UTILIZING GIS TO CREATE HABITAT SUITABILITY MODELS FOR DUNGENESS CRAB IN SOUTHEAST ALASKA

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THESIS APPROVED

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Abstract

Creating habitat suitability models for Dungeness crab in Southeast Alaska, based on already collected information, could help fill research voids at low costs with few employees, which were otherwise thought to be unavailable to the Alaska Department of Fish and Game. The objective of this research was to develop six habitat suitability models for Southeast Alaskan Dungeness crab at various sex or life cycles (adult female, adult male, and juvenile) during two seasonal periods of the year (spring and summer versus fall and winter), based on four environmental variables (depth, substrate, slope, and the distance from estuaries) using GIS. Once the final maps were compared with independent presence-only field data, the study found that more than 95% of all specimens for all age and sex classes were found in the designated highly suitable areas for both seasonal classes. It was decided that the habitat suitability models from this study were appropriate for all age and sex classes (adult female, adult male, and juveniles) for both seasonal periods (spring/summer and fall/winter), except for juvenile Dungeness crab during the spring and summer months due to the lack of specimen data used to test the accuracy of the HSM model. Future research could involve obtaining more specimen and habitat data for age and sex classes lacking sufficient numbers of specimens. The hope is that this habitat suitability information will be used by the Alaska Department of Fish and Game to help protect vital habitat and to focus future research efforts in known key habitats.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ACRONYMS

ADFG = Alaska Department of Fish and Wildlife

CPUE = Catch Per Unit of Effort

CW = Carapace Width

FIPS = Federal Information Processing Standard

FW = Fall and Winter Months

GIS = Geographic Information System

HSM = Habitat Suitability Model

NAD = North American Datum

NOAA = National Oceanic and Atmospheric Administration

PU = Personal Use

SEAK = Southeast Alaska

SS = Spring and Summer Months

SU = Subsistence Use

CHAPTER 1 - INTRODUCTION

1.1. Species Background

The Dungeness crab, *Metacarcinus magister*, is a crustacean from the order Decapoda and Infraorder Brachyura, or "true crab" (Figure 1.1). They can be found from as far south as Magdalena Bay, Mexico and as far north as Unalaska, Alaska (ADFG 1985). Most male Dungeness crab can reach a carapace width (CW) of up to 215.9 millimeters (mm), females up to 160.2 mm, and both living between eight and ten years old (Pauley et al. 1986). Most Dungeness crab in Southeast Alaska reach legal maturity (CW of 165.1 mm), which is the point at which male Dungeness crab may be harvested, around four to five years of age. A female Dungeness crab can lay up to 2.5 million eggs, annually.

The life cycle of Dungeness crab includes four major periods: zoeal, megalope, juvenile, and adult. The zoeal period happens immediately after hatching and includes five molting stages. This period typically occurs from the winter to spring months while suspended in the water column (Headstrom 1979). The megalope stage is noted as the period when the crab increases in size, begins to shorten its tail, and makes its way toward the more shallow and protected shore. This period typically last during the spring and summer months, which at the end of this phase, they molt to juvenile status (CW of around 5 mm) and settle on the marine floor during the late summer months (Pauley et al. 1986). The entire larval period lasts between three and four months (Headstrom 1979). Males typically reach sexual maturity around 116 mm and females around 100 mm, which is around two years of age and after incurring 11 to 12 molt periods (Pauley et al. 1986). Juvenile crab are typically found in shallow estuarine habitats that consists of protective shell or eelgrass beds (Pauley et al. 1986). Juveniles enter the adult period around when they have reached a CW of 135 mm in SEAK (Bishop et al. 2008).

Figure 1.1. Male Dungeness crab (Bergmann 2015).

1.2. Crab Research and Management Background

Dungeness crab is a highly sought-after shellfish species in Southeast Alaska, and harvest type can be broken down into four major types of fisheries: personal use (PU), subsistence use (SU), sport, and commercial. These four different Dungeness crab fisheries in Southeast Alaska (SEAK) are managed by the Alaska Department of Fish and Game (ADFG) in a management area known as Region I (Figure 1.2). The PU and SU fisheries are open year-round to both residents (PU and SU) and non-residents (sport use). Sport use is specific to non-Alaskan residents, which has a more restricted harvest bag and possession limit, where PU and SU are specific to Alaska residents and have a more liberal bag and possession limit for Dungeness crab. The largest difference between PU and SU is that SU can be used to barter or trade for items, whereas PU can only be used for personal or family consumption (Stratman et al. 2014). There are specifically defined SU areas within SEAK, which are considered traditional and customary use areas. The commercial Dungeness crab fishery is generally open from June 15 to August 15 and from October 1 to November 30 or February 28, depending on the area. These commercial openings were historically thought to help avoid major female molting, mating, and egg-hatching periods for Dungeness crab for all of SEAK (Stratman et al. 2014).

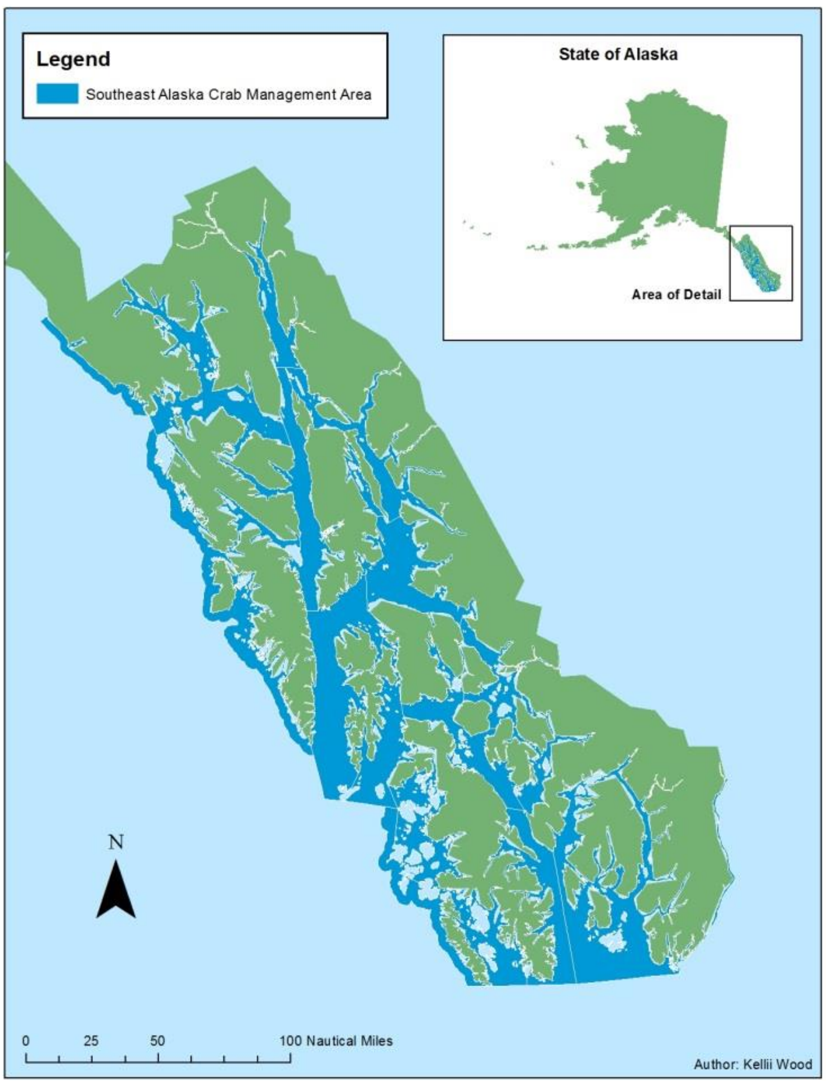

Figure 1.2. Southeast Alaska, management area Region I in the Alaska Department of Fish and Game.

There is no data on the amount of Dungeness crab harvested by PU fishermen, but on average, approximately 22,000 pounds (~10,000 crab) of legal male Dungeness crab are thought to be annually harvested by SU fishermen in SEAK (ADFG 2014).

There are currently 279 active commercial Dungeness crab fishery permits in SEAK, but a five-year average of approximately 174 permit holders have participated annually in the fishery since 2011 (Stratman et al. 2014). Southeast Alaska is the top exporter of Dungeness crab in Alaska and on average has a total market value of approximately $7.7 million (Stratman et al. 2014). ADFG currently does not conduct annual stock assessment surveys on the Dungeness crab population in SEAK. All information on Dungeness crab comes from dependent fisheries data in the form of fish tickets (a form of receipt of sale), dockside interviews, and biological information collected on Dungeness crab bycatch from annual Tanner and red king crab stock assessment surveys. An abundance-based Dungeness crab survey was conducted from 2000 to 2004, but due to a lack of funding and participants, this program was cut as funding had not been reissued and the ADFG Region I crab group has been and is currently understaffed. Obtaining better life history information on this species and determining better fishery periods for various areas of SEAK with minimal staff and funds could help ADFG better manage the Dungeness crab fishery.

Identifying key habitat requirements for various life cycle events for Dungeness crab can potentially help in determining nursery, mating, or other more susceptible areas throughout SEAK. Once these crucial areas are identified, ADFG could make more knowledgeable decisions to help protect them and, in the event more funding were to be granted to the crab group in the future, ADFG could focus its life history research efforts in areas of high suitability to Dungeness crab. Creating habitat suitability models based on already collected information for Dungeness crab can help fill research voids, at a low cost, that were otherwise thought to be unavailable.

1.3. Research Objective

The objective of this research was to develop a habitat suitability model for SEAK Dungeness crab at their various sex or life cycles during certain times of the year. For each age or sex class (male adults, female adults, or juveniles), two models were created based on seasonality: the fall/winter (September to December) versus the spring/summer months (March to August) using substrate, depth, slope, and distance from the estuaries as the four major factors. Dungeness crab data for January and February were unavailable.

1.4. Study Area Description

The marine waters of SEAK encompass the area from the United States and Canadian border from Dixon Entrance to the westernmost edge of Cape Fairweather, and three miles west off the coast of SEAK (Figure 1.3) (ADFG 2015a). These waters are home to many commercially viable species, including four species of crab, Pacific halibut, five species of Pacific salmon, various rockfish, Walleye Pollock, Pacific herring, and Pacific cod to name a few. Dungeness crab reside in these marine waters and are frequently harvested by residents of SEAK, as well as non-Alaskans. SEAK consists of nine boroughs, three major cities, and 23 towns and villages, with approximately 72,000 people living in SEAK year-round. This region neighbors British Columbia and Canada, contains four National parks, and incorporates the Tongass National Rainforest, which is considered a temperate rainforest.

The total area of these marine waters is approximately 37,000 square kilometers and has a shoreline length of approximately 21,053 kilometers. The body of water that encompasses SEAK consists of a series of fjords, sounds, inlets, and bays. The large number of rivers and creeks that discharge freshwater into these marine environments creates a great number of estuaries throughout SEAK. These estuaries are considered nursery and reproductive grounds for many marine species, including Dungeness crab, within this study area (Gunderson et al. 1990, Curtis and McGaw 2008). The depths of these waters at slack tide (no tidal movement) can range from zero to over 610 meters (2,000 feet) deep. Most of this area, depending on available data for the region, has been utilized for this project.

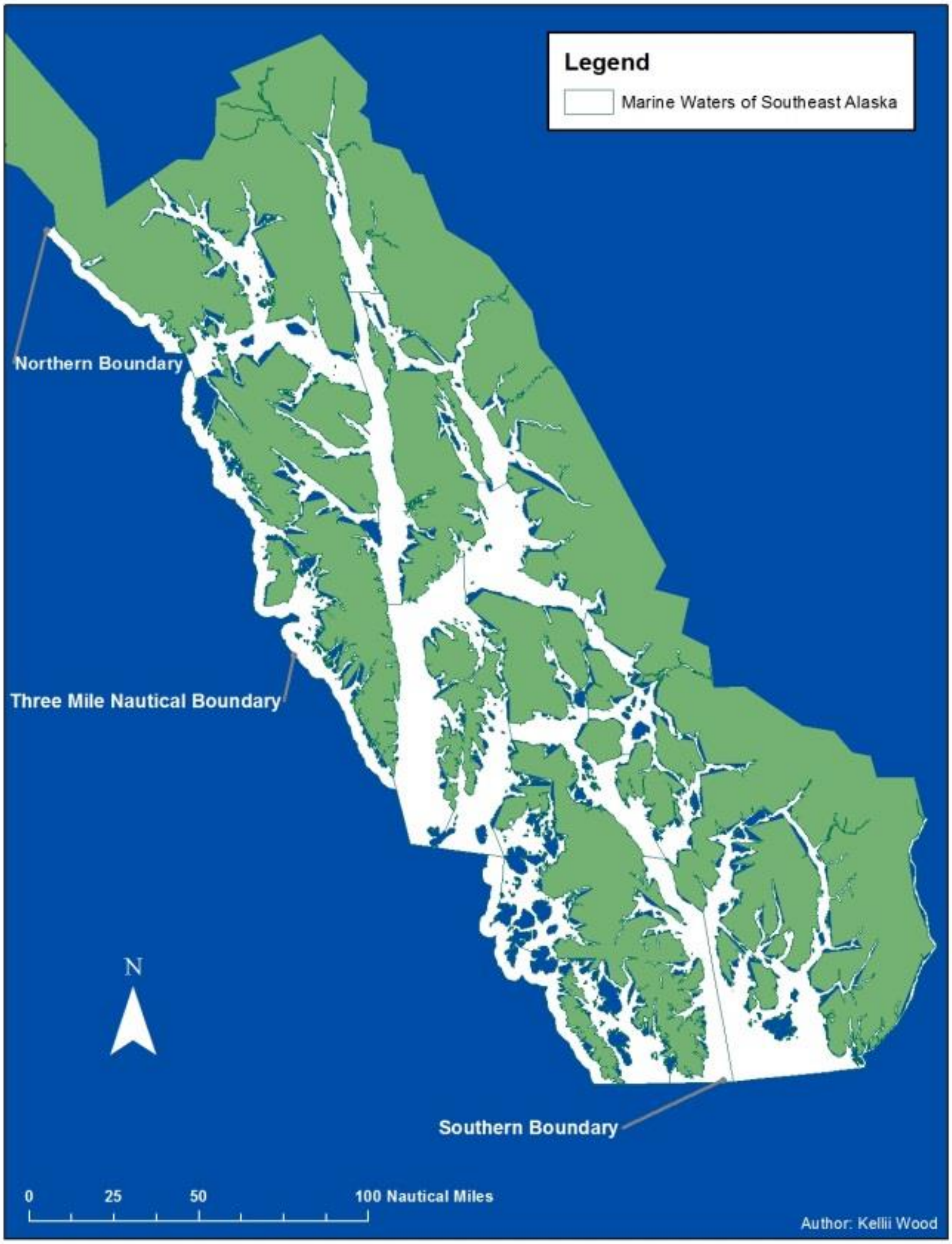

Figure 1.3. Marine waters of SEAK in the study area.

Chapter 2. Literature Review

2.1. Dungeness Crab Habitat

It has been noted by various crab experts that Dungeness crab can be found from the Aleutian Islands in Alaska to Santa Barbara, California, as well as others have mentioned they can be found as far south as Magdalena Bay, Mexico (ADFG 1985, Pauley et al. 1986, Fernandez et al. 1993, O'Clair and O'Clair 1998, Stone and O'Clair 2001, Holsman et al. 2006, Stratman et al. 2014). In Alaska, Dungeness crab are considered to be near the northern end of their range and can be found from the Dixon Entrance in Southeast Alaska (SEAK) to Unalaska on the Aleutian Islands in the Westward region of Alaska (ADFG 1985, Stratman et al. 2014). Dungeness crab can be found between 4 and 230 meters and on substrates that consists of mud and sand in SEAK (O'Clair and O'Clair 1998, Stratman et al. 2014). Further studies in SEAK have noted that Dungeness crab, in addition to mud and sand, can also be found on mixtures of sand, shell, silt, cobbles, and pebbles (O'Clair and O'Clair 1998).

In SEAK, various life events can affect the location of Dungeness crab. Both males and females have different distributions and seasonal movements depending on the time of year (O'Clair and O'Clair 1998, Stone and O'Clair 2001). On average, females can occupy a range of depths from 0.5 meters to 61.3 meters, can migrate around 1,500 meters (0.8 NM) from the head of estuaries, and can be found in slopes of about 10.2 to 18.3 degrees (Stone and O'Clair 2001). Adult male Dungeness crab typically occupy depths from 0.1 to 89.0 meters and migrate an average of 7,200 meters (3.9 NM) from the head of estuaries (Stone and O'Clair 2001).

2.1.1. Adult Dungeness Crab Mating Period

Mating typically occurs when crab become sexually mature, which for females is when their carapace width reaches 100 mm or greater and males with a carapace width of 116 mm or greater (Pauley et al. 1986, O'Clair and O'Clair 1998). Mating can only occur after the adult female Dungeness crab molts, which typically happens in the spring and summer and at shallow depths (less than 8 meters) within estuaries (ADFG 1985, Stone and O'Clair 2002, Stratman et al. 2014). Typically, after mating occurs, both adult females and males head to deeper waters (deeper than 10 meters) early in the fall to reduce environmental stress from lower salinities in estuaries while brooding eggs. Transitioning to deeper waters during this time also helps them deal with reduced food supplies and weather colder temperatures (ADFG 1985, Pauley et al. 1986, O'Clair and O'Clair 1998, Stone and O'Clair 2001, Stone and O'Clair 2002, Curtis and McGaw 2008).

2.1.2. Adult Female Dungeness Crab Life Events and Distribution

Various crab experts indicate that adult female Dungeness crab could possibly molt starting as early as May to as late as August or September in SEAK (ADFG 1985, Stone and O'Clair 2002, Stratman et al. 2014). The discrepancies between months may be due to the latitude in which the crab were studied, as molting can be delayed the further north Dungeness crab are found (ADFG 1985, Pauley et al. 1986). In addition, molt timing can vary year to year, depending on water temperature, salinity, or the availability of food sources (Weis 1976, ADFG 1985). Again, Dungeness crab can only mate after the adult female Dungeness crab has freshly molted, therefore mating occurs shortly after the female molt period (ADFG 1985, O'Clair and O'Clair 1998).

Soon after mating between July and October, adult female Dungeness crab move to water deeper than 10 meters, where they bury in sand and harden (Stone and O'Clair 2001, Stone and O'Clair 2002). Egg extrusion and brooding has been noted to begin around October to December and tends to continue until anywhere between March and June, where females tend to remain inactive and buried in loose sand substrate at depths greater than 10 to 20 meters deep in estuaries (ADFG 1985, Pauley et al. 1986, O'Clair and O'Clair 1998, Stone and O'Clair 2001, Stratman et al. 2014).

Starting around early April, adult female Dungeness crab begin to move inshore to depths of less than eight meters to hatch their eggs, which coincides with the spring phytoplankton bloom (Stone and O'Clair 2002,). However, Pauley et al. (1986) mentions that egg hatching and larvae release can begin as early as December and can continue to as late as June in British Columbia, which would be around a month sooner than SEAK, considering the difference in latitude. Adult females will typically stay at these shallow depths until around early June, when they will molt, mate, and head to deeper waters again in July (Stone and O'Clair 2002).

2.1.3. Adult Male Dungeness Crab Life Events and Distribution

The molt period for adult male Dungeness crab is from January until July (Stone and O'Clair 2001, Stratman et al. 2014). From April until July, adult males are typically found at depths shallower than 25 meters and segregated from females (ADFG 1985, Stone and O'Clair 2001). In late July, adult males become more active and are found moving back and forth vertically along the shoreline from estuaries to deeper water and back (Stone and O'Clair 2001). After mating occurs, adult males move to deeper water, greater than 30 meters. From November until April, they tend to reach even deeper waters, greater than 40 meters (ADFG 1985, Pauley et al. 1986, Stone and O'Clair 2001).

Younger and smaller adult males tend to be found on substrates that consists of sand and mud, in protected vegetation found in estuaries during various times of the year. Older and larger males can be found on a variety of substrates and in more unprotected environments (Pauley et al. 1986).

2.1.4. Juvenile Dungeness Crab Life Events and Distribution

The last larvae stage, megalope, molt to the sedentary juvenile stage around August in British Columbia, and possibly September in SEAK (Pauley et al. 1986). Juveniles are typically found in estuaries, eelgrass beds, or other protected coastal shallow waters (ADFG 1985, Pauley et al. 1986, Holsman et al. 2006, Curtis and McGaw 2008). Estuaries provide protection from predators and food for the young growing crab (Gunderson et al. 1990, Fernandez et al. 1993, Curtis and McGaw 2008). Juvenile Dungeness crab bury themselves in intertidal sandy substrate during the winter months in depths less than nine meters (ADFG 1985, Curtis and McGaw 2008). However, during the rest of the year, they can mostly be found in areas of high vegetation or substrates of shell for shelter (Fernandez et al. 1993, O'Clair and O'Clair 1998, Holsman et al. 2006, Curtis and McGaw 2008).

2.2. Habitat Suitability Modeling

The use of habitat suitability modeling using GIS requires few employees and could be a fiscally responsible method of determining potential Dungeness crab habitat data within SEAK, as habitat suitability modeling can be used for a great deal of management needs. Brown et al. (2000) mentioned that habitat suitability models, in the face of reduced funding or time constraints, could be a useful management tool in creating maps from poorly sampled environments, could help in identifying areas of conservation concern, and could identify areas that may be sensitive to environmental changes.

A habitat suitability analysis for Dungeness crab in Southeast Alaska has the potential to help locate potential habitat of this species by utilizing known environmental information in which a species in question exists. The creation of a habitat suitability model can take this known data and output a prediction of suitable habitat for a species during specific times or life cycles (Allen 1984, Bellamy et al. 2013, Belongie 2008, Brown et al. 2000, Burroughs 2013, Correa-Berger 2007, Vincenzi et al. 2005). Store and Kangas (2001) described habitat suitability modeling as a method to be used to identify the potential locations of a species in question based on environmental qualities of habitat preferred by said species. They also stated that habitat specifications are frequently identified by statistic correlation between the presence of a species and its surrounding environment (Store and Kangas 2001). Identifying key habitat features can be determined through literature; however, Lauver et al. (2002) determined viable habitat factors for the loggerhead shrike in Kansas by layering known locations of species on environmental data layers and extracting information through GIS. By doing this, they were able to identify key ranges of habitat data for particular HSM classes. Once these habitat factors are identified and reclassified in GIS for analysis and combined, the result is a map output showing a designated range of areas classified between suitable and unsuitable (Ball 2003).

Habitat suitability models assist in understanding habitat requirements for a species of focus based on specific variables associated with that habitat (Store and Kangas 2001, Ball 2003). Store and Kangas (2001) detailed four major steps to evaluating habitat for a species' habitat suitability model: 1) choosing factors or variables determined as significant to the fitness of a species, 2) acquiring and transforming data into a GIS application, 3) determining the area for analysis and combining variables for a final layer, and 4) conducting a sensitivity analysis in which various weights are applied to each factor to determine the best fit.

Brown et al. (2000) had a similar process as Store and Kangas (2001) for their habitat suitability models for eight fish and invertebrate estuarine species in Maine. They utilized temperature, salinity, depth, and substrate as important environmental conditions that pertained to their species and based the model around life history and critical seasons in which most life history changes occurred.

Classified ranks were assigned to each of these variables to determine low to high suitability for the species (Allen 1984, Bellamy et al. 2013, Brown et al. 2000, Burroughs 2013, Correa-Berger 2007, Toor et al. 2011, Vinagre et al. 2006, Vincenzi et al. 2005). Once these suitability layers had been created for each variable, assigned weights were applied (weighed overlay) and adjusted depending on the possible influence each has on the species' known preferences (Store and Kangas 2001). Brown et al. (2000) applied an equal weight of 25% to each variable, assuming that each environmental factor was equally important to species designation. They did not apply specific statistical analyses to determine their HSM levels, but rather chose ranges for each class, which provided a sufficient amount of area for their final HSM classifications (Brown et al. 2000). Vinagre et al. (2006) also chose to use an equal weighting system for all eight of their environmental factors, giving each a weight of 12.5%. These weighted suitability layers were then combined to create a final suitability layer showing areas of various levels or ranks of suitability for the species in question (Ball 2003, Brown et al. 2000, Mitchell et al. 2002, Store and Kangas 2001, Vinagre et al. 2006). Mitchell (2012) specified the importance of applying the same ranking to the individual suitability layers as what would be applied to the final suitability layers for a weighted suitability model. For example, if you were to apply a rank of '1' for low, '2' for moderate, and '3' for high, both the individual suitability layers (i.e. depth, substrate, slope, and distance) as well as the combined four layers would be designated the same 1-3 rank. Areas designated as having higher levels of suitability support greater rates of reproduction, growth, survivability, and a larger population of a species of focus, whereas areas deemed to be of lower suitability might not support a healthy population of said species (Brown et al. 2000).

2.3. Accuracy Assessment

To assess the accuracy of the final habitat suitability layers, several researchers compared the densities and location of their specimens against the final HSM map output (Belongie 2008, Brown et al. 2000, Toor et al. 2011, Vinagre at al. 2006). They found high accuracy (65% to 99% number of species found in highly suitable areas) in mapping habitat suitability in GIS for most land-based species (Bellamy et al. 2013, Belongie 2008, Brown et al. 2000, Burroughs 2013, Correa-Berger 2007, Lauver et al. 2002, Mitchell et al. 2002, Vincenzi et al. 2005).

Brown et al. (2000) compared the catch per unit of effort (CPUE) of each of their eight species in question to their final HSM maps. These comparisons were visually inspected by field experts to determine accuracies and potential outliers. In addition, the results from these comparisons were run through statistical tests, which will be detailed later. Toor et al. (2011) also layered the roosting locations of bats in their study with their final suitability maps and extracted HSM classification information along with known bat presences in order to determine the accuracy of their models. Vinagre et al. (2006) assessed accuracy by comparing the densities of two estuarine sole species found during surveys against their HSM models and then using statistical analyses to confirm significant differences between classification groups. Belongie (2008) compared known wolf pack ranges to HSM classifications and simply used a mean statistic to show the percentage of wolf populations within the study area. A statistical test was not used to show the significant differences between HSM classifications.

2.4. Findings

Ultimately, Brown et al. (2000) found that the estuarine species that had a well-known life history and were more substrate driven had results that were more significant when their CPUEs were compared against the final suitability maps. Creating HSM models for pelagic fish and species that were highly adaptable to most environments were found to be difficult in identifying highly suitable habitat. They also believed that their lack of environmental factor data for some of the species led to weak significance in statistical analyses.

Vinagre et al. (2006) identified clear and highly significant differences between HSM classifications for their study on two estuarine sole species. Initially, basic environmental factors such as substrate and depth did not produce significant differences. However, once they introduced food preference availability (amphipod densities), their statistical significance increased tremendously.

Lauver et al. (2002) found that the number of nesting trees was a valuable variable when determining ideal habitat for the loggerhead shrike. They had difficulty identifying appropriate vegetation with their aerial photography and believed that could have hindered the accuracy of their final models. They argued that for their research, fine scale digital imagery could have helped in a more accurate result.

In general, most studies showed that some manipulation to the various environmental factors and weights was necessary when comparing the final HSM maps to the known location, densities, or CPUE of the species of focus (Brown et al. 2000, Lauver et al. 2002, Mitchell et al. 2002, Rengstorf et al. 2013, Toor et al. 2011, Vinagre et al. 2006, Vincenzi et al. 2005).

CHAPTER 3 - METHODOLOGY

3.1. Data Descriptions

3.1.1. Data Sources

The data for this research was acquired or created from either ADFG or the National Oceanic and Atmospheric Administration (NOAA) databases. Table 3.1 shows the specific data that was used for the project, their sources, and creation or acquisition dates.

3.1.2. Dungeness crab specimen data

Dungeness crab locations were obtained from ADFG's directed Dungeness crab surveys from 2000 until 2004, and as bycatch from Tanner and red crab surveys from 1986 until 2017 (ADFG 2018). The information that was used from this data set included months, depths, coordinates of Dungeness crab presence, recruitment status (adult or juvenile), width (to determine juveniles from adults), and sex (for adult males and females only). This data set also included collection year, coordinates, pot and buoy numbers, depths at which specimens were located, and number of specimens collected at each coordinate. Specimen data from 1986 to 2016 was used to classify habitat layers and specimen data from 2017 was used to assess accuracy of the final suitability models.

ADFG sampled 53,605 Dungeness crab from 1986 to 2016 during their various crab surveys (Table 3.2). A total of 19,047 adult females were sampled during the spring and summer months and 8,330 adult females were sampled during the fall and winter months for a total sum of 27,377. The spring and summer total for sampled adult males was 19,232 and 6,137 for the fall and winter months leading to a total of 25,369 sampled adult males. Only 354 juvenile crab were sampled during the spring and summer months and 505 during the fall and winter months, leading to a total of 859 combined female and male juvenile crab sampled. For the accuracy assessment, a total of 966 crab were sampled in 2017 during various ADFG crab surveys. A total of 359 adult females were sampled during the spring and summer months, 48 adult females during the fall and winter months, 176 adult males during the spring and summer months, 173 adult males during the fall and winter months, 17 juveniles in the spring and summer, and 193 juveniles during the fall and winter months.

Table 3.1. Project data type, data sources, and date of data creation or acquisition.

Data	Sources	Date Created/Acquired
Dungeness crab specimens	ADFG	2016/2018
Substrate	NOAA, ADFG	2016
Bathymetry	NOAA	2013
Slope	NOAA	2016
Distance	ADFG	2016

Table 3.2. Number of Dungeness crab specimens for each age or sex class and for each seasonal class (1986 to 2016).

Season	Adult Females	Adult Males	Juveniles	Totals
Spring/Summer	19,047	19,232	354	38,633
Fall/Winter	8,330	6,137	505	14,972
Totals	27,377	25,369	859	53,605

Locations of Dungeness crab have been found in 16 major areas throughout SEAK between the months of March to December: Duncan Canal, Stikine Flats, Keku Strait, Thomas Bay, Farragut Bay, Pybus Bay, Gambier Bay, Seymour Canal, Juneau area, St. James Bay, Excursion Inlet, Icy Strait, Glacier Bay, Port Frederick, Tenakee Inlet, and Peril Straits (Figure 3.1). The crab found at these prime locations were used to identify key habitat requirements (1986 – 2016 ADFG surveys) and to assess the accuracy of the final habitat suitability maps (2017 ADFG surveys).

