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A Pilot Study to Conduct a Freshwater Fish Inventory of Small Tundra Ponds on the Bristol Bay Coastal Plain, Alaska, 2006

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A Pilot Study to Conduct a Freshwater Fish Inventory of Tundra Ponds on the Bristol Bay Coastal Plain, King Salmon, Alaska, 2006

Derek R. Hildreth

Abstract

State-owned lands on the Bristol Bay coastal plain in southwest Alaska have been opened for oil and gas exploration. This area encompasses numerous small lakes and ponds on the Nushagak and Alaska peninsulas. To date, there have been few data collected describing the fish species or subsistence use of the small tundra ponds in the region. During 2006, a pilot project was completed to sample fish communities in selected small tundra ponds near King Salmon, Alaska. Nineteen ponds were surveyed during early summer, and fish were found in all ponds with depths greater than 0.9 m. Alaska blackfish *Dallia pectoralis* were the most abundant and wide-spread species encountered and were found in all but one pond where fish were present. Ninespine stickleback *Pungitius pungitius* were captured in five ponds and threespine stickleback *Gasterosteus aculeatus* were captured in four ponds. Northern pike *Esox lucius*, longnose sucker *Catostomus catostomus*, and pond smelt *Hypomesus olidus* were also encountered, but each species was only found in single ponds. Our sampling methods may not have been sufficient to capture all species present. The most productive sampling gears were multifilament experimental gillnets and baited minnow traps. Our sampling during 2006 suggested that, for the tundra ponds we examined, those that do not experience winterkill should support fish populations even though all of the ponds we surveyed were small (< 0.5 km²), shallow (< 2.5 m), and had no temporally continuous outlets connecting them to streams. Future work should provide an inventory of the size and number of tundra ponds in areas of interest and representatively sample those ponds, including larger, deeper ponds that may be providing rearing habitat for anadromous fish. With this data, researchers could potentially develop a model for predicting fish presence or absence in these ponds. The model could be used to assess impacts from potential resource development and to guide resource development away from inhabited areas or to determine other mitigation options during the resource planning and development process.

Introduction

Alaska contains millions of freshwater ponds. Most formed as decaying glaciers retreated, leaving behind blocks of ice broken off from the main glacier (Honnold et al. 1996; Wentzel 1975). Eventually melting, these formed the many shallow ponds seen throughout the state. Such ponds are abundant in the coastal plains of the Nushagak and Alaska Peninsula (DeLorme 1999). These same areas hold significant oil and gas reserves (ADNR 2005). An Exploration License Solicitation has been issued for the upper Bristol Bay basin (Figure 1) that includes the lower Nushagak River and the entire Kvichak River. The remainder of the state-owned land on the Alaska Peninsula from Naknek to near Cold Bay was opened for lease bids in 2005, and several leases were issued in the Herendeen Bay area near Port Moller (ADNR 2005). As the Bristol Bay region experiences development, environmental degradation will likely occur and baseline data are needed with which to compare future environmental conditions.

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Mineral and oil and gas development can increase sediment quantity, and chemical or pollutant releases, (including oil spills) leading to degraded water quality (Hill 1974). Land disturbances such as construction of roads, docks, airstrips, and gravel pads may be required to access and develop the resource, possibly affecting aquatic resources (Nelson et al. 1991). A limited road network currently exists in the Bristol Bay area which may need to be expanded upon to meet development needs. If environmental impacts are not addressed road elements may cause great harm. Improperly designed stream crossings can be barriers that block access to spawning and rearing habitat (Furniss et al. 1991). Road construction near lakes, ponds, and tributary streams can lead to accelerated erosion and sedimentation rates through surface erosion or mass movements of destabilized soil. Excess sediment in streams and lakes can reduce egg-to-parr survival, primary production, invertebrate abundance, and overwinter survival by filling interstitial spaces, and can alter stream channel morphology (Meehan, 1991).

Road construction will require a source of rock and gravel. If this fill material is taken from spawning or rearing habitats, it could lead to decreases in productivity and declining fish populations. Roads can provide access to numerous fish populations that currently receive little fishing pressure. An increase in fishing pressure or harvest could jeopardize local populations of resident species such as rainbow trout *Oncorhynchus mykiss,* Arctic grayling, *Thymallus arcticus* and Dolly Varden *Salvelinus malma*.

Oil and gas development can lead to alterations of near-shore marine and freshwater fish habitat, which may cause changes in aquatic productivity. Mining activity may increase sediment production during initial excavation as vegetation is removed and during normal mining operations. Mines may produce acid waste by exposing acid-producing rock and soil to oxidation. Acid waste can create a low pH environment that can decrease the density and diversity of aquatic life (Hill 1974). Mines may also produce toxic metals as a bi-product of extraction, or as a bi-product of a low pH environment that allows these toxins to mobilize into the environment. Toxic metals can create barriers to fish movement, accumulate in sediments, enter the food chain, and can bioaccumulate to levels that affect aquatic productivity and fish survival (Fuller et al. 1978, Phillips 1985, Woodard et al. 1994).

Mining projects may require a source of freshwater for extraction and mine operations, and could capture headwater streams as a water source. Water removal from a system may result in alteration or destruction of aquatic habitat, and can alter stream flow and sediment transport dynamics. Changes in water quality could result in a direct fish kill, disrupt the aquatic food chain, and destroy freshwater and near-shore marine habitat.

Because road development and other construction will be necessary to support resource development in Bristol Bay (Furniss et al. 1991) some level of environmental degradation is likely. It is important to direct development away from richly inhabited areas toward areas where disturbance is less likely to have serious ecological consequences. Also, baseline data are needed to fully quantify impacts and determine options for mitigating any losses that may occur during development.

Subsistence Harvest

Non-salmon freshwater fish have long been used for food throughout the Bristol Bay region (Fall et al. 1996). Subsistence use of these ponds has included fishing for anadromous salmonids, as well as resident fishes including Arctic grayling, blackfish, burbot, Dolly Varden/Arctic char, lake trout, longnose sucker, northern pike, smelt, rainbow trout, and whitefish (Fall et al. 1996).

Tundra ponds also attract migratory and game birds which are gathered for subsistence use. Harvests of birds, including ptarmigan, waterfowl, and eggs, have made notable contributions (2.5% to 4%) to the resource harvests in a study of three communities along the inner coast of the Alaska Peninsula (Pilot Point, Ugashik, and Port Heiden). In addition to ptarmigan, households reported taking seven types of ducks, five types of geese, four types of eggs, swans, snipe, and cranes. (Fall and Morris 1987).

Information regarding fish distribution among the tundra ponds of the Bristol Bay Basin and Alaskan Peninsula is necessary to guide federal regulatory actions and planning efforts in order to avoid and minimize fish and game habitat losses. Regulatory decisions and land-use plans could inadvertently lead to habitat alteration and loss if they are made in the absence of information on the relationship between the characteristics of the ponds, and fish and wildlife distributions.

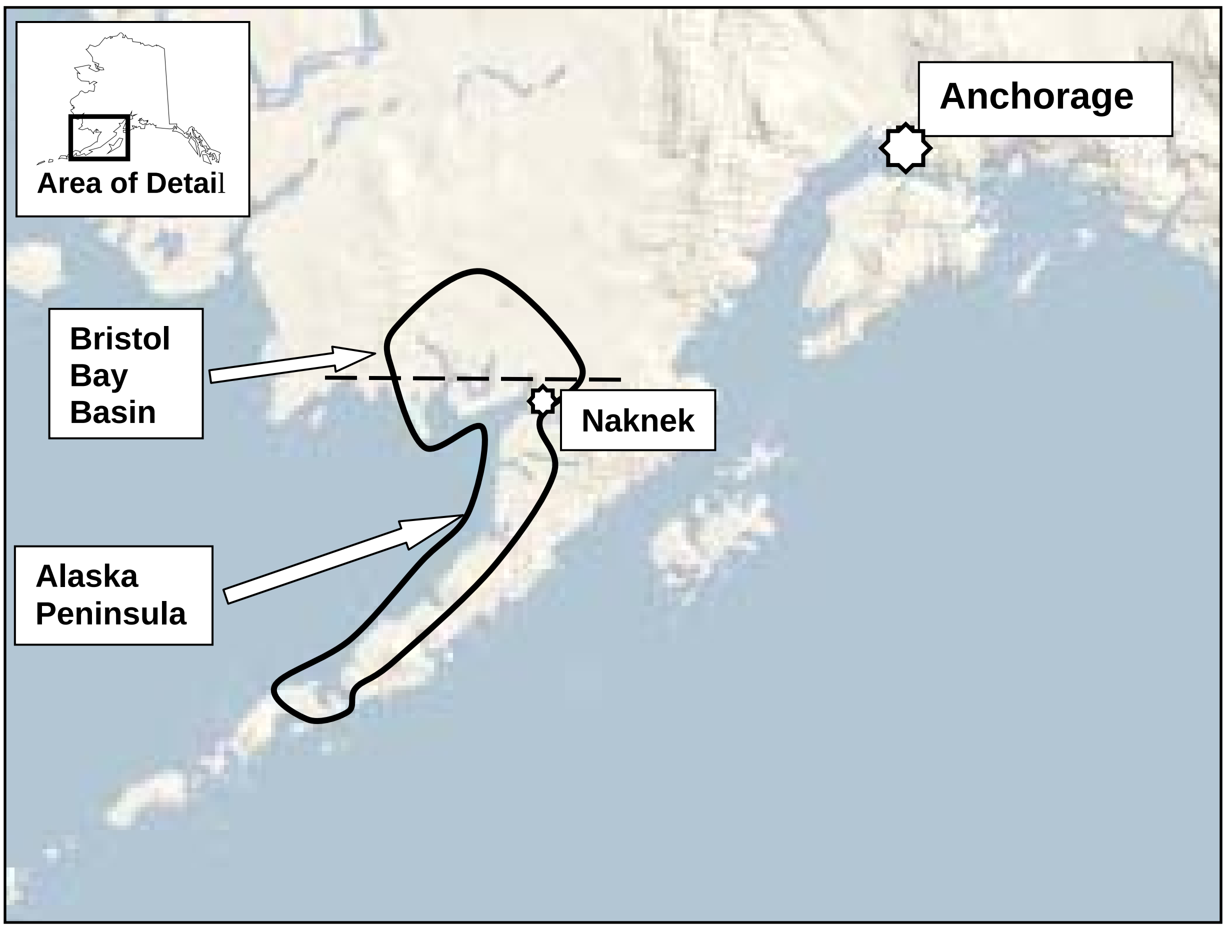

Figure 1. Bristol Bay Region and Alaska Peninsula, Oil and Gas Programs; proposed Bristol Bay Basin exploration (above dashed line) and proposed Alaska Peninsula (below dashed line) Area-wide oil and gas lease sale area (adapted from ADNR 2005).

