NOAA Technical Memorandum NMFS-AFSC-275

Smooth Sheet Bathymetry of Cook Inlet, Alaska

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center

April 2014

NOAA Technical Memorandum NMFS

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This document should be cited as follows:

Zimmermann, M., and M. M. Prescott. 2014. Smooth sheet bathymetry of Cook Inlet, Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-275, 32 p.

Document available: http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-275.pdf

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Alaska Fisheries Science Center
Resource Assessment and Conservation Engineering Division
7600 Sand Point Way N.E.
Seattle, WA 98115

www.afsc.noaa.gov

U.S. DEPARTMENT OF COMMERCE
Penny. S. Pritzker, Secretary
National Oceanic and Atmospheric Administration
Kathryn D. Sullivan, Under Secretary and Administrator
National Marine Fisheries Service
Eileen Sobeck, Assistant Administrator for Fisheries

April 2014

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Abstract

We assembled 1.4 million National Ocean Service (NOS) bathymetric soundings from 98 lead-line and single-beam echosounder hydrographic surveys conducted from 1910 to 1999 in Cook Inlet, Alaska. These bathymetry data are available from the National Geophysical Data Center (NGDC: http://www.ngdc.noaa.gov), which archives and distributes data that were originally collected by the NOS and others. While various bathymetry data have been downloaded previously from NGDC, compiled, and used for a variety of projects, our effort differed in that we compared and corrected the digital bathymetry by studying the original analog source documents - digital versions of the original survey maps, called smooth sheets. Our editing included deleting erroneous and superseded values, digitizing missing values, and properly aligning all data sets to a common, modern datum. There were six areas where these older surveys were superseded by compilations of reduced-resolution multibeam surveys. We digitized 12,000 features, such as rocky reefs, kelp beds, rocks and islets, adding them to what was originally available, and creating the most thorough source (n = 18,000) of these typically shallow, inshore features. We also digitized 2,418 km of the mainland and 529 km of island shoreline, generally at a resolution of 1:20,000, and digitized 9,271 verbal surficial sediment descriptions from the smooth sheets. The depth surface, shoreline, inshore features, and sediment data sets are mostly produced at a scale of 1:20,000.

Contents

Introduction

The bathymetry of Cook Inlet is unusually well-described for an Alaskan area, with a majority of the relevant surveys conducted since 1964, and the entire area well-surveyed except for some of the northern mud flats. Part of the reason for this wealth of information is that Cook Inlet is home to Alaska's largest city, Anchorage, which includes significant shipping routes and several active oil rigs. Approximately 11% of the area has also been mapped with multibeam acoustic methods in six sections, providing modern, higher resolution data. Still, there have been a number of obstacles for surveyors of all eras to overcome as noted in the Descriptive Reports for earlier National Ocean Service (NOS) hydrographic surveys, including rough weather (H03431/H03432), winter ice in the north end (H03431/H03432), "steep banks breaking off and falling into the water sounding like small explosions of dynamite" (H03431/H03432), large tidal range (H03431/H03432), a tidal bore 3 to 6 ft high (H03431/H03432), strong currents up to 8 knots (H03203), shifting channels (H03431/H03432), dangerous shoals (H03044), extensive mud flats (H03431/H03432), and atmospheric refraction causing superior mirages of landmarks on clear days (H03203). Later surveys also noted the difficulties caused by areas of sand waves.

Cook Inlet is a large, semi-enclosed body of water extending north off of the central Gulf of Alaska, between the Kenai Peninsula and the base of the Alaska Peninsula, with the Barren Islands lying just south of the 90 km wide opening (Fig. 1). Just inside the Inlet are the indentations of Kamishak Bay on the west and Kachemak Bay on the east, creating an expanse about 200 km across. There is a narrowing about 190 km from the mouth of Cook Inlet at two capes called the East and West Forelands, constricting the width of Cook Inlet to about 16 km. In the north end are two 70 km long arms with extensive mudflats: Knik Arm on the west side, which has the Matanuska and Knik rivers entering at its terminus, and Turnagain Arm on the east side which has Twentymile River, Portage Creek, and the Placer River entering near its terminus. The largest river in Cook Inlet, the Susitna, and its neighbor the Little Susitna, enter on the west side just below Knik Arm near Fire Island. Cook Inlet is about 320 km in length from its mouth to the tip of Knik Arm. There are four large islands within Cook Inlet: Augustine in Kamishak Bay, Kalgin and Chisik just south of the Forelands, and Fire Island at the division between Knik and Turnagain arms - there are over 500 other islands smaller than 5 km^2 in size. At 20,000 km^2 in size, Cook Inlet is larger than several other partially enclosed marine bodies of water in the lower 48 United States, including Chesapeake Bay, Long Island Sound, San Francisco Bay, and Puget Sound.

The history of the European discovery and charting of Cook Inlet is fairly brief and surprisingly collaborative, considering that nations such as Great Britain, Russia, Spain and France were vying for Pacific empires. The British explorer Captain James Cook in 1778 was the first to explore and chart Cook Inlet, ending his investigations with small boats dispatched to Knik and Turnagain Arms (Fig. 1), which proved to have enough freshwater in them to indicate that they were rivers, or led to rivers, therefore proving that the Atlantic Ocean could not be reached by a northwestern salt water passage, defeating one of Cook's main objectives (Beaglehole 1974). The inlet was initially named the Gulf of Good Hope in anticipation of finding the Northwest Passage, but posthumously named Cook's River (Beaglehole 1974). Cook benefitted from charts of Alaska that incorporated the findings of Captains Vitus Bering's and Alexei Chirikov's 1741 expeditions, gained more information by exchanging knowledge with the Spanish just prior to heading to Cook Inlet, and shared his discoveries with Russians such as the fur trader Gerasim Ismailov at Dutch Harbor on Unalaska Island (Hayes 2001). While Cook was exploring from the East, the Russians had been exploring from the West for years, building on the work of Bering and Chirikov, advancing along the Aleutians, which were explored and charted most accurately by Potap Zaikov in 1774-79 (Hayes 2001). The major French expedition of the time, led by Jean-Francois de Galaup, comte de LaPerouse, surveyed the south-eastern Alaskan coast in 1786, but did not reach Cook Inlet (Hayes 2001). Out of seven early Spanish cruises of the North Pacific, Captain Salvador Fidalgo in 1790 was the only to visit Cook Inlet, where he was hosted by Russians that had already established fur trading posts there (Olson 2004). In 1794, another British exploration and charting effort led by Captain George Vancouver, who had accompanied Cook 16 years earlier, added details to Cook's previous exploration and Vancouver renamed the area Cook's Inlet (Hayes 2001). Vancouver encountered Ismailov, who was fur-trading in Cook Inlet, found possession landmarks left by Fidalgo, and retained the place names of Valdez and Fidalgo in Prince William Sound where a member of Vancouver's expedition met Zaikov (Lamb 1984).

H. W. Rhodes of the U.S. Coast and Geodetic Survey (later called the NOS) led a reconnaissance hydrographic survey of Cook Inlet in 1909 on the vessel *McArthur* (H03044 Descriptive Report) which was followed by a preliminary mapping effort covering most of the area in 1910-14. Thus the area was mapped but the horizontal control or datum used for these early surveys was not stated, although it may have been the Valdez datum. There was a 3 km baseline surveyed at the town of Valdez, in Prince William Sound, in 1901 (Fig. 1). In subsequent years, triangulation stations were created along the coast west of Prince William Sound, eventually extending to the tip of the Kenai Peninsula and the Barren Islands in 1906 (Fig. 1). Triangulation stations were created throughout Cook Inlet in 1907-14, including several in the north end of Cook Inlet established during Rhodes' 1909 cruise.

Following the 1964 earthquake, which was centered near Valdez (National Research Council 1972), the entire Cook Inlet was resurveyed by the NOS. First, starting in 1964 a new network of triangulation stations were created in the North American Datum of 1927 (NAD 1927) datum spanning from Valdez, to Fairbanks, to Anchorage, and down to Homer (Fig. 1). Second, new hydrographic surveys were conducted from 1964 thru 1983. Additional single-beam acoustic surveys were added in the 1990s. A few multibeam surveys were also conducted in the 1990s, but no multibeam surfaces were completed for these. The first multibeam survey which resulted in a completed, interpolated depth surface, a practice which continues through today, was in 1998.