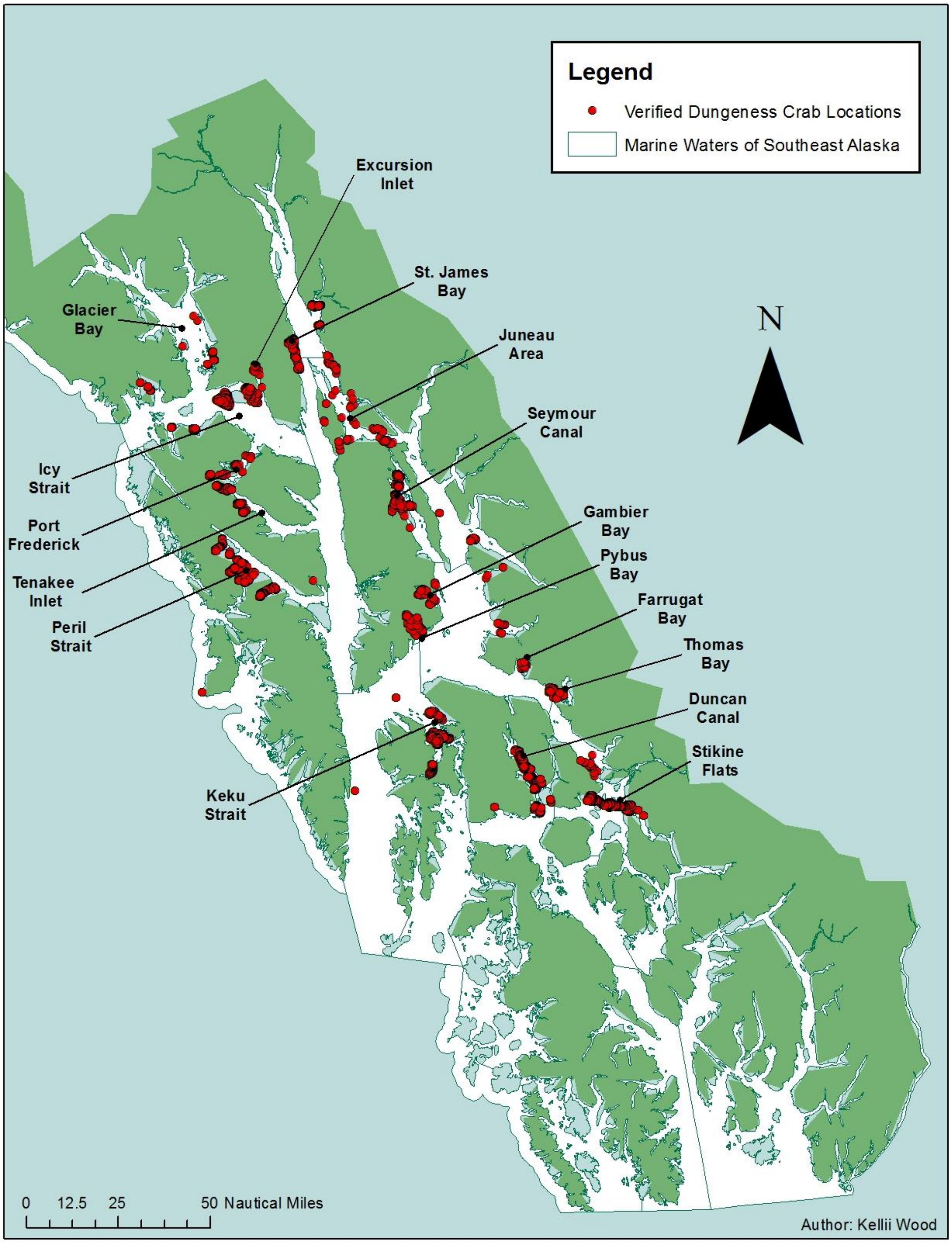

Figure 3.1. Known Dungeness crab locations identified by ADFG crab surveys.

3.1.3. Substrate data

Combined substrate data was documented by ADFG, which came from crab, shrimp, and dive surveys, as well as from the National Oceanic and Atmospheric Administration's (NOAA) Index to Marine and Lacustrine Geological Samples (IMLGS) (ADFG 2015b, ADFG 2016, Curators of Marine and Lacustrine Geological Samples Consortium 2016). Approximately 84% (33,737 points) of the substrate data was acquired from ADFG, with the remaining 16% (6,492 points) acquired from NOAA. There were 19 different types of substrate material found between ADFG and NOAA that were either wood (bark or larger wood types), fine material (sand, mud, silt, or clay), coarser or larger material (boulder, cobble, gravel, rock, pebble, or shell) or live-organic material (barnacle, mussels, seaweed, weed, grass, sponge, or coral) types (Table 3.3). Figure 3.2 shows the distribution of acquired combined substrate data points from both ADFG and NOAA.

Table 3.3. Substrate types found from ADFG and NOAA ocean bottom surveys.

Code	Substrate Type	Code	Substrate Type
1	Bark	11	Mussels
2	Barnacle	12	Pebble
3	Boulder	13	Sand
4	Clay	14	Seaweed
5	Cobble	15	Shell
6	Coral	16	Silt
7	Grass	17	Sponge
8	Gravel	18	Weed
9	Rock	19	Wood
10	Mud		

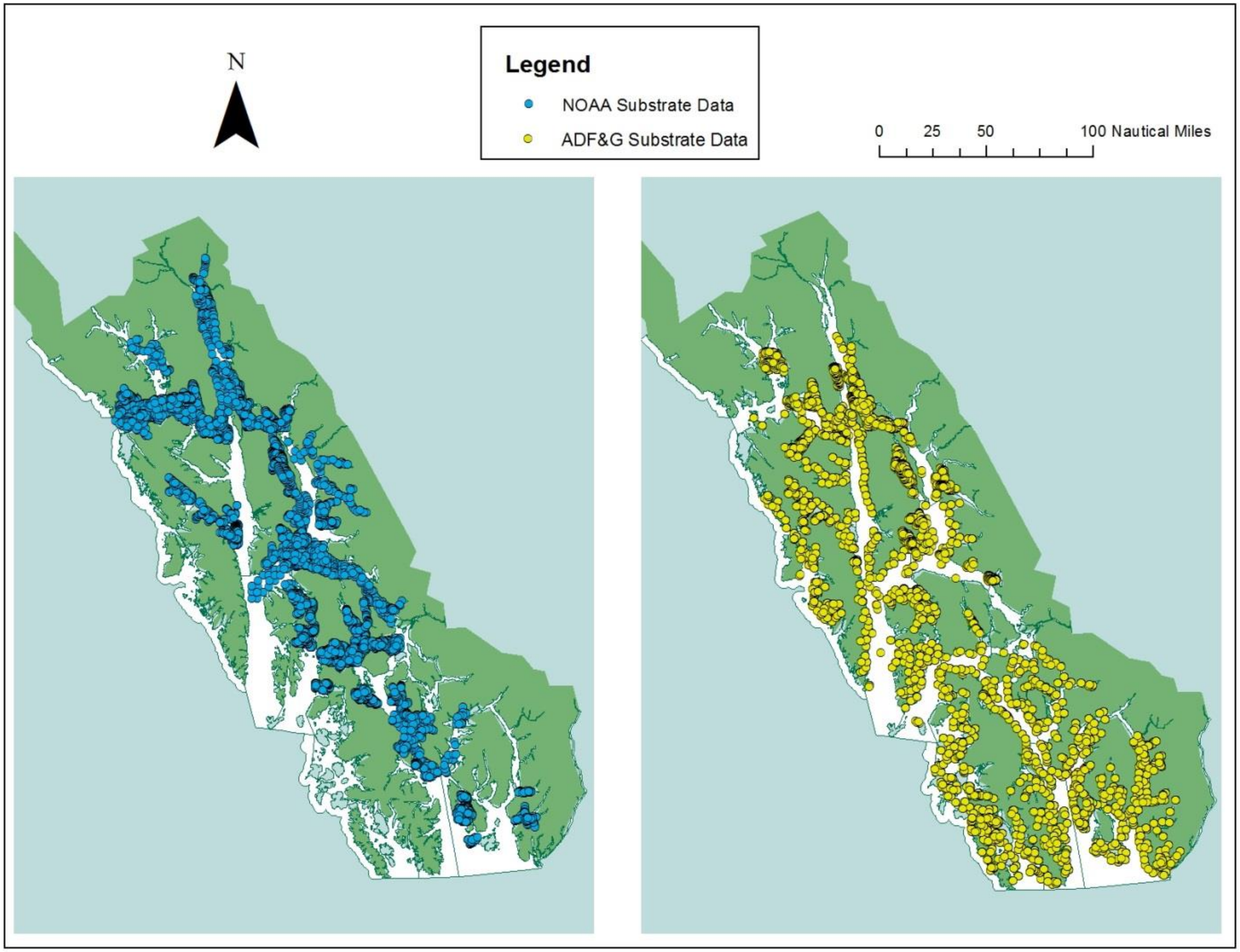

Figure 3.2. The distribution of known substrate types throughout SEAK.

3.1.4. Depth and Slope Data

Depth and slope were calculated from a 40-meter bathymetry raster acquired from NOAA (Lewis et al. 2013). Figure 3.3 shows the bathymetry raster and Figure 3.4 shows the slope raster, created from the bathymetry raster, which was used for this project.

3.1.5. Distance from Estuaries Data

The known locations of estuaries came from a polyline shapefile acquired by NOAA's Alaska ShoreZone (Figure 3.5). ShoreZone is a web-based mapping application that allows the user to download GIS data regarding shoreline characteristics, such as the location of estuaries, from the coasts of Washington State to the northern-most portion of Alaska (Harney 2008, Harper and Morris 2016). Estuaries, an environment where freshwater and saltwater meet to create brackish seawater conditions, are key habitats for various life cycle needs of Dungeness crab (Talley et al. 2011). Pauley et al. (1986) and Gunderson et al. (1990) found that estuaries were nursery grounds to juveniles and mating grounds for adult Dungeness crab. Stone and O'Clair (2001) and Holsman et al. (2006) established that once Dungeness crab settle in estuarine areas, they tend to stay within a certain range of their home site as adults, making vertical, seasonal migrations to and from intertidal zones to deeper waters throughout their lifetime. A distance raster was created from NOAA's estuary shapefile to determine ideal distances from estuaries during various Dungeness crab life cycles and seasonal migrations (Figure 3.5).

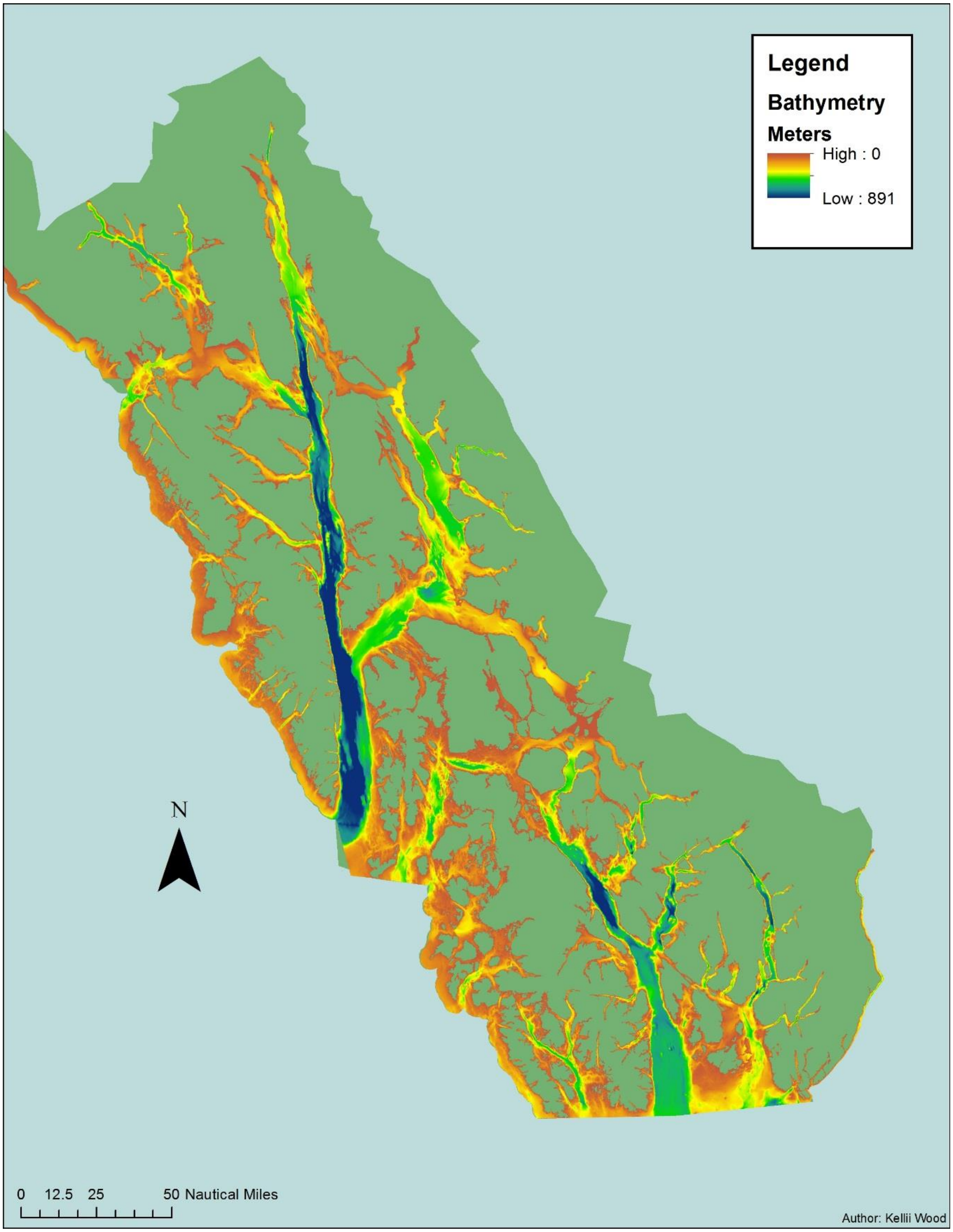

Figure 3.3. Bathymetry raster created from multibeam gridded data with 40-meter resolution acquired from NOAA.

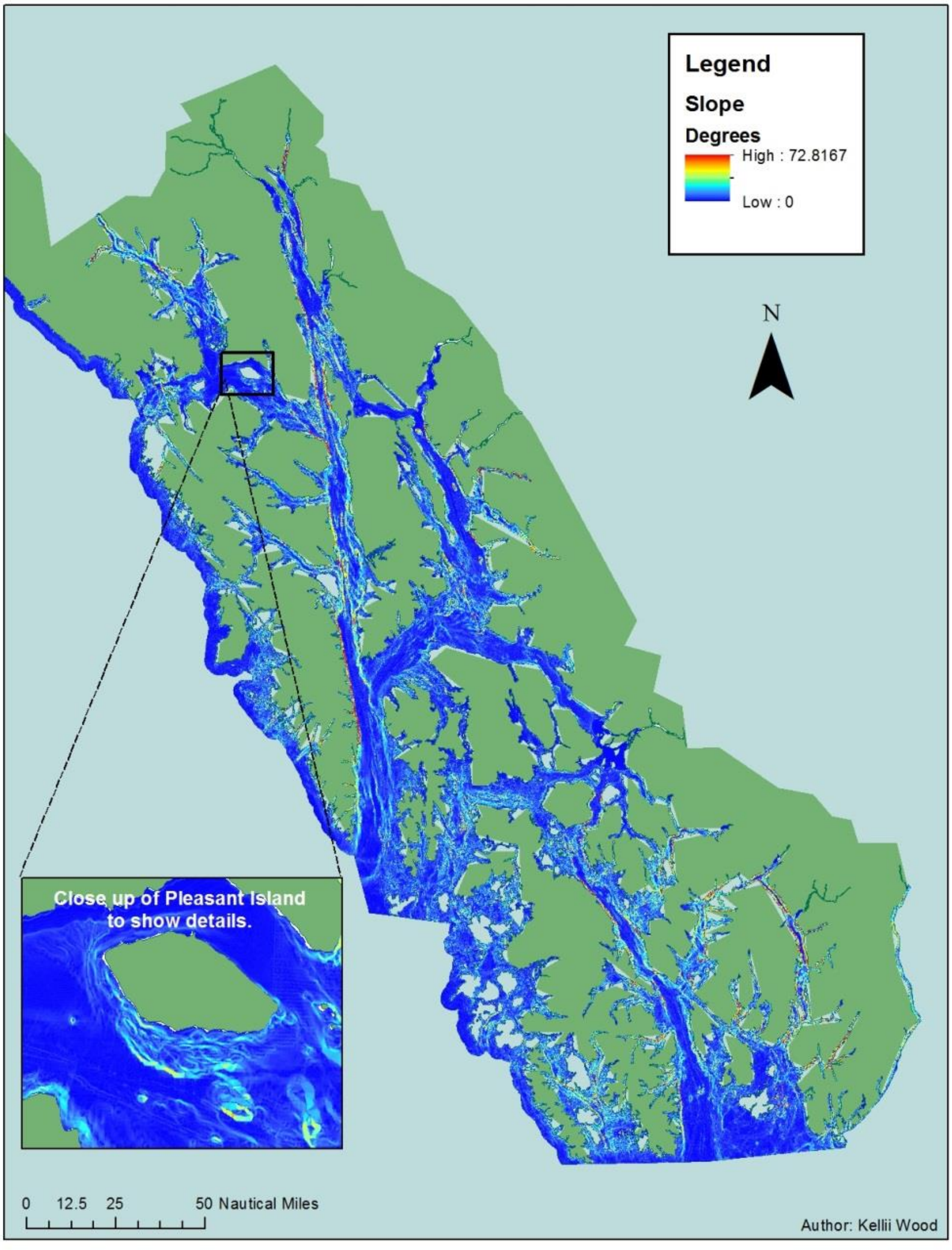

Figure 3.4. The slope raster (in degrees) created from the NOAA bathymetry raster.

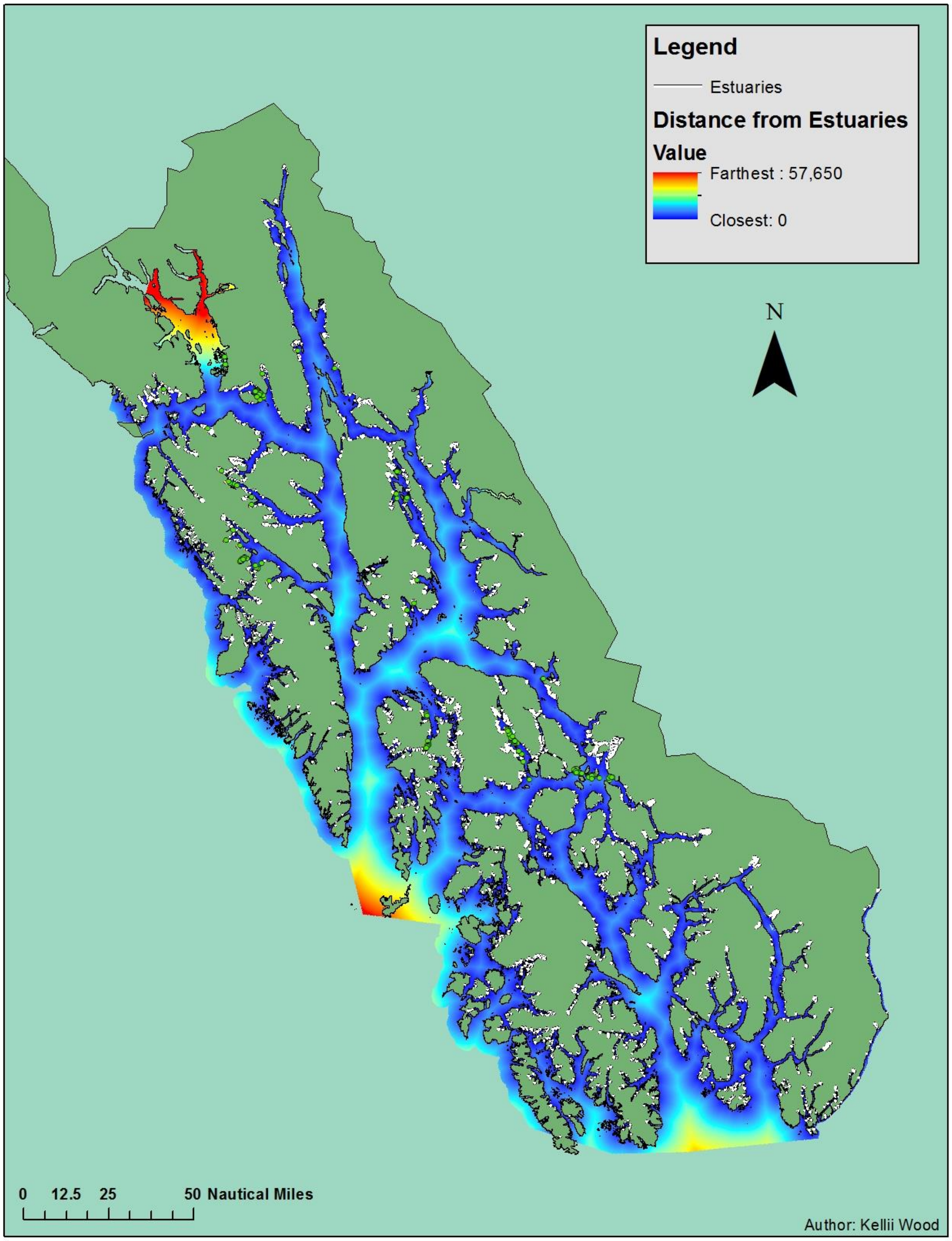

Figure 3.5. Known locations of estuaries and the Euclidean distance from these estuaries.

3.2. Dungeness Crab Habitat Variable Layers and Specifications

3.2.1. Model Overview

The flow chart in Figure 3.6 details the overall methodology for the entire project. In general, the four previously mentioned habitat variables (substrate type, depth, slope, and distance from estuaries) were obtained, transformed to rasters (if needed) with a cell size of 40-meters (same size as the source bathymetry raster), reclassified according to class specifics, and applied weights in a weighted overlay process using GIS. The projection and coordinate system used for this project are North American Datum (NAD) 1983 and State Plane Coordinate System for Alaska 1, using Federal Information Processing Standard (FIPS) 5001 in meters. This is the standard mapping system used for the State of Alaska.

In order to create habitat suitability models for adult and juvenile Dungeness crab; depth, substrate, slope, and distance from estuaries were considered as variables for each sex and age class during the fall/winter and spring/summer months. Highly suitable areas were classified as “3”, moderately suitable areas as “2”, and lower suitable areas as “1”. More specifically, for each variable type, a percentage of less than 1% of specimens found in any particular variable grouping was classified as having a rank of “1”, a percentage between 1% and 10% of the specimens found in a particular variable grouping was classified as having a rank of “2”, and any percentage of specimens found in a certain variable grouping above 10% was given a rank of “3”. Tables 3.4 through 3.9 detail the specific habitat needs for each sex and age class depending on the time of year in SEAK. A weight of 0.25 was applied to each variable for the final model.

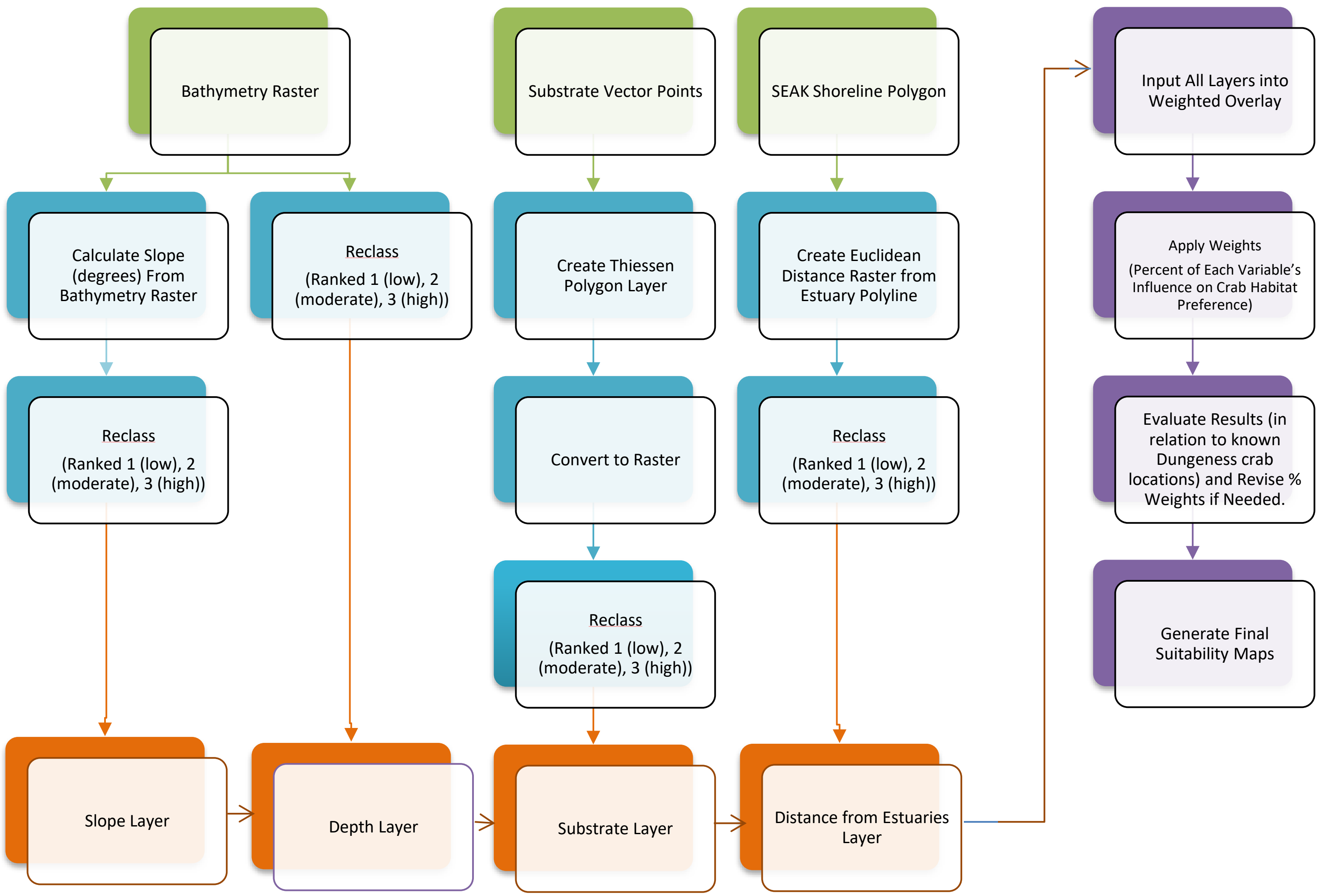

Figure 3.6. Methodology flowchart of the habitat suitability models for Dungeness crab in SEAK.

Table 3.4. Habitat requirements of adult female Dungeness crab – spring and summer months.

Habitat Variable	Suitability Rank[a]	Suitability Criteria	Applied Weight
Substrate	3	Mud	0.25
	2	Boulder, Cobble, Gravel, Rock, Sand, Shell, Silt	
	1	All Other Substrates	
Depth (m)	3	0 – 36.58	0.25
	2	36.59 – 91.44	
	1	>91.44	
Slope (degrees)	3	<=10.28	0.25
	2	10.29 - 20.85	
	1	>20.85	
Distance from Estuary (m)	3	0 – 4,391	0.25
	2	4,392 – 9,679	
	1	>9,679	

[a]3: High Suitability, 2: Moderate Suitability, 1: Low Suitability

Table 3.5. Habitat requirements of adult female Dungeness crab – fall and winter months.

Habitat Variable	Suitability Rank[a]	Suitability Criteria	Applied Weight
Substrate	3	Mud	0.25
	2	Cobble, Gravel, Rock, Sand, Shell, Silt	
	1	All Other Substrates	
Depth (m)	3	0 - 73.15	0.25
	2	73.16 – 91.44	
	1	>91.44	
Slope (degrees)	3	<=6.00	0.25
	2	6.01 - 20.85	
	1	>20.85	
Distance from Estuary (m)	3	866 – 6,154	0.25
	2	0-865, 6,155 – 9,679	
	1	>9,679	

[a]3: High Suitability, 2: Moderate Suitability, 1: Low Suitability

Table 3.6. Habitat requirements of adult male Dungeness crab – spring and summer months.

Habitat Variable	Suitability Rank[a]	Suitability Criteria	Applied Weight
Substrate	3	Mud	0.25
	2	Cobble, Rock, Sand, Shell	
	1	All Other Substrates	
Depth (m)	3	0 - 36.58	0.25
	2	36.59 - 73.15	
	1	>73.15	
Slope (degrees)	3	<=10.28	0.25
	2	10.29 - 20.85	
	1	>20.85	
Distance from Estuary (m)	3	0 - 6,154	0.25
	2	6,155 - 9,679	
	1	>9,679	

[a]3: High Suitability, 2: Moderate Suitability, 1: Low Suitability

Table 3.7. Habitat requirements of adult male Dungeness crab – fall and winter months.

Habitat Variable	Suitability Rank[a]	Suitability Criteria	Applied Weight
Substrate	3	Mud, Sand	0.25
	2	Cobble, Rock, Shell, Silt	
	1	All Other Substrates	
Depth (m)	3	0 - 36.58, 54.87 - 91.44	0.25
	2	36.59 - 54.86, 91.45 - 128.02	
	1	>128.02	
Slope (degrees)	3	<=10.28	0.25
	2	10.29 - 20.85	
	1	>20.85	
Distance from Estuary (m)	3	0 - 6,154	0.25
	2	6,155 - 9,679	
	1	>9,679	

[a]3: High Suitability, 2: Moderate Suitability, 1: Low Suitability

Table 3.8. Habitat requirements of juvenile Dungeness crab – spring and summer months.

Habitat Variable	Suitability Rank[a]	Suitability Criteria	Applied Weight
Substrate	3	Mud, Sand	0.25
	2	Rock, Shell, Silt	
	1	All Other Substrates	
Depth (m)	3	0 - 54.86	0.25
	2	54.87 - 91.44	
	1	>91.44	
Slope (degrees)	3	<=10.28	0.25
	2	10.29 - 15.13	
	1	>15.13	
Distance from Estuary (m)	3	0 - 4,391	0.25
	2	4,392 - 9,679	
	1	>9,679	

[a]3: High Suitability, 2: Moderate Suitability, 1: Low Suitability

Table 3.9. Habitat requirements of juvenile Dungeness crab – fall and winter months.

