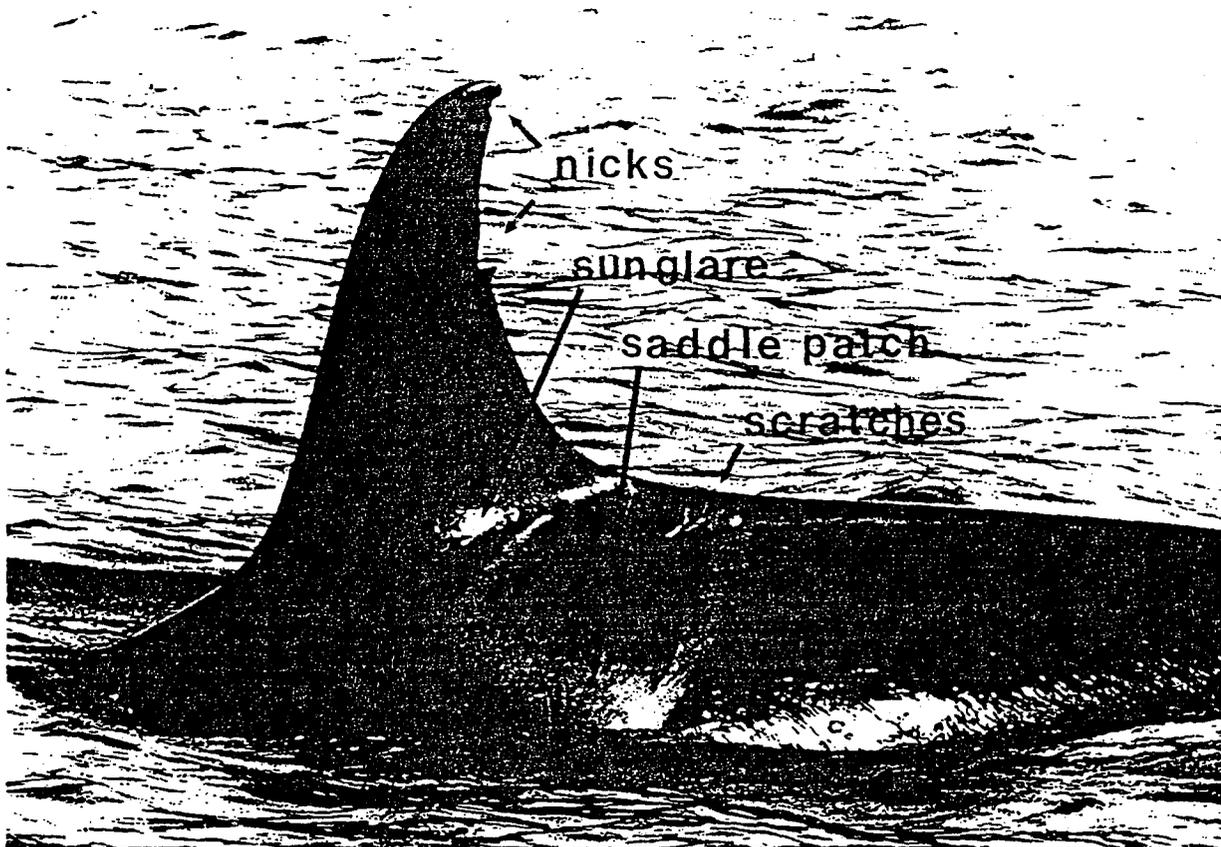


Figure 4. Examples of identification photographs of Prince William Sound killer whales showing various characteristics used to identify individuals.

