

## STUDY PLAN

### Testing the Effectiveness of a High Latitude Marine Reserve Network: A Multi-Species Movement Study in Glacier Bay National Park, Alaska

*Revised: January, 2002*

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#### INTRODUCTION

In 1999, after great controversy, the U.S. Congress created America's largest temperate marine reserve by closing commercial fishing in parts of Glacier Bay National Park, Alaska (Department of the Interior 1999). During the 1990's, collapsing fisheries around the world caused doubt about the long-term sustainability of certain fisheries (Agardy 1997, Hastings and Botsford 1999, Ludwig et al. 1993, Murray et al. 1999, National Research Council 1995, Rosenberg et al. 1993). Alaskan crustacean fisheries are particularly prone to serial depletion and collapse (Orensanz et al. 1998). An emerging theoretical and empirical body of information hypothesizes that "no-take marine reserves" may promote marine biodiversity, increase scientific understanding and enhance the long-term sustainability of many fisheries (Agardy 1995, Allison et al. 1998, Bohnsack and Ault 1996, Carr and Reed 1993, Coleman and Travis 1998, Garcia-Charton and Perez-Ruzafa 1999, Lauck et al. 1998, Murray et al. 1999, National Research Council 2000b, Plan Development Team 1990, Rowley 1994, Ticco 1995, Ward et al. 1999).

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 size, density, or fecundity to be realized (Polacheck 1990). In addition, an effective reserve must include relevant habitat for the protected species (Dugan and Davis 1993). In practice, however, reserve areas are often chosen pragmatically, on very limited information, and many reserves are created with no monitoring or evaluation procedures (Hockey and Branch 1997, McNeill 1994). Monitoring reserves to determine if they meet their objectives is essential (Allison et al. 1998, McNeill 1994) and the Executive Order 13518 on Marine Protected Areas (MPAs) (May 26, 2000) calls for the development of "practical, science-based criteria and protocols for monitoring and evaluating the effectiveness of MPAs." This executive order also directs the Department of Interior and the Department of Commerce to take a collaborative regional approach while developing a National Network of Marine Protected Areas. The regional nature of many marine processes will require developing management and research collaborations across jurisdictional boundaries if marine resource issues are going to be solved (National Research Council 2000a).

If the goal of a reserve is to export larvae (or genes, juveniles or adults) to a larger surrounding area, it needs to be located in a portion of the species' range that acts as an ecological source, rather than a sink (Carr and Perry 1997, Crowder et al. 2000, Pulliam 1988, Pulliam and Danielson 1991, Roberts 1998). 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 (Chiappone and Sealey 2000, Martell et al. 2000, Murawski et al. 2000, Nowlis and Roberts 1999, Pitcher et al. 2000, Roberts 2000, Warner et al. 2000). Reserve size and shape are also vital factors that influence whether a marine reserve will effectively protect adult breeding populations (Demartini 1993, Guenette and Pitcher 1999, Polacheck 1990). 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.

Although theoretical concepts and simulation models are rapidly developing for marine reserves, their effectiveness at protecting breeding adults has been demonstrated primarily in tropical areas (Agardy 2000). Data on the effectiveness of marine reserves are especially limited from temperate ecosystems (Murawski et al. 2000, Paddock and Estes 2000, Rogers-Bennett et al. 1995). High latitude reserves may be less effective than tropical reserves because temperate fish have broader movement patterns than coral reef fish (Fogarty 1999). Thus to be effective, temperate reserves may have to be much larger (Guenette et al. 2000, Martell et al. 2000, Murawski et al. 2000).

The commercial fishing closures in Glacier Bay created a network of five protected areas that vary in shape and range in size from 40 to 280 km<sup>2</sup> (Figure 1). Since so little is known about reserves in temperate waters and because the reserves created in Glacier Bay are potentially large enough to meet conservation objectives for many species, the opportunity in Glacier Bay to test the effectiveness of a marine reserve network as a marine conservation management tool is socially and scientifically important. The quantitative testing that we are proposing will allow managers, scientists and the public to evaluate the utility of reserves as a management tool for solving local, national, and global marine conservation issues.

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 (Demartini 1993, Guenette and Pitcher 1999, Polacheck 1990). We propose attaching sonic tags to Pacific halibut (*Hippoglossus stenolepis*), Tanner crab (*Chionoecetes bairdi*), and red king crab (*Paralithoides camtschaticus*), and measuring exchange between the newly created reserves and the area remaining open to commercial fishing by deploying ultrasonic gates along the boundary the reserves. This study will allow us to quantify the effectiveness of the reserves at protecting the adult breeding portion of selected populations. This is the first step in testing the effectiveness of marine reserves. If the reserves are large enough to protect the adult breeders, future studies could examine how the reserves influence adjacent populations.

## **BACKGROUND**

Commercial fishing has occurred in Glacier Bay since at least the turn of the century (Taylor and Perry 1990). Commercial fishing continued under federal regulation after the establishment of Glacier Bay National Monument in 1925 and its subsequent enlargement in 1939. Since 1966, however, federal regulation and legislation have prohibited commercial fishing in Glacier Bay. In addition, the Wilderness Act has prohibited commercial fishing within Glacier Bay's wilderness waters since 1980 (USNPS 1998). Despite these regulations, commercial fishing activities continued in Park waters.

Starting in 1990, the Department of the Interior attempted to resolve the commercial fishing issue through litigation and administrative rulemaking. In October 1998, Congress passed legislation that immediately closed Wilderness Waters and certain other areas within Glacier Bay to commercial fishing. A year later, the Department of the Interior published the *Final Rule* implementing Glacier Bay National Park commercial fishing legislation (Department of the Interior 1999). The legislation established special regulations for commercial fishing in the marine waters of Glacier Bay National Park and provides: “protection of Park values and purposes, prohibition of any new or expanded fisheries, and opportunity for the study of marine resources.”

Specifically, particular areas of non-wilderness waters (West Arm, West Arm, Geikie Inlet) in Glacier Bay proper and all wilderness waters within Glacier Bay National Park were closed to commercial fishing (Beardslee Islands and Scidmore-Charpentier). Commercial fishing in the central portion of Glacier Bay proper was limited to three specific commercial fisheries (Pacific halibut, Tanner crab and salmon) and there is a phase-out (or “grand-father”) process for these three fisheries. The phase-out-process allows qualifying fisherman in the three authorized commercial fisheries to continue fishing in specific areas of Glacier Bay proper with nontransferable, lifetime permits. At the end of the phase out period, all commercial fishing will be closed in Glacier Bay proper. Finally, the legislation clarified that the marine waters of the Park outside of Glacier Bay proper would remain open to existing commercial fisheries, and would be cooperatively managed by the State of Alaska and the Department of Interior. By closing commercial fishing in parts of the Park, the U.S. Congress has effectively created a network of five marine reserves that vary in size and shape.

Testing the effectiveness of a marine reserve depends largely on knowledge of movement patterns of the key species (Carr and Reed 1993, Demartini 1993, Polacheck 1990, Rowley 1994). Little is known about the movements of species that are commercially harvested in Glacier Bay except halibut. A telemetry study of halibut in Glacier Bay suggests that Pacific halibut exhibit a developmental shift in home range patterns. Juvenile fish in Glacier Bay move widely but often remain within Park waters. Sexually mature fish occupy home ranges that are often less than 0.5 km<sup>2</sup> in size. These larger fish exhibit site fidelity and home ranges appear to be maintained within and between years (Hooge and Taggart 1998).

Information on Tanner crab movements is limited and there are no data from Glacier Bay. Donaldson (1983) tagged male Tanner crab tagged near Kodiak, Alaska and found that animals tagged in bays tended to move offshore while those tagged offshore remained in that general area. The mean net movement of male Tanner crabs was 27.9 km during the 4 year study.

Movements of red king crab have not been studied in Glacier Bay. However, in nearby waters (Auke Bay, Alaska), female red king crab tagged with ultrasonic tags were located at weekly intervals for over a year (Stone et al. 1992). In spring following mating and egg extrusion, they gradually moved to deeper water and remained at these depths through early November. Female crabs abruptly moved into shallow water during November where they resided until late February or March. Females molt and mate during March through May. The home range of primiparous female red king crabs (11.9 km<sup>2</sup>) exceeded that of multiparous female crabs (avg. 3.6 km<sup>2</sup>) during a one-year period (Stone et al. 1992).

## **METHODS**

Marine reserve models demonstrate that understanding movement is central to evaluating reserve effectiveness (Demartini 1993, Guenette and Pitcher 1999, Polacheck 1990). We propose to estimate the relative density and relative abundance of Pacific halibut, Tanner crab, and red king crab inside and outside of the newly created reserves in Glacier Bay. Next we will attach sonic tags to a sample of Pacific halibut, Tanner crab, and red king crab, and estimate the movement between the newly created reserves in Glacier Bay and central portion of Glacier Bay (which remained open to commercial fishing), by deploying an ultrasonic gate along the boundary of each reserve for two years. Movement between the entire Bay and Icy Strait will be measured with an ultrasonic gate deployed near the mouth of Glacier Bay (Figure 1). The ultrasonic gates will be constructed by anchoring data loggers along the boundaries at regular intervals so that 100% of the boundary is monitored (Figures 2-7). This study will allow us to quantify the effectiveness of the reserves at protecting the adult breeding portion of the selected populations. It will also set the stage for future studies, which will address the effect of the reserves on larval supply and the role of reserves as ecological sources vs. sinks. The quantitative testing that we are proposing will help managers, scientists and the public to evaluate the utility of reserves as a management tool in the conservation of local and regional marine resources in Alaska.

### **1. Study Area**

Our study sites include the central part of Glacier Bay and five adjacent areas in the Park where commercial fishing was recently closed: Geikie Inlet, Scidmore Bay-Charpentier Inlet, West Arm, East Arm and Beardslee Islands (Figure 1). The central portion of the Bay remains open to commercial halibut and Tanner crab fishing. Thus, the five closed areas are reserves for Tanner crabs and halibut while the entire bay is a reserve for red king crab (and all other commercially fished species).

It is important to clarify that sport fishing and personal use fishing is allowed in all areas of Glacier Bay including the reserves. Thus it would be incorrect to classify the reserve areas as no-take-marine-reserves. We think, however, that the amount of sport fishing in the reserve areas is small. Furthermore the reserves which are wilderness waters (Scidmore Bay-Charpentier Inlet, and Beardslee Islands) are non-motorized during the summer (May 15 – September 15). Portions of two other reserves are wilderness waters (Adams Inlet which is part of the West Arm reserve; Rendu which is part of the East Arm reserve). Two parts of the East Arm are closed to motorized vessels for six weeks during the summer (Muir Inlet Head is closed from June 1 to August 31 and Wachusett Inlet is closed from July 16 to August 31). When areas are closed to motorized vessels it limits the sport harvest to people fishing from shore or from kayaks. From a scientific point of view we think that it is currently valid to study the movement dynamics as though the reserve areas are no-take-marine-reserves. The amount of sport fishing in the reserve areas could change in the future and compromise long term studies. If long term studies are undertaken it would be logical to monitor the level of sport harvest.

### **2. Research Vessels**

A 50' USGS research vessel, *R/V Alaskan Gyre*, will be used to deploy and retrieve data loggers, catch and tag organisms, and conduct the band-transect searches. A 26' USGS research vessel, *R/V Eider*, or a similar boat will also be used for retrieving data loggers and conducting band-transect searches. During band-transect searches, the location of the vessels will be continuously recorded by downloading Global Positioning System (GPS) fixes and times onto a computer.

### **3. Sonic Tags**

All halibut and crabs will be tagged with either V16-5H RCODE sonic tags manufactured by VEMCO (Shad Bay, Nova Scotia, Canada) or MAP16\_2 sonic tags manufactured by Lotek (Newmarket, Ontario, Canada). The V16-5H RCODE sonic tags are cylindrical and 92 mm long and 16 mm in diameter (Figure 8). The tags would be programmed for a pulse interval of 2.5 minutes and, with lithium batteries, would have a life expectancy of 2 years. All V16-5H RCODE sonic tags would transmit at the same frequency (50 kHz). Unlike conventional sonic tags that transmit a single ping, RCODE coded tags transmit a burst of 6 pings followed by an off time interval. The 6 pings encodes an identification number that can be decoded by a receiver and stored into memory. A total of 65,536 RCODE sonic tags can be programmed with unique codes. The duration of the off time interval is programmed to vary randomly about 10%, thus the pulses from multiple tags will only overlap briefly. A long pulse interval will conserve battery life as well as increase the number of tags that a single receiver can concurrently decode.