While mariners have routinely used the small-scale navigational charts (1:100,000) for about a century, the source data - the original, detailed hydrographic surveys (1:20,000) - remained relatively unknown to those outside of the NOS. In 2005, the National Geophysical Data Center (NGDC) began hosting electronic copies of the hydrographic surveys. This project focused on working with the original bathymetric survey data available from NGDC and combining them into a single data set, digitizing the sediment information, adding and correcting any features, and digitizing the shore line. These data are not to be used for navigation.

Methods

We downloaded and examined single-beam and lead line hydrographic survey data sets available in whole or in part from the NGDC (http://www.ngdc.noaa.gov), to create a bathymetry map of Cook Inlet (Fig. 2). The most recent single-beam survey - H10884, was actually a multibeam survey, but no multibeam depth surface was produced. Six regions of multibeam data were assembled and used to supersede the older soundings.

Each data set provided by NGDC generally consists of three parts: a typed or hand-written document called the Descriptive Report which contains much of the survey metadata, a nautical chart called the smooth sheet which depicts the geographical placement of the soundings written as numerals, and a text file of the soundings (Wong et al. 2007) from the smooth sheet. In general, many of these surveys were so modern that there was an original text or data file of the soundings, which was indicated by having more points than were on the smooth sheet, making proofing difficult at times. Older surveys that predated the computer era did not have an original file, and these were digitized from the smooth sheets (Wong et al. 2007). A paper smooth sheet with muslin backing was the final product of a hydrographic survey (Hawley 1931). The text file of soundings is a modern interpretation of the smooth sheet, produced in a vast and expensive digitizing effort to salvage millions of hydrographic soundings from thousands of aging paper smooth sheets in U.S. waters, done largely without any error-proofing (Wong et al. 2007).

It is simplest to download and plot the digitized soundings in a Geographic Information System (GIS) to produce a continuous, interpolated, bathymetric surface, which can be accomplished in a matter of hours or days. This is the goal of most users. A generalized surface which shows the central bathymetric tendency is a valuable product in the relatively unknown and unexplored Alaskan waters, but such efforts have limited value in that they tend to smooth errors and blur seafloor features. Our goal is to describe the individual features (flats, bumps, and dips) that create the bathymetry, and we have found that there are too many errors in the digitization process to ignore. Therefore, over the course of several years, we made very careful comparisons between the smooth sheet soundings and the digitized soundings, correcting any errors, and producing an edited version of the NGDC bathymetry. We accomplished this error-proofing in a GIS by georeferencing the smooth sheets, custom datum-shifting them into a common, modern datum, and making comparisons to the digitized text file provided by NGDC. Details of the methods are described in Zimmermann and Benson (2013).

Sediment samples were taken with grabs from most of these surveys because the surveys were conducted with single-beam echosounders rather than lead lines. The older surveys (1910-14) relied on lead-line sediment observations (Hawley 1931). Verbal sediment descriptions were also digitized from the smooth sheets. Short abbreviations such as "S" and "M" were translated into their full names of "Sand" and "Mud". Position of the sediment points were centered on the written description. Some sediment descriptions were also available within the Descriptive Reports and since these sometimes varied from what was written on the smooth sheets, these were entered into a separate column.

Bathymetric features such as rocky reefs, kelp beds, rocks and islets were also proofed, edited, and digitized. All of these features, except for the kelp beds, sometimes have depths associated with them, and these were added to the bathymetric data set. Features indicating rocky ground were added to the sediment data set.

We also digitized the smooth sheet shorelines, which are defined as Mean High Water (MHW), roughly 12 to 30 feet (4 to 9 m) above low tide, as derived from tidal measurements made during each survey and summarized in the Descriptive Reports. The purpose of this shoreline digitizing was to provide bathymetry shallower than MLLW (Mean Lower Low Water) or zero depth, which is often as shallow as the surveys go, resulting in a gap or "white space" between the end of the bathymetry and the beginning of the land. By combining the digitized shoreline with the soundings and some of the features, a solid depth surface can be interpolated across the entire water area, spanning the "white space" and ending neatly at the shoreline.

Results

Our efforts resulted in the inclusion of 98 hydrographic surveys or data sets (Table 1; Fig. 2): seven from the older lead-line era (1910-1914), and 91 from the newer single-beam era (1964-1999). Twenty-nine of these required full or partial digitization of missing soundings and 69 required digitizing of features that were depicted on the smooth sheets, but not present in the files downloaded from NGDC. Altogether there were approximately 1.4 million soundings which we proofed, edited, or digitized. A few additional surveys, such as H09075, were examined and rejected for inclusion, because they were superseded by more recent surveys.

We used multibeam data sets to supersede areas of the single-beam or lead-line bathymetry (Fig. 2, Table 2). Most of these multibeam surveys occurred in groups with neighboring surveys slightly overlapping each other and sometimes differing in their horizontal resolution (e.g., 5 m or 10 m rasters). There was a single survey NW of Kalgin Island (H10909, 5 m), two surveys NE of Kalgin (H10904 5 m and H10910 15 m), three surveys north of Kalgin (H10802 10 m, H10833 5 m, H10971 5 m), three surveys near Anchorage (H11031, H11248, H11249 all 5 m), 5 surveys south of Anchorage (H11837-H11842, all 4 m), and 13 surveys in Kachemak Bay (H11933-35, H11938, H12084-H12090 H11214, H12146; 2 m to 8 m). Each member of the group of neighboring surveys were subsampled at the lowest resolution data set in the group and then combined into a larger group at this lowest resolution. This combined group was then subsampled at a resolution of 50 m, converted into points, and then added to the older bathymetry. This process resulted in the addition of 0.8 million multibeam soundings which reduced the number of older soundings to about 1 million.

Features

About 12,000 features such as rocky reefs, kelp beds, rocks, islets and others were digitized from the smooth sheets and added to the original files from NGDC, resulting in a total of 18,000 features (available at http://www.afsc.noaa.gov/RACE/groundfish/bathymetry/; Fig. 3). Almost 10,000 of these points indicated the edge of rocky reefs (Fig. 3a), covering much of the shore in Kamishak Bay, the southern shore of Kachemak Bay, and near Chisik Island, but reefs were rare north of that. Over 7,000 rocks (Fig. 3b) and over 800 islets (Fig. 3c) were found along most of the Cook Inlet shore except for the heads of some bays, southern Kamishak Bay, along the western shore north and south of the West Foreland, near the Susitna River, in upper Knik Arm, and in lower Turnagain Arm. There were less than 300 kelp beds (Fig. 3d), almost all of which were in outer Kachemak Bay. Altogether there were almost 18,000 rocks or rock ally features, such as rocky reefs, kelp beds, and islets, which were added to the sediment data set. Almost 5,000 of these features had a depth associated with them which we added to the bathymetry data set, generally adding more information in the nearshore area where soundings are typically sparse.

Shorelines

We digitized 2,418.3 km of mainland shoreline, mostly from the 1:20,000 or larger scale smooth sheets, ranging from Cape Douglas at the western entrance to Koyuktolik Bay at the eastern entrance (available at http://www.afsc.noaa.gov/RACE/groundfish/bathymetry/; Fig. 4). Small shoreline sections, typically upper ends of bays, were digitized from navigational charts as smaller scale patches. We also digitized 528.9 km of island shoreline from 507 individual islands. Kalgin (67.7 km) and Augustine (61.1 km) Islands had the longest shorelines while the smallest island digitized had a shoreline of 0.015 km - we did not digitize numerous islands smaller than 50 m in length. The digitized islands had a total surface area of 227.6 km^2 with Augustine (84.5 km^2) and Kalgin (59.3 km^2) being the largest. Islands only accounted for about 1% of the total surface area of Cook Inlet. We assigned a MHW depth or elevation (obtained from the Descriptive Report that accompanied each smooth sheet) to each section of digitized mainland and island shoreline. Shore sections digitized from navigational charts were assigned MHW based on neighboring smooth sheet Descriptive Reports. MHW was highest in the northern end of Cook Inlet, ranging up to -9.2 m in Turnagain Arm, -9.1 m in Knik Arm, and down to about -7 m in the Fire Island area. South of Fire Island to the Forelands and east of Kalgin Island MHW was -5.5 to -6.9 m except at the Ninilchik River (-5.4 m), the mouth of Kasilof River (-5.2 m) and inside the Kasilof River (-3.9 m). At Kalgin Island, west of Kalgin Island, and in Kachemak Bay, MHW was -5.4 to -4.4 m, except Halibut Cove Lagoon (-3.4 m), which had the lowest MHW in Cook Inlet. Altogether there were about 95,000 mainland and island MHW shoreline points digitized and these were added to the bathymetry data set.

