NORTH PACIFIC RESEARCH BOARD PROJECT FINAL REPORT

Assessment of Bristol Bay red king crab (*Paralithodes camtschaticus*) resource for future management action--a new approach

NPRB Project 625 Final Report

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Abstract

The Bering Sea Fisheries Research Foundation (BSFRF) cooperating with the National Marine Fisheries Service (NMFS) conducted a 40 day assessment survey of Bristol Bay red king crab (BBRKC) in late May-early July 2007 aboard the chartered 120 ft F/V *American Eagle* using specialized trawl gear, a new survey design and new analytical methods. The BSFRF survey was coordinated with the long standing NMFS survey of this resource to test the hypothesis that a different trawl design, a new survey methodology and principals of geostatistics would estimate mean and variance of BBRKC abundance with more accuracy and precision than the standard NMFS annual trawl survey. Final plans for the 2007 BSFRF assessment survey were completed in April 2007 following a successful pilot study conducted during the summer of 2005 and testing of purchased survey gear and trawl mensuration sensors during the fall of 2006. The 2007 BSFRF survey was conducted over an approximate 24,000 square nautical mile region consisting of 241 random site tows. The area swept estimates for each trawl tow were accurately measured by the trawl mensuration equipment and estimates benefited greatly from use of a new and improved trawl bottom contact sensor developed by NMFS. The new survey gear, sampling methodology and goestatistics proved highly effective and generated more precise BBRKC abundance estimates than those from the standard NMFS survey in the same area and time. Precision estimates (95% CI) for large male BBRKC from the standard NMFS survey have averaged +/- 37% over the past 10 years compared to +/- 13% from the BSFRF survey. A standard normal test for a difference in population means (Z-test) was used to test the differences between BSFRF and NMFS surveys. Results showed statistically significant higher estimated mean abundance and reduced variance from the BSFRF survey for all sizes and sexes of BBRKC. Separate from the assessment survey, the F/V *American Eagle* and the two NMFS survey vessels worked together over a two day period and completed a planned pilot study of 20 paired side by side tows. Results are discussed and being used to design further comparative trials.

Key Words

Management, king crab, resource assessment, trawl, catchability coefficient

Citation

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Study Chronology

Project 625 followed the time line identified in the statement of work as amended and approved by North Pacific Research Board (NPRB). All Progress Reports have been submitted to NPRB on time. Tested procedures and results of a pilot study conducted in 2005 provided the basis for planning the 2007 survey that began in the fall of 2005 (Hughes and Goodman 2005). Survey gear was purchased and bench tested in early 2006. A field test in Puget Sound onboard the *American Eagle* was conducted in the fall of 2006 resulting in excellent performance of the new net mensuration system but some problems with the trawl gear. Corrections were made to the trawl gear during the winter of 2006/07 and Dr. Gerard Conan's (Marine Geomatics) involvement in the project ended during this period with NPRB approval. Final survey plans were completed in the spring 2007. The full survey assessment was conducted during a 40 day period of May 25 - July 5, 2007 as scheduled. Data summaries and preliminary results were presented to the North Pacific Fishery Management Council (NPFMC) Crab Plan Team in September 2007 and to several industry meetings during September 2007-January 2008. Project results were presented to NPRB at the Alaska Marine Science Symposium in January 2008 followed by this final report at project completion in March 2008.

Introduction

The determination of Bering Sea crab densities, abundance and biomass estimates, recruitment patterns and other biological parameters important to modeling and yield projections have long suffered from uncertainty due to assessment methodology. The assessment has heavily relied on the annual NMFS bottom trawl survey of fish and crab conducted over the Bering Sea shelf and slope since the 1970's. This standard survey design includes more that 160,000 square nautical miles divided into about 400 survey blocks, each measuring 400 square nautical miles. The basic NMFS survey design calls for completion of a measured 30 minute tow near the center of each block for purposes of catch enumeration, density calculations, abundance and biomass estimates and biological parameters for management. The ability of the standard survey trawl configuration to continuously remain in contact with the seabed and to capture animals (particularly crab) on or burrowed in the seabed has long been questioned. For Bristol Bay red king crab (BBRKC), surveys in recent years have shown a tendency for the survey trawl footrope to often skip along the seabed so that even the legal sized male king crab catchability coefficient is substantially less than 1.0 (Weinberg et al. 2004). Smaller crab, juveniles and females are known to have an even lower catchability than legal sized males. Improved crab assessment certainty must start with the use of survey trawl gear that captures and retains nearly all the crab in the path of the trawl. Such performance requires specialized trawl gear that maintains seabed contact throughout the tow, uncovers crab within the substrate and retains small juvenile crab. Further assessment certainty comes from increasing sampling density. Because BBRKC exhibit high patchiness, the NMFS survey's low sampling density of one 30 minute tow per 400 square nautical miles suffers from unacceptably high variance estimates (Dew and Austring 2007). Concerns by both industry and government for the ability of the standard NMFS multi-purpose trawl survey to accurately assess Bering Sea crab stocks led to discussions and cooperative industry-government agreements for further research (Appendix 1). The interest in further research directly addressed the feasibility of developing a crab specific survey, beginning with a focus on BBRKC.

During the summer of 2005, BSFRF designed and conducted, in cooperation with NMFS and the Alaska Department of Fish and Game (ADF&G), a pilot survey of BBRKC. The pilot survey was conducted aboard the 120 ft trawler F/V *American Eagle* over a 4,000 square nautical mile area in the heart of the BBRKC management district (Figure 1). The trawl gear chosen for the pilot survey was a *Nephrops* trawl modified for conducting surveys of *opilio* Tanner crab in the Gulf of St. Lawrence, Canada. The pilot survey design called for the completion of 129 randomly selected tow locations, each of 5 minute tow duration, over the 4,000 square nautical mile test area. This area comprised about 10 standard NMFS 20 x 20 nautical mile survey blocks where NMFS conducted 10 standard tows as the BSFRF survey was being conducted. Abundance estimates of BBRKC by standardized crab size sex categories were calculated using area swept densities by both standard methods and principles of geostatistics from the pilot survey and compared with NMFS estimates of crab abundance within the same region.

The 2005 BSFRF survey was completed as planned. The tested BSFRF survey trawl proved highly effective in maintaining contact with the seabed and in capturing high numbers of crab including smaller juvenile and female crab. The population estimates from the NMFS survey in the compared study area were smaller and had higher variance compared to the BSFRF pilot survey (Figure 2).

Given results of the pilot survey and the presentation of those results to the North Pacific Fishery Management Council's Crab Plan Team in September 2005, cooperative research plans continued and focused on conducting a full scale assessment survey of BBRKC during the summer of 2007 (Figure 1). This research project was funded by BSFRF, NPRB (Project 625) and NMFS. This document provides the details of the basis for this research, survey methodology, logistics of the cooperative research, survey results compared to the results of the standard NMFS survey with statistical comparisons, and conclusions. Discussion of establishing a long term protocol between industry/NMFS/ADF&G for conducting this survey for future management is provided.

The project successfully tested the proposed hypothesis that “cooperative BBRKC survey strategy based on principles of geostatistics using methods developed for Canadian Gulf of St. Lawrence *opilio* crab will estimate the mean and variance of abundance and biomass with more accuracy and precision than standard NMFS annual survey.”

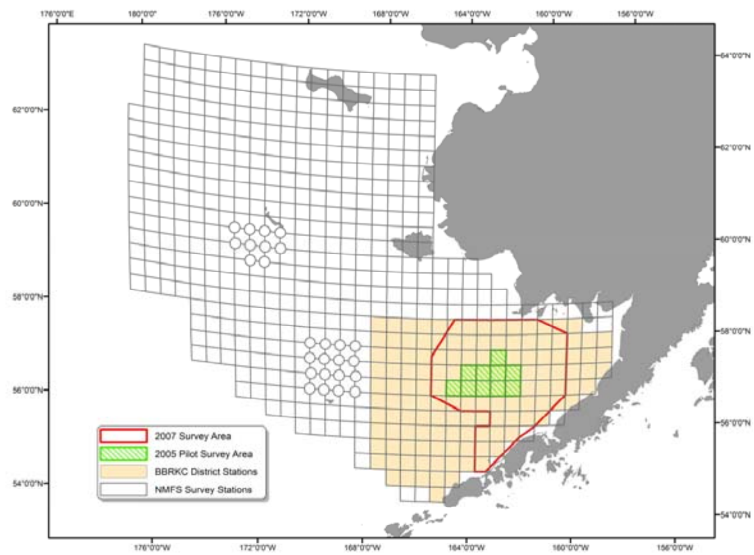


Figure 1. Bering Sea map showing NMFS survey grid, BBRKC District, 2005 BSFRF pilot study and 2007 full survey area.

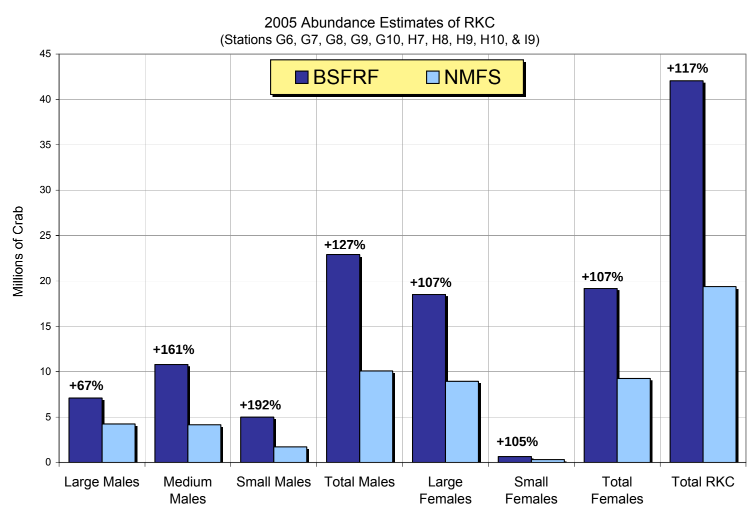


Figure 2. Comparative summary of abundance estimates NMFS v. BSFRF from 2005 pilot study results.

Objectives

Primary objectives of Project 625 remained unchanged from those as submitted in the proposal, as amended and approved by NPRB. Objective 5 was added as a pilot test study based on recommendations provided by NPRB and with the agreed cooperation of NMFS.

1) Accomplish a full-scale resource assessment survey of Bristol Bay red king crab successfully utilizing a modified survey trawl design, new survey sampling design, and apply new analytic methodology based on results from pilot work in 2005.
2) Improve area swept estimation based on results from 2005 that highlighted important questions about survey trawl time on bottom and total area swept per tow.
3) Provide sound data and results from the new BBRKC assessment to statistically test the Project 625 hypothesis that the new BSFRF survey could estimate abundance of BBRKC with more accuracy and precision than the annual Bering Sea NMFS survey.
4) Provide a basis for future surveys of this type and build upon existing information toward improving crab stock assessment and management.
5) Conduct a pilot experiment of a side by side comparative towing, designed by NMFS scientists, coordinating with the two Bering Sea NMFS survey vessels.

Methods

Methodology for this project was split into five main elements: 1) survey design, 2) sampling gear and instrumentation, 3) sampling logistics, 4) data collection, and 5) data analysis. While these methods are described separately they are interrelated during survey planning, notably between design and analysis. Portions of these methodologies were informed by prior bottom trawl surveys and expertise (Stauffer 2004), and some improvements in this survey design were based on the experience from the 2005 pilot study.

Survey Design

The survey was designed with four basic elements: 1) how many survey days were available, 2) what were the boundaries of the survey area, 3) how many tows could be completed and 4) how far apart on average each tow station would be. These elements were interdependent and were based on results from the 2005 pilot project. Geostatistical summaries from the 2005 pilot work provided an estimation tool (plot) of survey days at sea versus biomass precision of population estimates of large male red king crab (Figure 3). This figure was based on kriging estimates from 2005 of mean male density and showed that precision of the mean flattened out once sampling cell size was reduced to approximately 5.6 nautical miles between cell centers. From the relationship in Figure 3 it was determined that more survey effort beyond approximately 32-33 survey days would not yield much more precision. This information provided a guideline for choosing appropriate survey effort with expected precision of results versus funding and other survey resources available. Based on this trade off between expected precision and available funds for the survey, a target of 32 vessel survey days was chosen.

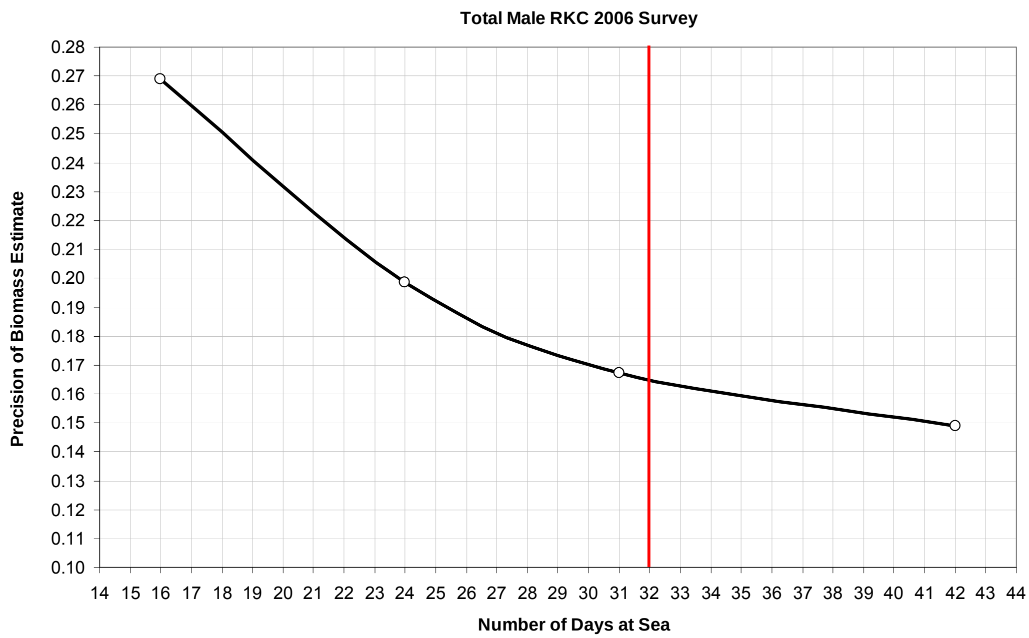


Figure 3. Estimated precision of survey biomass versus number of survey days. This relationship is based on 2005 pilot study geostatistical summaries of total male red king crab biomass.

The BSFRF survey area boundary was determined by a review of NMFS standard survey red king crab densities from 2001 through 2006. NMFS densities were plotted for these years showing the annual summer survey distributions of red king crab by size and sex category within the surveyed area. Figure 4 shows a subset of the density plots used with a preliminary BSFRF survey area boundary. Within the BBRKC management district, several NMFS survey grids showed few or no crab over the period of review. The BSFRF survey area was chosen to provide survey coverage of male and female red king crab over the entire distribution of red king crab within trawlable areas of the district. The district includes 136 standard NMFS stations covering 54,400 square nautical miles and the selected BSFRF survey area overlapped or enclosed 67 of those stations with approximate survey coverage of 24,197 square nautical miles (Figure 5). This 24,197 square nautical mile area was estimated to comprise more than 95% of the BBRKC stock.

After the survey area was defined, an estimate of total number of tows required inside the BSFRF survey area yielded a target of approximately 240 tows, based on the geostatistical summaries from the 2005 data. This was refined based on total number of tows possible within the time and funding constraints, and a target average distance apart per tow of approximately 10 nautical miles. The BSFRF survey final plan contained 241 total tows with an average distance apart of 9.9 nautical miles (Figure 5). While this average distance between tows was approximately 75% farther than the 2005 pilot survey average distance between tows of 5.6 nautical miles, it was still determined to be well within the range able to measure autocorrelation.

Figure 6 shows several of the steps in the process of tow selection. Tow site selection was consistent with the planned geostatistical analysis requiring that tow sites be selected semi-randomly where tows were random within a distance range but not too far apart to make autocorrelation immeasurable. The development of the semivariograms is based on tows grouped by distance apart (bins). Survey station selection was semi-random to generate a variety of relatively close station pairs, an important element of the geostatistical analysis. A subgrid was developed within the BSFRF survey area that fit the prescribed average distance of 9.9 nautical miles apart on center. Within that subgrid, 10 randomly generated targets were plotted. From those 10 targets, one was selected randomly to be the actual tow target. This provided a basis for a random alternate station in the event that a station was placed on an untrawlable area. A set of tow site "filters" that contained information about known areas to avoid was applied. In two cases during the planning of actual tow site selection, the first random target was not the one chosen. In one instance, a BSFRF tow target would have interfered with a known long term trawl effects study area (McConnaughey et al. 2000). The other instance was in the northeast corner of the BSFRF survey area and was based on shared information from the NMFS survey data that provided overlays of untrawlable areas and areas where significant gear damage had occurred before. In both cases, a random alternate tow site was chosen, allowing the problem area to be avoided without missing coverage of the intended assessment area. Once tow targets were selected, an optimized route based on a shortest sailing distance routine was utilized to maximize time efficiency (Applegate et al. 2006). The route selection was optimized as an important survey element (Harbitz and Pennington 2004). Once this was complete, an ordered path for survey stations was known and the survey starting point was chosen. Further planning was completed with approximate survey start and end dates chosen for a two-leg survey with a scheduled break between leg 1 and leg 2 for a change of scientific personnel in Dutch Harbor.