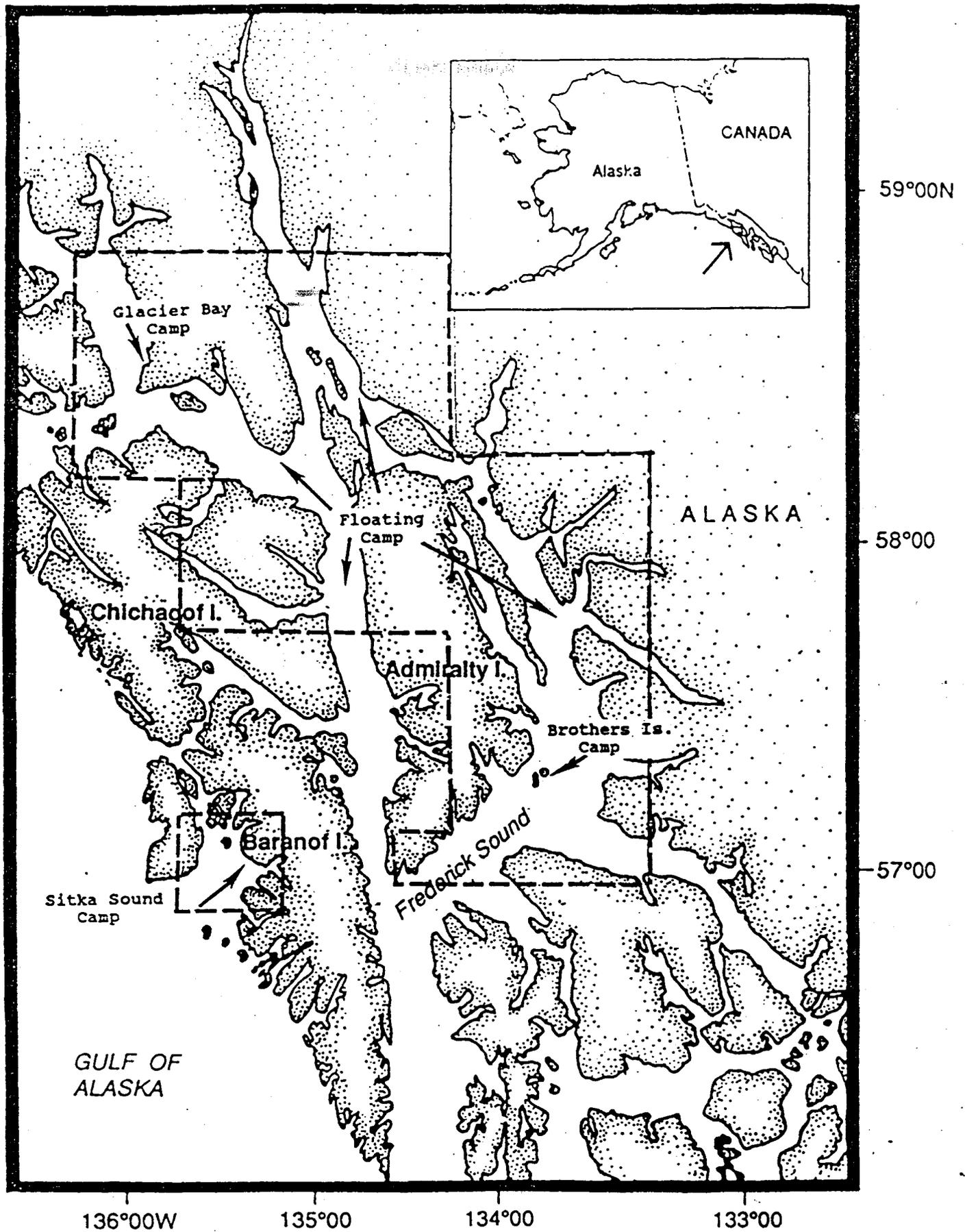


Figure 5. Approximate range covered by the four field research stations in Southeast Alaska.