Bathymetric Surface

The edited smooth sheet bathymetry points, along with the digitized shoreline points, features with elevations, and superseding multibeam data set points, were processed into a solid surface of variably-sized triangles (Triangular Irregular Network or TIN) which utilized the points as corners of the triangles. The TIN was then converted by linear interpolation into a solid surface of 50 m squares (GRID). Those grid cells that appeared on land, or outside of the area covered by the smooth sheets, were eliminated and a new grid was made which only covered the water (available at http://www.afsc.noaa.gov/RACE/groundfish/bathymetry/; Fig. 5). Overall the Inlet is shallow, with an area-weighted mean depth of 44.7 m and a range from 212 m at the south end to -17 m (due to one of 16 islets with an elevation exceeding MHW, accounting for only 31 of 8,217,208 pixels).

At MHW the total volume of the Inlet is 1,024.1 km^3 and the total surface area is 20,540 km^2. When the tide drops from MHW to MLLW, the Inlet loses 99.7 km^3 of water, or 9.7% of its volume, and exposes 1,616 km^2 of seabed, or 7.9% of its surface area. The majority of these tidally exposed areas are in Knik and Turnagain arms, the Susitna River area, and near the West Foreland. Between MLLW and a depth of 10 m, the volume is 176.3 km^3 (or 17.2%) but covers 2,563 km^2 (or 12.5%). Thus, the shallows (MHW to < 10 m) contain one-fifth of the Inlet's volume and over one-quarter of its surface area. At a depth of 30 m the Inlet has lost 53.6% of its volume and 46.5% of its surface area. Depths greater than 50 m occupy the central core of the Inlet and extend only in narrow bands past Kalgin Island, occur in small patches within Kamishak Bay, and occur in about half of Kachemak Bay. Depths greater than 100 m occur almost entirely at the entrance to the Inlet, where about 10.1% of the total volume occupies only 11.7% of the surface area.

The horizontal area, or cross-section, of the water column, as drawn at select locations from shore to shore (see Fig. 5) and from the MLLW sea surface to the seafloor, decreases substantially inside of the entrance to Cook Inlet (Fig. 6). From Cape Douglas to Point Adams, at the entrance, the vertical distance is 85 km and the horizontal area is 228,000 km^2. The Cape Douglas side is steeper, deeper, and flatter than the Point Adams side. Inside of Cook Inlet, from Chinitna Point to Poginshi Point, the vertical distance is similar to that at the entrance (72 vs. 85 km) but the horizontal area drops to only 73,300 km^2, or about one-third of the area at the entrance. Progressing north in Cook Inlet past lines drawn between Spring Point to Anchor Point, Redoubt Point to Cape Ninilchik, and between the Forelands, the horizontal area drops down to about one-fifth, one-seventh, and then to one-twentieth, respectively, of the entrance. Just south of Fire Island, along a line from the Little Susitna River to Possession Point, the horizontal area is only one-fiftieth of the entrance. Summing the horizontal areas of the five interior cross-sections results in an area less than three-quarters of that of the entrance.

Sediment

There were 9,271 verbal sediment descriptions digitized from 96 smooth sheets, resulting in 1,172 unique verbal descriptions (available at http://www.afsc.noaa.gov/RACE/groundfish/bathymetry/; Fig. 7). There were three smooth sheets used for bathymetry (H08963, H09074, H10538) that did not have any verbal sediment descriptions on them, and there were two smooth sheets not used for bathymetry, but from which verbal sediments were digitized (H09075, H10012). Sediment sample positions and descriptions were available and entered directly from tables within 20 of the Descriptive Reports, but these sediment descriptions were generally much more detailed than appearing on the smooth sheets. Therefore the sediment descriptions were also digitized as the names appearing on the smooth sheets, providing two descriptions for these records. All of the sediment data digitized from the Descriptive Report tables aligned well with the verbal descriptions written on the smooth sheets except for the H09940 sediment data, which had to be shifted about 140 m to the southwest in order to align with the smooth sheet - no explanation was given for the apparent offset. "Hard" (n = 1335), "Sand" (n = 721), "Rocky" (n = 608), and "Mud" (n = 365) were the most common sediment descriptions. In addition there were descriptions which provided more detail about a sample. For example, aside from the simplistic description of "Sand", there were also numerous instances of "Fine Gray Sand" (n = 193), "Gray Sand" (n = 89), "Fine Black Sand" (n = 76), and "Fine Green Sand" (n = 60). There were also numerous, complicated or specific sediment descriptions, with 58% of the sediment description categories only having a single occurrence. Sediment observations ranged from Rock to Clay, Sand Ridges to Mud Flats, Weeds to Stumps, and Mud to Coral. Adding the nearly 18,000 rock or rock ally observations from the bathymetry data set nearly tripled the sediment data set.

Age of Surveys

The bathymetry surveys conducted in Cook Inlet are among the newest in Alaska (Table 1). The bulk of the surveys (n = 82) were from 1964 to 1987, with nine relatively recent surveys from the early 1990s. Only seven surveys from the 1910s were used as patches in Knik and Turnagain Arms, where shifting, shallow mud flats have not been resurveyed. Numerous multibeam surveys were also utilized in this project and they ranged from 1998 to 2009.

Datums

Most of the datums used for these surveys were relatively modern, in comparison with other places in Alaska, such as the Aleutian Islands (Zimmermann et al. 2013). The bulk of the surveys were conducted in NAD 1927. Only the seven oldest surveys, from 1910 to 1914, predated NAD 1927 and were probably conducted in the Valdez datum. The nine newest single-beam surveys were conducted in the North American Datum of 1983 (NAD 1983). All of the multibeam surveys were conducted in NAD 1983.

Datum Shifts

Most of the smooth sheets required unique datum shifts, which were variable in location and survey era. The oldest surveys, which only occurred in the north end of Cook Inlet, needed to be shifted about 250 m north and about 280 m east. This shift corresponds to other contemporary surveys which are identified as Valdez datum in the Kodiak and Kenai areas and therefore it seems reasonable to assume that they are also in the same datum. The NAD 1927 surveys needed shifts of about 70 m to the south and about 130 m to the west. The NAD 1983 surveys did not require any shifting.

Soundings

The soundings downloaded from NGDC were plotted in a GIS to determine if their positions corresponded to the sounding numerals written on the georeferenced and datum-shifted smooth sheets. We defined agreement between the digital soundings and the soundings on the smooth sheet to be when the digital soundings were "on or near" the written soundings on the smooth sheet. In general, there were numerous substantial differences between many of the sounding data sets which required shifting the soundings as a group to align with the smooth sheets. Some of these shifts corresponded to the difference between the original smooth sheet datum and NAD 1983 HARN (a few hundred meters). However, some data sets aligned perfectly. Each data set needed to be checked individually.

This comparison between the soundings and the smooth sheets also served the purpose of checking for errors or incompleteness in the soundings files. Errors in the soundings such as those misplaced, missing, incorrectly entered, or otherwise in disagreement, were corrected (Zimmermann and Benson 2013). Sometimes there was little or nothing to correct. Other times there were numerous or significant errors to correct which made this tedious and time-intensive error-checking process seem worthwhile. For example, survey H09379 was missing nearly 9,000 soundings and H09073 was missing almost 7,000 soundings. Just portions of surveys H03199 and H03200 had to be digitized in order to provide patches between more modern surveys. Surveys H08790, H09074 and H09075 were missing some soundings of zero (MLLW) depth. Many surveys were missing some of the features.

Scale and Coverage

The majority of the surveys were conducted at a scale of 1:20,000 (n = 53) or larger scale (n = 31), ranging up to a scale of 1:5000, generally covering the nearshore area and major islands (Fig. 2). There were seven medium-scale surveys (1:40,000) covering the central area of lower Cook Inlet, far away from shore. The remaining medium-scale surveys, two at 1:30,000, four at 1:40,000, and a single small-scale survey at 1:100,000, were in the north end, often overlapping each other and large-scale surveys. Some smooth sheets included insets, but these were not counted separately from the main smooth sheet. The large-scale surveys covered only about 14,500 km^2 or 56%, the intermediate surveys covered about 9,100 km^2 or 35%, and the single small-scale survey covered about 2,200 km^2 or 8% of total study area, but this was mostly overlapped with large-scale surveys.