Fish Species

At present, resource managers know little about the fish distributions in the numerous small ponds of Bristol Bay and the Alaska Peninsula. Most aquatic studies completed in the region have focused on salmonid species of major lakes and rivers (Russell 1980; MacDonald 1996;

Adams 1999; Jones and Hamon 2005). Adams et al. (1993), however, sampled four small lakes of the southern part of Bristol Bay, in the Izembek and Alaska Peninsula National Wildlife Refuges. The fish species that were documented in these four lakes included Dolly Varden, Arctic char *Salvelinus alpinus*, coastrange sculpin *Cottus aleuticus*, and threespine stickleback *Gasterosteus aculeatus*. Because these ponds are somewhat similar in size and depth to the tundra ponds in the northern part of the Alaska Peninsula, these northern ponds may contain fish populations, perhaps similar fish assemblages, as seen in the southern part of the peninsula. There are other fish species that might inhabit these northern ponds (Mecklenberg et al. 2002). Non-salmonid species that might be present include Alaska blackfish *Dallia pectoralis*, Alaskan brook lamprey *Lampetra alaskense*, Arctic lamprey *L. japonica*, Pacific lamprey *Entosphenus tridentatu*, burbot *Lota lota*, longnose sucker *Catostomus catostomus*, ninespine stickleback *Pungitius pungitius*, northern pike *Esox lucius*, and pond smelt *Hypomesus olidus*, (Mecklenberg et al. 2002). Resident salmonids that may inhabit these northern ponds include Arctic grayling, humpback whitefish *Coregonus pidschian*, least cisco *C. sardinella*, lake trout *Salvelinus namaycush*, and pygmy whitefish *Prospoium coulterii* (Mecklenberg et al. 2002).

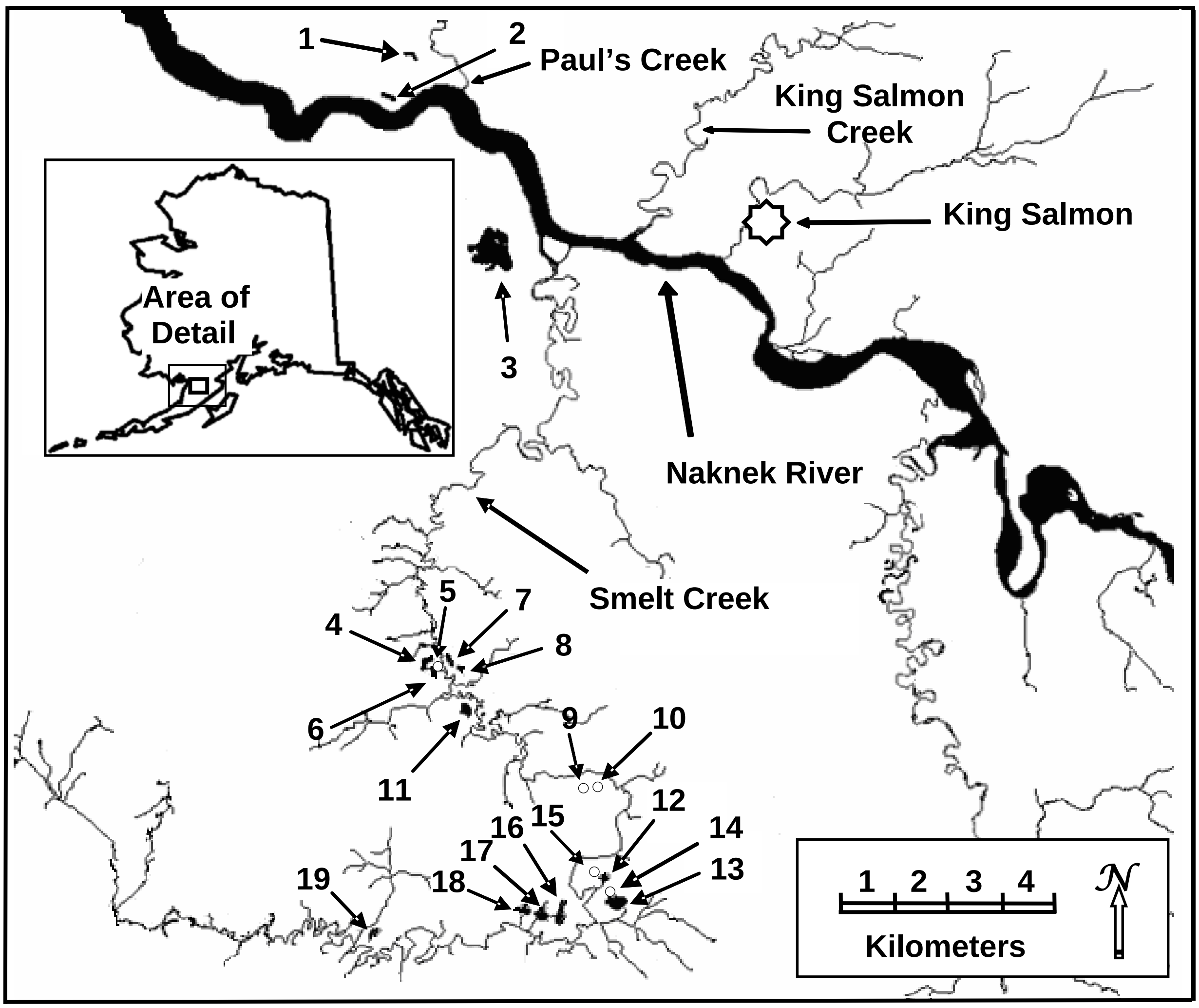

Figure 2. Tundra pond study sites, ponds 1 through 19, near King Salmon, Alaska, 2006. Small circles ( ) denote ponds too small to depict on map.

Pond and lake systems are classified as either open or closed. Open systems are connected to streams and inevitably, the ocean; closed systems are not (Adams et al. 1993). Based upon discussions with local residents, biologists, and fishers, we expected to find mostly closed systems harboring Alaska blackfish, coastrange sculpin, ninespine stickleback, threespine stickleback, and northern pike. Because some of the ponds appeared to be open, we also believed we might find some salmonid species.

Tundra ponds containing fish populations would be indicative of ecosystem communities having higher complexity than those containing invertebrate fauna alone, and deserving of greater protection. If fish presence can be correlated with specific pond characteristics, then these pond characteristics might be used to determine which areas are so inhabited and in need of greater protection from harmful environmental impacts. Information on pond characteristics, including presence and distribution of fish, as well as ecology, limnology, and spatial characteristics of the habitat, can be used to help steer harmful development away from these sensitive habitats, or to plan developments so that they result in minimal impacts to sensitive habitats. Because we lacked such baseline data, the King Salmon Fish and Wildlife Field Office (now the Anchorage Fish and Wildlife Field Office) conducted a pilot survey of accessible small ponds on the Bristol Bay coastal plain. The study focused on ponds near King Salmon, along the Naknek River and Smelt Creek (Figure 2). The intent of this study was to gather information on the presence or absence of fish in these ponds. We also wanted to collect ecological, limnological, and spatial data that could be used to classify the ponds. These data could be used to develop a baseline inventory in select water bodies, develop and prioritize a management strategy for fish and aquatic resources on the Bristol Bay coastal plain, and guide resource development away from sensitive, inhabited areas. Therefore, in addition to the baseline data this study would provide, it could also lead to the development of a predictive model to estimate the presence or absence of fish or fish species in un-sampled ponds, based on spatial features, physical habitat or other ecological characteristics of tundra systems. This could allow us to predict species occurrence and distributions and could be used as a rapid assessment tool for use in future development planning and mitigation. Finally, this pilot study would help determine whether a more in-depth assessment was warranted.

Objectives of the study were to:

1. determine fish species composition and distribution in tundra ponds,
2. identify plants, mammals, birds, and aquatic insects found at each pond, and
3. obtain descriptive data about the limnology and spatial characteristics of these waters.

Study Area

The tundra ponds surveyed during 2006 were located along the Naknek River and Smelt Creek (Figure 2), both in close proximity to King Salmon, Alaska. The climate in King Salmon is polar maritime with temperatures ranging from -43°C to 31°C (USFWS 1985). The area has frequent high winds and approximately 48 cm per year of precipitation. Fog and drizzle is common, even during summer, and cloud cover can be prolonged; King Salmon averages only 55 clear days per year. Landforms are generally low tundra, tussock-ridden wetlands, vegetated by wild berries *Vaccinium* spp., moss *Huperzia* spp., *Lycopodium* spp., or *Selaginella* spp., lichen *Cladonia* spp., grasses (family Poaceae), sedges *Carex* spp., and scrub (stunted deciduous and coniferous trees).

The Naknek River runs next to, and just south of, King Salmon, and supports a major fishery consisting of five species of salmon *Oncorhynchus* spp. as well as trophy-sized rainbow trout (USFWS 1985). Smelt Creek, a tributary of the Naknek River, is a low-gradient, meandering, turbid waterway with many oxbow ponds and marshes (J. Larsen, personal communication).

Tundra ponds in the area provide habitat for diving ducks, other diving birds, and various raptors, along with many mammals such as mink *Mustela vison*, beaver *Castor canadensis*, moose *Alces alces* and brown bears *Ursus arctos* (J. Larsen, personal communication).

Methods

Pond Selection

Nineteen ponds were surveyed in the Naknek River and Smelt Creek study area between 31 May and 29 June 2006. Ponds were arbitrarily assigned numbers (1–19) for identification purposes and will be referred to as such; ponds had no formal names, and local names, if any, were unknown to the investigator. Ponds were chosen due to their proximity to the road or river systems and most lacked obvious human impact (no nearby housing, no 4-wheeler paths). The first two ponds sampled (1 and 2) were selected for their proximity to the King Salmon Fish and Wildlife Field Office, and were used as “shake-down” trips which allowed us an opportunity to test our sampling procedures prior to traveling to the remaining ponds which were located along Smelt Creek. Both ponds 1 and 2 were in relatively close proximity to human civilization and were therefore considered more likely to have been affected by anthropomorphic influences. Pond 1 was accessed by truck and pond 2 was accessed by boating on the Naknek. The remaining ponds were accessed by boating on Smelt Creek to the point closest to the chosen pond, landing the boat, and hiking the remainder of the distance. Ponds that were over 0.5 km from the road or river, or ponds that were surrounded by heavy alder *Alnus* spp. thickets or extensive marsh were not sampled, due to the level of difficulty reaching them and the limited parameters of the study. Ponds were classified as either open or closed following an adaptation of Adams et al. (1993). Open ponds were defined as those having apparent waterway connections to the ocean, whether or not water was flowing between pond and stream during sampling. Closed ponds had no such connections.

Fish Sampling

The number of days each pond was sampled varied with the size of the pond, but averaged approximately one pond per day. Sampling methods were selected to maximize the number of fish species captured in the ponds. Locations within each pond were selected to sample each habitat type found in the pond. Habitats of specific interest included marshes, vegetated backwaters and shorelines, and deeper open waters. Ponds were fished with both passive and active methods. To help minimize selection bias we deployed several gear types. We used both monofilament and multifilament sinking experimental gillnets. Gillnets were 60 m long and 1.8 m wide. Initially, we used nets (both mono- and multifilament) comprised of 6, 10 m panels having bar sizes of 10, 12.5, 16, 19, 22, and 25 mm respectively. After sampling the first two ponds, we switched to nets having panels of bar sizes 10, 19, 33, 45, 55, and 60 mm in order to sample a wider range of fish sizes. We used these wider-ranging gillnets for the remainder of the study; one mono- and one multifilament net. Long-handled dip-nets (fine mesh), a beach seine (10 m long, 1.5 m wide, 0.6 cm delta mesh), baited 0.6 cm mesh minnow traps (Gee’s model G-40), and a backpack electrofisher (Smith-Root model 15A) were also used to sample fish.

Gillnets were set offshore, on the bottom, near the center of the pond, end-to-end if the pond was long enough to accommodate this. If not, nets were placed parallel to each other, approximately two meters apart. The water depth and set- and removal times for each net were recorded. The average depths of the nets were determined using a global positioning/depth-sounding (GPS/Sounding) combined unit (Garmin GPSMap model 278) operated from an inflatable, fishing pontoon boat (Arrow, Backpacker model). Gillnets were originally set overnight (approximately 12 hours) but excessive bird mortality required us to change the protocol and only fish the nets during daylight hours.