The MAP16\_2 sonic tags are cylindrical and 82 mm long and 16 mm in diameter. Lotek sonic tags incorporate Code Division Multiple Access (CDMA) technology adapted from the cell phone industry. This technology has several advantages: 1) each pulse has a very low power requirement so the tags can have a long operation life with a short burst interval; 2) the digital spread spectrum technology allows 100's of tags to be decoded simultaneously; and 3) these tags can be decoded in the presence of significant background noise. The tags would be programmed for a pulse interval of 15 seconds, would have a life expectancy of 3 years, and would transmit at 69 kHz.

Because female Tanner crabs are small, we will tag females with shorter tags. These tags would either have lower power output or a shorter life expectancy. Both of these scenarios would make female Tanner crabs more difficult to locate during band transects (see section 5 below "Band –transect searches").

### **4. Data Loggers**

The ultrasonic gates will be constructed by mooring a series of independent submersible data loggers (Figure 8) along the boundary of each reserve and the mouth of Glacier Bay (Figures 2-7). VEMCO manufactures VR2 Single Channel Monitor data loggers that are dedicated remote monitors designed to detect RCODE sonic tags. The data loggers record the sonic tags' individual identification and the date and time when a tagged animal comes into range. The VR2 monitors have a battery life of 180 days and can store 300,000 sonic tag detections. They must be retrieved to be downloaded but can be redeployed at the same time. If we tagged 480 animals and those animals moved randomly in the Bay, each data logger would record, on average, 177,800 fixes in 6 months. This estimate was calculated by: (area of Bay/reception area of each logger) X (total number of transmitters) X (number of codes each transmitter sends in 6 months). Based on preliminary field tests of the VEMCO data loggers in Glacier Bay (December 2000), the VR2 data loggers can detect and decode signals from any direction at 800 meters.

Lotek is developing a submersible Wireless Hydrophone System which houses the MAP receiver in an waterproof housing. This approach takes advantage of a sophisticated receiver but has the disadvantage of being expensive. Whichever data logger we use, we will start with a frequent data logger retrieval schedule of every two months. Based on the amount of memory filled during the first two months, we will develop an appropriate retrieval schedule for each gate so that the datalogger memory will not be exceeded.

We estimate that the data loggers should be placed 1600 meters apart along the reserve boundary. There are three factors, however, that affect the reception radius of the data loggers: 1) distance the tagged animal is from the bottom, 2) swimming speed of the tagged organism, and 3) the pulse rate of the sonic tags. As all of these factors increase, the effective radius of the data logger reception decreases (Figure 9). If all of the organisms to be tagged were slow moving and stayed on the bottom, then we would place the data loggers 1600 meters apart. However, because we are also tagging halibut that can swim fast and may swim up into the water column, we will decrease the spacing of the data loggers to maintain a high reception probability. Exact spacing will be determined by Equation 1.

Equation 1:

$$ER = \sqrt{(R^2 - D^2) - \left(\frac{FS \times P}{2}\right)^2}$$

Where:  $ER$ = Effective Radius of the data logger;  $R$ = 800 m (the reception radius of the data loggers on the bottom);  $D$ = depth (meters);  $FS$ = fish speed (meter/min); and  $P$ = pulse rate interval of the sonic tags (min.). (Equation derived by authors).

Data loggers will be suspended 5-10 meters off the bottom on short moorings with subsurface floatation (Figure 10). Subsurface floatation eliminates numerous problems associated with surface buoys (e.g. navigational hazard, fouling with kelp or logs, visual impact to visitors, freezing in ice during the winter). Disposable, degradable anchors will be used to secure the moorings to the bottom. The mooring configuration (i.e. anchor, hardware, floatation, line, etc.) will be modeled by Marinna Martini, an ocean engineer with the USGS Woods Hole Field Center to determine the necessary specifications required for the currents in Glacier Bay. Dr. Gary Bowen (University of Alaska Southeast, Juneau) will also be providing input on anchor design and construction. We will initially take a dual approach for deployment of these moorings. Acoustic release units (Figure 11) will allow individual moorings (Figure 10) with data loggers to be set and retrieved through the remote activation of the release mechanism. As a backup, we will attach subsurface moorings to a retrievable longline (Figure 12), which will allow us to retrieve the data loggers if an acoustic release fails. The inclusion of both the individual mooring method and the long-lining method of deployment allows for added security and flexibility in retrieval.

## 5. Band-transect Searches

Band-transect searches will be performed in parts of the reserves every time the data loggers are retrieved (approximately every 2 months) and throughout the entire bay, every 6 months, to determine the location of tagged animals. The band-transects will also be used to detect if each sonic tag is still attached to a live animal by determining if the animals have moved since the last search. We also are working with VEMCO and Lotek to develop sonic tag with “mortality” sensors which would change code when an animal stops moving.

VEMCO manufactures a system for accurately monitoring the position of sonic tagged animals with a moored hydrophone array called Radio-Linked Acoustic Positioning (RAP). Lotek’s MAP\_500 animal monitoring system provides two and three dimension positions of tagged animals. Both of these systems determine an animal’s location by measuring the difference in arrival time of the sonic signal to pairs of hydrophones.

We are also exploring the use of towed hydrophone arrays (engineered by Marschall Acoustics) that could be linked to either manufacturers' positioning system and used for conducting band-transect searches. During preliminary testing in December 2000, we were able to tow VEMCO's VH65 hydrophone 10 meters below the surface at 8km/hour by trailing the hydrophone behind a side-scan sonar housing. At this speed, the VR60 was able to decode 50 kHz tags up to 1050 meters away. However, the reception distance of a receiver is influenced by water depth and boat towing speed, as shown in Equation 2, and band-transect width will be adjusted accordingly.

Equation 2: 
$$ET = 2 \times \sqrt{(R^2 - D^2) - \left(\frac{BS \times P}{2}\right)^2}$$

Where: *ET*= Effective Band-transect Width (m); *R*= 800 m (the reception radius of the data loggers on the bottom); *D*= depth (meters); *BS*= boat speed (meter/min); and *P*= pulse rate interval of the sonic tags (min.). (Equation derived by authors).

Figure 13a shows a hypothetical band-transect search for the entire bay. There are some inlets in the Bay that are narrow enough to be searched in one strip and the speed of the boat would not be limited on the return. These "fast track" areas are shown in Figure 13b. We estimate that the time required to accomplish the band-transect searches will range from 104 to 157 hours depending upon the vessel(s) used and the towing speed (Table 1).

## 6. Data basing and archival

Data from this project will be incorporated into the Glacier Bay Ecosystem Project data model. All attribute data will be placed in databases linked to the ARC/Info Geographic Information System. All purely spatial databases will be in ARC/Info format. Spatial data will also be archived as SDTS (Spatial Data Transfer Standard) format. All completed data sets will also be archived on CD-ROMS at the Glacier Bay Field Station. Project field notes will be written according to Glacier Bay Data Plan protocol standards and archived at the Glacier Bay Field Station.

**Table 1.** Estimates of band-transect tracking time.

<b>Estimates of total tracking time using the AK Gyre with a fast track speed = 18.5 km/hour.</b>					
	<b>Search Time (hours) at different towing speeds:</b>				
	<b>6 km/hr</b>	<b>7 km/hr</b>	<b>8 km/hr</b>	<b>8.5 km/hr</b>	<b>9 km/hour</b>
Slow Track (towing)	150	129	113	106	100
Fast Track (not towing)	7	7	7	7	7
<b>TOTAL:</b>	157 hrs	136 hrs	120 hrs	113 hrs	107 hrs
<b>Estimates of total tracking time using the Eider with a fast track speed = 37 km/hour.</b>					
	<b>Search Time (hours) at different towing speeds:</b>				
	<b>6 km/hr</b>	<b>7 km/hr</b>	<b>8 km/hr</b>	<b>8.5 km/hr</b>	<b>9 km/hour</b>
Slow Track (towing)	150	129	113	106	100
Fast Track (not towing)	4	4	4	4	4
<b>TOTAL:</b>	154 hrs	133 hrs	117 hrs	110 hrs	104 hrs

## **RESEARCH OBJECTIVES**

**1.a Estimate the relative density of crabs and halibut in the reserves and in the central Bay.** The reserves are composed of protected fjords and bays while the open portion of the bay is less enclosed shallow water. Thus, there are large differences in the type of habitat contained in the reserves and the open area. Consequently, we expect differences in relative density between the reserves and the open area. We expect different age classes or sex ratios in the reserves compared to the open area. For example, one hypothesis is that the protected bays and fjords are the female Tanner crab brooding areas and nursery areas for immature crabs. If this is true, we should find higher relative density of females and immature crabs in the reserves than in the open area.

**1.b Estimate the relative abundance of crabs and halibut in the reserves and in the central Bay.** What proportion of the population is inside and outside the reserve? Forty-one percent (610 km<sup>2</sup>) of Glacier Bay was closed to halibut and Tanner crab fishing. The proportion of the population contained in the reserves is one of the first criteria for assessing the effectiveness of a reserve. Some of the reserve areas may contain very few individuals and thus would have minimal value as a reserve for that species. The relative abundance is estimated by weighting the relative density (1.a above) by area.

### Methods:

Crabs will be collected with conical, top-loading 7.3 ft X 3 ft commercial Tanner crab pots which will have the same specifications as pots used by the ADF&G for king crab and Tanner crab surveys. We will use the same methods (soak time, bait type, bait quantity) (Clark et al. 1999a), since standardized methods will facilitate interagency analyses of the pooled data. As the pots are retrieved, we will count and identify all organisms to species (rarely to genus). Tanner crab and king crabs will be measured, examined and returned to the water at the location of capture. We will record the sex, carapace size, shell condition, and appendage damage for all crabs. Carapace will be measured to the nearest mm with vernier calipers. Shell condition will be categorized as soft, new, old or skip molt (Jadamec et al. 1999). We will examine the appendages and recorded missing, or regenerating appendages.

Halibut will be captured using snap-on longline fishing gear baited with herring. Longlines will be short (100 hooks spaced every 2 fathoms on 200 fathoms of ground line) so that we can set numerous lines and distribute the effort across the sampling grid. Set times will be staggered to achieve a standard soak time of six hours. In addition, all halibut will be tagged with International Pacific Halibut Commission (IPHC) harvest tags, and measured for total length. Other fish species will be identified and measured for total length.

Crab pots and longlines will be set in a systematic random sampling design. To estimate appropriate sample size for halibut we estimated the standard deviation from halibut CPUE data previously collected in Glacier Bay in 1994-1995. These data were from 400 hook longlines. Because the hook number for each halibut was recorded, it was possible to split the sets into 100 hook sets post hoc. Although four 100 hook sets created by splitting 400 hook sets are not likely to have the same variance as 100 hook sets placed randomly, we feel the data are adequate for precision estimates. We estimated the standard deviation for Tanner and king crab CPUE from data collected by the ADF&G during their Tanner crab stock assessment surveys (Clark et al. 1999b). We used data from all sites surveyed (Holkham Bay, West Douglas Island, Pleasant Island) and we estimated precision for female Tanner crabs, male Tanner crabs, female king crabs and male king crabs. We defined precision as half of the 95% confidence interval. To



facilitate comparison among species and sex we expressed precision as a percent of the mean [ $((95\% \text{ CI})/2)/\text{mean}$ ] (Figure 14).