Data Quality

Data quality appears to be high on most of these smooth sheets, presumably due to the relative modernity of most of these surveys, when electronic navigation was available, and due to the enclosed nature of the inlet, where shore landmarks could be viewed. The biggest obstacle to overcome for most these surveys, according to their Descriptive Reports, was large tidal changes and strong currents. Both Cook (Beaglehole 1974) and Vancouver (Hayes 2001) reported having to wait to be carried north on the flood tide and then having to anchor during the ebb tide in order to reach the upper part of Cook Inlet. Sand wave areas, were also problematic as some sand waves reached 4 fathoms in height. Bouma et al. (1978) noted a large area of sand waves in the central, southern part of the Inlet, but the Descriptive Reports and multibeam data sets showed them in other areas too.

Discussion

We consider this smooth sheet bathymetry, feature, shoreline and sediment compilation a fairly complete first draft. This project was small enough, and we had enough time, to work on all four of these interrelated smooth sheet elements, unlike our Aleutian Islands compilation where our efforts were limited to smooth sheet bathymetry and sediments (Zimmermann et al. 2013). Additionally we were able to supersede some areas with more modern and detailed multibeam data, something we could not do in the Aleutians. Due to the uncharacteristically thorough and modern coverage of these smooth sheets, we felt confident in producing a 50 m resolution grid for Cook Inlet, offering four times as much detail as our 100 m Aleutians grid.

Our slow method of data editing and compilation, which relied on comparing the digitized soundings (Wong et al. 2007) to the smooth sheets in a GIS, was vindicated by the discovery and elimination of numerous errors, such as incorrect, misplaced and missing soundings. Properly accounting for the horizontal shift from the original datum to NAD 1983 HARN was the most important part of our error-checking. Another bathymetry compilation effort (Goetz et al. 2007) produced a 100 m grid by adding two data sources; soundings from the smooth sheet data sets that we used (but unedited) and soundings from the smaller-scale navigational charts, which repeats some of the same soundings from the smooth sheets. Other bathymetry compilations have been produced by the NMFS' Alaska Regional Office (http://alaskafisheries.noaa.gov/) and for the Alaska Ocean Observing System (http://www.aoos.org/), but the compilation methods are not clear as no publications were produced. Various tsunami inundation grids (http://www.ngdc.noaa.gov/mgg/inundation/) have been produced for areas within Cook Inlet. The Alaska Department of Natural Resources produced an Alaskan statewide shoreline by digitizing1:63,360 USGS topographic quadrangles in 1998, and the NOS, Office of Response and Restoration, Hazardous Materials Response Division produced a coastline for Cook Inlet and Kenai Peninsula by digitizing the same sources in 2002.

LIDAR

There were also several sections of Cook Inlet that have LIDAR (Light Detection and Ranging) data, which is collected from an airplane by timing laser pulses reflected off the Earth's surface. LIDAR data set are typically much denser, and therefore more detailed, than underwater sound-based mapping data sets. Sections of the east side of Cook Inlet have been mapped with LIDAR by the Kenai Watershed Forum (http://www.kenaiwatershed.org/ ;data available at http://www.alaskamapped.org/) and the Susitna River area and the west side of Knik Arm were mapped with LIDAR by the Matanuska-Susitna Borough (http://www.matsugov.us/) which also hosts the data. However these data sets were collected in a different vertical datum (NAVD83) and there is no available method for transforming them into tidal datum we used for this project.

Multibeam Surveys

Our project was improved by adding multibeam data that superseded older, less-comprehensive single-beam echosounder data. As more multibeam data sets become available, and more time permits, we may update the bathymetry surface.

Acknowledgments

Funding for much of the work was provided by NOAA's Essential Fish Habitat (EFH), Habitat and Ecological Processes Research (HEPR) through the Alaska NMFS Regional Office. B. McMahon, G. Nelson (retired) and especially C. Barry (Pacific Hydrographic Branch of the NOS) provided assistance with interpreting smooth sheets, bathymetric sounding files, and descriptive reports. D. Doyle and J. Benson provided valuable datum and GIS advice, respectively. D. Fischman, G. Glover, J.A. Bunn, J. Campagnoli, M. Frydrych, and M. Cole from the National Geophysical Data Center helped with accessing smooth sheets on the NGDC web site.

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Table 1. -- List of smooth sheet bathymetry and sediment data sets for Cook Inlet.

Survey	Scale	Year	Vessel	Datum
H03199	100,000	1910	*McArthur*	Unknown
H03200	40,000	1910	*McArthur*	Unknown
H03203	40,000	1910	*McArthur*	Unknown
H03211	40,000	1910	*McArthur*	Unknown
H03431	30,000	1912	*Yukon*	Unknown
H03432	30,000	1912	*Yukon*	Unknown
H03674	40,000	1914	*Explorer*	Unknown
H08789	10,000	1964	*Pathfinder*	NAD 1927
H08790	10,000	1964	*Pathfinder*	NAD 1927
H08841	20,000	1965	*Pathfinder*	NAD 1927
H08842	20,000	1965-1966	*Pathfinder*	NAD 1927
H08843	40,000	1965-1968	*Pathfinder*	NAD 1927
H08856	5,000	1965	*Pathfinder*	NAD 1927
H08962	20,000	1967-1968, 1970	*Pathfinder*	NAD 1927
H08963**	10,000	1967	*Surveyor*	NAD 1927
H08964	20,000	1967, 1974	*Surveyor*	NAD 1927
H08965	20,000	1967, 1974	*Fairweather, Surveyor*	NAD 1927
H09001	20,000	1968-1970	*Pathfinder*	NAD 1927
H09014	10,000	1968	*Pathfinder*	NAD 1927
H09071	10,000	1969	*Pathfinder*	NAD 1927
H09072	20,000	1969-1974	*Pathfinder*	NAD 1927
H09073	20,000	1969, 1971, 1974	*Pathfinder, Fairweather*	NAD 1927
H09074**	5,000	1969	*Pathfinder*	NAD 1927
H09075*	5,000	1969	*Pathfinder*	NAD 1927
H09100	10,000	1968-1971	*Pathfinder*	NAD 1927
H09327	20,000	1972	*Fairweather*	NAD 1927
H09328	10,000	1972-1973	*Fairweather*	NAD 1927
H09329	10,000	1972-1973	*Fairweather*	NAD 1927
H09378	40,000	1973	*Fairweather*	NAD 1927
H09379	20,000	1973	*Fairweather*	NAD 1927
H09435	20,000	1974	*Fairweather*	NAD 1927
H09436	20,000	1974	*Fairweather*	NAD 1927
H09437	20,000	1974	*Fairweather*	NAD 1927
H09439	10,000	1974	*Rainier*	NAD 1927
H09440	10,000	1974	*Rainier*	NAD 1927
H09441	10,000	1974	*Rainier*	NAD 1927
H09442	10,000	1974	*Rainier*	NAD 1927
H09443	20,000	1974	*Rainier*	NAD 1927

Table 1. -- Cont'd.

