TESTING THE EFFECTIVENESS OF A HIGH LATITUDE MARINE RESERVE NETWORK IN GLACIER BAY NATIONAL PARK, ALASKA

ANNUAL PROGRESS REPORT

S. James Taggart
Jennifer Mondragon
Alexander G. Andrews
Julie K. Nielsen
L. James de La bruere

USGS - Alaska Science Center
Glacier Bay Field Station
3100 National Park Road
Juneau, Alaska 99801

April 2004

Table of Contents

I. INTRODUCTION

Starting in the late 1800's, the nutrient rich waters of Glacier Bay, Alaska, supported highly productive commercial fisheries. In 1999, however, the US Congress closed fishing in parts of Glacier Bay National Park creating one of North America's largest marine reserves. The legislation that closed commercial fishing in Glacier Bay National Park is specific for different species and different areas of the Park. All commercial fishing was left open in a three-mile band of water adjacent to the Park's shore along Icy Strait and the Gulf of Alaska while it was closed in Glacier Bay proper (Figure 1). Commercial fishing for Tanner crab (*Chionoecetes bairdi*) and Pacific halibut *(Hippoglossus stenolepis)* was immediately closed in five distinct areas that vary in shape and range in size from 40 to 280 km^2. A grandfather clause allows fishermen to continue fishing in the central part of the Bay for Tanner crab and Pacific halibut, but over the next several decades, as fishermen retire, Glacier Bay proper will become a single large reserve for all species. For red king crabs (*Paralithodes camtschaticus*) and Dungeness crabs (*Cancer magister)* the legislation immediately closed commercial fishing in all of Glacier Bay proper. Thus, for the immediate future, there is a reserve network of five closed areas for Tanner crabs and halibut while the entire bay proper is a reserve for red king crabs and Dungeness crabs. The network of closed areas adjacent to the open portion of the Bay provides a large-scale laboratory to study marine reserve effectiveness.

Declining fish and invertebrate stocks around the world are creating concerns about the long-term sustainability of many fisheries (Jackson et al. 2001, Stergiou 2002, Myers and Worm 2003). Fisheries in Alaska are not immune to these declines, and crustacean fisheries in particular are prone to serial depletion and collapse (Orensanz et al. 1998). In response to worldwide fisheries concerns, marine reserves are being promoted as effective tools for managing fisheries while simultaneously meeting marine conservation goals and maintaining marine biodiversity. Increases in individual size, density, biomass, and diversity have been demonstrated in studies of fish and invertebrates from both temperate and tropical marine reserves (Halpern 2003). Studies on the effectiveness of marine reserves at high latitudes, however, are rare. The formation of marine reserves in Glacier Bay National Park provides a unique opportunity for marine reserve research in a high latitude ecosystem.

In order to be effective, a marine reserve must be large enough to protect a sufficient proportion of the population for positive effects such as increased body size, density, or fecundity to be realized (Polacheck 1990). Reserve size and shape can greatly influence the ability of a marine reserve to protect adult breeding populations (Polacheck 1990, Demartini

1993, Guenette and Pitcher 1999). A small boundary to reserve area ratio can result in lower movement across the reserve boundary, and thus increase the spawner stock biomass within the reserve, and shift the age structure of the population to older individuals. Marine reserves are likely to be an effective conservation tool for organisms that have relatively sedentary adult life stages (compared to the size of the reserve) and highly mobile larval stages, so the reserve can "seed" surrounding areas (Nowlis and Roberts 1999, Chiappone and Sealey 2000, Martell et al. 2000, Murawski et al. 2000, Pitcher et al. 2000, Roberts 2000, Warner et al. 2000). The retention of breeding adults in marine reserves is quantified in simulation models as transfer rate; these models demonstrate that transfer rate is central to reserve effectiveness (Polacheck 1990, Demartini 1993, Guenette and Pitcher 1999).

Many marine organisms, including benthic crustaceans, have complex life histories that involve a pelagic larval stage, which may involve large-scale transport, settlement of juveniles or larvae, and a comparatively sedentary adult stage. Recruitment for marine species may be greatly influenced by post-settlement variables such as available habitat (Wahle and Steneck 1991) or post-settlement predation (Heck et al. 2001). Habitat, environmental conditions, and biotic communities often vary in space. The existence of areas that provide favorable conditions for settlement and increased survivorship for juveniles, or nursery areas, within reserves is an important spatial component of marine reserve effectiveness.

The term "nursery area" or "nursery habitat" has been used to refer to areas that have high densities of juveniles. Beck et al. (2001) proposed a more rigorous definition, with four criteria to be examined before an area can be defined as a nursery area: 1) juveniles occur at higher densities, 2) survival is greater, 3) growth is greater, and 4) juveniles move from the nursery area to adjacent adult areas. An area can be called a nursery area if it contributes more animals to adult populations per unit area than other areas do (Beck et al. 2001). Therefore, two broad components comprise this nursery area definition: 1) habitat attributes that result in increased density, survival, or growth of juveniles, and 2) movement of juveniles from nursery to adult populations.

The goal of this project is to test the effectiveness of the marine reserves in Glacier Bay. We are accomplishing this goal through several research objectives. First, since marine reserves only protect the animals that reside within the boundaries of the protected area, we are studying the distribution and abundance of resources in the reserves. Specifically, we are describing the distribution and abundance of Tanner crab (*Chionoecetes* *bairdi*) and Red King crab (*Paralithoides camtschaticus*) in the newly created reserves and the adjacent area remaining open to commercial fishing.

Secondly, we are investigating the patterns of distribution and abundance of juvenile Tanner crabs and the potential presence of nursery areas in the reserves. We are comparing habitat attributes (depth, temperature, substrate) between areas where juveniles occur at high and low densities. We are also trying to infer whether or not movement from the nursery areas is occurring by monitoring size frequency and age structure patterns over time as well as performing spatial analysis techniques on “age” classes of female Tanner crabs.

Finally, in order to test marine reserve effectiveness it is important to understand how animals are moving in relation to the reserve boundaries (transfer rate) and how much time they are spending in the protected areas. We are using a combination of ultrasonic gates and sonic tags to measure the transfer rate of adult Tanner and red king crab between the East Arm reserve and the area remaining open to commercial fishing. If animals are spending a significant portion of time inside the reserves, then we may start to observe some of the population changes, such as higher abundance, that have been demonstrated in protected areas in other parts of the world.

In addition to protecting commercial species, marine reserves can increase biodiversity because they protect a large array of species. The research we are conducting has been effective at sampling the distribution of benthic marine species. This information has rich potential for helping us to understand the interactions between benthic species and other marine resources in a recently deglaciated fjord ecosystem. In this progress report, we include a comparison of the distribution of sleeper sharks caught in the crab survey pots and locations of major harbor seal haulouts in Glacier Bay.

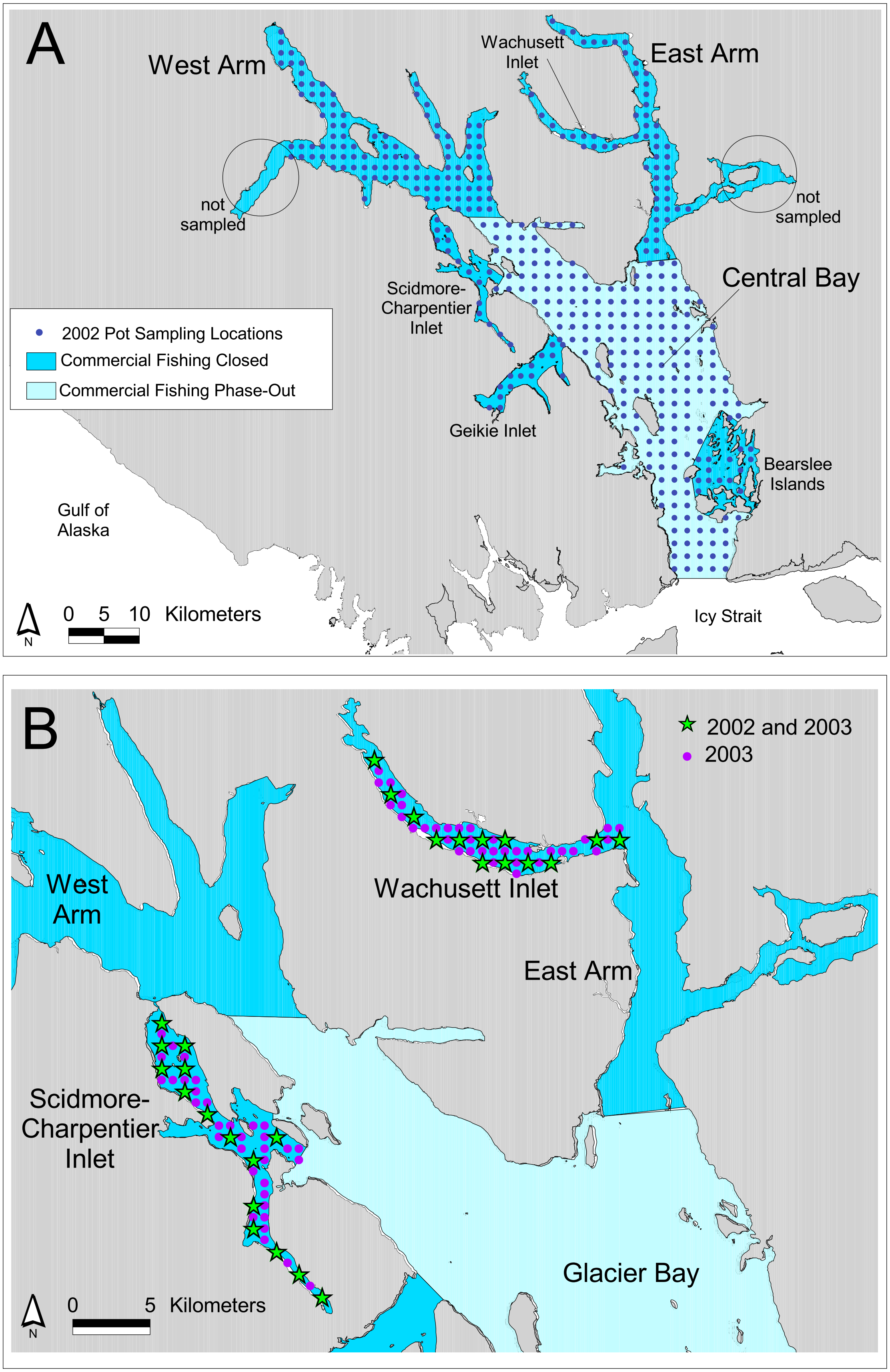

Figure 1. A. The 415 systematic stations that were sampled throughout Glacier Bay in July and August, 2002. Two areas were not sampled due to navigational hazards. B. The 48 stations sampled in Wachusett Inlet and Scidmore-Charpeniter Inlet in October, 2003.

II. DISTRIBUTION AND ABUNDANCE OF CRABS

Methods

Pot sampling

During July and August 2002, the relative abundance of crabs was estimated at 415 systematic stations throughout the Bay (Figure 1). Since the area remaining open to commercial fishing is slightly larger than the reserve area, sampling stations were spaced 1.5 and 1.8 km respectively to achieve a sample size of 200 pots in each area. Stations were clustered into sets of 16 (the number of pots we sampled each day) and during each of the three 11-day sampling trips, effort was distributed from the mouth of Glacier Bay to the head of the fjord. The only stations we did not sample were areas that are hazardous to navigation (Johns Hopkins Inlet, Adams Inlet, and a few stations in the Beardslee Islands). In October 2003, Wachusett Inlet and Scidmore-Charpentier Inlet were sampled on a finer scale grid (750 m) with 48 stations (roughly 4 times the number set in the same location in 2002) (Figure 1). The 750 m sampling grid was superimposed on the 1500 m sampling grid from the 2002 survey, so the same stations were sampled in both years (Figure 1). In both 2002 and 2003, crabs were collected using conical, top-loading, 2.3 m by 1 m commercial Tanner crab pots with a purse and body webbing of 8.9 cm. In order to target juvenile and female crabs, a 1 m-diameter commercial shrimp pot (with 4.4 cm mesh) was attached to each of the conical Tanner crab pots with a 20 m tether. All pots were baited with chopped herring and salmon hanging bait. Procedures were the same as those used on the ADF&G stock assessment surveys (Clark et al. 1999). StowAway TidbiT temperature loggers (Onset Computer Corporation, Bourne, MA) were attached to every pot and recorded ambient water temperature on the bottom at 150 sec intervals.

A 15.2 m USGS research vessel, the R/V Alaskan Gyre, was used to deploy and retrieve crab pots. Sixteen pots were set each afternoon and pulled the next morning after a soak time of 15 to 20 hours. As the pots were retrieved, we counted and identified all organisms to species. Carapace size, width for Tanner crab and length for king crab, was measured to the nearest mm with vernier calipers. Female Tanner crab sexual maturity was assessed by the relative size of the abdominal flap (Jadamec et al. 1999) (Figure 2) and the presence of eggs. In contrast to females, the sexual maturity of male Tanner crabs is more difficult to determine. In mating experiments in the laboratory, it has been shown that all males over 80 mm produce spermatophores and fertilize mates (Paul and Paul 1990). For this survey, males were categorized as small (<80 mm) or large (>=80 mm).

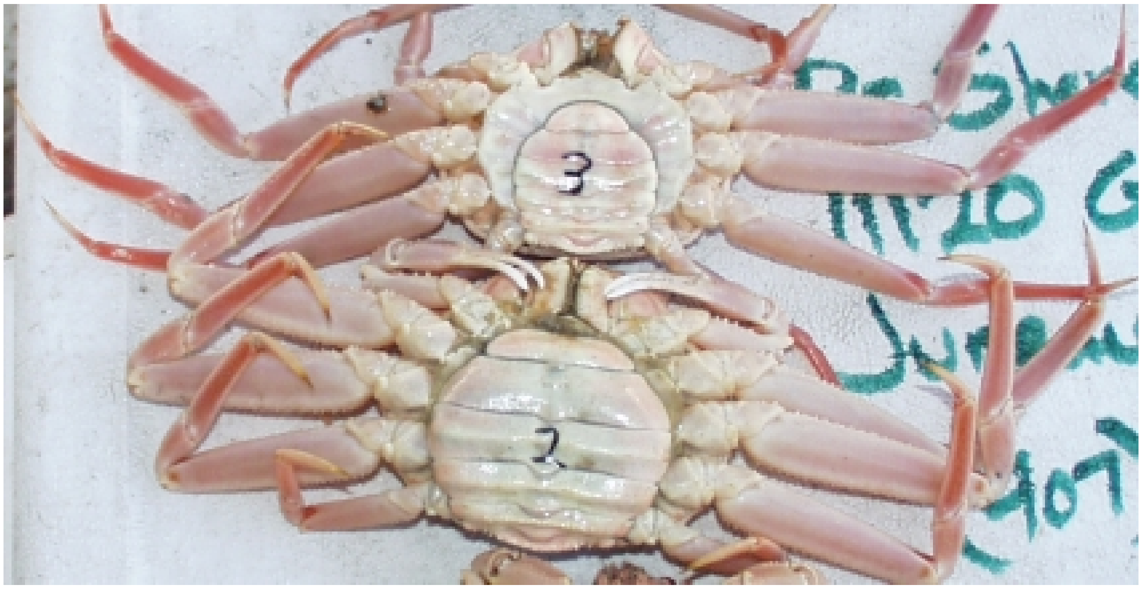

Figure 2. Photo of the ventral surface a juvenile female Tanner crab (top) and a mature female Tanner crab (bottom). The abdominal flap covers about 2/3 of the ventral surface of a juvenile crab, whereas the abdominal flap covers most of the ventral surface of mature female crabs.