Salmon eggs, a conventionally used bait, were unavailable. Therefore, minnow traps were baited with granola; it was available, and it attracted fish. These traps were set in a string of four along the shoreline, and in a string of two or three in the waters near the center of each pond, in areas where the depth sounder indicated deepest water. Consideration for trap location also involved choosing areas in which traps would not be interfered by, nor interfere with, the gillnets. Electrofishing was conducted in the shallow portions along the pond edge when it was possible to do so. Due to the deep, silty nature of the substrate, this was very limited. For those ponds that were electrofished, conductivity was measured to properly adjust the electrical output using a conductivity meter (Yellow Springs Instruments Model 33). A beach seine was used near shore in areas free of snags and adjacent to grasses. Dip-netting was conducted either opportunistically, or dip-nets were dipped to the base of grasses and other aquatic plants and swept up along the plant stems to capture any unobserved fish or aquatic insects. All fish captured were identified and measured from the tip of the snout to the fork of the tail (mm). Voucher specimens were retained and preserved in 95% ethanol for species verification.

Ecology

Plants, invertebrates, birds, and mammals in and around the ponds were identified to the finest possible level using commercial field guides.

Limnology and Spatial Detail

Water parameters collected from each pond included: temperature, measured 0.3 m below the surface; clarity, measured with a Secchi disk; and pH, measured with a “BAKER-pHIX” test kit (J.T. Baker, Inc.). Way-points for the first pond were taken at the point of closest proximity to the nearest road. Way-points for all other ponds were taken at the point of closest proximity to the nearest river. During gear deployment, location and depth data were continuously collected along multiple transects using the GPS/Sounding unit/pontoon boat apparatus. Transects were made by first rowing the boat shore-to-shore along the longest axis of the pond, then diagonally between the two longer sides of the pond multiple times, forming a crosshatch pattern. The number of passes made in this manner ranged from 5 to 14 depending on the size of the pond; more transects were performed on larger ponds. After transects were completed, the data were downloaded to a computer. The transect recordings were super-imposed on MapSource (Garmin International Inc.) computer-generated maps. For each pond we drew lines that connected the terminal ends of the transects with each other. This created a perimeter outline of each pond. The corresponding perimeter data were added to the GPS/Sounding data, which were transferred to and processed by Surfer mapping software (Golden Software, Inc.). This generated a pond map with depth contours as well as estimated surface area and volume.

Results

Fish Sampling

All 19 ponds were sampled for fish (Table 1). Five of the ponds sampled were little more than marshlands and no fish were collected by sampling. There was a total of 592 fish captured and measured from the 14 ponds that contained fish (Tables 2 and 3). We found no anadromous fish in any of the ponds we sampled. Northern pike was the only species found in the largest pond (pond 3) sampled. We examined the stomachs of these northern pike and found invertebrates but no fish species, reinforcing evidence that there were no other fish species present. Alaska blackfish, found in 13 ponds, were the most numerous of fish. Threespine stickleback, ninespine stickleback, longnose sucker, and pond smelt were found in a few of the ponds having Alaska blackfish. Species diversity was low with eight ponds having only one species. The greatest diversity occurred in two ponds that each held four species (ponds 11 and 18). One smelt was captured in one pond. This individual was partially eaten; therefore its length was estimated (Table 3).

Ecology

Tundra vegetation consisted of small, herbaceous plants such as wild blueberry/cranberry *Vaccinium* spp., moss *Huperzia* spp., *Lycopodium* spp., or *Selaginella* spp., lichen *Cladonia* spp., sedges *Carex* spp., and grasses (family Poaceae), as well as individual or small patches of alder *Alnus* spp., willow *Salix* spp. or birch *Betula* spp. Conifers (family Pinaceae) were rare.

A number of invertebrate and insect species were captured with the fishing gear. Many larvae specimens were found: dragonflies and damselflies (Odonata), mayflies (Ephemeropta), mosquitoes (Diptera), and caddisflies (Tricoptera). We also found water beetles (Coleoptera), leeches (Hirudinea), snails (Gastropoda), and mussels/clams (Bivalva). An examination of some of the fish stomachs revealed that fish were using most of these as food resources.

Table 1: Sampling dates and time spent using each gear type at Bristol Bay tundra ponds, 2006.

Pond	Sampling	Beach Seine	Dip Net	Electrofishing	Minnow Trap		Gillnet-Mono	Gillnet-Mult
ID	Dates	Time(hrs.)	Time(hrs.)	Time(hrs.)	No.	Time(hrs.)	Time(hrs.)	Time(hrs.)
1	5/31 to 6/01	-	-	-	5	10.50	21.38	21.42
2	6/02 to 6/03	4.07	-	-	19	13.46	21.38	21.93
3	6/05 to 6/07	0.75	-	-	6	10.00	38.13	23.70
4	6/12 to 6/13	-	0.02	0.18	7	17.38	18.00	16.75
5	6/13 to 6/14	-	-	-	1	20.33	-	-
6	6/13 to 6/14	-	0.17	-	6	20.66	20.12	19.42
7	6/14 to 6/15	-	0.02	-	6	19.14	18.92	18.95
8	6/14 to 6/15	-	0.02	-	2	19.48	-	-
9	6/15 to 6/15	-	-	-	1	4.53	-	-
10	6/15 to 6/15	-	-	-	1	4.45	-	-
11	6/19 to 6/20	-	0.17	-	7	16.38	11.25	14.33
12	6/21 to 6/22	-	-	-	6	21.46	21.00	19.32
13	6/20 to 6/21	-	-	-	7	18.56	18.57	18.92
14	6/20 to 6/21	-	-	-	4	18.75	-	-
15	6/21 to 6/22	-	-	-	4	20.73	-	-
16	6/22 to 6/23	-	0.17	-	7	19.17	19.37	19.00
17	6/27 to 6/28	-	-	-	11	11.25	7.28	8.43
18	6/27 to 6/28	-	-	-	4	13.60	-	6.92
19	6/29 to 6/29	-	-	-	6	6.19	4.65	4.05

Dashes indicate no sampling; Mono = monofilament; Mult = multifilament.

Table 2. Maximum, minimum, and mean length (mm) and number sampled by species in Bristol Bay tundra ponds, 2006.

	Alaska Blackfish	Longnose Sucker	Northern Pike	Ninespine Stickleback	Pond Smelt	Threespine Stickleback
Max. Length	220	102	615	87	~100	90
Min. Length	42	90	200	48	–	53
Mean.Length	88	96	446	63	–	74
n	413	2	38	102	1	37

~ = approximate

Table 3. Total number of fish sampled by pond and species in Bristol Bay tundra ponds, 2006.

Pond ID	Alaska Blackfish	Longnose Sucker	Northern Pike	Ninespine Stickleback	Pond Smelt	Threespine Stickleback	Totals
1	38	-	-	-	-	-	38
2	96	-	-	-	-	-	96
3	-	-	38	-	-	-	38
4	41	-	-	-	-	-	41
5	-	-	-	-	-	-	-
6	33	-	-	36	-	1	70
7	20	-	-	6	-	-	26
8	11	-	-	-	-	1	12
9	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-
11	8	-	-	41	1	16	66
12	39	-	-	-	-	-	39
13	66	-	-	-	-	-	66
14	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-
16	28	-	-	3	-	-	31
17	19	-	-	-	-	-	19
18	4	2	-	16	-	19	41
19	9	-	-	-	-	-	9
Totals	412	2	38	102	1	37	592

Many bird species were observed in or near tundra ponds: loons *Gavia* spp., grebes *Podiceps* spp., mergansers *Mergus* spp., dabbling ducks *Anus* spp., sea ducks *Melanitta* spp., swans *Cygnus* spp., gulls *Larus* spp., yellow legs *Triaga* spp., and bald eagles *Haliaectus leucocephalus*. Mammals that were reported include: mink, beaver, moose, brown bear, and river otter *Lutra canadensis*.

Limnology and Spatial Detail

Most ponds were closed from the main water channel and were located in tundra regions several hundred meters from the nearest river. At the time of sampling, no water flowed in channels between ponds and the river. However, because the channels leading from the ponds to the river were present, three ponds were classified as “open”; ponds 7, 8, and 19. Because the water was relatively shallow, it was not possible to accurately measure the turbidity of the pond waters with the equipment on hand. The pH tests indicated the ponds were slightly acidic; pH ranged from

5.0 to 6.3 (Table 4). Water temperatures ranged from 11°C to 18.5°C. Temperatures of ponds 5, 10, and 11 were not recorded because the water was less than the protocol requirements of 0.3 m. GPS coordinates, perimeter, area, depth, and volume were determined for each pond when possible. We were able to produce bathymetric maps of most ponds using the Surfer software. Average depth was less than one meter (0.86 m); the range was 0.1 m to 2.1 m. There was not much texture to the depth gradients and some of the deepest recordings were of areas too small to leave a visible trace on the bathymetric maps (see Appendices A – M). Perimeter, area, and volume could not be accurately measured on five of the ponds (5, 9, 10, 14, and 15) because they did not occur on any of our maps and were too marshy in nature to run transects. Depth and volume of pond 2 were not established because the bathymetry data was lost due to computer error. No bathymetry map could be graphed due to the loss of this data.

Discussion

Fish Sampling

The majority of fish in the tundra pond survey were caught in minnow traps and multifilament gillnets (Table 5), Alaska blackfish, sticklebacks, and northern pike in particular. Pond smelt and longnose sucker were caught in very small numbers. It is possible that there were species in these ponds that went entirely undetected. Contrary to expectations, we found no coastrange sculpin. They are normally found in areas having fresh water and silty substrates, (such as these ponds), and were found in the Izembek/Alaska Peninsula study (Adams et al. 1993). Perhaps they do not dwell this far north. They tend to be bottom feeders, as are the longnose sucker, of which we caught only two. Perhaps they occur in low numbers or occur in ponds that were not sampled. It is also possible that the gear used did not sufficiently sample bottom-feeding fish.

Table 4. Geographic and physical characteristics of Bristol Bay tundra ponds, 2006 (dashes indicate missing data; n/a indicates undetermined).

Pond	Open or Closed	Perimeter (m)	Surface Area (m^2)	Volume (m^3)	Maximum Depth (m)	pH	Water Temp C°
1	Closed	772	18,120	12,012	1.3	5.5	13.5
2	Closed	1,100	48,893	-	-	6.0	13.5
3	Closed	4,000	481,738	353,699	1.5	5.5	13.6
4	Closed	952	32,429	19,209	0.9	5.5	11.0
5	Closed	20	32	68	0.2	5.0	14.0
6	Closed	446	8,038	6,040	1.7	6.0	11.0
7	Open	295	3,957	2,271	1.1	5.5	14.0
8	Open	300	3,660	2,608	1.0	6.0	14.5
9	Closed	n/a	n/a	n/a	0.1	5.5	11.0
10	Closed	n/a	n/a	n/a	0.1	5.5	11.0
11	Closed	963	43,975	25,172	1.0	6.3	15.0
12	Closed	1,400	86,662	52,789	1.3	6.0	16.0
13	Closed	453	8,116	5,017	1.3	5.5	15.0
14	Closed	n/a	n/a	n/a	0.3	5.5	17.5
15	Closed	n/a	n/a	n/a	0.3	5.5	12.0
16	Closed	725	26,277	15,372	1.4	5.5	17.0
17	Closed	598	12,695	7,683	1.4	6.0	14.0
18	Closed	777	32,138	22,383	1.4	6.0	14.5
19	Open	604	13,908	11,850	2.2	6.0	16.0

Although we used sinking gillnets and bottom-set minnow traps, these methods may have been ineffective in capturing some fish species in these ponds, such as sculpin. The use of fish eggs or some other animal protein as bait may attract different species than did the granola, and should be considered. A 10 m beach seine was used in anticipation of capturing species that were less vulnerable to gillnets and minnow traps. Perhaps a longer seine stretching across a larger section of pond, may collect species that are missed by gillnets, minnow traps and shorter seines. If the objective is merely to determine fish presence, using multifilament gillnets in conjunction with minnow traps may prove sufficient for the task.