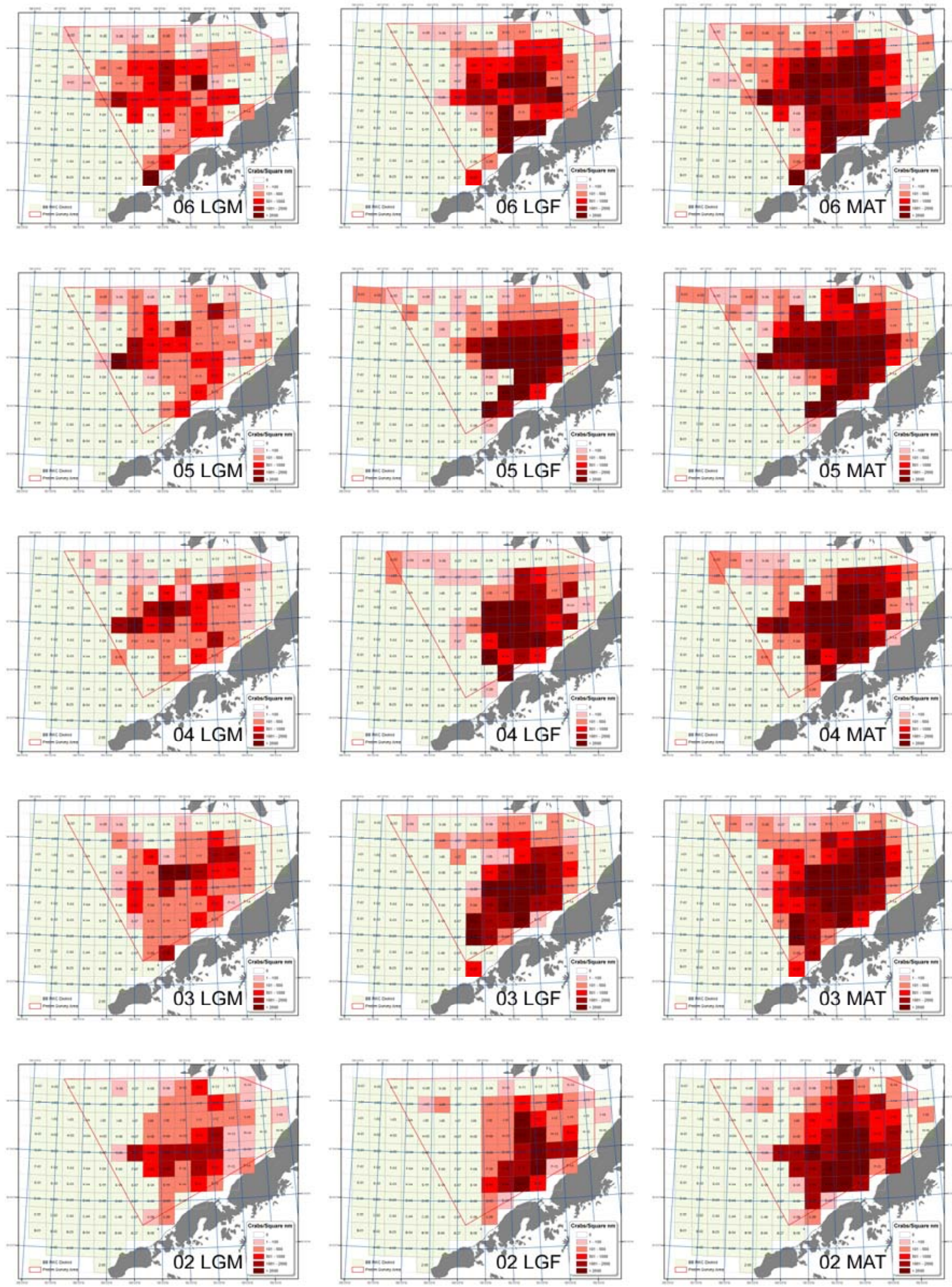
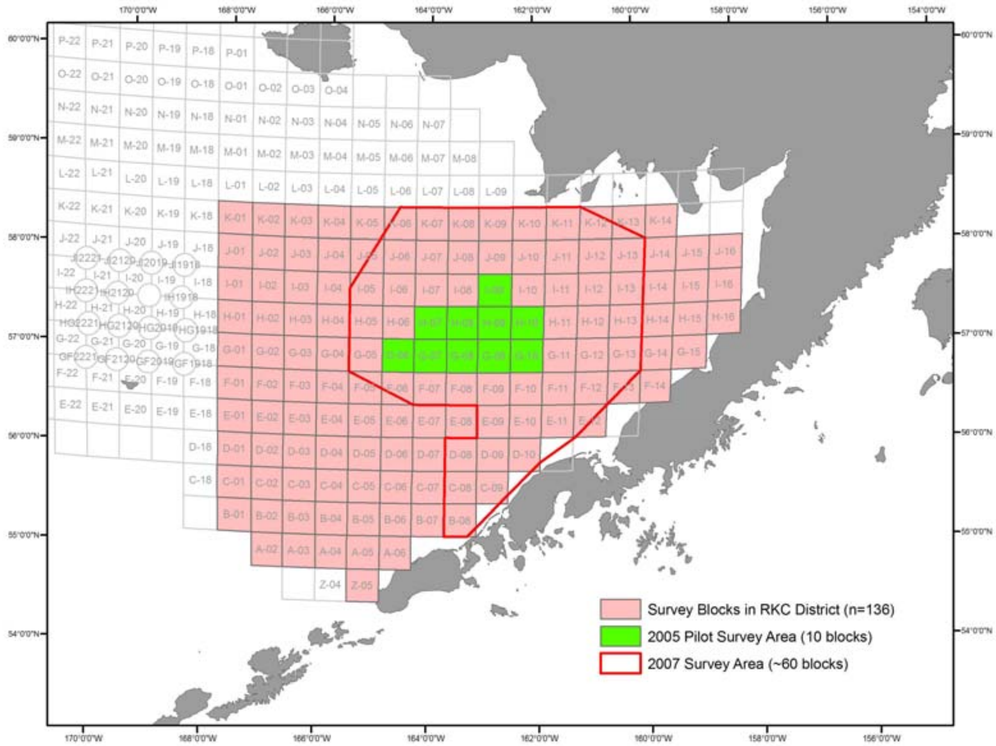


Figure 4. Subset of density plots of large male, large female and mature male red king crab per square nautical mile from the annual Bering Sea NMFS bottom trawl surveys, 2002-2006, used to define 2007 BSFRF survey boundary. Preliminary BSFRF survey coverage (red polygon) is shown.



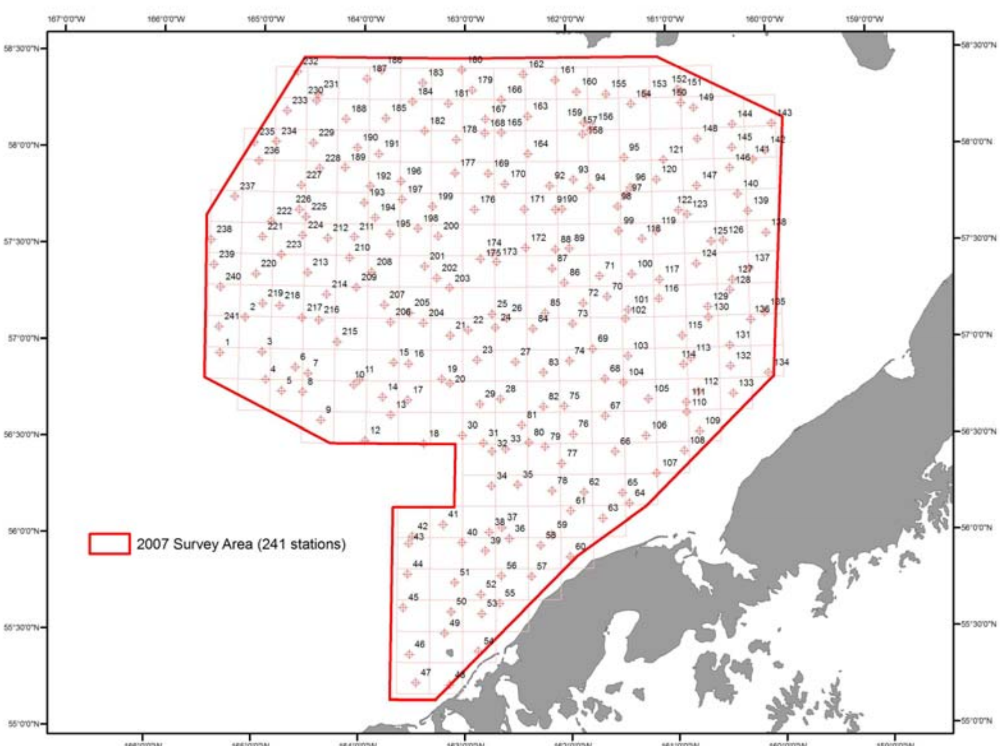


Figure 5. Map of Bristol Bay red king crab district and the 2005 pilot study survey and 2007 BSFRF full scale survey.

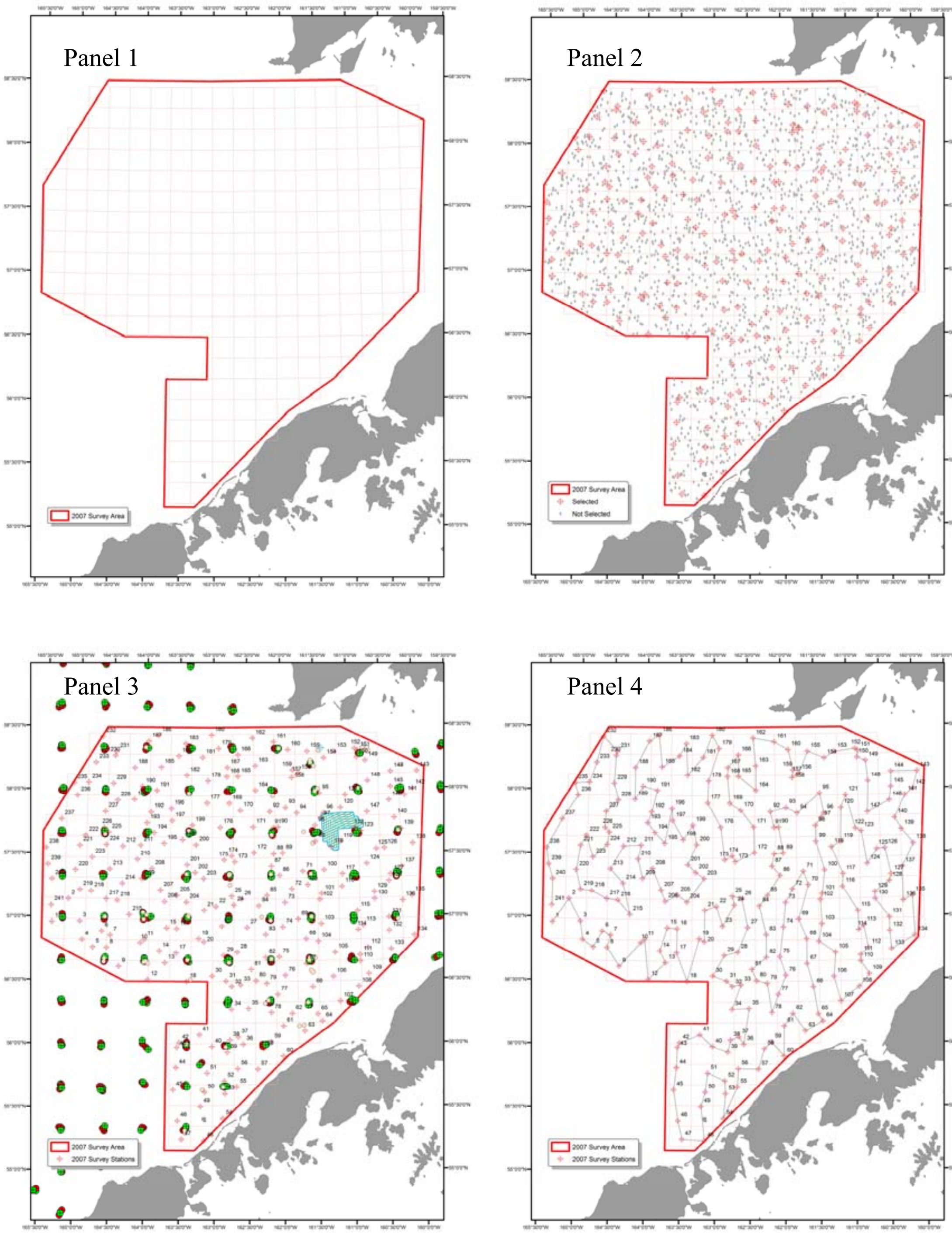


Figure 6. Mapped steps of survey design for selecting semi-random tow targets within the defined survey area. Panel 1 is the subgrid splitting the area into approximately 240 substations. Panel 2 is the randomly selected 10 points per subgrid square where single selected tow target is in red. Panel 3 shows filters used to reselect another random point where necessary. Panel 4 shows the optimized route through the selected points with chosen survey start and end stations.

Final survey design was reconciled by several logistical factors, including the estimated time to complete a tow from start to finish at each station (0.75 hrs), expected average vessel speed transiting between stations (10 knots), expected average travel times between stations (1.0 hrs), and travel times to and from survey grounds at the start and end of survey legs (variable, dependent on start and end locations, weather, seas, etc.). Importantly, these estimates were conservative to provide a cushion in case problems arose. The final survey design was distributed to NMFS, ADF&G and to the U.S. Coast Guard (USCG). A Notice to Mariners was also issued for both legs of the survey. Final coordination between Seattle and Dutch Harbor included meetings between the BSFRF Board of Directors, NRC and NMFS and the issuance of final cruise orders (Appendix 2).

A separate pilot gear comparison study was incorporated into the Project 625 timeline (Appendix 3). NMFS scientists designed a five statistical block paired towing test to be conducted between the *American Eagle* and the two NMFS survey vessels, F/V *Arcturus* and F/V *Aldebaron*. The comparative towing was planned to be conducted with the two gear packages and towing protocols unchanged from actual survey tows. The *American Eagle* tows were planned according to BSFRF survey methods of short tow duration and slow tow speed, while the *Arcturus* and *Aldebaron* conducted 30 minute tows at three knot tow speeds consistent with methods during their surveys. The design called for paired tows where four pairs comprised a test block and five blocks were planned for a total of 40 tows in total, 20 by the *American Eagle* and 10 each by the NMFS vessels (Figure 7). The survey was set to be timed with the beginning of the NMFS annual survey and after approximately 10 days of leg 1 of the BSFRF survey. This plan provided the opportunity to use the first several days of the BSFRF survey to locate an appropriate area to conduct the side by side testing with the goal to conduct the test in a local area where there were known to be relatively high densities of red king crab. The general location of the study was left unplanned dependent on preliminary findings of the first several days from the BSFRF survey. The specific area procedures were planned to have paired tows conducted at no closer than 0.2 nautical miles and no further than 0.5 nautical miles apart between the two paired tow paths. For alternating pairs in one block, the *American Eagle* would switch sides of alternating NMFS vessels planning to tow four times within one block, paired twice with both NMFS vessels.

The biological data planned to be collected during this test comparison included enumerating all red king crab by appropriate size and sex categories. In addition to carapace length measurements, total basket weights and individual weights were taken for all red king crab during these tows. Other typical biological data including chela width, shell condition and reproductive condition were ignored as no subsampling occurred and time constraints of the two day test required streamlining data recording. Size and sex area swept densities were planned to be used for both mean and variance estimates of abundance and biomass. Statistical summaries and testing of this side by side work was planned to be conducted as a paired t-test and possibly with a nested ANOVA to review any vessel effect. The methods prescribed here were for a simple test with a relatively small sample size, amidst significant time and funding constraints for all three vessels. This limited study was designed with the thought that the results might be informative toward the larger issue of survey comparison.

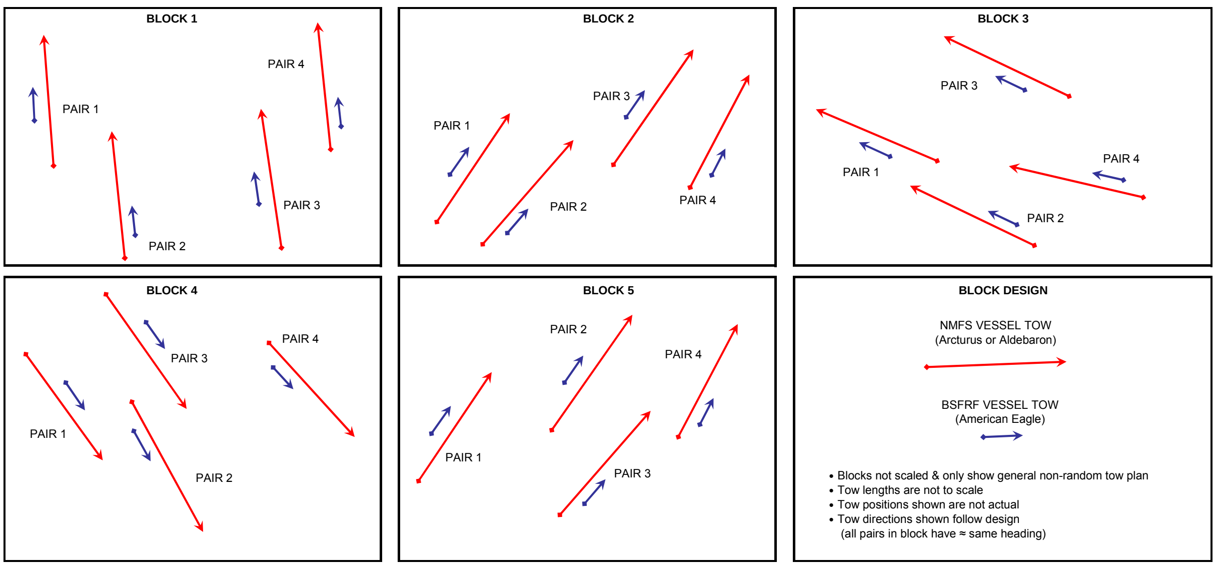


Figure 7. Planned layout of pilot gear comparison study towing plan.

Sampling Gear and Instrumentation

The trawl vessel F/V *American Eagle* was under charter to BSFRF for both the 2005 pilot survey and the 2007 full assessment. The F/V *American Eagle* is a 124 foot stern trawler fitted with a variable pitch propeller that allows it to tow at the required slow speeds. F/V *American Eagle* is a house forward steel trawl vessel with quarters for 9 people. The vessel has historically operated in both Bering Sea groundfish and crab fisheries and is a well known, ably-crewed boat with a good reputation.

Survey design called for redundancy in trawl gear equipment. BSFRF purchased three survey trawl nets with rigging and two sets of doors with rigging. The survey trawl is a modified commercial *Nephrops* trawl package originally used for Mediterranean lobster. The survey trawl was most closely documented prior to the pilot study in 2005 as reported in Conan et al. (1994). The 2005 pilot study survey trawl net had a footrope configuration that differed from the published design. The 2007 footrope configuration was matched to the survey trawl as used in 2005. The trawl footrope for both surveys (2005 and 2007) was modified from published designs to be more heavily weighted along the wing lengths of the footrope. In addition to the chain dentures near the throat of the trawl, further chain was spiral wrapped along the footrope as shown in Figure 8.

Sampling Logistics

At each station during the BSFRF survey, a prescribed routine was followed. The skipper stopped the vessel and 2 crew members and 1 scientific party member deployed and retrieved the CTD device. NETMIND and GPS data recording were initialized at the main computer station in the wheelhouse. The field party chief initialized the modified bottom contact sensor (MBCS) and placed the sensor in the housing on the footrope of the net. The skipper then oriented the vessel for the beginning of the tow and the trawl was deployed. One crew member and one scientific party member deployed the paravane and hydrophone using the deck crane. During trawl deployment, vessel speed ranged from approximately 2.5 to 3.5 knots. Winch speed while paying out the wire (warp scope) was relatively constant, pausing briefly as trawl doors were attached. Winches stopped and the tow duration was timed for 5 minutes. The skipper monitored vessel speed and changed propeller pitch or vessel rpm's as needed to maintain as closely as possible to the targeted tow speed of 2.0 knots. During the tow, the NETMIND data stream was monitored for consistency. After 5 minutes, haulback began. Vessel speed and winch speed increased during haulback relative to trawl deployment. When the trawl doors reached the surface, the NETMIND and GPS data recording were stopped. When the codend approached the stern ramp, one member of the scientific party began taking a series of pictures with a placard labeling the station number. The codend was dumped on the sorting table and a final catch picture was taken. The crew and scientific party sorted all crab into sorting baskets and discarded all remaining catch. The scientific party began collecting crab measurements. The field party chief retrieved the MBCS sensor from the housing on the trawl footrope and downloaded the data in the wheelhouse. The crew prepared the trawl for the next deployment and the skipper began transiting to the next trawl station. The time from start to finish at each station for this routine was approximately 40 minutes.

Data Collection

The survey collected three main types of data including several vessel and trawl performance indicators, biological information from captured crab, and environmental information at each station. For all stations, members of the scientific party followed the same routine to collect these data types.

Figure 8. Photos from the 2007 BSFRF trawl showing footrope configuration along wing sections (upper) and the throat section (lower).

Vessel and trawl data were recorded from several sensors. The F/V *American Eagle* was fitted with a separate primary and secondary GPS system to accurately provide positional and speed information every second per tow. These GPS systems were separate from the vessel's navigational equipment. The primary survey GPS system was a Novatel ProPak-V3 which was augmented with a secondary GPS signal from a USCG beacon receiver. This data was recorded in a single daily GPS log file that was started and stopped at each station prior to the beginning of each tow and at the end of the station when the trawl doors reached the surface. This data was checked at the end of each tow to verify recording and general data quality.