Habitat Variable	Suitability Rank[a]	Suitability Criteria	Applied Weight
Substrate	3	Mud, Sand	0.25
	2	Cobble, Gravel, Rock	
	1	All Other Substrates	
Depth (m)	3	0 - 91.44 m	0.25
	2	91.45 - 109.73 m	
	1	>109.73 m	
Slope (degrees)	3	<=10.28	0.25
	2	10.29 - 15.13	
	1	>15.13	
Distance from Estuary (m)	3	866 - 6,154	0.25
	2	0 - 865, 6,155 - 7,917	
	1	>7,917	

[a]3: High Suitability, 2: Moderate Suitability, 1: Low Suitability

3.2.2. Habitat Variable: Depth

Stone and O'Clair (2001), based on ten female and eight male samples in Fritz Cove, Alaska, determined that adult female Dungeness crab were typically found in depths deeper than 20 meters (66 feet) and males were found in depths greater than 40 meters (131 feet) between the months of November and April. They also found that females went to shallower depths (less than 8 meters or 26 feet) between April and June and then back to deeper depths in July, whereas males went to less than 25 meters (82 feet) between April and July. Males then went deep again (more than 30 meters or 98 feet deep) during the fall months until the following April (Stone and O'Clair 2001).

Creating the depth suitability layer involved reclassifying the acquired 40-meter bathymetry raster from NOAA. Due to the small sample size and restricted study area used by Stone and O'Clair (2001), it was determined that utilizing the known locations of Dungeness crab and depth at which they were found from ADFG (2016) would be a better measure for ideal depths. These depths were classified into 10 classes based on 10 fathom differences, which is the measurement used in the original dataset, but were converted to meters for analyses (Table 3.10).

The number of specimens (adult females, adult males, or juveniles) found at each depth class and associated percentages for each season class can be found in Table 3.11 and as a bar graph in Figure 3.7. Table 3.12 details the total percentages of each class found within each rank. Tables 3.4 through 3.9 show the specific criteria used for each suitability rank for all age, sex, and seasonal classes.

Table 3.10. Depth bins or classes (fathoms to meters) used to identify specimen frequencies.

Class	Fathoms	Meters
1	0-10	0 - 18.29
2	11-20	18.30 - 36.58
3	21-30	36.59 - 54.86
4	31-40	54.87 - 73.15
5	41-50	73.16 - 91.44
6	51-60	91.45 - 109.73
7	61-70	109.74 - 128.02
8	71-80	128.03 - 146.30
9	81-90	146.31 - 164.59
10	91-100	164.60 - 182.88

Table 3.11. The number and percentage of specimens found at various depths (in meters) at each age or sex class and during either the spring and summer or fall and winter months.

Depth (Meters)	Females				Males				Juveniles			
	Spring/Summer		Fall/Winter		Spring/Summer		Fall/Winter		Spring/Summer		Fall/Winter	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
0 - 18.29	6,281	32.98%	1,312	15.75%	8,486	44.12%	1,952	31.81%	96	27.12%	85	16.83%
18.30 - 36.58	9,457	49.65%	2,082	24.99%	9,247	48.08%	1,864	30.37%	171	48.31%	202	40.00%
36.59 - 54.86	1,385	7.27%	978	11.74%	718	3.73%	467	7.61%	68	19.21%	53	10.50%
54.87 - 73.15	1,461	7.67%	3,319	39.84%	617	3.21%	824	13.43%	12	3.39%	85	16.83%
73.16 - 91.44	245	1.29%	573	6.88%	64	0.33%	719	11.72%	5	1.41%	74	14.65%
91.45 - 109.73	133	0.70%	59	0.71%	62	0.32%	231	3.76%	2	0.56%	6	1.19%
109.74 - 128.02	82	0.43%	6	0.07%	35	0.18%	63	1.03%	0	0.00%	0	0.00%
128.03 - 146.30	2	0.01%	0	0.00%	1	0.01%	11	0.18%	0	0.00%	0	0.00%
146.31 - 164.59	1	0.01%	1	0.01%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
164.60 - 182.88	0	0.00%	0	0.00%	2	0.01%	6	0.10%	0	0.00%	0	0.00%
Total Specimens Sampled	19,047		8,330		19,232		6,137		354		505	

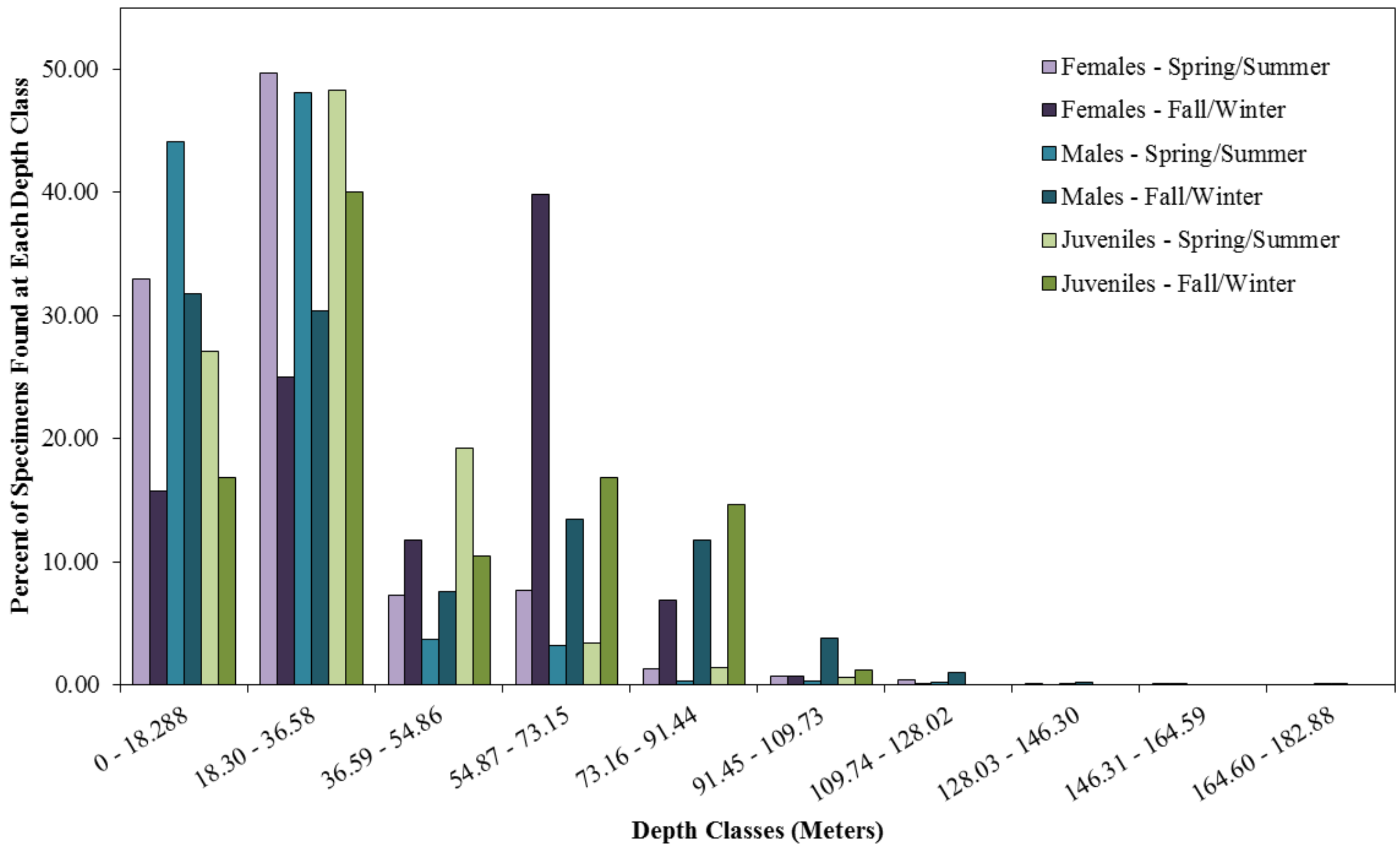

Figure 3.7. Percent of specimen classes found at each depth class.

Table 3.12. The total percentages of each age or sex class during either the spring and summer or fall and winter season for each classified suitability rank for depth.

Age or Sex Class	Seasonal Class	Rank Classification 3	2	1
Females	SS	82.63%	16.23%	1.14%
	FW	92.33%	6.88%	0.79%
Males	SS	92.21%	6.94%	0.85%
	FW	87.32%	12.40%	0.28%
Juveniles	SS	94.63%	4.80%	0.56%
	FW	98.81%	1.19%	0.00%

SS: spring and summer months.
FW: fall and winter months

3.2.3. Habitat Variable: Substrate

A combination of acquired literature stated that Dungeness crab of all sex and age class preferred sand, mud, and silt as their substrate of choice (ADFG 1985, O'Clair and O'Clair 1998, Pauley et al. 1989, Stone and O'Clair 2001, Stone and O'Clair 2002). In order to confirm ideal substrate types for this study, the known locations of Dungeness crab for each sex and age class were compared against the substrate layer created from NOAA and ADFG data.

The substrate layer was created using the Thiessen method, in which the known substrate points are interpolated, or used to estimate substrate for areas with no data based on the known neighboring data points (Figure 3.8). As mentioned in the literature review, the Thiessen method is a preferred interpolation process for categorical data, as categorical data do not carry any form of measurement or rank (Mulcan et al. 2015). The resulting Thiessen polygon layer consisting of the 19 different substrate types was then converted to a raster format and reclassified to the three classified ranks used for analyses.

The number of specimens (adult females, adult males, or juveniles) found at each substrate type and associated percentages for each season class can be found in Table 3.13 and as a bar graph in Figure 3.9. Table 3.14 details the total percentages of each class found within each rank. Tables 3.4 through 3.9 illustrate the specific criteria used for each suitability rank for all age, sex, and seasonal classes.

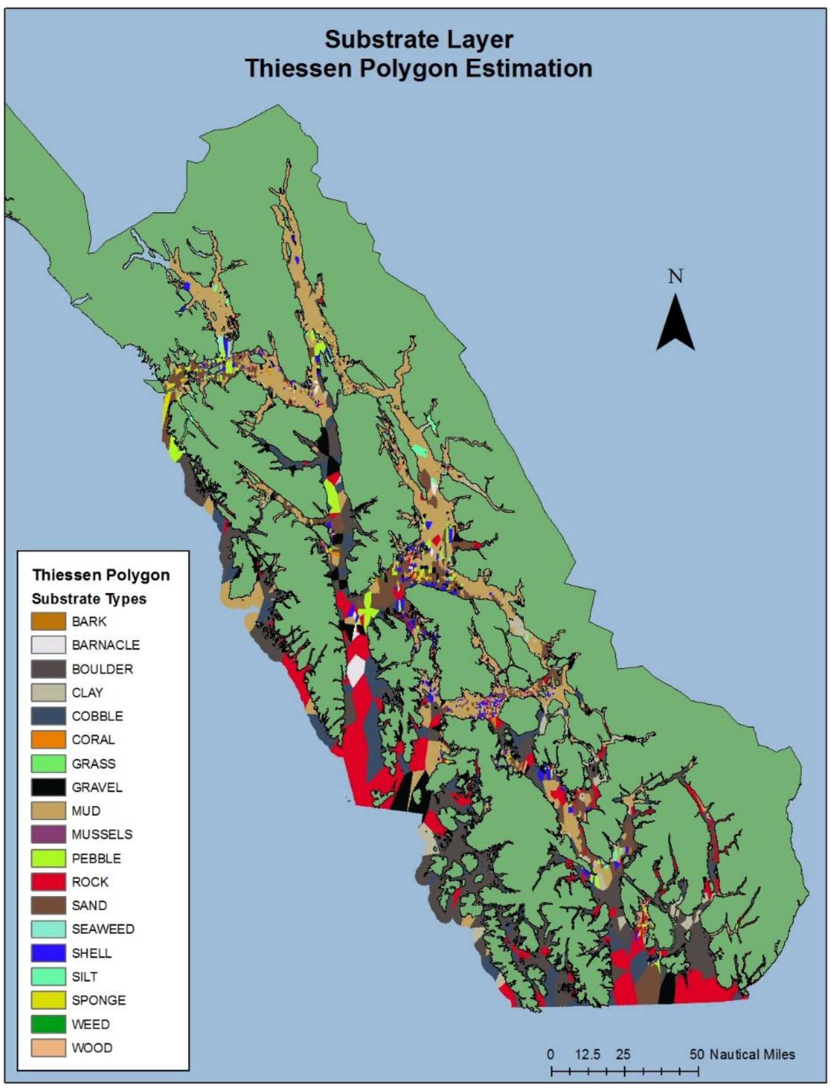

Figure 3.8. Thiessen polygon substrate layer based on ADFG and NOAA data.

Table 3.13. The number and percentage of specimens found in various substrates at each age or sex class and during either the spring and summer or fall and winter months.

Substrate	Females				Males				Juveniles			
	Spring/Summer		Fall/Winter		Spring/Summer		Fall/Winter		Spring/Summer		Fall/Winter	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Bark	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Barnacle	0	0.00%	0	0.00%	2	0.01%	0	0.00%	0	0.00%	0	0.00%
Boulder	217	1.14%	33	0.40%	133	0.69%	11	0.18%	0	0.00%	0	0.00%
Clay	21	0.11%	4	0.05%	4	0.02%	2	0.03%	0	0.00%	0	0.00%
Cobble	441	2.32%	156	1.87%	480	2.50%	97	1.58%	3	0.85%	8	1.60%
Coral	5	0.03%	0	0.00%	4	0.02%	0	0.00%	0	0.00%	0	0.00%
Grass	2	0.01%	0	0.00%	35	0.18%	0	0.00%	0	0.00%	0	0.00%
Gravel	204	1.08%	87	1.04%	148	0.77%	41	0.67%	2	0.56%	7	1.40%
Rock	979	5.16%	480	5.76%	964	5.03%	281	4.58%	13	3.67%	10	2.00%
Mud	15,363	80.96%	6,394	76.78%	14,700	76.63%	4,745	77.32%	262	76.01%	400	79.84%
Mussels	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Pebble	62	0.33%	51	0.61%	54	0.28%	33	0.54%	1	0.28%	0	0.00%
Sand	736	3.88%	446	5.36%	1,868	9.74%	677	11.03%	43	12.15%	72	14.37%
Seaweed	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Shell	731	3.85%	147	1.77%	697	3.63%	133	2.17%	21	5.93%	1	0.20%
Silt	214	1.13%	530	6.36%	95	0.50%	117	1.91%	9	2.54%	3	0.60%
Sponge	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Weed	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Wood	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Total Specimens Sampled	18,975*		8,328*		19,184*		6,137		354		501*	

*Number differs from original dataset due to not all specimens falling within substrate layer.

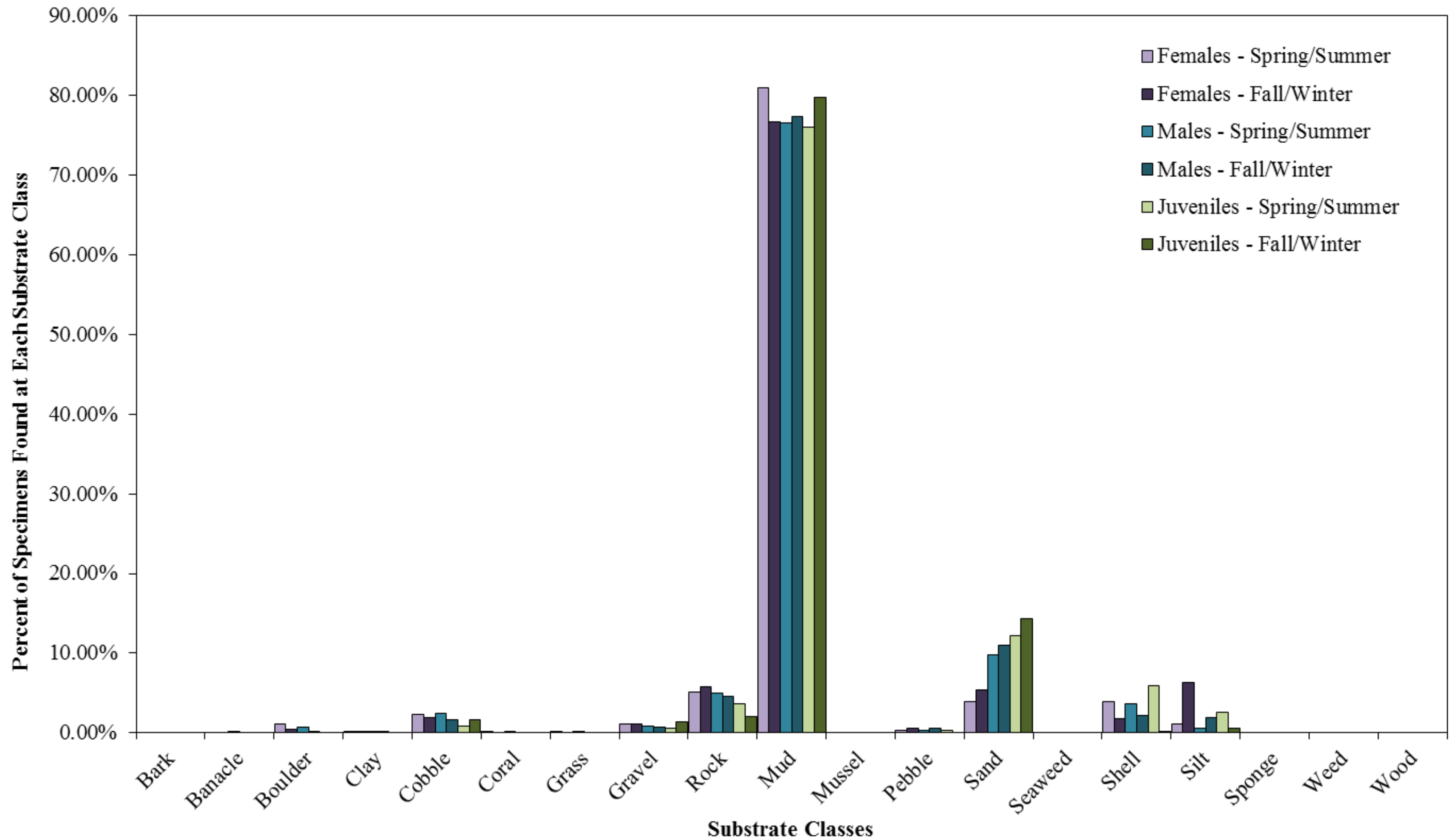

Figure 3.9. Percent of specimens found in each substrate type.

Table 3.14. The total percentages of each age or sex class during either the spring and summer or fall and winter season for each classified suitability rank for substrate.

Age or Sex Class	Seasonal Class	Rank Classification 3	2	1
Females	SS	80.96%	18.56%	0.47%
	FW	76.78%	22.17%	1.06%
Males	SS	76.63%	20.90%	2.48%
	FW	88.35%	10.23%	1.42%
Juveniles	SS	88.16%	12.15%	1.69%
	FW	94.21%	5.00%	0.80%

SS: spring and summer months.
FW: fall and winter months

3.2.4. Habitat Variable: Slope

Stone and O'Clair's (2001) study was the only publication found in regard to Dungeness crab and slope preference in SEAK. The only mention of slope was in regard to ovigerous females favoring moderate slopes between 18 to 33% (10.20 to 18.26 degrees), and these observations were only based on ten female specimens. Anecdotal information from discussions with local Alaskan divers indicates that Dungeness males can be found on nearly all degrees of slope throughout the region.

To get a better idea of preferred slope for each age and sex class for this study, as done with previous habitat variables, the known locations of Dungeness crab were compared against the slope layer created from NOAA's bathymetry layer.

Slope was calculated in degrees based on the bathymetry layer acquired from NOAA (Lewis et al. 2013) and outputted as a 40-meter raster. Slope is computed by calculating the maximum rate of variation from one cell value in a raster to the neighboring cell values (Chang 2008). The resulting slope raster was then reclassified to match the specifications for each age and sex class by season.

In order to identify ideal slope, the slope raster was classified into eight classes using the natural breaks classification. A natural break classification breaks data up into clustered groups based on distribution of the data (Chang 2008). These eight classification breaks can be seen in Table 3.15. Table 3.16 and Figure 3.10 show the percent of specimens of each class and season found in each slope class using the method previously detailed. The total percentages for each rank classification for all age and sex classes for slope can be seen in Table 3.17. Tables 3.4 through 3.9 shows the specific criteria used for each suitability rank for all age, sex, and seasonal classes.

Table 3.15. Slope bins or classes (natural breaks classification) used to identify specimen frequencies.

Class	Slope (Degrees)
1	0 - 2.57
2	2.57 - 6.00
3	6.01 - 10.28
4	10.29 - 15.13
5	15.14 - 20.85
6	20.86 - 27.98
7	27.99 - 37.41
8	37.42 - 72.82

Table 3.16. The number and percentage of specimens found within various ranges of slope (degrees) at each age or sex class and during either the spring and summer or fall and winter months.

Slope in Degrees	Females				Males				Juveniles			
	Spring/Summer		Fall/Winter		Spring/Summer		Fall/Winter		Spring/Summer		Fall/Winter	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
0 - 2.57	10,775	56.57%	5,373	64.50%	8,617	44.84%	3,189	51.96%	172	48.59%	242	48.30%
2.57 - 6.00	3,981	20.90%	1,812	21.75%	5,157	26.83%	1,800	29.33%	111	31.36%	194	38.72%
6.01 - 10.28	2,563	13.46%	654	7.85%	3,365	17.51%	684	11.15%	55	15.54%	54	10.78%
10.29 - 15.13	1,112	5.84%	301	3.61%	1,534	7.98%	335	5.46%	15	4.24%	10	2.00%
15.14 - 20.85	601	3.16%	181	2.17%	522	2.72%	118	1.92%	1	0.28%	1	0.20%
20.86 - 27.98	15	0.08%	9	0.11%	24	0.12%	11	0.18%	0	0.00%	0	0.00%
27.99 - 37.41	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
37.42 - 72.82	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Total Specimens Sampled	19,047		8,330		19,219*		6,137		354		501*	

*Number differs from original dataset due to not all specimens falling within slope layer.

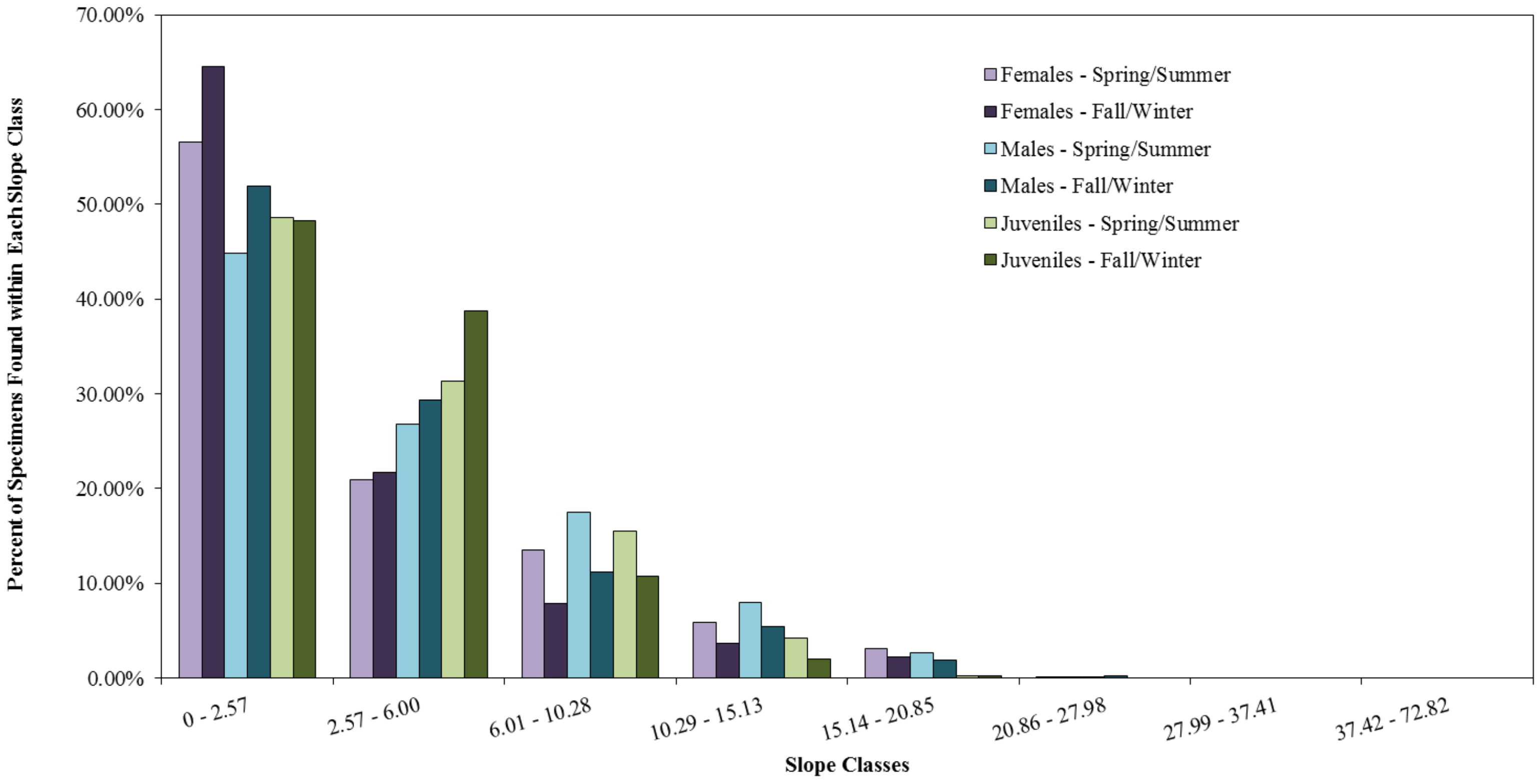

Figure 3.10. Percent of specimens found in each slope classification (natural breaks).

Table 3.17. The total percentages of each age or sex class during either the spring and summer or fall and winter season for each classified suitability rank for slope.

Age or Sex Class	Seasonal Class	Rank Classification		
		3	2	1
Females	SS	90.93%	9.00%	0.08%
	FW	86.25%	13.64%	0.11%
Males	SS	89.18%	10.70%	0.12%
	FW	92.44%	7.38%	0.18%
Juveniles	SS	95.48%	4.24%	0.28%
	FW	97.80%	2.00%	0.20%

SS: spring and summer months.
FW: fall and winter months.

3.2.5. Habitat Variable: Distance from Estuaries

Stone and O'Clair (2001) stated in their study that females seasonally moved a small range from the head of their estuarine location toward the mouth of the cove and back. They found that the adult females tended to migrate an average of 400 meters (0.22 NM), whereas the adult males tended to migrate an average of 3,750 meters (2.02 NM) seasonally. To validate Stone and O'Clair's (2001) finding for this study, the known locations of Dungeness crab were compared against the Euclidean distance layer created from NOAA's estuary polyline data.

Euclidean distance calculates the distance in each raster cell from a particular source (i.e. the estuary polyline) (Chang 2008). This raster layer was reclassified to the three ranks to match the specifications for each age and sex class by season (Tables 3.4 to 3.9). In order to identify ideal distance from estuaries, the Euclidean distance raster was classified into 17 classes using the natural breaks classification. These 17 classification breaks can be seen in Table 3.18. Table 3.19 and Figure 3.11 show the percent of specimens of each class and season found in each distance class using the method detailed above. The total percentages for each rank classification for all age and sex classes for distance from estuaries can be seen in Table 3.20.

Table 3.18. Euclidean distance from estuaries bins or classes (natural breaks classification) used to identify specimen frequencies.

Classes	Distance from Estuaries (meters)
1	0 - 865
2	866 – 2,628
3	2,629 – 4,391
4	4,392 – 6,154
5	6,155 – 7,917
6	7,918 – 9,679
7	9,680 – 11,442
8	11,443 – 13,205
9	13,206 – 14,968
10	14,969 – 16,731
11	16,732 – 18,493
12	18,494 – 20,256
13	20,257 – 22,019
14	22,020 – 23,782
15	23,783 – 25,545
16	25,546 – 27,308
17	27,309 – 57,651

Table 3.19. The number and percentage of specimens found within various classifications of Euclidean distance from estuaries at each age or sex class and during either the spring and summer or fall and winter months.

Distance from Estuaries	Females				Males				Juveniles			
	Spring/Summer		Fall/Winter		Spring/Summer		Fall/Winter		Spring/Summer		Fall/Winter	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
0 - 865	3,767	19.82%	761	9.14%	4,570	23.90%	833	13.57%	104	29.63%	33	6.59%
865 – 2,628	7,091	37.32%	2,049	24.60%	5,637	29.48%	1,279	20.84%	117	33.33%	65	12.97%
2,628 – 4,391	5,714	30.07%	3,788	45.47%	4,118	21.54%	1,745	28.43%	70	19.94%	214	42.71%
4,391 – 6,154	1,490	7.84%	1,298	15.58%	2,843	14.87%	1,640	26.72%	24	6.84%	150	29.94%
6,154 – 7,917	484	2.55%	276	3.31%	1,186	6.20%	458	7.46%	23	6.55%	36	7.19%
7,917 – 9,679	216	1.14%	158	1.90%	568	2.97%	178	2.90%	11	3.13%	2	0.40%
9,679 – 11,442	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
11,442 – 13,205	128	0.67%	0	0.00%	84	0.44%	0	0.00%	0	0.00%	0	0.00%
13,205 – 14,968	76	0.40%	0	0.00%	44	0.23%	2	0.03%	1	0.28%	0	0.00%
14,968 – 16,731	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
16,731 – 18,493	37	0.19%	0	0.00%	70	0.37%	0	0.00%	1	0.28%	0	0.00%
18,493 – 20,256	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
20,256 – 22,019	0	0.00%	0	0.00%	0	0.00%	1	0.02%	0	0.00%	0	0.00%
22,019 – 23,782	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
23,782 – 25,545	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
25,545 – 27,308	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
27,308 – 57,651	0	0.00%	0	0.00%	0	0.00%	1	0.02%	0	0.00%	1	0.20%
Total Specimens Sampled	19,003*		8,330		19,120*		6,137		351*		501*	

*Number differs from original dataset due to not all specimens falling within distance layer.