Table 5. Number of fish in each species category by sampling method in Bristol Bay tundra ponds, 2006.

Capture Method	Alaska Blackfish	Longnose Sucker	Northern Pike	Ninespine Stickleback	Pond Smelt	Threespine Stickleback	Total
Beach seine	11	–	1	–	–	–	12
Dipnet	2	–	–	3	–	1	6
Electroshocker	4	–	–	–	–	–	4
Minnowtrap-near shore	162	–	–	88	–	2	252
Minnowtrap-offshore	45	–	–	11	–	23	79
Monofilament gillnet	4	–	17	–	–	–	21
Multifiliment gillnet	184	2	20	–	1	11	218
Total	412	2	38	102	1	37	592

We changed the gillnetting protocol during the final three ponds we sampled to reduce bird mortalities. Alternative methods that deter birds from nets without affecting fish behavior may need to be developed because the change to daytime gillnetting appeared to result in lower capture-rates for some fish species. The changes resulted in a decreased amount of time nets were set; from approximately 12 hours to about 8 hours. This may account for some of the observed changes. The changes may also have been due to preferences of particular species; different fish species appear to be at different places during different times of the day. Though not tested in a scientifically rigorous fashion, we did note some general fish behaviors that may provide some insight on the structure of the fish communities in these ponds (Table 6). Threespine stickleback and longnose sucker were caught offshore in multifilament nets, during daylight hours. Alaska blackfish and ninespine stickleback were only collected from these nets when they were left to soak overnight. Alaska blackfish and ninespine stickleback were, however, collected from these ponds, as were threespine stickleback, using minnow traps (Table 5). Most ninespine sticklebacks were caught in traps when left to soak overnight and for the most part, near shore. Alaska blackfish and threespine stickleback were caught in traps both day and night. Alaska blackfish tended to be caught near-shore. Threespine stickleback were caught mostly off-shore. Northern pike were only caught in gill nets. We are not certain if there was a diel patten to the northern pike activity because the nets were left out for approximately 24 hours due the presence of several brown bears during the sampling of that pond.

Minnow traps were very effective at capturing smaller fish. However, we expected to capture juvenile northern pike in the minnow traps, and did not, even though we spent two days sampling the pond where we had found adults. It is possible that we did not sample enough of the pond to get a representative sample. It is also possible that the juvenile northern pike merely had no interest in the bait we were using in the traps.

Table 6. Majority of fish species caught in multifilament gillnets and minnow traps, by time and location, for Bristol Bay tundra ponds, 2006.

Location	Soak Time: Day	Soak Time: Overnight
Near shore	• Alaska Blackfish	• Alaska Blackfish • Ninespine Stickleback
Offshore	• Long-nose Sucker • Threespine Stickleback	• Alaska Blackfish • Threespine Stickleback

Fish Species

Under the Alaska statutes, anadromous fish streams have a high level of protection from development activities (Johnson and Weiss 2006). Because most of our sampling was from small ponds blocked from ocean access, we did not expect to find many anadromous fish, but we did expect to find some, in particular, in so-called "open ponds". However, of the three ponds classified as open, pond 7 held Alaska blackfish and ninespine stickleback, and ponds 8 and 19 held only Alaska blackfish. There were no anadromous fish in any sampled ponds, including those classified as open. Maybe our timing for sampling missed the juvenile salmonid out-migration. Though unlikely, the gear may have been selective against salmonids. Because anadromous fish were not found to reside in these ponds, they would not be subject to Anadromous Fish Act regulations. However, the juxtaposition and importance of these small water bodies in the overall ecosystem and their resident fish resources would need to be acknowledged and appropriately considered in planning and potential development of roads or other facilities. The four "marshland" ponds notwithstanding, Alaska blackfish were found in all but the largest pond. Whereas many of the ponds that held Alaska blackfish also contained other small fish such as sticklebacks and suckers, the largest pond held only northern pike and no other fish species. Additional work is needed to determine whether the presence of northern pike precludes the occurrence of other species in these small ponds or if the absence is due to some other factor. Where both ninespine and threespine sticklebacks were found, fewer Alaska blackfish were captured (Table 1). A more rigorous and extensive sampling protocol could determine whether this was an anomaly, a product of the gear used, a result of community competition, or some other interaction or process.

Ecology

Ponds were initially selected by examining topographic maps of the area. The topographic maps were found to be somewhat inaccurate. Some of the ponds had dried up, while others were not as accessible as they appeared on the maps due to heavy brush, or were surrounded by marshy terrain, which made access difficult. This limited the number of ponds we were able to access and sample. Also, additional ponds were selected as they were discovered en route because they were more extensive than they appeared on the maps. Three ponds may have been affected by human activities, either by development, hunting and fishing, or contamination. The first two ponds sampled were near the Alaska Peninsula Highway near Paul's Creek and were closer to human activity than any other ponds we surveyed. The third pond, at the confluence of Smelt Creek and the Naknek River, had an off-road vehicle trail running from a homestead on the Naknek River to the pond. Because this pond was 500 m from the nearest river, and it was the only pond harboring northern pike, one must consider whether this species is native to this closed pond and if not, what relationship an introduction of this kind may have in connection with the absence of other fish species.

During the field season, fish eating bird species such as loons, grebes, and mergansers were seen feeding in the ponds. Several grebes were caught and drowned in gillnets. Afterward, gillnets were fished only during the day which eliminated bird mortalities. Though unfortunate, these mortalities reinforced the observation that these birds were feeding on the fish in the ponds. Necropsies were not performed and we do not know on which species of fish the birds had been feeding, but it was likely that the fish resources of small tundra ponds were being used by several bird species. Additional exploration might yield more specific information on the ecological niche filled by ponds and fish.

Limnology and Spatial Detail

The ponds were slightly acidic; pH tests indicated a range of 5.0 to 6.3 (Table 4). This is somewhat more acidic than in the closed lakes found in the Izembek/Alaska Peninsula study where the range was a more neutral 6.5 to 7.3 (Adams et al.1993). Although it was not subjected to experimental testing, a pattern of pH levels and associated fish species was detected. Alaska blackfish and ninespine stickleback appear to be most tolerant of acidic waters, being found virtually everywhere. Pike seemed plentiful in the one pond in which they were found. This pond had a pH of 5.5, so this species also appeared to be tolerant of more acidic waters. The threespine sticklebacks, longnose suckers, and the one pond smelt we collected appeared to be less tolerant of higher acidity levels–they were not found in any ponds having a pH less than 6.0. This potential pH effect on species distribution provides clues to the ecological effects of mining activities (Hill 1974) because acidic tailings created during mining activities can migrate to nearby ponds. Acidity levels in these waters may increase, causing nearby soils to leech toxic elements by breaking down the parent materials and releasing these elements into the waters (Hill 1974; Fuller et al. 1978). This leeching/acidification could have an effect on fish communities as well as on animals that use these fish as a resource (West et al. 1987; Woodard et al. 1994).

Shallow ponds subject to frequent winds often adopt a muddy appearance due to the agitation of the substrate by the waves created by these winds. Though most of the ponds had a substrate of deep, soft silt, they also had a layer of plant or decaying plant material. This plant material may have acted as a buffer and could account for the tannic rather than muddy appearance of the waters. It was not possible to measure the turbidity of most pond waters with equipment on hand. The Secchi disk we used to measure turbidity was usually visible from the surface when lowered to the bottom of the deepest sections of each pond. Therefore, we never reached a depth where the disk disappeared from view (Table 4). The exceptions were pond 1 and pond 19. In pond 1, light did not penetrate below 0.8 m. Pond 1 was located alongside residential property, and may have been affected by anthropogenic forces that increased turbidity (neighborhood dogs swimming in or residents canoeing in the ponds, etc.). Pond 19 was the deepest at 2.1 m and was deep enough for the Secchi disk to disappear from view at 1.4 m. In contrast, pond 6, though not as deep as pond 19, was clearer with visibility to the bottom depth of 1.7 m.

Conclusion

With the exception of the few marshlands we sampled, the tundra ponds contained fish. Fish were found in all ponds with a maximum depth greater than or equal to 0.9 m. Ponds with a maximum depth of less than 0.3 m did not contain fish. Additional sampling will be needed to better estimate the maximum depth where fish are safe from winter kill since we did not sample any ponds with a maximum depth between 0.3 and 0.9 m.

By far, Alaska blackfish inhabited the greatest number of ponds and collectively were the most abundant species. This suggests that Alaska blackfish will be found in most northern peninsula ponds that are not subject to winter kill. The distribution and abundance reveal why Alaska blackfish were probably used by local residents as a subsistence food. Although the use of Alaska blackfish as a subsistence food is probably not as widespread as it once was, a more thorough review of current subsistence practices is warranted if resource development is proposed near villages.

With the exception of pond 3, this study sampled smaller ponds on the Alaska Peninsula than have previously been sampled, such as those in the Izembek/Alaska Peninsula study (Adams et al. 1993). We focused on the small ponds in the belief that if we found significant populations of fish in them, then they would also be found in the larger ponds. Though this may often be the case, the fact remains that we found only northern pike in the one larger pond. For now, this remains a noteworthy difference between the smaller ponds and the larger ones. Future studies will need to include the larger ponds in the sample to develop a more complete understanding of the tundra ponds, the fish in those ponds, and the ecological niches they fill. The evidence that fish resources of tundra ponds are utilized by several bird species reiterates the need for this understanding.

As a pilot project, the present study only represented a small subset of the tundra ponds in the Bristol Bay coastal plain and should not be used to generalize the occurrence of fish in other ponds. A more systematic sample is needed that encompasses the broad range of pond location, depth, and size found on the Bristol Bay coastal plain before a generalized model of fish distribution can be made. Future work should provide an inventory of the size and number of tundra ponds in areas of interest; and representatively sample those tundra ponds, including larger and deeper ponds that might contain different fish assemblages including anadromous and salmonid species. Fish and limnology sampling should be more rigorous. After a more intensive project has been conducted, we should be able to describe what is needed to construct a model to predict fish presence or absence in these ponds. Although additional sampling of tundra ponds will be expensive due to their remote access, this may provide us with less expensive rapid assessment measures to use prior to development. Resulting information should allow for timely diversion of activities and facilities away from the most sensitive fish habitats, toward less critical areas, and minimization of potential habitat alteration and loss where avoidance of such impacts is not possible.