The primary and secondary GPS were simultaneously configured to record vessel positions and speed, and also to integrate with the trawl performance sensors and software (NETMIND™). The trawl was monitored with two types of sensors (Figure 9). The main sensors were from the NETMIND package consisting of 5 sensors fixed to the net and one hydrophone receiver. These sensors were customized by the manufacturer to send and receive data (pings) at the fastest rates possible. This enabled the highest rate of communicate or the greatest number of possible pings from the NETMIND sensors to be received. The second sensor type was an improved MBCS from a customized NFMS design. The placement of the sensors was consistent with methods used in the 2005 pilot study with the exception of the improved MBCS which was not available in 2005. Wing spread was measured with a NETMIND master and slave attached at each trawl wingtip sewn in a separate mesh sensor bag inside the net approximately 20 inches behind the trawl wingtip. The master wing sensor was affixed into the port wingtip and the slave sensor on the starboard wingtip for all tows. This configuration is the reverse of standard NETMIND wing sensor placement but was appropriate as the hydrophone was deployed on the port side of the vessel and receives data best when the master sensor is on the same side. Trawl net depth and vertical opening were measured from two NETMIND sensors affixed in a mesh bag sewn outside the trawl (on top of the trawl) approximately 2 inches behind the center of the head rope. A touchdown sensor similar to the 2005 pilot study was affixed inside the trawl net floor approximately 20 inches behind the footrope. This NETMIND bottom contact sensor was placed inside a custom made stainless steel sled which was configured to show when the floor of the net was in contact with the seabed. The NETMIND bottom contact sensor in the custom steel sled was intended to measure the angle of the floor of the trawl. All NETMIND sensors on the survey trawl sent data to a hydrophone which was connected to the main data recording computer in the wheelhouse. The vessel's crane was used to lift and deploy the hydrophone inside its paravane from the port side of the vessel each tow. The paravane for the hydrophone was a composite structure of fiberglass and steel that roughly resembled a space shuttle (Figure 10). Attachments to the paravane for both the hardwired hydrophone and the rigging to the crane hook were adjustable for fine tuning hydrophone ping reception and how the paravane swam.

The improved MBCS housing was similar to standard NMFS survey bottom contact sensors but smaller and lighter and was attached to the footrope with 2 long link D-shackles that allowed it to hang freely. This sensor was positioned slightly off-center to have no interference with the bottom contact sensor in the sled. The improved MBCS sensor was contained inside the MBCS housing and did not transmit data via hydroacoustic telemetry. The unit was an Onset Hobo data logger and was initialized at the beginning of each tow and then read out manually after each tow using Onset software Hoboware Lite v. 2.3.0. At each station, real time readings from the NETMIND sensors were used to verify the tow quality during towing. The MBCS data was also used to verify typical trawl performance at the end of each tow.

Figure 9. NETMIND sensors (left) and improved modified bottom contact sensor (MBCS) (right) as used in the BSFRF 2007 survey.

Figure 10. NETMIND hydrophone and paravane as used in the BSFRF 2007 survey.

At each station a SeaBird™ SB19 CTD was “fastcast” using the vessel’s crab winch. Data included temperature, depth and salinity profiles. This occurred prior to towing at each station while the vessel was stationary. The unit in its cage was lowered to the bottom and the retrieved. The device was utilized with daily data sets where it was initialized at the beginning of the day and then turned off. For each tow, the device was turned on, deployed, and then turned off. At the end of the day, the data was downloaded and verified. Seabird electronics provided data uploading and processing software for CTD data collected for each tow.

All BBRKC (*Paralithodes camtschaticus*), snow crab (*Chionoecetes opilio*), Tanner crab (*Chionoecetes bairdi*) crab and Korean horsehair crab (*Erimacrus isenbeckii*) captured during the BSFRF survey were held for collection of the biological data. There was no subsampling of crab catches for any tow during the survey. For each crab, data collected were consistent with NMFS crab data collection protocols.

High quality electronic waterproof calipers were used for crab measurement. Some additional data were also collected including both carapace length and width for red king crab and individual crab weights were taken using a motion compensated Marel scale. Data were recorded on data forms. Data were checked for consistency prior to the next tow and further error checked and entered into the electronic database during the survey.

At each station, the catch was photographed several times with a placard noting the tow station. Several pictures per tow were taken showing the catch in the codend before dumping and in the sorting table after emptying the codend. Pictures were uploaded and saved daily. Several times during the survey there was video footage taken of the survey trawl operation, catches being sorted and processed, CTD casting, and the several other survey elements.

Data Analysis

All data analysis for abundance and biomass estimating in this survey relies on accurately measuring the area swept footprint of the survey trawl for each tow. The methodology for area swept estimation from trawl net sensors incorporated some improvements to methods used in 2005. The 2007 net mensuration data provided a basis for developing a new software tool that calculates area swept. This was done in collaboration with NMFS (Appendix 4). The data from the NETMIND sensors, MBCS and the GPS unit were incorporated into a relational database utility for reviewing synchronized data from all sources. For each tow, all sensor data were incorporated and reviewed graphically allowing for the times to be clearly chosen for on-bottom at the beginning of the tow and off-bottom at the end of the tow. These times determined the start and end points for effective fishing of the survey trawl on the seabed and were important to the determination of distance fished per tow. Distance fished was calculated for three periods of the tow. This was required as it was clear from the synchronized data that the net was traveling at different speeds on the seabed during these periods. For the first period where the trawl was determined to be on bottom and the winches were still paying out scope, the speed of the net was calculated by adjusting the vessel speed minus the winch speed. Winch speed was estimated from converted winch drum measurement (average length of one turn full and one turn with wire out) and winch rpm from the automated trawl system. During the middle period of the tow when the winches were stopped, the net speed was equivalent to the vessel speed. In the third period, when the winches were on during haulback but the net was still on bottom, net speed was the sum of the vessel speed plus the winch speed. These estimates provided the best estimate for the distance fished per tow in three periods of on-bottom time, finalizing the length component of swept area per tow.

Because the NETMIND wing sensors intermittently provided raw data containing erroneous readings, survey trawl spread readings were filtered and smoothed. Filtering routines for wing spread readings threw out values that were not possible based on adjacent readings. Smoothing of the filtered readings provided a smoothed interpolated value at each second during the tow. The smoothed and filtered spread readings were then averaged for the three periods of the tow. These averages were the final width component of the swept area per tow. Total tow area swept was then calculated by taking the sum of the products of length and width per tow period.

The calculation of area swept densities of BBRKC by size and sex category were completed using the standard area swept technique (Alverson and Pereyra 1969) where the number of captured crab are divided by the area swept yielding a density expressed in numbers of crab per square nautical mile. In this survey, captured BBRKC were split into size and sex categories to be consistent with NMFS protocols for crab surveys and for comparisons to NMFS abundance and biomass estimates. One additional category for mature males was added as an important management category (NPFMC, 2007 – this is the CRAB SAFE). The size and sex categories of BBRKC used in this report following these protocols are as follows:

Size / Sex Category	Abbreviation	Carapace Length (CL)
Large Males	LGM	≥ 135 mm CL
Mature Males	MTM	≥ 120 mm CL
Medium Males	MDM	110 - 134 mm CL
Small Males	SMM	< 110 mm CL
Total Males	TLM	All Sizes
Large Females	LGF	≥ 90 mm CL
Small Females	SMF	< 90 mm CL
Total Females	TLF	All Sizes
Total Red King Crab	RKC	All Sizes / Sexes

The general summary of abundance and biomass from the BSFRF survey area swept densities was completed using the standard statistical approach of multiplying area-wide red king crab density averages times the total survey area (Rugolo et al. 2006). This provided the basis for a direct comparison to be made between NMFS and BSFRF survey results.

For the more detailed and statistically tested comparison between NMFS and BSFRF survey results, a second set of estimates of crab abundance for the BSFRF survey were derived using geostatistical methods as proposed for Project 625. Originally, the geostatistical methodology was expected to follow a more subjective development of semivariograms and then utilize an abundance and biomass estimation method known as polygon kriging (Clark 2001, Conan 1985, Conan et al. 1988). In actuality, a variant of these geostatistical methods was used that followed a more objective approach to develop the semivariograms and utilize block instead of polygon kriging as detailed by Dr. G. Swartzman from the College of Ocean and Fisheries Sciences at the University of Washington (Appendix 5). The geostatistical methodology prescribed using the densities in numbers of BBRKC to develop empirical variograms for a starting point. The variograms were reviewed for shape and fit to the distance-binned density data and for each size and sex category a variogram was utilized for the block kriging. The kriging produced both estimates of abundance and its associated variance. Sensitivity analyses for variogram shape and fit selection for a number of variants were completed to assess the changes in both abundance and variance depending on which variograms were utilized for the kriging. Geostatistical summaries were generated for abundance only, as there were no direct biomass results available from the NMFS survey for comparison in terms of weight.

Results

Performance of the survey trawl, improved net mensuration from modified instrumentation, and improved area swept calculations provide a basis for both the general and statistically tested comparison between results of the BSFRF and NMFS surveys. Other results are also presented for the side by side comparative tow test, correlation of crab densities to bottom temperature, high red king crab densities observed along the Alaska Peninsula, and reproductive condition of sampled female red king crab.

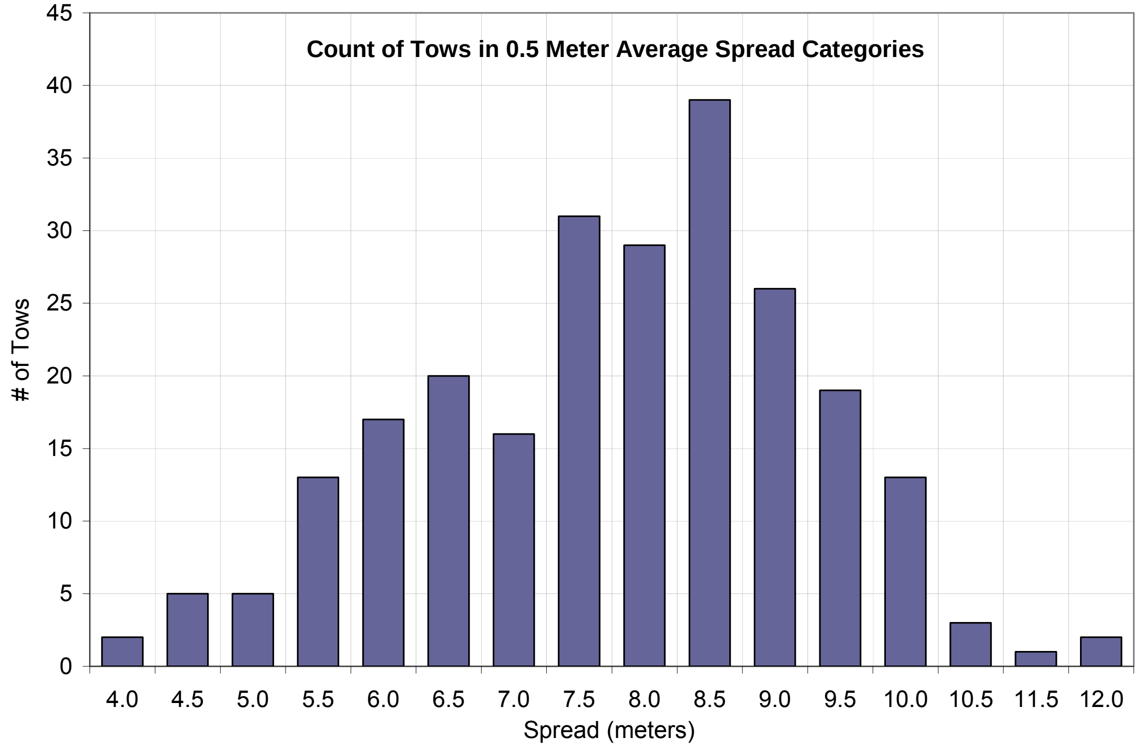
Logistics

All BSFRF net mensuration equipment and electronics purchased and tested during the fall of 2006 along with three *Nephrops* survey trawls with sets of trawl doors, hardware and deck sampling gear were shipped to Dutch Harbor for loading and installation in early May, 2007. Preparations of the trawl gear and testing of electronics were completed by the *American Eagle*'s crew and the scientific party May 24-27 and the vessel departed Dutch Harbor for the Bristol Bay red king crab survey area as planned and on schedule. All 241 tow targets were successfully completed within the planned survey schedule. Additional tows planned as part of the comparative test with the NFMS survey vessels were also successfully completed in two days (June 9-10) near the BSFRF tow 60 station. Additional tows occurred in 4 locations near the center of the survey area and also at 2 stations where trawl performance was uncertain and the tows were repeated (stations 44 and 188). The survey stayed on or ahead of schedule for both legs 1 and 2, with an average of 9 tows completed per day. Survey leg 1 was completed as scheduled with a break in Dutch Harbor on June 15-16 to take on supplies and change NMFS personnel in the scientific party. Leg 2 commenced June 17 with transit back to the survey grounds and was completed July 4 with a mid-day return to Dutch Harbor. All survey gear was offloaded for short-term storage in Dutch Harbor and later transshipment to Seattle. The *American Eagle* charter ended as scheduled July 5, 2007 and the scientific party returned to Seattle with all survey data.

Vessel, Gear and Operations

As was the case during the 2005 pilot survey, F/V *American Eagle* served as an excellent platform for conducting the 2007 survey. This provided a basis for the BSFRF survey to stay on or ahead of schedule and to address any areas of concern quickly and efficiently. The initial 4 test tows on May 28 and the first 18 tows of the survey (May 29-30) indicated some uncertainties about the trawl. The rigging of the forward section of the tickler chain on the wing sections of the footrope did not reveal consistent contact with the seabed nor consistent performance of the trawl wing sections. After the fifth tow on May 30 (station 18), the forward section of tickler chain was removed and re-wrapped to match the 2005 configuration. Tows continued that day and throughout the remainder of the survey with the survey trawl performing consistently and as expected in proper contact with the seabed. At the conclusion of the standard survey, the initial 18 tows were repeated as the survey team was ahead of schedule and time allowed. Data from these tows replaced initial tow data to remove any uncertainties about gear performance during the initial 18 survey tows.

Trawl mensuration data was collected from every tow without failures. The newly designed NMFS bottom contact sensor proved to be extremely effective and provided excellent data for trawl footrope contact with the seabed required to accurately calculate distance towed for the area swept calculations. This piece of gear was a major improvement over the bottom contact sensor used during the pilot survey of 2005. The results from the net instrumentation for the entire survey showed the survey trawl performed very well as expected. Survey-wide averages for trawl performance variables are: tow speed of 2.13 knots, distance fished of approximately 498 meters, net spread of 7.6 meters and tow duration of 7.28 minutes. The expected area swept of the BSFRF trawl was 3,935 square meters based on preliminary estimates. Actual area swept per tow averaged 3,739 square meters or 0.00109 square nautical miles, 95% of expected. The expected area swept ratio of a NMFS trawl tow to a BSFRF trawl tow was 10.89. Using an approximate NMFS value for average area swept of 1/80th of a square nautical mile per tow, the actual area swept ratio for the two surveys averaged 11.47. The consistency of the trawl performance is shown in Figure 11 where net spread and tow duration are plotted for tows from the entire survey. Figure 12 shows a more detailed distribution plot of area swept in 200 square meter categories from all tows during the survey.



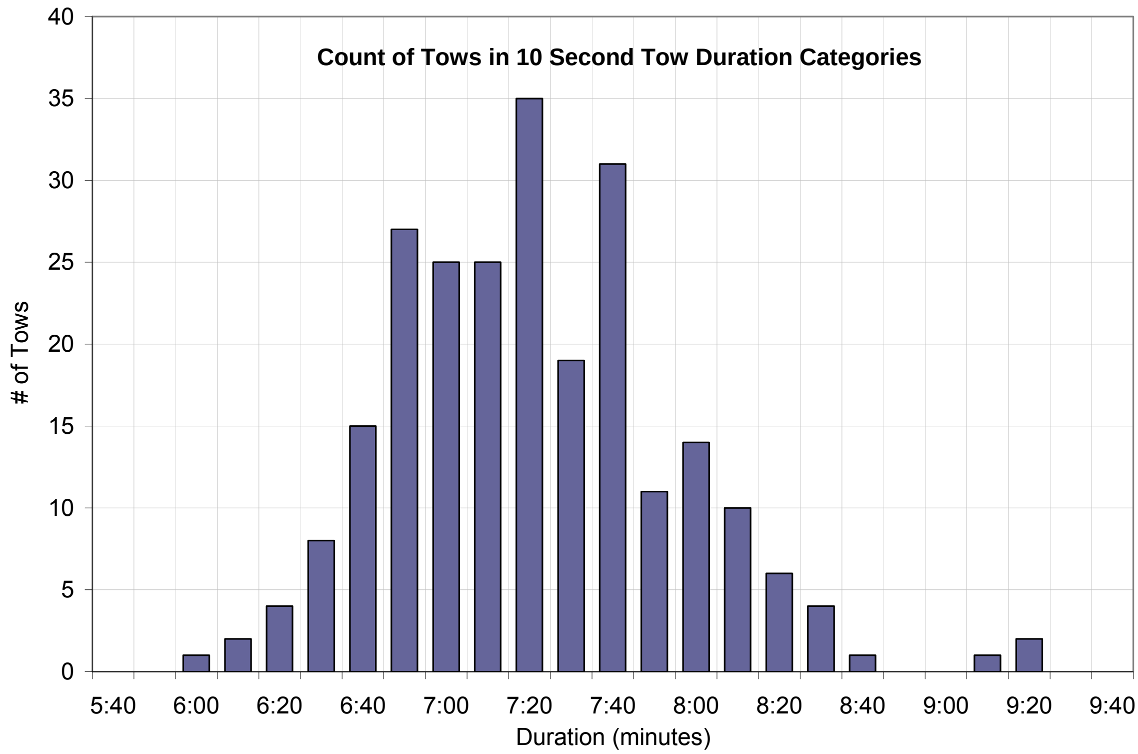


Figure 11. Distributions of net spread and tow duration from all tows in the BSFRF 2007 survey.

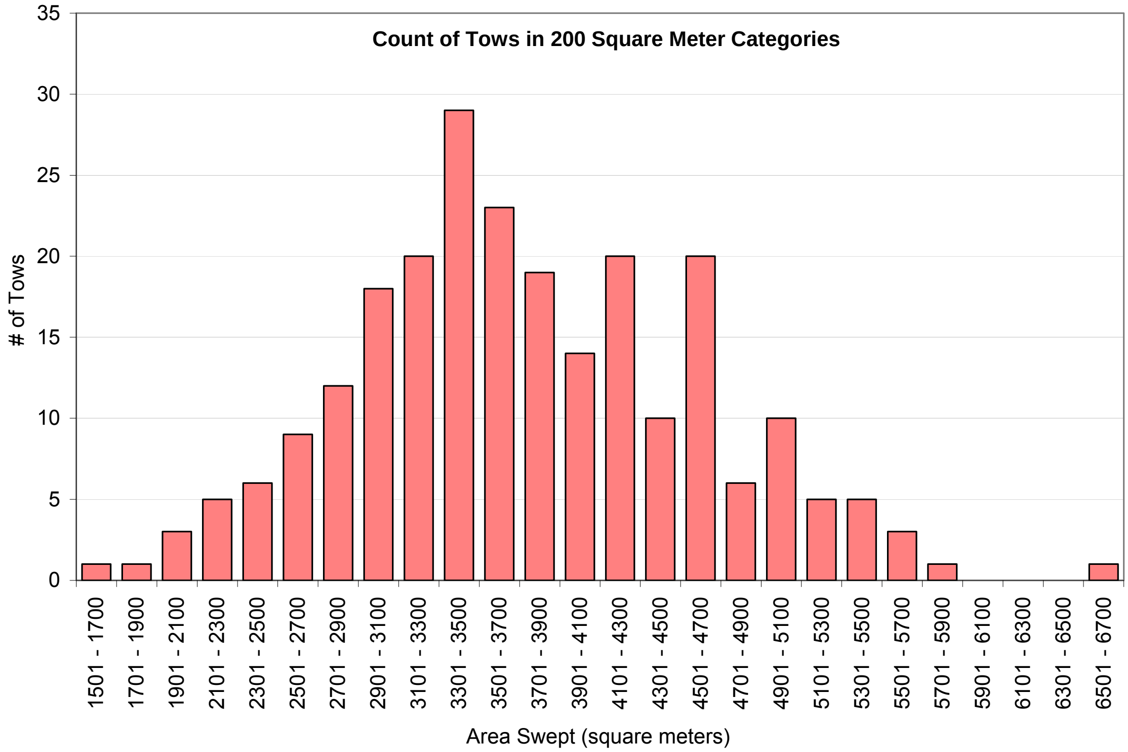
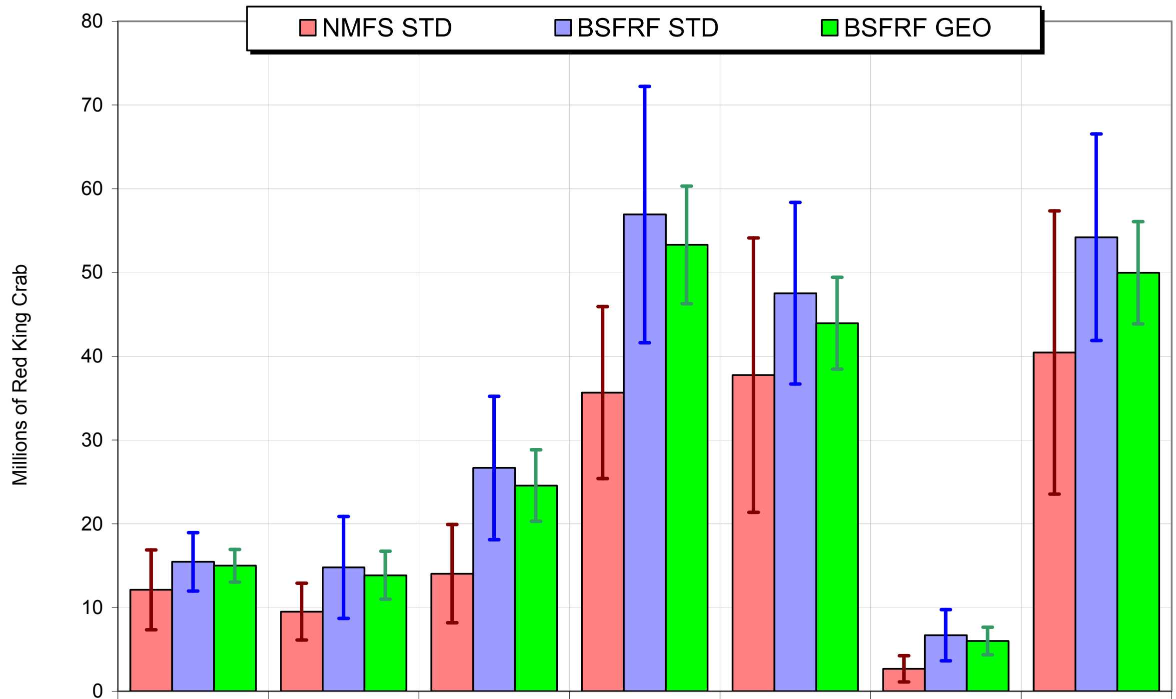


Figure 12. Distribution of area swept per tow from all tows in the BSFRF 2007 survey.