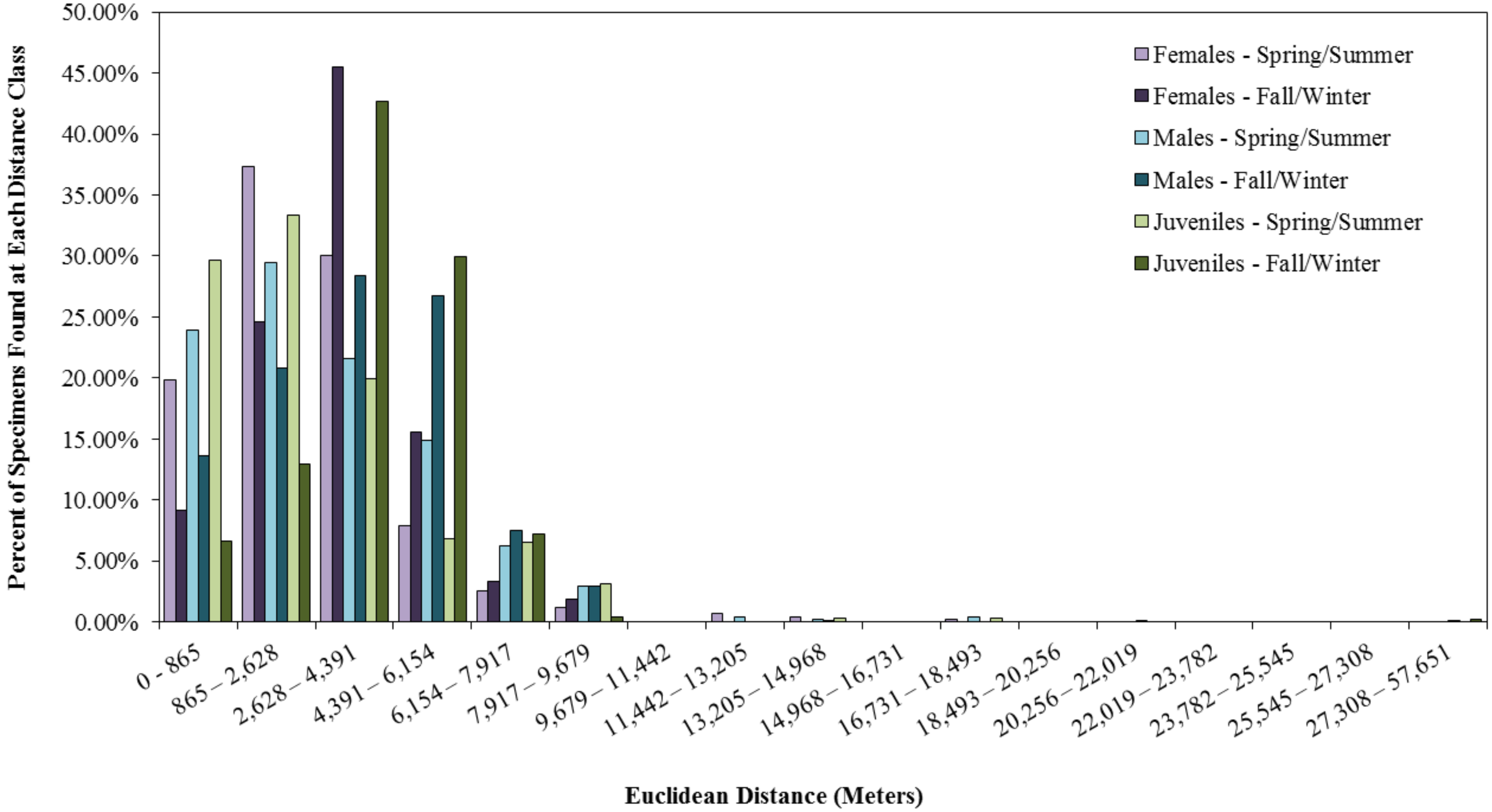

Figure 3.11. Percent of specimens found in each Euclidean distance from estuaries classification (natural breaks).

Table 3.20. The total percentages of each age or sex class during either the spring and summer or fall and winter season for each Euclidean distance from estuaries suitability rank.

Age or Sex Class	Seasonal Class	Rank Classification		
		3	2	1
Females	SS	87.21%	11.52%	1.27%
	FW	85.65%	14.35%	0.00%
Males	SS	89.79%	9.17%	1.04%
	FW	89.57%	10.36%	0.07%
Juveniles	SS	82.91%	16.52%	0.57%
	FW	85.63%	13.77%	0.60%

SS: spring and summer months.
FW: fall and winter months.

3.3. Final Habitat Suitability Layers

For each classification group (adult female, adult male, or juvenile) in each temporal class (spring and summer or fall and winter), the reclassified variables were used in a weighted overlay analysis to create a final suitability layer, resulting in six final suitability maps. Equal weights were applied to each variable in the analysis (Tables 3.4 to 3.9):

*Final Habitat Suitability = ((Depth * 0.25) + (Substrate * 0.25) + (Slope * 0.25) + (Euclidean Distance from Estuaries * 0.25))*

For each suitability layer (depth, substrate, slope, and distance from estuaries), each rank was multiplied by the weight value of 0.25 (or 25%), and then each column of the weighted suitability value was summed for each rank, resulting in a total suitability value of 1.00 for low, 2.00 for moderate, and 3.00 for high suitability areas (Table 3.21) (Mitchell 2012). According to Mitchell (2012), the same ranking scale used for the individual habitat layers should be used for the final suitability layers; therefore, the final layers showed areas of highly suitable (a rank of 3), moderately suitable (a rank of 2), and lowest suitable (rank of 1) regions for Dungeness crab within SEAK. The final layers were then compared to the known locations of each classification group for each season to identify the fit of the model.

Table 3.21. Weighted values for each criteria and rank.

Suitability Layer	Suitability Rank			Weight Value	Weighted Suitability Value		
	Low	Moderate	High		Low	Moderate	High
Depth	1	2	3	0.25	0.25	0.5	0.75
Substrate	1	2	3	0.25	0.25	0.5	0.75
Slope	1	2	3	0.25	0.25	0.5	0.75
Distance	1	2	3	0.25	0.25	0.5	0.75
Sum				1.00	1.00	2.00	3.00

3.4. Model Validation

To assess the accuracy of the final habitat suitability layers, a comparison of observed juvenile (n=210), female adult (n=407), and male adult (n=349) Dungeness crab during the two seasonal groups (spring/summer and fall/winter) were joined with the final habitat suitability layers. These data were acquired from the 2017 ADFG red king crab surveys (June 20-28, 2017 and July 11-31, 2017) and the 2017 ADFG Tanner crab surveys (October 9-16, 2017 and October 23-29, 2017). Past researchers have found a high accuracy level (65% to 99% number of species found in highly suitable areas) in mapping habitat suitability in GIS for most land-based species (Bellamy et al. 2013, Belongie 2008, Brown et al. 2000, Burroughs 2013, Correa-Berger 2007, Lauver et al. 2002, Mitchell et al. 2002, Vincenzi et al. 2005). Belongie (2008) only used the percentage of specimens found in each suitability rank to determine the effectiveness of the model. This study ultimately chose Belongie's (2008) model validation method due to the lack of specimen data for certain age and sex classes and the high percentage of specimens found in the high suitability areas.

CHAPTER 4 - RESULTS

4.1. Habitat Variable Results

4.1.1. Depth Suitability

The depth suitability classification process resulted in six maps (Figures 4.1 to 4.6), one for each sex or age class for spring and summer or fall and winter. Tables 4.1 and 4.2 detail the changes in square nautical miles and percentages recorded for habitat found in each suitability rank for each sex or age class from spring and summer to fall and winter. The amount of area showed a minimal increase of 3.65% (349.99 NM^2) for low suitability areas from spring and summer to fall and winter for female adult crab, in regard to depth. The area decreased by 20.14% (-2,088.09 NM^2) in moderate areas and increased by 16.49% (1,689.36 NM^2) in the highly suitable areas from the spring and summer months to the fall and winter months for female crab. Male Dungeness crab depth habitat decreased for the lower suitability areas (-17.16%, -1,766.91 NM^2), increased by 2.08% (214.62 NM^2) in moderate areas, and increased by 15.07% (1,552.29 NM^2) in the highly suitable areas. For juvenile Dungeness crab, the low suitable habitat decreased by 5.56% (-572.85 NM^2) from spring and summer to fall and winter and by 9.51% (-979.44 NM^2) in moderately suitable habitat. However, the depth habitat increased in size for highly suitable habitat from the spring and summer to the fall and winter months (15.07%, 1,522.3 NM^2).

Table 4.1. Area of various suitability ranks per sex or age class in square nautical miles and the difference in area from the spring and summer to the fall and winter months for depth.

Suitability	Female SS	Female FW	Difference	Male SS	Male FW	Difference	Juvenile SS	Juvenile FW	Difference
Low	5,344.65	5,694.64	349.99	6,387.49	4,620.58	-1,766.91	5,695.64	5,122.79	-572.85
Moderate	2,779.95	691.86	-2,088.09	1,737.10	1,951.72	214.62	1,552.30	572.86	-979.44
High	2,224.98	3,912.34	1,687.36	2,175.24	3,727.53	1,552.29	3,051.89	4,604.19	1552.3

Table 4.2. Area of various suitability ranks per sex or age class as a percentage of total area and the difference in area from the spring and summer to the fall and winter months for depth.

Suitability	Female SS	Female FW	% Difference	Male SS	Male FW	% Difference	Juvenile SS	Juvenile FW	% Difference
Low	51.64	55.29	3.65	62.02	44.86	-17.16	55.30	49.74	-5.56
Moderate	26.86	6.72	-20.14	16.87	18.95	2.08	15.07	5.56	-9.51
High	21.50	37.99	16.49	21.12	36.19	15.07	29.63	44.70	15.07

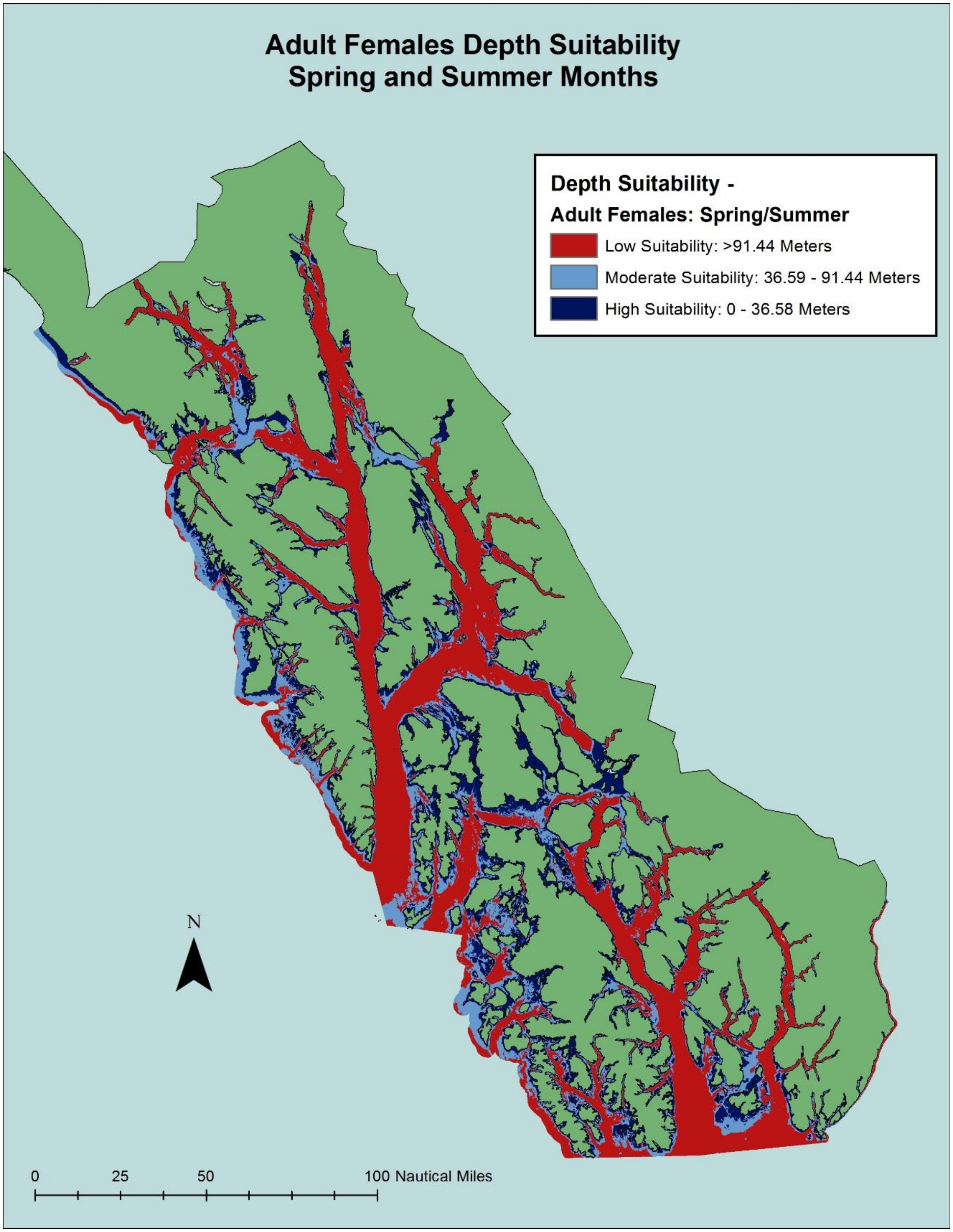

Figure 4.1. Suitability ranks of depth for adult females in the spring/summer months.

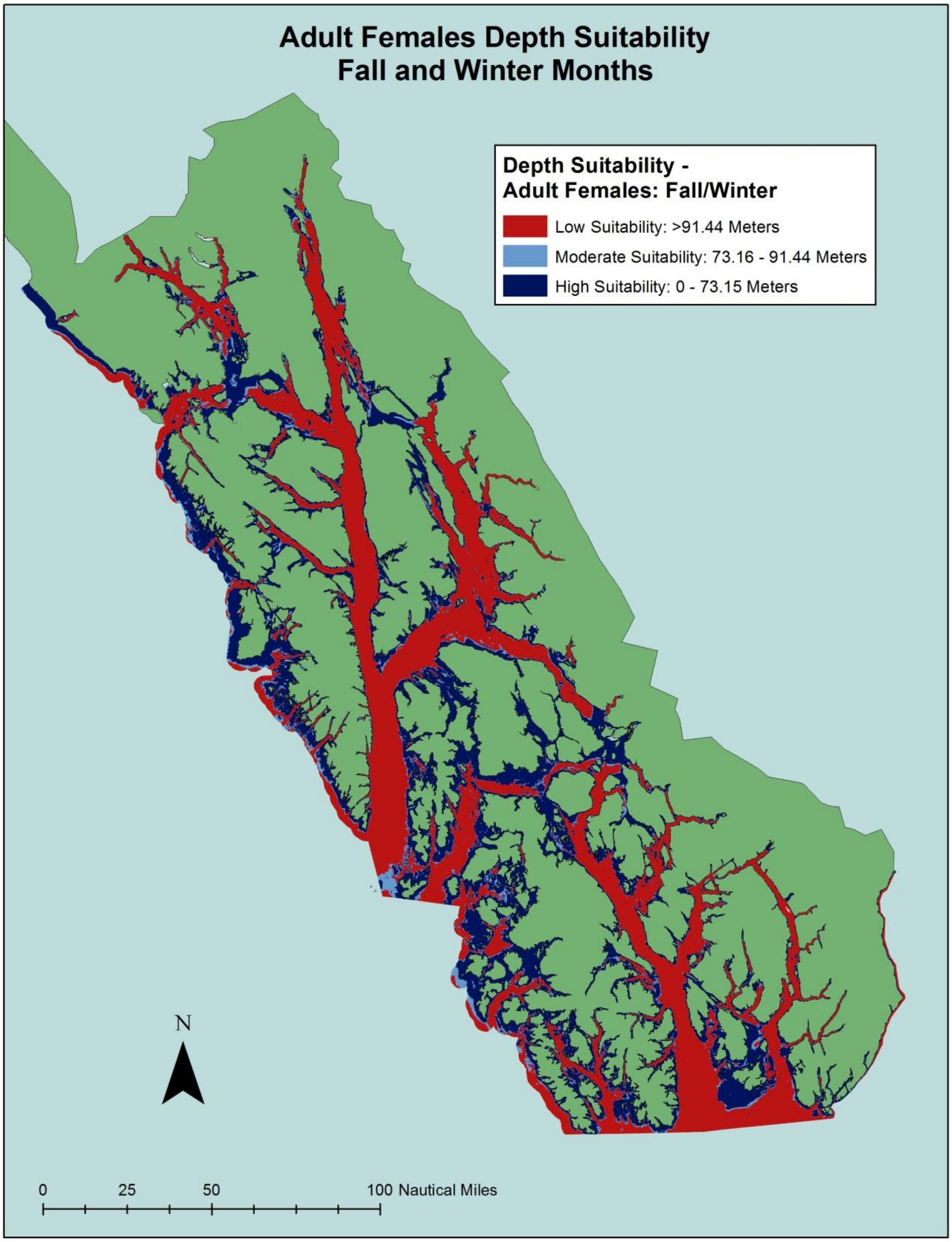

Figure 4.2. Suitability ranks of depth for adult females in the fall/winter months.

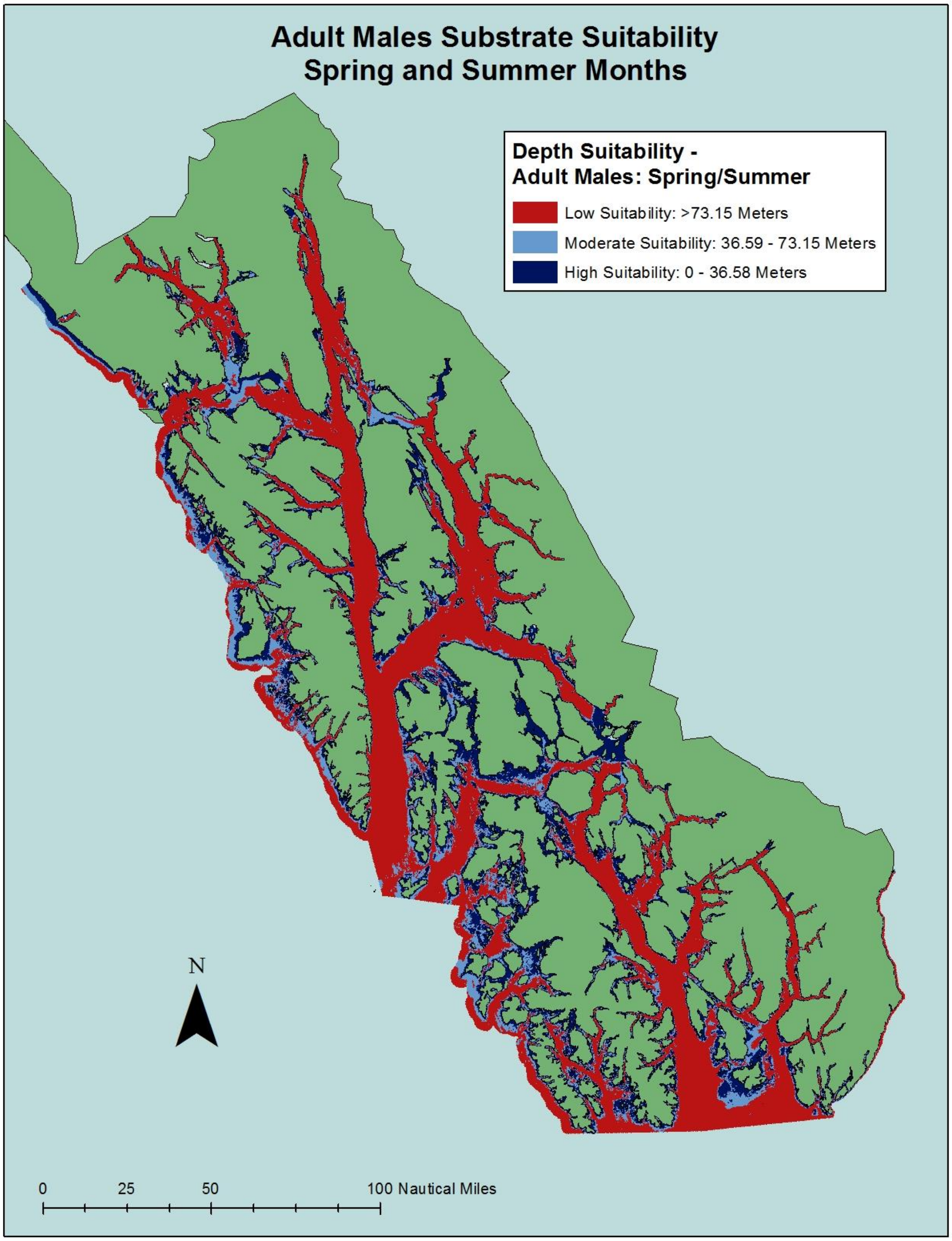

Figure 4.3. Suitability ranks of depth for adult males in the spring/summer months.

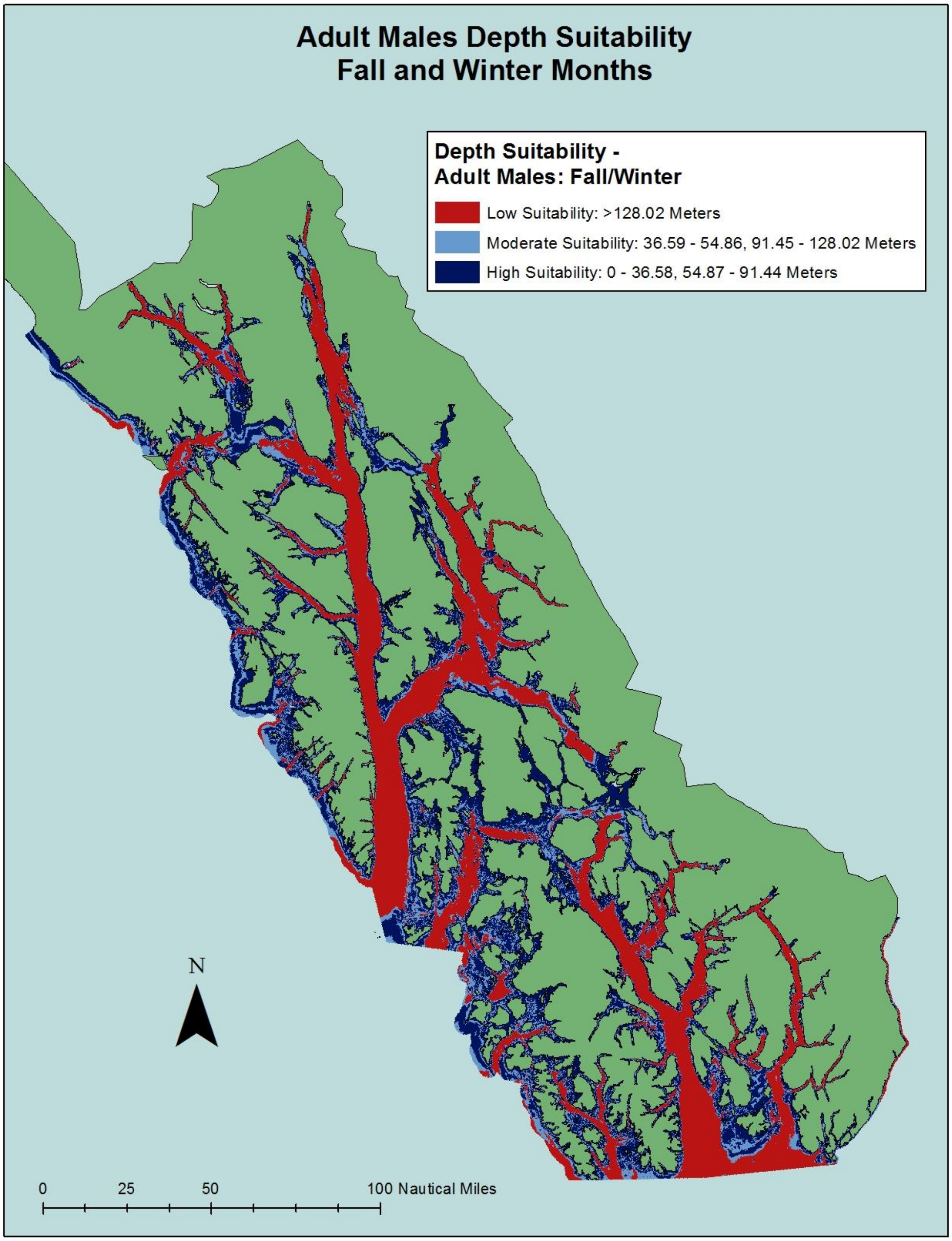

Figure 4.4. Suitability ranks of depth for adult males in the fall/winter months.

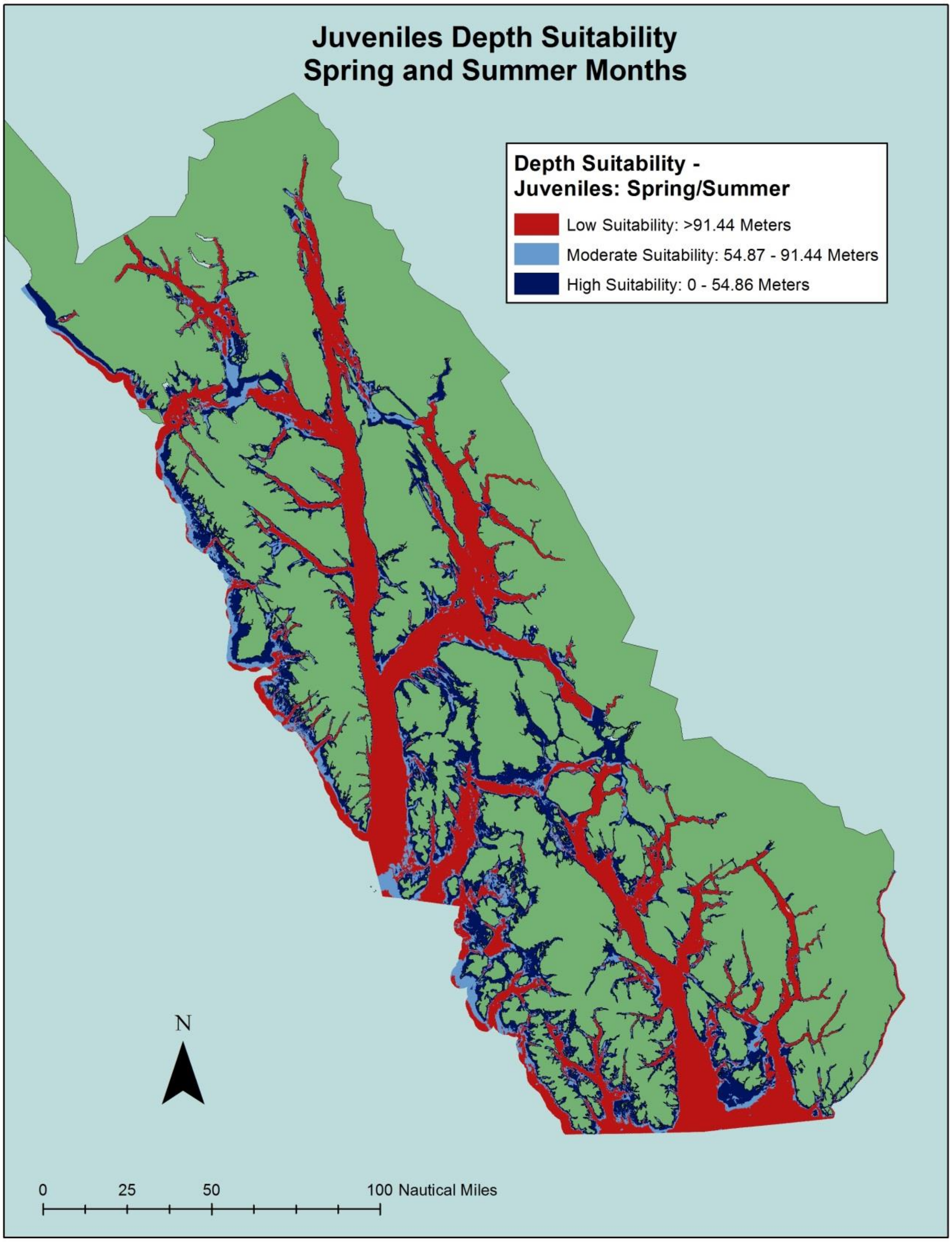

Figure 4.5. Suitability ranks of depth for juveniles in the spring/summer months.

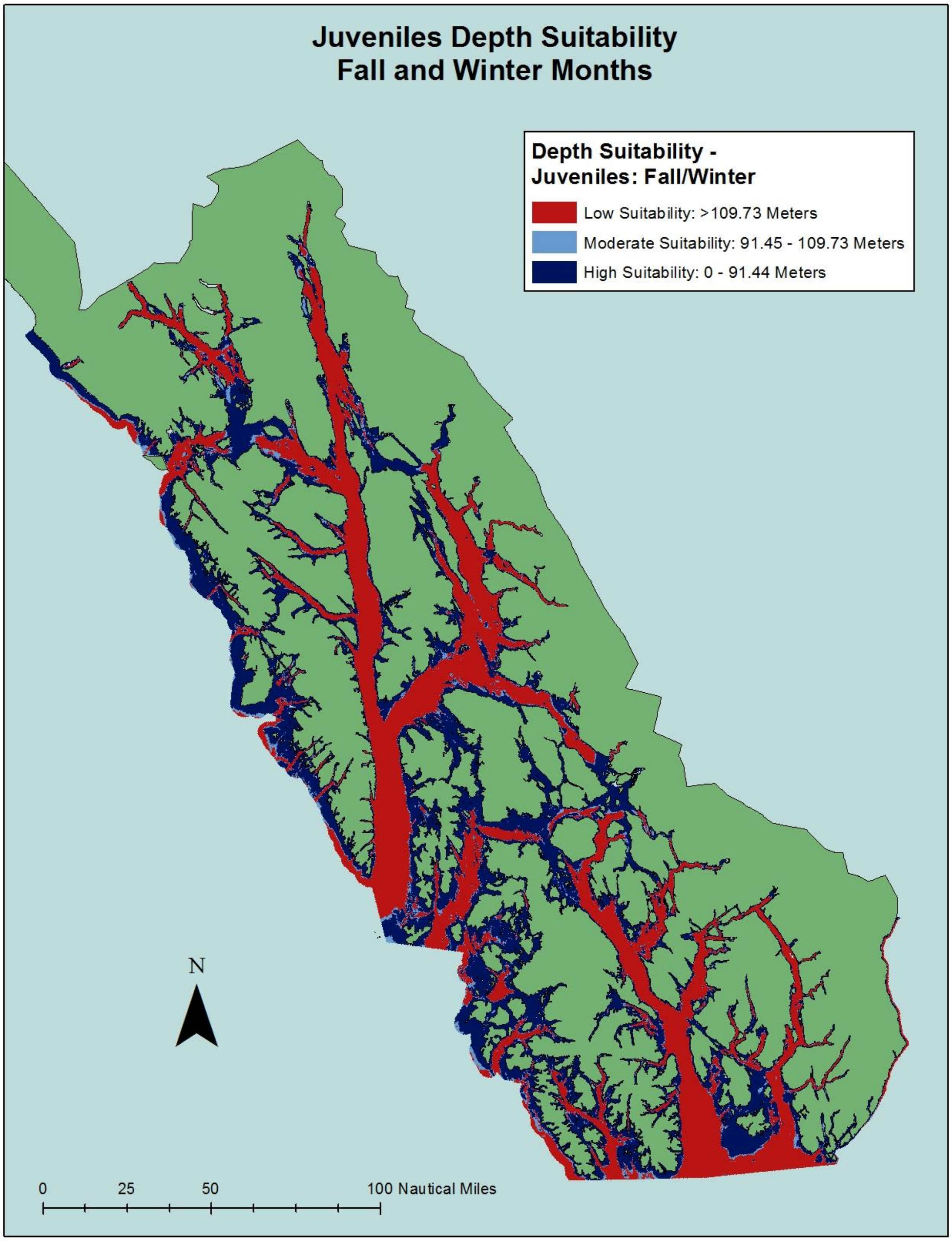

Figure 4.6. Suitability ranks of depth for juveniles in the fall/winter months.