Acknowledgements

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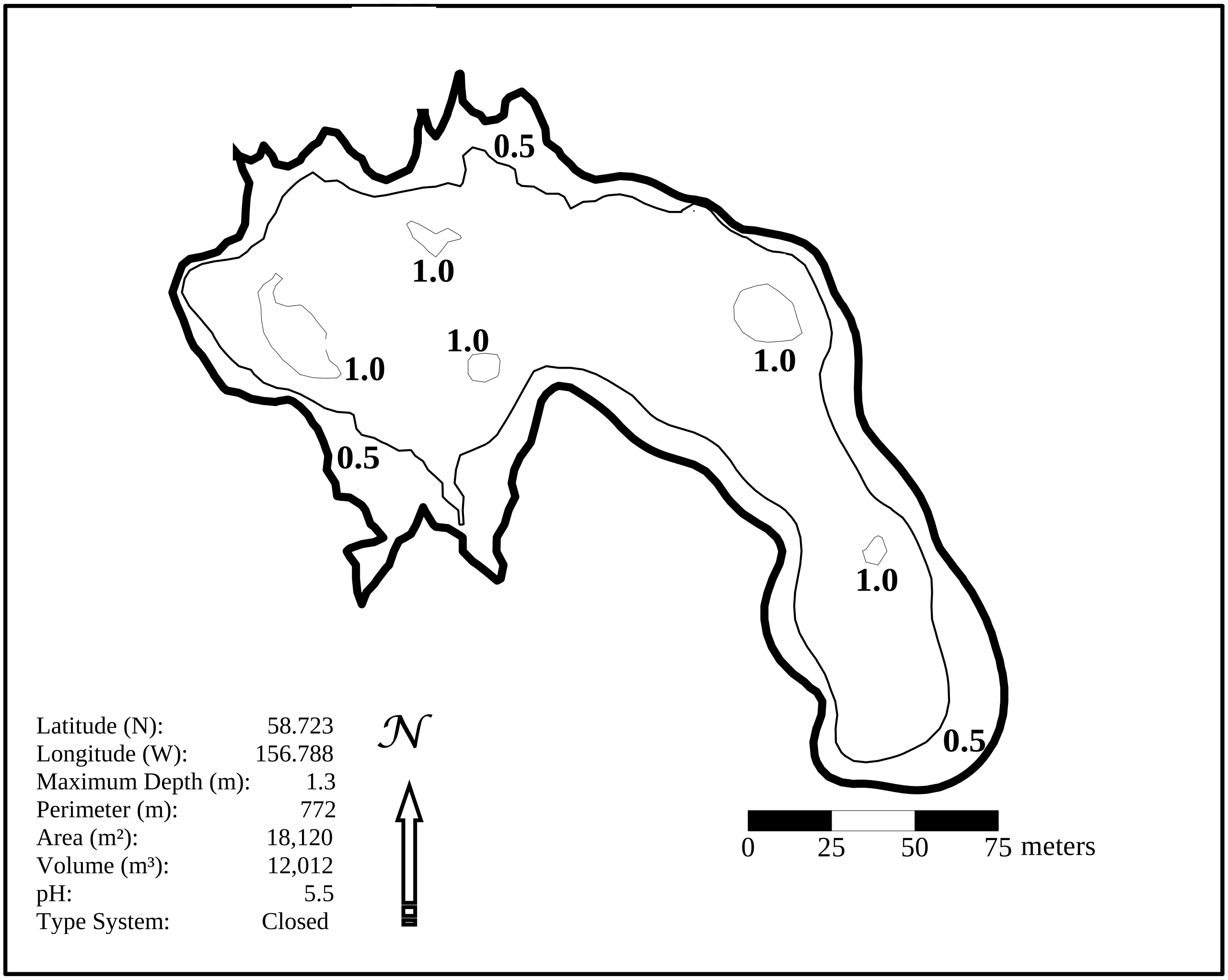
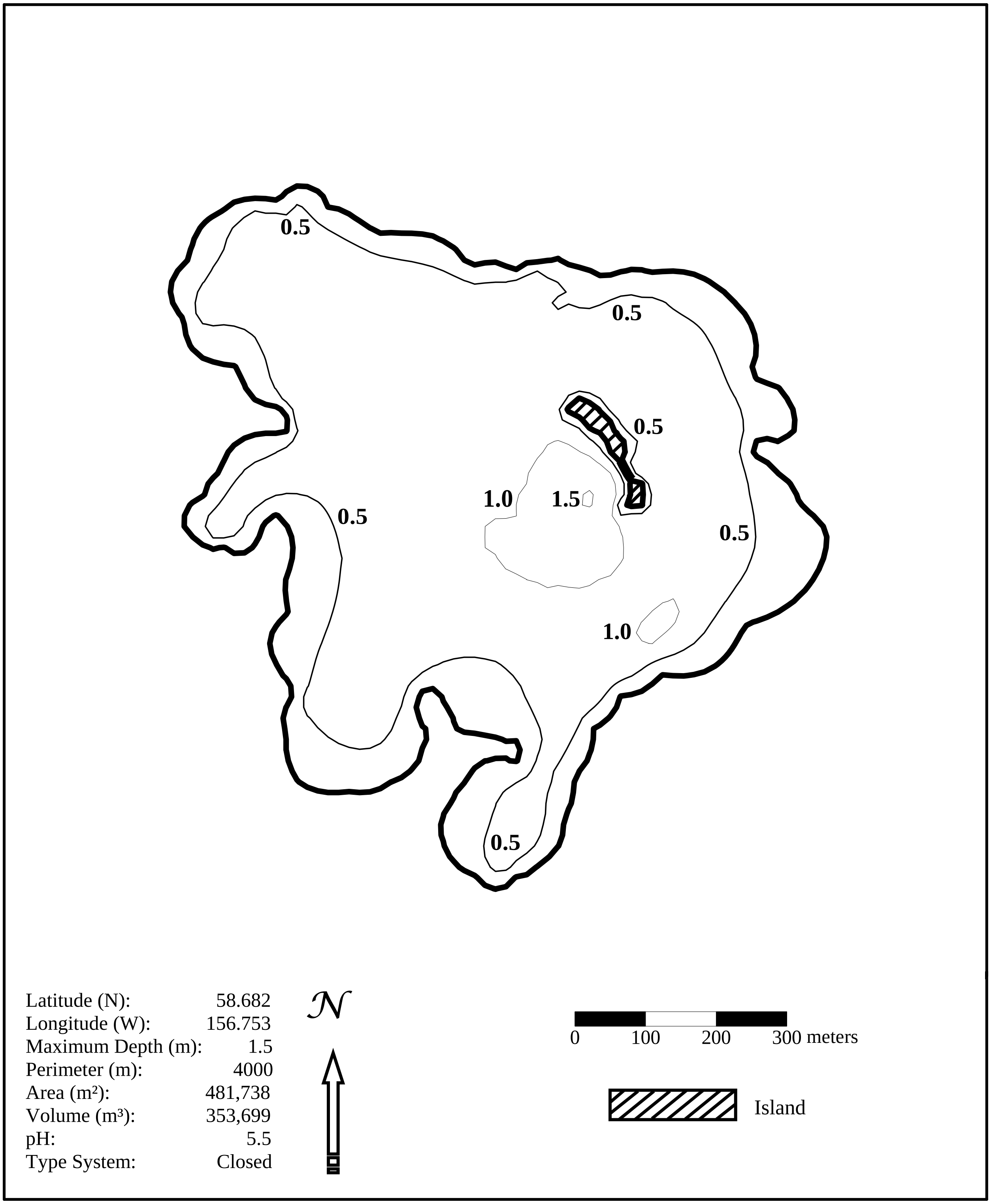
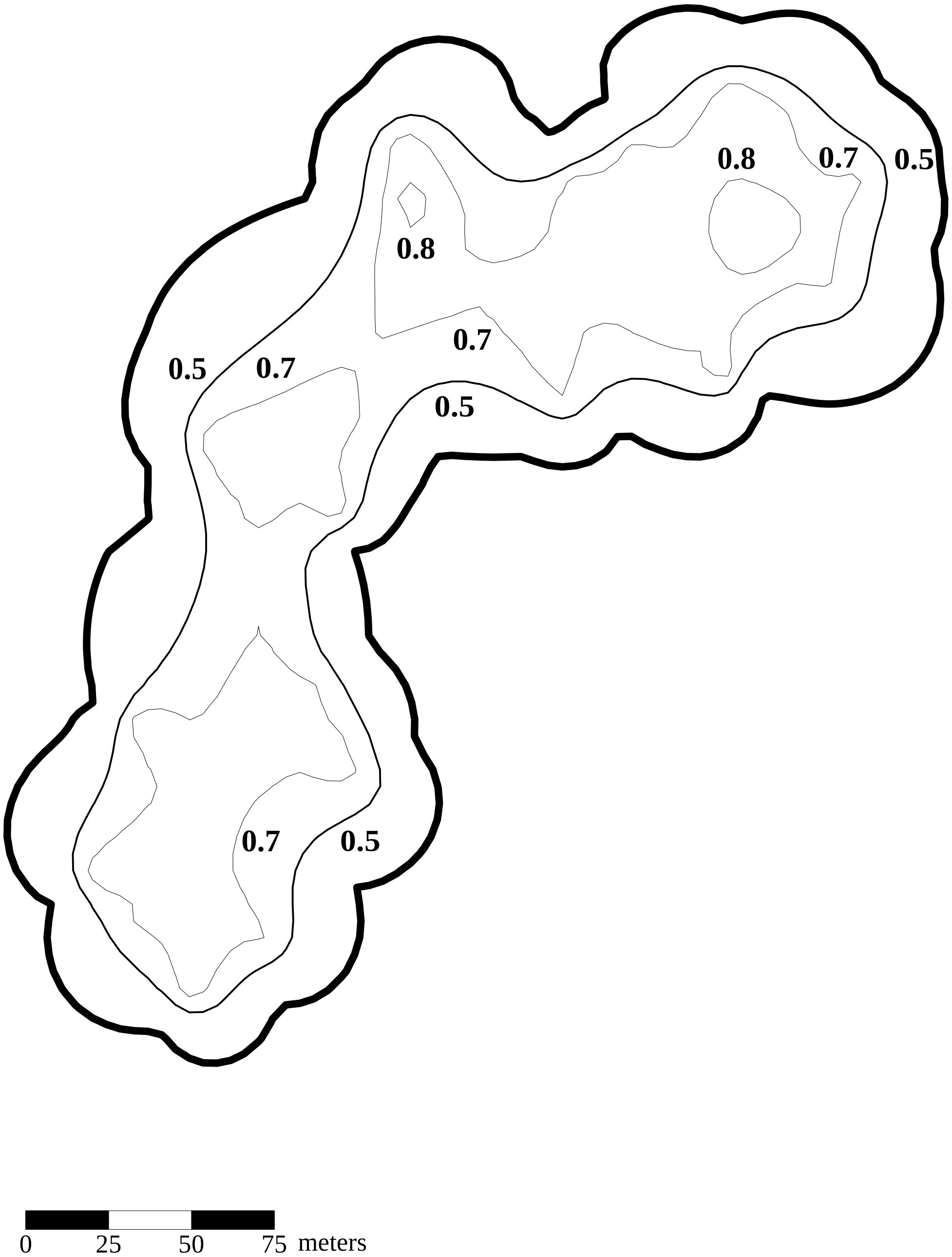
Appendix A: Bathymetric map and physical characteristics of pond 1, Bristol Bay tundra ponds, 2006.



Appendix B: Bathymetric map and physical characteristics of pond 3, Bristol Bay tundra ponds, 2006.