Although age is extremely difficult to estimate for crabs, it can be ranked by shell condition for crabs of a given size class. Because female *Chionoecetes* crabs do not molt again after molting to maturity, shell condition can be used as an approximate rank of age since the molt to maturity (Jadamec et al. 1999). Shell condition of all crabs was categorized as soft, new, old, or very old (Jadamec et al. 1999). We also recorded missing or regenerating appendages and noted any disease and parasites.

Commercial Tanner crab vessels usually deploy pots within a set depth range and they coil the buoy line into 45.7 or 91.4 m (25 or 50 fathom) sections. In contrast, our sampling design required us to sample all locations independent of water depth and a large portion of Glacier Bay has water depths greater than 200 m. There were many days when we set and retrieved 8 km of buoy line and managing the buoy line was a serious logistical obstacle. To reduce the fatigue associated with coiling the buoy line, we used 1.27 cm (0.5 inch) “soft lay” line, manufactured by Everson Rope Inc., and flaked the line into tubs.

Substrate sampling

Substrate samples were collected during October 2003, at approximately 3-km intervals along transects that extend from the distal ends (high degree of glacial influence/high density juvenile areas) to the mouths (lesser degree of glacial influence/adult areas) of both Wachusett and Scidmore-Charpentier Inlets (Figure 3). Sediment samples were collected with a modified Van Veen grab. A digital photo of the sediment grab was taken to qualitatively describe benthic community and substrate characteristics. Subsamples of the grab were collected using 50 cc syringes with plungers to sample the upper 5 cm of the sediment. Subsamples were kept frozen for analysis of organic carbon content and grain size composition in the laboratory.

Organic carbon content will be determined by removing carbonates with an acid treatment and measuring the difference in sample mass following combustion of the sample in a muffle furnace at 600°C (Holme and McIntyre, 1971). Grain size composition will be determined by placing a weighed sample in a sieve shaker with sieve sizes of 4 mm, 2 mm, 1 mm, 500 µm, 250 µm, 125 µm, and 64 µm. The portion of the total sample found in each sieve after 15 minutes of shaking will be weighed to determine the percentage by dry weight for each sediment size fraction (Scheding et al. 2001).

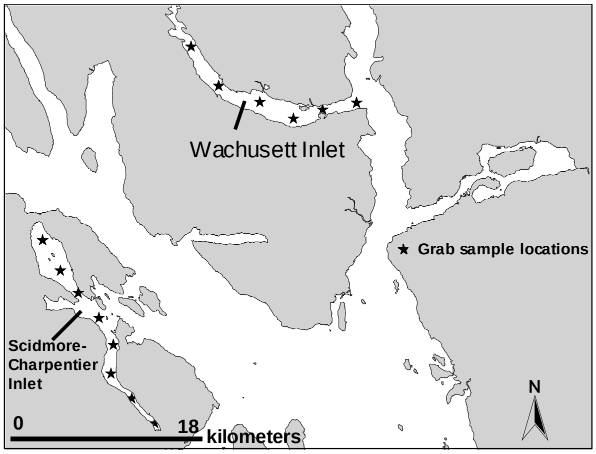

Figure 3. Location of grab samples collected in Wachusett Inlet and Scidmore-Charpentier Inlet in October, 2003.

Data Analysis

We tested for differences between the spatial distributions of different size and sex classes of Tanner crabs with a generalization of a two-sample Cramer-von Mises test and a QuickBasic permutation software program, GeoDistn (Syrjala 1996); 1000 random permutations were used to calculate the p-value. Spatial distributions were compared for juvenile females, old-shell adult females, new-shell adult females, large males (>80mm), and small males (<80mm).

We tested for habitat associations for different size and sex classes of Tanner crabs by generating cumulative distribution functions (CDF) of the habitat (temperature and depth) sampled and a corresponding CDF of catch of crabs for each class of Tanner crab. We tested for differences between the CDFs with a Kolmogorov-Smirnov test (Perry and Smith 1994, Reynolds 2003). The values at the 10th and 90th percentile were used to summarize the depth and temperature range for 80% of the population.

High density areas for different size and shell condition classes of female Tanner crabs were mapped using kriging, a geostatistical tool (Warren 1998, Roa and Tapia 2000). The ESRI ArcGIS extension Geostatistical Analyst was used to perform kriging and to generate a surface that represents probabilities of catch-per-unit-effort (CPUE) greater than the mean CPUE for all stations for each age class. High-density areas were defined as greater than 75% and low-density areas (generated for juvenile females only) were defined as between 50-75% probability of having a CPUE that is greater than the mean of all CPUE for that particular age class. The degree of overlap between distributions of age and size classes was determined using polygons created by probability kriging in Geostatistical Analyst.

Results & Discussion

Both male and female Tanner crabs were widely distributed throughout Glacier Bay (Figure 4). Large males, however, were the most widespread and were found in 60% of the pots surveyed in 2002. Old-shell adult females were found in 37% of the pots; new-shell adult females, juvenile females and small males were found in 26%, 32% and 27% of the pots, respectively. The only area where crabs were consistently not captured was the main channel of the lower Bay, between Willoughby Island and the mouth of the Bay (Figure 4). Juvenile crabs predominated in Wachusett Inlet and the distal ends of Scidmore-Charpentier Inlet, both narrow glacial fjords (Figure 4). Juveniles also predominated, but at lower densities, in a patch in the open part of Glacier Bay.

We found no difference between the spatial distribution of large males and old-shell adult females. Large males, however, had a significantly different spatial distribution from every other size/sex class (Table 1). In contrast, small males were not significantly different from every other size/sex class except for large males. Female crabs also showed

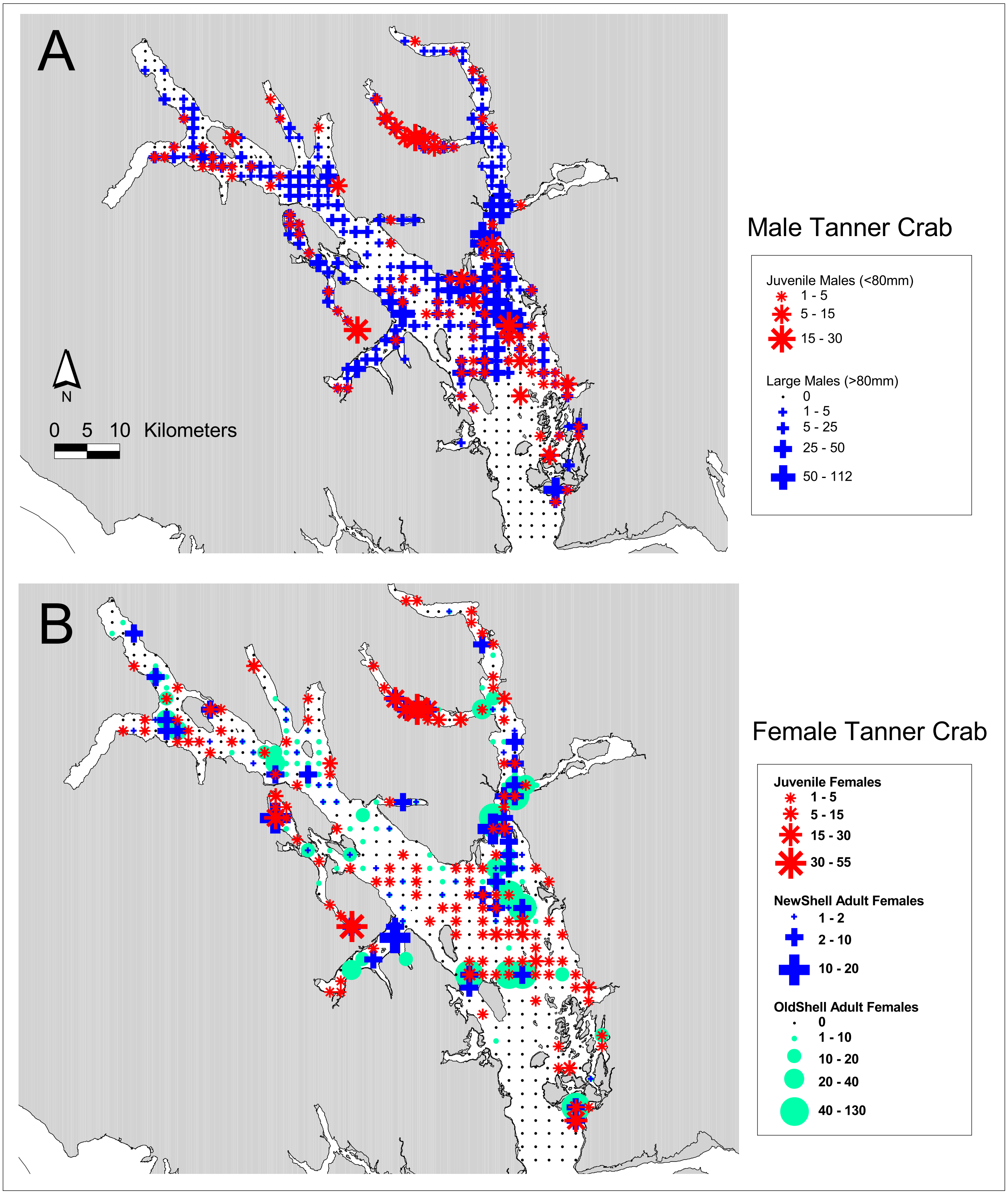

Figure 4. Catch per pot of male (A) and female (B) tanner crab by size and shell condition.

Table 1. Results test for differences in spatial distributions of sex and size classes of Tanner crabs in Glacier Bay. Distributions were compared for juvenile females, old shell adult females, new shell adult females, large males (>80mm) and small males (<80mm). Numbers are p-values from Cramer-von Mises test of differences between each pair of distributions, asterisks denote significantly different distributions at the 0.05 significance level.

	Juv. Female			
New Shell Female	0.053	New Shell Female		
Old Shell Female	0.04*	0.024*	Old Shell Female	
Small Male	0.191	0.09	0.178	Small Male
Large Male	0.008*	0.004*	0.188	0.029*

Table 2. Range of habitat conditions sampled and depth where crabs were caught. The values were calculated from a cumulative distribution function (CDF) of the habitat (temperature and depth) sampled and a CDF of catch of crabs. The values at the 10th and 90th percentile were used to summarize the depth and temperature range for 80% of the population.

Depth (m)

	Large Male	OS Female	NS Female	Sm. Male	Juv. Female	Habitat Sampled
10th percentile	51.2	51.2	60.4	27.4	25.6	34.8
90th percentile	343.8	376.8	347.5	201.2	243.3	334.7

Temperature (°C)

	Large Male	OS Female	NS Female	Sm. Male	Juv. Female	Habitat Sampled
10th percentile	4.6	4.6	4.5	4.5	4.5	4.6
90th percentile	6.6	6.4	6.3	6.8	7.5	7.5

differences in distribution with size and age. The spatial distribution of new-shell adult females and juvenile females was not significantly different. However, the spatial distribution of old shell females was significantly different from both new-shell adult and juvenile females (Table 1).

In order to determine whether different classes of Tanner crabs were associated with particular depths or temperatures, we compared cumulative distribution functions (CDFs) of depth and temperature to CDFs of Tanner crab split by size/sex classes (Figure 5). If Tanner crabs were randomly distributed with respect to the habitat variable sampled, there would be no difference between the CDF of the habitat sampled and the CDF of the crab catch. We found, however, a significant difference between the CDF of depths sampled and the CDF of each size/sex class (juvenile females, new-shell adult females, old-shell adult females, large males, and small males, $p<0.001$ for each test). The differences in these distributions indicate a strong association between the distribution of Tanner crab and depth (i.e. a non-random association with depth).

When we compared the CDF among the size/sex classes we found no difference in the depth preference between males and females, but juveniles and adults differed. There was no significant difference between the CDF by depth for juvenile females and small males ($p=0.0512$). Eighty percent of the population of small males was found in depths between 27 and 201m (Table 2). Juvenile females had a similar depth distribution with 80% between 26 and 243m. Large male crabs and old-shell adult female crabs showed no significant difference in their CDF by depth ($p=0.1974$). In general the distribution of the adult crabs was deeper than that of juveniles; 80% of the large males were found between 51 and 343m and 80% of the old-shell adult females were found between 51 and 376m (Table 2).

The CDF by depth for new-shell adult females was significantly different than the CDF for all other size/sex classes. In terms of depth, the distribution of new shell females was closer to other adults than to juvenile females and small males (large males, $p=0.0232$; old-shell adult females, $p=0.0152$; juvenile females, $p<0.0001$; small males, $p<0.0001$). Since the spatial distribution of new-shell adult females was more similar to juvenile females and small males (Table 1), we hypothesize that females molt to maturity within the juvenile areas and move to deeper depths (thus the differences in depth distribution, but not spatial distribution, compared to juveniles). We further hypothesize that as they age, these females disperse to adult areas.