Survey	Scale	Year	Vessel	Datum
H09444	20,000	1974	*Rainier*	NAD 1927
H09445	20,000	1974	*Rainier*	NAD 1927
H09446	20,000	1974, 1977	*Rainier, Fairweather*	NAD 1927
H09447	20,000	1974	*Rainier*	NAD 1927
H09539	20,000	1975	*Rainier*	NAD 1927
H09541	20,000	1975	*Rainier*	NAD 1927
H09545	20,000	1975	*Davidson*	NAD 1927
H09569	10,000	1980	*Rainier*	NAD 1927
H09619	20,000	1976	*Fairweather*	NAD 1927
H09620	20,000	1976	*Fairweather*	NAD 1927
H09621	20,000	1976	*Fairweather*	NAD 1927
H09648	20,000	1976-1977	*Fairweather*	NAD 1927
H09696	20,000	1977	*Fairweather*	NAD 1927
H09697	20,000	1977	*Fairweather*	NAD 1927
H09698	20,000	1977	*Fairweather*	NAD 1927
H09707	10,000	1977	*Rainier*	NAD 1927
H09708	40,000	1977	*Rainier*	NAD 1927
H09770	20,000	1978	*Fairweather*	NAD 1927
H09771	20,000	1978	*Fairweather*	NAD 1927
H09773	20,000	1978-1979	*Fairweather*	NAD 1927
H09776	20,000	1978	*Fairweather*	NAD 1927
H09777	20,000	1978	*Rainier*	NAD 1927
H09827	20,000	1979	*Fairweather*	NAD 1927
H09828	20,000	1979	*Fairweather*	NAD 1927
H09833	20,000	1979	*Rainier*	NAD 1927
H09835	20,000	1979	*Rainier*	NAD 1927
H09836	20,000	1979	*Fairweather*	NAD 1927
H09837	20,000	1979	*Fairweather*	NAD 1927
H09840	20,000	1981	*Rainier*	NAD 1927
H09876	20,000	1980	*Rainier*	NAD 1927
H09877	20,000	1980-1981	*Rainier*	NAD 1927
H09878	10,000	1980	*Fairweather*	NAD 1927
H09879	20,000	1980	*Fairweather*	NAD 1927
H09884	10,000	1980	*Rainier*	NAD 1927
H09891	5,000	1980	*Rainier*	NAD 1927
H09892	5,000	1980	*Rainier*	NAD 1927
H09893	10,000	1980	*Rainier*	NAD 1927
H09900	5,000	1980	*Rainier*	NAD 1927

Table 1. -- Cont'd.

Survey	Scale	Year	Vessel	Datum
H09940	5,000	1981	*Rainier*	NAD 1927
H09941	10,000	1981	*Rainier*	NAD 1927
H09945	20,000	1981	*Rainier*	NAD 1927
H09958	20,000	1981	*Rainier*	NAD 1927
H09967	20,000	1981	*Rainier*	NAD 1927
H10000	20,000	1982	*Rainier*	NAD 1927
H10012*	10,000	1982	*Rainier*	NAD 1927
H10017	20,000	1982	*Rainier*	NAD 1927
H10018	20,000	1982	*Rainier*	NAD 1927
H10091	40,000	1983	*Rainier*	NAD 1927
H10099	40,000	1983	*Rainier*	NAD 1927
H10104	40,000	1983	*Rainier*	NAD 1927
H10105	40,000	1983	*Rainier*	NAD 1927
H10106	20,000	1983	*Rainier*	NAD 1927
H10252	5,000	1987	*Fairweather*	NAD 1927
H10430	10,000	1992	*Rainier*	NAD 1983
H10431	10,000	1992	*Rainier*	NAD 1983
H10432	20,000	1992	*Rainier*	NAD 1983
H10433	20,000	1992	*Rainier*	NAD 1983
H10538**	10,000	1994	*Rainier*	NAD 1983
H10610	10,000	1995	*Rainier*	NAD 1983
H10615	10,000	1995	*Rainier*	NAD 1983
H10617	10,000	1995	*Rainier*	NAD 1983
H10884	10,000	1999	*Sea Ducer*	NAD 1983

* Used for sediments only.
** Used for bathymetry only.

Table 2. -- List of multibeam data sets used in Cook Inlet bathymetry compilation. Each survey was available at a single or multiple resolutions, and then grouped together at the lowest resolution. Then all neighboring surveys were grouped together at the lowest common resolution. Then all survey groups were grouped together at a resolution of 50 m.

Survey	Resolution	Year	Vessel
H10909	5 m	1999	*Rainier*
H109xx (Combined at 15 m resolution)			
H10904	5 m	1999	*Sea Ducer*
H10910	15 m	1999	*Rainier*
H108xx (Combined at 10 m resolution)			
H10802	10 m	1998	*Sea Ducer*
H10833	5 m	1998	*Sea Ducer*
H10971	5 m	2000	*Quicksilver*
H112xx (Combined at 5 m resolution)			
H11031 (patch)	5 m	2001	*Sea Ducer*
H11248	5 m	2004	*Luna Sea, Sea Ducer*
H11249	5 m	2004	*Luna Sea, Sea Ducer*
H118xx (Combined at 4 m resolution)			
H11837	4 m	2008	*Mt. Augustine*
H11838	4 m	2008	*Mt. Mitchell, Mt. Augustine*
H11839	4 m	2008	*Mt. Mitchell, Mt. Augustine*
H11840	4 m	2008	*Mt. Mitchell, Mt. Augustine*
H11841	4 m	2008	*Mt. Mitchell, Mt. Augustine*
H11842	4 m	2008	*Mt. Mitchell, Mt. Augustine*
Hydropalooza (Combined at 8 m resolution)			
H11933	4 m	2008	*Rainier*
H11934	4 m	2008	*Rainier*
H11935	8 m	2008	*Fairweather*
H11938	8 m	2008	*Fairweather*
H12084	8 m	2009	*Rainier*
H12085	8 m	2009	*Rainier*
H12086	8 m	2009	*Rainier*

Table 2. -- Cont'd.

Survey	Resolution	Year	Vessel
H12087	8 m	2009	*Rainier*
H12088	4 m	2009	*Rainier*
H12089	4 m	2009	*Fairweather*
H12090	8 m	2009	*Fairweather*
H12114	4 m	2009	*Fairweather*
H12146	2 m	2009	*Rainier*

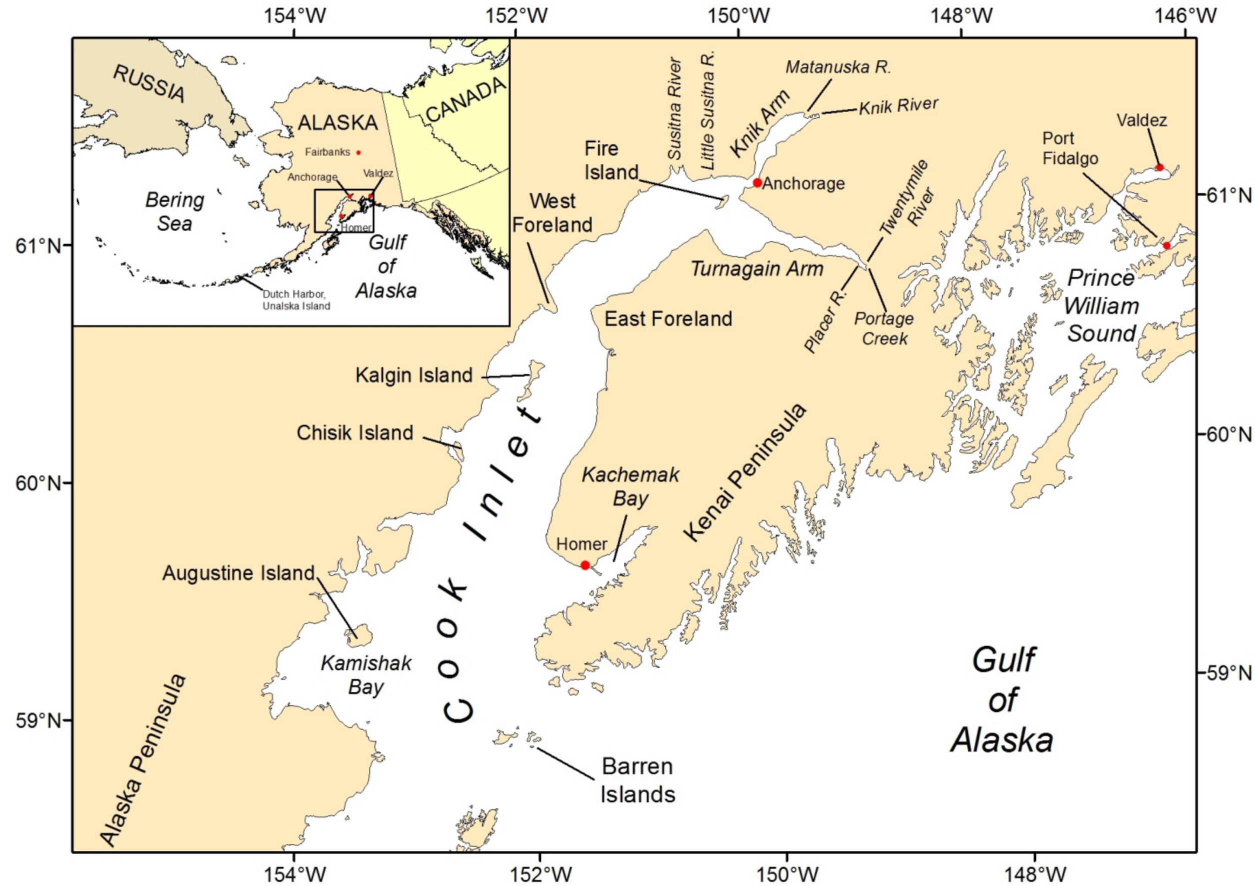

Figure 1. -- Cook Inlet is a large, semi-enclosed body of water off the central Gulf of Alaska.