Although the halibut relative density estimates were more precise than the crab estimates for the same sample size, we can collect 5 times as many pot samples as longlines per unit of time. Logistic constraints limit the number of longlines we can set to approximately 100 longlines (50 in the reserves and 50 in the open area), which would require 25 sample days. With a sample size of 50, our precision is above 20% and we would like it to be less than 20%. We are exploring an alternative method for capturing halibut, which could increase our sample size. Pots are effective at capturing halibut and consequently several studies have focused on ways to reduce halibut bycatch in the king crab and cod pot fisheries (Carlile et al. 1997, Watson et al. 1998a, Watson et al. 1998b, Williams et al. 1982, Zhou and Kruse 2000). The standard error for unmodified square king crabs pots was estimated in one of these studies (Williams et al. 1982). A precision estimate based on these data is very similar to our precision estimate for longlines. The obvious advantage is that pots are faster to set than longlines thus we could increase our precision by increasing our sample size. We plan to test pots as an alternative method for sampling halibut in August 2001. If we find handling the pots is efficient and that the precision (for a particular sample size) is equal or better than the longlines, we will sample with pots. We will select 200-300 random sites from a systematic 1.5 km grid (total possible stations = 660). If we determine that modified pots are not feasible, we will sample 100 stations with longlines randomly selected from a systematic 3 km grid (total stations = 165).

The precision estimate for male Tanner crabs was similar to halibut while the precision estimates for king crab and female Tanner crabs were poor. The ADF&G stock assessment survey was designed for male Tanner crabs and thus the estimates for female Tanner crabs or king crabs may be overly pessimistic. Alternatively, male Tanner crab surveys may decline in precision when sampled with a systematic random sample. It is clear that we need large samples to estimate relative density for crabs. For crabs, we propose sampling 500-600 randomly selected stations from a 1.5 km grid (total possible stations = 660). Adaptive sampling can improve precision for species with aggregated distributions (Thompson 1990). Adaptive sampling improves precision when the within “neighborhood variance” is greater than the population variance (Thompson 1990). We are exploring the utility of adaptive sampling especially for female Tanner and king crab.

#### Data Analysis:

Density is assumed to be proportional to CPUE (Quinn II and Deriso 1999). Thus, the relative density in the reserves and in the open area can be estimated from the CPUE. These data will probably not be normally distributed and will need to be transformed. A square root transformation has been successfully used to normalize halibut CPUE data (Quinn II 1985). Relative density in the reserves and the open area will be estimated with a 95% confidence interval. The relative abundance in the reserves and in the open area will be estimated from CPUE according to the equation 3:

$$\text{Equation 3. } R_o = (A_o \times U_o) / [(A_o \times U_o) + (A_r \times U_r)]$$

$$R_r = (A_r \times U_r) / [(A_o \times U_o) + (A_r \times U_r)]$$

Where:  $R_o$  = Relative abundance of open area;  $R_r$  = Relative abundance of reserves;  $A_o$  = area of area;  $A_r$  = area of reserves;  $U_o$  = CPUE of open area; and  $U_r$  = CPUE of reserves. (Equation modified from equation 1.42 in (Quinn II and Deriso 1999)).

We will estimate the relative density and relative abundance of immature and mature individuals; for crabs, we will compare males and female. We will test for differences in relative density between the reserves and open area with a T-test. We will test for differences in relative abundance with a z-test.

**2.a Estimate the length of time (residence time) halibut and Tanner crabs remain in the reserves.**

**2.b Estimate the length of time (residence time) halibut and Tanner crabs remain in the open area.**

**2.c Estimate the length of time (residence time) halibut, Tanner crabs and king crabs remain in Glacier Bay.**

#### Methods:

Sonic tags will be attached to a random sample of the mature portion of the populations inside the combined reserve area and in the area open to fishing. Sonic tags will be attached while we are conducting the relative density sampling in objective 1. Initially we will estimate the average catch per station (mature animals) from previous data collected at Glacier Bay. We will estimate the total catch (number of stations X average catch mature animals). The proportion of animals we will tag will be estimated by dividing the total catch by the number of sonic tags we plan to attach. For example, if have 500 station, an average estimated CPUE=10 animals/station and we want to attach 100 sonic tags we would attach a sonic tag to every 50<sup>th</sup> mature animal we encounter ( $500 \times 10 / 100 = 50$ ). We will start by sampling every other station until we sample half of our stations (250 in our example). If our CPUE estimate is accurate, we will have attached half of the tags. We will sum the catch from the first 250 stations and assume that the catch will be the same for the second 250 stations. We will recalculate the proportion of animals to tag by dividing the total catch in the first 250 stations by the number sonic tags remaining from the first sampling cycle. All sonic tagged animals will be released at the location they were captured.

For all species, tags will be attached to mature individuals. The growth rate of male halibut is slower than females; male halibut rarely exceed 35 kg while females frequently exceed 100 kg (Schmitt and Skud 1978). Since most female halibut are mature at 120-cm and few males reach 120-cm (Clark et al. 1999c), we will select mature females by simply selecting individuals greater than 120-cm. The sonic tags will be implanted into halibut using techniques previously developed at Glacier Bay (Hooge and Taggart 1998). We plan to limit tagging in this study to mature female halibut for two reasons: 1) if movements rates of females are determined to be low, we will design new studies which will focus on measuring changes in the size structure of the female portion of the population, and 2) it is difficult to differentiate mature males from immature females unless you examine the gonads which requires surgery or sacrifice of the animal.

Mature male Tanner crabs greater than 110-mm have a molt interval greater than two years (Paul and Paul 1995) and recently molted males can be identified by carapace condition (Jadamec et al. 1999). We will select recently molted male crabs greater than 110-mm to minimized tag loss by molting during the two-year study. Mature female Tanner crabs have a low probability of molting once they reach sexual maturity. Individual females that are sexually mature will be identified by the shape of the abdominal flap (Jadamec et al. 1999).

There is limited information on the molt interval of red king crab. Weber and Miyahara (1962) reported that king crabs with carapace length of 126 mm, 142 mm, 158 mm, and 174 mm had molting probabilities of .87, .65, .37, and .03 respectively. To minimize tag loss from molting we will select recently molted

king crabs and select crabs with a carapace length greater than 158 mm. Tags will be glued to the carapace with epoxy (Stone et al. 1992).

We do not have preliminary data to calculate variance of residence time. As a conservative way to estimate precision we calculated precision from a binomial distribution by varying the proportion of the population detected by the sonic gates (Figure 15). A sample size of 50 yielded adequate precision (.06-.12, depending on proportion of the population), but to compensate for expected tag loss a sample size of 60 will be used. Sixty tags will be placed inside and outside the reserves on Tanner Crab females, Tanner Crab males, and female Pacific Halibut. Since all of Glacier Bay is closed to red king crab commercial fishing, we will attach the sonic tags to 60 female and 60 male king crabs randomly throughout the entire bay-wide reserve (Table 2).

**Table 2.** Proposed number of sonic tags in the reserve area and open portion of Glacier Bay per species by gender.

	Tags in Reserve Area	Tags in Open Area	Total Tags
Red King Crab (males)			60
Red King Crab (females)			60
Tanner Crab (males)	60	60	120
Tanner Crabs (females)	60	60	120
Halibut (females)	60	60	120
<b>Total:</b>			480

#### Data Analysis:

The acoustic gates will allow us to accurately measure the length of time individual animals remain in the reserve. For these analyses, we will calculate residence time as the number of days from date of tagging until the animal is first detected at an acoustic gate. We will estimate the mean residence time with a 95% confidence interval.

A number of factors may affect residence time. The distance from the tagging location to the nearest acoustic gate is likely to influence the residence time and we will test this relationship with linear regression. For each tagging location we will run random movement Monte Carlo simulation to estimate the mean relative length of time it would take for an individual tagged at that location to contact a gate (Program developed by P. Hooe, <http://www.absc.usgs.gov/glba/gistools/>). This approach will integrate the effects of distance to gate, shoreline complexity, and width of gate. We will test this random movement parameter against the measured residence time with linear regression.

We will analyze the residence time data with survival statistics. We are interested in estimating the “residence duration” instead of survival time which is the most common use of survival statistics. With survival statistics, we will generate “residence curves” and we will compare the curves among species and by sex.

### **3. Measure the proportion of time animals tagged in the reserves reside in the reserve and the proportion of time individuals tagged outside the reserve spend in the reserve.**

#### Methods:

The acoustic gates will accurately measure the date an animal first comes within range of a reserve boundary but the gates cannot distinguish between an animal that crosses the boundary from an animal that approaches but turns around without crossing the boundary. To measure the amount of time that

individual animals spend in the reserves we need to know when an animal crosses a reserve boundary. We will solve this problem with the following procedure. When we download the data from the gates (approximately every 2 months) we will immediately process the data onboard the research vessel and identify which animals were recorded. We will initiate a systematic band transect search for these animals radiating out from the boundary. Once they have been located, we will stop searching. In some cases it will be faster to conduct complete band transect surveys of smaller reserves to determine whether individuals are present or absent. The combination of the sonic gates and limited band transect searches will allow us to split an animals year into time segments which would be classified as time segments spent in the reserve or the open area. An alternate method for determining when an animal crosses a boundary would be to construct 2 parallel gates along each boundary. Thus the direction an animal is moving can be inferred by which gate detects him first. The primary problem with this solution is that it would increase the cost of this project. If all reserve boundaries were “double gated” the budget would increase approximately \$70K.

Data Analysis:

The percentage of time an animal spends in the reserve will be calculated by summing the time segments spent in the reserve and dividing by total time:

Equation 4. 
$$T_{\%} = \sum t_r / T$$

Where:  $T_{\%}$  = % of time an individual is in a reserve;  $t_r$  = time segments in the reserves; and  $T$  = total time.

The percentage of time the population spends in the reserves will be estimated by the equation:

Equation 5. 
$$T_{r,o} = \sum T_{\%} / N \pm 1.96(\sigma / \sqrt{N})$$

Where:  $T_o$  = the percentage of time the population in the open area spends in the reserves;  $T_r$  = the percentage of time the population in the reserves spends in the reserves;  $N$  = number of animals with tagged with sonic tags; and  $\sigma$  = standard deviation.

These data will probably not be normally distributed, and will need to be transformed. An arcsine transformation is likely to be appropriate (Sokal and Rohlf 1981). We will estimate the percentage of time and a 95% confidence interval for reserves and the open area.

The percentage of time that the Glacier Bay population resides in a reserve is proportional to the relative abundance in the two areas. The percentage of time that the Glacier Bay population is in one of the reserve areas will be calculated by the equation:

Equation 6. 
$$T_{GB} = (T_r \times R_r) + (T_o \times R_o)$$

Where:  $T_r$  and  $T_o$  are calculated in Equation 5;  $R_r$  and  $R_o$  are calculated in Equation 3.

The percentage of time that an animal spends in the reserves affects fishing mortality only during the portion of the year that fishing is open to commercial fishing. To estimate how the reserves might change fishing mortality we will calculate the percentage of time that individuals spend in the reserves during the fishing season. Equations 4, 5, and 6 will be recalculated with the following changes (changes are underlined):

Equation 4:  $T_{\%}$  = % of time an individual is in a reserve during the fishing season,  $t_r$ = time segments in the reserves during the fishing season, and  $T$ =total time of the fishing season.

Equation 5.  $T_o$  = the percentage of time the population in the open area spends in the reserves during the fishing season,  $T_r$  = the percentage of time the population in the reserves spends in the reserves during the fishing season.

**4a. Test the current paradigm that halibut migrate from inside waters and spawn along the edge of the shelf (St-Pierre 1984).**

**4b. Determine if the halibut spawning migration occurs when the commercial fishing is closed.**

Hypothesis: There is no change in the number of halibut detected by the gate at the mouth of Glacier Bay during the spawning period.

Methods:

If halibut travel to the edge of the continental shelf to spawn, they will pass through the gate at the mouth of Glacier Bay. If halibut return to Glacier Bay after spawning they will be recorded again during the return migration. We will measure the number of halibut that are detected by the gate located at the mouth of Glacier Bay and test for seasonal changes. We expect a small number of halibut to leave Glacier Bay during the year through random movements or changes in home range and these animals will also be detected by the gates. However, if a large proportion of halibut migrate, we expect a spike in the number of detections per month during the spawning and these months should be significantly different from non-spawning months.

Data Analysis:

We will test for differences in the number of detections among months with a chi square test using a uniform distribution as the null hypothesis (Zar 1996).