Abundance Estimation and Comparison

Final results for Project 625 show that the abundance estimates using the mean and variance of area swept densities of BBRKC for all size and sex categories for the BSFRF survey are significantly more accurate and precise than the NMFS survey. The abundance estimates for the NMFS survey derived from standard statistics (mean crab density times the survey area) were compared to estimates for the BSFRF survey using standard statistics and the geostatistical method prescribed in the survey design. This comparison only includes those stations in both surveys that are within the BSFRF survey area. A total of 63 stations from the NMFS survey fell within the boundary of the BSFRF survey area. BBRKC density results from the BSFRF survey used for these comparisons are from the 241 planned station tows only (Appendix 6). Figure 13 shows abundance estimates with the 95% confidence intervals (95% CI) for NMFS standard sampling statistics versus those for the BSFRF survey using both standard sampling statistics and geostatistics for each size and sex category.

In Figure 13, red, blue and green bars distinguish the abundance estimates by the standard size and sex categories. Variance estimates (95% CI) are shown by the Y-error bar +/- line above and below each column. NMFS abundance estimates are the red columns while BSFRF estimates are blue for standard statistics and green for geostatistical estimates. In each size and sex category, BSFRF estimates for both standard and geostatistical summaries are higher than NMFS estimates.



	Lg Males	Md Males	Sm Males	Males	Lg Females	Sm Females	Females
NMFS STD	12.113	9.512	14.043	35.668	37.746	2.690	40.436
BSFRF STD	15.462	14.795	26.664	56.921	47.526	6.694	54.221
BSFRF GEO	14.991	13.856	24.565	53.296	43.943	6.014	49.962

Figure 13. Comparative summary of abundance estimates of BBRKC by size and sex category for BSFRF 2007 survey versus NMFS 2007 survey within the same time and area.

Importantly, these results shows that the NMFS abundance estimate for each size and sex category is below the lower bound of the confidence interval of the BSFRF survey geostatistical abundance estimates. These general results also highlight substantial improvement in precision when applying the geostatistics to the BSFRF data. For instance, comparing 95% CI estimates, the large male category shows NMFS at +/- 41% compared with BSFRF at +/- 13%. For the large female category, the difference is +/- 45% for NMFS versus +/- 13% for the BSFRF estimate. For these two categories this represents an approximate 70% reduction in the variance expressed as 95% confidence intervals. Further details in Table 1 show the estimates of mean and variance for all size and sex categories and the percent reduction in variance.

Table 1 shows that there are some significant gains in precision based on both the difference in the survey design and the analytic method used to summarize results. In the lower panel, the A to B comparison reflects a precision improvement (reduction in variance) from the increased sampling density even though

Table 1. A comparison of variances (95% confidence intervals) showing the percent reduction from the 2007 NMFS survey estimates to the BSFRF 2007 standard and geostatistical survey estimates per size sex category of BBRKC.

	A			B			C		
BBRKC	NMFS			BSFRF - Std Stat			BSFRF - Geostat		
Size/Sex	Abundance	Variance (95% CI)		Abundance	Variance (95% CI)		Abundance	Variance (95% CI)	
Category	Estimate	+/- Crab	+/- %	Estimate	+/- Crab	+/- %	Estimate	+/- Crab	+/- %
Lg Males	12.113	4.761	39.3%	15.462	3.489	22.6%	14.991	1.949	13.0%
Md Males	9.512	3.407	35.8%	14.795	6.093	41.2%	13.856	2.854	20.6%
Sm Males	14.043	5.869	41.8%	26.664	8.550	32.1%	24.565	4.274	17.4%
Males	35.668	10.260	28.8%	56.921	15.302	26.9%	53.296	7.035	13.2%
Lg Females	37.746	16.377	43.4%	47.526	10.845	22.8%	43.943	5.493	12.5%
Sm Females	2.690	1.569	58.3%	6.694	3.054	45.6%	6.014	1.654	27.5%
Females	40.436	16.900	41.8%	54.221	12.335	22.7%	49.962	6.095	12.2%
RKC	75.657	24.567	32.5%	111.142	26.069	23.5%	103.495	11.902	11.5%

Percent Reduction of Variance per Size Sex Category

	A to B	B to C	A to C
Lg Males	-42.6%	-42.4%	-66.9%
Md Males	+15.0%	-50.0%	-42.5%
Sm Males	-23.3%	-45.7%	-58.4%
Males	-6.5%	-50.9%	-54.1%
Lg Females	-47.4%	-45.2%	-71.2%
Sm Females	-21.8%	-39.7%	-52.9%
Females	-45.6%	-46.4%	-70.8%
RKC	-27.8%	-51.0%	-64.6%

the area swept is over 11 times larger for a NMFS tow compared to a BSFRF tow. Although the medium males category shows a poorer precision for the BSFRF survey, the precision is a substantial improvement in most categories. The gain in precision from the application of geostatistical method is shown in the B to C comparison. In all cases, the 95% confidence interval around the abundance estimate is nearly cut in half. The important A to C comparison combines the precision improvement from both the survey design (gear and increased sampling density) and the application of the geostatistical method. In only one case (medium males) is the reduction less than 50% and overall it is reduced by approximately 65%.

For all size sex categories of red king crab, the estimate of abundance from the NMFS survey is below the lower boundary of the 95% confidence interval for the BSFRF geostatistical estimates of variance (Figure

14). A statistical test was conducted to determine whether these differences in abundance estimates were statistically significant. The 95% confidence intervals are twice the standard deviation of the density estimates. The null hypothesis of the statistical test was that the surveyed abundance estimates from densities are equal, and the alternative hypothesis is that the BSFRF abundance estimates are higher (one tailed test). The statistic calculated is:

$$Z = (\mu_1 - \mu_2)/\mathrm{sqrt}(\sigma_1^2\ /n_1 + \ \sigma_2^2/n_2)$$

The calculated mean and variances of density estimates are substituted for the theoretical mean and variance terms and subscript 1 is used for BSFRF and subscript 2 for NMFS. Results from this statistical test are reported below in Table 2. In each case (for all size-sex categories), the statistical test yielded z-values greater than 1.645 such that the null hypothesis is rejected, and the alternative hypothesis is accepted indicating that the BSFRF abundance estimates are statistically higher. The values were significantly higher than a cutoff value of 1.645 for a type 1 error at the 0.05 level.

As shown, the results from the geostatistics proved to be an integral part of these results as expected. The geostatistical results were derived using the method known as ordinary (block) kriging. Kriging was based on empirical and eye fit variograms computed from the calculated densities and the distances between tows. The resulting variograms in Figure 15 are all 'classical' in that they show increasing semi-variance with increasing distance up to a distance where the pattern is more variable but not consistently increasing or decreasing.

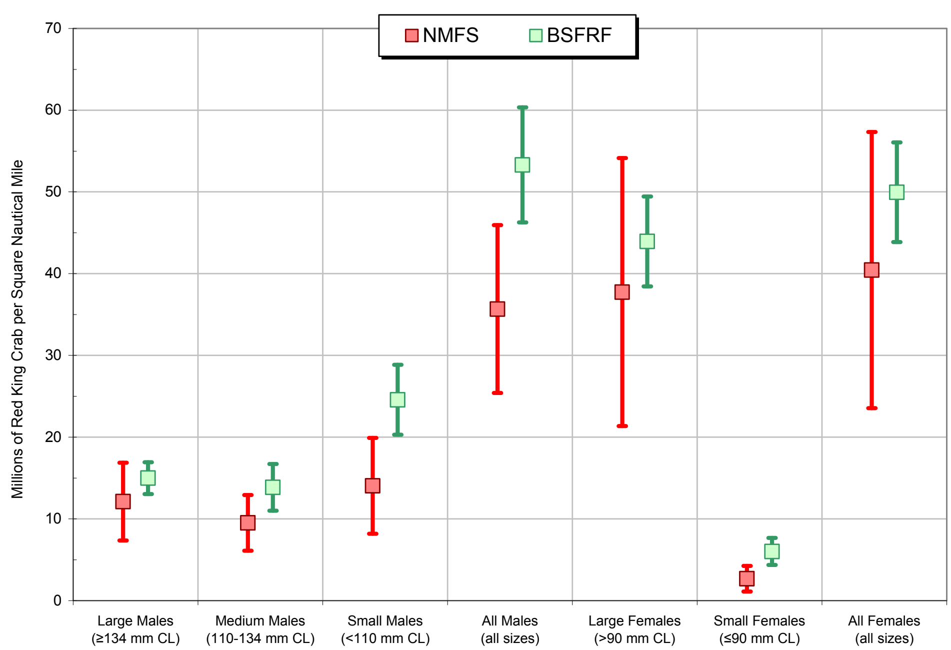


Figure 14. Mean and variance of red king crab survey abundance estimates for NMFS 2007 versus BSFRF 2007 survey by size and sex category used in statistical comparison.

Table 2. Z-test statistics calculated for each red king crab size sex category comparison between NMFS results and BSFRF results from 2007 survey abundance estimates.

Abbr	RKC Size Sex	z-value
LGM	Large Males (≥ 134 mm CL)	9.40
MDM	Medium Males (110 mm - 134 mm CL)	18.62
SMM	Small Males (< 110 mm CL)	26.67
TLM	Total Males (all sizes)	25.74
LGF	Large Females (≥ 90 mm CL)	5.91
SMF	Small Females (<90 mm CL)	29.57
TLF	Total Females (all sizes)	8.79
RKC	Total Red King Crab (all sexes/sizes)	17.46

NMFS densities: $n = 63$
BSFRF densities: $n = 241$
For all size sex tests, $p < 0.00001$

These variograms support the expected reduction in variance from the use of geostatistics in these survey abundance and biomass estimates from the surveyed crab area swept densities. Examining the variograms at different directions showed no apparent directional patterns in spatial autocorrelation, allowing a non-directional kriging to be used. Variograms were produced for all 9 crab categories of interest and an exponential model was fit to these variograms using likelihood methods. Because the fit of the data depended on the entire distance range, the fits at small distances were not as close. As such, additional fitting of the variograms by eye was required, but constraining the parameters to be linked to the original likelihood fit parameters was included to keep this fitting objective and repeatable. Sensitivity analysis showed that kriging results for both abundance and variance estimation did not change significantly when using the eye fit versus the empirical variograms (Appendix 4).

Initial kriging maps were plotted of crab abundance and variance over a fine mesh grid originally, with similar parameters later producing refined kriging maps (Figures 16-21). The kriging estimation was limited to a non-rectangular area chosen to represent the crab range and spanning the range of the survey samples. Overall abundance and variance were estimated using an equation including the autocorrelation between grid points, data points and data and grid points. Confidence limits (95%) for crab abundance generated from these estimates were between 11.5% and 27.5% of overall abundance. There was some difference between the likelihood estimated and by-eye estimated variograms but this was not significant and incorporated further in the kriging and sensitivity analyses showed these differences to be small.

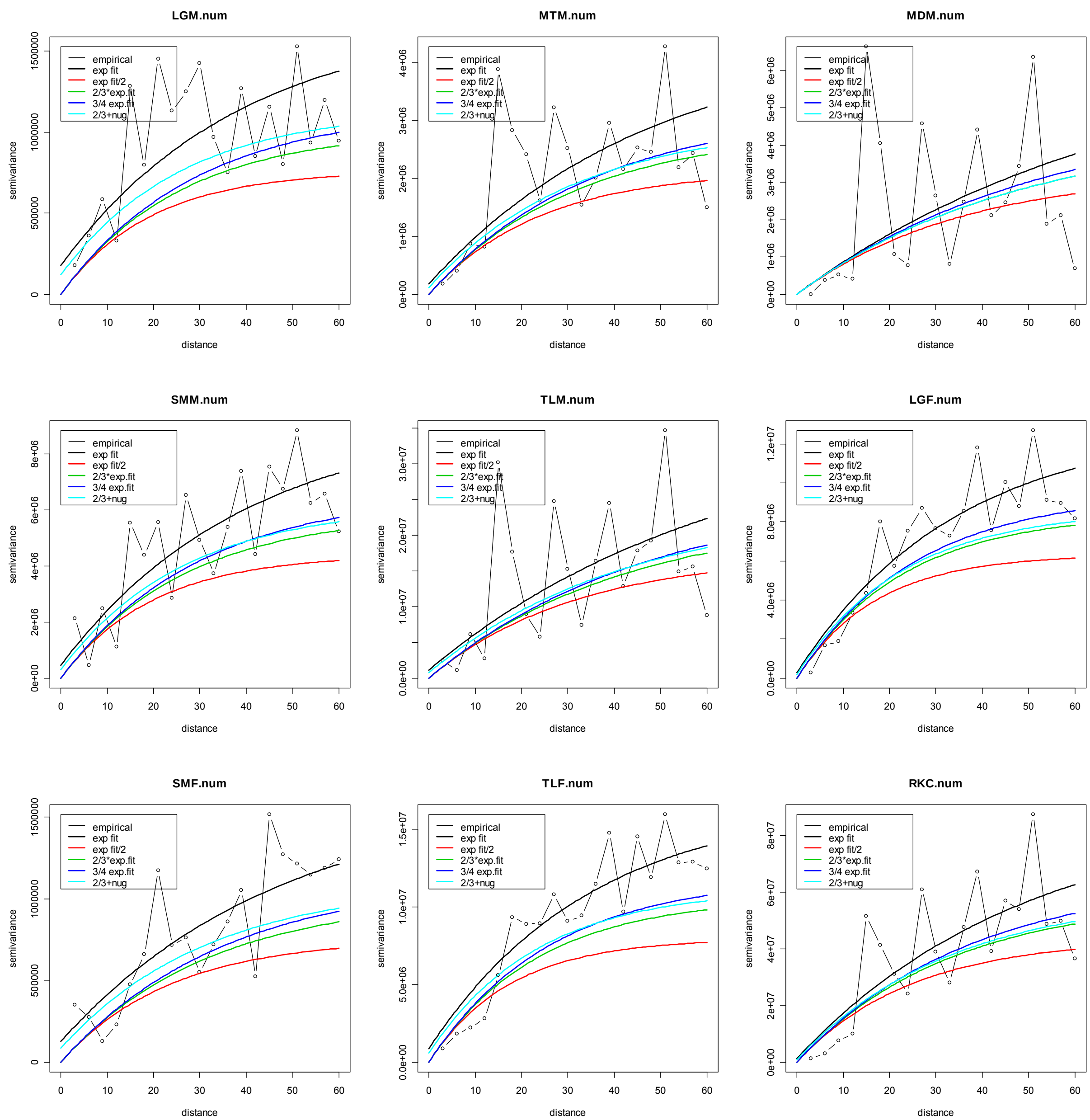


Figure 15. Empirical and eye fit variograms for all size/sex classes of red king crab from 2007 BSFRF survey. Distance on all chart x-axes are kilometers. “Num” depicts abundance of crabs. LGM = large males, MTM = mature males, MDM = medium males, SMM = small males, TLM = total males, LGF = large females, SMF = small females, and TLF = total females.

While some small details are different than utilized in results from the 2005 pilot survey, the application of geostatistics to this data was not done arbitrarily and is appropriate as part of the 2007 survey design and is consistent with the overall intent and results from the 2005 pilot study. The range in variograms is an important indicator that implies a distance at which the autocorrelation being measured reaches a point of flattening out in a variogram – or a distance beyond which point there is no measurable autocorrelation. As an example, the range from 2005 geostatistical summaries in the pilot study for large male red king crab was computed at approximately 47 kilometers. While the value computed for large males from abundance estimates is 39 kilometers for this survey, adjacent size and sex categories are in the appropriate range –for mature males from abundance estimates is 47.8 kilometers. Table 3 below shows several of the geostatistical parameters computed from the variograms and included in the kriging results.

Table 3. Geostatistical parameter values for variograms and ordinary kriging estimates. Nugget and sill are semivariance and range is in kilometers.

	Variable	Nugget	Sill	Range
Abundance (number of RKC)	Large Males	177,690	1,525,041	39.0
	Mature Males	177,691	4,269,028	47.8
	Medium Males	0	6,634,806	71.8
	Small Males	462,127	8,835,244	40.0
	Total Males	1,122,740	34,587,215	63.3
	Large Females	283,447	12,678,616	34.4
	Small Females	126,414	1,513,675	47.6
	Total Females	872,258	15,933,434	35.0
	Total Red King Crab	1,286,317	87,319,920	49.5
Biomass (Lbs of RKC)	Large Males	13,444,969	59,840,776	60.8
	Mature Males	13,444,937	99,147,737	53.5
	Medium Males	0	57,591,856	67.0
	Small Males	1,381,819	26,965,594	52.6
	Total Males	10,053,476	286,641,434	61.0
	Large Females	2,439,865	48,324,463	24.5
	Small Females	69,517	1,435,659	46.1
	Total Females	3,003,419	53,130,419	25.6
	Total Red King Crab	22,787,111	393,502,817	48.5

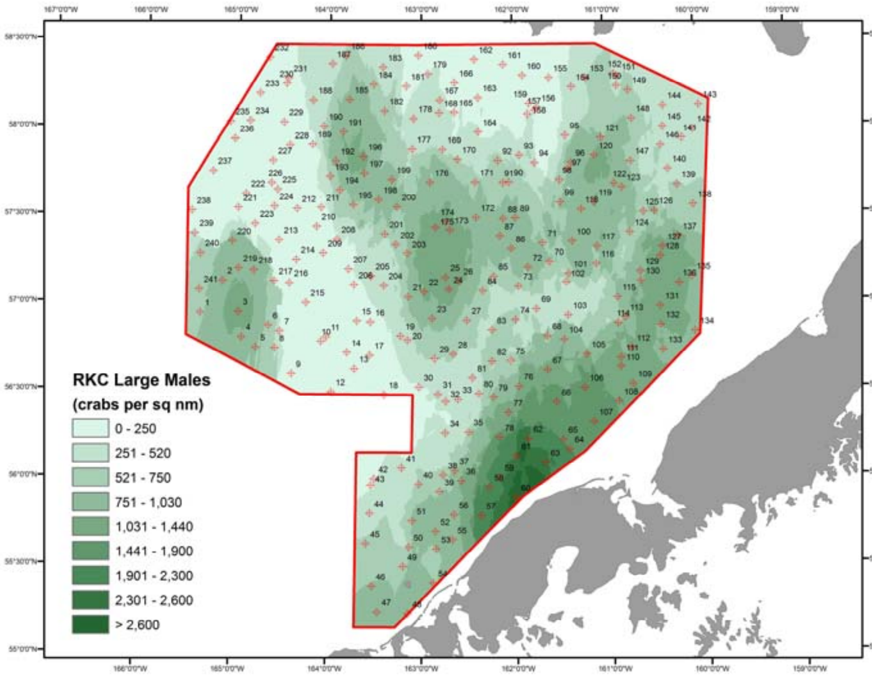


Figure 16. Kriging results mapped in the BSFRF survey area for large male (≥ 135 mm CL) red king crab .