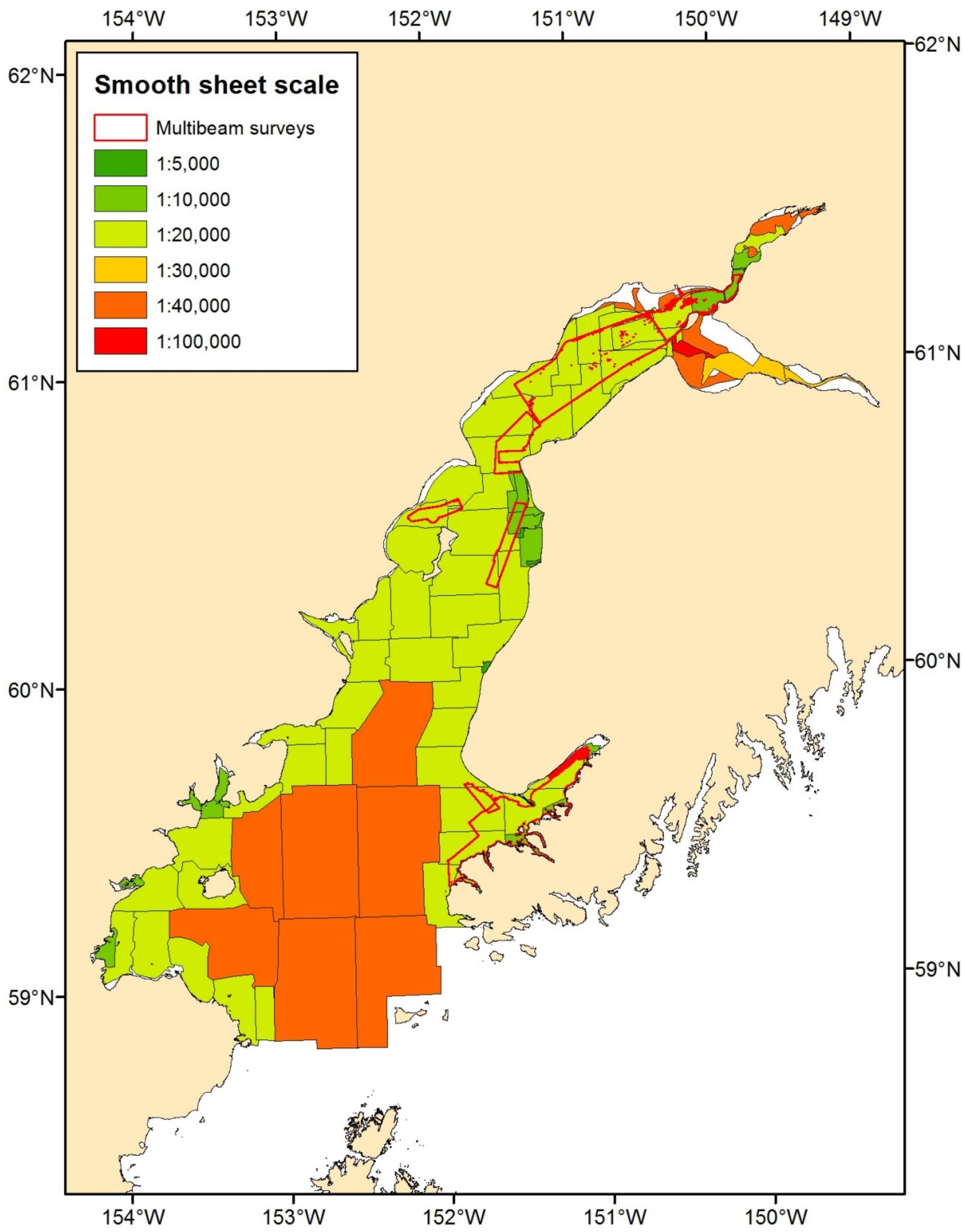

Figure 2. -- Areal extent of each hydrographic survey, its scale and multibeam coverage utilized for constructing the Cook Inlet bathymetry.

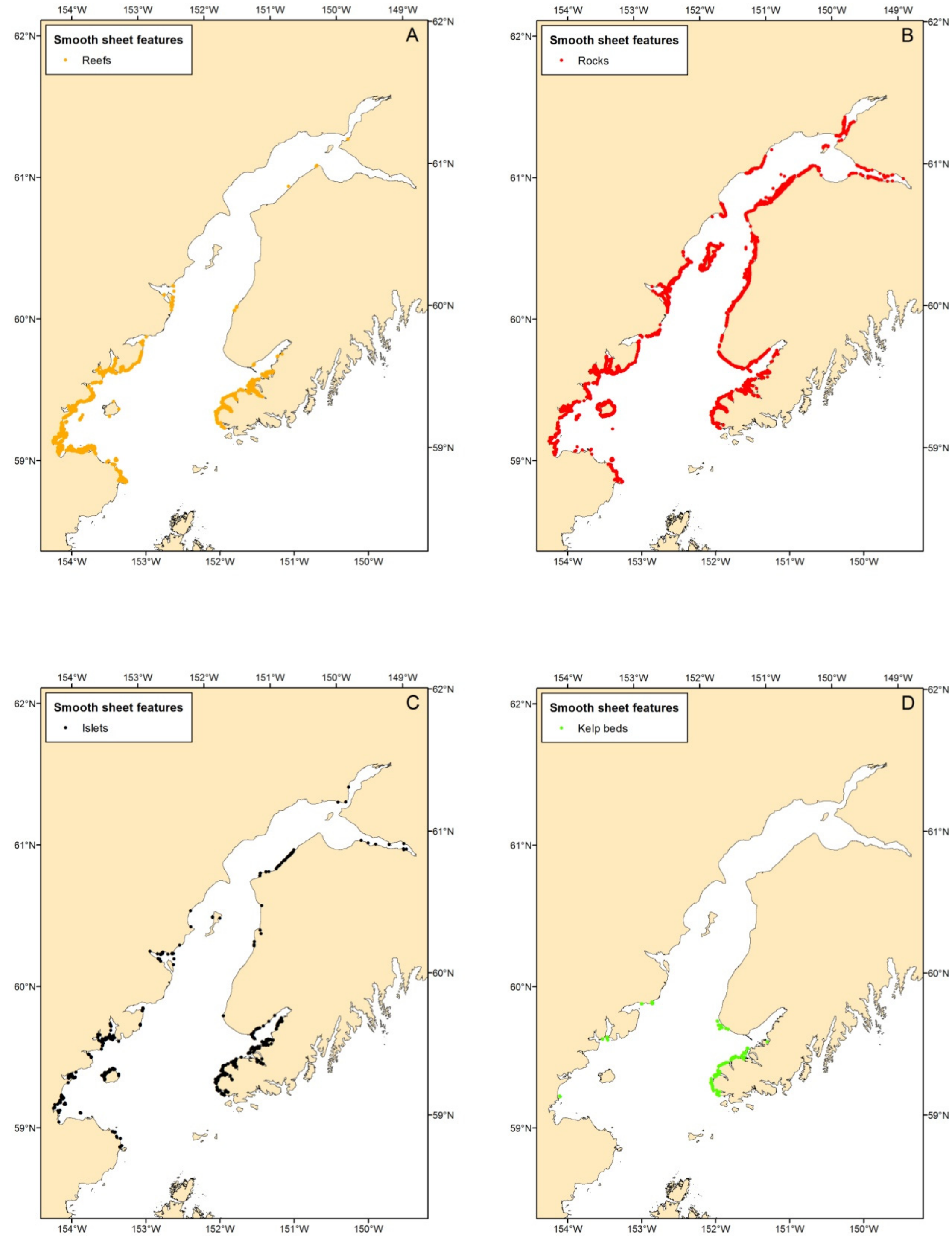

Figure 3. -- Inshore features from the smooth sheets indicating hard or rocky areas: a) reefs, b) rocks, c) islets, and d) kelp beds.