If a spawning migration occurs we will describe it's characteristics. We will estimate the proportion of the population that participates in the spawning migration with the following equation:

Equation 7. 
$$P_m = \frac{N_m}{N} \pm 1.96 \sqrt{\frac{\frac{N_m}{N} (1 - \frac{N_m}{N})}{N}}$$

Where:  $P_m$ = proportion of population departing during migration;  $N_m$ =number of sonic tags departing during spawning period; and  $N$ =number of halibut with sonic tags. (Equation modified from equation 9.2 (Pfaffenberger and Patterson 1987)).

We will estimate the timing of the departure and the timing of the return (if they return) with a 95% confidence interval with the following equation:

Equation 8. 
$$T_m = \sum t_i / N_m \pm 1.96\sigma \frac{\sigma}{\sqrt{N_m}}$$

Where:  $T_m$ = mean date of migration;  $t_i$ =day each halibut crosses the gate; and  $N_m$ =number of sonic tags departing during spawning period.

We will estimate the duration of the migration with the following equation:

Equation 9. 
$$D_m = \frac{\sum t_i - t_{ii}}{N_m} \pm 1.96 \frac{\sigma}{\sqrt{N_m}}$$

Where:  $D_m$ = mean duration of migration;  $t_i$ =day each halibut crosses the gate (departure);  $t_{ii}$ =day each halibut crosses the gate (return); and  $N_m$ =number of sonic tags departing during spawning period.

### 5. Model the Bay-Wide interaction between the reserves and the open area.

We have initiated a collaboration with Dr. Carl Walters and Dr. Sylvie Guenette (University of British Columbia, Canada) to develop a spatially and age-specific population model for Glacier Bay halibut, Tanner crabs and king crab. These models will be developed from a generic model (FISHMOD) developed by Walters. For example, FISHMOD has recently been used to model the response of lingcod (*Ophiodon elongates*) (Martell et al. 2000) and Atlantic cod (*Gadus morhua*) (Guenette et al. 2000) populations to various management options including marine reserves. Cod have much higher transfer rates than lingcod and consequently much larger reserves are required for effective conservation. At the end of this study, we will update the models with the movement data and the relative density and spatial size structure of the populations inside and outside the reserves. We will use FISHMOD to predict changes in the population structure of crab and halibut which will be used in the design of future studies.

**TIME-LINE**

	<b>FY 2002</b>												<b>FY 2003</b>				<b>FY 04</b>		<b>FY 05</b>		
	<b>Months</b>												<b>Quarters</b>				<b>Halves</b>		<b>Halves</b>		
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	1st	2nd	3rd	4th	1st	2nd	1st	2nd	
Purchase equipment																					
Test equipment																					
Prepare for sampling																					
Estimate relative abundance of Tanner crab																					
Deploy Tanner crab & king crab tags in first reserve (East Arm of Glacier Bay)																					
Deploy ultrasonic gate across first reserve boundary (East Arm of Glacier Bay) & mouth of Glacier Bay																					
Tag halibut in first reserve (East Arm of Glacier Bay)																					
Begin band-transect searches - repeat every 6 months																					
Monitor East Arm ultrasonic gate																					
Deploy remainder of ultrasonic gates																					
Deploy remainder of tags																					
Monitor and maintain all ultrasonic gates																					
Data Analysis and writing																					

## PRODUCTS

March 2003. Testing the Effectiveness of Marine Reserves at Glacier Bay National Park: Implementation of Phase I. Annual Progress Report.

March 2004. Testing the Effectiveness of Marine Reserves at Glacier Bay National Park: Implementation of Phase II. Annual Progress Report.

March 2005. Testing the Effectiveness of Marine Reserves at Glacier Bay National Park. Annual Progress Report.

2006. Testing the Effectiveness of Marine Reserves at Glacier Bay National Park. Final Report.

2007. The transfer rate of high latitude Marine Reserves: A Multi-Species, Multi-Reserve Experiment. Scientific Journal Publication.

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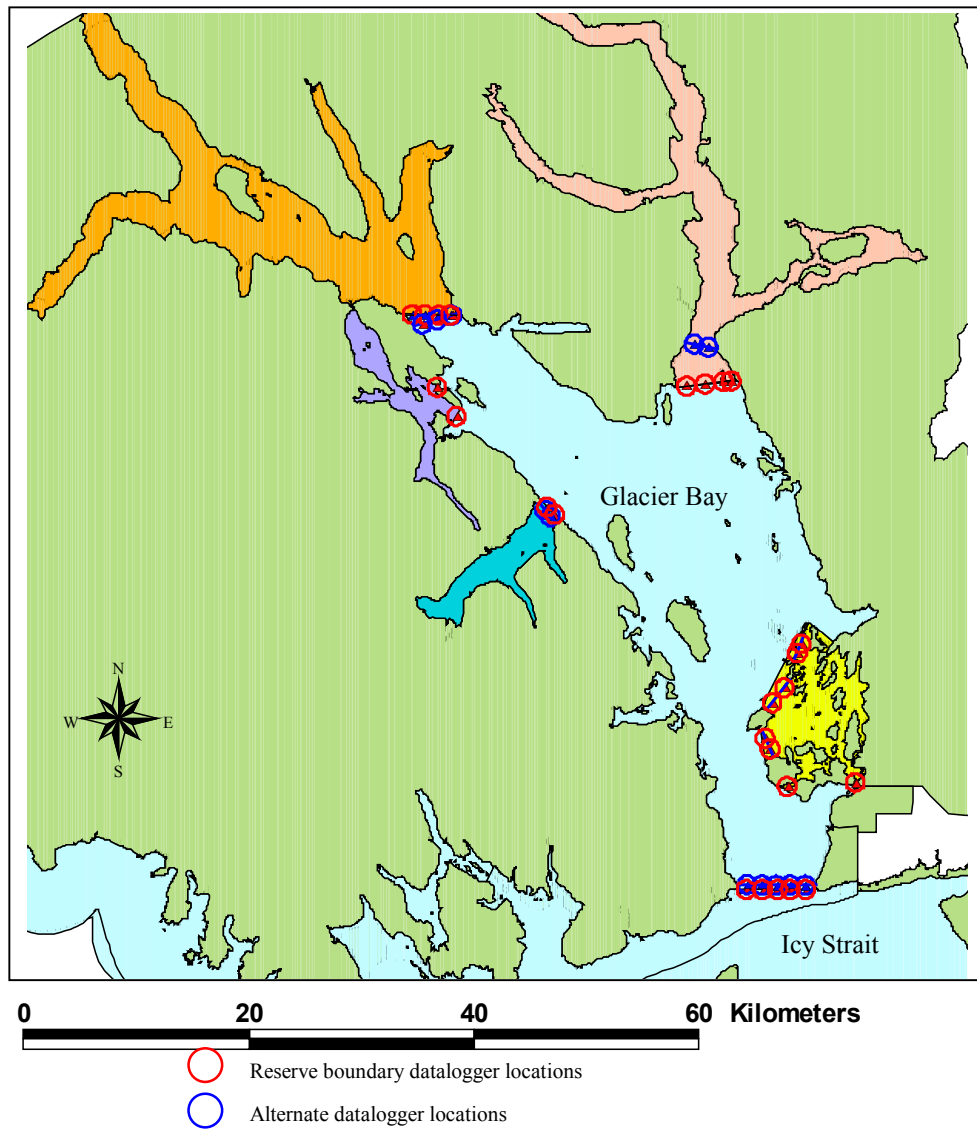
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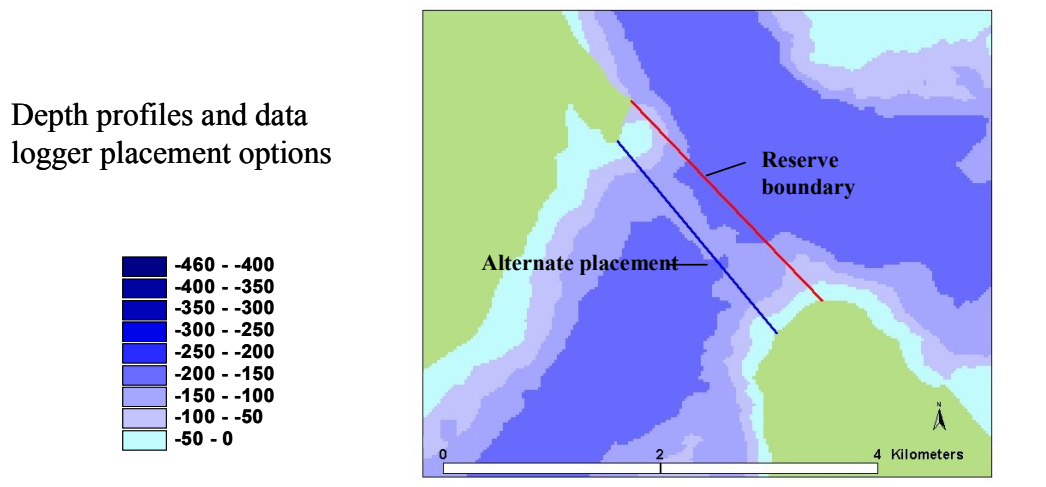
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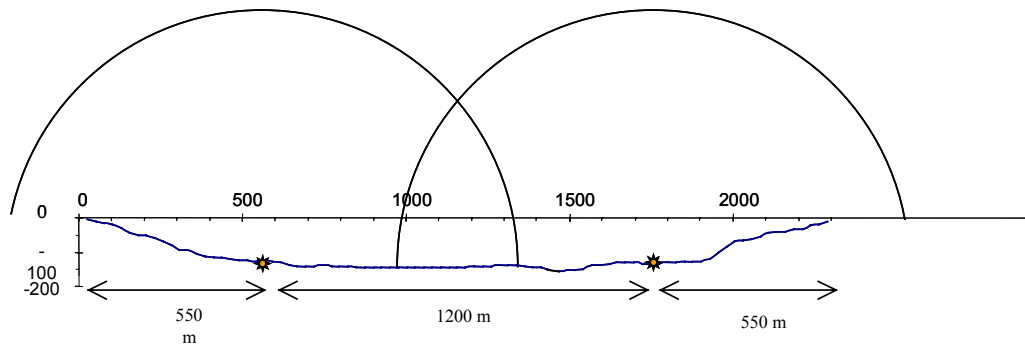
Reserve	Area (km <sup>2</sup> )	Number of datalogger stations:	
		Reserve boundary	Alternate
West Arm	280	4	3
East Arm	180	4	2
Scidmore-Charpentier	40	2	2
Geikie Inlet	40	2	2
Beardslee Islands	70	8	8
Main Bay	875	5	5
TOTAL:	1485	25	22

**Figure 1.** Datalogger stations (including alternate stations when appropriate) at the boundaries of the reserves and the mouth of Glacier Bay, Alaska.