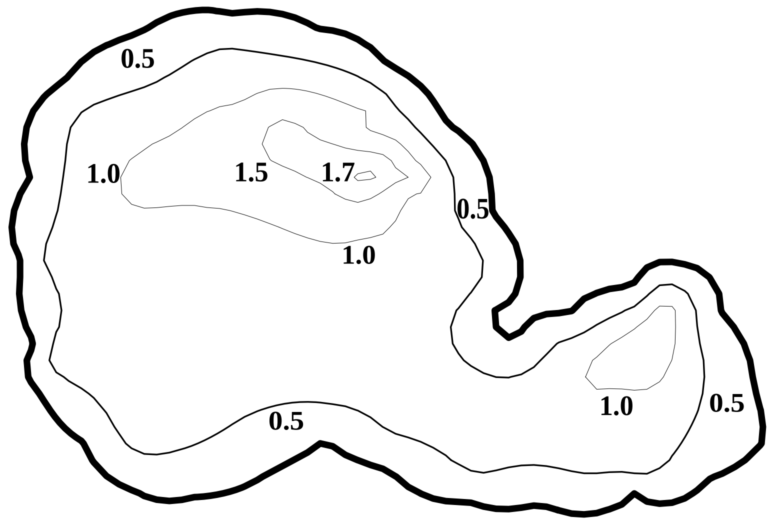


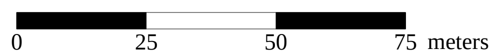
Appendix C: Bathymetric map and physical characteristics of pond 4, Bristol Bay tundra ponds, 2006.



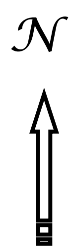
Latitude (N):	58.607
Longitude (W):	156.788
Maximum Depth (m):	0.9
Perimeter (m):	952
Area (m²):	32,429
Volume (m³):	19,209
pH:	5.5
Type System:	Closed

Appendix D: Bathymetric map and physical characteristics of pond 6, Bristol Bay tundra ponds, 2006.

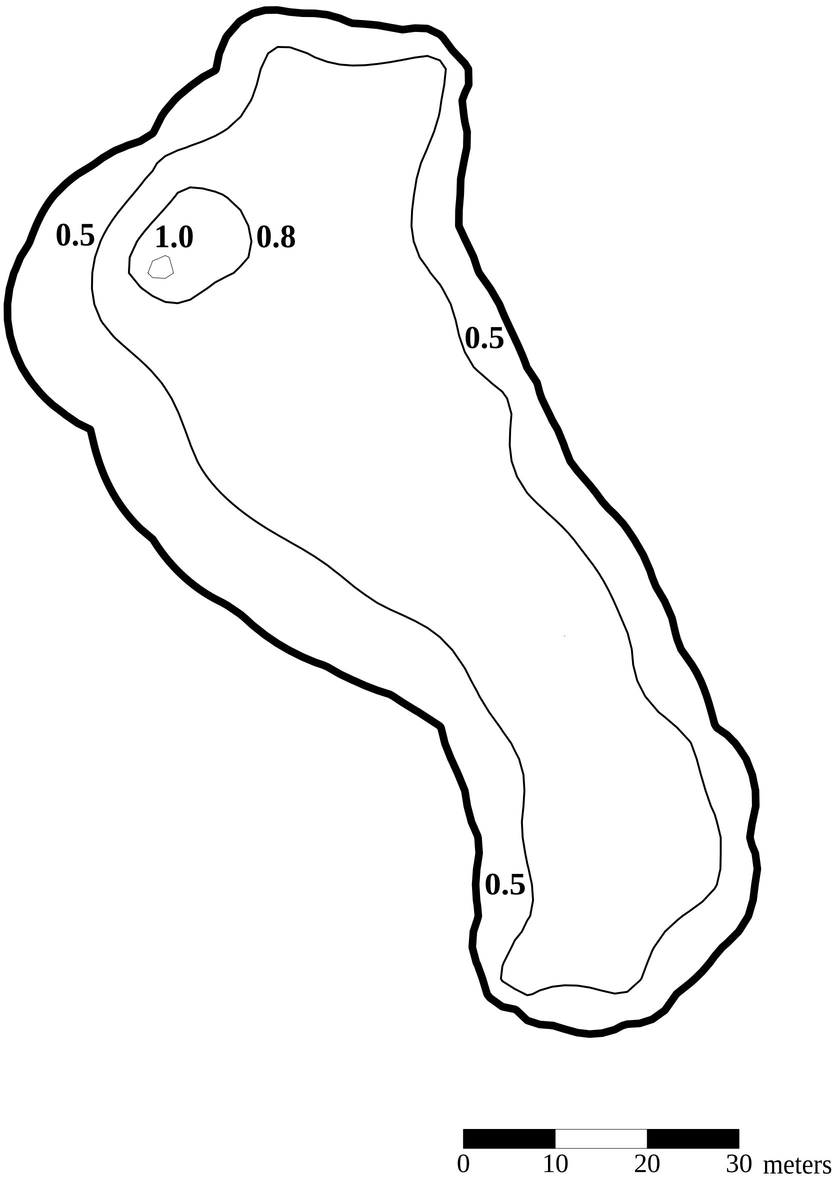




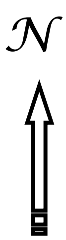
Latitude (N):	58.606
Longitude (W):	156.788
Maximum Depth (m):	1.7
Perimeter (m):	446
Area (m²):	8,038
Volume (m³):	6,040
pH:	6.0
Type System:	Closed



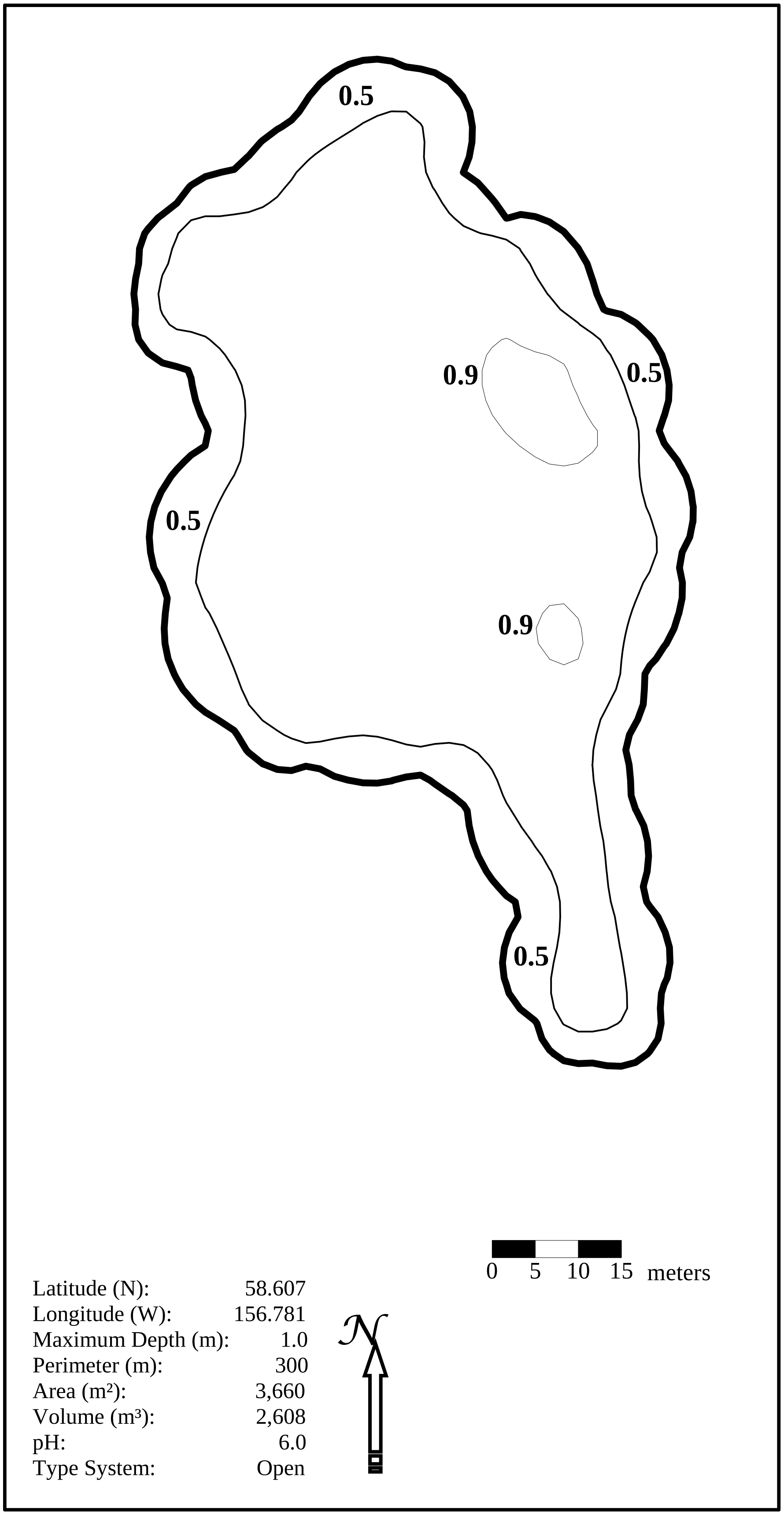
Appendix E: Bathymetric map and physical characteristics of pond 7, Bristol Bay tundra ponds, 2006.



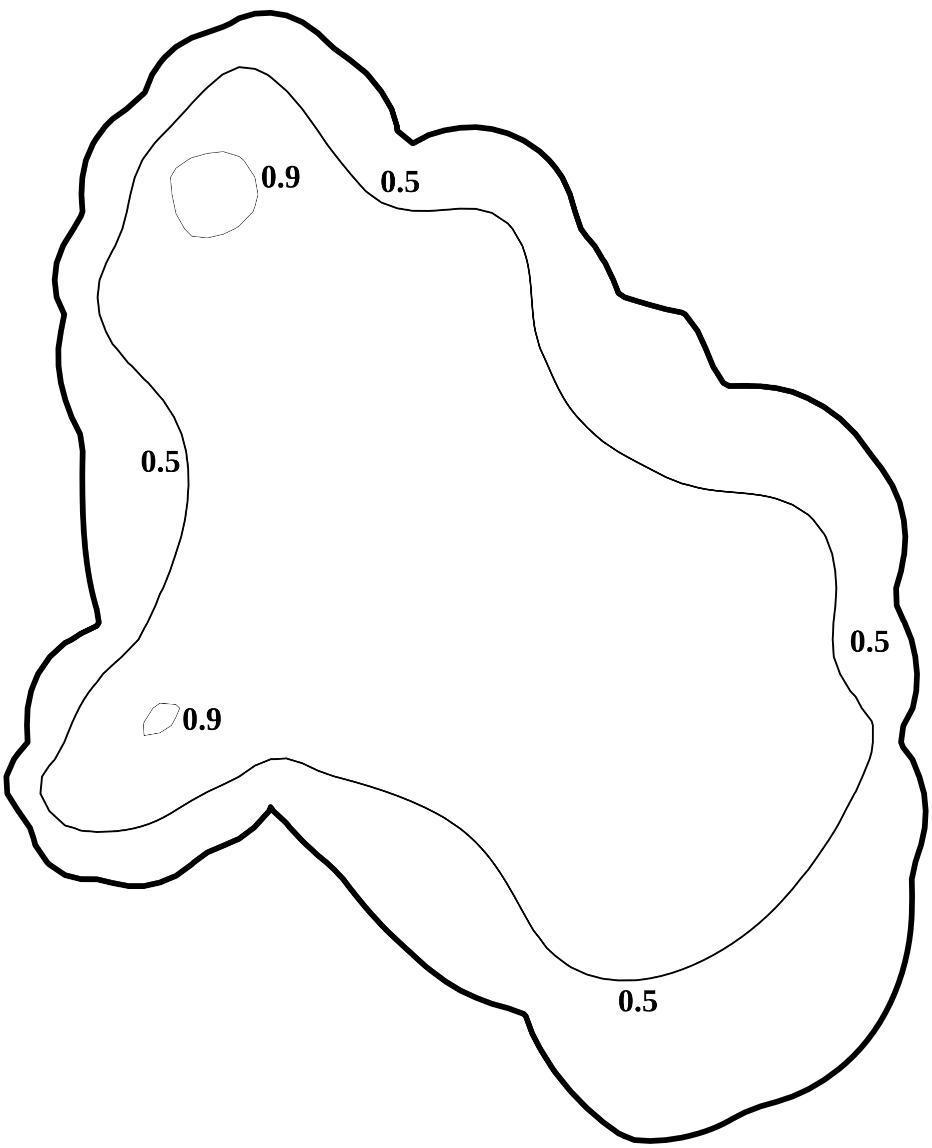
Latitude (N):	58.607
Longitude (W):	156.782
Maximum Depth (m):	1.1
Perimeter (m):	295
Area (m²):	3,958
Volume (m³):	2,271
pH:	5.5
Type System:	Open



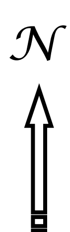
Appendix F: Bathymetric map and physical characteristics of pond 8, Bristol Bay tundra ponds, 2006.