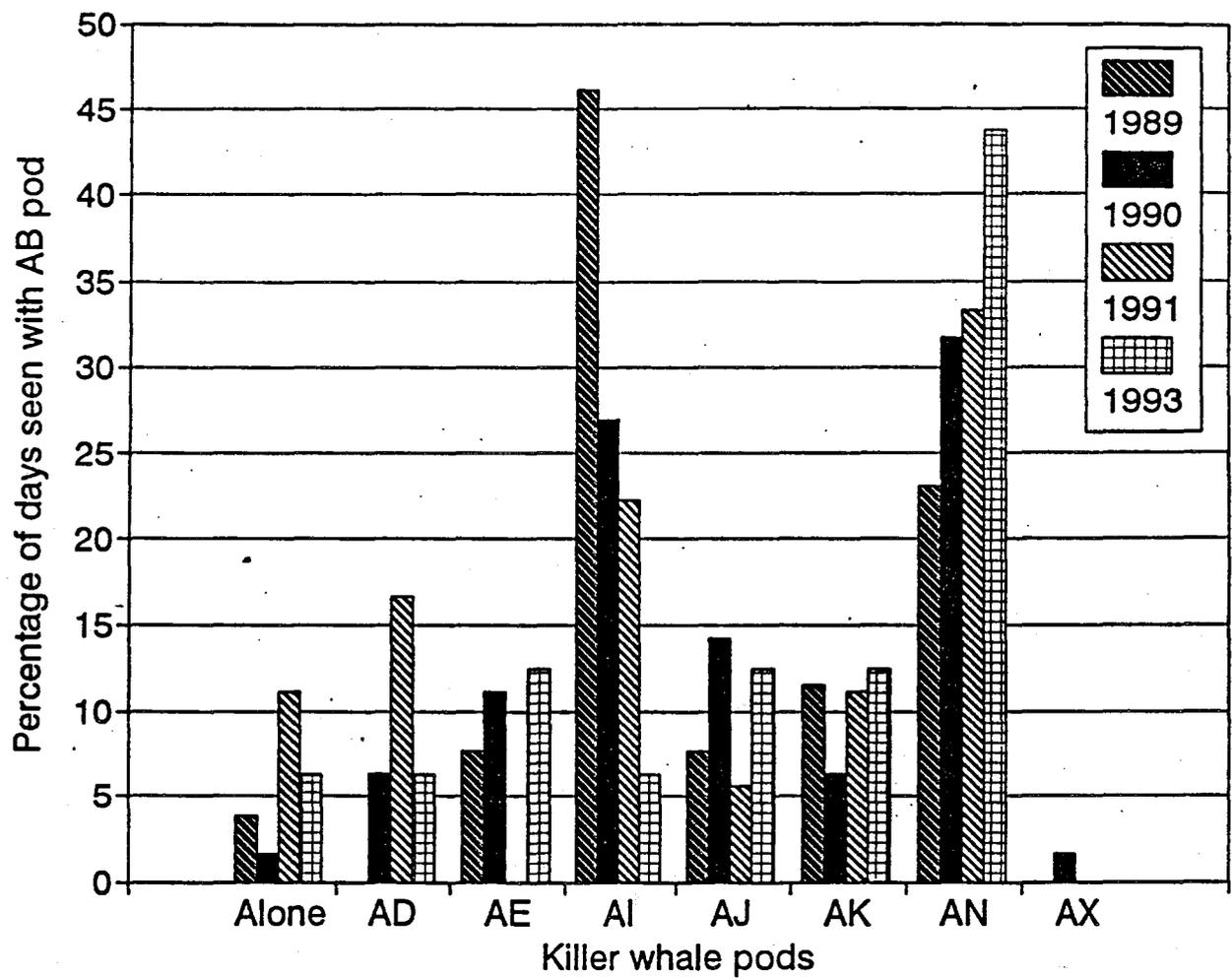


Figure 6. Resident killer whale pod associations (1989-1991, and 1993).