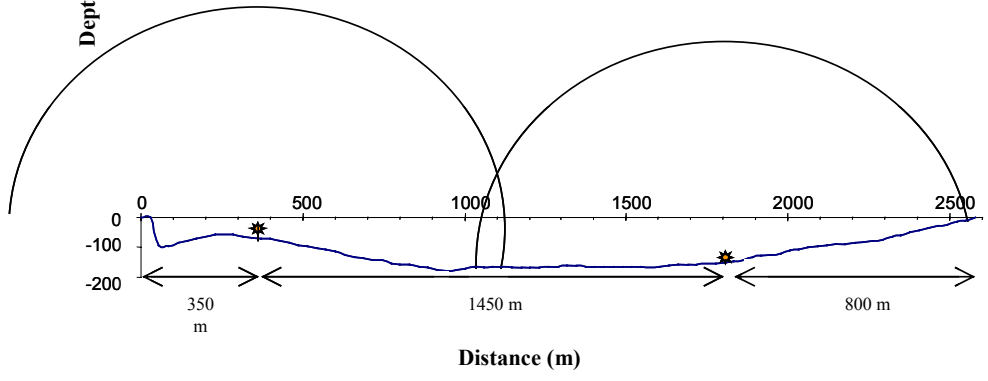
# Geikie Inlet Reserve



Reserve boundary placement profile:



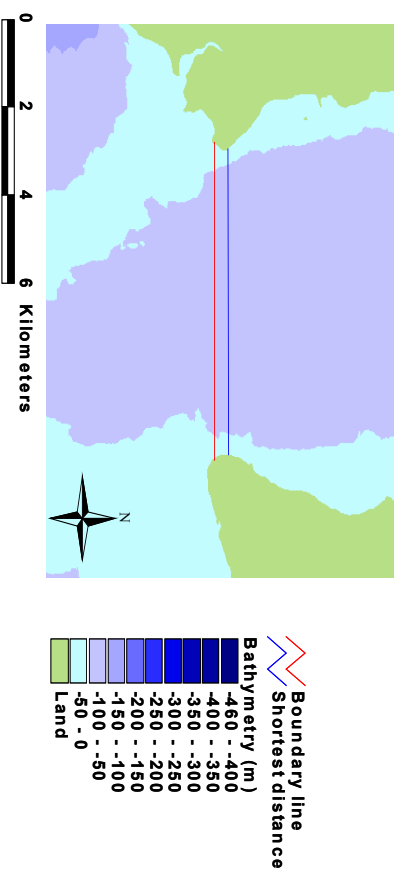
Alternate placement profile:



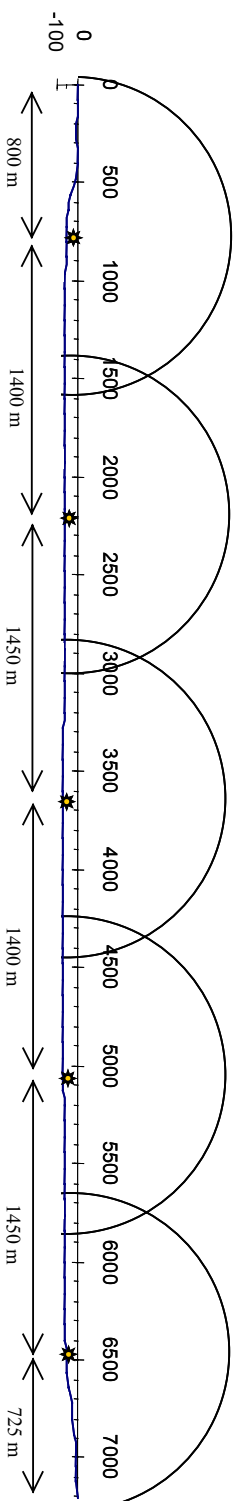
**Figure 2.** Map and depth profiles of the mouth of Geikie Inlet marine reserve. Two data logger placement options are shown: 1) reserve boundary or 2) a shorter distance across the reserve. Rings around the logger location show the effective radius of data loggers (=785 m; assuming fish swimming speed of 125 m/min and a sonic pulse rate interval of 2.5 minutes). Maximum distance between loggers at depth calculated using Equation 1.

# Mouth of Glacier Bay

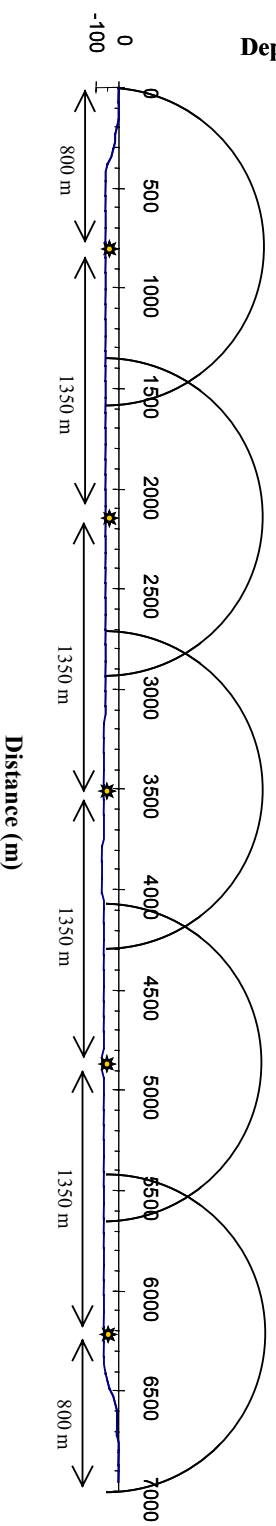
Depth profiles and data  
logger placement options



## Boundary line profile:



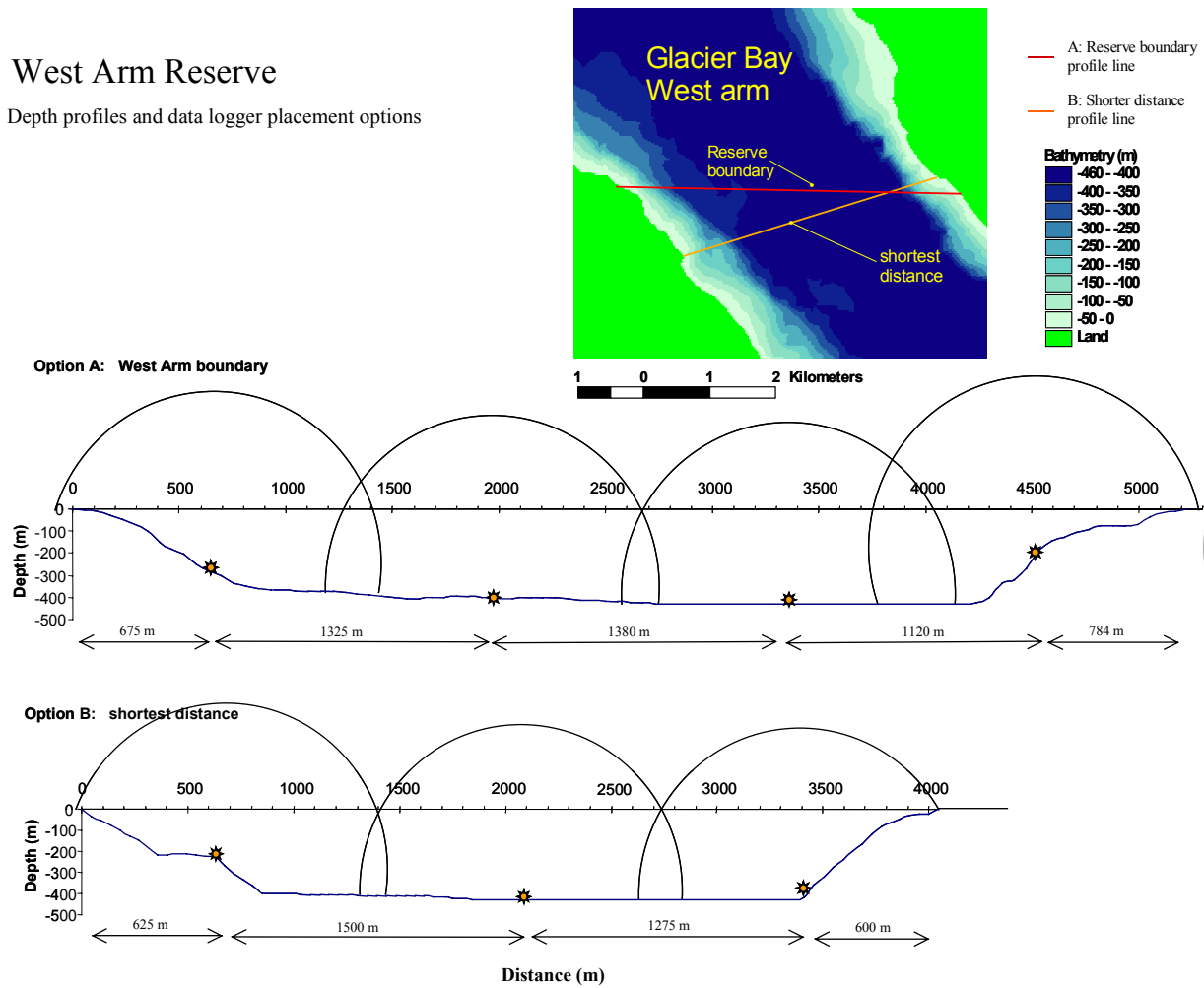
## Shortest distance profile:



**Figure 3.** Map and depth profiles of the mouth of the Glacier Bay. The first profile shows data logger locations along the boundary of the area closed to commercial fishing. The second depth profile shows data logger locations across the inlet at the shortest point. Rings around the logger location show the effective radius of data loggers (= 785 m; assuming a fish swimming speed of 125 m/min and a sonic tag pulse rate interval of 2.5 minutes). Maximum distance between loggers at depth calculated using Equation 1.

# West Arm Reserve

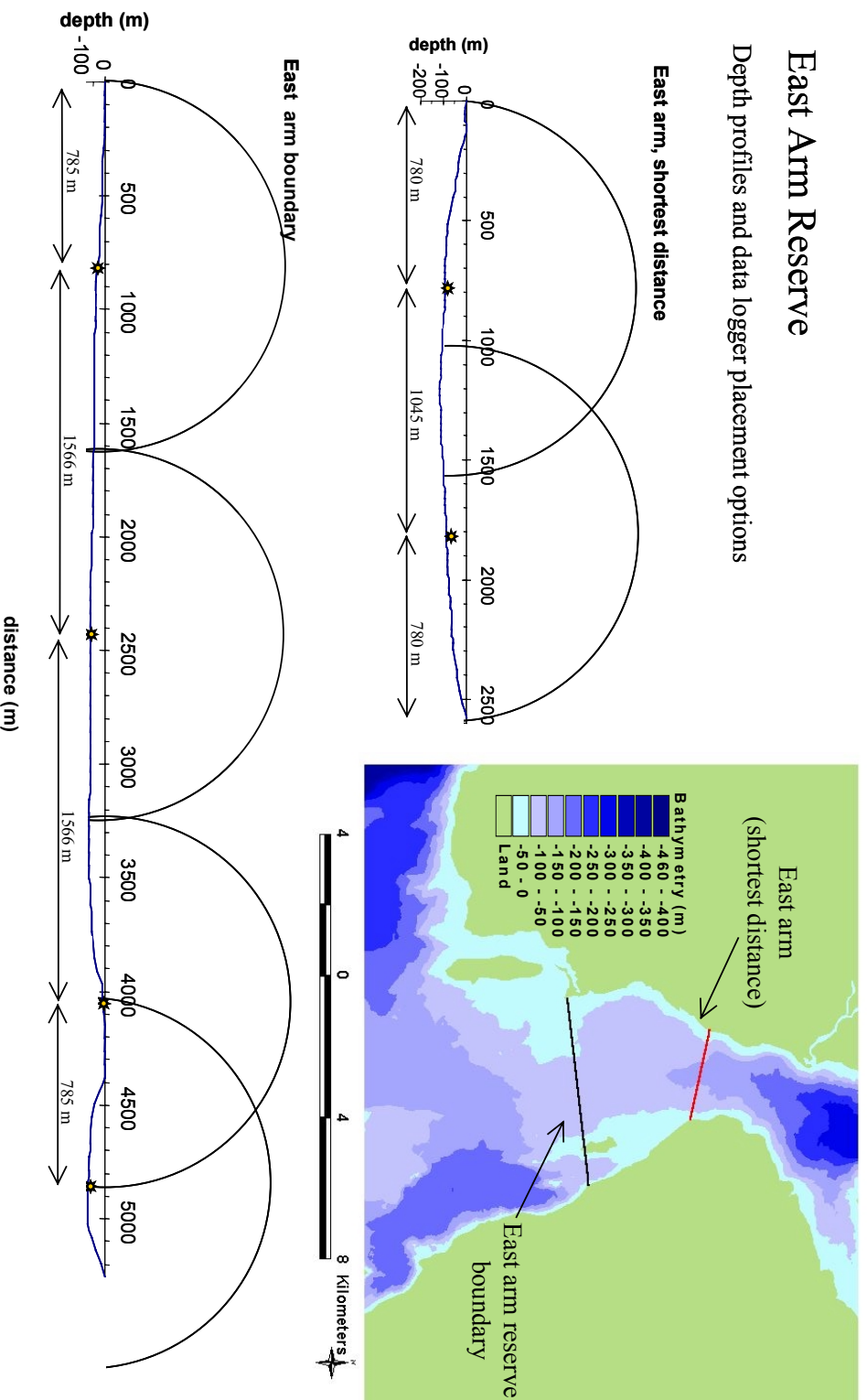
Depth profiles and data logger placement options



**Figure 4.** Map and depth profiles of the mouth of the West Arm marine reserve. Option A shows the depth profile and data logger locations along the bottom along the reserve boundary. Option B shows the depth profile and data logger locations across the inlet at the shortest point. Rings around the logger location show the effective radius of data loggers (= 785 m; assuming a fish swimming speed of 125m/min and a sonic tag pulse rate interval of 2.5 mins). Maximum distance between data loggers at depth calculated using Equation 1.