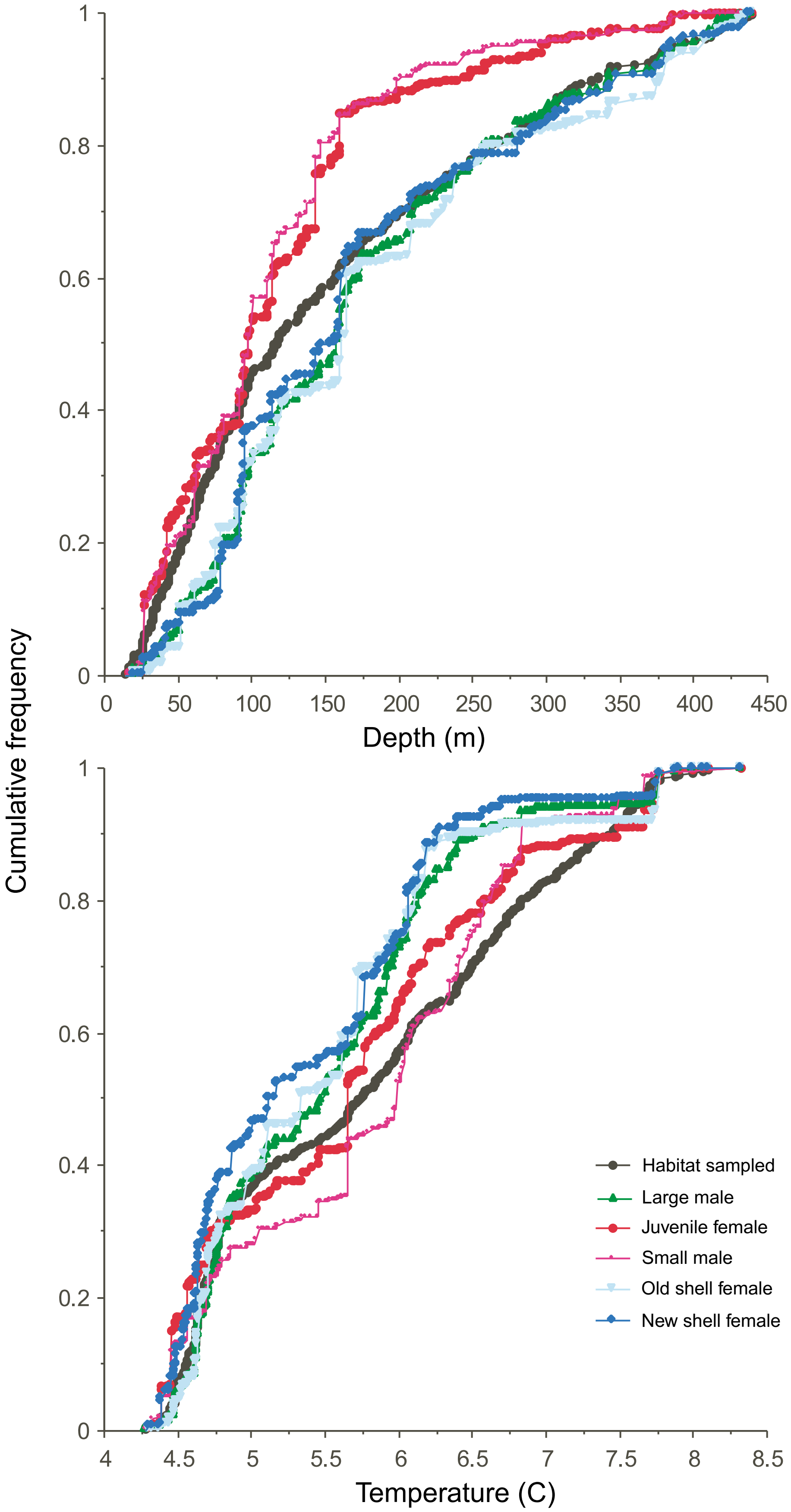

Figure 5. Cumulative frequency distribution functions (CDF) for observed bottom depth and bottom temperature and catch of size/sex classes of Tanner crabs captured in Glacier Bay in 2002.

When we compared CDF of temperature to the CDFs of each size/sex class of Tanner crab, we found a significant difference between the temperature of the habitat sampled and crabs (Figure 5); $p<0.001$ for each test. In addition, there were significant differences between each size and sex class ($p<0.0001$ for each test). Juvenile females and small males tended to be in warmer water than adults (Figure 5) and 80% of the juvenile crabs were associated with bottom temperatures between 4.5 and 7.5 ^{o}C (Table 2).

Very few crabs were captured within a bottom temperature range of 6.75 to 7.75 ^{o}C although 20% of the habitat sampled was within that temperature range (Figure 5). The plateau of the CDF curves at these temperatures could indicate a limit-function with an upper limit for temperature at around 6.75 ^{o}C. However, a large number of crabs from all size/sex classes were caught at temperatures above 7.75 ^{o}C, which suggests that temperature is not a limiting factor in the distribution of Tanner crabs. Instead, spatial patterns in Tanner crab catch appear to be responsible for generating the plateau on the CDF curves for this temperature range. In the lower portion of the Bay, between Willoughby Island and the mouth of the Bay, temperatures between 6.75 and 7.75 ^{o}C predominated (Figure 6). A large portion of this area, the main channel, was devoid of crabs (Figure 4). However, crabs were caught in the same temperature range in areas outside of the main channel (e.g., Bartlett Cove and Beardslee Islands) (Figure 6). The absence of crabs in the main channel appears to drive the plateau on the CDF curves in this temperature range. The spatial patterns in catch data with respect to temperature suggest that some other factor, such as habitat or current, could be limiting the distribution of crabs in the main channel of the lower Bay.

For the purposes of age structure analysis, areas with high densities of each class of female Tanner crabs were identified using geostatistical analysis of catch-per-unit-effort of juvenile females at each station (Figure 7). A large portion of the 578 juvenile female crabs caught in the 2002 survey was caught in Wachusett and Scidmore-Charpentier Inlets (Table 3). New-shell adult female high-density areas occurred in conjunction with high-density juvenile areas in the hypothesized nursery areas (Figure 7) but otherwise few adult females occurred in these fjords. In other juvenile areas, like the Central Bay, the juveniles overlap or are in close proximity to old and very-old shell female high-density areas.

We compared the depth distribution of juveniles in the presence of high densities of adults (Central Bay) to areas without many adults where juveniles predominate (Wachusett and Scidmore-Charpentier Inlets) (Figure 8). In Wachusett and Scidmore-Charpentier Inlets there was no significant difference between the distributions of juvenile or adult Tanner crabs and the depths sampled. In the central bay, however, there was a significant ($p<0.001$)

difference between the cumulative distribution of juvenile Tanner crabs and depths sampled and between adult females and depths sampled ($p<0.01$). There was also a significant difference between the distributions of juveniles vs. adults ($p< 0.001$). In the central bay, between depths of 100 and 150 m, juvenile female Tanner crabs were shallower than the depths sampled whereas adult females were deeper than the depths sampled (Figure 8). This suggests that juveniles may be forced to shallower depths in the presence of high densities of adults, whereas they are distributed randomly with respect to depth in areas where adults are rare.

Table 3. Number of adult and juvenile Tanner crab females caught in each of the high-density areas defined from the kreiging analysis of catch per pot data.

High density area	# Stations	# Adult females	# Juvenile females	% of total juvenile female catch
Wachusett Inlet	13	85	142	25%
Scidmore-Charpentier Inlet	15	49	98	17%
Central Bay	28	302	51	9%
Willoughby	17	220	35	6%
Russell Island	26	128	34	6%
Bartlett Cove	4	94	28	5%
Muir Entrance	18	273	16	3%
Goose Cove	7	37	15	3%
Geikie Inlet	15	89	12	2%

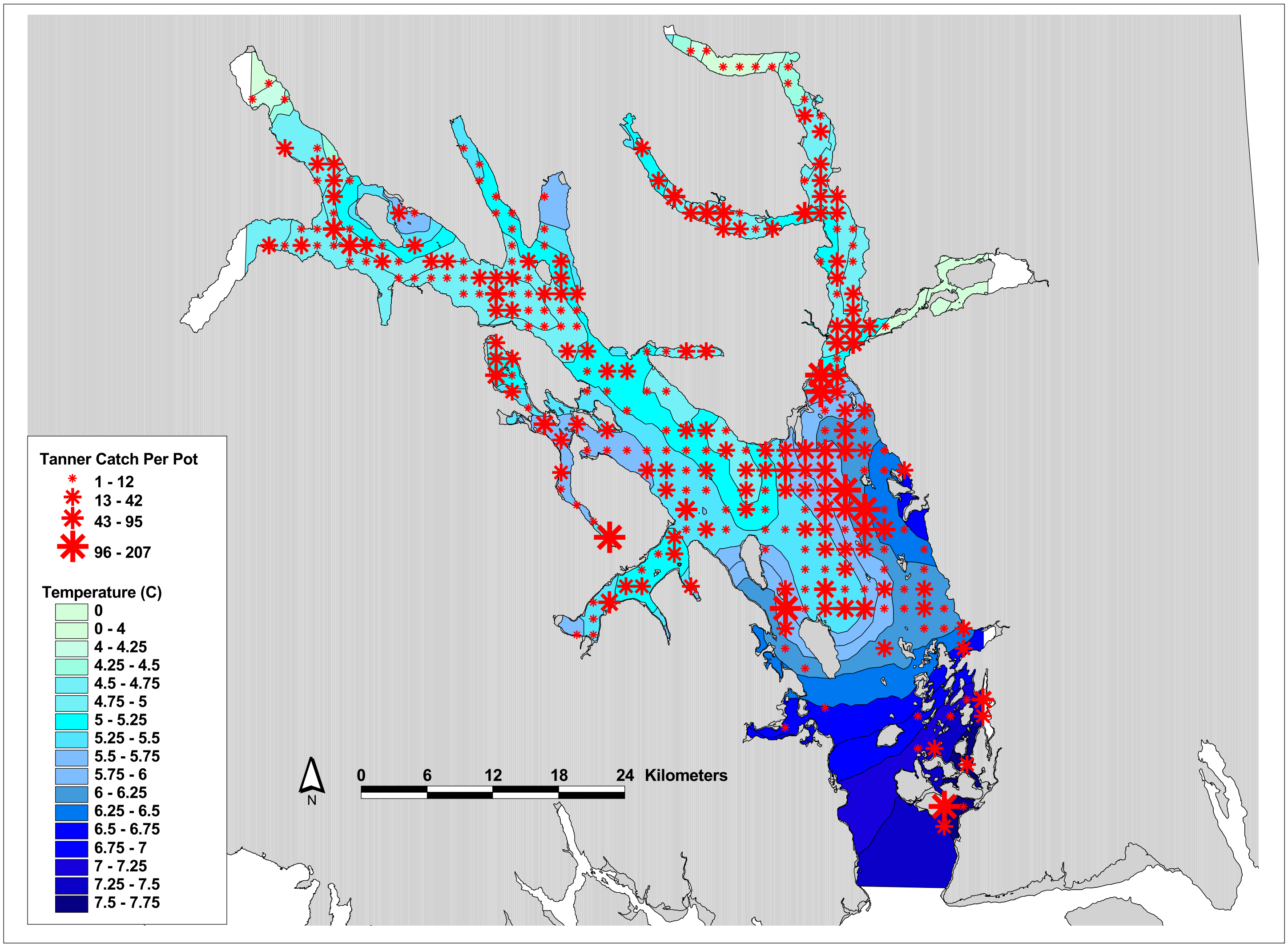

Figure 6. Catch per pot of all Tanner crabs and bottom temperature (degrees C). Temperature map derived from krieging analysis of the temperature data collected with dataloggers on pots.

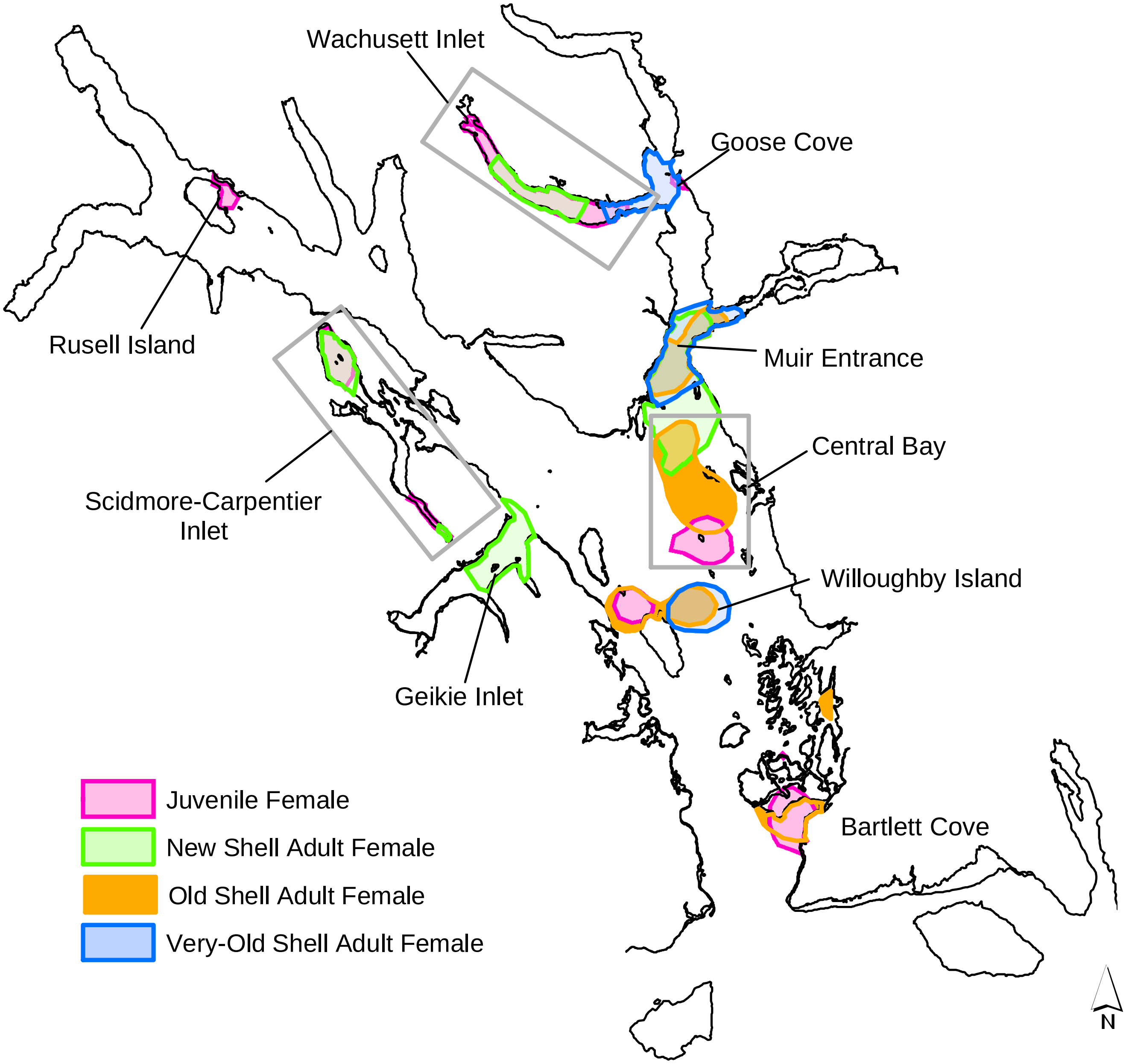

Figure 7. High density areas for each size/shell condition class for female Tanner crab. Wachusett Inlet and Scidmore-Charpentier Inlet contain high density juvenile areas and very few adult female Tanner crabs. The Central Bay contains both high density of juveniles and adult females.