4.1.2. Substrate Suitability

The substrate suitability classification process resulted in six maps (Figures 4.7 to 4.12), one for each sex or age class for spring and summer or fall and winter. Tables 4.3 and 4.4 detail the changes recorded for habitat found in each suitability rank for each sex or age class from spring and summer to fall and winter. The amount of area changed the most drastically for females for low and moderate suitability from spring and summer to fall and winter, in regard to substrate. There was a 22.33% area (2,316.09 NM^2) gain in low suitable areas and a 22.33% (-2,316.10 NM^2) loss in area for moderate areas. The difference in area change in highly suitable areas from the spring and summer to fall and winter months was close to zero. Male Dungeness crab substrate habitat experienced a minimal decline in low suitable habitat from spring and summer to fall and winter (-110.18 NM^2, -1.06%). Males lost -793.05 NM^2 (-7.65%) of moderately suitable habitat from season to season but gained 903.24 NM^2 (8.71%) in highly suitable habitat from spring and summer to fall and winter. Juvenile Dungeness crab habitat changed moderately in the low and moderately ranked habitat areas (decreased by 12.36% in the low areas and increased by 12.36% in the moderate areas). The area of highly suitable juvenile crab habitat remained the same when going from spring and summer months to fall and winter months.

Table 4.3. Area of various suitability ranks per sex or age class in square nautical miles and the difference in area from the spring and summer to the fall and winter months for substrate.

Suitability	Female SS	Female FW	Difference	Male SS	Male FW	Difference	Juvenile SS	Juvenile FW	Difference
Low	812.91	3,129.00	2,316.09	3,749.23	3,639.05	-110.18	4,785.72	3,503.79	-1281.93
Moderate	6,787.64	4,471.54	-2,316.10	3,851.31	3,058.26	-793.05	1,911.58	3,193.52	1281.94
High	2,770.48	2,770.48	0.00	2,770.48	3,673.72	903.24	3,673.72	3,673.72	0.00

Table 4.4. Area of various suitability ranks per sex or age class as a percentage of total area and the difference in area from the spring and summer to the fall and winter months for substrate.

Suitability	Female SS	Female FW	% Difference	Male SS	Male FW	% Difference	Juvenile SS	Juvenile FW	% Difference
Low	7.84	30.17	22.33	36.15	35.09	-1.06	46.15	33.78	-12.36
Moderate	65.45	43.12	-22.33	37.14	29.49	-7.65	18.43	30.79	12.36
High	26.71	26.71	0.00	26.71	35.42	8.71	35.42	35.42	0.00

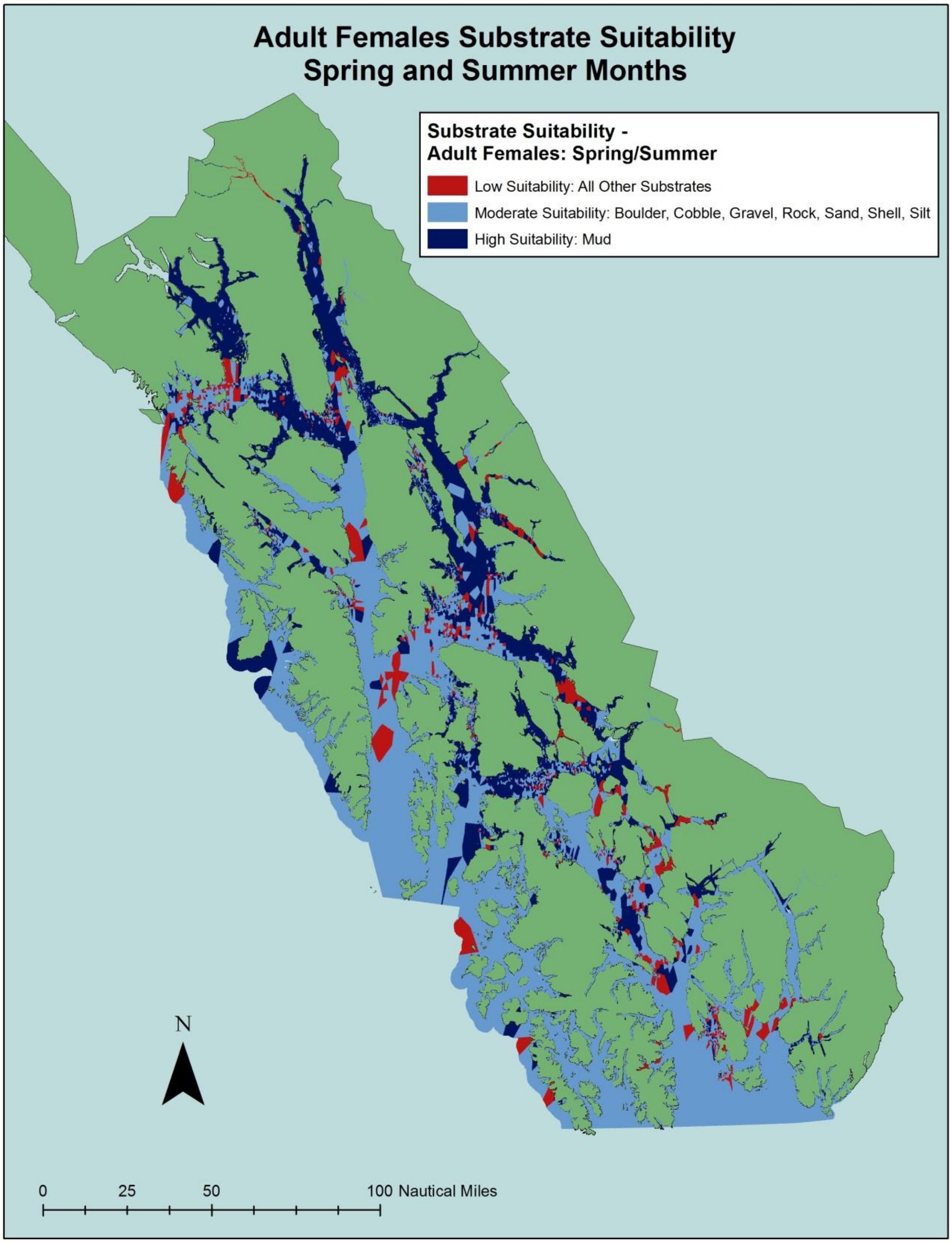

Figure 4.7. Suitability ranks of substrate for adult females in the spring/summer months.

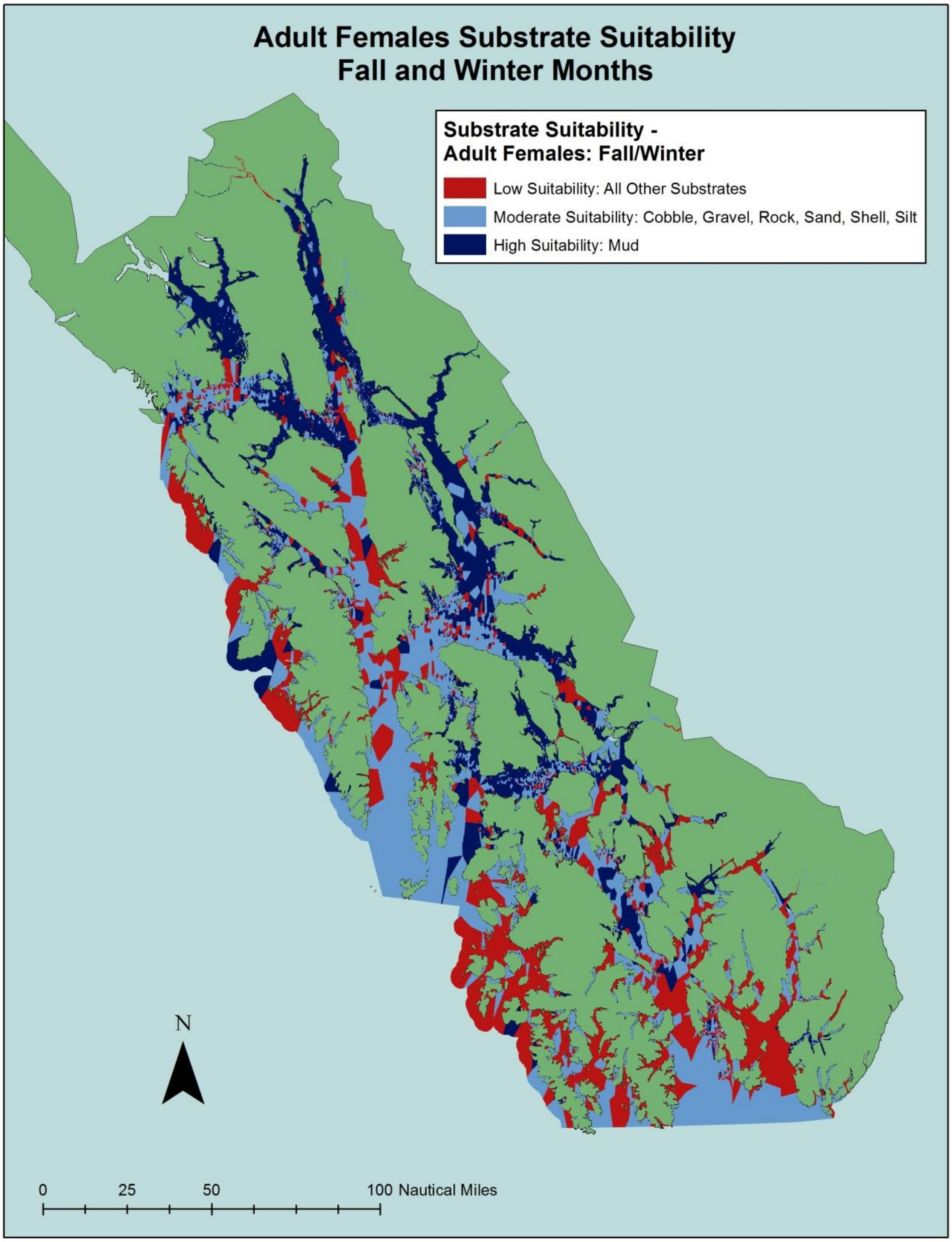

Figure 4.8. Suitability ranks of substrate for adult females in the fall/winter months.

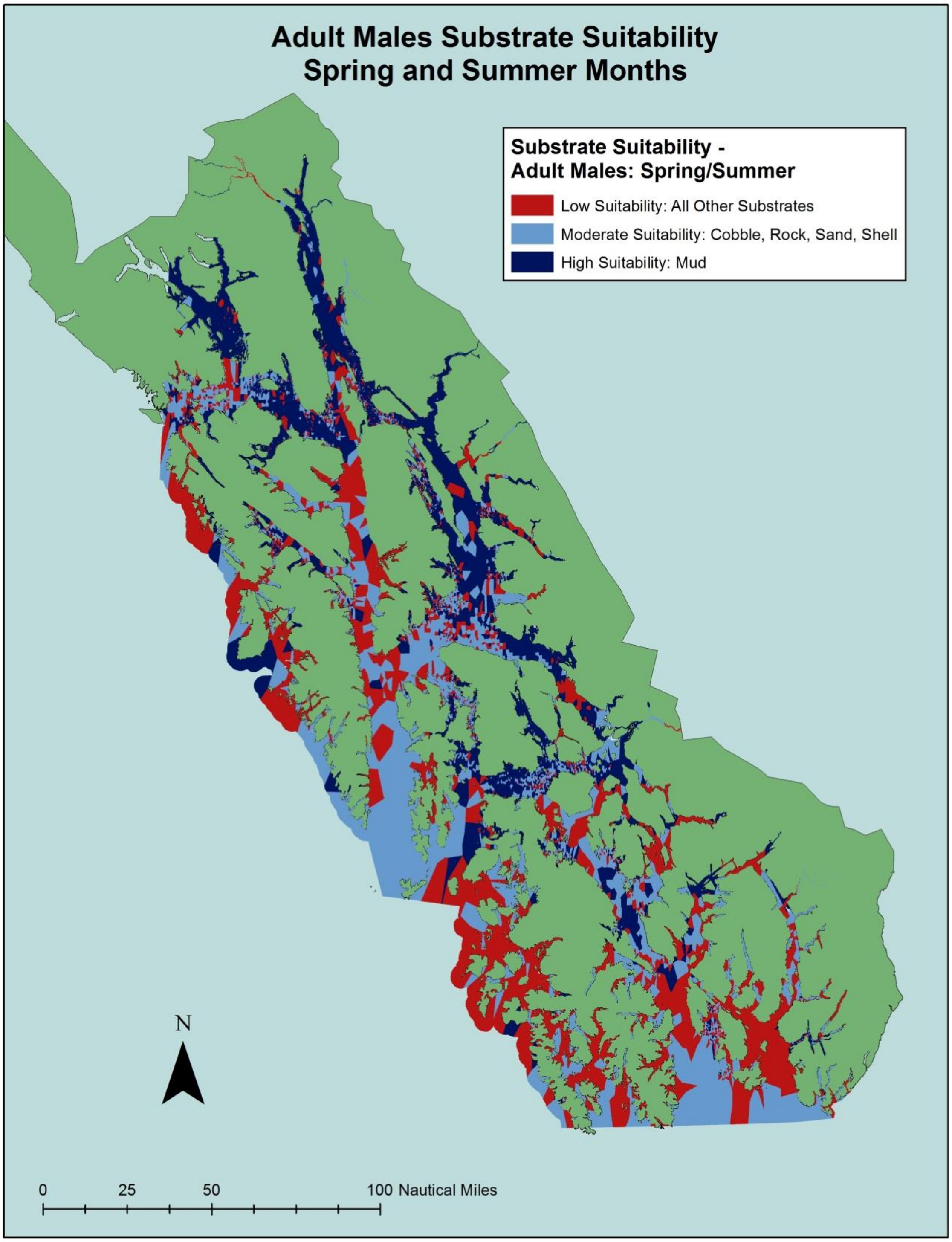

Figure 4.9. Suitability ranks of substrate for adult males in the spring/summer months.

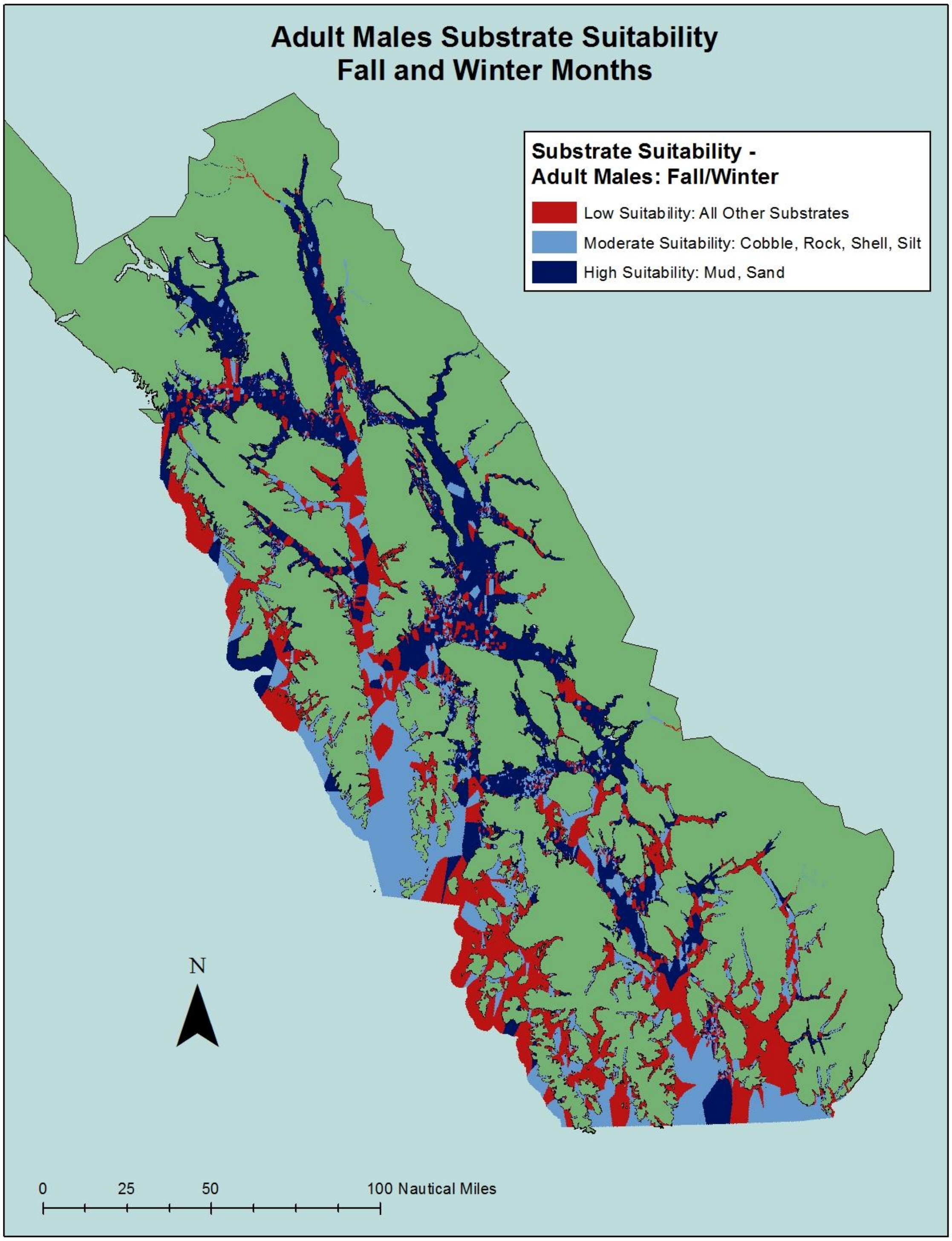

Figure 4.10. Suitability ranks of substrate for adult males in the fall/winter months.

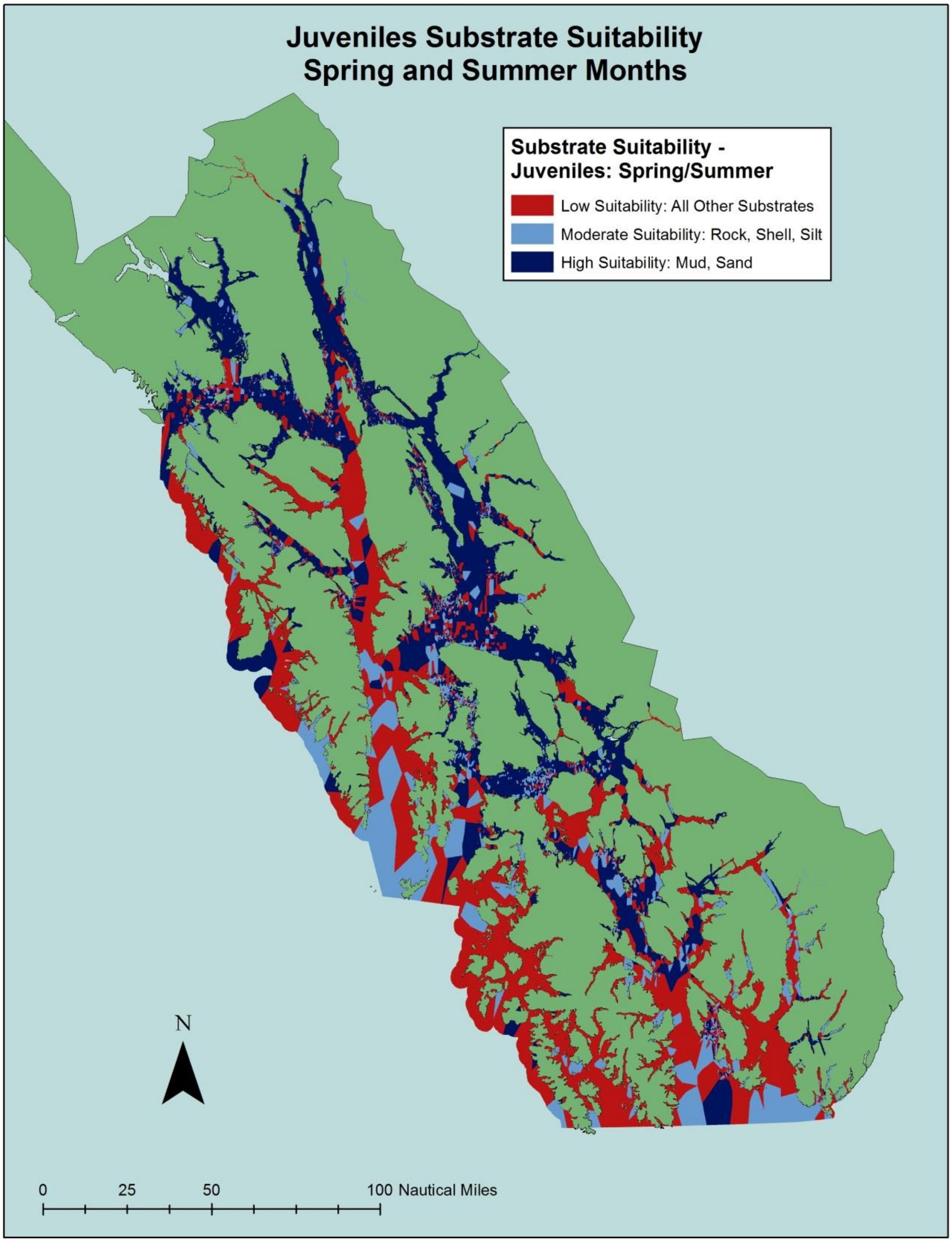

Figure 4.11. Suitability ranks of substrate for juveniles in the spring/summer months.

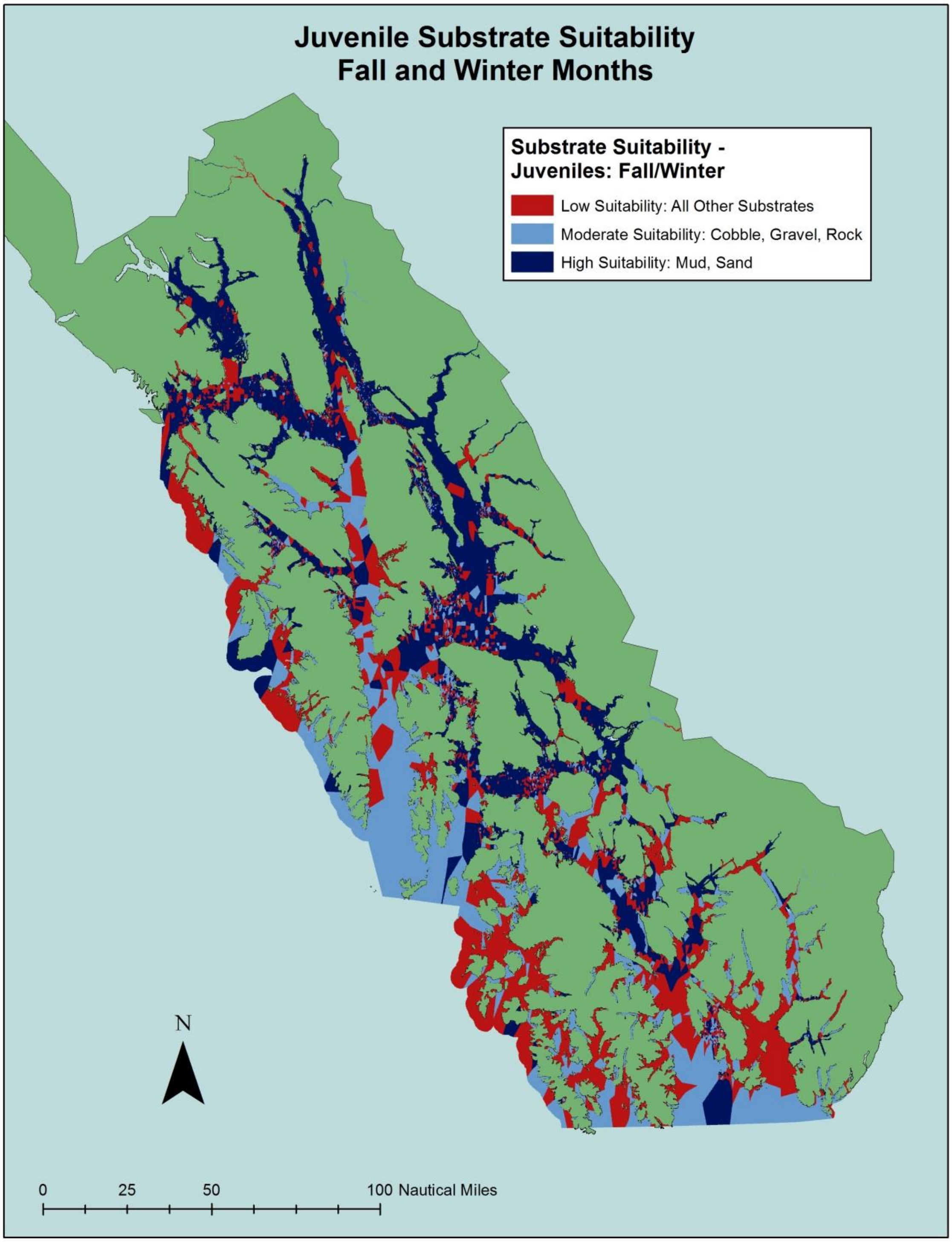

Figure 4.12. Suitability ranks of substrate for juveniles in the fall/winter months.

4.1.3. Slope Suitability

The slope suitability classification process resulted in six maps (Figures 4.13 to 4.18), one for each sex or age class for spring and summer or fall and winter. Tables 4.5 and 4.6 detail the changes recorded for habitat found in each suitability rank for each sex or age class from spring and summer to fall and winter. The amount of area changed the most drastically for females for moderate and high suitability areas from spring and summer to fall and winter, in regard to slope. There was a 13.70% area (1,417.96 NM^2) gain in moderately suitable areas and a 13.70% (-1,417.97 NM^2) loss for high suitability areas. The difference in area change in low suitable areas from the spring and summer to fall and winter months was close to zero. Male Dungeness crab slope habitat experienced no change in the area for all suitability ranks. The area for juvenile crab habitat also remained unchanged for all ranks when going from spring and summer months to fall and winter months.

Table 4.5. Area of various suitability ranks per sex or age class in square nautical miles and the difference in area from the spring and summer to the fall and winter months for slope.

Suitability	Female SS	Female FW	Difference	Male SS	Male FW	Difference	Juvenile SS	Juvenile FW	Difference
Low	479.72	479.72	0.00	479.72	479.72	0.00	960.68	960.68	0.00
Moderate	1,272.34	2,690.30	1,417.96	1272.34	1272.34	0.00	791.38	791.38	0.00
High	8,597.51	7,179.54	-1,417.97	8597.51	8597.51	0.00	8597.51	8597.51	0.00

Table 4.6. Area of various suitability ranks per sex or age class as a percentage of total area and the difference in area from the spring and summer to the fall and winter months for slope.