## East Arm Reserve

### Depth profiles and data logger placement options

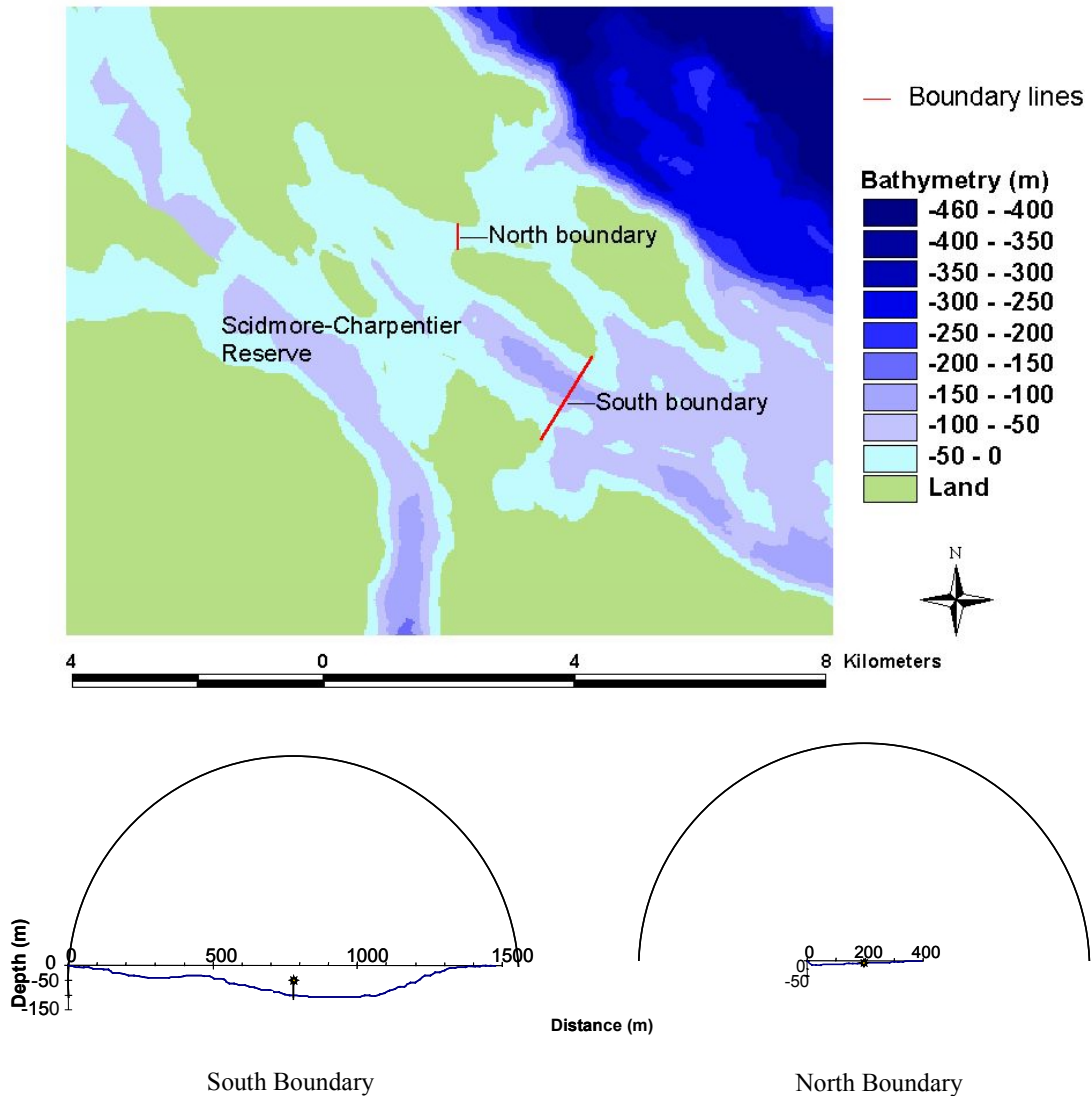


**Figure 5.** Map and depth profiles of the mouth of the East Arm marine reserve. Option A shows the depth profile and data logger locations across the inlet at the shortest point. Option B shows the depth profile and data logger locations along the bottom along the reserve boundary. Arcs around the loggers represent the effective radius of data loggers (= 785 m; assuming a fish swimming speed of 125m/min and a sonic tag pulse rate interval of 2.5 mins). Maximum distance between loggers at depth calculated using Equation 1.



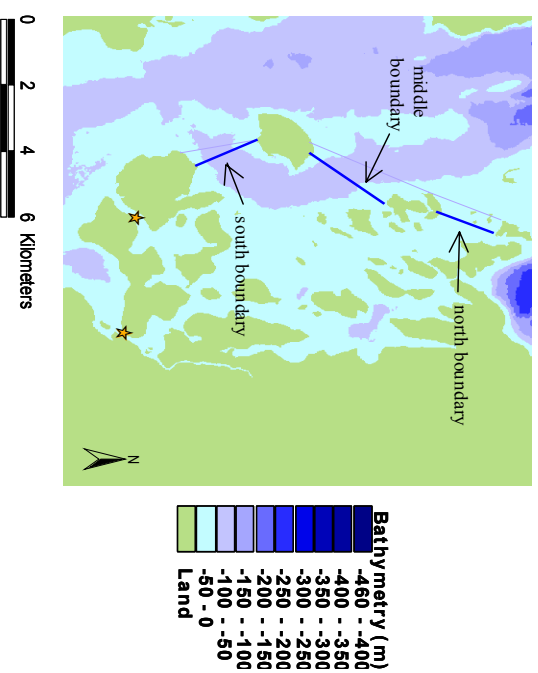
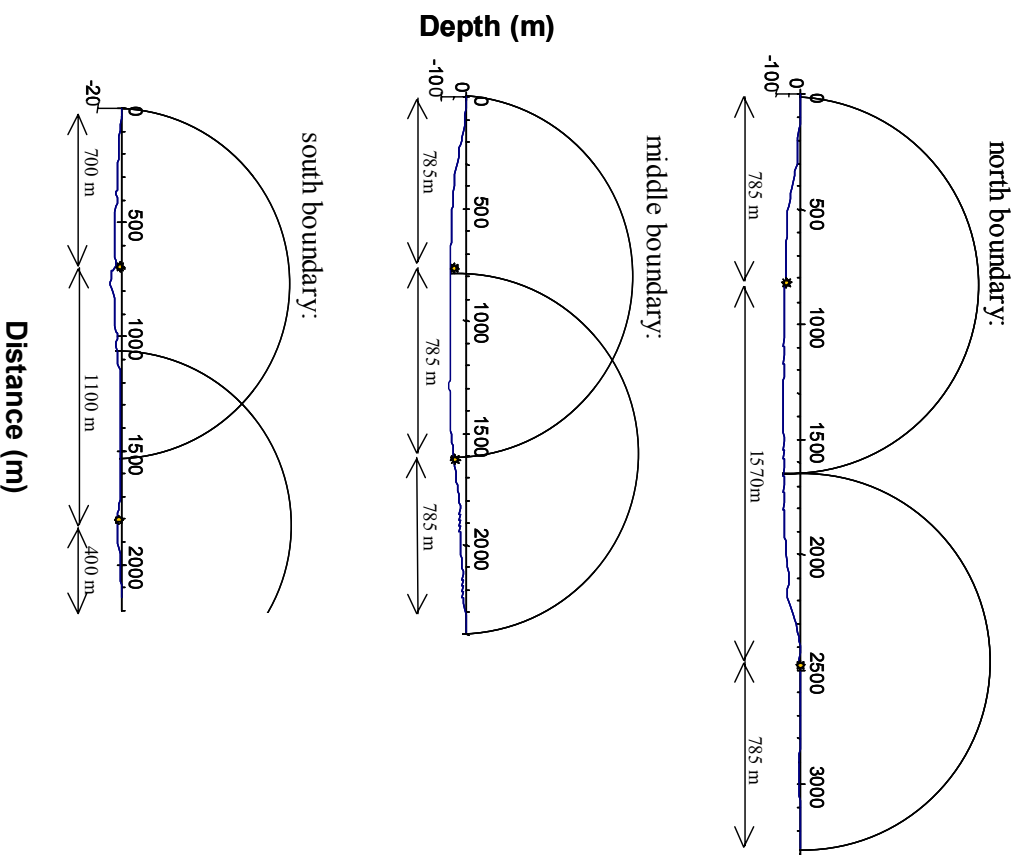
# Scidmore-Charpentier Reserve

## Depth profiles and data logger locations



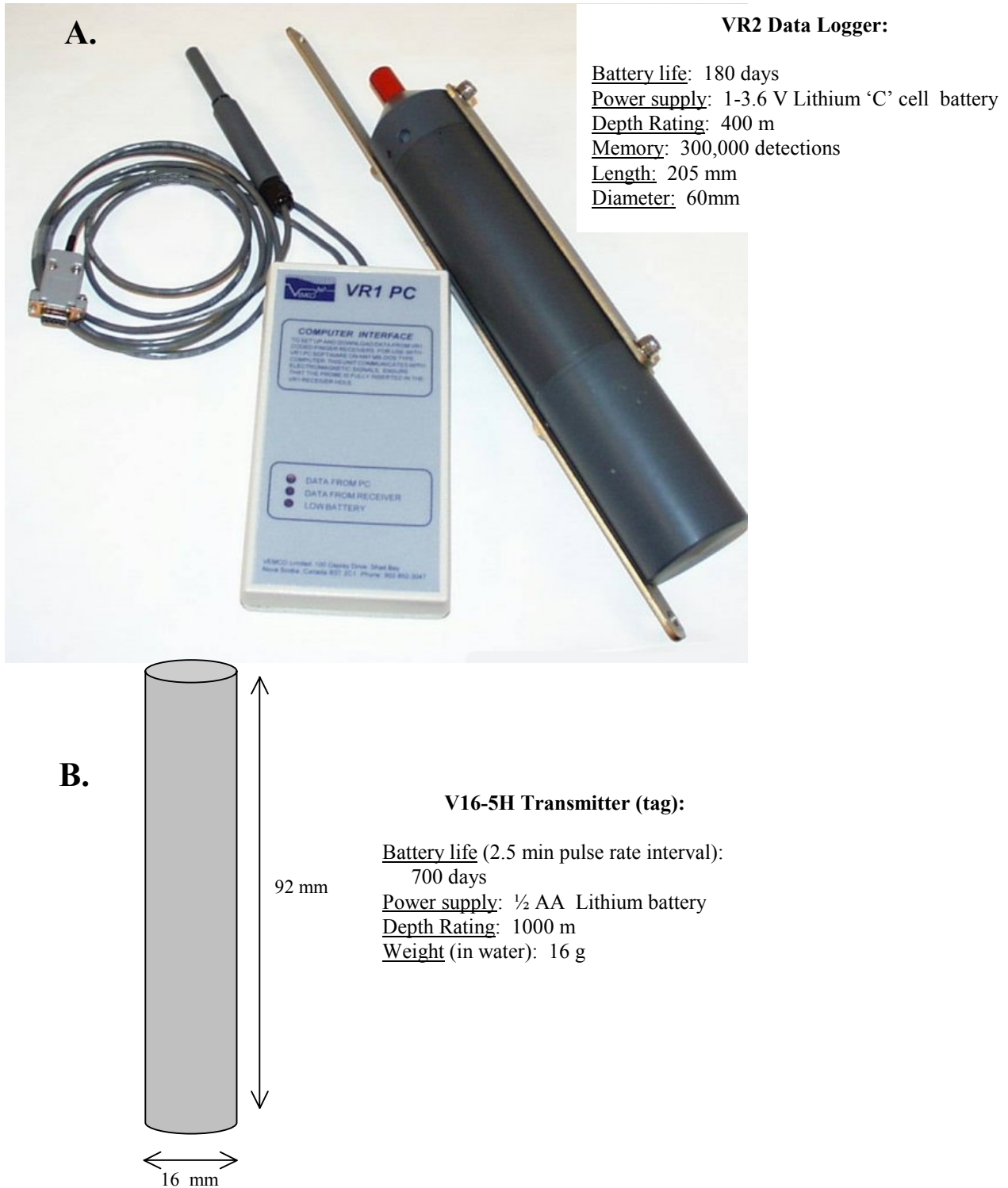
**Figure 6.** Map and depth profiles of the mouth of the Scidmore Bay-Charpentier Inlet reserve. Arcs around the logger location show the effective radius of data loggers ( $= 785$  m; assuming a fish swimming speed of 125 m/min and a sonic tag pulse rate interval of 2.5 minutes). Maximum distance between loggers at depth calculated using Equation 1.