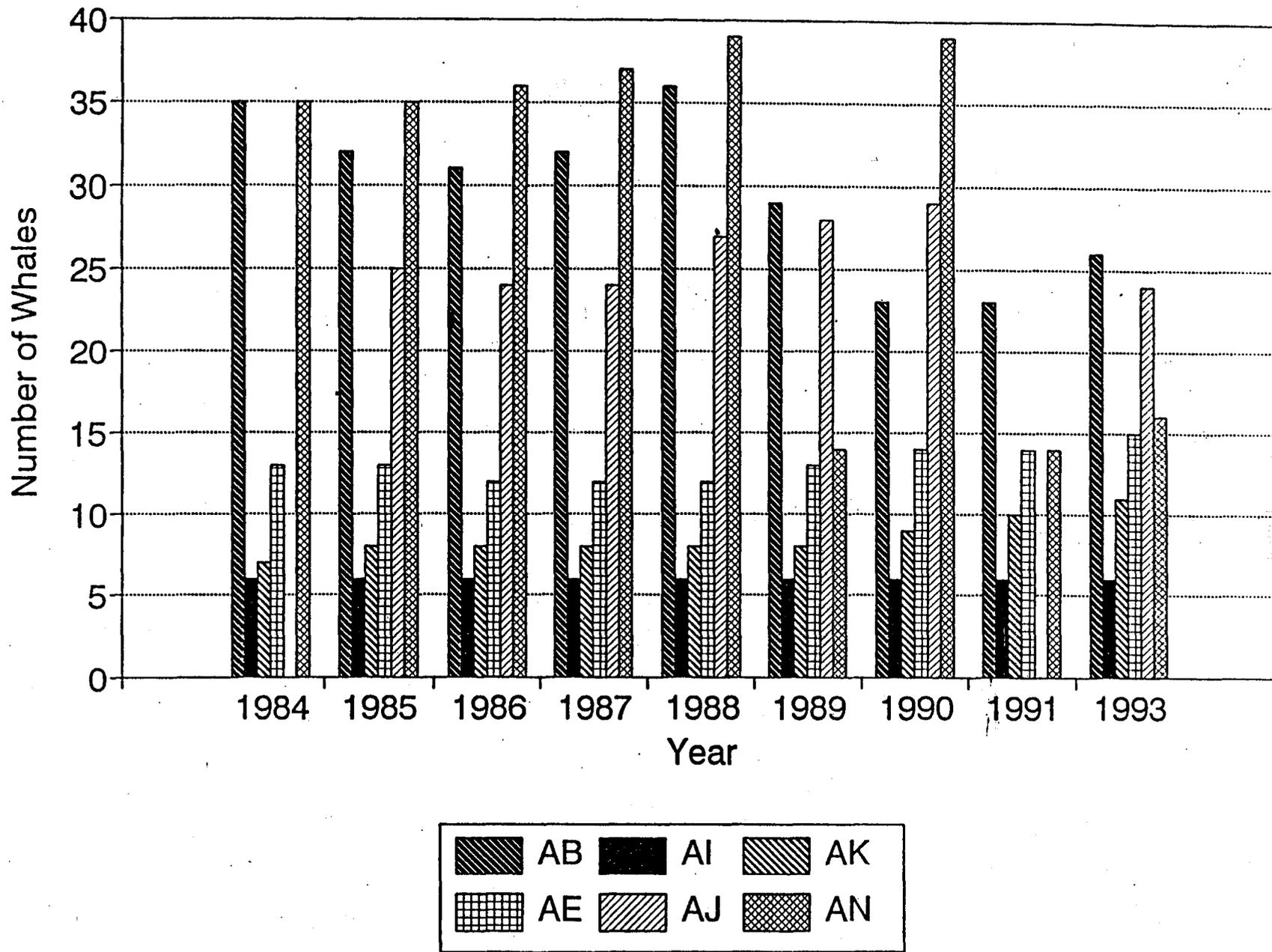


Figure 7. Summary of the number of killer whales in each resident pod in Prince William Sound (1984-1991, 1993).