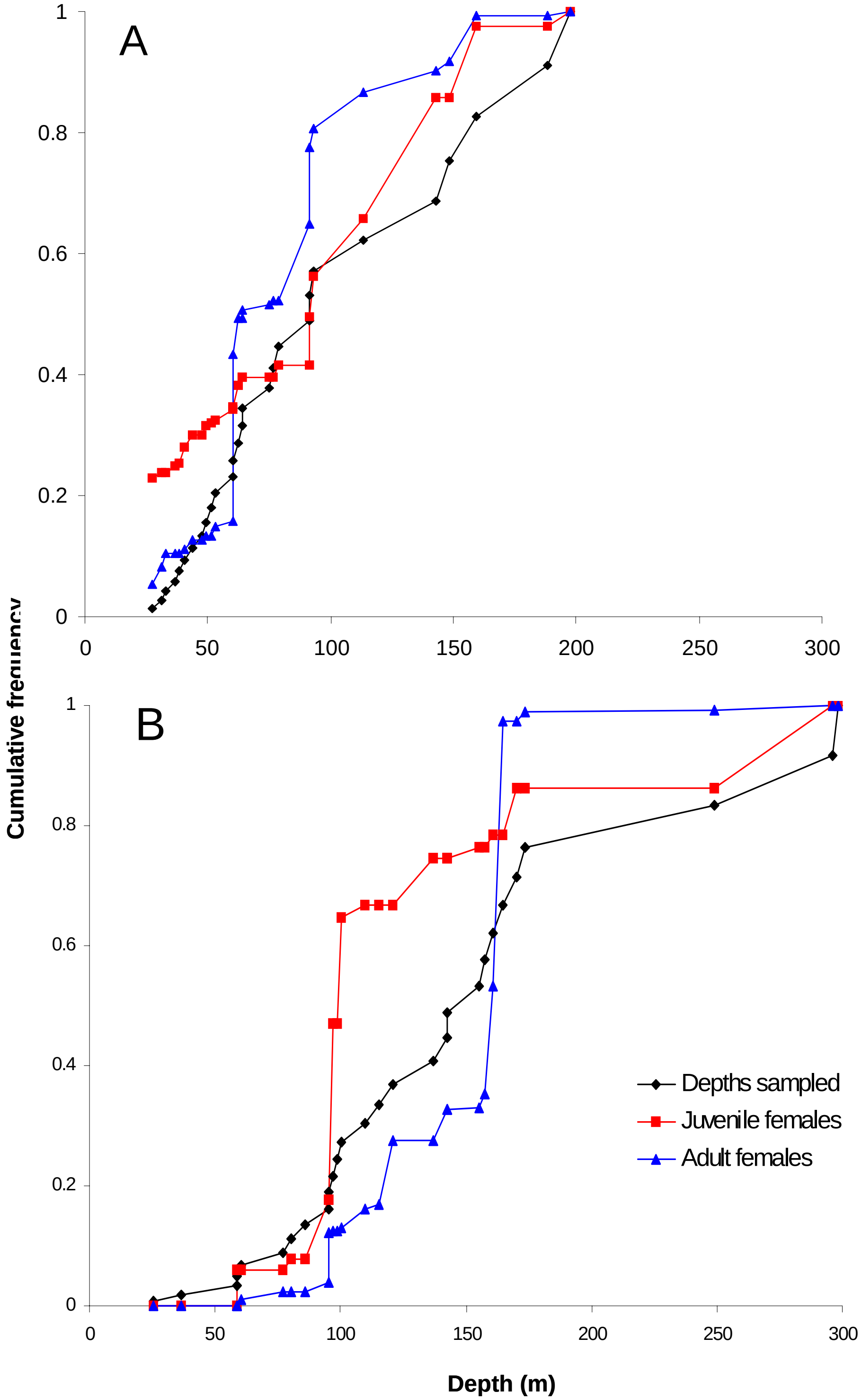

Figure 8. Cumulative frequency distributions for depths sampled in: (A) Wachusett Inlet and Scidmore-Charpentier Inlet that contain high density juvenile areas but very few adults females; and (B) the central bay that contains high density areas of both juvenile and adult female Tanner crabs.

III. MOVEMENTS OF RED KING AND TANNER CRABS

Methods

Sonic Tags

Crabs were tagged with ultrasonic transmitters manufactured by Lotek Wireless Inc. The transmitters incorporate advanced code division multiple access (CDMA) technology that makes it possible for small tags to have a long operational life and short burst interval. This allows for efficient tracking and more precise positioning. King crabs (male and female) and male Tanner crabs were tagged with MAP16_2 sonic tags, which are cylindrical and measure 16 mm in diameter by 88 mm long. The tags have a burst interval of 20 seconds and transmit at 77 kHz. The expected operational life is 3 years. Tags have activity sensors to determine if the transmitter is still on a “live” crab (i.e. determine if the crab molted or died). Because female Tanner crabs are small, we did not tag females; they will be tagged with smaller tags during a future phase of the study.

Our goal is to estimate the movement of the king and Tanner crab populations in the study area. To accomplish this objective, the tags were attached to a random sample of the mature portion of the populations inside the East Arm reserve. Sonic tags were attached while we conducted the relative density sampling. During 2002, we conducted 3 consecutive research cruises to estimate relative abundance throughout the Bay. On the second cruise we sampled every other station in the East Arm. On the third cruise (September) we sampled the remaining stations and distributed the sonic tags in the East Arm proportional to the relative abundance estimated from the previous sampling trip. During October 2003, we attached additional tags to crabs in the East Arm; the tags were distributed proportional to the relative abundance observed in 2002. To minimize the loss of sonic tags by molting we tagged male Tanner crabs that had recently molted and were greater than 125 mm; these crabs should have a molt interval greater than two years (Paul and Paul 1995). Recently molted male crabs, were identified by carapace condition (Jadamec et al. 1999). To minimize tag loss from molting we selected recently molted king crabs with a carapace length greater than 140 mm. The sonic tags were glued to the carapace with fast cure epoxy resin (Stone et al. 1992)(epoxy: BioFix 911, Progressive Epoxy Polymers, Inc) and fiberglass tape (Figure 9). Thirty-one transmitters were attached to Tanner crabs and 30 were attached to king crabs (Table 4).

Table 4. Size and sex and crabs tagged in 2002 and 2003.

Year Tagged	Crab Number	Species	Sex	Size (mm)
2002	28574	Tanner	Male	145
	28528	Tanner	Male	139
	28628	Tanner	Male	143
	28588	Tanner	Male	159
	28500	Tanner	Male	140
	28522	Tanner	Male	125
	28596	Tanner	Male	154
	28616	Tanner	Male	132
	28548	Tanner	Male	136
	28576	Tanner	Male	128
	28606	Tanner	Male	151
	28582	Tanner	Male	134
	28506	Tanner	Male	130
	28536	Tanner	Male	131
	28542	Tanner	Male	159
	28578	Tanner	Male	160
	28622	Tanner	Male	132
	28630	Tanner	Male	142
	28624	Tanner	Male	160
	28626	Tanner	Male	141
	28600	Tanner	Male	151
	28574	Tanner	Male	145
	28528	Tanner	Male	139
	28628	Tanner	Male	143
	28558	Red King	Female	158
	28568	Red King	Female	146
	28612	Red King	Female	145
	28598	Red King	Female	161
	28526	Red King	Female	151
	28570	Red King	Female	150
	28590	Red King	Female	154
	28602	Red King	Female	143
	28530	Red King	Male	181
	28560	Red King	Male	152
	28618	Red King	Male	157
	28554	Red King	Male	173
	28610	Red King	Male	150

Year Tagged	Crab Number	Species	Sex	Size (mm)
2003	28586	Tanner	Male	143
	28614	Tanner	Male	135
	28580	Tanner	Male	151
	28538	Tanner	Male	147
	28520	Tanner	Male	139
	28518	Tanner	Male	132
	28544	Tanner	Male	141
	28592	Red King	Male	162
	28508	Red King	Male	163
	28604	Red King	Male	166
	28608	Red King	Male	167
	54656	Red King	Male	163
	28504	Red King	Male	172
	28540	Red King	Male	161
	28564	Red King	Male	167
	28552	Red King	Male	172
	28584	Red King	Male	168
	28620	Red King	Male	165
	28592	Red King	Male	162
	28508	Red King	Male	163
	28604	Red King	Male	166
	54760	Blue King	Male	156
	28546	Blue King	Male	157
	54864	Golden King	Female	117

Figure 9. A male Tanner crab with a MAP16_2 sonic tag glued to the carapace with fast cure epoxy resin.

Table 5. The timing of tagging and tracking trips completed in 2002 and 2003.

Year	**Month**	**Event**
2002	September	Tags Attached
	November	Tracking
2003	February	Tracking
	May	Tracking
	August	Tracking
	October	Tags Attached
	November	Tracking
2004	February	Tracking

Tracking

Crabs were located with a Lotek MAP_600 RT mobile tracking receiver with two LHP_1 omni-directional hydrophones. The MAP RT digitally detects and decodes (including sensor data) the signals from the sonic tags, which eliminates the need for an observer to listen for sonic tags with headphones. The dual port input capability of the receiver allows detection and processing from two independent channels which permits processing of very accurate time differences of signal arrival time that can be use for determining accurate direction-of-arrival estimates. Initially, crabs were located by systematically listening for tags at stations 1.5 km apart. The research vessel stopped at each station and a hydrophone was suspended in the water. To increase tag recovery the distance between stations was reduced to 0.75 km. Searches were conducted approximately 4 times per year (Table 5).

Recently we tested a towed hydrophone as an alternative method for locating tagged crabs. During February 2004, we towed a LHP_1 omnidirectional hydrophone 20 meters below the surface at 8km/hour. The hydrophone was depressed with a side scan fish. The hydrophone was secured with black tape to the deployment cable 2 meters above the fish and the hydrophone cable was secured to the deployment cable with black tape at approximately 1-meter intervals. At 8 km/hr, we were able to decode tags up to 700 meters away. The success of this simple prototype was very encouraging and we think that development of hydrophones specifically engineered for towing would be a large breakthrough.

Dataloggers

An ultrasonic gate was constructed by mooring four Lotek WHS_3100 submersible dataloggers along the boundary of the East Arm reserve. The dataloggers record the sonic tags' individual identification and the date and time when a tagged animal comes into range. Dataloggers were suspended 20 meters from the bottom with subsurface flotation. Subsurface flotation eliminates numerous problems associated with surface buoys (e.g., navigational hazard, fouling with kelp or logs, visual impact to visitors, and freezing in ice during the winter). Disposable anchors were used to secure the moorings to the bottom. Marinna Martini, an ocean engineer with the USGS Woods Hole Field Center, modeled the mooring configuration (i.e. anchor, hardware, flotation, line, etc.) based on estimated current at the East Arm reserve boundary. Dataloggers are retrieved by remotely activating the acoustic release (iXSEA Oceano, Brest, France).

The ultrasonic gate was initially deployed in November 2002. The GPS positions of the dataloggers were carefully recorded and we also verified that it was visible on the depth sounder. Our first trip to recover the dataloggers was in February 2003. We, however, were only able to retrieve one of the dataloggers. The retrieved datalogger had heavy corrosion on the housing and cable swedges. Since the other three dataloggers were not visible on the depth sounder, we concluded that that the mooring had probably failed due to corrosion. We subsequently flew aerial surveys of the nearby beaches and located the buoys from 2 dataloggers. Examination of the recovered buoys further supported the conclusion corrosion was the likely cause of the mooring failure. To address this problem, Lotek redesigned the housing and tested it in an accelerated corrosion chamber. The copper swedges on the mooring were replaced with stainless steel swedges and the size and number of sacrificial zincs was increased on the mooring and the datalogger housing. The redesigned dataloggers and mooring were redeployed in May 2003. The new design has solved the corrosion problems; since May 2002 we have retrieved the dataloggers 4 times and the corrosion has been minimal. On the February 2004 datalogger recovery cruise, however, one of the dataloggers was missing. We currently do not have an explanation for the failure, but we plan to conduct an aerial search for the data logger this spring.

Results & Discussion

We are currently processing the data we have downloaded from the dataloggers and we are combining it with the data collected from the manual searches. In this report we present a preliminary graphical display of the data.

Tanner crab

We tagged 31 male Tanner crabs (21 during September 2002 and 10 during October 2003) (Table 4). Four of these animals have not been heard since they were released (Figure 10), 2 of these crabs were tagged in 2003 and 2 in 2002. Crabs 28614 and 28518 were tagged in October, 2003, when the ultrasonic gate was functioning but neither crab was detected by the gate. It is possible that the tags failed or that they were missed on the 2 manual surveys that have been conducted since October 2003. Crabs 28596 and 28548 have not been detected in the 6 manual surveys since they were tagged in September, 2002. Since we did not have a functioning gate in 2002, they may have departed the East Arm quickly without detection. Three of the crabs tagged in 2003, quickly moved to the mouth off the East Arm and were detected by the ultrasonic gate (Figures 11C, 12B-C). These data demonstrate that Tanner crabs are able to move considerable distances in a short amount of time and support the hypothesis that crabs 28596 and 28548 have left the East Arm reserve.

A total of 9 crabs have crossed the East Arm boundary (Figures 11, 12 and 13A). Three of these crabs were found outside the ultrasonic gate with manual tracking (Figures 11A-B, 12A) before the ultrasonic gate was functioning. One crab was detected by the gate but not found manually (Figure 11C). Four crabs were detected by the gate and were also located outside the boundary with manual tracking (Figures 11D, 12B-D). One animal was detected by the gate on January 04, 2004 and was captured in the commercial fishery northeast of Drake Island on February 4, 2004 (Figure13A).

Crab 28588 was tagged in 2002 in upper Muir Inlet, approximately 6 km from Muir Glacier. This individual was detected by the gate in December, 2003, which means that he has traversed almost the full length of the East Arm. Subsequently he was located back inside the East Arm reserve in February 2004, suggesting that the crab came into range of the gate and then turned around (Figure 13B). Since the gate cannot differentiate between an animal that approaches the gate and an animal that crosses the boundary, data from the gate could overestimate transfer rate. The data from this individual demonstrates the importance of combining manual tracking data with the gate detections.

Seventeen of the male Tanner crabs have been relocated only inside the East Arm reserve (Figures 14-17). Some of these individuals, however, have moved a lot more than others. Examples of crabs with larger movement pattern are displayed in figures 14 and 15A. Crabs with small movement patterns are displayed in figures 15B-D and 16A-C. Four of these 17 crabs have only been relocated once (Figures 16D, 17A-C) and 2 apparently died or molted soon after they were tagged (Figure 17D).

King crab

The Tanner crab movement maps demonstrate there is large variation between individual crabs both in distance and direction traveled. In contrast, the king crabs have moved from their release locations to subsequent locations and maintained an aggregated distribution. During 2 manual tracking surveys conducted in November 2002 and 2003, the king crabs were located north of Admas Inlet and were aggregated; during February 2002 and 2003 they were relocated near the mouth of Muir Inlet and they were again aggregated (Figure 18). This pattern suggests that the crabs migrate seasonally between the area north of Adams Inlet and the mouth of Muir Inlet. Our relocation of crabs was poor during surveys conducted in May 2003 and August 2003 and thus it is inconclusive where the king crabs reside during the summer and whether they maintain an aggregated distribution as they move seasonally between Adams Inlet and the mouth of Muir Inlet.

King crabs have been observed to form pods (Powell and Nickerson 1964) and juvenile pods have been observed moving as a unit (Dew 1990a, b). Coordinated movements of adult king crabs have not previously been documented and have important implications to the management of the king crabs fishery.