Suitability	Female SS	Female FW	% Difference	Male SS	Male FW	% Difference	Juvenile SS	Juvenile FW	% Difference
Low	4.64	4.64	0.00	4.64	4.64	0.00	9.28	9.28	0.00
Moderate	12.29	25.99	13.70	12.29	12.29	0.00	7.65	7.65	0.00
High	83.07	69.37	-13.70	83.07	83.07	0.00	83.07	83.07	0.00

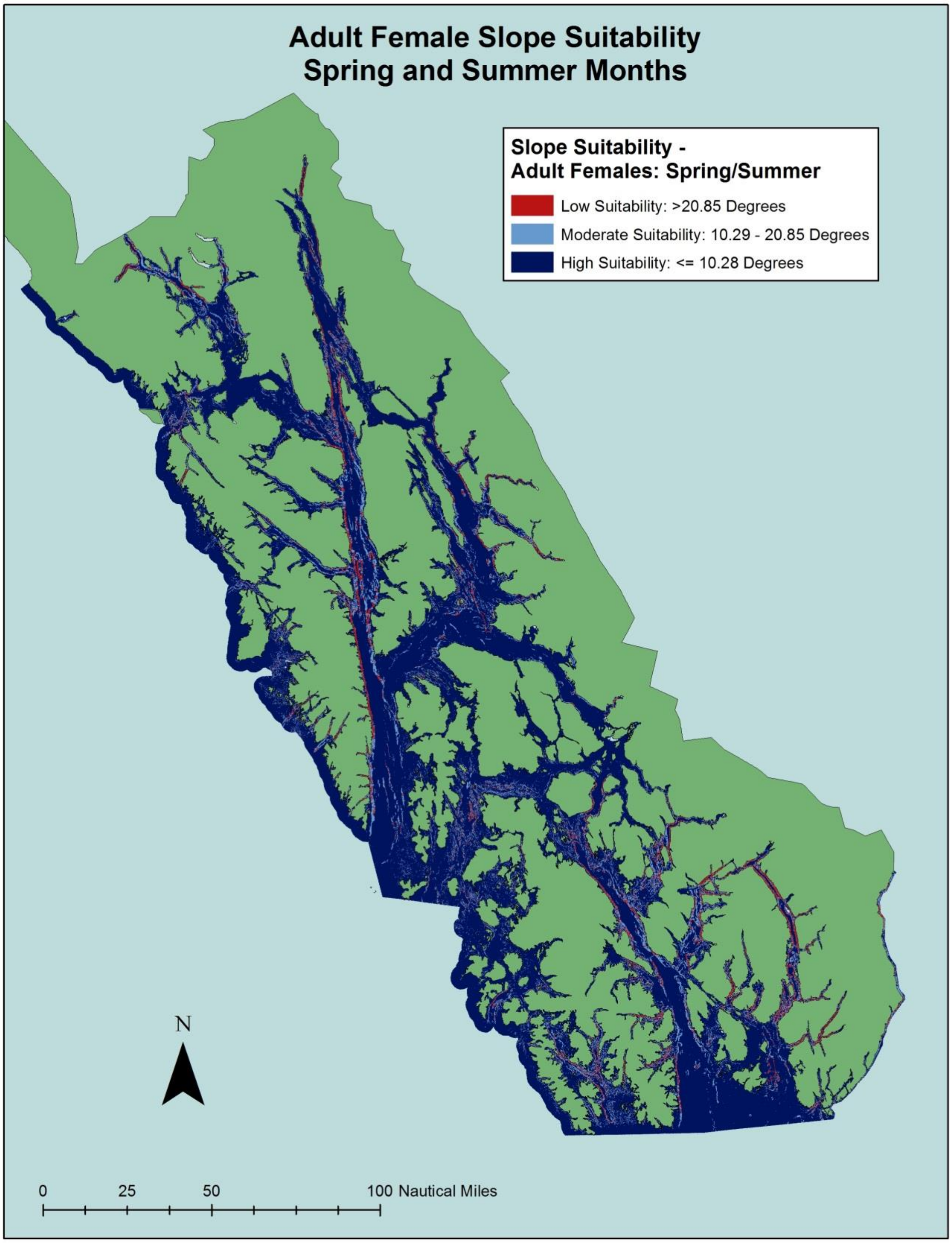

Figure 4.13. Suitability ranks of slope for adult females in the spring/summer months.

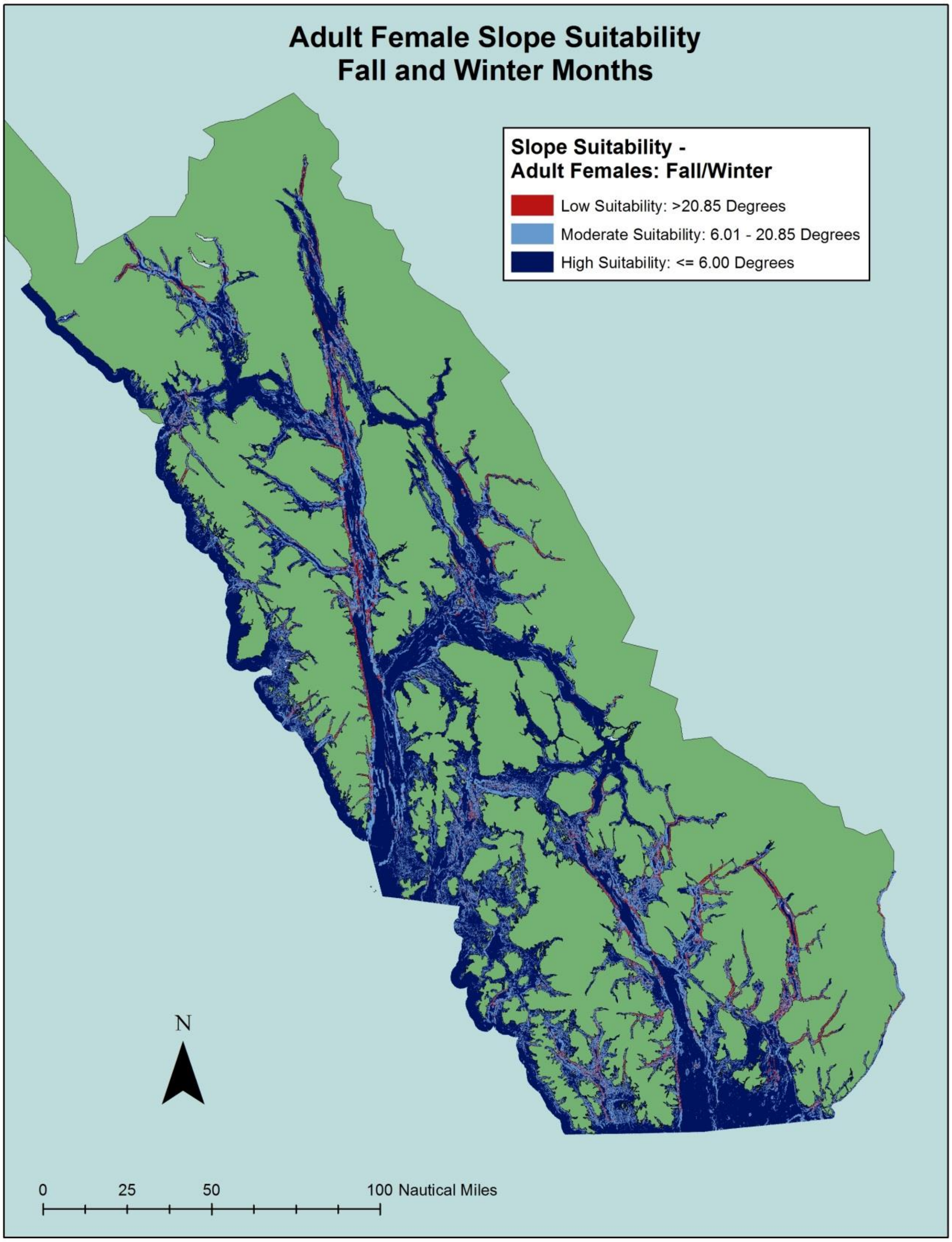

Figure 4.14. Suitability ranks of slope for adult females in the fall/winter months.

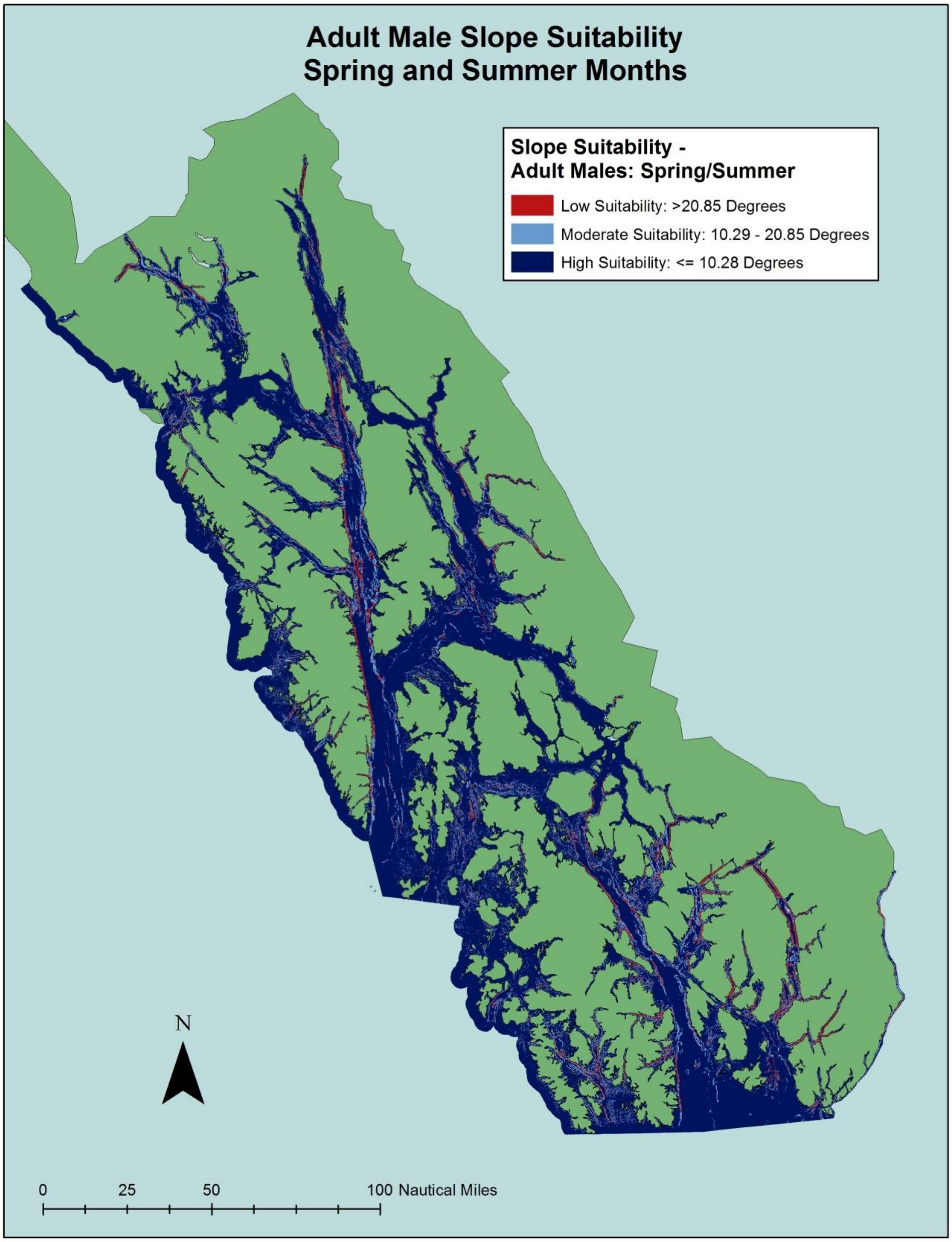

Figure 4.15. Suitability ranks of slope for adult males in the spring/summer months.

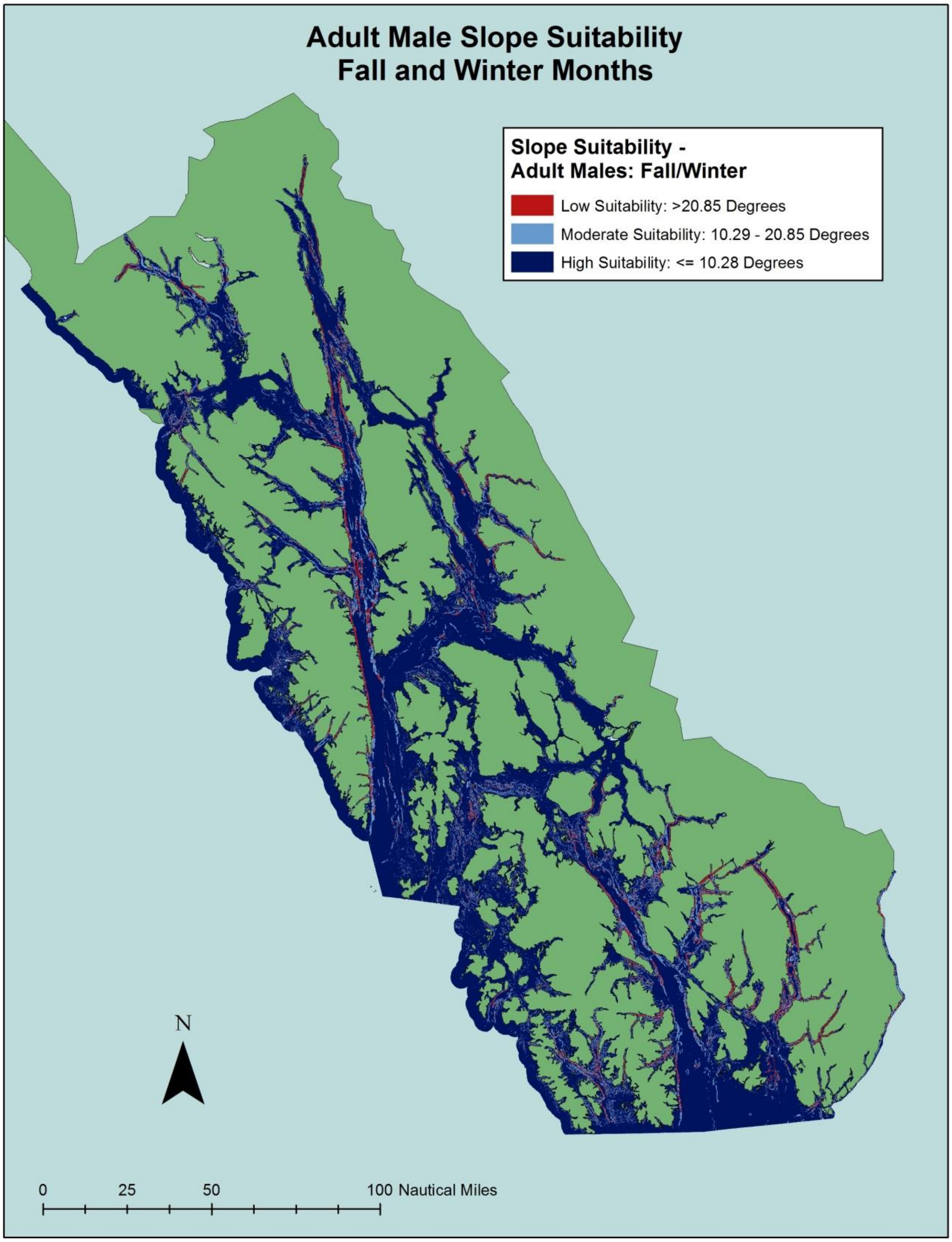

Figure 4.16. Suitability ranks of slope for adult males in the fall/winter months.

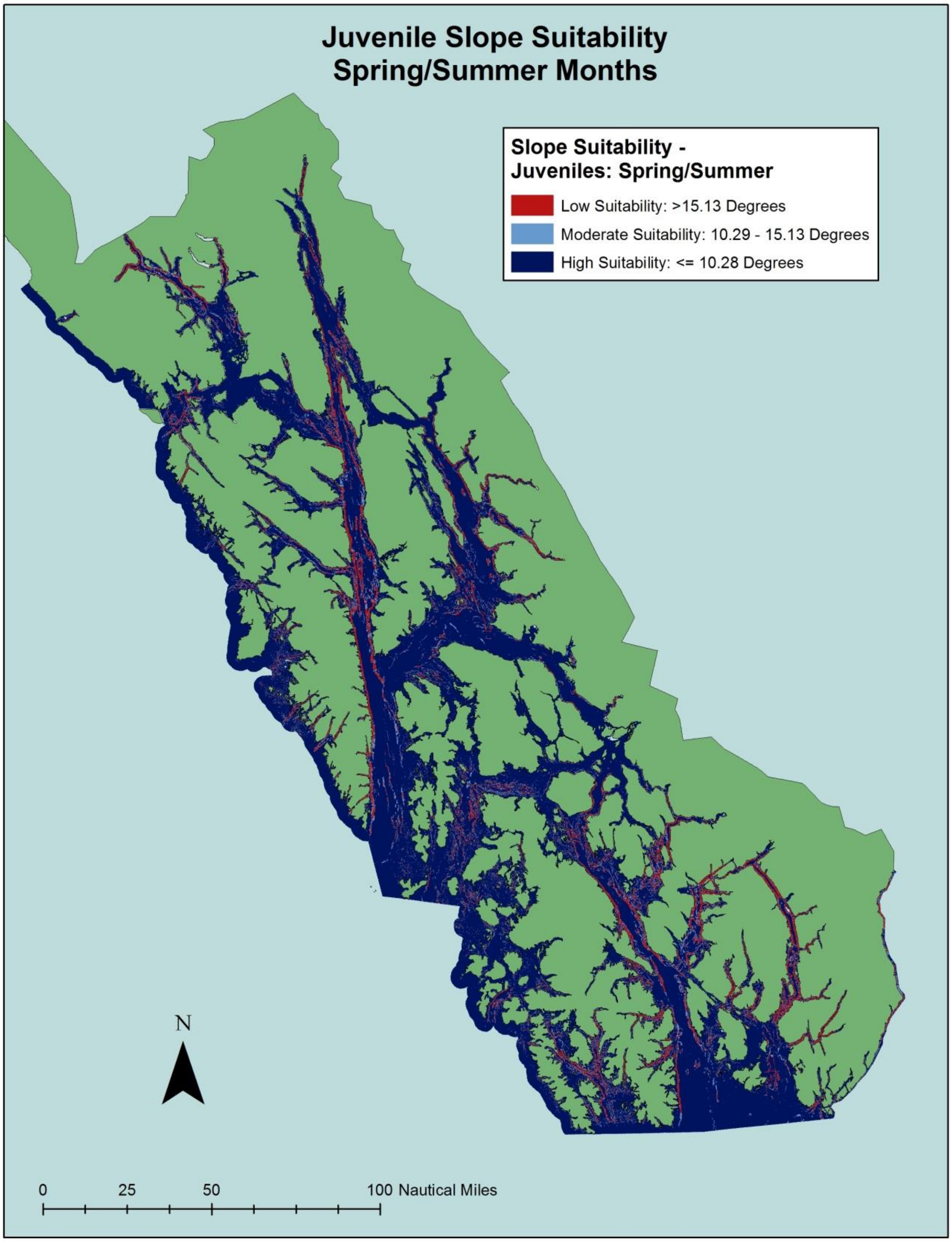

Figure 4.17. Suitability ranks of slope for juveniles in the spring/summer months.

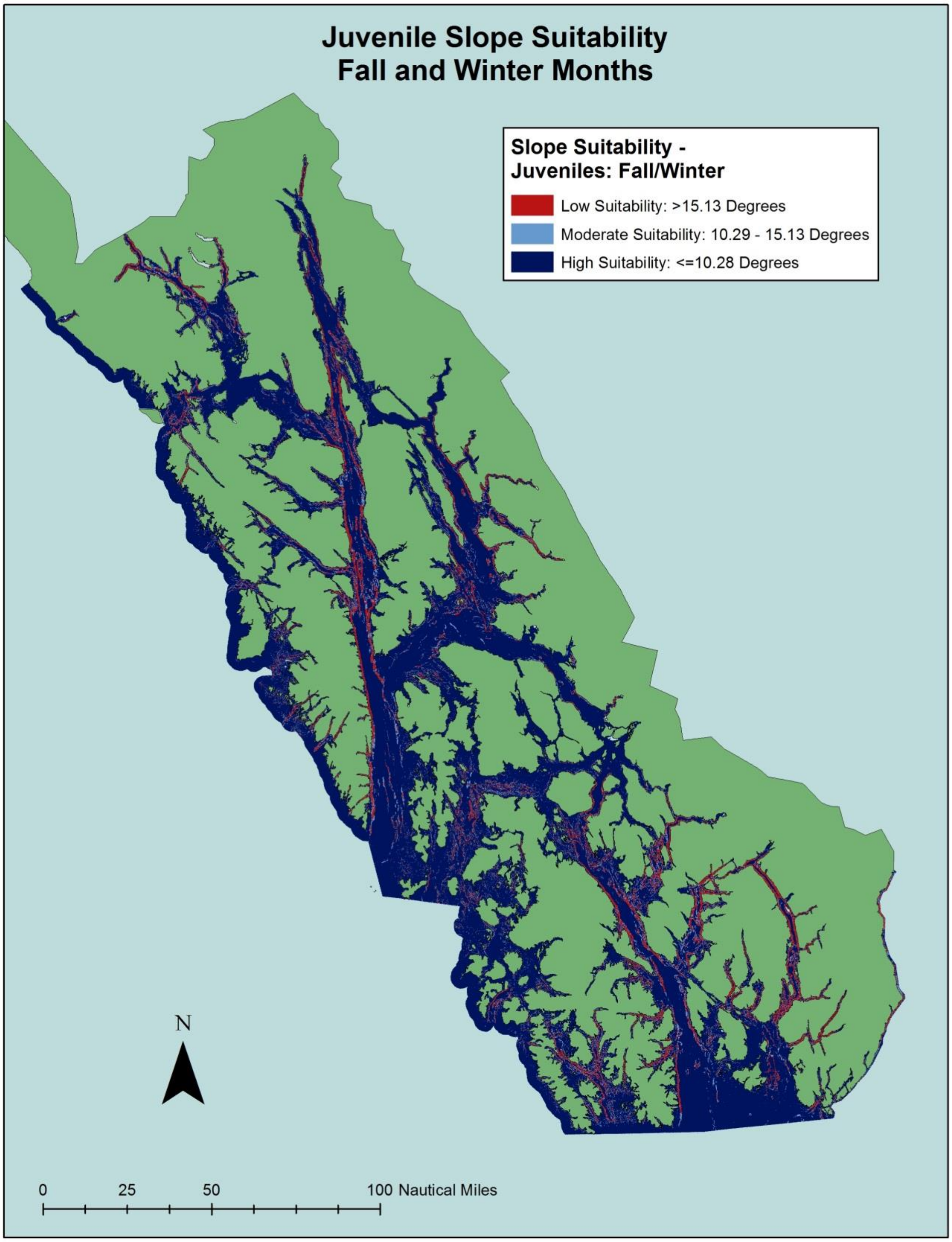

Figure 4.18. Suitability ranks of slope for juveniles in the fall/winter months.

4.1.4. Distance from Estuaries Suitability

The distance from estuaries suitability classification process resulted in six maps (Figures 4.19 to 4.24), one for each sex or age class for spring and summer or fall and winter. Tables 4.7 and 4.8 detail the changes recorded for habitat found in each suitability rank for each sex or age class from spring and summer to fall and winter. For female Dungeness crab, the amount of area decreased by 8.14% in moderately suitable areas and increased by 8.14% in high suitability areas from spring and summer to fall and winter, in regard to distance from estuaries. There was an 821.03 NM^2 loss for moderate areas and an 821.03 NM^2 gain in area for highly suitable areas. There was zero change in area for low suitable areas. Male Dungeness crab distance from estuaries habitat, again, experienced no change in the area of all suitability ranks. The area for juvenile crab habitat changed the most radically with a 28.71% (2,899.21 NM^2) gain in low suitability areas, 48.02% (4,692.21 NM^2) loss in moderate, and a 19.31% (2,017.56 NM^2) gain in high suitability areas.

Table 4.7. Area of various suitability ranks per sex or age class in square nautical miles and the difference in area from the spring and summer to the fall and winter months for distance from estuaries.

Suitability	Female SS	Female FW	Difference	Male SS	Male FW	Difference	Juvenile SS	Juvenile FW	Difference
Low	2,289.97	2,289.97	0.00	2,289.97	2,289.97	0.00	205.54	3104.75	2899.21
Moderate	3,513.27	2,692.24	-821.03	1,977.72	1,977.72	0.00	6,569.67	1,877.46	-4692.21
High	4,278.98	5,100.01	821.03	5,814.54	5,814.54	0.00	3,082.45	5,100.01	2017.56

Table 4.8. Area of various suitability ranks per sex or age class as a percentage of total area and the difference in area from the spring and summer to the fall and winter months for distance from estuaries.

Suitability	Female SS	Female FW	% Difference	Male SS	Male FW	% Difference	Juvenile SS	Juvenile FW	% Difference
Low	22.71	22.71	0.00	22.71	22.71	0.00	2.09	30.79	28.71
Moderate	34.85	26.70	-8.14	19.62	19.62	0.00	66.65	18.62	-48.02
High	42.44	50.58	8.14	57.67	57.67	0.00	31.27	50.58	19.31

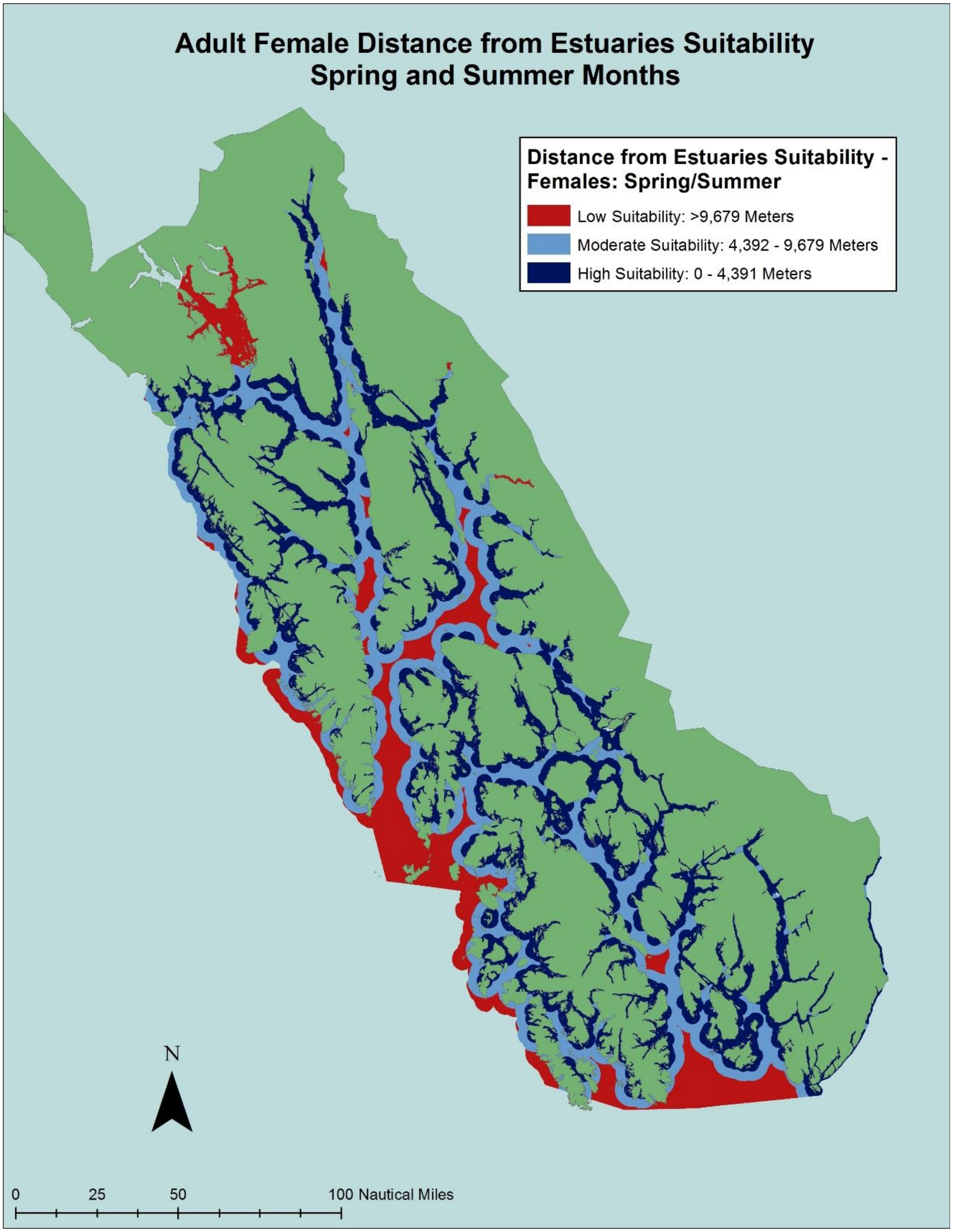

Figure 4.19. Suitability ranks of distance from estuaries for adult females in the spring/summer months.

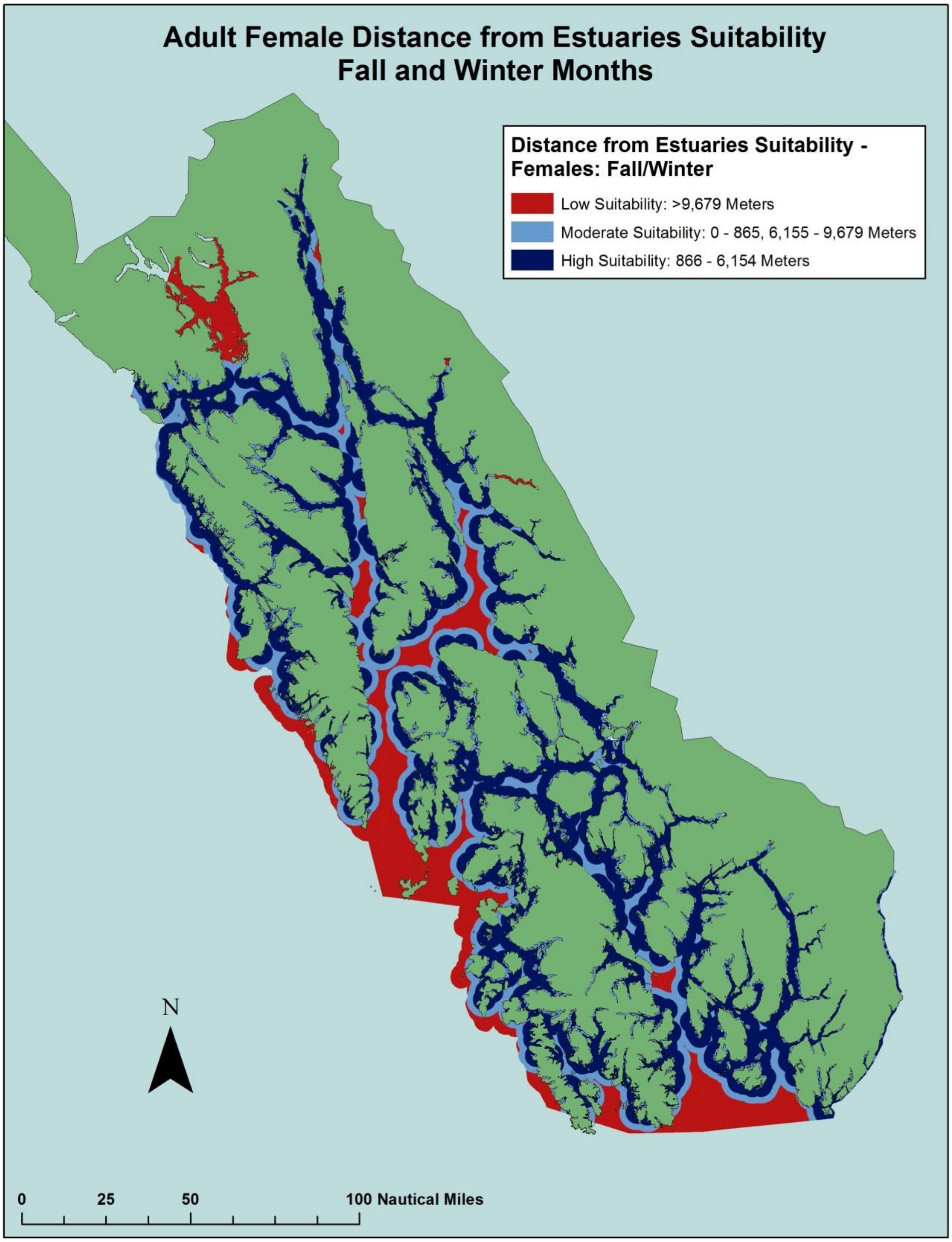

Figure 4.20. Suitability ranks of distance from estuaries for adult females in the fall/winter months.