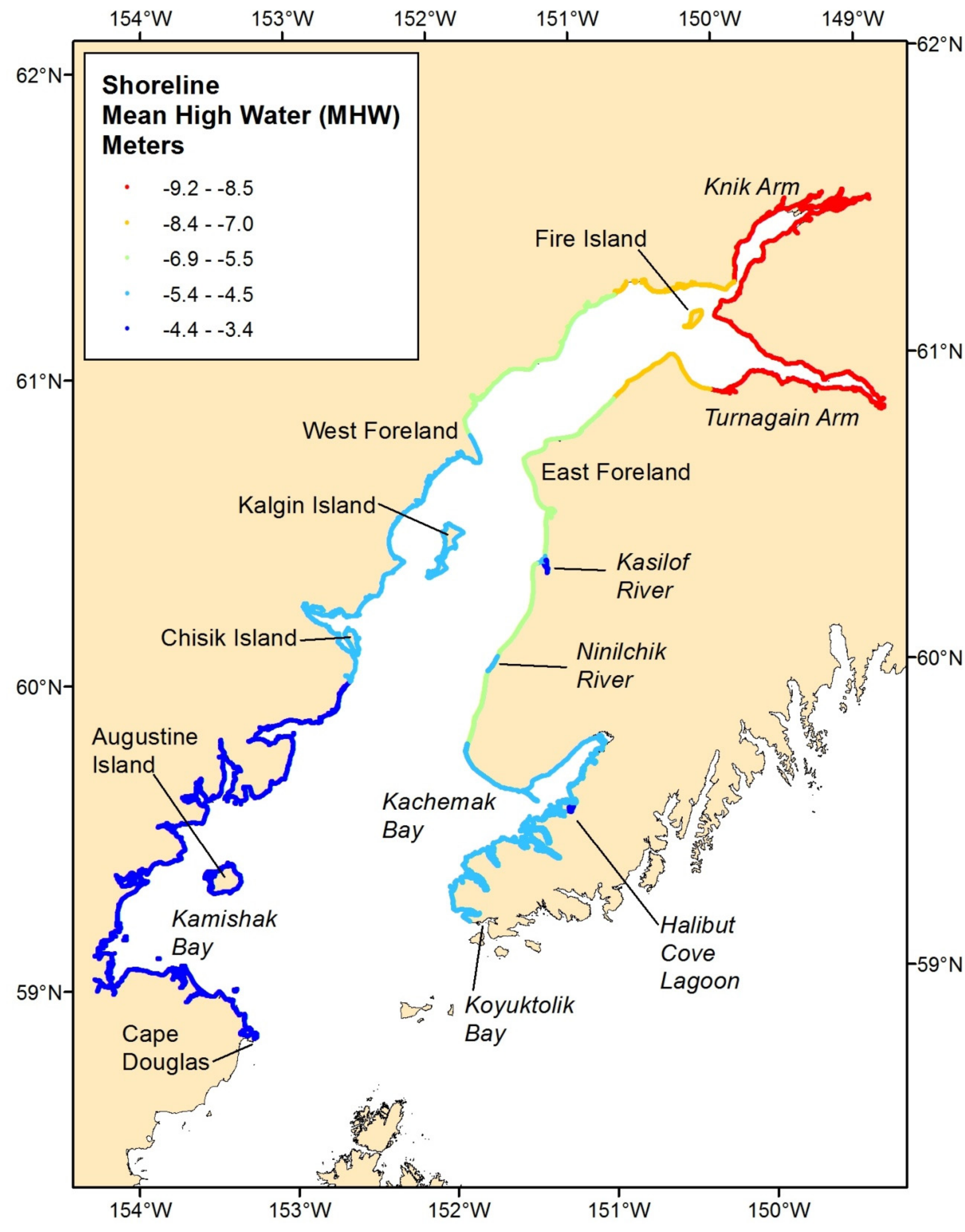

Figure 4. -- Shoreline digitized from the smooth sheets, mostly at a scale of 1:20,000.

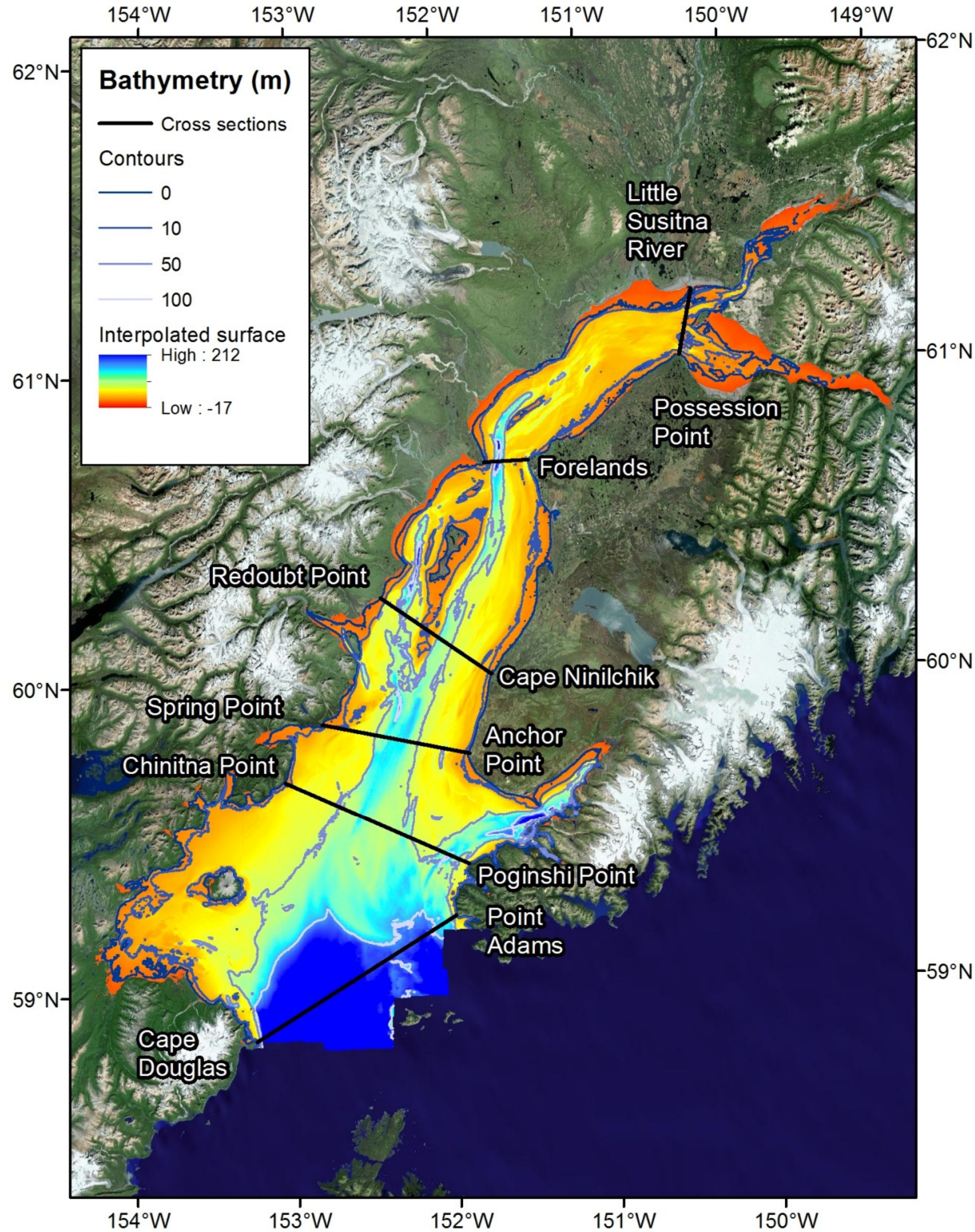

Figure 5. -- Bathymetry of Cook Inlet, Alaska, with an interpolated depth surface (50 m grid) and selected depth contour intervals. Straight black lines spanning the Inlet are six locations where horizontal areas or cross-sections of the water column were calculated. These data are not to be used for navigation.