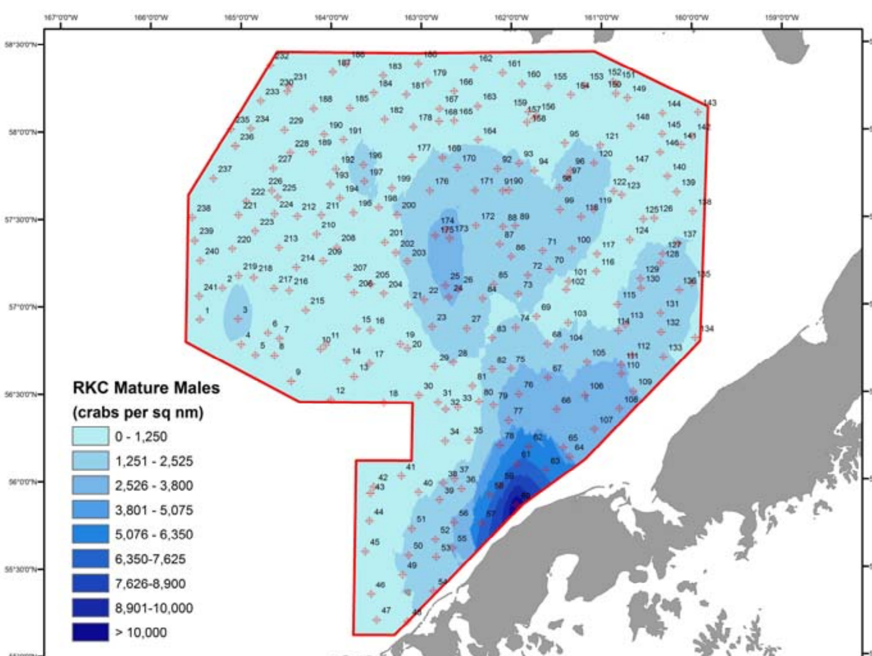


Figure 17. Kriging results mapped in the BSFRF survey area for mature male (≥ 120 mm CL) red king crab.

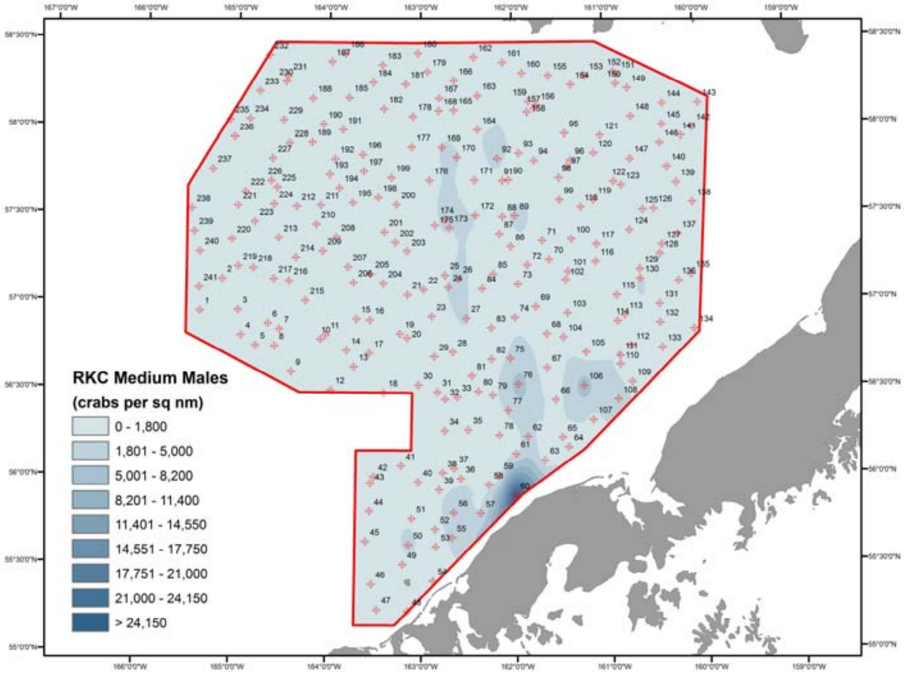


Figure 18. Kriging results mapped in the BSFRF survey area for medium male (110-134 mm CL) red king crab. Note: Computed nugget was 0.

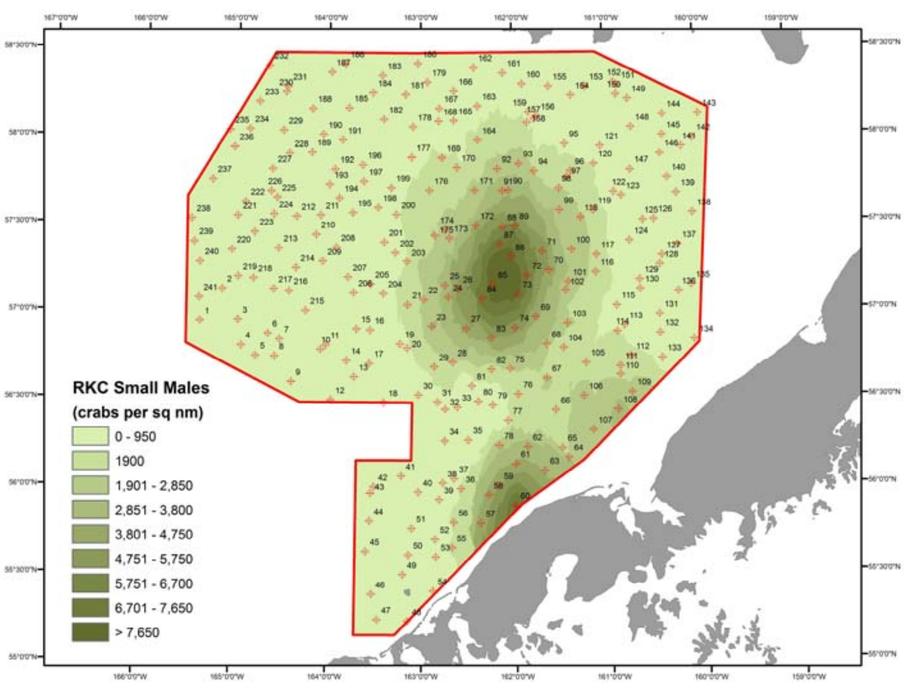


Figure 19. Kriging results mapped in the BSFRF survey area for small male (< 110 mm CL) red king crab.

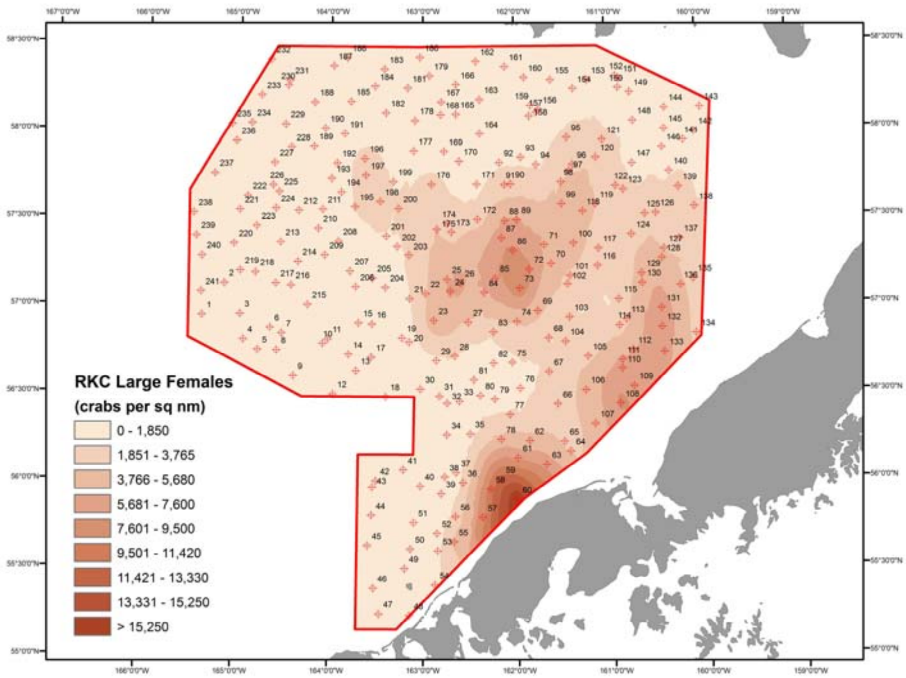


Figure 20. Kriging results mapped in the BSFRF survey area for large female (≥ 90 mm CL) red king crab.

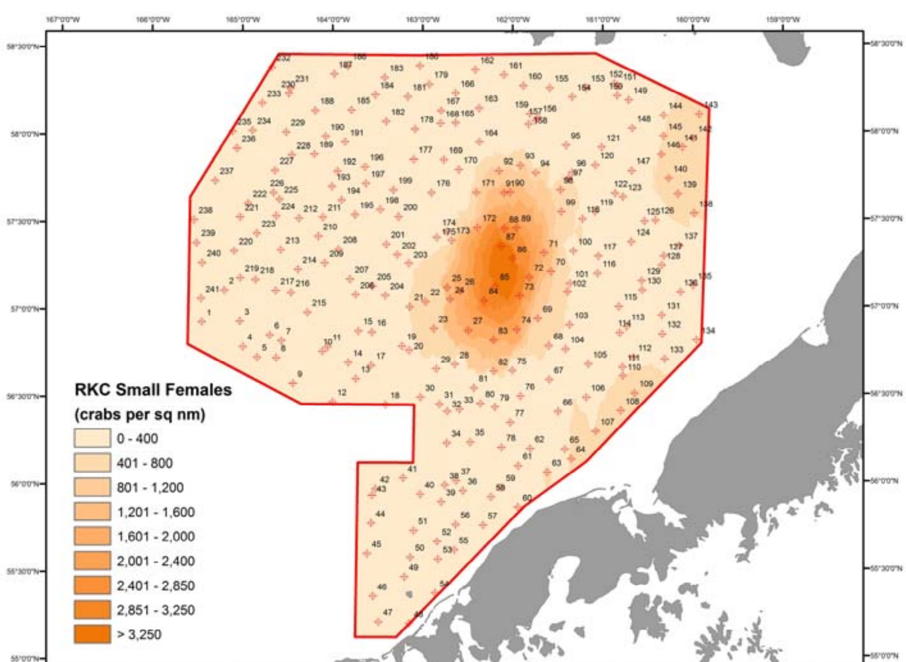


Figure 21. Kriging results mapped in the BSFRF survey area for small female (< 90 mm CL) red king crab.

The results from the pilot gear comparison study showed that the BSFRF survey trawl functioned successfully during the side by side test work as it did during the rest of the survey. Data collection for all trawl function and biological data was successful. The area for the experiment was chosen based on relatively high catch tows completed by the F/V *American Eagle* in the vicinity of stations 58 through 60 in the southeast portion of the survey area along the Alaska Peninsula. Coordination with both NMFS vessels for completion of the test work on June 9 and June 10 was successful with only one tow out of 40 resulting in less than satisfactory tow performance. The *Aldebaron's* 2^{nd} tow resulted in significant damage to their trawl requiring them to miss one scheduled test pair. Results for computed densities were completed cooperatively between NMFS Resource Assessment and Conservation Engineering (RACE) division and BSFRF (Appendix 3). There was high variability in the catch of red king crab from the side by side test tows (Figure 22). This was evident not only when comparing the BSFRF vessel to NMFS vessels together but also between the NMFS vessels. Preliminary investigations of mean and variance of abundance and biomass from the densities revealed inconsistent results as expected from these small sample sizes. Further work to increase the sample size and add to these test results is needed.

Project 625 yielded several other results from biological and environmental data that may prove to be very important. Some preliminary investigations have been completed and are provided here but are outside the scope of this comparative survey resource assessment.

There were higher than expected densities of all red king crab size and sex categories near shore along the Alaska Peninsula. These are especially evident in the kriging plots as shown in Figures 16-21. Investigation of portions of the survey data for temperature and salinity relationships to red king crab density has been reviewed (Figure 23). Preliminary data suggest that there may be a relationship evident from this survey data that shows a correlation between warmer water along the Alaska Peninsula and the high densities observed. This requires a closer, more comprehensive look at the environmental and biological data. Any results from this future work will be reported at a later date. Results of female BBRKC reproductive condition were consistent with results found from both of the NMFS vessels concurrently conducting their Bristol Bay red king crab assessment. The Bering Sea in 2007 experienced another cold water year resulting in the sampled females at the time of the survey showing either completely empty clutches or eggs that were indicative of no mating.

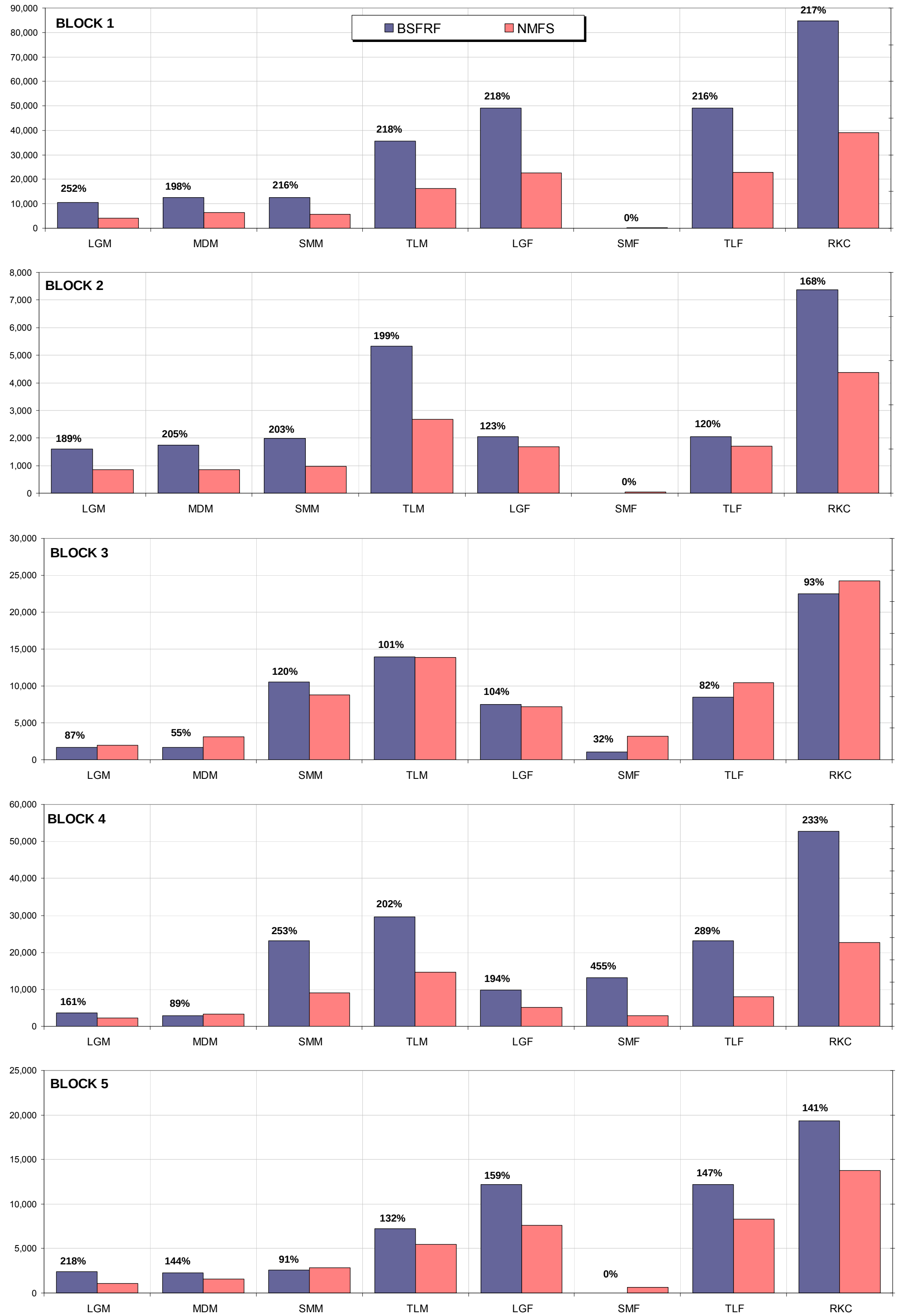


Figure 22. Plot of pair averaged densities by block for red king crab size and sex category and the ration of BSFRF to NMFS density for the pilot comparative test study.

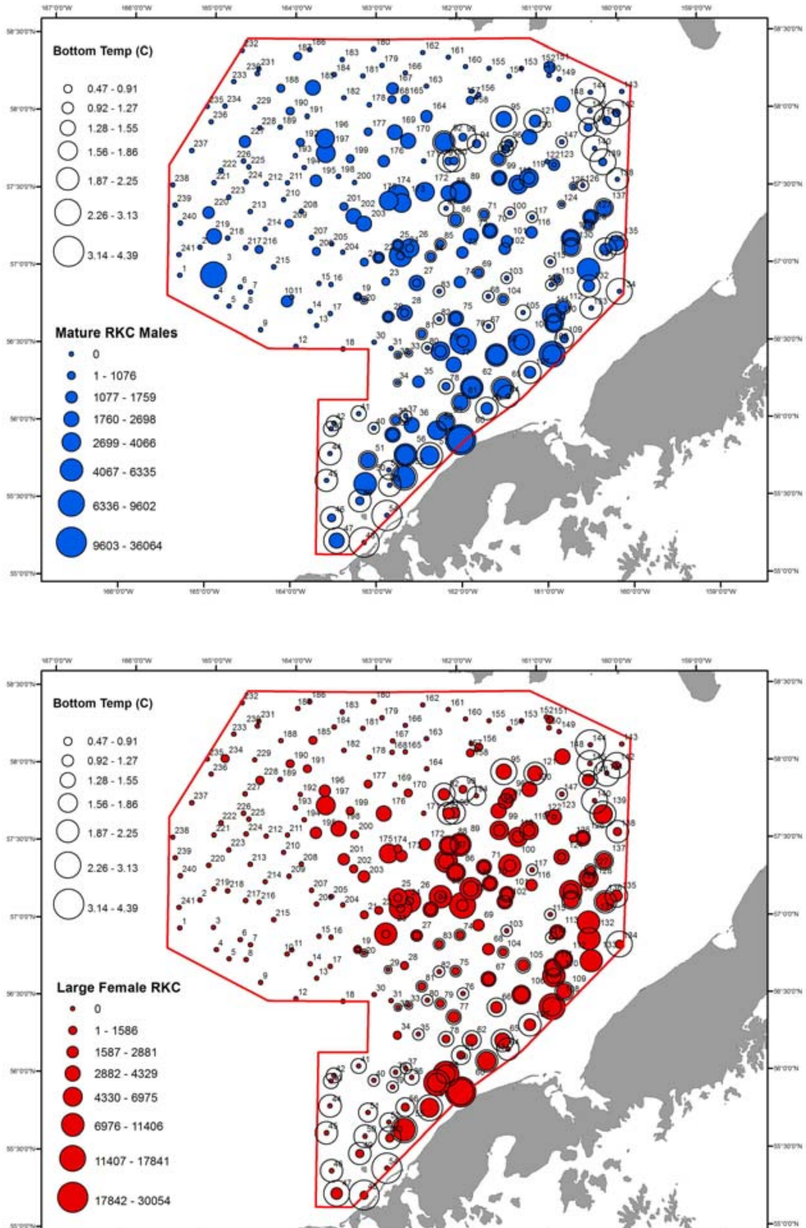


Figure 23. Preliminary plot of relationship of mature male and large female red king crab densities to bottom water temperature along the Alaska Peninsula within the BSFRF 2007 survey area based on partial survey summary.