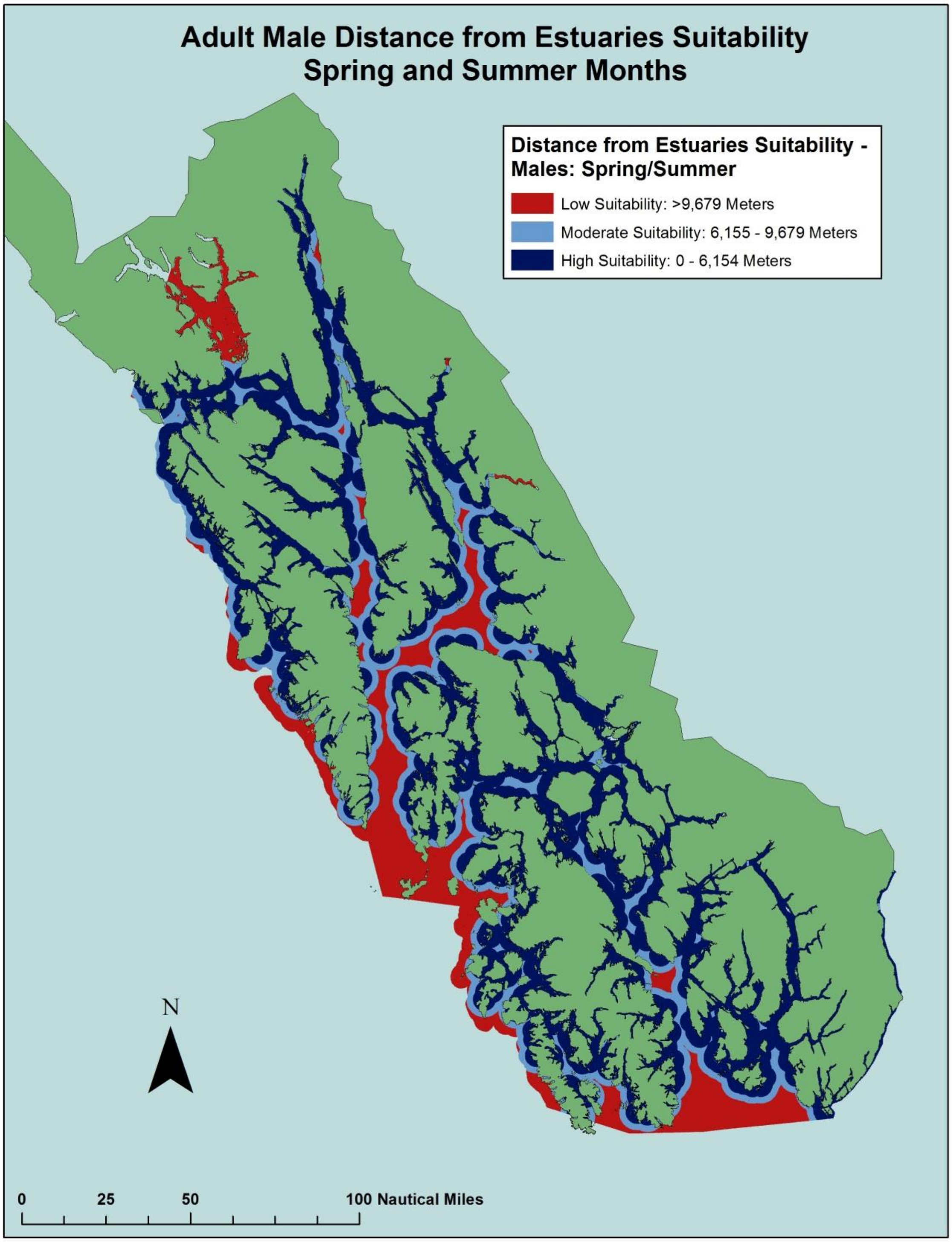

Figure 4.21. Suitability ranks of distance from estuaries for adult males in the spring/summer months.

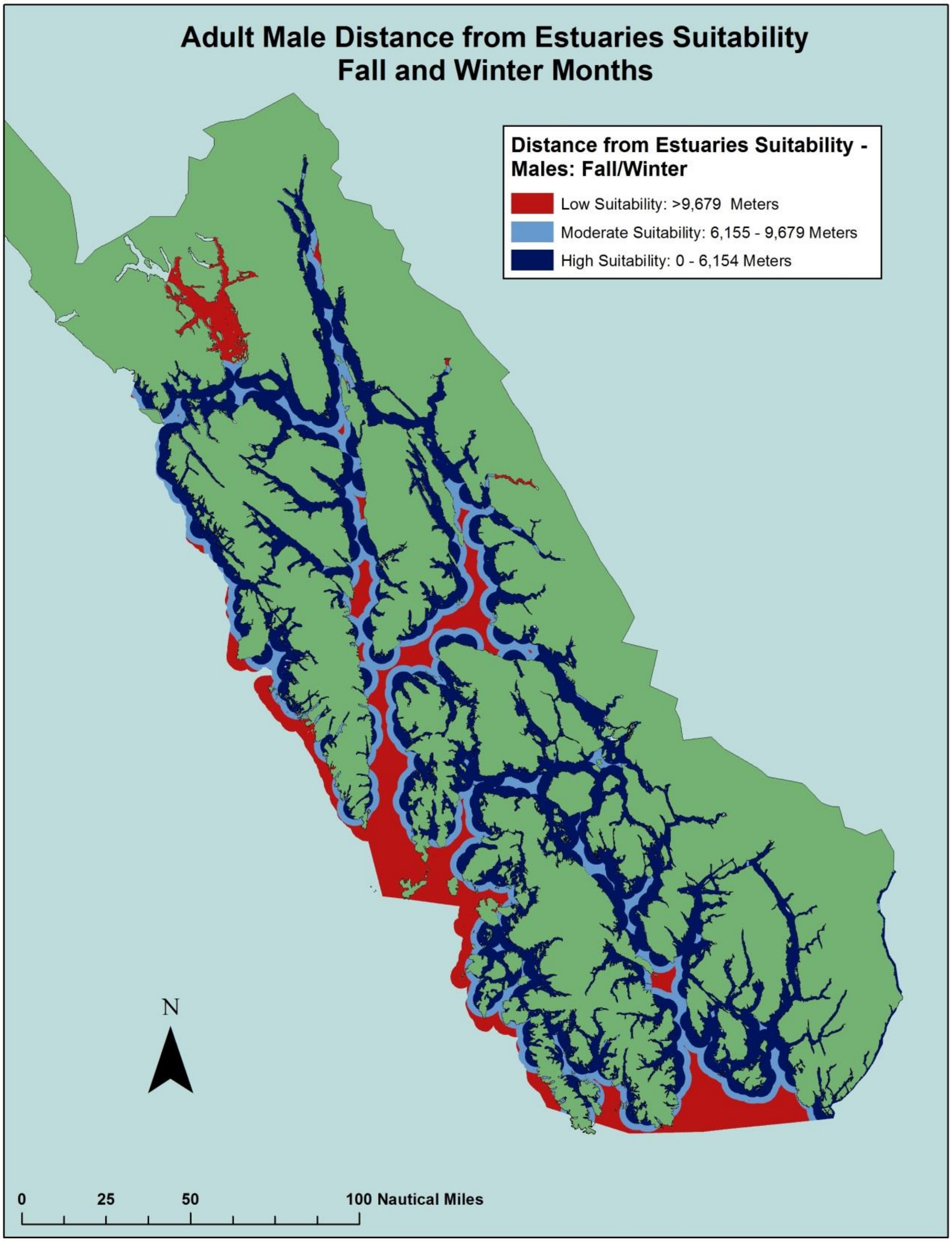

Figure 4.22. Suitability ranks of distance from estuaries for adult males in the fall/winter months.

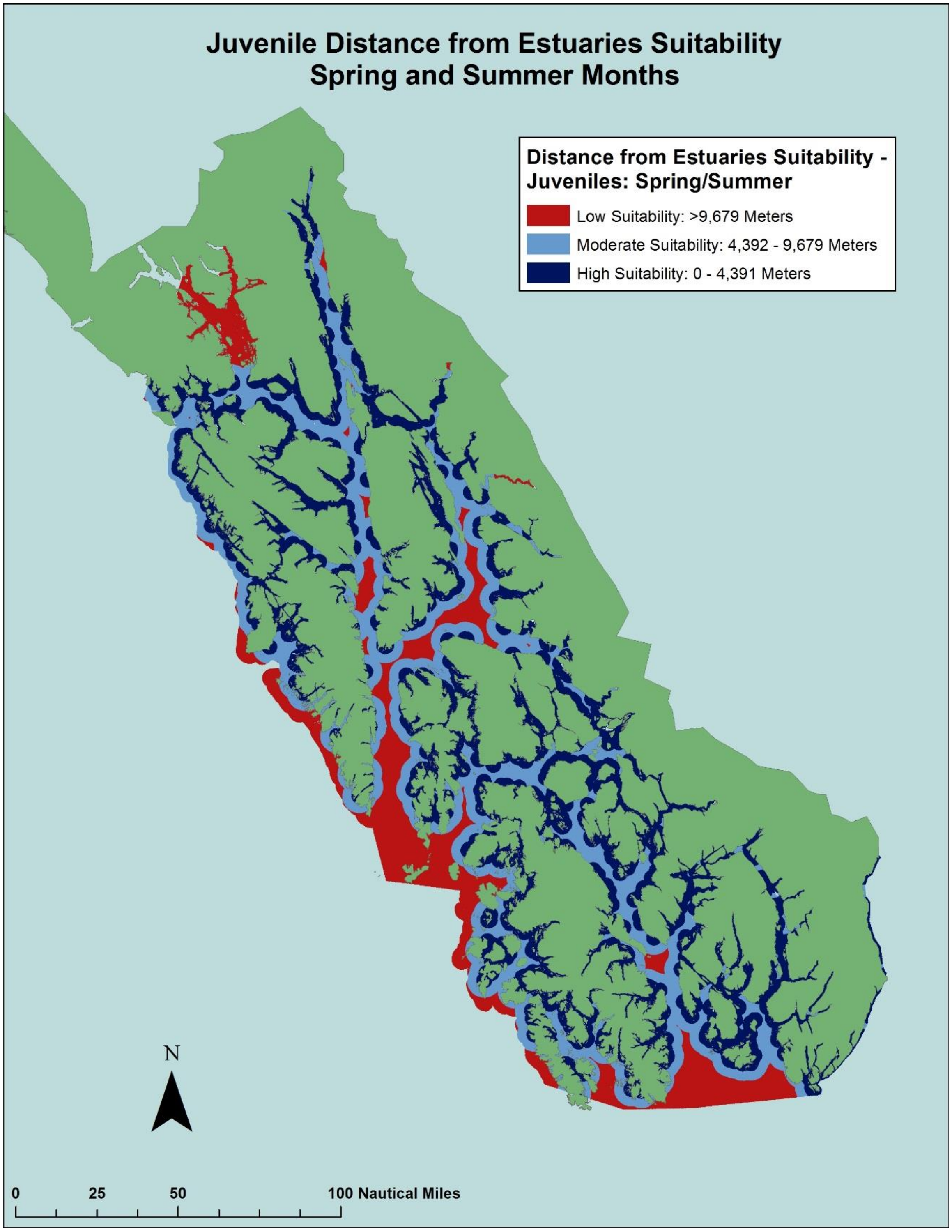

Figure 4.23. Suitability ranks of distance from estuaries for juveniles in the spring/summer months.

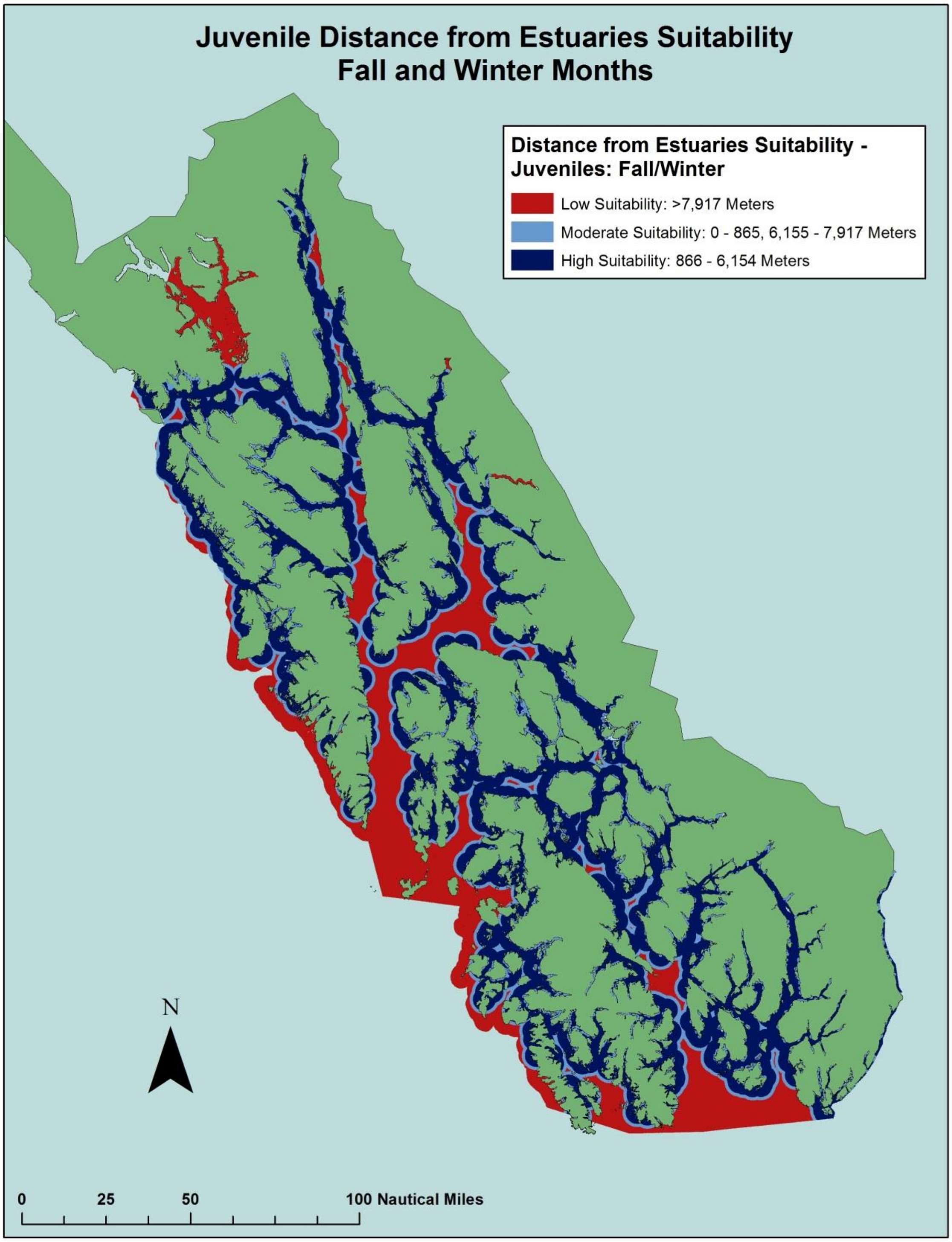

Figure 4.24. Suitability ranks of distance from estuaries for juveniles in the fall/winter months.

4.2. Final Habitat Results

Specific details regarding the total square nautical miles and percentage of study area associated with each suitability rank and classification can be found in Tables 4.9 and 4.10. For all classifications, much of the low suitable habitat (weighted suitability value of 1.00) incorporated an average of 1.32% of the total study area. The moderately suitable habitat (weighted suitability value of 2.00) incorporated most of the total study area, with an average percentage of 62.99%. The highly suitable habitat (weighted suitability value of 3.00) incorporated an average of 35.69% of the total study area.

There was a minimal amount of gain between the final low habitat suitability areas for female Dungeness crab (0.57%), a 1.65% loss of moderate habitat, and a 1.09% gain in highly suitable habitat from the spring and summer to the fall and winter months. There was a minimal amount of change between the final low habitat suitability areas for male Dungeness crab (1.38%), however there was a 9.48% loss of moderate habitat and a 10.84% gain in highly suitable habitat from the spring and summer to the fall and winter months (Tables 4.9 and 4.10). Juvenile Dungeness crab habitat experienced a 9.06% loss in habitat for the moderately suitable areas from spring and summer to fall and winter, but a 9.65% gain in highly suitable habitat from spring and summer to fall and winter. There was a minute, 0.60% loss of habitat in the low suitability areas for juvenile Dungeness crab (Tables 4.9 and 4.10).

Table 4.9. Square nautical miles of the study area associated with each suitability rank and specimen classification, and the differences in areas between both seasons for the final suitability models.

Suitability	Female SS	Female FW	Difference	Male SS	Male FW	Difference	Juvenile SS	Juvenile FW	Difference
Low	50.74	106.32	55.58	205.54	70.34	-135.20	205.54	147.3	-58.24
Moderate	6,531.11	6,368.33	-162.78	6,569.67	5,635.96	-933.71	6,569.67	5,676.85	-892.82
High	3,275.81	3,383.01	107.20	3,082.45	4,151.36	1,068.91	3,082.45	4,033.50	951.05

Table 4.10. Percentage of the study area associated with each suitability rank and specimen classification, and the percentage of differences between both seasons for the final suitability models.

Suitability	Female SS	Female FW	Difference	Male SS	Male FW	Difference	Juvenile SS	Juvenile FW	Difference
Low	0.51	1.08	0.57	2.09	0.71	-1.38	2.09	1.49	-0.60
Moderate	66.25	64.60	-1.65	66.65	57.17	-9.48	66.65	57.59	-9.06
High	33.23	34.32	1.09	31.27	42.11	10.84	31.27	40.92	9.65

4.3. Model Validation – Specimen and Model Comparisons

When comparing the location of specimen points with the final suitability models, there appeared to have been a high accuracy rate between the percentages found in highly suitable areas. The Dungeness crab bycatch from the 2017 ADFG red king crab surveys (June and July) and Tanner crab surveys (October) were used to identify the presence of specimens between ranks. These data were independent of what was used to create suitability layers for this study. The specimen counts and percentages for each suitability rank and specimen classification can be found in Tables 4.11 and 4.12. For all sex and age classes for all seasons, between 95.83% and 100.00% of Dungeness crab were found in highly suitable areas. More specifically for the spring and summer months, 359 (100.00%) adult female Dungeness crab were found in the areas designated as highly suitable habitat and zero crab were found in areas of both moderate and low suitable habitat (Figure 4.25). For the fall and winter months, 46 crab (95.83%) adult female Dungeness crab were found in highly suitable areas, two crab (4.17%) were found in moderately suitable areas, and again, zero crab were found in low suitable areas (Figure 4.26).

For adult male Dungeness crab in the spring and summer months, 171 (97.16%) were found in areas of highly suitable habitat, five (2.84%) were found in moderately suitable habitat, and zero were found in areas of low suitability (Figure 4.27). For the fall and winter months, 173 (100.00%) adult male Dungeness crab were found in highly suitable habitat and zero crab were found in both the moderate suitability areas and areas designated as low suitable habitat (Figure 4.28).

For both female and male juvenile Dungeness crab in the spring and summer months, 17 (100.00%) were found in high suitability habitat areas and zero crab were found in both the moderate and low suitable habitat areas (Figure 4.29). For the fall and winter months, 186 (96.37%) juveniles were found in highly suitable areas, seven (3.63%) were found in moderately suitable areas, and zero were found in low suitability areas (Figure 4.30).

The results showed that more than 95% of all specimens were found in the highly suitable areas and that there was a low specimen count for adult females in the fall and winter months and for juveniles in the spring and summer months (Table 4.12). Although it appeared that the high percentage of specimens found in the highly suitable habitat was sufficient evidence that the habitat suitability models were accurately depicting specimen preference for habitat, due to the lack of validation data, significance of these results could not be determined, as statistical tests could be conducted.

Table 4.13 shows the number of pots used in each suitability class to obtain specimens for model validation. Most pots from the 2017 ADFG crab surveys happen to be set in the high suitability areas, most likely due to the fact that the surveys were targeting crab that prefer habitats similar to Dungeness crab preferences (i.e. Tanner and red king crab). A total of zero pots (0.00%) were set in the low suitability areas, ten pots (2.56%) were set in the moderate suitability areas, and 380 pots (97.44%) were set in the high suitability areas. When calculating the number of specimens that were caught per pot (as ADFG crab managers do to estimate the harvest strength of the fishery), for the areas that pots were set, only males in the spring and summer months had a higher catch per unit of effort (CPUE) in the moderate suitability areas than in the high suitability areas (Table 4.14). These comparisons between at least two ranks could only be made for females in the fall and winter, males in the spring and summer, and juveniles in the fall and winter months.

Table 4.11. The number of specimens associated with each suitability rank and specimen classification.

Suitability	Female SS	Female FW	Male SS	Male FW	Juvenile SS	Juvenile FW
Low	0	0	0	0	0	0
Moderate	0	2	5	0	0	7
High	359	46	171	173	17	186

Table 4.12. Percentage of specimens associated with each suitability rank and specimen classification.

Suitability	Female SS	Female FW	Male SS	Male FW	Juvenile SS	Juvenile FW
Low	0.00	0.00	0.00	0.00	0.00	0.00
Moderate	0.00	4.17	2.84	0.00	0.00	3.63
High	100.00	95.83	97.16	100.00	100.00	96.37

Table 4.13. The number of pots used to catch Dungeness crab in each rank for each classification. Pot data were used from the ADFG 2017 red king crab and Tanner crab surveys.

Classification	Low	Moderate	High
Females - Spring/Summer	0	0	122
Females - Fall/Winter	0	2	18
Males - Spring/Summer	0	3	127
Males - Fall/Winter	0	0	71
Juveniles - Spring/Summer	0	0	10
Juveniles - Fall/Winter	0	5	32

Table 4.14. The number of specimens caught per pot in each rank for each classification. Data were used from the ADFG 2017 red king crab and Tanner crab surveys. Classes marked as “N/A” were areas where pots were not set.

Classification	Low	Moderate	High
Females - Spring/Summer	N/A	N/A	2.94
Females - Fall/Winter	N/A	1.00	2.56
Males - Spring/Summer	N/A	1.67	1.35
Males - Fall/Winter	N/A	N/A	2.44
Juveniles - Spring/Summer	N/A	N/A	1.70
Juveniles - Fall/Winter	N/A	1.40	5.81

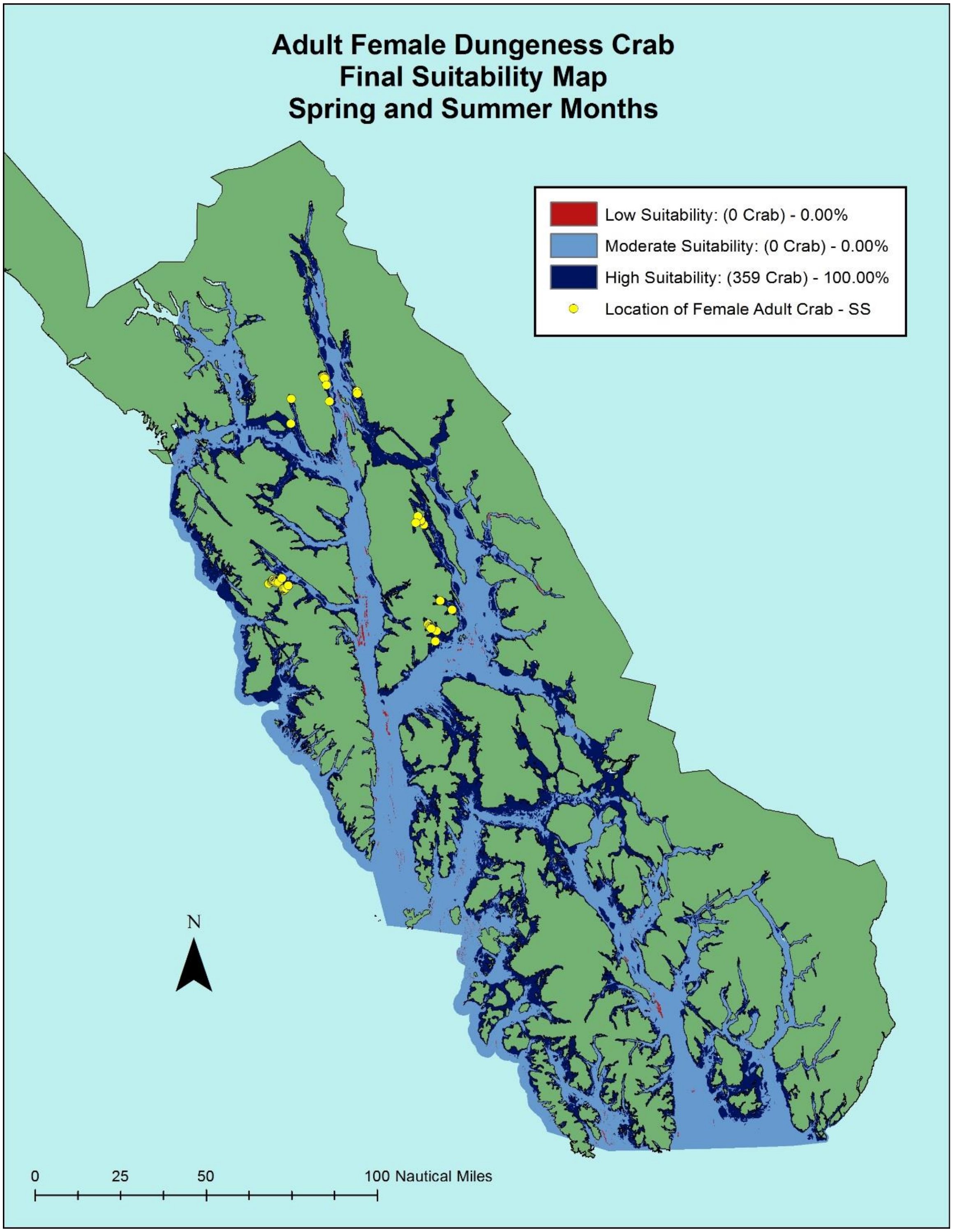

Figure 4.25. Areas determined as low, moderate, and highly suitable for adult female Dungeness crab during the spring and summer months in Southeast Alaska. In order to show the correlation between actual crab catch and suitability ranks, location of specimens were also added.

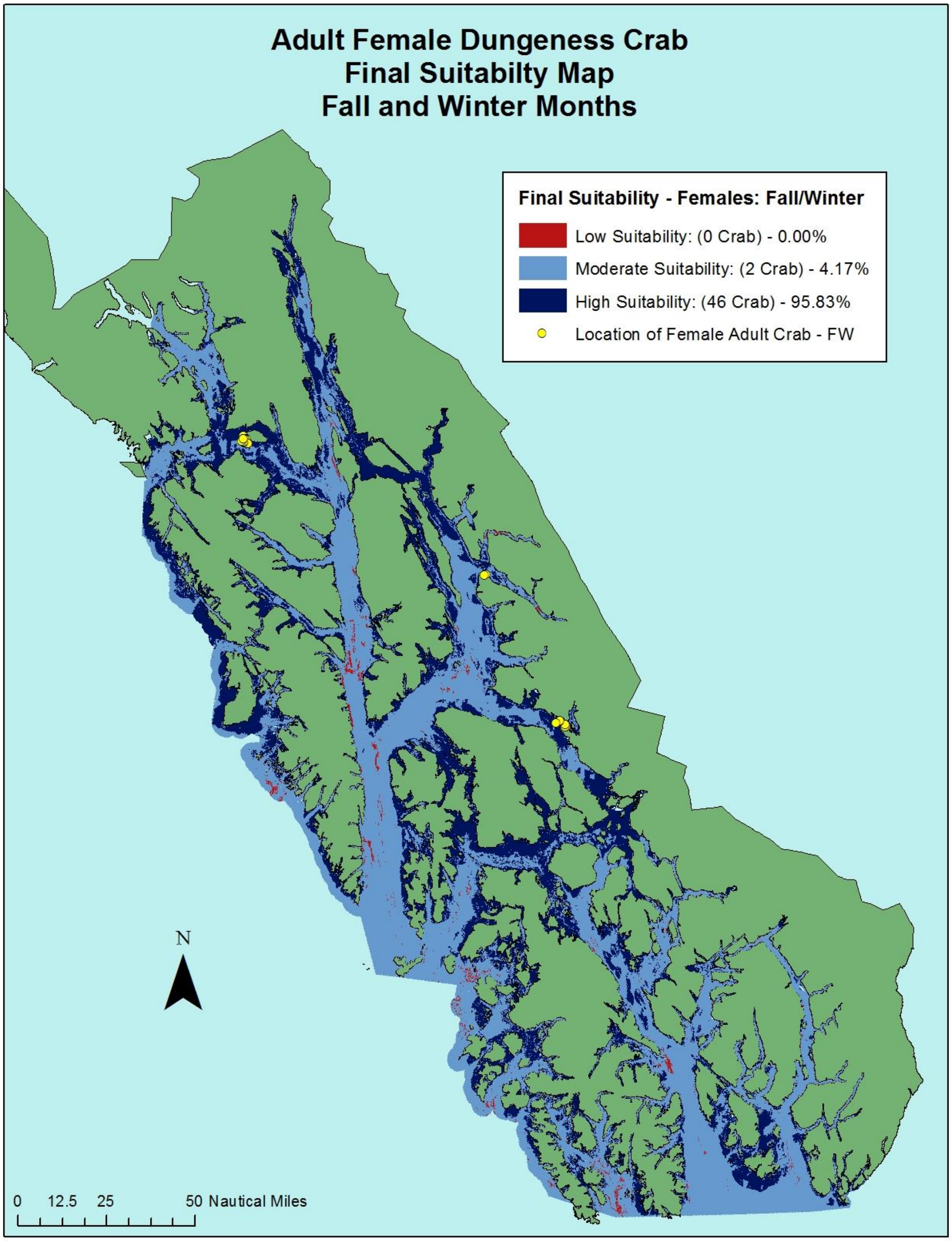

Figure 4.26. Areas determined as low, moderate, and highly suitable for adult female Dungeness crab during the fall and winter months in Southeast Alaska. In order to show the correlation between actual crab catch and suitability ranks, location of specimens were also added.