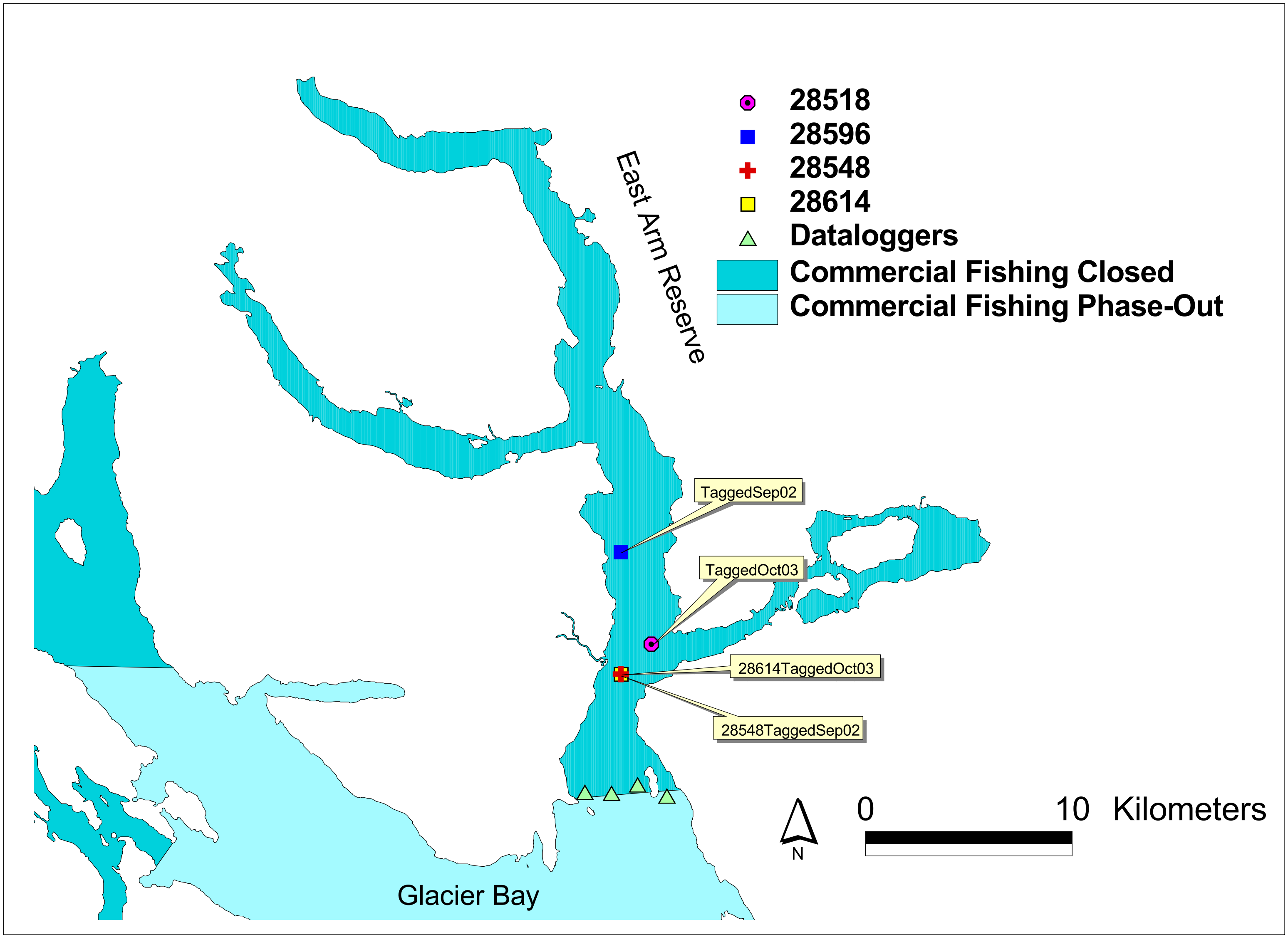

Figure 10. The month and location where 4 male Tanner crabs were tagged in the East Arm Reserve of Glacier Bay. We were unable to relocate these crabs.

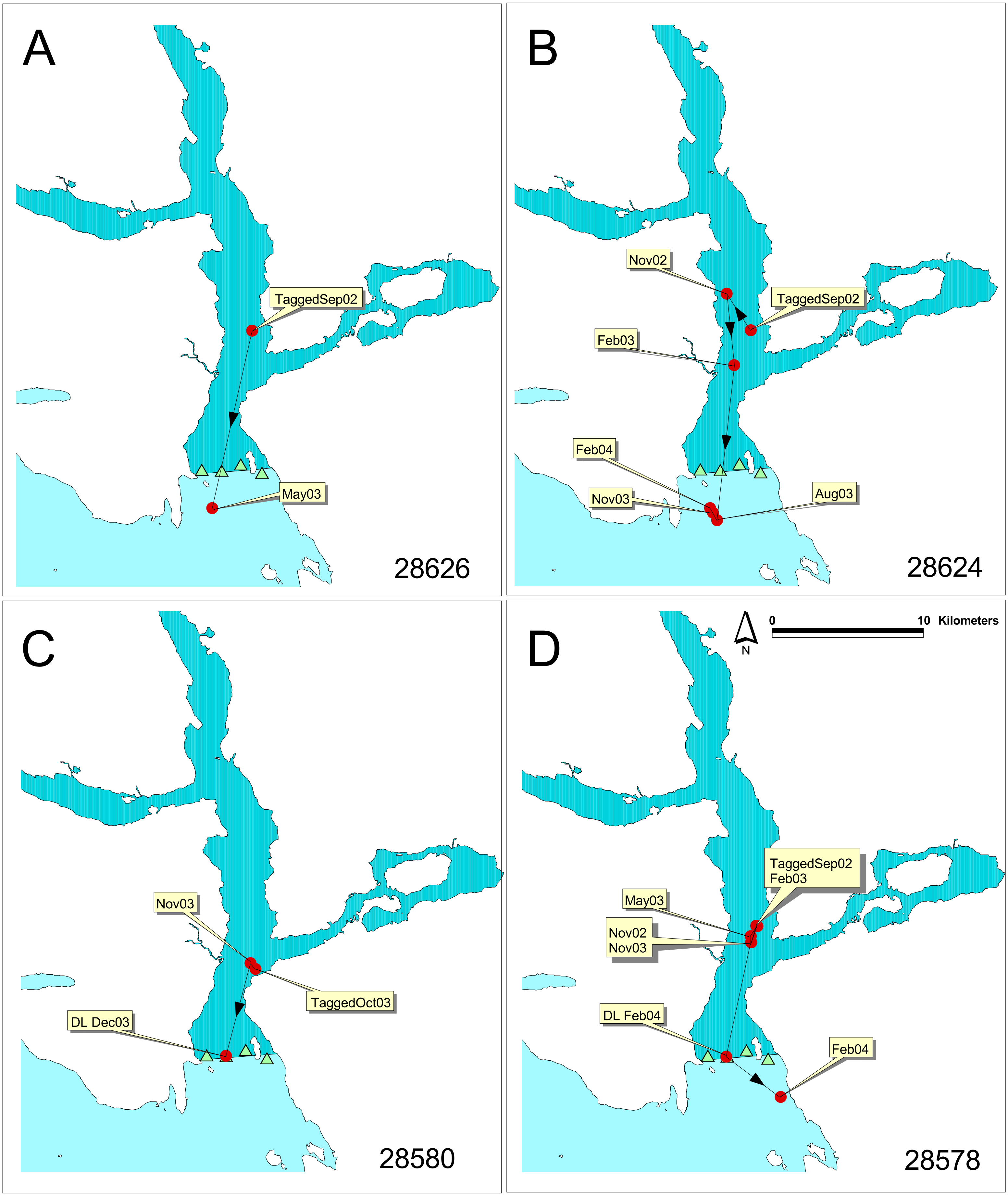

Figure 11. The month and location where 4 male Tanner crabs were tagged and relocated in the East Arm Reserve of Glacier Bay. The identification number of each crab is listed. DL indicates detection by one of the 4 dataloggers, which are represented by green triangles along the reserve boundary.

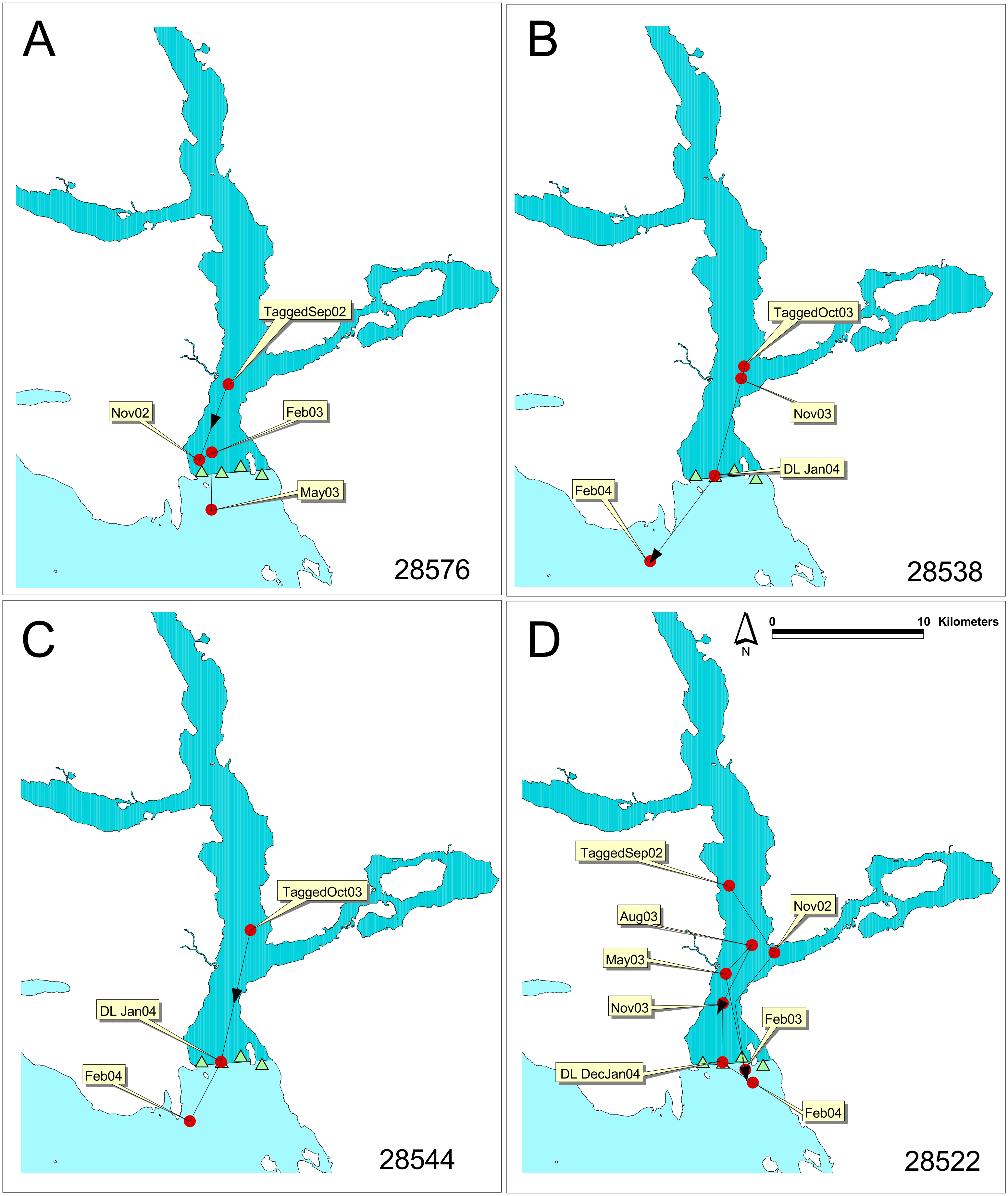

Figure 12. The month and location where 4 male Tanner crabs were tagged and relocated in the East Arm Reserve of Glacier Bay. The identification number of each crab is listed. DL indicates detection by one of the 4 dataloggers, which are represented by green triangles along the reserve boundary.

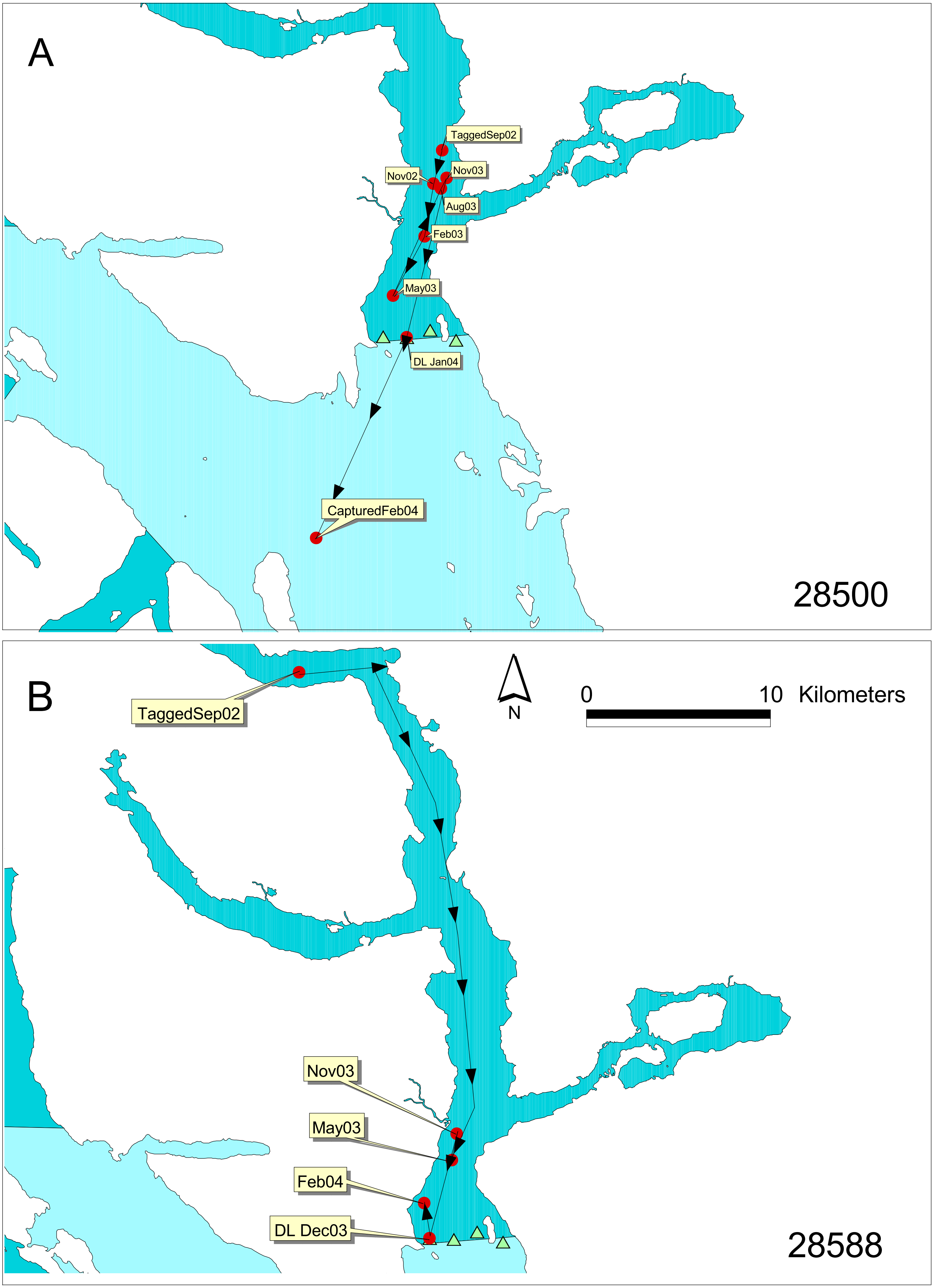

Figure 13. The month and location where 2 Tanner crabs were tagged and relocated. Crab 28500 was captured 17 months later in the commercial fishery in the Central Bay.