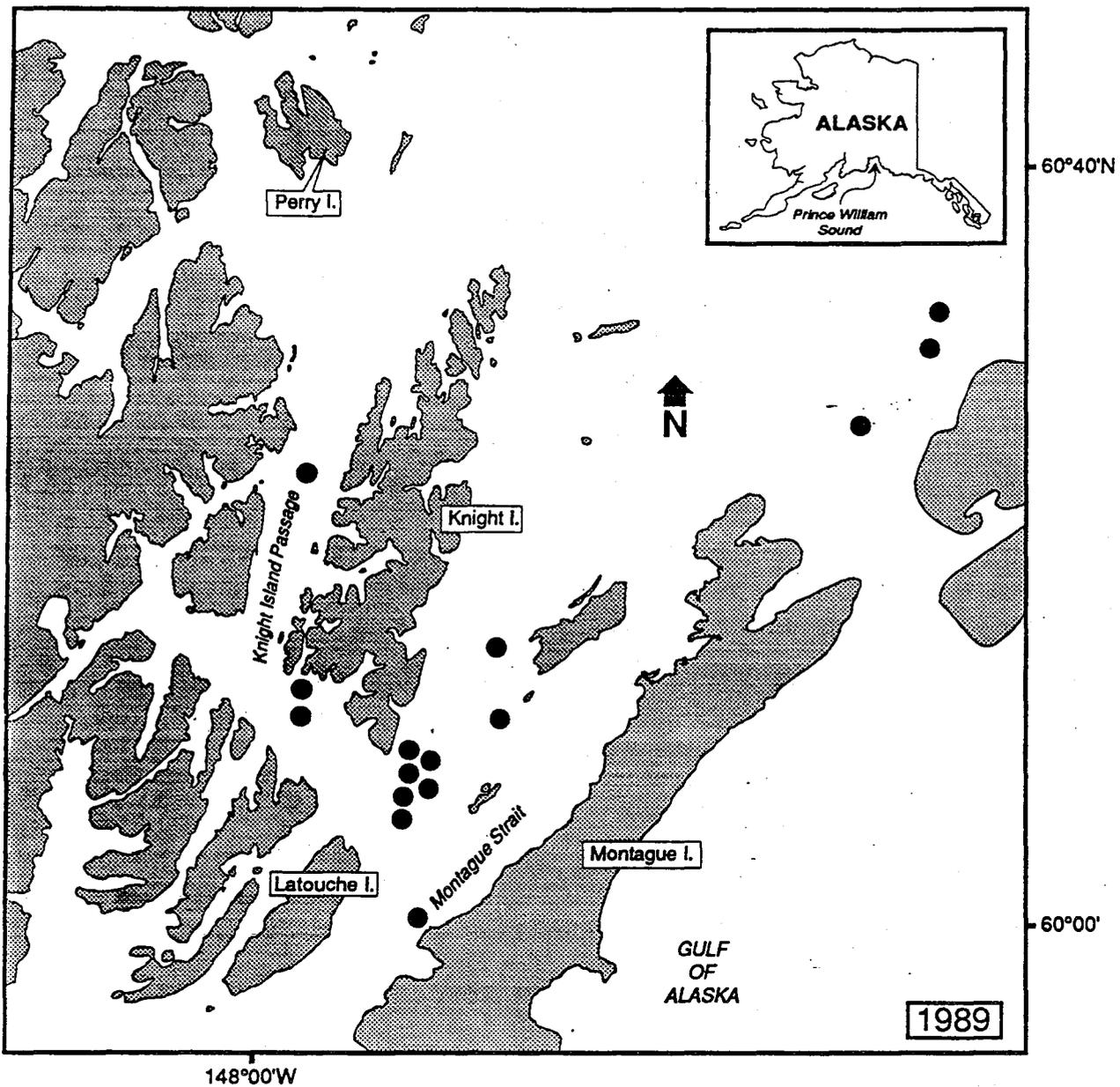


Figure 8. 1989 sighting locations of AB pod in Prince William Sound.