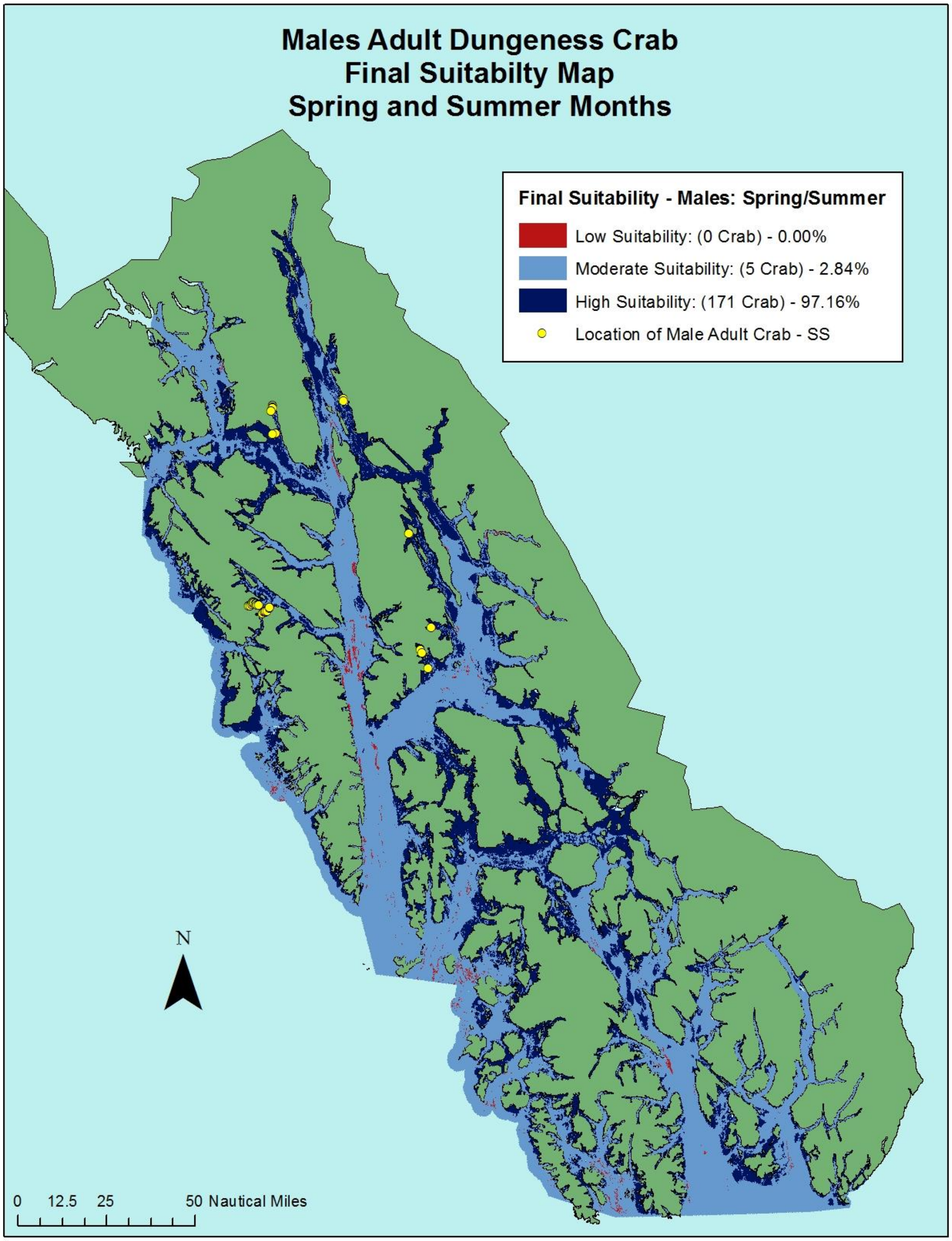

Figure 4.27. Areas showing areas determined as low, moderate, and highly suitable for adult male Dungeness crab during the spring and summer months in Southeast Alaska. In order to show the correlation between actual crab catch and suitability ranks, location of specimens were also added.

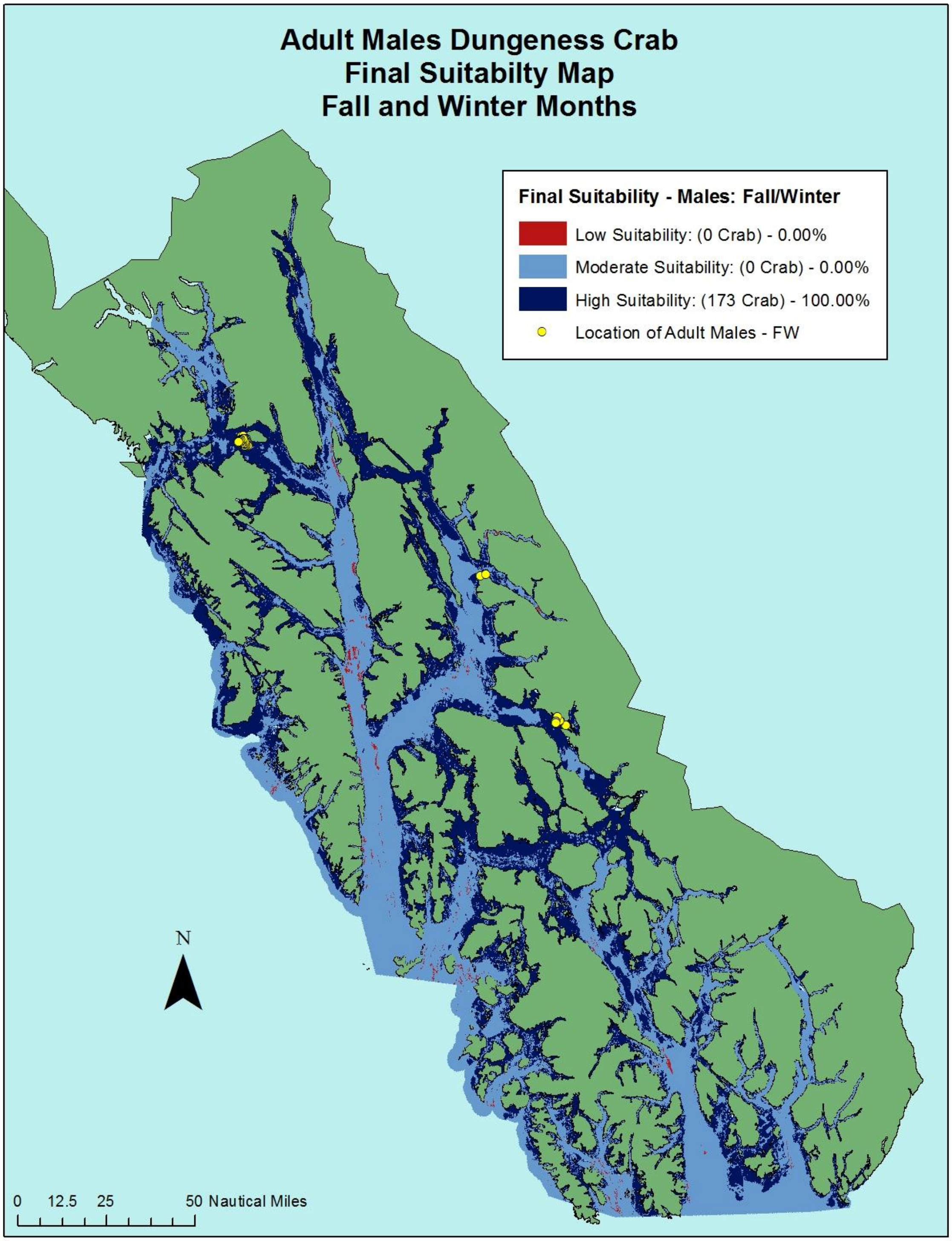

Figure 4.28. Areas determined as low, moderate, and highly suitable for adult male Dungeness crab during the fall and winter months in Southeast Alaska. In order to show the correlation between actual crab catch and suitability ranks, location of specimens were also added.

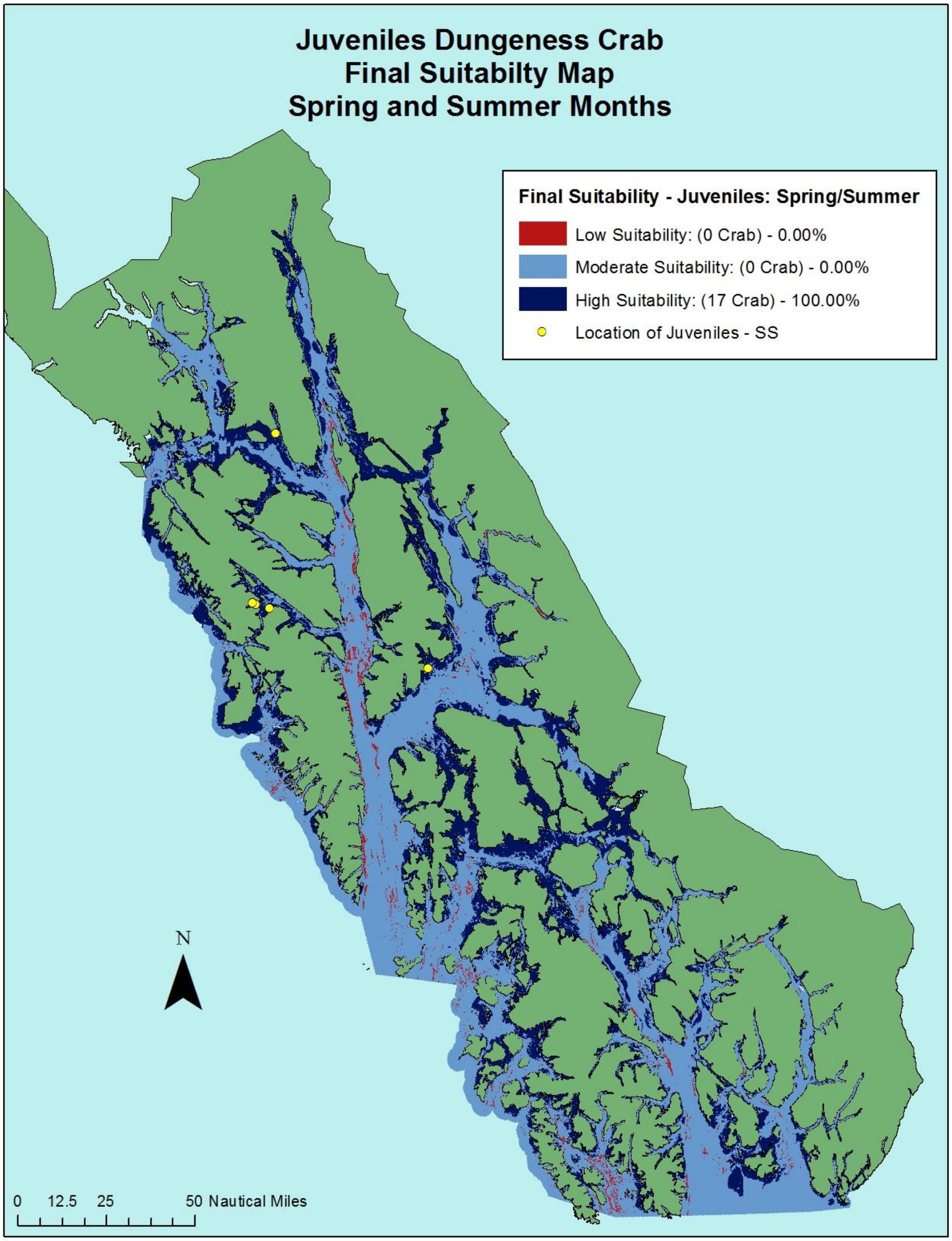

Figure 4.29. Areas determined as low, moderate, and highly suitable for juvenile Dungeness crab during the spring and summer months in Southeast Alaska. In order to show the correlation between actual crab catch and suitability ranks, location of specimens were also added.

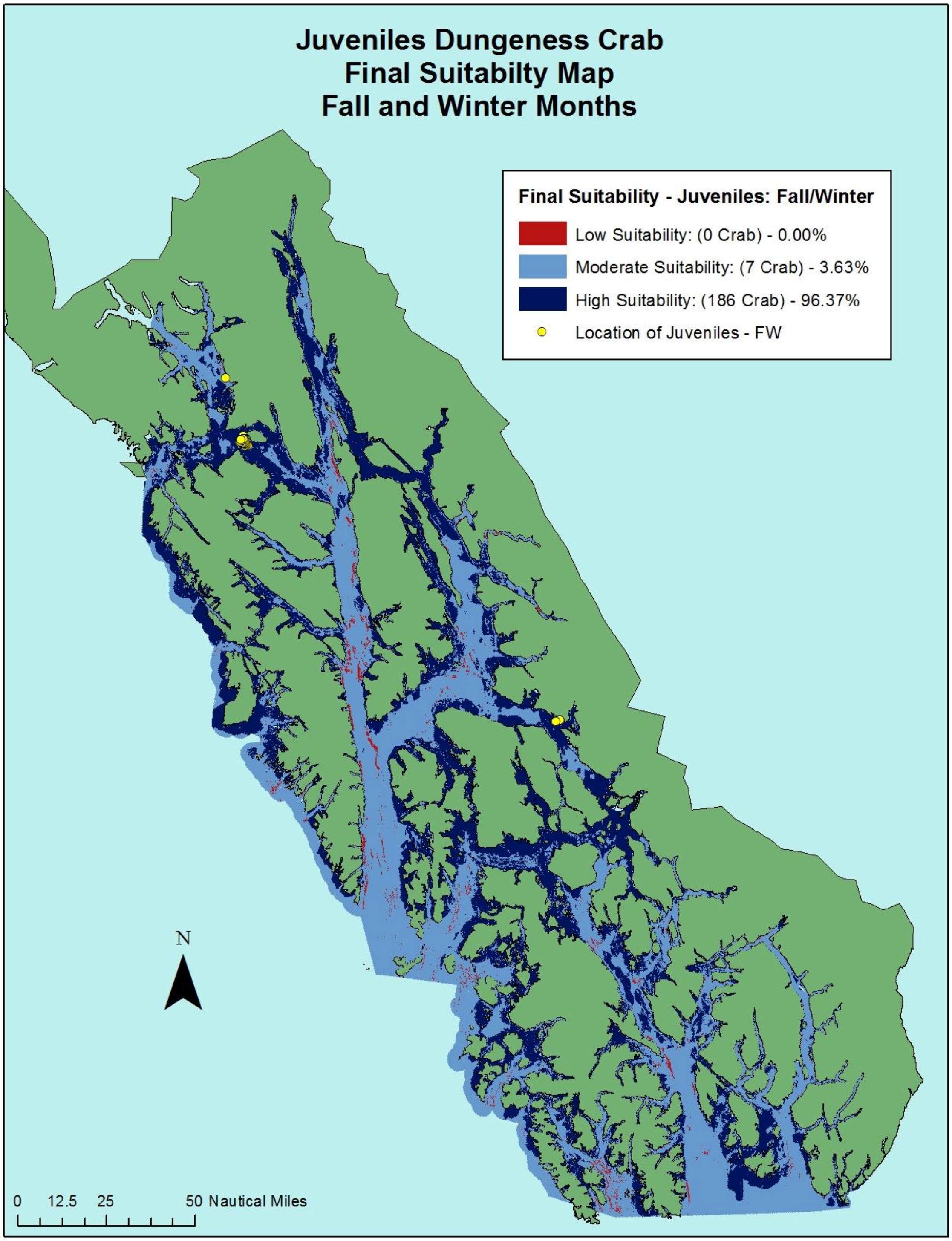

Figure 4.30. Areas determined as low, moderate, and highly suitable for juvenile Dungeness crab during the fall and winter months in Southeast Alaska. In order to show the correlation between actual crab catch and suitability ranks, location of specimens were also added. Four specimens were found outside of the final layer and were excluded for the final comparison between habitat ranks and specimen locations.

CHAPTER 5 - DISCUSSION AND CONCLUSION

5.1. Research Objective Review

The objective of this research was to develop a habitat suitability model for SEAK Dungeness crab at their various sex or life cycles during certain times of the year. For each age or sex class (male adults, female adults, or juveniles), two models were created based on seasonality: the fall/winter (September to December) versus the spring/summer months (March to August) using substrate, depth, slope, and distance from estuaries as the four major environmental factors.

5.2. Habitat Factors

5.2.1. Depth Suitability Discussion

When comparing adult female Dungeness crab between the spring and summer months and the fall and winter months for the suitability of depth, it was discovered that the total area for their highly suitable depth habitat increased by 16.49%. The moderate areas dropped by 20.14% and the low suitability areas increased by 3.65% (Table 4.2). Adult female Dungeness crab seem to gain highly suitable area, in regard to depth, in the fall and winter months. This appears to be due to their natural advancement to deeper water during this time of year.

The adult male Dungeness crab suitability area increased by 15.07% for high suitability areas, increased by 2.08% in the moderate areas, and decreased by 17.16% in the low suitability areas (Table 4.2). Adult male Dungeness crab also gained highly suitable area, in regard to depth, in the fall and winter months. Again, this appears to be due to their natural advancement to deeper water during this time of year.

The juvenile Dungeness crab suitability area increased by 15.07% for high suitability areas, decreased by 9.51% in the moderate areas, and decreased by 5.56% in the low suitability areas (Table 4.2). The gain of depth suitability in the winter was considered a previously unknown fact about this age class, as the literature states that juvenile crab tend to stay in shallow waters during the fall and winter months. Despite common knowledge about juvenile Dungeness crab in Southeast Alaska, this information appears to show contrary information and that juveniles tend to inhabit deeper waters than previously thought (ADFG 1985 and Curtis and McGaw 2008).

5.2.2. Substrate Suitability Discussion

For adult female and juvenile Dungeness crab, there was no change in the amount of area from the spring and summer to the fall and winter months, in regard to highly suitable substrate habitat. Adult females lost 23.33% of their moderately suitable habitat to the lower suitable habitat from the seasonal change (Table 4.4). Adult males experienced an 8.71% gain in high substrate suitability from the spring and summer to the fall and winter months and a 7.65% loss in moderate and 1.06% loss in low suitability from one seasonal rank to the other. Juveniles gained 12.36% in moderate suitability habitat in the fall and winter months, which was lost in the low suitability areas during this time (Table 4.4). These results suggested that seasonal changes do not affect the substrate preference of adult female and juvenile Dungeness crab, but for some reason adult male Dungeness crab prefer habitats with both mud and sand in the fall and winter, and only mud in the spring and summer months, thus increasing their area of high suitability.

5.2.3. Slope Suitability Discussion

Only adult female Dungeness crab experienced a seasonal change for slope suitability. This group lost 13.70% of their high suitability area, in regard to slope, and gained that 13.70% in the moderately suitable areas (Table 4.6). For unknown reasons, adult female Dungeness crab prefer a flatter plane of sea floor in the fall and winter months, leading to a loss in higher suitable area. It may have to do with egg brooding during this time of year. According to the results, adult males and juveniles do not have a seasonal slope preference in SEAK.

5.2.4. Distance from Estuaries Suitability Discussion

Adult female Dungeness crab experienced an increase (8.14%) in highly suitable habitat from the spring and summer months to the fall and winter months, in regard to their distance from estuaries in SEAK (Table 4.8). This is most likely explained by their natural tendencies to move to deeper waters in the fall and winter months, which are further from the mouth of estuaries in SEAK. Adult females lost 8.14% of area in the moderate areas to highly suitable areas with the seasonal change but did not experience any change in regards the lower suitability areas. Juveniles experienced a 48.02% loss in moderate areas, of which 28.71% was lost to the lower suitability areas and 19.31% to high suitability areas (Table 4.8).

Surprisingly, although adult males also tend to move toward deeper waters in the fall and winter months, they lost zero highly suitable area for distance from estuaries. In fact, males experienced zero change between all ranks of suitability for distance from estuaries.

5.3. Final Habitat Suitability Model

5.3.1. Female Final Habitat Suitability Discussion

Even though great differences were seen among individual environmental variables when comparing seasons, very little change occurred for females when the habitat factors were combined. Regarding area, a minimal amount of habitat loss or gain happened between the spring and summer to the fall and winter months for the final suitability maps, a 1.06% increase in area occurred for females in the highly suitable habitat areas, a loss of 1.63% was seen in the moderate areas, and a slight increase of 0.57% was seen in the low suitability areas (Table 4.10). This suggests that very little area is gained or lost from season to season for adult female Dungeness crab.

Again, there were 359 (100.00%) crab found in the highly suitable areas, zero crab found in the moderately suitable areas and zero crab found in the low suitable areas for the spring and summer months (Tables 4.11 and 4.12); however, pots were only set in the high suitability areas for the spring and summer months (Table 4.13). The CPUE for females in the high suitability areas in the spring and summer months was 2.94 crab per pot. For the fall and winter months, there were 46 (95.83%) found in the highly suitable habitat, two (4.17%) found in the moderately suitable areas, and zero found in the areas considered as low suitability (Tables 4.11 and 4.12); however, zero pots were set in the low suitability areas, two pots were set in the moderate suitability areas, and 18 pots were set in the high suitability areas (Table 4.13). The CPUE for females in the moderate areas was 1.00 crab per pot and was 2.56 crab per pot in the high suitability areas (Table 4.14). Although a high percentage of female Dungeness crab found in the highly suitable areas appears significant and suggests that the HSM was accurately identifying highly suitable habitat for adult female crab for both the spring and summer and the fall and winter months in SEAK, zero pots were set in the low suitability areas and only two pots were set in the moderately suitable areas in the fall and winter months (Table 4.13). The higher CPUE in the high suitability areas for the fall and winter months may be significant when comparing the number of specimens to the moderate areas, but with only two pots in the moderate areas, it is difficult to definitively say the high percentage of specimens and CPUE in the highly suitable areas is significant. The low and moderately suitable habitat may be considered unsuitable to this class of Dungeness crab; however, further research in low and moderately suitable areas will need to be conducted.

5.3.2. Male Final Habitat Suitability Discussion

Again, even though great differences were seen among individual environmental variables when comparing seasons, very little change occurred for males when the habitat factors where combined. A minimal to moderate amount of habitat loss or gain happened between the spring and summer to the fall and winter months for the final suitability maps. A 10.84% increase in area occurred for males in the highly suitable habitat areas, a loss of 9.48% was seen in the moderate areas, and a decrease of 1.38% was seen in the low suitability areas (Table 4.10). This suggests that the total area of highly suitable habitat increased moderately from the spring and summer months to the fall and winter months.

There were 171 (97.16%) crab found in the highly suitable areas, five (2.84%) crab found in the moderately suitable areas and zero crab found in the low suitable areas for the spring and summer months (Tables 4.11 and 4.12); however, as with the adult female crab, data was lacking in the low and moderately suitable areas. Zero pots were pulled from low suitability areas, and only three pots were pulled in the moderately suitable areas for the spring and summer months (Table 4.13). The CPUE for the moderately suitable areas in the spring and summer months was 1.67 crab per pot, which was higher than the CPUE for the highly suitable areas (1.35 crab per pot) (Table 4.14). It is difficult to determine whether the high percentage of specimens found in the high suitability areas was significant or if the higher CPUE in the moderate areas was more significant, as the number of pots used for the model validation was nonexistent or limited for the low and moderately suitable areas (Tables 4.11 to 4.14). For the fall and winter months, all 173 (100.00%) specimens were only found in the highly suitable habitat (Tables 4.11 and 4.12), but once again, only the highly suitable areas had pots associated with validation; therefore, it was impossible to determine if this high percentage was significant (Table 4.13). As with the adult female Dungeness crab, the high percentage of male Dungeness crab found in the highly suitable areas cannot be determined to be significant or not and cannot suggest that the HSM was accurately identifying highly suitable habitat for adult male crab for both the spring and summer and the fall and winter months in SEAK. Also, as with the adult female Dungeness crab, a determination that the areas designated as low and possibly moderately suitable habitat could not be considered as unsuitable due to the lack of specimens found in this area during both these seasonal classes, as the number of pots pulled from these locations was either zero or considered low.

5.3.3. Juvenile Final Habitat Suitability Discussion

Again, even though great differences were seen among individual environmental variables when comparing seasons, a minimal to moderate change occurred for juveniles when the habitat factors where combined. A 9.65% increase in area occurred for juveniles in the highly suitable habitat areas, a loss of 9.06% was seen in the moderate areas, and a decrease of 0.60% was seen in the low suitability areas (Table 4.10). This suggests that the total area of highly suitable habitat increased moderately from the spring and summer months to the fall and winter months.

All 17 (100.00%) juvenile crab were found in the highly suitable areas for the spring and summer months (Tables 4.11 and 4.12), but as it was for the previous classes, zero pots were surveyed in the low and moderately suitable areas; therefore, the significance of these numbers is impossible to determine at this time (Table 4.13). Also, the total number of specimens found for the spring and summer months for the high suitability areas was minimal and more specimen data would be beneficial for this particular habitat class. Proosdij et al. (2015) found that a minimum of 20 specimens is needed to identify accurate results in distribution for field studies. They found that any number of specimens less than 20 resulted in inaccurate information.

For the fall and winter months, 186 (96.37%) specimens were found in the highly suitable habitat, seven (3.63%) were found in moderate areas, and zero were found in low areas (Tables 4.11 and 4.12); however, as with all other classes, zero pots were sampled in the low suitability areas, only five pots were sampled in the moderately suitable areas, and 32 pots were sampled in the high suitability areas. The CPUE for juvenile crab in the high suitability areas was the highest sampled (5.81 crab per pot) when compared with the moderately suitable areas (1.40 crab per pot) or any other CPUE calculated for all other classes. Again, it is impossible to determine whether this was significant without obtaining data from all habitat suitability ranks. As with the other Dungeness crab classifications, it cannot be determined that the high percentage of juvenile Dungeness crab found in the highly suitable areas was substantial, nor can it suggest that the HSM was accurately identifying highly suitable habitat for juvenile crab for both the spring and summer and the fall and winter months in SEAK. Also, as with the other Dungeness crab classifications, it cannot be suggested that the areas designated as low and possibly moderately suitable habitat should be considered as unsuitable due to the lack of specimens found in this area during both these seasonal classes due to the lack of data from the lower ranks.

5.4. Conclusion

This study made a potentially surprising discovery regarding juvenile Dungeness crab. Contrary to the literature cited, much of the highly suitable depths in which juvenile Dungeness crab were found were frequently as deep as 73 meters during the fall and winter months. This was found during the process of determining habitat preferences for creating the habitat suitability model. The literature stated that juvenile Dungeness crab are found at depths less than nine meters during the winter months (ADFG 1985, Curtis and McGaw 2008). This newfound information could be important for protecting nursery grounds and juvenile habitat and ensuring the safety of future Dungeness crab populations in SEAK. The literature also stated that adult female Dungeness crab preferred slopes between 10.2 and 18.3 degrees, however, this study suggested that females prefer much less angled slopes (Stone and O'Clair 2001). The research conducted for this study found that females preferred a slope of less than around ten degrees in the spring and summer months and a slope of less than six degrees in the fall and winter months. This was also found during the process of determining habitat preferences for creating the habitat suitability model.

Habitat suitability models have the potential for fiscally responsible research with the support of few employees. A great deal of information can be visually represented by creating habitat suitability models of an area for species with environmental information that can be obtained by aerial photography, field studies, data collected from agencies for other purposes, or published literature (Brown et al. 2000, Lauver et al. 2002, Vinagre et al. 2006, Belongie 2008, Harney 2008, Toor et al. 2011, Rengstorf et al. 2013). Researchers can use these models to identify how annual or decadal changes to habitat could affect Dungeness crab in SEAK. Climate change and ocean acidification are potentially negative issues that many Alaskan coastal habitats and their species could face in the next century and beyond (McConnaughey and Armstrong 1995). These HSMs have the potential to help managers determine if populations are decreasing in response to temporal changes to habitat. HSMs also help researchers and managers determine key habitats for Dungeness crab, which should be protected from anthropogenic structures.

Although this study created potentially strong HSMs, there is no way to determine if these findings are significant at this time due to the lack of validation data in the lower suitability ranks. Due to this study being completely dependent on bycatch crab data from other crab species surveys, it may take time to acquire a sufficient amount of validation data for each age, sex, and seasonal class for all suitability ranks in the future. The hope is that eventually researchers and managers with the Alaska Department of Fish and Game will be able to utilize this information to protect critical habitat, be able to focus future research efforts in areas of highly suitable habitat, and monitor changes to habitat on a periodic basis as environmental conditions change as variations to climate occur in SEAK. If ADFG acquire funding in the near future for Dungeness crab research, this study may be able to quickly gain validation data to specifically test the lower suitability ranks for specimen data by setting Dungeness gear in some of these areas.

5.5. Further Research

An extension of this study will focus on acquiring more specimen data for juvenile Dungeness crab in the spring and summer months, as the specimen data for this time period was lacking. Future research for this age class during the spring and summer months will aim to acquire a dataset of greater than 20 individuals. An analysis of other potential environmental factors could also be utilized, such as potential food sources or the effects of temperature on all age and sex classes.

Also, as previously mentioned, more validation data will be required from the areas designated as low and moderate suitability areas in the future to determine the significance of this model. This can come from either the ADFG red king and Tanner crab surveys or if funding allows it, a directed Dungeness crab survey.

In addition to acquiring more specimen data, an alternative method to determining classification breaks for habitat suitability criteria should be analyzed. This study utilized three breaks (>10% as high suitability, 1-10% as moderate, and <1% as low) of specimens found in each habitat classification bin for habitat rank criteria (Tables 3.4, 3.13, 3.16, and 3.19). A possible alternative would be to calculate the statistical standard deviation of specimens for each class and create breaks based on those results, as this may give a more statistically significant understanding of breaks in classifications. Future classifications could be broken into three ranks that are one (high suitability), two (moderate suitability), and three (low suitability) standard deviations from the mean, depending on the range of standard deviations. This method could result in more accurate suitability ranks.

Once adequate models have been established for all groups of Dungeness crab in SEAK, an annual assessment could be created to monitor changes to Dungeness crab habitat for years to come with the Alaska Department of Fish and Game.

Also, a potential goal would be to take the HSM methods used in this study and apply them to other commercially managed crab species in SEAK, such as red king crab, golden king crab, and Tanner crab species, in order to learn more about their habitat and to help manage and protect them in the future as well.

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