# Beardslee Islands Marine Reserve



The true reserve boundary is represented by the lighter blue line. Due to strong currents across this reserve boundary, the loggers will be placed slightly inside the boundary, on the dark blue lines. A logger will also be placed in Bartlett Cove and another in the channel between Young and Lester Islands. These two loggers will be located in very shallow channels; no depth profiles are shown for these stations.

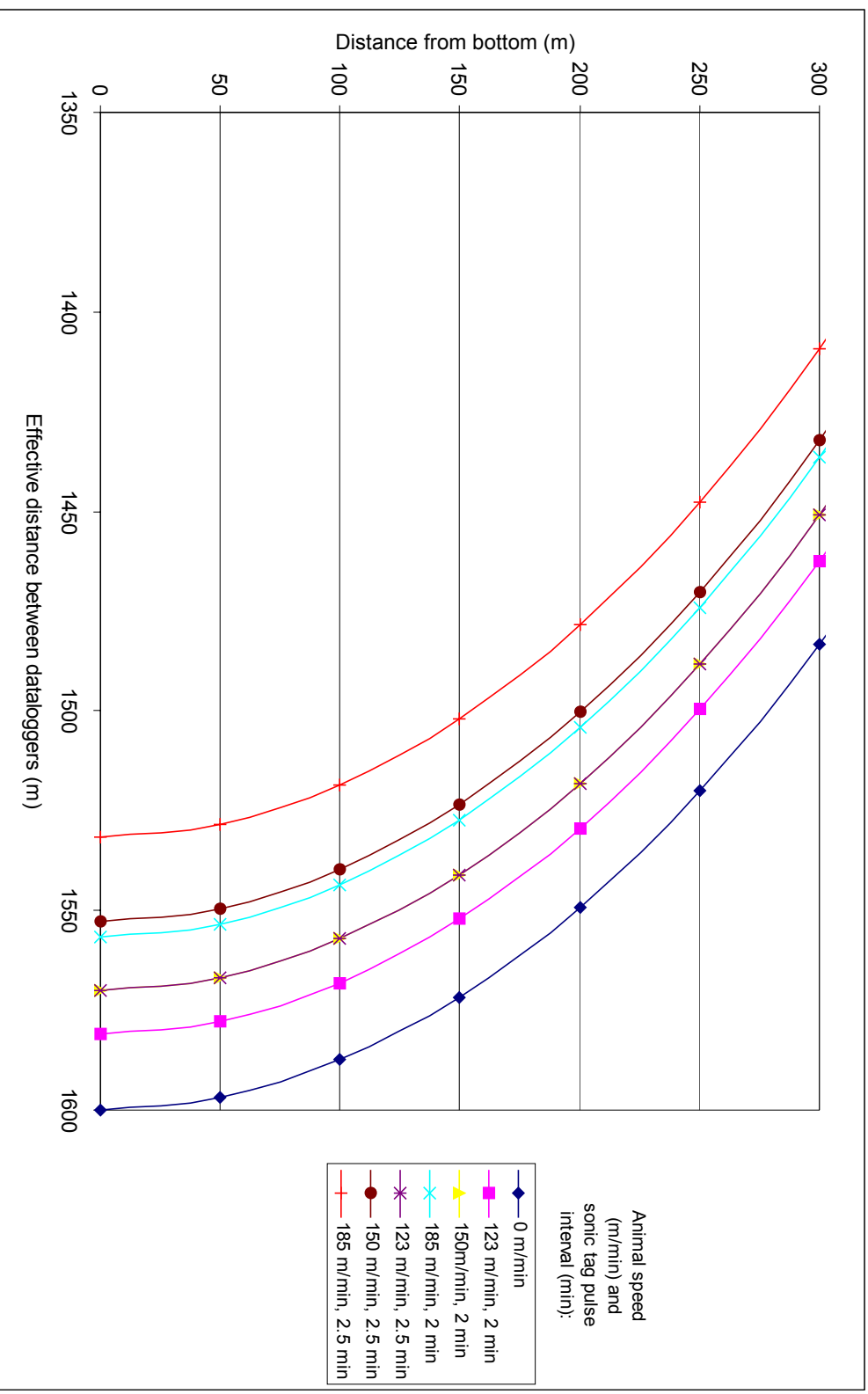
**Figure 7.** Map and depth profile for the Beardslee Islands reserve showing placement of data loggers. Arcs around the logger location represent the effective radius of data loggers (= 785 m; assuming a fish swimming speed of 125m/min and a sonic tag pulse rate interval of 2.5 mins). Maximum distance between loggers at depth calculated using Equation 1.



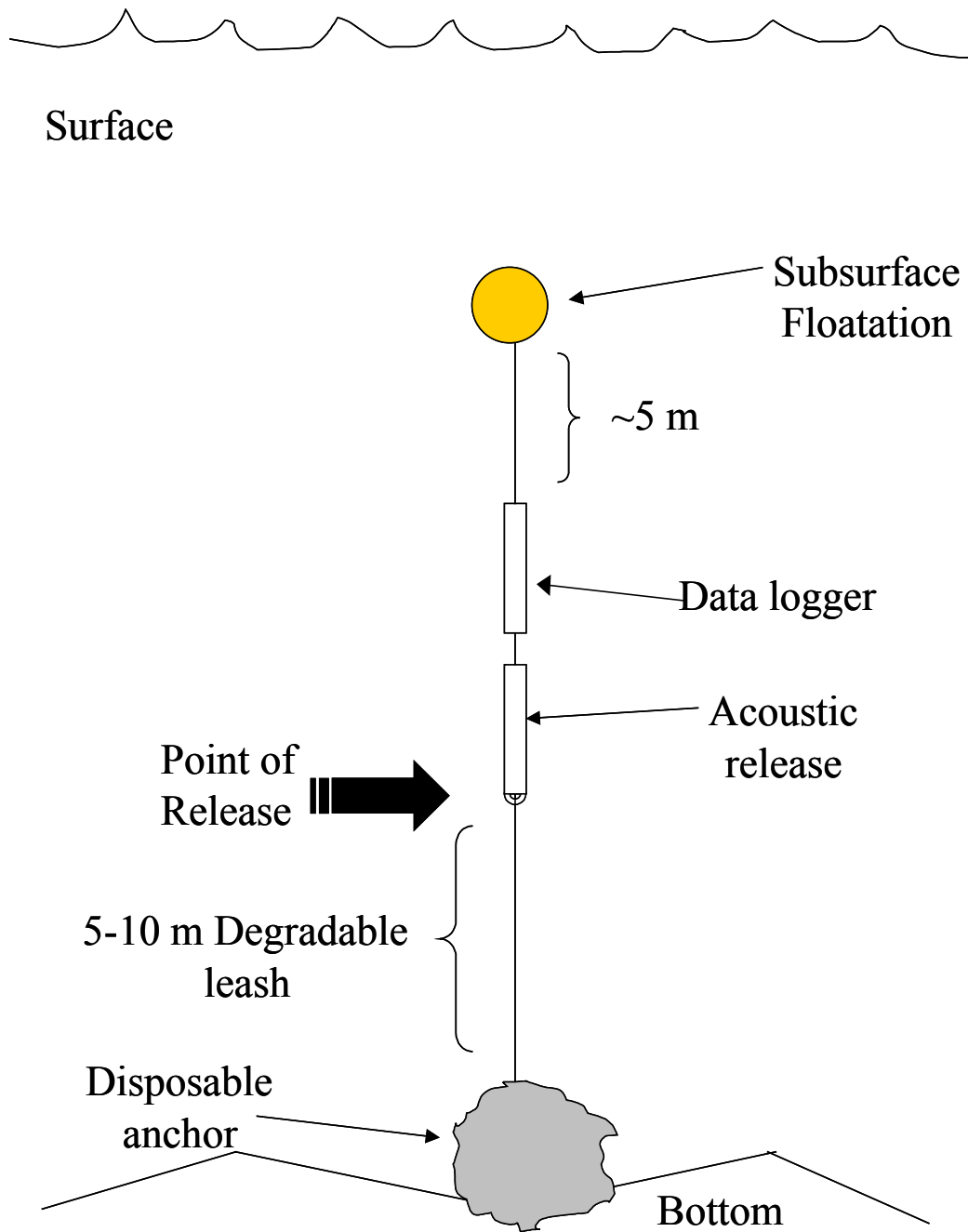
**Figure 8.**

**A.** Photo of VR2 Single Channel Monitor data logger and a magnetically coupled probe unit used to download data stored in the loggers.

**B.** Diagram and specifications of a V16-5H ultrasonic transmitter.



**Figure 9.** Distance required between data loggers at different water depths for various fish swimming speeds and sonic tag pulse intervals. Distance between data loggers calculated as twice the Effective Radius (ER) in Equation 1.



**Figure 10.** Individual mooring configuration with an acoustic release.



**Figure 11.** Several examples of acoustic release units. A signal sent from a surface command unit will activate the release mechanism allowing the acoustic release unit, data logger and subsurface floatation to rise to the surface for retrieval.