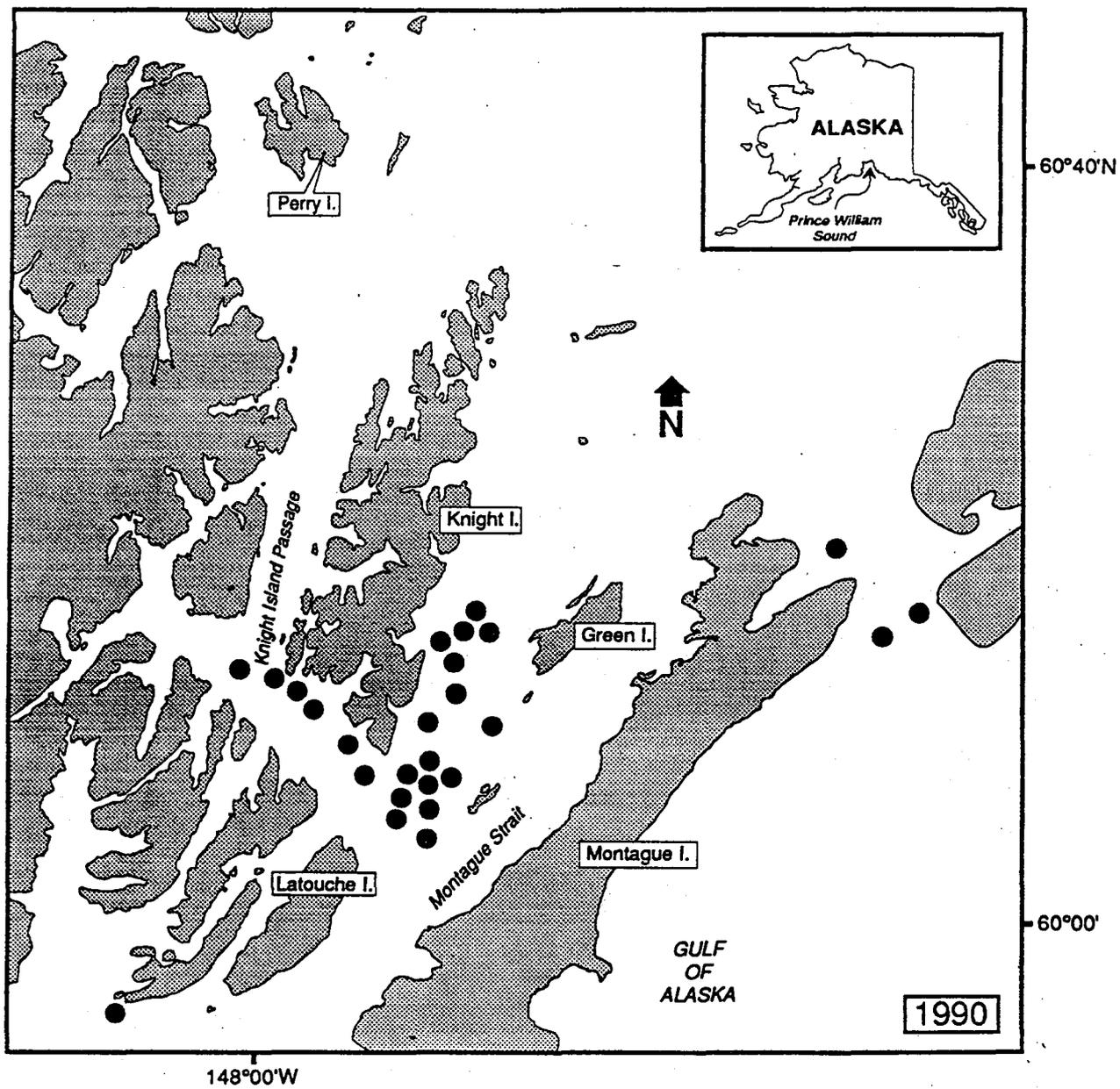


Figure 9. 1990 sighting locations of AB pod in Prince William Sound.