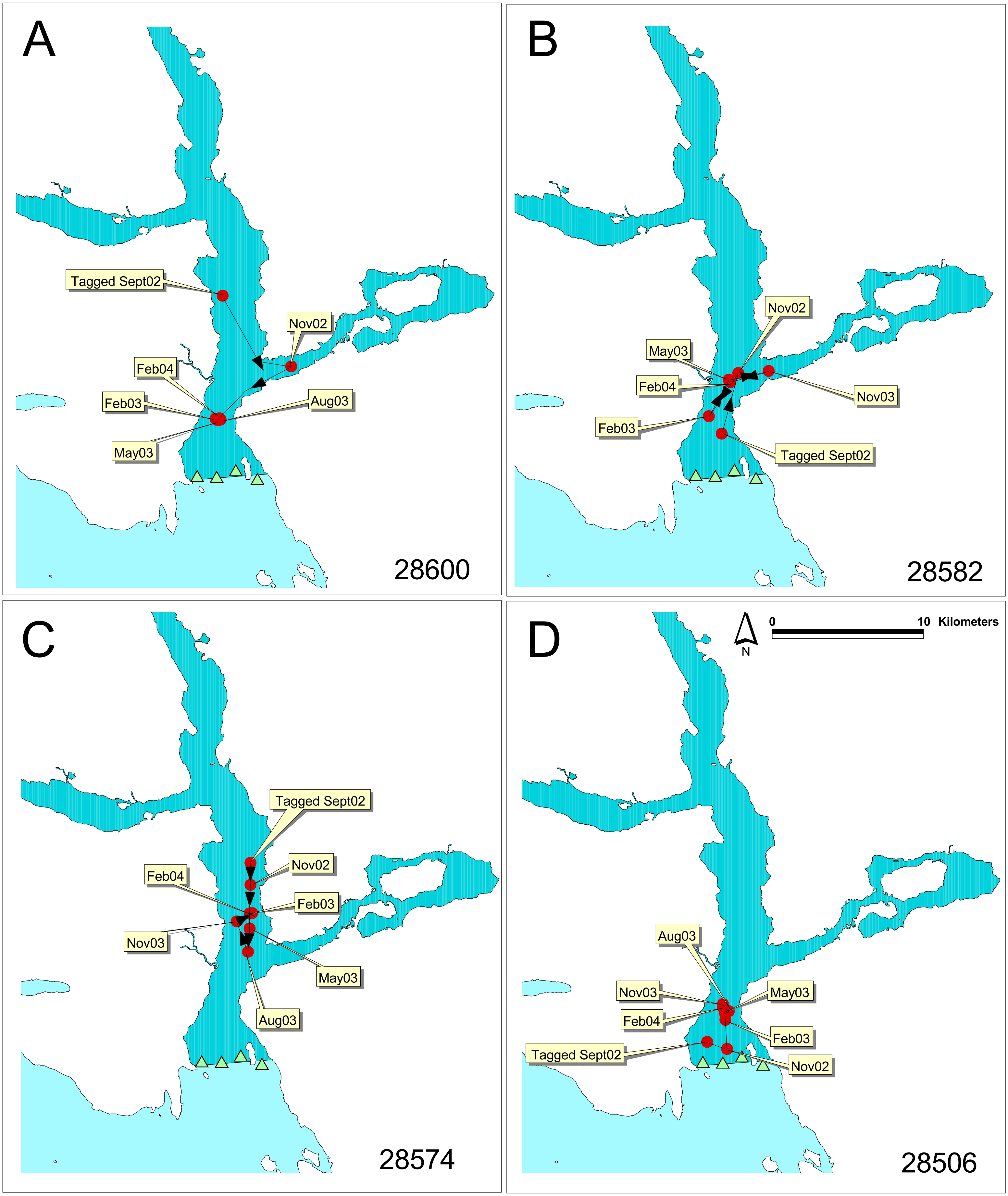

Figure 14. The month and location where 4 male Tanner crabs were tagged and relocated in the East Arm Reserve of Glacier Bay. The identification number of each crab is listed. The 4 dataloggers along the reserve boundary are represented by green triangles.

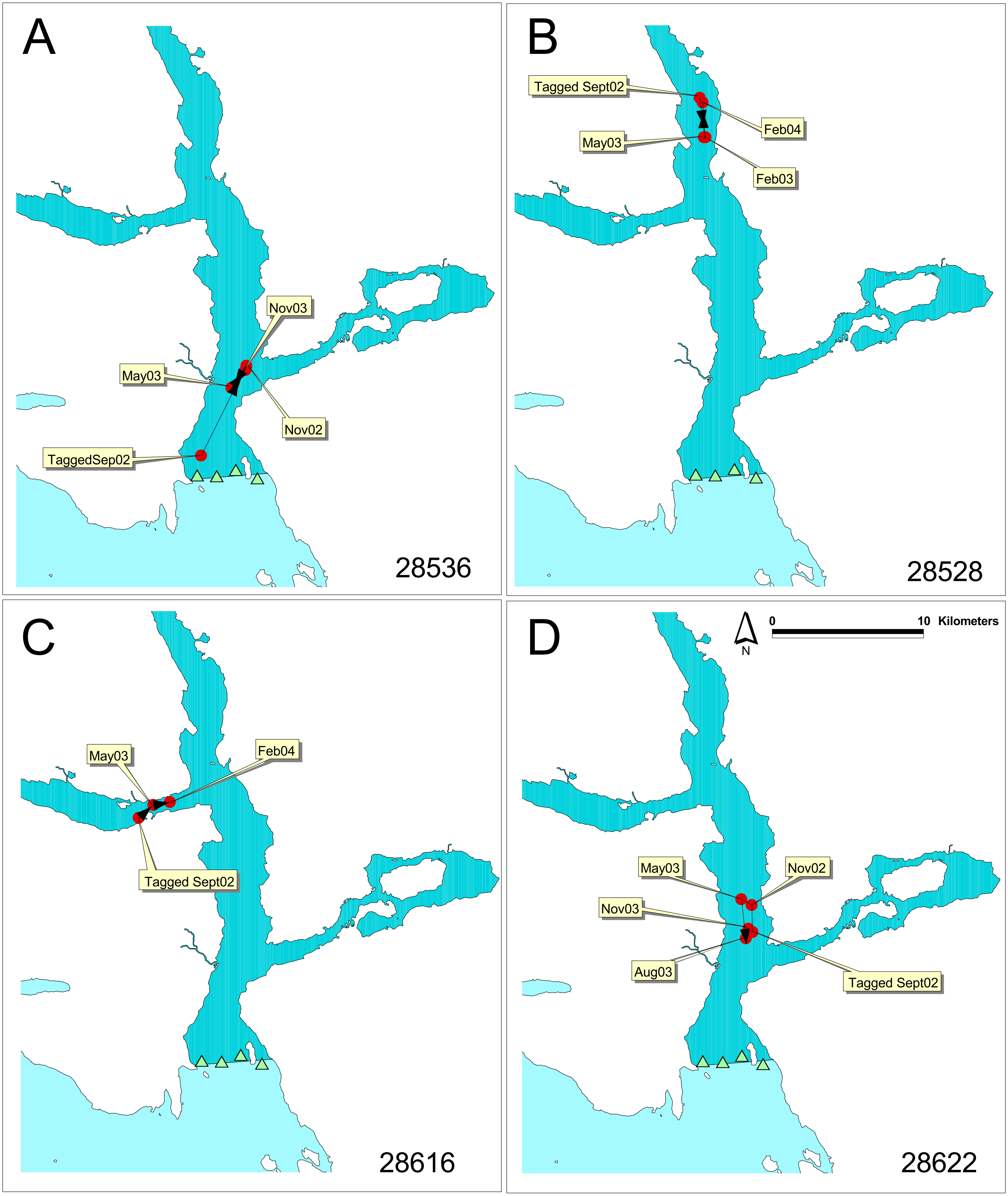

Figure 15. The month and location where 4 male Tanner crabs were tagged and relocated in the East Arm Reserve of Glacier Bay. The identification number of each crab is listed. The 4 dataloggers along the reserve boundary are represented by green triangles.

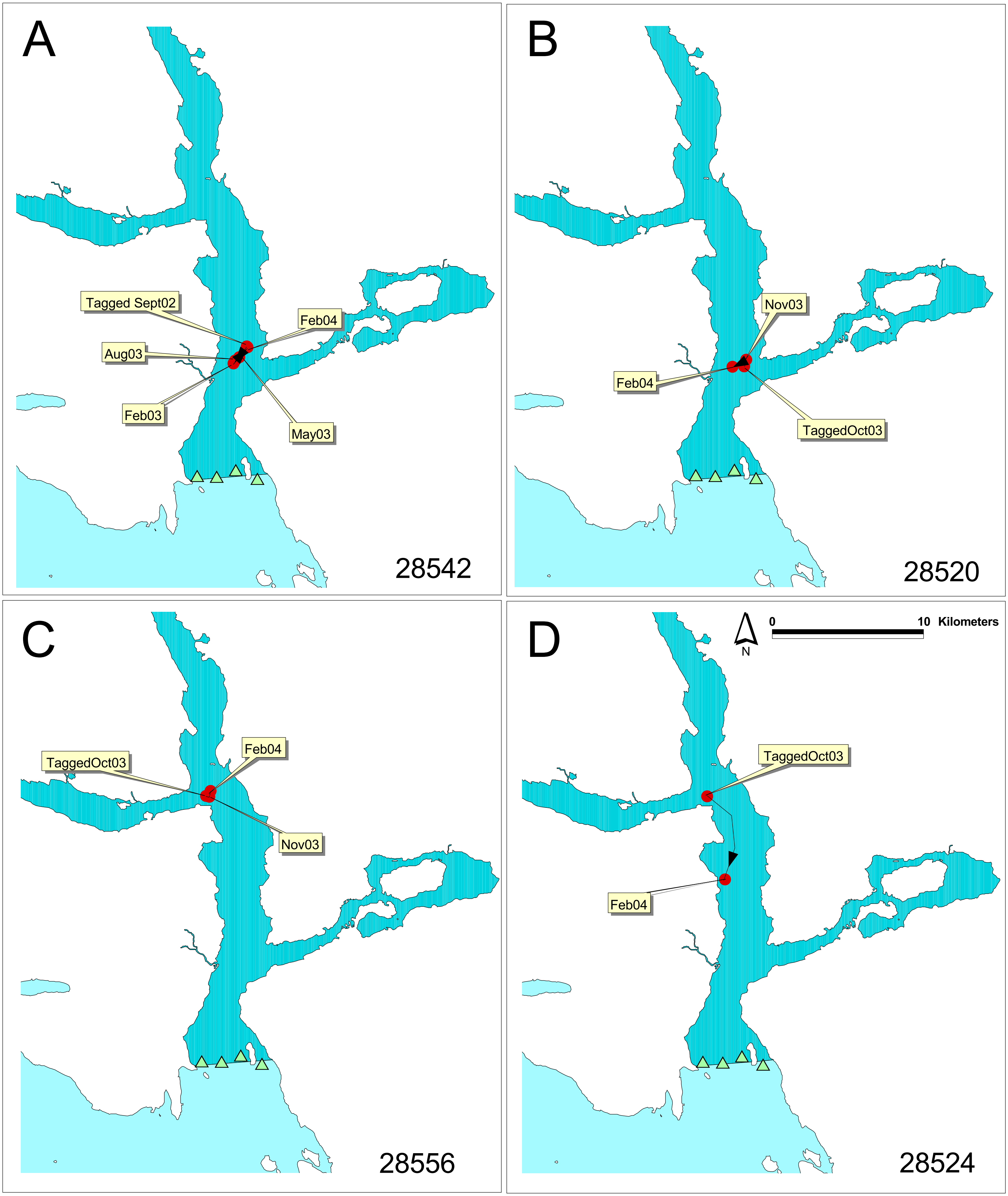

Figure 16. The month and location where 4 male Tanner crabs were tagged and relocated in the East Arm Reserve of Glacier Bay. The identification number of each crab is listed. The 4 dataloggers along the reserve boundary are represented by green triangles.

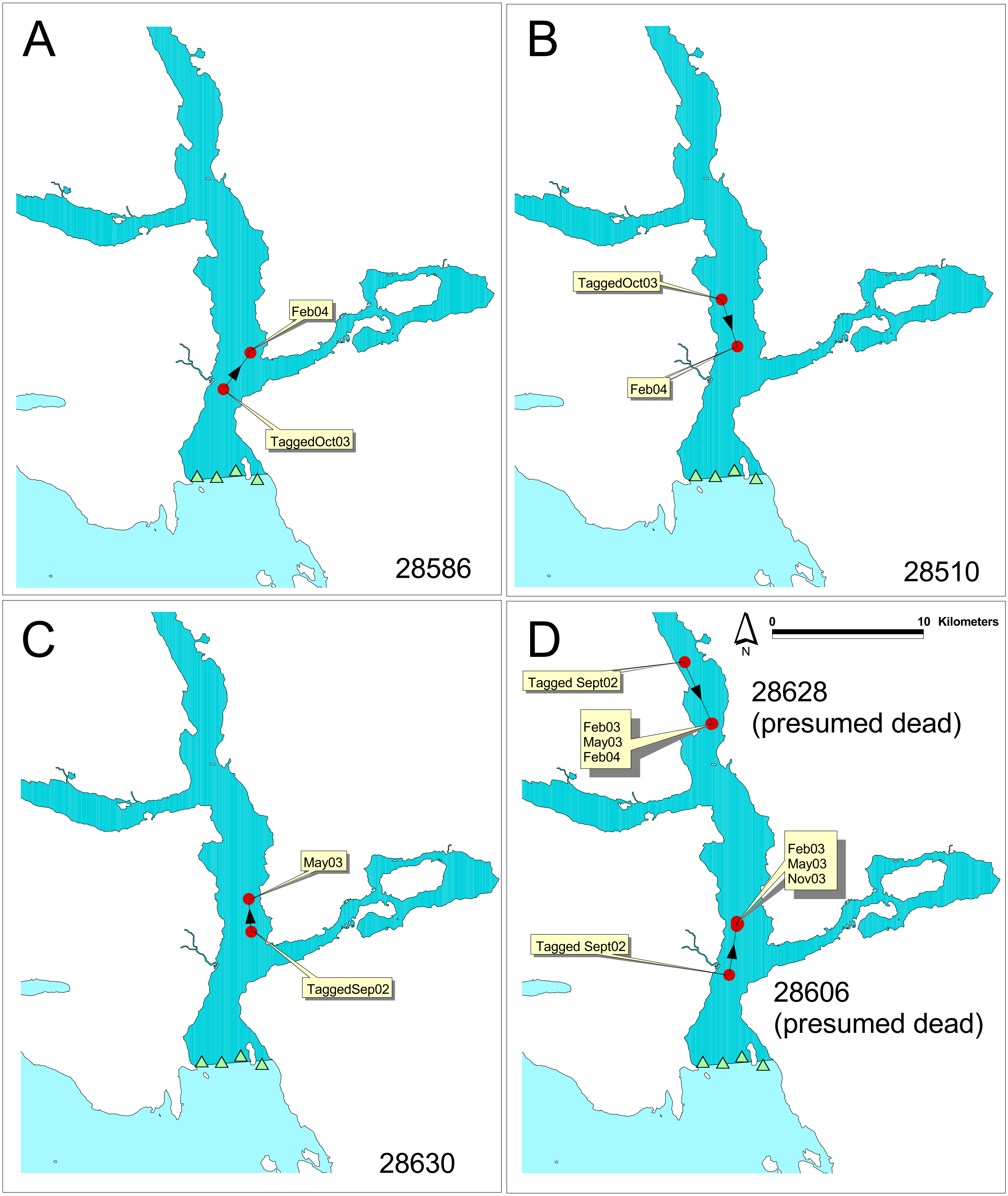

Figure 17. The month and location where 5 male Tanner crabs were tagged and relocated in the East Arm Reserve of Glacier Bay. The identification number of each crab is listed. The 4 dataloggers along the reserve boundary are represented by green triangles.