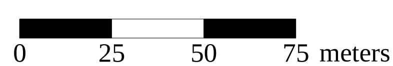


Appendix G: Bathymetric map and physical characteristics of pond 11, Bristol Bay tundra ponds, 2006.

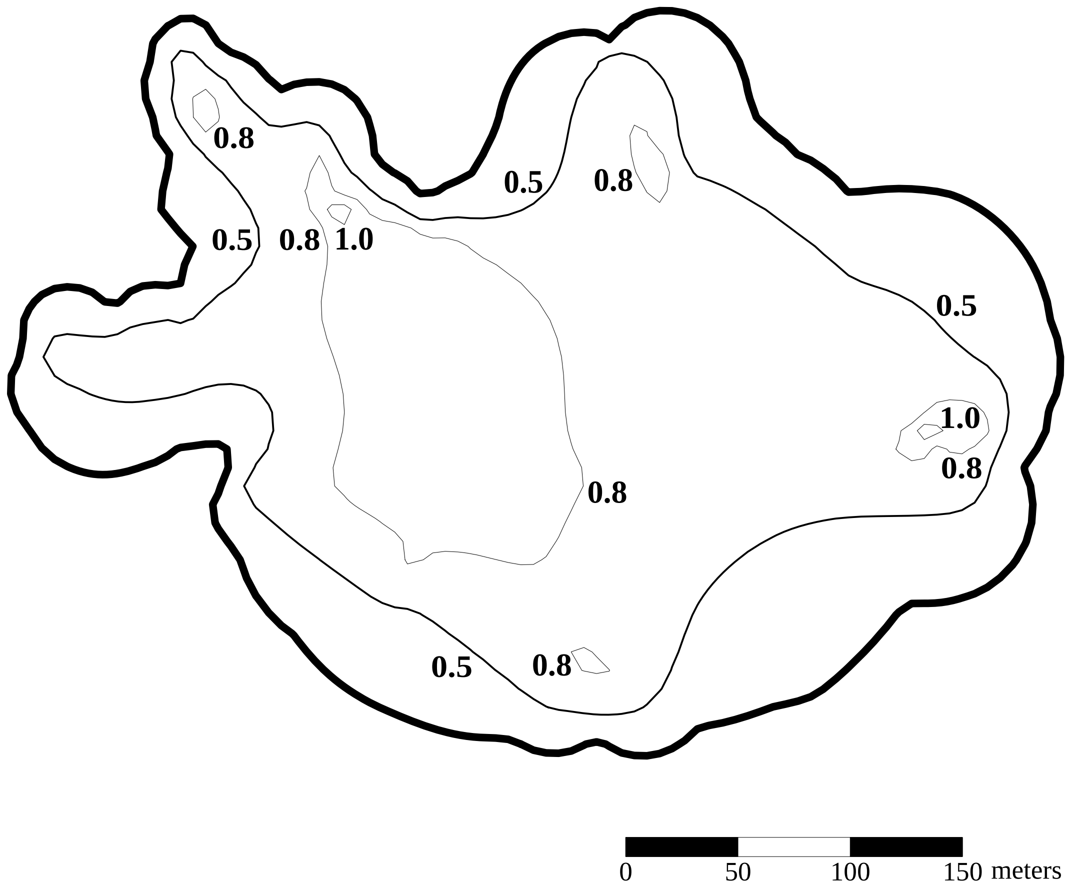


Latitude (N):	58.597
Longitude (W):	156.774
Maximum Depth (m):	1.0
Perimeter (m):	963
Area (m²):	43,975
Volume (m³):	25,172
pH:	6.3
Type System:	Closed

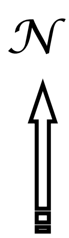




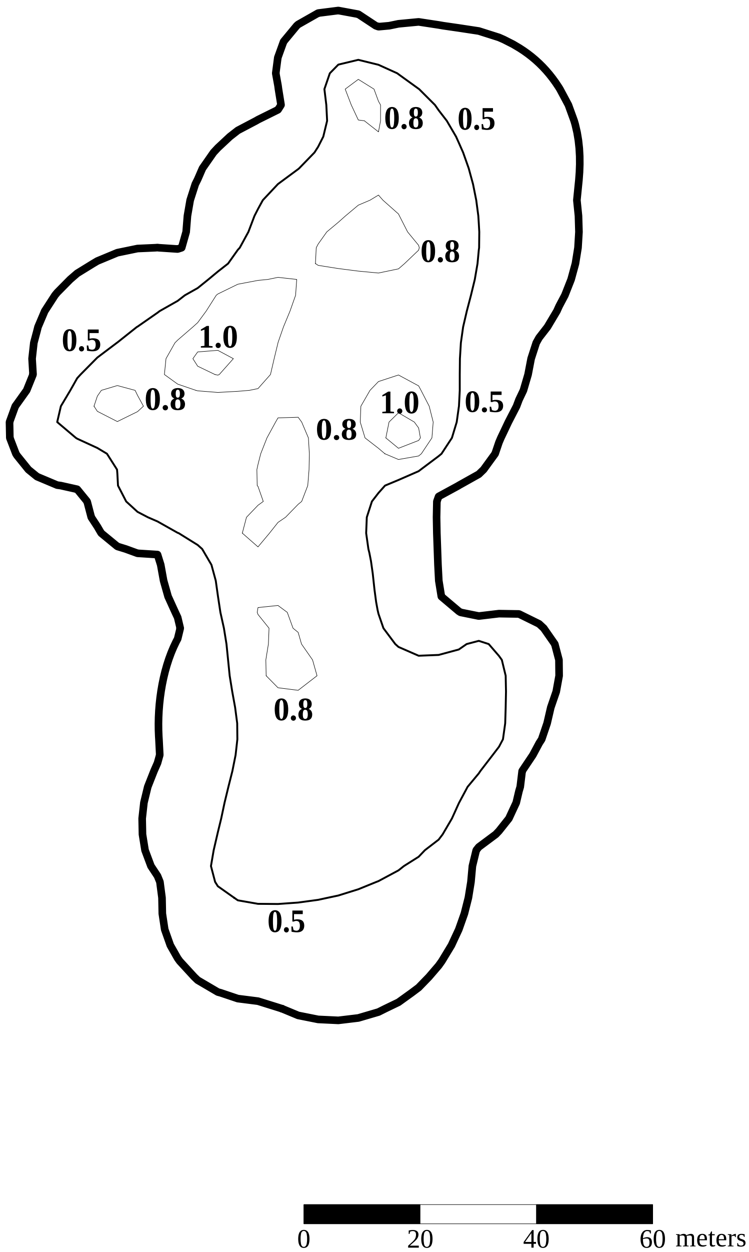
Appendix H: Bathymetric map and physical characteristics of pond 12, Bristol Bay tundra ponds, 2006.



Latitude (N):	58.561
Longitude (W):	156.726
Maximum Depth (m):	1.2
Perimeter (m):	1400
Area (m²):	86,662
Volume (m³):	52,789
pH:	6.0
Type System:	Closed



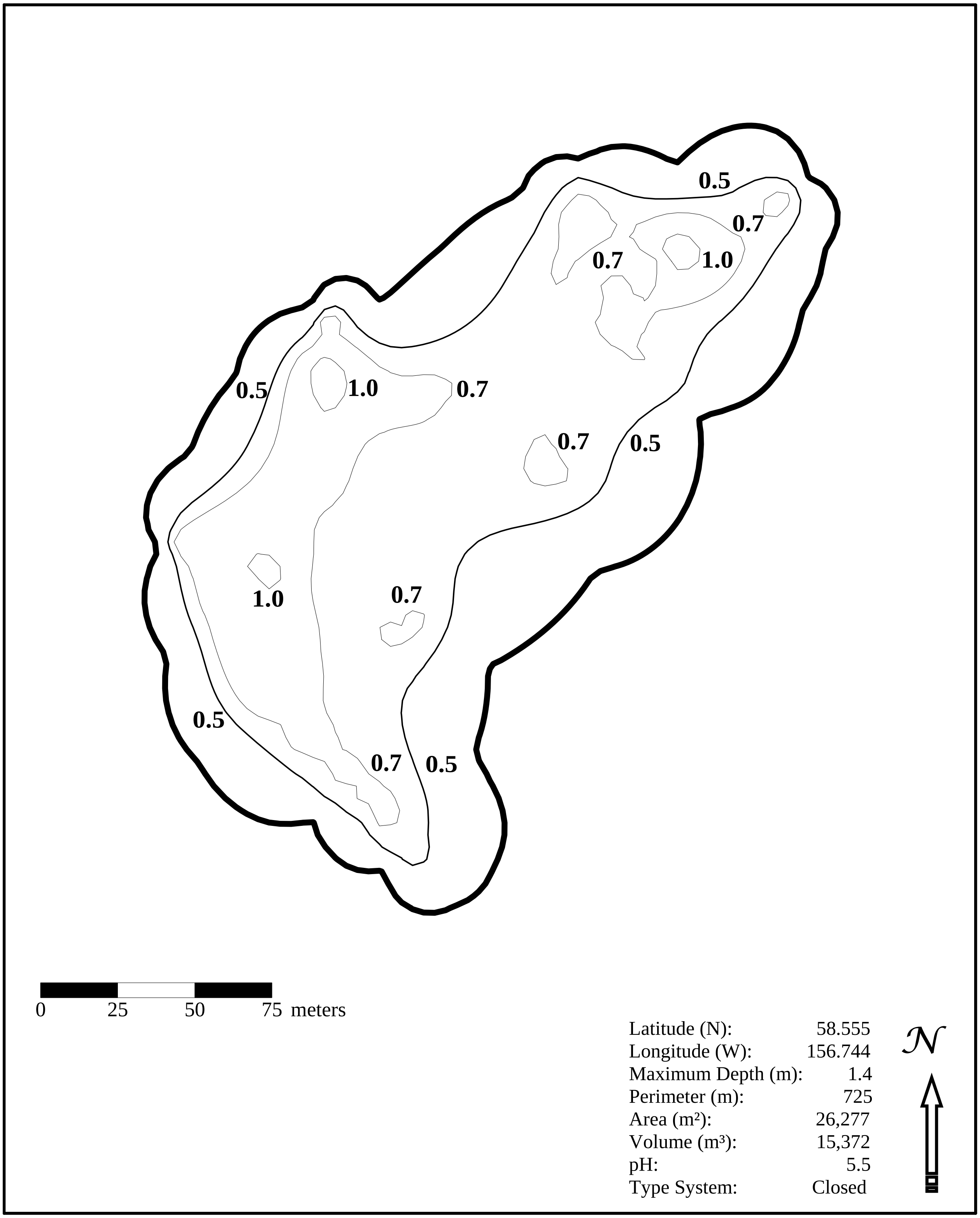
Appendix I: Bathymetric map and physical characteristics of pond 13, Bristol Bay tundra ponds, 2006.