Discussion

Results from Project 625 are important in the context of improving accuracy and precision for Bering Sea crab survey estimates of abundance and biomass. In the larger context of better understanding survey methodologies used for fisheries resource assessment, Project 625 results are a testament to how far survey gear and research has come. Quantifying catch per unit effort (CPUE) from trawl surveys has historically been a dynamic undertaking going back at least 20 years (Rose and Walters 1990). While some research from two decades ago sought to begin carefully quantifying trawl survey effort, some other current trawl surveys still rely on variable methodologies with some marginally defined survey protocols (NEFSC 2008). Catches standardized by a measure of effort from trawl surveys in particular can yield variable or erroneous results depending on the defined unit of effort. A trawl survey that measured its catch in units per tow (i.e. tons per haul) with flexible or undefined methods for defining many important parameters such as tow duration, tow speed, trawl net specifications, trawl door dimensions, etc. will lend to misleading results. Other recent research has recognized that even with standardized methods to closely measure a survey trawl's effort, there are still measurement difficulties (Wallace and West 2005).

In Alaska, the annual eastern Bering Sea standard NMFS survey has proven to be an important resource assessment tool. It has developed a long time series of relative abundance and biomass estimates for several commercially important fish and shellfish stocks. While it has provided a basis for sustainable management of fish stocks, its uncertainties have highlighted the difficulties in managing BSAI crab resources. The Alaska Fisheries Science Center (AFSC) of NMFS has been responsible for this survey and has taken extensive measures to improve and document the performance of the survey gear. In many respects, the NMFS survey in the BSAI has been on the leading edge of survey refinement. AFSC has understood the importance of focusing on standardizing a survey trawl gear's performance and that methods for this have been improving in direct relationship to improving technology for net instrumentation and other shipboard devices. Hydroacoustic sensors attached to nets send important net performance indicators via telemetry. Underwater video cameras attached to trawls record important gear behavior, and both environmental and biological information. Other sensors allow for data logging with no telemetry. New shipboard devices including improved GPS systems can very accurately measure ship speed, winch speed, trawl cable length out, water depth, and several environmental factors with many unseen new improvements on the horizon.

Despite the successes of the standard NMFS survey in the Bering Sea, AFSC scientists have undertaken some efforts to measure the uncertainties that affect crab resource assessment (Somerton and Otto 1999, Weinberg et al. 2004). In one study focusing on BBRKC survey trawl capture efficiency (catchability), an experiment was conducted with an auxiliary net (Weinberg et al. 2004). This study used an "underbag" trawl and video camera attached to the standard NMFS trawl to document and measure red king crab passing under the footrope of the standard net and being captured in the auxiliary trawl. Catchability coefficients were calculated based on the likelihood of capture in the standard net considering the measured height that the trawl footrope was off the seabed and the size of the BBBRKC in the path of the trawl. Results from this study have provided some important guidelines for crab stock assessment bias from this survey data. For instance, the underbag experiment estimated that legal male crab at 135 mm CL had an 84.1% capture probability. An application of results from this study is provided here to further clarify the importance of Project 625 results.

Using the length based capture probability provided in the underbag experiment, and comparing results from Project 625 to expanded 2007 NMFS estimates in the BSFRF area shows some relative importance but also shortcomings of these estimated length based catchability coefficients. Expanding the 2007 NMFS abundances in each size and sex category by applying the category's midpoint estimated capture probabilities implies in 4 out of 5 size sex category comparisons that the BSFRF survey crab catch rates using the geostatistical methods were still higher than the NMFS survey catch rates even after the NMFS abundance estimates were adjusted upward for catchability (based on escapement under the footrope).

This research to measure efficacy of current NMFS survey gear has provided some basis for understanding bias in BSAI crab surveys. It is further clarified by some comparisons from Project 625 results. There are however, two critical problems in addressing this comparison from the most current research to address BBRKC survey bias. The first is that very low catchability coefficients were estimated for the smaller size crab from this work, providing evidence that small pre-recruit crab are missed in the NMFS surveys. These catchability estimates differ from those for other larger size crab where some fraction of crab in front of the trawl are captured, due to the fact that an expansion can be applied only when a crab is captured. In a tow that missed all small crab, the resulting zero density cannot be expanded upward as the product of a catchability coefficient multiplied by a zero density. The second critical problem in the attempt to quantify bias in survey results deals with how to apply the measured bias. Application of these results to other management functions for BSAI crab fisheries should prove to be very valuable. It is currently not adequately used in the co-managed BBRKC modeled survey results in the management process. Aside from the political balance between co-managers and somewhat volatile stakeholders, further cooperative government-industry research toward a longer term BBRKC crab-specific survey would provide additional consistency similar to Project 625 results and further impetus for improving BSAI crab management choices.

The overall conduct of the BSFRF survey for BBRKC in 2007 proved to be very successful. While there were some obstacles early in the planning, design and timing for conducting the survey, all were overcome. Planning and design elements relied heavily on prior work and were subject to some limitations beyond the control of BSFRF. Project 625 management revisions ending Marine Geomatics' involvement and increasing NRC's responsibilities provided for improved learning and development opportunity where BSFRF is now better prepared for future research than initially expected. Some conservative planning elements left room for significant gains during the actual survey. The focus on crab only during the survey allowed for sorting and biological data collection to be done very efficiently. Good weather and relatively calm seas allowed the *American Eagle* to transit from Dutch Harbor to the survey grounds and between stations during the survey more quickly than planned. Redundancy of survey trawl gear, instrumentation, data collection devices and computers was a required insurance to the timely success of the survey. There were, however, no instances where any backup gear had to be used due to loss, damage or other circumstance. The 2nd and 3rd survey nets and the 2nd set of trawl doors remain unused and ready for future use. Primary computer hardware and software systems remained in use during the entire survey without relying on secondary or backup systems.

There were some logistical obstacles in acquiring the newly purchased BSFRF survey trawls that required some important gear modifications to be undertaken at the beginning of the Project 625 survey. Three trawls were purchased by BSFRF from the Canadian trawl net manufacturer Crimond. The trawl nets as delivered were built according to specifications both inconsistent with the published *Nephrops* design and explicit directions to have the new trawls match the trawl as used in the 2005 pilot study. One of these trawls was used during the initial test tows and the initial 18 tows (1.5 days) at the beginning of the 2007 survey in an attempt to assess performance of the trawl as delivered. After close inspection it became evident that performance of the forward wing sections of the trawl footrope, where chain denturing was affixed contrary to plans, was showing wear on the wrong side. The polished upper surface of the chain links showed evidence that the wing footrope denturing (tickler chain attached by drop-link setbacks) was not preceding the footrope during towing, but was rolling under and dragging behind the rubber discs on the footrope. After the tow was complete at station 18, during the long transit to station 19, the trawl footrope was reconfigured to match the rigging used in the 2005 pilot study. Once this reconfiguration was complete there was no other modification made to the trawl net during the rest of the survey. The *American Eagle* ended the planned survey finish point (station 241) ahead of schedule with enough time to retow all of the first 18 stations again. Since the tow route selection through the survey targets was not spatially bound to anything but transit efficiency, the retowed data was treated identically to other tows in the survey and data from the initial 18 tows was not included in any analyses. The retowed stations were completed within 0.5 nautical miles of the original tow track in the same orientation. Interestingly, a comparison of catches between the initial tows and the retows showed fewer BBRKC in the retows.

A few key problems were highlighted during the analysis of the survey area swept (trawl footprint) results from the BSFRF 2005 pilot study that required redress. The trawl area swept estimation per tow based on data from the 2005 net instrumentation showed some inadequacies. While not uncommon for survey trawl instrumentation, the data reception from the leased gear package in 2005 provided intermittent communication and was not performing as well as expected. Inadequacies in the net mensuration data from the 2005 survey data were shown in three areas, including poor bottom contact indication, lower quality of signal than expected from NETMIND sensors, and inadequate, subjective methods for summarizing the sensor data for area swept estimation per tow. Each of these areas was directly addressed for the BSFRF 2007 survey.

The realized improvement in net mensuration data for Project 625 was greatly supplemented by the modified bottom contact sensor (MBCS) that was developed as a customized sensor and housing by NMFS in cooperation with BSFRF. The housing was designed to be smaller and lighter as it was an additional element of the gear package that was attached to the survey trawl footrope as an additional item not used in the 2005 pilot study. The housing was a steel tube approximately 9” long and 3” wide weighing approximately 7 lbs with the inner housing and the sensor loaded. The device was a three dimensional data logger (x, y and z axes oscilloscope) that recorded a data stream at one second intervals when triggered from a USB docking station. The time stamp for the sensor was easily synchronized with the rest of the trawl mensuration equipment. The unit required manual control at each tow where start and stop data logging were controlled by the software interface, and a manual download of the data at the end of each tow. Time requirements for manual use of the device were minimal. Some simple external measurements while the unit was attached to the footrope of the trawl and some trigonometry informed the determination of the sensor values (x-tilt angle) indicating on bottom and off bottom times for the trawl.

The lower than expected quality of data from the 2005 pilot study was addressed directly with the manufacturer of the NETMIND sensors, Northstar Technical, prior to beginning the BSFRF 2007 survey. Because the BSFRF survey design calls for relatively short duration tows, the number of pings that can be received is very important. All NETMIND sensors purchased and used for Project 625 were configured to ping at the fastest rates possible. These rates ranged from 5 to 7 seconds for all sensors used during the 2007 BSFRF survey. For wing spread sensors, the total time between received readings from the slave sensor to the master sensor was 12 seconds as two sensor cycles were required. In light of some unsatisfactory readings and ping reception in 2005, the BSFRF 2007 survey monitored and quantified the quality of the data. For each tow, after the total duration of on bottom time of the tow in seconds was calculated, the total possible pings sent and received per sensor was estimated. The duration of the tow was split into highest rate intervals (maximum pings possible) and then a success percentage was calculated from the actual pings received out of the maximum possible. These results showed that for the most important telemetry-dependent sensor, the trawl net spread, the reception rate of good ping data during towing was 86%. This compared to tows in the 2005 pilot survey where average reception was nearer 60%. For the most critical sensor to the area swept calculation (MBCS), the ping rate was 100% as no telemetry was involved, all data was recorded onboard the device and downloaded, and there were no device failures.

The third area of improvement for area swept calculations was in the development of more objective methods for synchronizing, error checking and smoothing raw sensor data into tow by tow summaries. This was completed in collaboration with NMFS RACE Division scientists. The main improvements in these methods came from the transparent design that did not attempt to automate all sensor data summary tasks. The text files produced by the sensor readings and the software interface record some erroneous readings that preclude completely automating their use. In summary, the improved routine used for area swept estimation per tow followed a manual, multi-step process (19 steps) that required approximately 5 – 8 minutes processing time per tow. All sensor readings were aligned in a graphical format similar to other trawl mensuration data summaries (Scanplot) but were easily modified. Data concerns could be easily spotted in this format. Filtering out or "gating" erroneous readings prior to summary was partially automated requiring a visual check of the plotted filtered data. Filtering was followed by interpolation for appropriate sensors. This was a smoothing process that filled in gaps in data pings that were not received. It further filled in gaps between actual data to build a contiguous 1-second database of the important trawl performance variables. The elements used in area swept calculation from this refined dataset were trawl net spread, GPS speed over ground (SOG) and the 1 second readings from the MBCS. This integrated approach, when following the steps through both manual and automated evaluation of the data on a tow by tow basis, provided a very objective methodology to be usable by any independent reviewer of data from this survey, or importantly, to be used in 'real-time' immediately following tows for future surveys using this trawl survey package and mensuration equipment.

This survey has been conducted as part of a larger process of continuing efforts between industry and both state and federal fisheries managers towards improving the science used to manage Bering Sea crab stocks. An annual cooperative effort under the Memorandum of Agreement between NMFS and the BSFRF (Appendix 1) has covered several cooperative research tasks including the sharing of the annual NMFS abundance densities of red king, *opilio* and *bairdi* crab from the summer surveys. For the last five years, this cooperation has followed a process of an independent (industry) audit of the raw NMFS survey data – namely, the catch and haul files used to compute densities. The final step in recent years has been to receive the final NMFS estimates of abundance and biomass from the same data and compare. In 2007, final estimates of the NMFS survey data from NMFS were unavailable. For the comparisons in this report, the "NMFS" estimates of abundance are the independent (BSFRF) summaries of the NMFS data as provided.

The selection of the area for the pilot comparative test tow study completed on June 9 and 10 may have biased the results from this pilot work. The intent was to find an area of trawlable grounds that had high enough densities of BBRKC to make the side by side tow tests effective in isolating as much as possible temporal and spatial variability of BBRKC densities. The area chosen may have been ineffective at isolating variability for both of these factors. The second tow of the *Aldebaron* revealed significant trawl damage. In 4 tows in the area, the BSFRF trawl, while exhibiting no damage, had substantial catch of rocks ranging from 10 – 15 centimeters in diameter up to small boulder size (approximately 60 – 80 centimeters). The cold water year in the Bering Sea in 2007 likely affected distributions of several size sex categories of BBRKC, especially in the near shore warmer water area (as measured by the CTD). Future supplemental work to this pilot study to increase sample size and strengthen the test should more closely consider the location of the test area and possibly measure other environmental factors of significance.

Conclusions

Bering Sea fisheries have had a history of being managed to some of the highest fisheries research standards in the world and cooperative industry/government research has had major contributions to this effort over many years. This concept and the bringing together of expertise and experience was utilized in NPRB Project 625 in identifying and quantifying some long known BBRKC assessment deficiencies with the goal of developing improved resource assessment methods to address those deficiencies, testing their merits and comparing results of the new procedures with results of the long term assessment standards. The performance of the *Nephrops* trawl in properly tending the BBRKC district seabed, the detailed measuring of the trawl's area swept, the conduct of a short tow duration higher density sampling survey to better deal with crab patchy distributions, the whole haul sampling of all catches and the geostastical analysis of measured crab densities has proven highly effective in providing a more accurate survey of this crab population with significantly greater precision. The BSFRF survey as conducted is improved science and it better addresses the goal of managing this commercially important resource for maximum sustained yield with much greater certainty for both utilization and conservation.

While the compared survey results showing statistical significance speak for themselves as a means to improving fisheries science and crab management, the need remains to fully peer review this research, perhaps including a repeat in 2008 of the 2007 survey and to develop a long term tri-party policy of implementation. A tri-party policy developed by industry/NMFS/ADF&G which addresses the cooperative funding, conduct of this specialized survey, analysis of data, use of results in management of this resource and its associated commercial fishery needs to be evaluated and developed. In potentially making this change, further comparative gear work could be completed to provide a quantitative link between population estimates derived by the long term standard survey and the new survey methodology.

Publications

None at this time

Outreach

NPRB Project 625 outreach occurred throughout project duration via scheduled monthly meetings with the Bering Sea Fisheries Research Foundation's 13 industry member Board of Directors and via various public presentations. Outreach presentations included:

Conference Presentations

April 17, 2007, Seattle Washington. Presentation to North Pacific Fishery Management Council's Pacific Northwest Crab Industry Advisory Committee on the Bering Sea Fisheries Foundation 2005 Bristol Bay red king crab pilot survey, results of that survey and plans for the Bering Sea Fisheries Research Foundation 2007 Bristol Bay red king crab survey. Presentation by Steve Hughes and attended by advisory committee members and about 75 members of the industry/public.

September 14, 2007, Seattle Washington. Presentation to the North Pacific Fishery Management Council's Crab Plan Team Meeting on 2007 BSFRF's Bristol Bay red king survey and survey results compared to NMFS standard survey determined by area swept analysis. Presentation by Steve Hughes and Scott Goodman and attended by team members and industry/public.

January 21, 2008, Anchorage, Alaska. Presentation to Alaska Marine Science Symposium, "Assessment of Bristol Bay red king crab resource for future management action : a new approach". Presentation by Steve Hughes and Scott Goodman to symposium audience of 300+.

Workshop Participations

September 20-22, 2007. Presentation by invitation to international workshop on Hematodinium Associated Disease - Research Status and Future Directions. Presentation by Steve Hughes on NPRB Project 625 cooperative industry/government research on Bristol Bay red king crab. Attended by about 75 international scientists working on crustacean fisheries and diseases.

Community Meetings

September 19, 2007 and January 14, 2008, Seattle Washington. Presentations to Alaskan Crab industry Forum. Presentations by Scott Goodman (September) and Steve Hughes (January) on NPRB Project 625 research, results and future plans. Attended by about 150 members of the crab industry between the two meetings.

Industry Targeted Newsletter

February 21, 2008 letter to Alaska crab industry including presentation summary from Alaska Marine Science Symposium.

Video Produced

January 2008. Brief video included in Alaska Marine Science Symposium presentation and also linked in the newsletter listed above. Video is available online at:
http://www.youtube.com/watch?v=nhQHbGhRvUs

Acknowledgements

This cooperative industry-government research would not have been possible without the financial assistance of NPRB together with the NMFS Alaska Fisheries Science Center and a major component of the Bering Sea crab fleet. NPRB Project 625 was a substantial undertaking and special thanks are extended to Dr. Gary Stauffer (retired NMFS/ AFSC) and his successor Russ Nelson for their assistance and dedication to this cooperative research program, to Denby Lloyd and his ADF&G staff for their support throughout and participation in the 2005 pilot survey, to Captain John Wood and his crew of the F/V *American Eagle* for their professionalism and strong dedication to "doing a great job," to NMFS scientists Dave Somerton and Keith Smith for their participation in the 2007 survey, and Bob Lauth for his effective coordination of the pilot comparative tow work and assistance with area swept estimation, and to the many owners of Bering Sea crab vessels who contributed assessments from their crab landings to help pay the research bills.

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Appendix 1

2007 Memorandum of Agreement between NMFS & BSFRF

~~DRAFT 3~~

MEMORANDUM OF AGREEMENT
ESTABLISHING A JOINT PROJECT
BETWEEN THE
ALASKA FISHERIES SCIENCE CENTER
NATIONAL MARINE FISHERIES SERVICE
U.S. DEPARTMENT OF COMMERCE

AND

BERING SEA FISHERIES RESEARCH FOUNDATION

Agreement No. AKC-~~0XX~~ 060

I. PARTIES

This Memorandum of Agreement (MOA) establishes a third joint project agreement between the Alaska Fisheries Science Center (AFSC), National Marine Fisheries Service (NMFS), U.S. Department of Commerce (DOC) and the Bering Sea Fisheries Research Foundation (BSFRF), which is a non-profit organization. In 2004, both parties agreed to conduct a joint cooperative project that added supplemental bottom trawl survey stations to the AFSC's annual bottom trawl survey to improve the precision of the population and biomass estimates resulting from the survey. In 2005, both parties again worked together to conduct a pilot survey of Bristol Bay red king crab using a new survey design and new fishing gear used in eastern Canada. It is the intention of both parties to continue to conduct joint cooperative projects in future years to improve our understanding of the biology and assessment of Bering Sea crabs and to establish new agreements to carry out those projects. Both parties support a multiyear research partnership to conduct cooperative joint projects on Bering Sea crabs. This agreement applies to the 2007 cooperative effort.