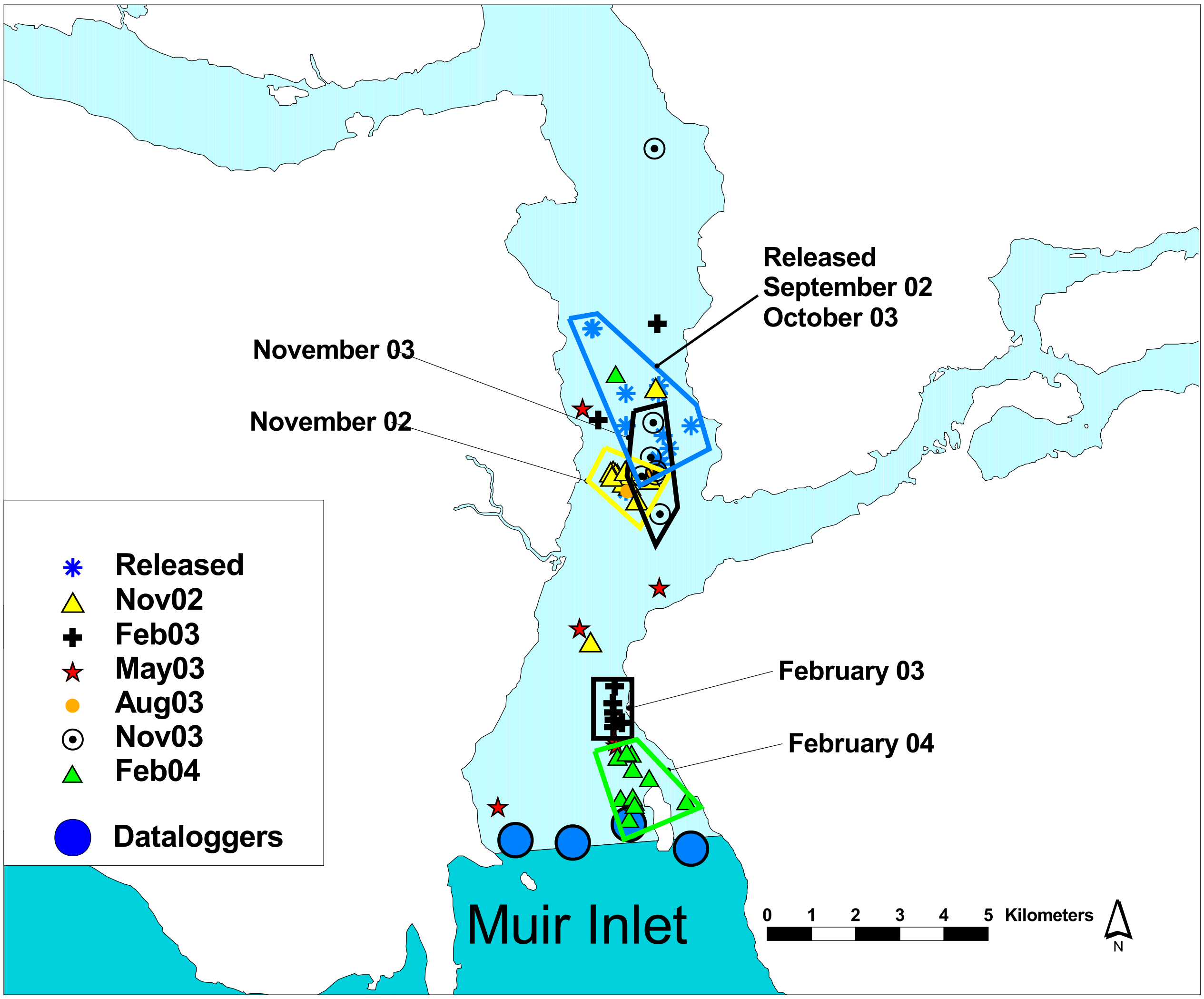

Figure 18. Movement of tagged male and female red king crabs in the east arm of Glacier Bay.

IV. CO-OCCURRENCE OF PACIFIC SLEEPER SHARKS & HARBOR SEALS: ARE SLEEPER SHARKS PREDATORS, COMPETITORS, OR SCAVENGERS OF HARBOR SEALS?

S. J. Taggart, A. G. Andrews, J. Mondragon, & E. A. Mathews

Glacier Bay National Park has had one of the largest breeding colonies of harbor seals (*Phoca vitulina richardsii*) in Alaska (Mathews 1995). The number of seals, however, has declined steeply; estimates of approximately 11,200 seals in early 1992 dropped to fewer than 5,000 animals in 2000 (Mathews and Pendleton Submitted). The cause of this population decline is not known but increased mortality, possibly due to predation by killer whales (*Orcinus orca*), Steller sea lions (*Eumetopias jubatus*), or Pacific sleeper sharks (*Somniosus pacificus*) is one of the several hypotheses (Mathews and Pendleton Submitted). Sleeper sharks in the North Pacific (*Somniosus pacificus*) and North Atlantic (*Somniosus microcephalus*) are known to feed on marine mammal carrion, but they may also be active predators on marine mammals, including seals (Bigelow and Schroeder 1948, Bright 1959, Compagno 1984, Crovetto et al. 1992, Ridoux et al. 1998, Smith et al. 2002). There is no direct information on abundance or trend for Pacific sleeper sharks in Glacier Bay, however significant increases were detected from 1984 to 1996 in the central Gulf of Alaska (Mueter and Norcross 2002). Here, we present evidence that Pacific sleeper sharks co-occur with breeding harbor seals in Glacier Bay and that these sharks scavenge or prey on marine mammals, including harbor seals.

In July and August, 2002, 415 top-loading conical Tanner crab pots were fished throughout Glacier Bay on a 1.5 km systematic sampling grid to assess the distribution and relative abundance of Tanner (*Chionoecetes bairdi*) and king (*Paralithodes camtschaticus*) crab (Figure 19). Locations and depths were sampled with a 20-hour soak; pot depths ranged from 15 to 439 m. Three of the 415 pots contained Pacific sleeper sharks and a fourth pot contained a large (100 cm) Pacific halibut (*Hippoglossus stenolepis*) with a fresh sleeper shark bite.

All three sharks were caught in pots set at the mouth of Johns Hopkins Inlet (Figure 19), a tidewater glacial fjord used by approximately 3,600 harbor seals, which is the highest concentration of seals in Glacier Bay (Mathews and Pendleton Submitted). The halibut with the shark bite was caught within 19 km of the mouth of Johns Hopkins Inlet. Using a bootstrap technique (Blank et al. 2001), we estimated the probability of sampling the sharks (and the shark bitten halibut) in the vicinity of Johns Hopkins Inlet if the sharks were randomly distributed throughout Glacier Bay. We measured the through-water distance from each pot containing a shark to Jaw Point (a location inside Johns Hopkins Inlet near the eastern edge of the area where seals rest and raise their pups) and summed the distance of the four pots. The sum of the distance between Jaw Point and each of the pots that captured a shark (=35 km) was then compared to the sum of the distances between Jaw Point and four randomly selected pots in 10,000 bootstrap simulations. All of the sharks were captured at depths greater than 182 m (100 fa); we therefore limited the bootstrap sampling to pot locations with depths greater than 182 m (133 of 415 pots). A p-value was calculated as the proportion of the randomly selected trial sum distances that were less than the sample sum distance. If sharks were randomly distributed in Glacier Bay in water deeper than 182 m, the probability of sampling all four sharks at the mouth of Johns Hopkins Inlet was very low (p=0.0009).

The lengths (distance from snout to the tip of the upper caudal) of the 3 sleeper sharks recovered near the entrance of Johns Hopkins Inlet were 3.0 m, 1.9 m, and 1.6 m, and we examined the stomachs of all sharks. Numerous cephalopod beaks, ranging from 7 to 76, were collected from all 3 specimens. Combined stomach contents included shrimp, teleost fishes, and tapeworms. The largest shark also contained cetacean tissue in its stomach. Further evidence of consumption of marine mammal tissue is available from 1995 where a 2.2 m Pacific sleeper shark was caught on a long line hook during a Pacific halibut (*Hippoglossus stenolepis*) survey in Glacier Bay. The shark regurgitated harbor seal tissue when it was brought onboard the research vessel (Taggart, unpublished data).

Marine mammal tissue in the stomachs of 2 of 4 sleeper sharks demonstrates that marine mammals are part of the Pacific sleeper shark’s diet in Glacier Bay. Pinniped and cetacean tissue have also been found in sleeper shark stomachs in other parts of Alaska (Hulbert *et al.* 2001; (Orlov 1999) and off Chile (Crovetto et al. 1992). A 3.45 m female sleeper shark caught in Kachemak Bay, Alaska, contained the remains of at least 3 harbor seals (Bright 1959). Greenland sleeper sharks (*Somniosus microcephalus*), a congener of the Pacific sleeper shark, have also been captured with marine mammal tissue in their stomachs and may increase their consumption of marine mammals as they get bigger (Ridoux et al. 1998, Fisk et al. 2002).

Whether sleeper sharks are active predators on marine mammals or carrion-feeders is currently under debate. Since sleeper sharks have been directly observed feeding on dead marine mammals it is clear that sleeper sharks feed on marine mammal carrion. Pacific sleeper sharks are one of the predominant scavengers on whale carcasses on the seafloor

(Smith et al. 2002) and Greenland sleeper sharks have been observed around whaling stations "greedily" devouring whale meat and blubber (Bigelow and Schroeder 1948).

In addition to feeding on dead marine mammals, sleeper sharks may also be active predators of marine mammals. A 3.6 m female Pacific sleeper shark was captured in Chilean waters with a fetus from a southern right whale dolphin (*Lissodelphis peronii*) and the genital area of an adult female in its stomach. The location of the bite and freshness of the specimen strongly argues for active predation of this pregnant female which is surprising since right whale dolphins are among the fastest swimming cetaceans (Crovetto et al. 1992).

Other large, fast prey, in addition to marine mammals, have been found in the stomachs of Pacific sleeper sharks including: salmon (Gotshall and Jow 1965, Orlov 1999, Yang and Page 1999), squid (Gotshall and Jow 1965, Ebert et al. 1987, Orlov 1999, Yang and Page 1999), albacore tuna (Ebert et al. 1987), and Pacific halibut (Gotshall and Jow 1965). Remarkably, even giant squid have been found in the stomachs of Greenland sleeper sharks (Cherel and Duhamel 2004).

The evidence for sharks eating marine mammals and fast prey in other areas supports the hypothesis that sharks may be preying on harbor seals in Johns Hopkins Inlet and may be a factor in their population decline. The evidence, however, is far from conclusive. At Sable Island in Nova Scotia, where shark predation on harbor seals has been linked to population declines, harbor seal pup production declined dramatically from 1980 to 1997 and shark inflicted mortality climbed from 10% to 46% during the same time period (Lucas and Stobo 2000). Currently, the primary species suspected as the cause of the shark-inflicted mortality on this population of harbor seals is Greenland sleeper sharks[1]. At Sable Island dead seals were found washed up on the beach with shark bites. In contrast, dead harbor seals with shark wounds have not been observed in Glacier Bay. Sable Island, however, is a large sandbar with gradual sloping beaches and onshore currents that could transport the dead animals ashore (Lucas and Stobo 2000). Glacier Bay, on the other hand, is a deep fjord (approximately 300-400 m) with steep submarine walls, which would likely prevent shoreward transport.

In addition to preying or scavenging on harbor seals, another possible explanation for the non-random distribution of Pacific sleeper sharks in Glacier Bay is that they co-occur with seals because the two species have prey in common and those prey are in the vicinity of Johns Hopkins Inlet. Stomach analyses demonstrate that there is overlap in their preferred

---

[1] Personal communication from Z. Lucas, Biologist, Sable Island, Nova Scotia, December 2003.

prey. Pitcher (1980) examined 351 harbor seal stomachs from Alaska and most commonly found: walleye pollock (*Theragra chalcogramma*), cephalopods, capelin (*Mallotus villosus*), and flatfishes (decreasing order of occurrence). Two studies in the Gulf of Alaska and the Bering Sea, determined that cephalopods were the most common prey in stomachs of 161 Pacific sleeper sharks; flatfishes and walleye pollock were among the top 7 prey items (Gotshall and Jow 1965, Ebert et al. 1987, Orlov 1999, Yang and Page 1999). Walleye pollock and flatfish were the first and fifth most common prey found in harbor seal fecal samples collected in Johns Hopkins Inlet during August (Mathews 2002), the same month when sharks were concentrated there. Mathews (2002) did not find cephalopod remains in the feces, but fecal analyses can be biased against cephalopods because seals regurgitate cephalopod beaks (Pitcher 1980).

In addition to overlap in diet, harbor seals and Pacific sleeper sharks also overlap in their depth distribution. Swain *et al.* (1996) attached satellite-linked time depth recorders to 17 harbor seals in southeastern Alaska. Although the majority of the dives were < 50 m, the average maximum daily dive depth ranged from 146 to 362 m and maximum dive depths of 508 m were recorded on two adult males (Swain et al. 1996). At the mouth of Johns Hopkins Inlet, where we found sleeper sharks, the deepest water is 375 m. The 3 sleeper sharks caught at the entrance of Johns Hopkins Inlet were trapped at an average depth of 325 m. Such actual overlap in diet and potential overlap in vertical distribution of these two species could mean that both species are attracted to areas with high prey densities. Whether there is spatial and temporal overlap in these two species remains to be determined.

The sample size of sleeper sharks in this study was very low. However, the extensive systematic sampling of a large area and the highly non-random distribution of the sleeper sharks concentrated near the largest harbor seal breeding area in Glacier Bay suggest that an ecologically important interaction is occurring between these two species. The co-occurrence of sharks and seals combined with clear evidence that sleeper sharks in Glacier Bay consume marine mammals clearly warrants further study of this potential predator, scavenger, and/or competitor.