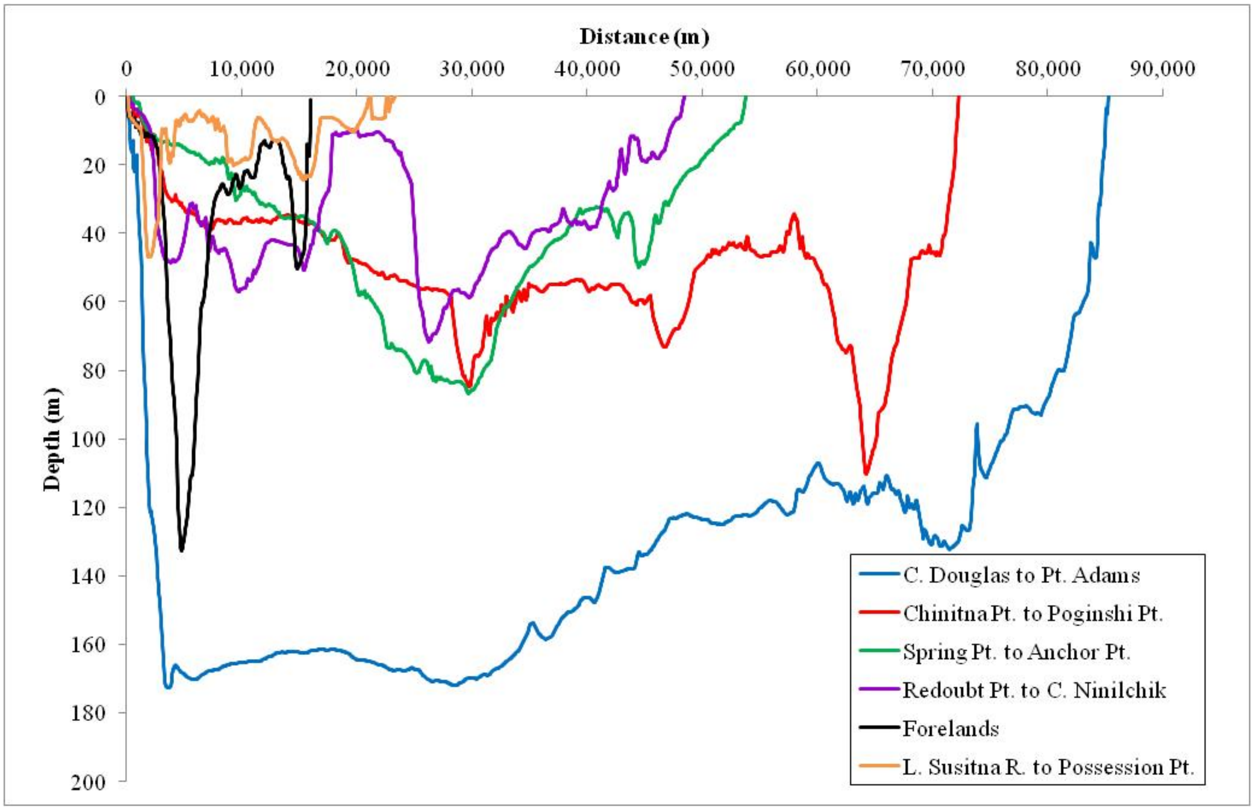

Figure 6. -- The horizontal profile, or cross-section, of the MLLW water column, as measured at six locations (see Fig. 5) ranging from the south end to the north end in Cook Inlet. The blue line shows a total horizontal area of 228,000 km^2 across the 85 km entrance to the Inlet, ranging from Cape Douglas on the left to Point Adams on the right. The next horizontal profile, shown in red, ranges from Chinitna Point to Poginshi Point, is nearly as far across as at the entrance, but only has one-third of the horizontal area. The next three lines - Spring Point (green), Redoubt Point (purple), and the Forelands (black) - have only one-fifth, one-seventh, and one-twentieth, respectively, of the horizontal area at the entrance. The northernmost horizontal profile, at the Little Susitna River, is only one-fiftieth of that at the entrance.

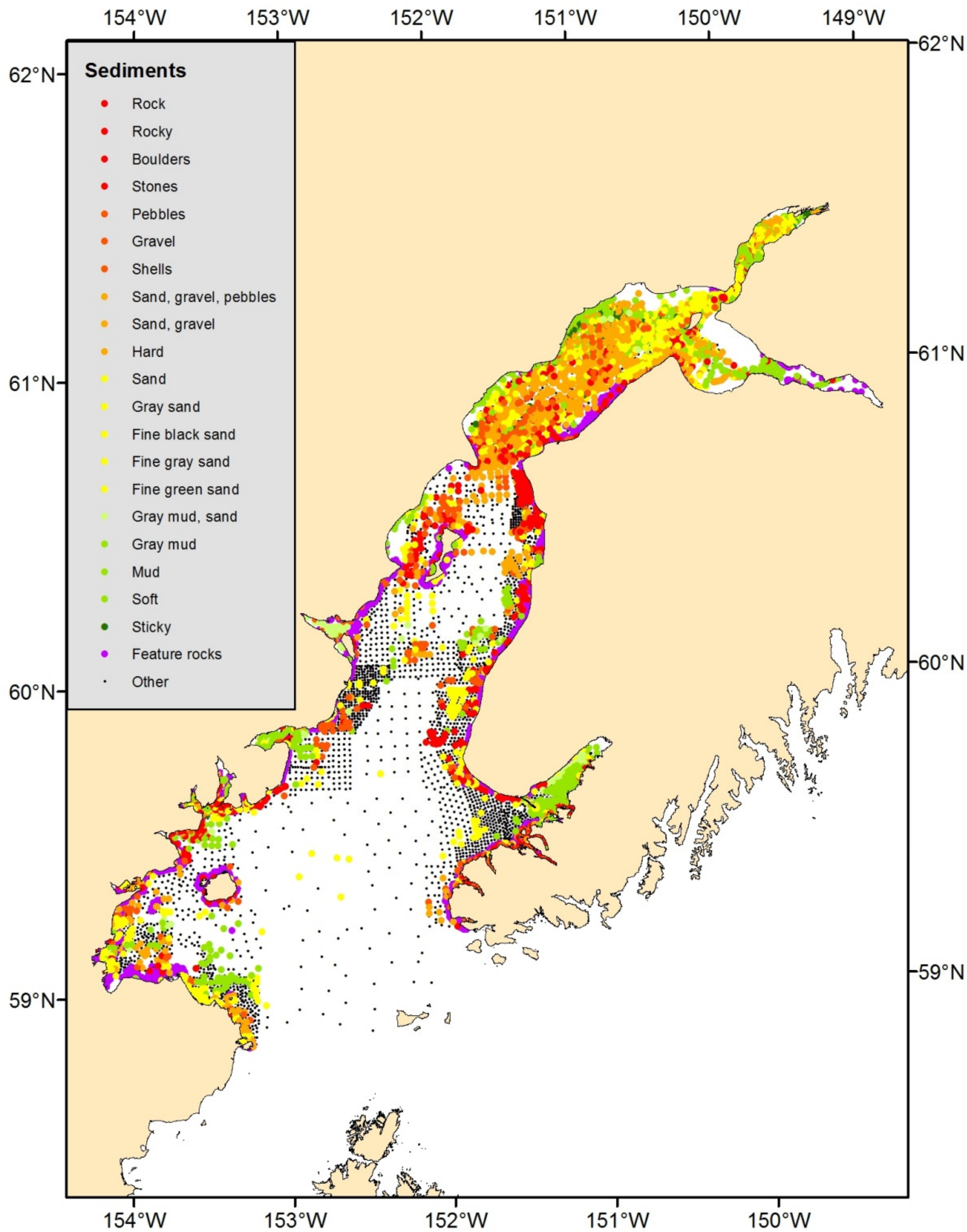

Figure 7. --Sediments digitized (n = 9,271) from the smooth sheets and Descriptive Reports. The top twenty categories, accounting for about 57% of the total number of samples, are colored on a scale ranging from large (red) to small (green) grain size diameter. The less abundant categories are indicated with smaller black dots. The 18,000 rock and rock allies (Feature rocks, islets, reefs and kelp beds) digitized from the smooth sheet bathymetry are represented as purple dots.

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