II. AUTHORITIES

NMFS is authorized to enter into this Agreement with the BSFRF pursuant to the Department of Commerce's Joint Project Authority, 15 U.S.C. 1525. NMFS has determined that this arrangement is of mutual benefit to both parties and that the costs will be equitably apportioned. The NMFS has programmatic authority to engage in areas of research to support the conservation and management of marine fisheries resources pursuant to the Magnuson-Stevens Fishery Conservation and Management Act, 16 U.S.C. 1801 et seq.

III. PURPOSE

Pursuant to this joint project agreement, the parties will work jointly to improve the knowledge of the biology, abundance, and distribution of eastern Bering Sea king crabs, Tanner crabs, and snow crabs. As directed by the Magnuson-Stevens Fishery Conservation and Management Act, the NMFS conducts research in the eastern Bering Sea on the distribution, abundance, and biology of stocks of king crabs, Tanner crabs and snow crabs. Annual bottom trawl stock assessment surveys and research conducted by the NMFS provide basic information utilized by NMFS, the Alaska Department of Fish and Game, and the North Pacific Fishery Management Council to annually assess the status of eastern Bering Sea crab stocks and to develop and implement management measures to manage crab fisheries in the eastern Bering Sea and provide for conservation of the resource. The BSFRF is a non-profit organization formed by members of the fishing industry and public to support research essential to the conservation and management of eastern Bering Sea crab resources. The need for additional research on the biology of Bering Sea crabs and additional stock assessment survey effort to improve the precision and abundance estimates is acknowledged and apparent to both parties. The mission of the BSFRF is to "assist in developing and determining the best scientific approach and information for management of the Bering Sea fisheries, so that these fisheries will be protected and preserved while producing the optimum yield." By joining efforts on mutually agreed joint projects, the parties to this Agreement believe the understanding of the biology and assessment of eastern Bering Sea crab stocks can be greatly improved.

The NMFS has determined that this joint project cannot be done at all or done as effectively without the participation of the BSFRF because the NMFS has insufficient fiscal and personnel resources to carry out the activities described in this agreement without the assistance of the BSFRF. Participation from the BSFRF provides access to valuable traditional knowledge and information gained by participants in the commercial fisheries and internationally recognized scientists who both have the potential for improving our basic understanding and knowledge of crab biology and populations. The continuation of this partnership and joint project are necessary and essential to further the mission of the Department to manage and conserve the nation's living marine resources under the Magnuson-Stevens Fishery Conservation and Management Act and to achieve NOAA's goal to "Protect, restore, and manage the use of the coastal and ocean resources through an ecosystem approach to management."

The cooperative research effort supported by this joint project agreement in 2007 will consist of a joint survey of Bristol Bay red king crab, an initial calibration of the joint survey with the NMFS standard annual survey, estimation of the abundance and associated variance of those estimates of juvenile and mature male and female Bristol Bay red king crab, comparison of estimates of crab density by crab size/sex categories from the cooperative survey with estimates from NMFS standard survey of Bristol Bay, and addition of the 29 northern stations added to the NMFS standard survey in 2004 to continue assessment of snow crab in the area north of the standard survey area. The joint survey must occur in June to coincide with the NMFS annual Bering Sea crab/groundfish survey of this area to ensure that both surveys are sampling the same segment of the red king crab population.

IV. <u>MUTUAL INTEREST OF THE PARTIES</u>

The cooperative research and survey assessment of eastern Bering Sea crabs at issue in this joint project agreement is of mutual interest to the parties because it will improve the parties' understanding of Bering Sea crab biology and the assessment of the condition of the stocks of crabs. This is important to the NMFS because of its responsibility under the Magnuson-Stevens Fishery Conservation Act to manage and conserve the living marine resources of the United States. It is of importance to the BSFRF because of the interest of their contributors to ensure the long-term conservation and sustainability of Bering Sea crab stocks on which their livelihood depends.

V. <u>RESPONSIBILITIES OF THE PARTIES</u>

A. The NMFS shall:

a. Provide guidance in the design and evaluation of the joint crab survey to be conducted in 2007 and in the initial calibration of the joint survey with the standard NMFS annual survey.
b. Provide funding for the fuel for the BSFRF charter vessel to conduct the joint cooperative survey.
c. Provide staff and resources to continue the expansion of the standard AFSC annual eastern Bering Sea bottom trawl survey to include the additional northern trawl stations surveyed in the 2004 joint NMFS/BSFRF survey effort and continued as part of the AFSC's standard eastern Bering Sea survey in 2005 and 2006, depending on availability of FY 2007 NMFS funding.
d. Provide staff and resources to assist in the analysis and review of the joint survey and survey calibration and to lead the editing, analysis, and reporting of the expanded standard NMFS annual survey data.
e. Provide the edited data and results from the expanded standard NMFS annual survey to the Alaska Department of Fish and Game (ADF&G) for the Bering Sea crab stocks from the AFSC's 2007 standard annual Bering Sea survey and the expanded area for the snow crab stock in time to be included in the annual crab assessment process for setting quotas for the 2007-8 fishing seasons.
f. Upon review of the scientific operations plan for the joint survey charter vessel, NMFS will issue a Letter of Acknowledgement to the BSFRF verifying the survey will be conducting scientific research during its cruise to distinguish the cruise from commercial fishing and exempt the cruise from the regulations under Magnuson-Stevens Fishery Conservation and Management Act.

B. The BSFRF shall:

a. Provide a chartered trawl vessel to conduct the joint cooperative survey including the initial calibration with the NMFS standard survey at no cost to the NMFS except for fuel as specified above for the period of the joint cooperative survey. The chartered vessel will at a minimum meet the same specifications to carryout the survey following the procedures required by the 2005 pilot survey method. The 2007 joint cooperative survey and therefore the charter of the vessel will be 35 days.

b. Assure NMFS that the captain and crew of the chartered vessel will follow the scientific operating plan developed by the BSFRF to conduct the joint cooperative survey and will follow the direction of the BSFRF Chief Scientist in all aspects of the survey, except in matters relating to the safe operation of the vessel and the safety of the crew and scientific staff.
c. Agree to be responsible for the balance of all costs relating to the operation of the vessel and crew, including the vessel, captain and crew, lube oil, P&I insurance, food for the crew and scientific staff, bedding, crew communications from the vessel to shore.
d. Provide the vessel charter with at least four scientific staff members for the joint cooperative survey operations. Make available the data, analysis, and report of the joint cooperative survey to NMFS, ADF&G, and the research community for review and further study.
e. Provide staff and resources to edit, analyze, and report on the joint cooperative survey, review the analysis and results of the expanded standard NMFS annual survey, and prepare an annual report on the results of the 2007 joint cooperative survey effort with NMFS participation.

VI. EQUITABLE APPORTIONMENT OF COSTS

The costs of these activities are apportioned between the NMFS and the BSFRF. The NMFS's estimated cost for the joint cooperative survey, initial survey calibration and the expansion for the AFSC annual bottom trawl survey will be $297,329 which represents 41.5% of the project costs (Attachment 1). The BSFRF's contribution to this project of $419,725 or 58.5% of the project costs.

VII. CONTACTS

The contacts for each party to this agreement are:

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The parties agree that if there is a change regarding the information in this section, the party making the change will notify the other party in writing of such change.

VIII. PERIOD OF AGREEMENT AND MODIFICATION/TERMINATION

This agreement will become effective when signed by both parties. The agreement will terminate on June 1, 2008, but may be amended at any time by mutual written consent of the parties. Either party may terminate this agreement by providing 90 days written notice to the other party. In the event this agreement is terminated, each party shall be solely responsible for the payment of any expenses it has incurred. This agreement is subject to the availability of funds by both parties.

IX. OTHER PROVISIONS

Performance by each party is dependent upon the receipt of the necessary funding and support required. In the case of the NMFS, funds to support this cooperative effort have been allocated from the FY 2007 National Cooperative Research Program and AFSC/RACE Division and for the BSFRF funds are from the North Pacific Research Board and donations to the Foundation from participating companies and communities involved in the crab industry.

Should disagreement arise on the interpretation of the provisions of this agreement, or amendments and/or revisions thereto, that cannot be resolved at the operating level, the area(s) of disagreement shall be stated in writing by each party and presented to the other party for consideration. If agreement on interpretation is not reached within thirty days, the parties shall forward the written presentation of the disagreement to the President of the BSFRF and the NMFS Science and Research Director, Alaska Region for appropriate resolution.

Under the Inspector General Act of 1978, as amended, 5 USC App. 3, a review of this agreement may be conducted at any time. The Inspector General of the Department of Commerce, or any of his or her duly authorized representatives, shall have access to any pertinent books, documents, papers and records of the parties to this agreement, whether written, printed, recorded, produced, or reproduced by any mechanical, magnetic or other process or medium, in order to make audits, inspections, excerpts, transcripts, or other examinations as authorized by law.

Any materials or statements offered to inform the public of the nature of this joint cooperative project, or to promote knowledge of the existence of the project and the parties, shall only be released to the public upon the mutual written agreement of the parties.

Gary Reisner CFO

for William T. Hogarth, Ph.D.
Assistant Administrator for Fisheries

6/4/07
Date

Gary L. Painter

Gary Painter
President
Bering Sea Fisheries Research Foundation
620 Sixth Street South
Kirkland, Washington 98033

6/12/07
Date

Appendix 2

Final Cruise Orders for BSFRF 2007 BBRKC Survey

B S F R F

BERING SEA FISHERIES RESEARCH FOUNDATION

620 6TH ST. SOUTH   KIRKLAND, WA 98033

FORGING COOPERATIVE RESEARCH PARTNERSHIPS IN THE BERING SEA

May 15, 2007

CRUISE ANNOUNCEMENT AND SAILING ORDERS
F/V *AMERICAN EAGLE*:   (Official Number: 558605) WYX3564

<u>ANNOUNCEMENT:</u>
The Bering Sea Fisheries Research Foundation (BSFRF) with support from the National Marine Fisheries Service (NMFS) announces a research project on Bering Sea red king crab, *bairdi* Tanner crab and *opilio* snow crab.

<u>OBJECTIVES:</u>
Research objectives are:

1. To conduct a full Bering Sea red king crab assessment survey using a survey gear/equipment package designed and used in Eastern Canada, targeting Bristol Bay red king crab, and secondarily *bairdi* Tanner crab and *opilio* snow crab in a selected area of the SE Bering Sea,

2. To conduct pilot study comparative gear test between *American Eagle* study gear and standard NMFS Bering Sea survey gear, including 2 to 3 days of side by side test trawling in coordination with both 2007 NMFS chartered Bering Sea survey vessels in a location to be determined within the larger survey area,

3. To estimate mean and variance of the densities of juvenile and mature male and female Bristol Bay red king crab, Tanner crab and snow crab in the assessment survey,

4. To compare estimates of crab abundances by crab species/size/sex categories from the BSFRF survey with estimates from NMFS standard survey in the same area based on standard area swept technique, and

5. To compare estimates of crab abundance and biomass by species/size/sex categories from the BSFRF survey using geostatistical techniques with area swept estimates from NMFS standard survey.

VESSEL AND SURVEY GEAR:

Gear tests and survey operations will be conducted from the 120 ft LOA, house forward, stern ramp trawler, F/V *American Eagle* which has been chartered for this research by the BSFRF. The gear package consists of otter trawls and trawl doors, specially designed and rigged for “heavy on bottom tending characteristics,” Net Mind acoustical sensors for trawl spread and performance measurements and associated instrumentation for performance readouts and recordings. The research trawls measure 20 meters on the head rope by 27 meters on the footrope which is attached to an array of tickler chain gear. Deck gear includes temperature/salinity probe, deck catch sorting table and standard equipment for sorting, weighing and documenting crab catches and the collection of biological data.

RESEARCH AREA AND SURVEY DESIGN:

The research area is located within the boundary of the historical distribution of Bristol Bay red king crab in the region of the SE Bering Sea and spans an area of about 24,000 square nautical miles (Exhibit 1). The survey design (Exhibit 2) calls for 240 tows in this region randomly chosen from a pre-determined sampling grid. The BSFRF survey design is different from the standard NMFS survey as it utilizes a higher sampling density of shorter duration tows. This new approach is expected to produce a survey result of greater accuracy with lower variance.

SURVEY METHODOLOGY:

Initial trawl hauls will be conducted to test, measure and calibrate the trawl gear in the study area environment. Initial trawl hauls will also be used to determine tow durations that will subsequently be used in the survey. This is necessary to balance trawl area swept with catch handling capabilities and substrate debris that may be retained in the trawl. Survey tows will be completed at or near the stations shown in Exhibit 2. Trawl durations are expected to be 5-10 minutes. Trawl area swept will be measured and documented from each tow by the net mind and GPS systems. Catches from each trawl will be placed in the deck sorting table and crab catches enumerated by species/size/sex categories. Crab catches will be whole haul sampled and biological data collected and results recorded in data collection forms and into onboard computers for later analysis. Any fish catches and crab not retained for scientific purposes after completion of sampling will be returned to the sea.

The pilot comparative tow study will be conducted by *American Eagle* and NMFS Bering Sea survey vessels during a 2 to 3 day period. Side by side tows will be completed in a high density king crab area following a NMFS experimental design to compare crab density and catchability coefficients between vessels.

ITINERARY:

Vessel crew and scientific party will board F/V *American Eagle* at the UniSea dock in Dutch Harbor, Alaska, the afternoon of May 23-24, 2007. Vessel preparations for sailing including provisioning, gear offload/loading and instrument installations/calibrations will be completed May 25-26. *American Eagle* will depart Dutch Harbor May 26-27, 2007, for the study area. The survey schedule includes two 20 day legs, split by a one day break when the *American Eagle* will transit back to Dutch Harbor on or about June 15, 2007. The survey will resume for the second leg after the break and return to Dutch Harbor on July 5, 2006, which terminates the operation.

PERSONNEL:
F/V *American Eagle* Crew:
Captain John Wood
Crewman Pete Lafavor
Crewman Michael Hugev
Crewman Kris Blasikiewicz

Scientific Crew:
Scott Goodman, Chief Scientist, Natural Resources Consultants (leg 1 and 2)
David Somerton, Fishery Biologist, National Marine Fisheries Service (leg 1)
Keith Smith, Fishery Biologist, National Marine Fisheries Service (leg 2)
Margie Kearns, Biologist, BSFRF (leg 1 & 2)
Susan Strand, Biologist, BSFRF (leg 1 & 2)
David Bennett, Biologist, BSFRF (leg 1 & 2)

NOAA/NMFS CONTRIBUTION OF FUNDING FOR BSFRF RESEARCH:
Cost of fuel consumed aboard American Eagle during the BSFRF survey work will be paid for by NMFS, Alaska Fisheries Science Center.

FURTHER INFORMATION:
Please contact BSFRF President Gary Painter (541-574-0256) or Steve Hughes, President, Natural Resources Consultants (206-285-3480)

F/V *American Eagle* is black hull, white house (forward), and will fly bright yellow banners with black text “FISH RESEARCH.”

Exhibit 1. Chartlet showing planned boundary (red shaded area) of BSFRF 2007 Bering Sea red king crab survey area.

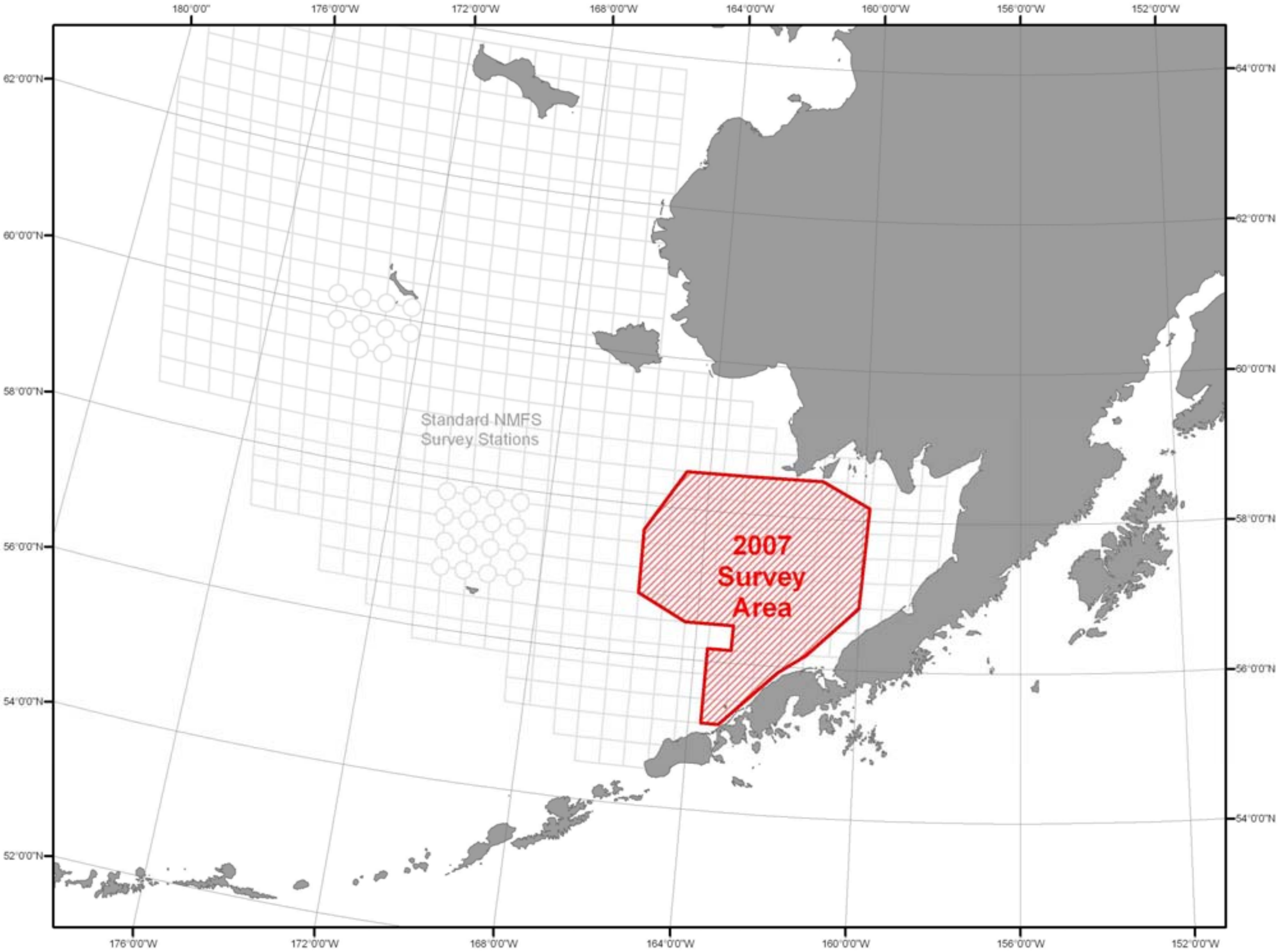
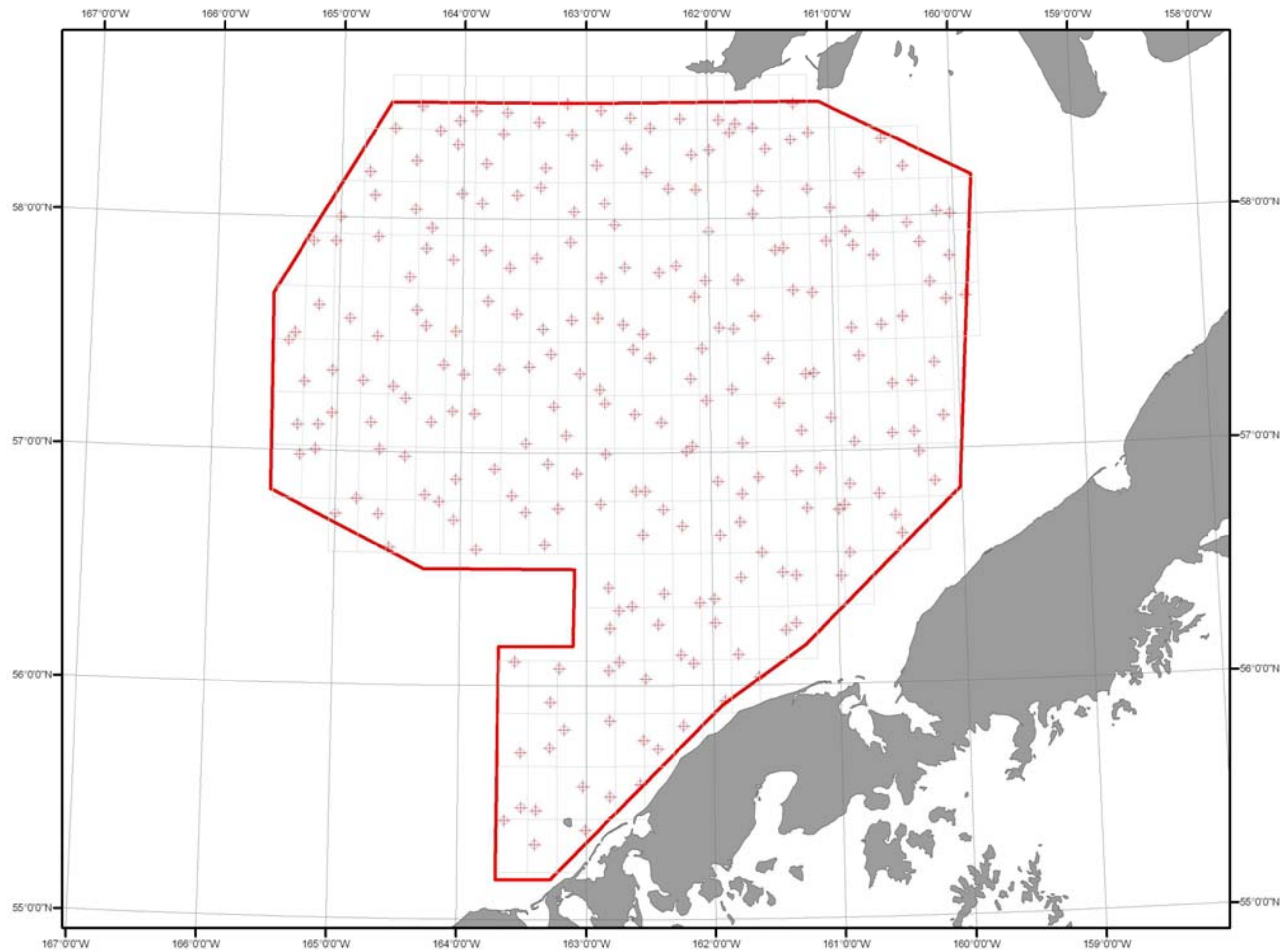


Exhibit 2. Chartlet showing planned trawl targets (red cross hairs) within the boundary of BSFRF 2007 Bering Sea red king crab survey area.