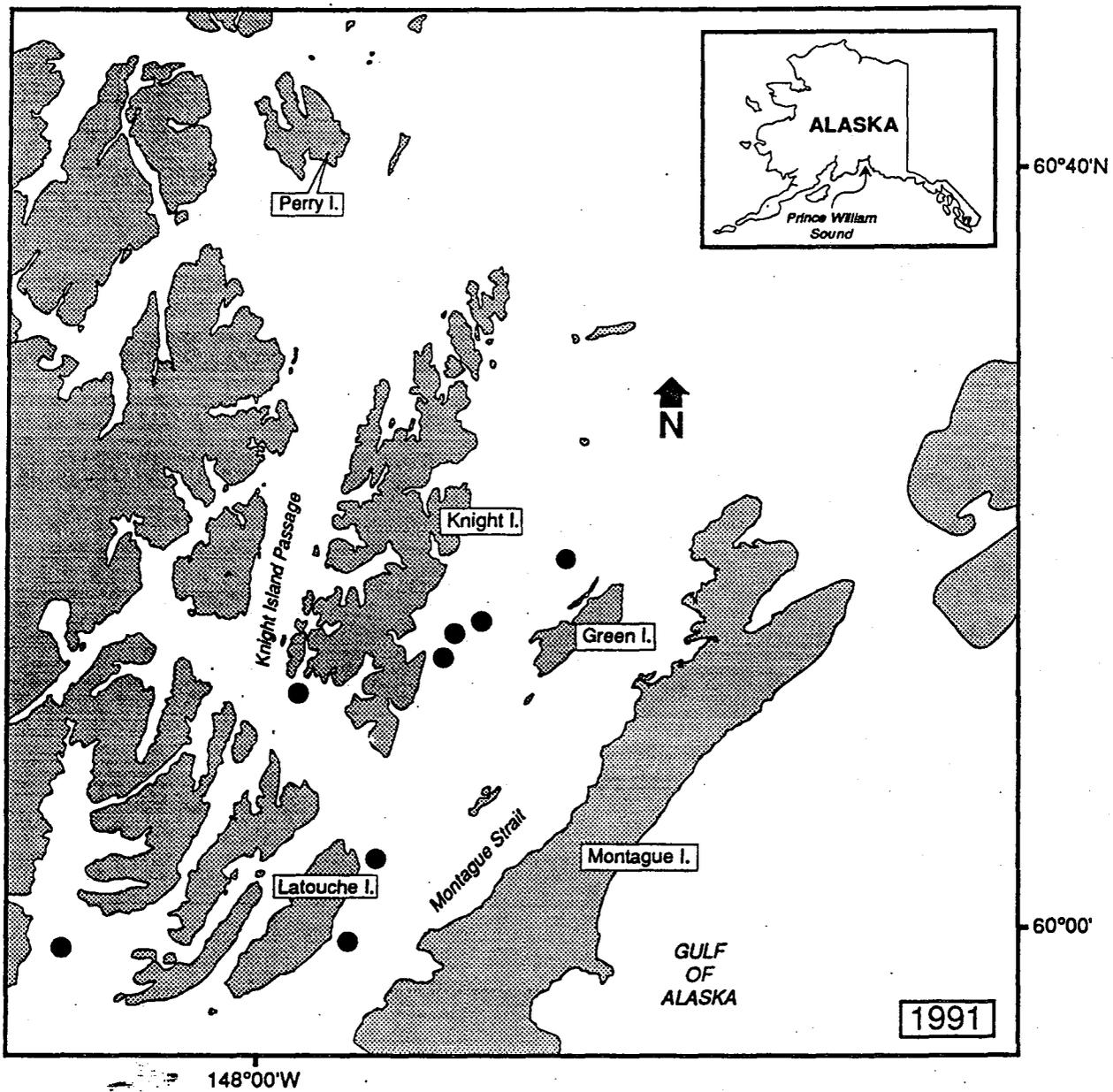


Figure 10. 1991 sighting locations of AB pod in Prince William Sound.