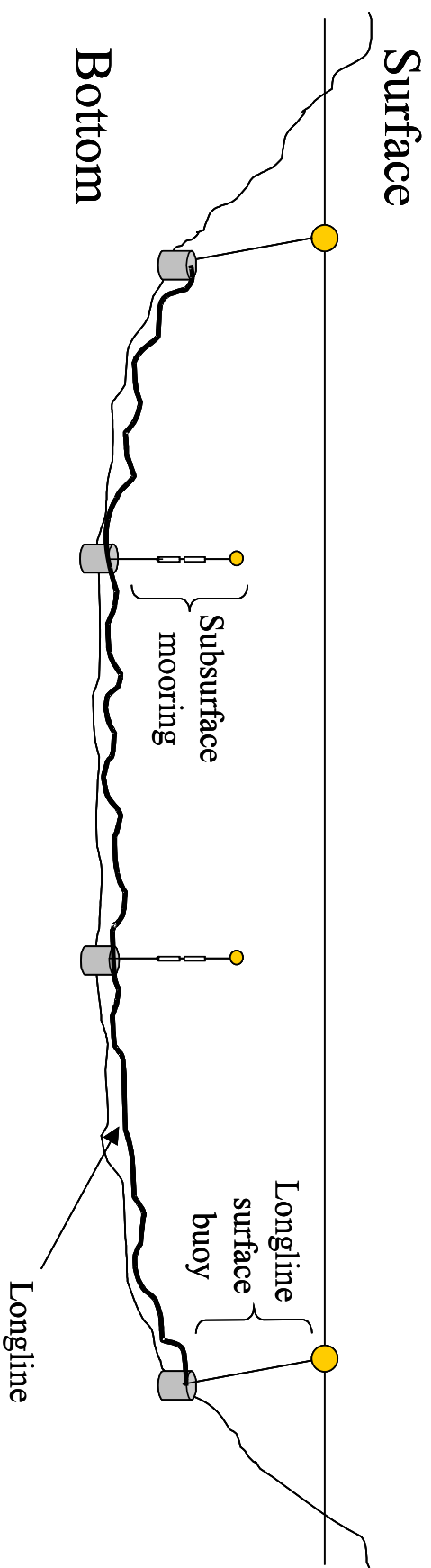
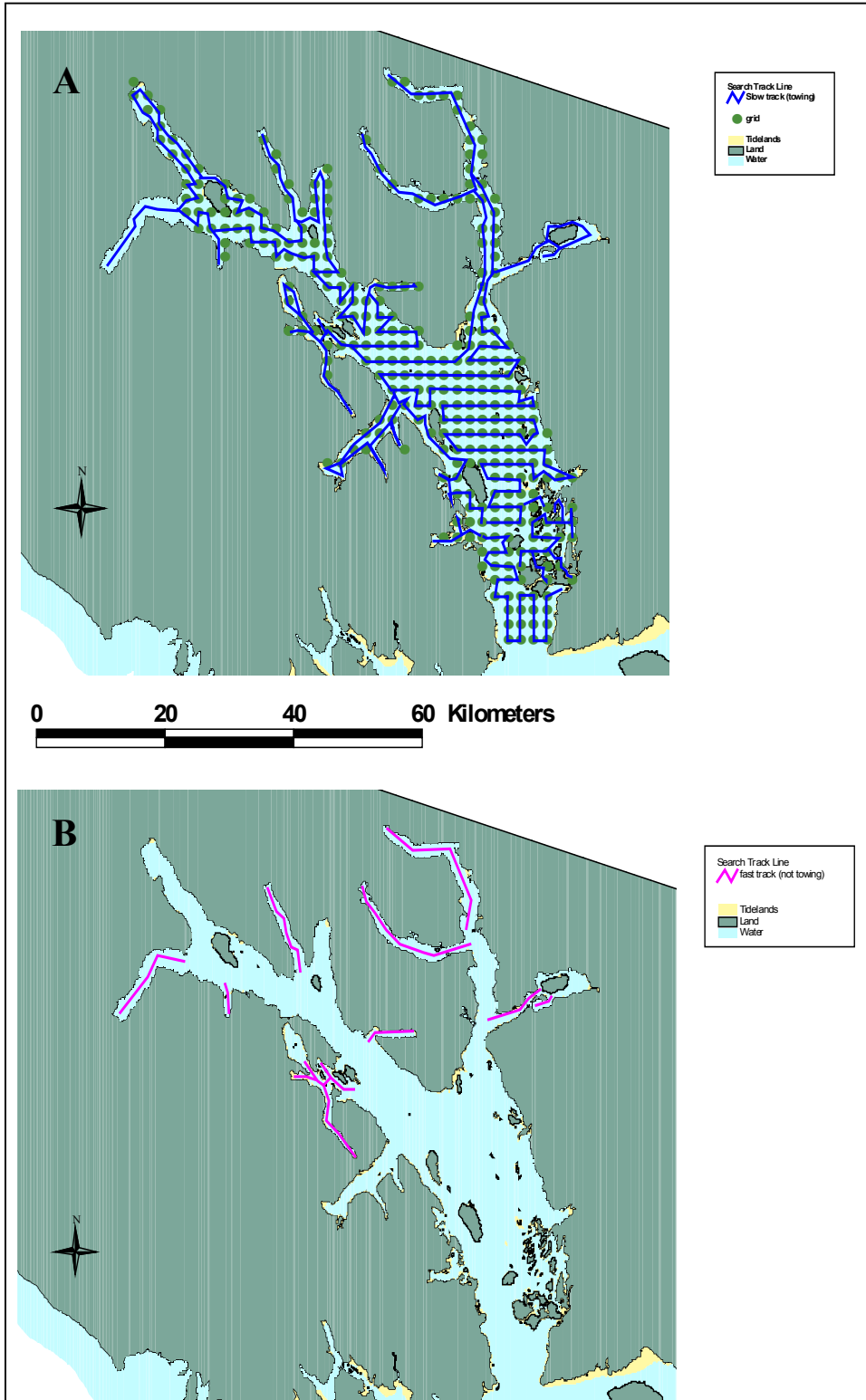
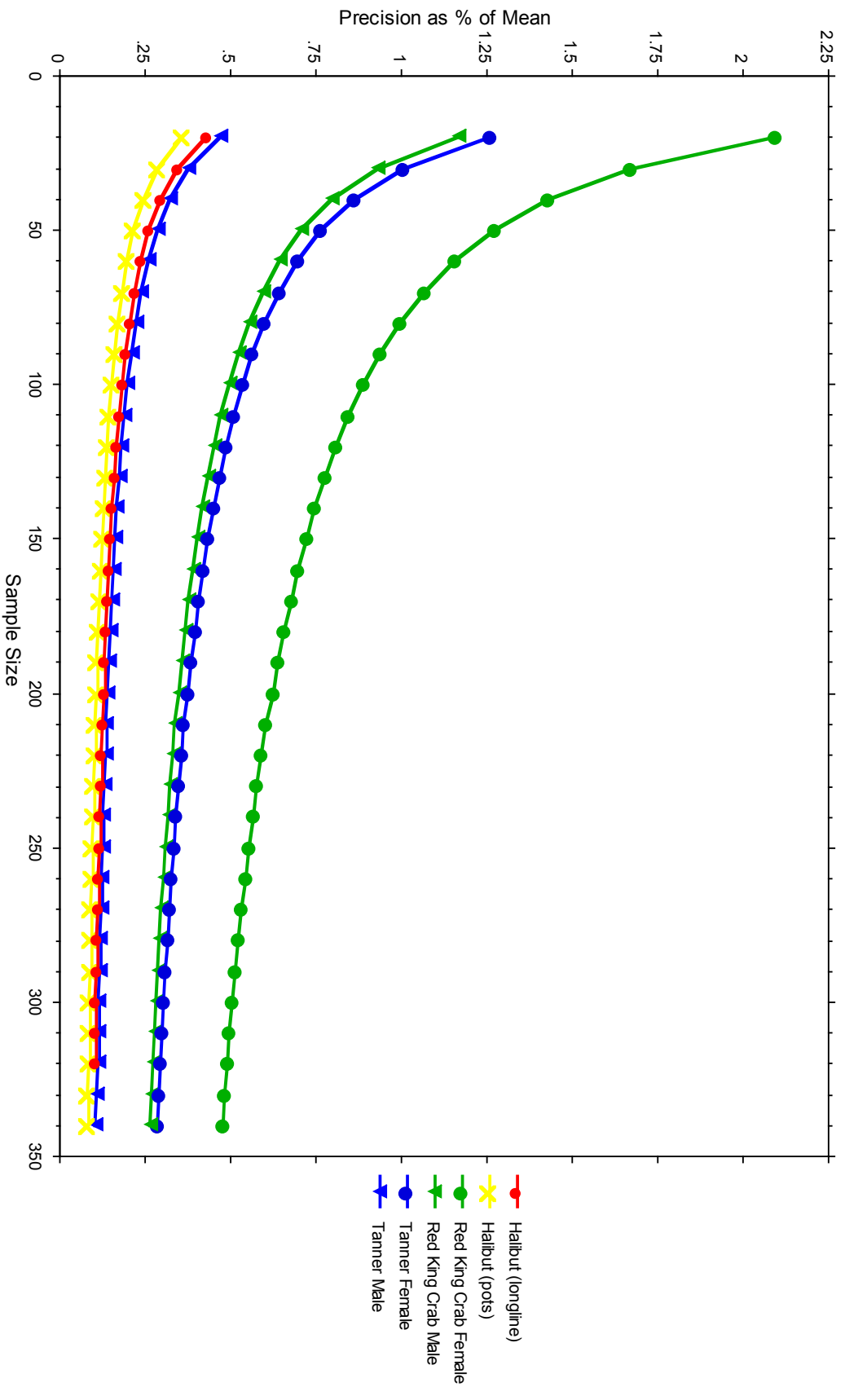


Figure 12. Longlined subsurface moorings.

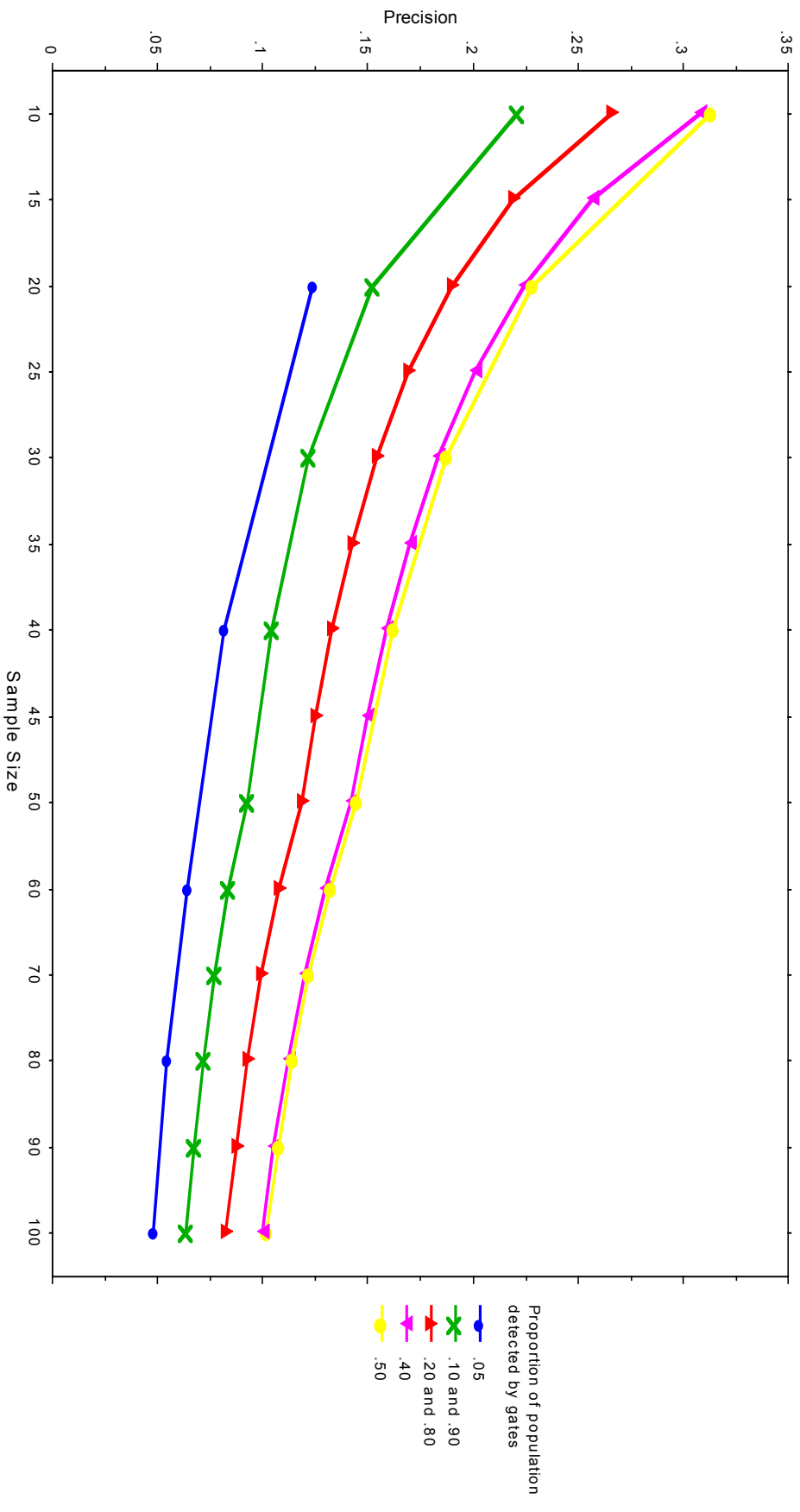


**Figure 13.** A. Hypothetical band-transect search track covering the entire bay. B. Areas that can be covered at fast, non-towing speeds.





**Figure 14.** Precision calculated as half of the 95% confidence interval and expressed precision as a percent of the mean [  $((95\% \text{ CI})/2)/\text{mean}$  ] at different sample sizes for species to be sampled in Glacier Bay. Tanner and king crab precision estimated from ADF&G Tanner crab stock assessment surveys (Clark et al. 1999b). Halibut longline precision estimated from USGS surveys in Glacier Bay in 1994-1995. Halibut pot precision estimated from IPHC (Williams et al. 1982).



**Figure 15.** Precision at different samples sizes for varying proportions of the population detected by the sonic gates. Based on a binomial distribution. Precision calculated as half of the 95% confidence interval.