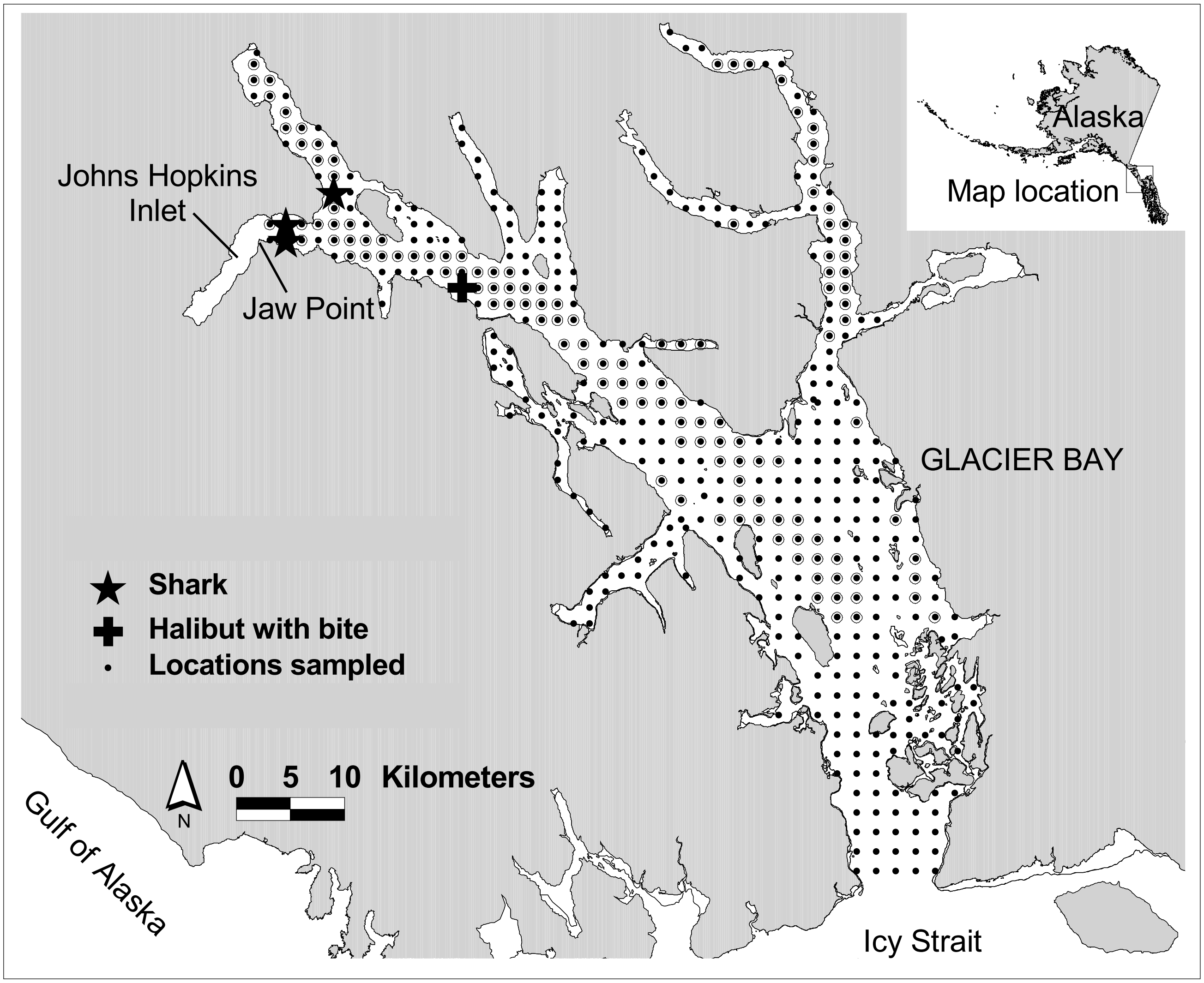

Figure 19. The 415 locations in Glacier Bay, Alaska, that were sampled with commercial Tanner pots. The 133 locations deeper than 182 m are indicated with an additional circle and were used in the bootstrap analysis. Stars indicate where three Pacific Sleeper sharks were caught and a cross indicates where a halibut with a shark bite was captured.

V. REFERENCES

Beck, M. W., K. L. Heck, Jr., K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B. Halpern, C. G. Hays, K. Hoshino, T. J. Minello, R. J. Orth, P. F. Sheridan, and M. P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience **51**:633-641.

Bigelow, H. B., and W. C. Schroeder. 1948. Part One Lancelets, Cyclostomes, Sharks. Pages 576 *in* A. E. Parr and Y. H. Olsen, editors. Fishes fo the Western North Atlantic. Sears foundation for marine research, New Haven.

Blank, S., C. Seiter, and P. Bruce. 2001. Resampling Stats in Excel Version 2. Resampling Stats, Inc., Arlington, VA.

Bright, D. B. 1959. The occurrence and food of the sleeper shark, *Somniosus pacificus*, in a central Alaska bay. Copeia **1**:76-77.

Cherel, Y., and G. Duhamel. 2004. Antarctic jaws: cephalopod prey of sharks in Kerguelen waters. Deep-Sea Research **I**:17-31.

Chiappone, M., and K. M. S. Sealey. 2000. Marine reserve design criteria and measures of success: lessons learned from the Exuma Cays Land and Sea Park, Bahamas. Bulletin of Marine Science **66**:691-705.

Clark, J., C. Botelho, D. Woodby, and G. Bishop. 1999. Project operational plan: Tanner crab population estimation in southeast Alaska. Regional Information Report 1J99-31, Alaska Department of Fish and Game.

Compagno, L. J. V. 1984. FAO species catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 1 - Hexanchiformes to Lamniformes. United Nations Development Programme. Food and Agriculture Organization of the United Nations, Rome.

Crovetto, A., J. Lamilla, and G. Pequeno. 1992. *Lissodelphis peronii*, Lacepede 1804 (Delphinidae Cetacea) within the stomach contents of a sleeping shark *Somniosus cf. pacificus* Bigelow and Schroeder 1944, in chilean waters. Marine Mammal Science **8**:312-314.

Demartini, E. E. 1993. Modeling the potential of fishery reserves for managing Pacific coral reef fishes. Fishery Bulletin **91**:414-427.

Dew, C. B. 1990a. Behavioral ecology of podding red king crab, *(Paralithodes camtschatica)*. Canadian Journal of Fisheries and Aquatic Sciences **47**:1944-1958.

Dew, C. B. 1990b. Behavioral ecology of podding red king crab, *Paralithodes camtschatica*. Pages 131 *in* International Symposium on King and Tanner Crabs, November 28-30, 1989, Anchorage, Alaska.

Ebert, D. A., L. J. V. Compagno, and L. J. Natanson. 1987. Biological Notes on the Pacific Sleeper Shark, *Somniosus pacificus* (Chondrichthyes: Squalidae). California Fish and Game **73**:117-123.

Fisk, A. T., S. A. Tittlemier, J. L. Pranschke, and R. J. Norstrom. 2002. Using anthropogenic contaminants and stable isotopes to assess the feeding ecology of Greenland sharks. Ecology **83**:2162-2172.

Gotshall, D. W., and T. Jow. 1965. Sleeper sharks (*Somniosus pacificus*) off Trinidad, California, with life history notes. California Fish and Game **51**:294-298.

Guenette, S., and T. J. Pitcher. 1999. An age-structured model showing the benefits of marine reserves in controlling overexploitation. Fisheries Research (Amsterdam) **39**:295-303.

Halpern, B. S. 2003. The impact of marine reserves: do reserves work and does reserve size matter? Ecological Applications **13**:S117-S137.

Heck, K. L., Jr., L. D. Coen, and S. G. Morgan. 2001. Pre- and post-settlement factors as determinants of juvenile blue crab *Callinectes sapidus* abundance: Results from the north-central Gulf of Mexico. Marine Ecology Progress Series **222**:163-176.

Holme, N. A., and A. D. McIntyre. 1971. Methods for the study of marine benthos. Blackwell Scientific Publications, Oxford and Edinburgh.

Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kidwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. J. Tegner, and R. R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science **293**:629-638.

Jadamec, L. S., W. E. Donaldson, and P. Cullenberg. 1999. Biological field techniques for Chionoecetes crabs. AK-SG-99-02, University of Alaska Sea Grant College Program, Fairbanks.

Lucas, Z., and W. T. Stobo. 2000. Shark-inflicted mortality on a population of harbour seals *(Phoca vitulina)* at Sable Island, Nova Scotia. Journal of Zoology **252**:405-414.

Martell, S. J. D., C. J. Walters, and S. S. Wallace. 2000. The use of marine protected areas for conservation of lingcod (*Ophiodon elongatus*). Bulletin of Marine Science **66**:729-743.

Mathews, E. A. 1995. Longterm trends in abundance of harbor seals (*Phoca vitulina richardsi*) and development of monitoring methods in Glacier Bay National Park, Southeast Alaska. Pages 254-263 *in* D. R. Engstrom, editor. Third Glacier Bay Science Symposium. U.S. National Park Service, Glacier Bay National Park & Preserve, AK.

Mathews, E. A. 2002. Diet of harbor seals at a glacial fjord and a terrestrial haulout in Glacier Bay: 1996-2001. Glacier Bay National Park and Preserve. 17 pp., Gustavus, Alaska.

Mathews, E. A., and G. W. Pendleton. Submitted. Declines in harbor seal *(Phoca vitulina richardsi)* numbers in Glacier Bay National Park, Alaska, 1992-2002. Marine Mammal Science **00**:000-000.

Mueter, F. J., and B. L. Norcross. 2002. Spatial and temporal patterns in the demersal fish community on the shelf on upper slope regions of the Gulf of Alaska. Fisheries Bulletin **100**:559-581.

Murawski, S. A., R. Brown, and L. Hendrickson. 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: the Georges Bank experience. Bulletin of Marine Science **66**:775-798.

Myers, R. A., and B. Worm. 2003. Rapid worldwide depletion of predatory fish communities. Nature **423**:280-283.

Nowlis, J. S., and C. M. Roberts. 1999. Fisheries benefits and optimal design of marine reserves. Fishery Bulletin **97**:604-616.

Orensanz, J. M., J. Armstrong, D. Armstrong, and R. Hilborn. 1998. Crustacean resources are vulnerable to serial depletion - the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. Reviews in Fish Biology and Fisheries **8**:117-176.

Orlov, A. M. 1999. Capture of especially large sleeper shark *Somniosus pacificus* (Squalidae) with some notes on its ecology in northwestern Pacific. Journal of Ichthyology **39**:548-553.

Paul, A. J., and J. M. Paul. 1990. The size at the onset of maturity in male *Chionoecetes bairdi* (Decapoda, Majidae). Pages 95-103 *in* International Symposium on King and Tanner Crabs, November 28-30, 1989, Anchorage, Alaska.

Paul, A. J., and J. M. Paul. 1995. Molting of functionally mature male *Chionoecetes bairdi* Rathbun (Decapoda: Majidae) and changes in carapace and chela measurements. Journal of Crustacean Biology **15**:686-692.

Perry, R. I., and S. J. Smith. 1994. Identifying habitat associations of marine fishes using survey data: an application to the northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences **51**:589-602.

Pitcher, K. W. 1980. Stomach contents and feces as indicators of harbor seal *(Phoca vitulina)* foods in the Gulf of Alaska. Fishery Bulletin **78**:797-798.

Pitcher, T. J., R. Watson, and A. Leung. 2000. Marine reserves and the restoration of fisheries and marine ecosystems in the South China Sea. Bulletin of Marine Science **66**:543-566.

Polacheck, T. 1990. Year round closed areas as a management tool. Natural Resource Modeling **4**:327-354.

Powell, G. C., and R. B. Nickerson. 1964. Aggregations among juvenile king crab, *Paralithodes camtschatica*, Kodiak, Alaska. Animal Behaviour **13**:374-380.

Reynolds, J. A. 2003. Quantifying habitat associations in marine fisheries: a generalization of the Kolmogorov-Smirnov statistic using commercial logbook records linked to archived environmental data. Canadian Journal of Fisheries and Aquatic Sciences **60**:370-378.

Ridoux, V., A. J. Hall, G. Steingrimsson, and G. Olafsson. 1998. An inadvertent homing experiment with a young ringed seal, *Phoca hispida*. Marine Mammal Science **14**:883-888.

Roa, R., and F. Tapia. 2000. Cohorts in space: geostatistical mapping of the age structure of the squat lobster *Pleuroncodes monodon* population off central Chile. Marine Ecology Progress Series **196**:239-251.

Roberts, C. M. 2000. Selecting marine reserve locations: optimality versus opportunism. Bulletin of Marine Science **66**:581-592.

Scheding, K., T. C. Shirley, C. E. O'Clair, and S. J. Taggart. 2001. Critical habitat for Ovigerous Dungeness crabs. Pages 431-446 *in* G. H. Kruse, N. Bez, A. Booth, M. W. Dorn, S. Hills, R. N. Lipcius, D. Pelletier, C. Roy, S. J. Smith, and D. Witherell, editors. Spatial Processes and Management of Fish Populations. University of Alaska Sea Grant, AK-SG-01-02, University of Alaska Fairbanks.

Smith, C. R., A. R. Baco, and A. Glover. 2002. Faunal successionon replicate deep-sea whale falls: time scales and vent-seep affinities. Cahier de Marine Biologie **41**:311-354.

Stergiou, K. I. 2002. Overfishing, tropicalization of fish stocks, uncertainty and ecosystem management: resharpening Ockham's razor. Fisheries Research **55**:1-9.

Stone, R. P., C. E. O'Clair, and T. C. Shirley. 1992. Seasonal migration and distribution of female red king crabs in a southeast Alaskan estuary. Journal of Crustacean Biology **12(4)**:546-560.

Swain, U., J. Lewis, G. Pendleton, and K. Pitcher. 1996. Movements, haulout, and diving behavior of harbor seals in Southeast Alaska and Kodiak Island. annual report NA57FX0367, Alaska Department of Fish and Game Division of Wildlife Conservation, Douglas, Alaska.

Syrjala, S. E. 1996. A statistical test for a difference between the spatial distributions of two populations. Ecology **77**:75-80.

Wahle, R. A., and R. S. Steneck. 1991. Recruitment habitats and nursery grounds of the American lobster *Homarus americanus*: a demographic bottleneck? Marine Ecology Progress Series **69**:231-243.

Warner, R. R., S. E. Swearer, and J. E. Caselle. 2000. Larval accumulation and retention: implications for the design of marine reserves and essential habitat. Bulletin of Marine Science **66**:821-830.

Warren, W. G. 1998. Spatial analysis for marine populations: Factors to be considered. Pages 21-28 *in* G. Jamieson and A. Campbell, editors. Proceedings of the North Pacific symposium on invertebrate stock assessment and management. Canadian Special Publication of Fisheries and Aquatic Sciences.

Yang, M. S., and B. N. Page. 1999. Diet of Pacific sleeper shark, *Sominiosus pacificus*, in the Gulf of Alaska. Fishery Bulletin **97**:406-409.