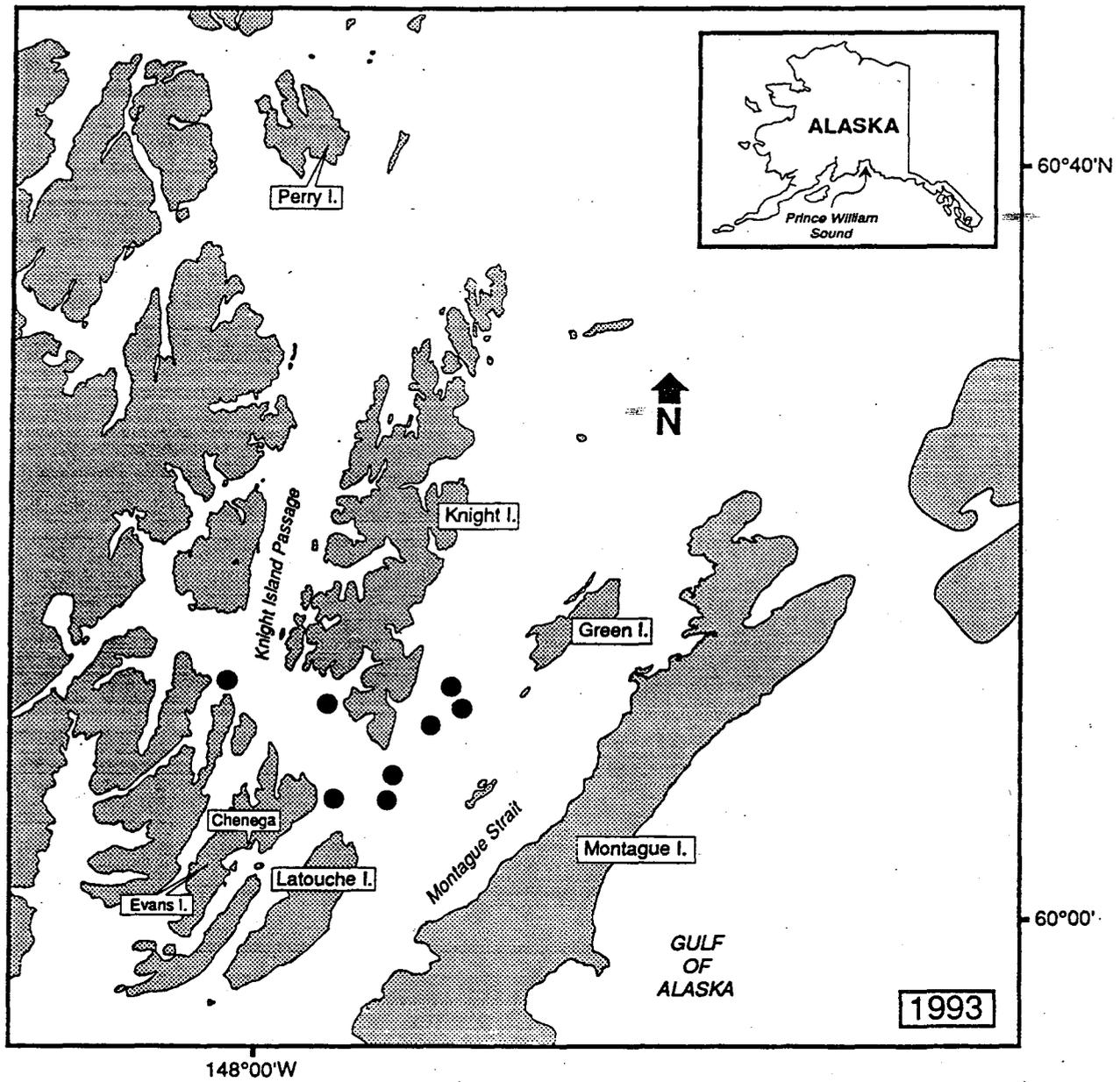


Figure 11. 1993 sighting locations of AB pod in Prince William Sound.