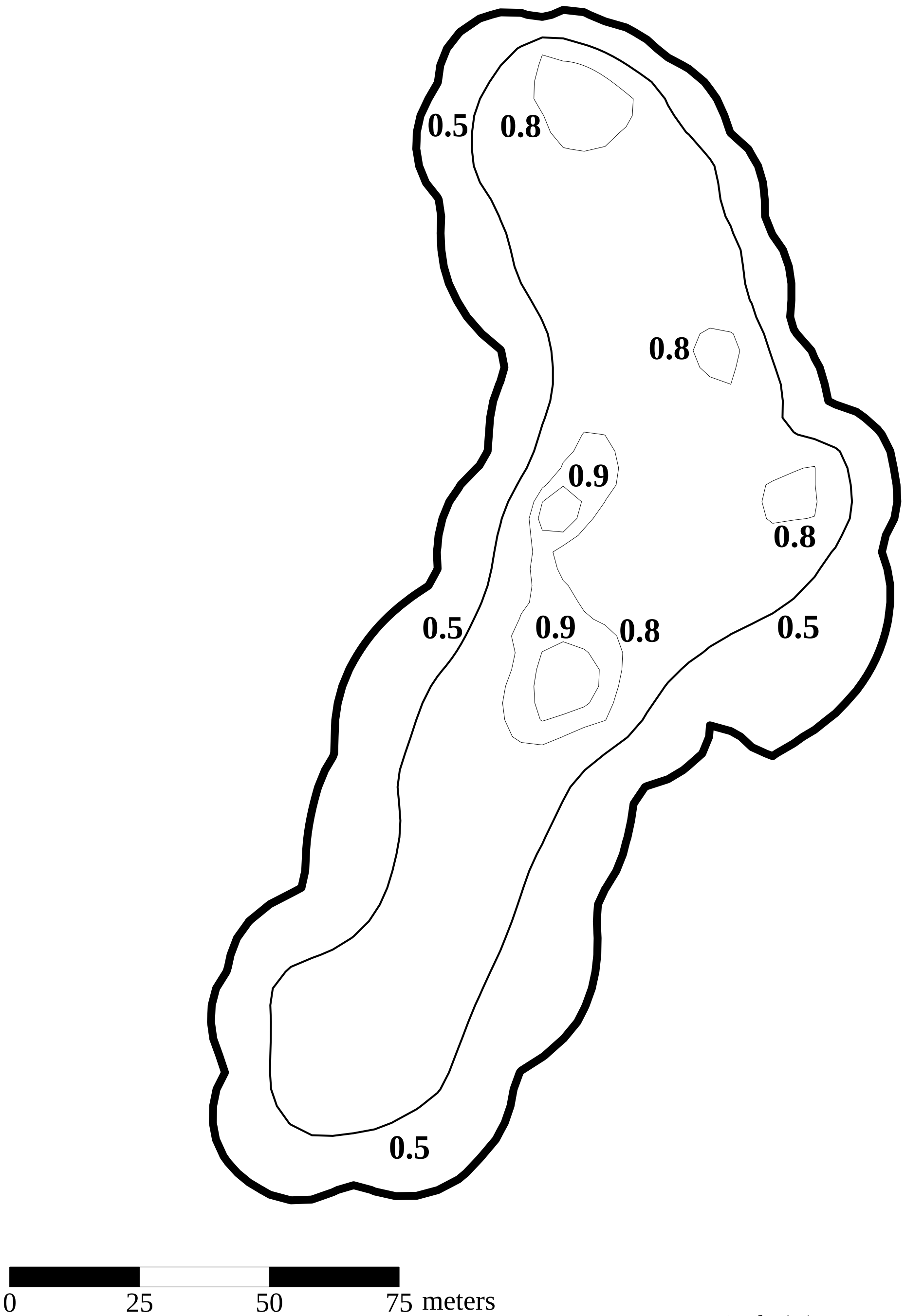
Latitude (N):	58.564
Longitude (W):	156.728
Maximum Depth (m):	1.2
Perimeter (m):	453
Area (m²):	8,116
Volume (m³):	5,017
pH:	6.0
Type System:	Closed

N

Appendix J: Bathymetric map and physical characteristics of pond 16, Bristol Bay tundra ponds, 2006.

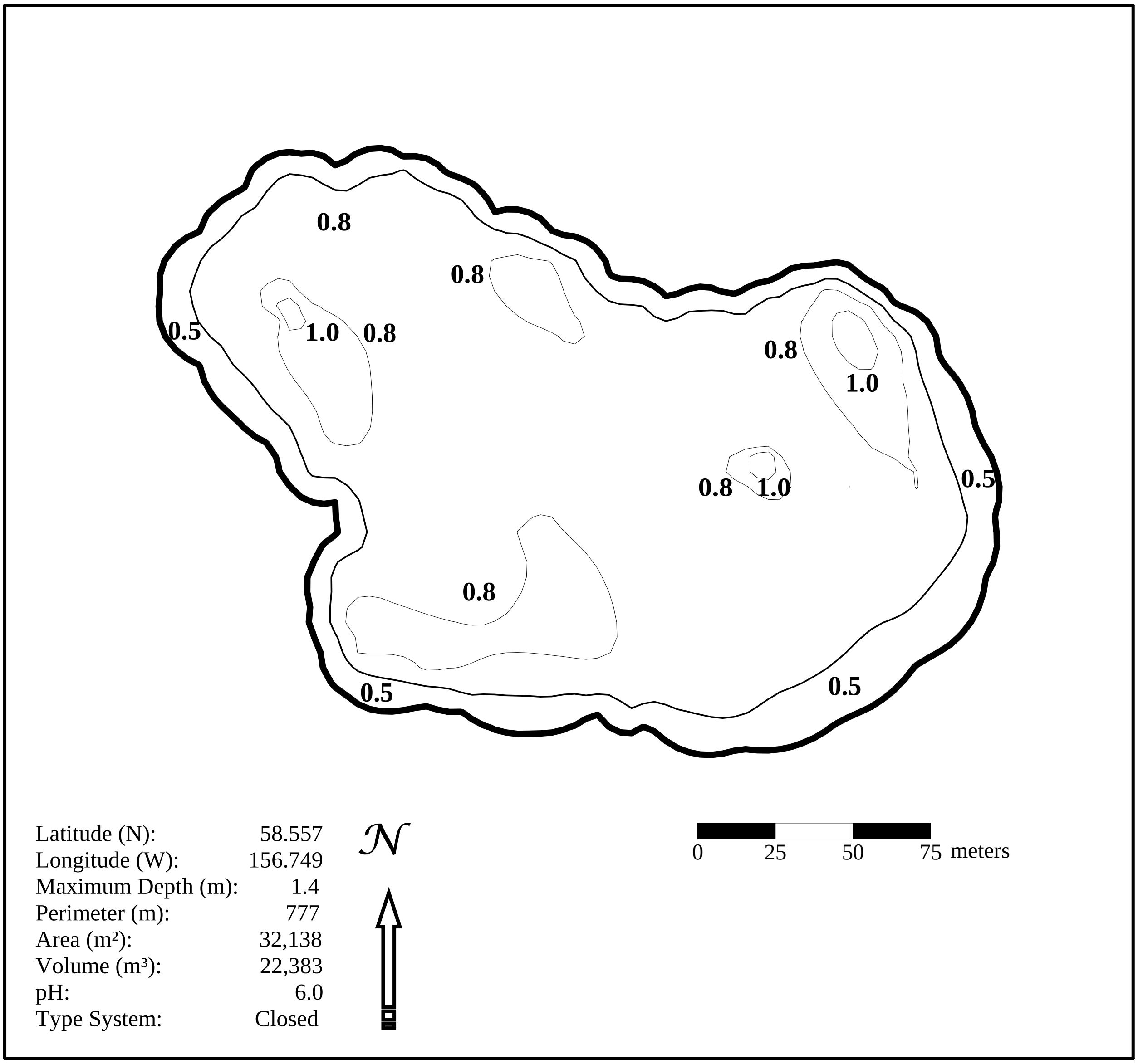


Appendix K: Bathymetric map and physical characteristics of pond 17, Bristol Bay tundra ponds, 2006.

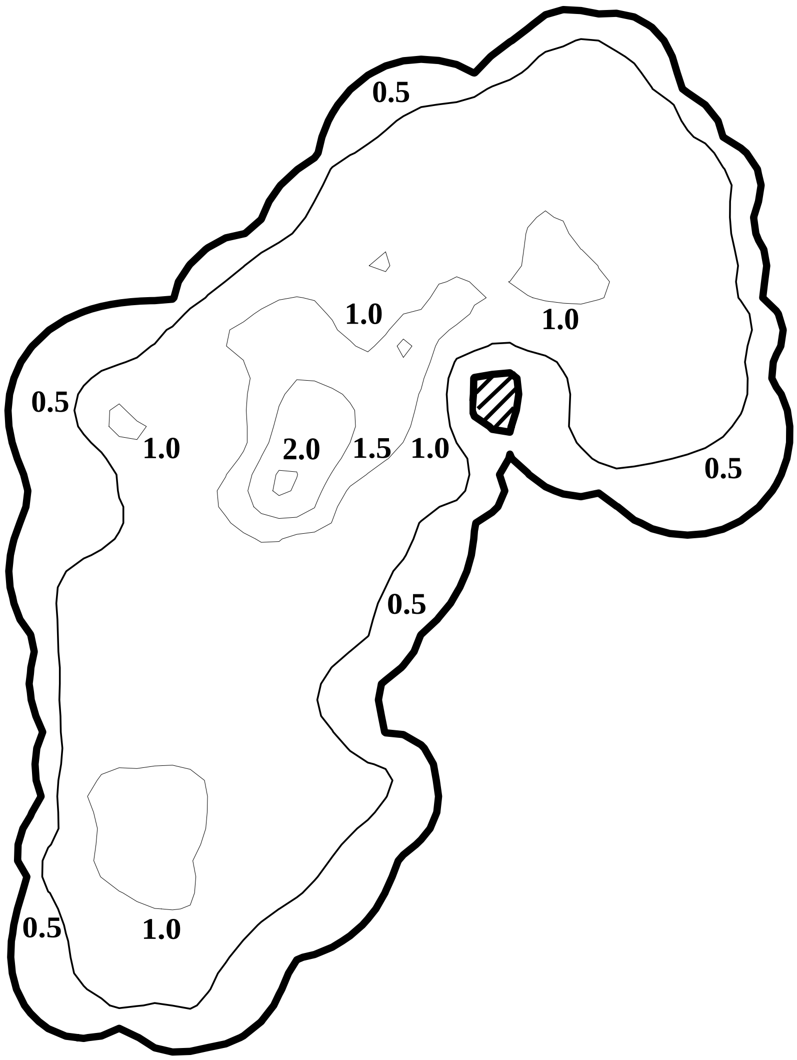


Latitude (N):	58.558
Longitude (W):	156.745
Maximum Depth (m):	1.4
Perimeter (m):	598
Area (m²):	12,695
Volume (m³):	7,683
pH:	6.0
Type System:	Closed

Appendix L: Bathymetric map and physical characteristics of pond 18, Bristol Bay tundra ponds, 2006.



Appendix M: Bathymetric map and physical characteristics of pond 19, Bristol Bay tundra ponds, 2006.



Latitude (N):	58.554
Longitude (W):	156.814
Maximum Depth (m):	2.2
Perimeter (m):	604
Area (m²):	13,908
Volume (m³):	11,850
pH:	6.0
Type System:	Open