Appendix 3

Pilot Study Comparative Tow Methods

Cruise Plan for Pilot Gear Comparison Study of Bering Sea Research Foundation and Alaska Fisheries Science Center Survey Trawls

Introduction

A 2-day pilot trawl comparison study in Bristol Bay, Alaska is being planned with the Bering Sea Research Foundation (BSRF) and at the he Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering (RACE) Division in June 2007. Catch rates of Bristol Bay red king crab (BBRKC) will be compared with two different gear types: 1) the 83-112 eastern trawl used in the annual eastern Bering Sea (EBS) shelf bottom trawl survey, and 2) the nephrops trawl used in crab surveys in the Canadian Gulf of St. Lawrence. Given the brief time period for the study, the differing spatial scales over which the two gear types sample, and the spatial patchiness of BBRKC, the resulting number of tows will not be sufficient to provide a statistically valid comparison between the two gear types. However, data from the comparison study will be useful for doing a power analysis to estimate the number of paired tows necessary for conducting a scientifically valid comparison of the two gear types.

Methods and Gear

Area of Operation. The area of operation will be in Bristol Bay, Alaska in a predetermined area with a high density of BBRKC.

General standardized procedures. Two AFSC charter vessels and one BSRF charter boat will be used in the gear comparison study. Comparison tows will consist of an AFSC charter vessel and the BSRF vessel doing a series of paired side-by-side tows. The AFSC and BSRF will each use their respective standard survey methodologies. Standard procedures for the AFSC annual EBS trawl survey are outlined in Stauffer (2001) and standard procedures for the BSRF survey are described in NPRB Proposal #625.

Experimental design. The experimental design is a non-random complete-block design. During a two day period, there will be time for about 5 blocks with a total of 20 paired tows. Within each block are a set of four paired tows: the first paired tow is with the BSRF charter vessel FV American Eagle and NMFS Charter Vessel A, and the second paired tow is with the BSRF charter vessel FV American Eagle and NMFS Charter Vessel B. This set of two paired tows is completed twice per block for a total of 4 paired tows within a block. Each block will be completed before the next block has begun. Selection of the initial tow direction for each block will be made by the skippers depending on weather and current conditions. Once a tow direction for a block is chosen, all vessel towpaths within the block must be parallel and towed in the same direction. Towpaths between vessels of a paired tow and within a block can be offset by a maximum of 0.2 nm (i.e., ≤ 1.0 nm between towpaths on the perimeter of the block). The BSRF charter vessel will randomize which side, port or starboard relative to the NMFS vessel, to do each paired towed. The standard tow length by the NMFS vessel is 30 minutes and the standard tow length for the BSRF vessel is 5 minutes. The entire tow by the BSRF vessel will be conducted within the same time frame and parallel to the tow made by the NMFS vessel. Towpaths, not vessels, are required to be side-by-side during each paired tow. Trawl tows should not be made at scheduled survey stations. Sampling will be done during daylight hours.

Tow site selection. Tow sites will be in areas that have historically produced favorable numbers and crab lengths.

Catch processing. All red king crab will be enumerated and measured for size (carapace length measured to the nearest millimeter), maturity, and sex composition.

Itinerary

25-26 May	Mobilization of BSRF charter vessel FV *American Eagle* in Dutch Harbor
26 May	FV *American Eagle* departs for Bristol Bay
27-28 May	FV *American Eagle* conducts gear check of nephrops trawl
29-30 May	FV *American Eagle* begins BSFRF survey
4-5 June	Mobilization of FV *Arcturus* and FV Aldebaran charter vessel in Dutch Harbor
5 June	FV *Arcturus* and FV *Aldebaran* depart for Bristol Bay
6 June	FV *Arcturus* and FV *Aldebaran* conduct gear checks of 83-112 eastern trawl and FV *American Eagle* takes break in survey to rendezvous with NMFS survey vessels
7-8 June	BSRF and NMFS vessels meet and conduct gear comparison pilot study on high-density BBRKC grounds
9 June	BSRF and NMFS vessels complete gear comparison pilot study and depart for survey grounds
10 June	BSRF and NMFS vessels resume survey operations

Analyses - trawl area swept considerations. Given the huge difference in the spatial coverage of the NMFS standard tow and the BSRF standard tow, it will be extremely important that components of the area swept estimation are agreed upon prior to the cruise, and that they are carefully measured and documented from each tow. Following is a list of measured variables used in the area swept estimation and additional considerations that should be made for each.

Additional considerations using vessel GPS data to calculate distance fished

1. When winches are engaged at haulback the speed of the trawl over ground increases and the distance covered by the trawl net ("liftoff lag distance") can be greater than the distance covered by the vessel. Both the trawl performance and the catching efficiency of the trawl are affected during the liftoff lag period and the liftoff lag distance, if not considered, would be a considerable source of bias among charter vessels (Wallace and West 2006). Although NMFS does not currently add this distance to their area swept estimation, it will be important to do when comparing BSRF and NMFS vessels because the liftoff lag period for the 5-minute BSRF tow is a much greater percentage of the total tow time. Both BSRF and NMFS should use the Trigonomic Method described by Wallace and West (2006) for estimating the liftoff lag distance.
2. On and Off Bottom Times – On and Off Bottom Times will be determined using the NMFS Bottom Contact Sensor (BCS). On Bottom Time is usually a "knife edge" event that is easily selected using a plot of the NMFS BCS. Off Bottom Time, however, is less clear because of the liftoff lag period when the net is only slightly off bottom and still fishing and catching crab at less than full catching efficiency of the trawl. It will be important that Off Bottom Times for the BSRF and NMFS tows are selected the same.
3. GPS tow track smoothing – Michael Martin (AFSC) modeled the effects of curved tows and noisy GPS data on the distanced fished calculation. Model simulations showed that systematic error could be introduced in curvy or noisy towpath data when using a moving average or a simple exponential smoother to calculate distance fished. A cubic spline method performed the best and was not affected by noisy or curvey GPS data. Given that different GPS systems will be used on the BSRF and NMFS charters, and that the BSRF GPS data may be prone to noise, it will be important to choose a method that does not introduce systematic error. For the EBS survey, the AFSC currently uses average beginning and ending points for calculating a straight-line distance.
4. "Gating" net width data for net width estimation – Stan Kotwicki (AFSC) looked at Netmind width data and found that spurious or outlier data is not symmetrical. Furthermore, it is difficult for different observers to objectively eliminate outliers in a consistent manner ("gate" the data). To minimize this potential bias, Stan wrote a program that does a sequential outlier rejection. The program iteratively removes outliers and runs the cubic spline smoother (same smoother as distanced fished because does well with curvy and noisy data) to reduce residual error in the observed data. Currently, NMFS uses a fixed net width for estimating area swept for crab CPUEs.
5. Poor quality Netmind data and tows without netwidth obseravations – see attached questions to Netmind. We will be having conference call with Netmind this Wednesday morning.

Appendix 4

Letter acknowledging collaboration from AFSC, NMFS/RACE

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Alaska Fisheries Science Center
Resource Assessment and Conservation Engineering Division
7600 Sand Point Way NE
Seattle, Washington 98115-0070

26 March 2008

Scott Goodman
Bering Sea Research Foundation
c/o Natural Resource Consultants
1900 West Nickerson Street, Suite 207
Seattle, WA 98119
Email: sgoodman@nrccorp.com

Dear Scott,

This letter acknowledges your collaboration on a regular basis with the Alaska Fisheries Science Center (AFSC) Resource Assessment Conservation Engineering (RACE) survey staff in regards to the current scientific equipment, methods and analysis used for estimating area swept of a survey trawl. The 2-day pilot trawl comparison study of the standard NMFS bottom trawl and the BSRF nephrops trawl that the AFSC and BSRF conducted last June used similar equipment for measuring bottom contact, distance fished, and net spread. Although the spatial coverage of the two trawl gears differed substantially and there were a limited number of tows for a statistically valid comparison, the methodology used for estimating area swept was standardized for the NMFS and BSRF research vessels so that a preliminary comparison of Bristol Bay red king crab catch rates could be made between the vessels.

Best regards,

Robert Lauth

Supervisory Research Fishery Biologist
Bering Sea Groundfish Survey Group
Phone: (206) 526-4121 FAX: (206) 526-6723
E-mail: bob.lauth@noaa.gov

cc: Russ Nelson

Appendix 5

Geostatistical Report from G. Swartzman

Abundance Estimation for Bristol Bay Red King Crab (*Paralithodes Camtschaticus*) in the Eastern Bering Sea, Based on an Industry Cooperative Bottom Trawl Survey in 2007, Using Geostatistical Methods

December 2007

Prepared for:
Bering Sea Fisheries Research Foundation
620 6th St. South
Kirkland, WA 98033

Prepared by:
Gordon Swartzman, PhD
Research Professor Emeritus
School of Aquatic & Fishery Sciences
Box 355020 University of Washington
Seattle, WA 98195-9020

Introduction

This report provides estimates for overall biomass and abundance and standard deviations for the 2007 industry cooperative bottom trawl survey conducted by the Bering Sea Fisheries Research Foundation (BSFRF) in conjunction with the National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center (AFSC) summer bottom trawl survey (referred to as the standard survey; STD). A total of 241 trawl stations were sampled in the BSFRF cooperative survey. The estimates of abundance and biomass were derived using the geostatistical method known as ordinary kriging. Computed variance is also based on ordinary kriging and is reported as 95% confidence intervals.

Estimation Procedure

1. Transform the data into UTM (Mercator) coordinates. This assures that distances between points (needed for variogram estimation) are sum of square distances independent of latitude.
2. Compute empirical variograms for each size/sex class of crab assuming a) no directional component and b) directional components.
3. Decide whether directionality is important or whether we can assume isotropy.
4. Fit the variograms to an underlying model. Both circular and exponential models were considered. Fitting was done using a maximum likelihood (nonlinear least squares) method and also with a modification of these fitted parameters using a comparison by eye. The main criterion was to best fit the points for small distances where the variograms were low (i.e. relatively high spatial autocorrelation between points at the smaller distances).
5. Decide on the region to be used for estimation. Considerations are the distribution of the trawl locations and possible ancillary information (e.g. bottom depth). In this case the estimation region (see Figure 1) was provided by Scott Goodman of Natural Resources Consultants (NRC).
6. Use the fitted variograms and the underlying data to estimate abundance over the estimation region on a square grid (standard kriging) and the variance (standard deviation) of abundance. Map the abundance and standard deviation on a coordinate map (in UTM coordinates). I used a 30x30 grid, but this is general in the code.
7. Estimate total abundance by summing all abundances over the grid (multiplied by the area per grid location). Estimate standard deviation for the total abundance. This is somewhat complicated and time consuming. First add all the variances, multiplied by the square of the area of each grid 'cell'. Add to this the spatial covariance between all the grid locations, between the grid locations and the sample locations and between the sample locations. The equations for this part of the calculation are given in Appendix 1. Finally, take the square root of this total to get the standard deviation of the abundance.

Results

Throughout the remainder of this report, and in the Appendices mnemonics are used for the different groups of red king crab. Definitions for these mnemonics are given in Table 1.

Table 1. Definition of mnemonics for king crab surveys. The suffix .num is used for numbers and .lbs for biomass.

Category	Description	Size (carapace length [CL] in mm)
LGM	large (legal) males	≥ 135 mm CL
MTM	mature males	≥ 120 mm CL
MDM	medium males	110 – 134 mm CL
SMM	small males	< 110 mm CL
TLM	total males	all male sizes
LGF	large females	≥ 90 mm CL
SMF	small females	< 90 mm CL
TLF	total females	all female sizes
RKC	all red king crab	all male & female sizes

In addition to the 241 standard trawl locations there were also 21 experimental side-by-side comparative trawl tows, done as an independent comparative experiment in an area chosen because abundance in hauls from the standard survey were high. Intensive trawling was done in this region (Figure 1). This report does not include abundance estimation using the experiment data, but only the standard survey 241 tows.

Figure 1 shows the distribution for mature males. Much of the texture of the other areas is de-emphasized due to the high crab densities in the standard survey area near tow 60. The other size groups show about the same pattern changes.

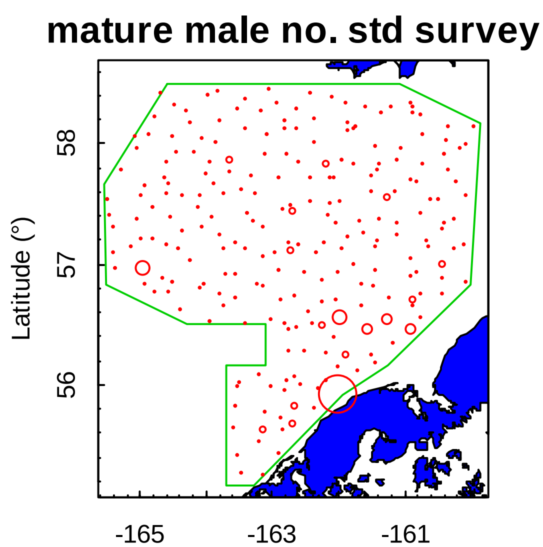
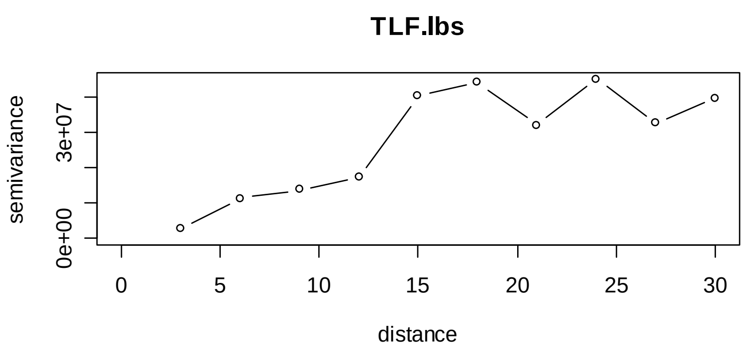
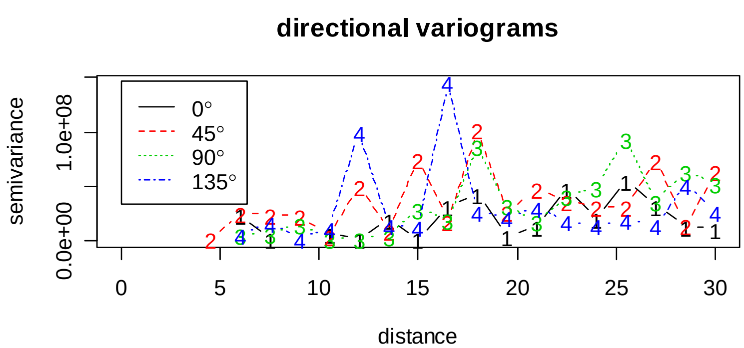


Figure 1. Plot of relative mature male red king crab densities measured during the 2007 BSFRF survey.

Empirical Variograms and Directionality

The analysis to evaluate whether directionality would be an issue was examined for the cooperative survey data. This plot (Figure 2) has distance in kilometers based on units of easting and northing on a Mercator projection (UTM), which was done to produce equal distance in both directions for calculating distances (and areas). The non-directional variograms were fit to an exponential model using maximum likelihood methods. The range of prediction was limited to the defined abundance estimation area. A circular model was also tried and gave a worse fit. There was no evidence for consistent directionality in any of the variograms. Although the directional components are not all identical, there is no consistent variogram pattern with changing angle, suggesting a lack of clear directionality. These variograms are all 'classical' in that they show increasing semi-variance with increasing distance up to a distance where the pattern is more variable but not consistently increasing or decreasing.





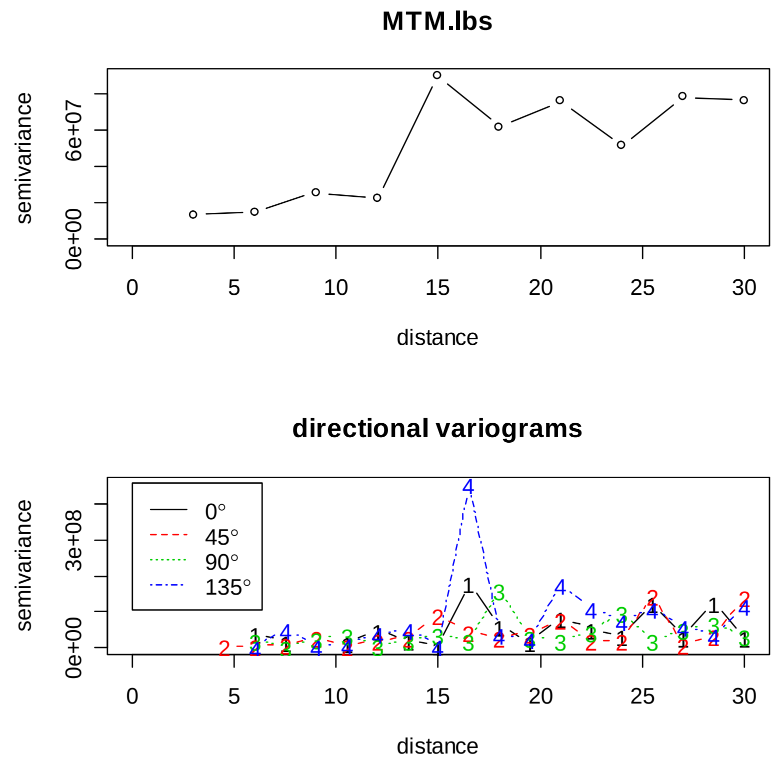
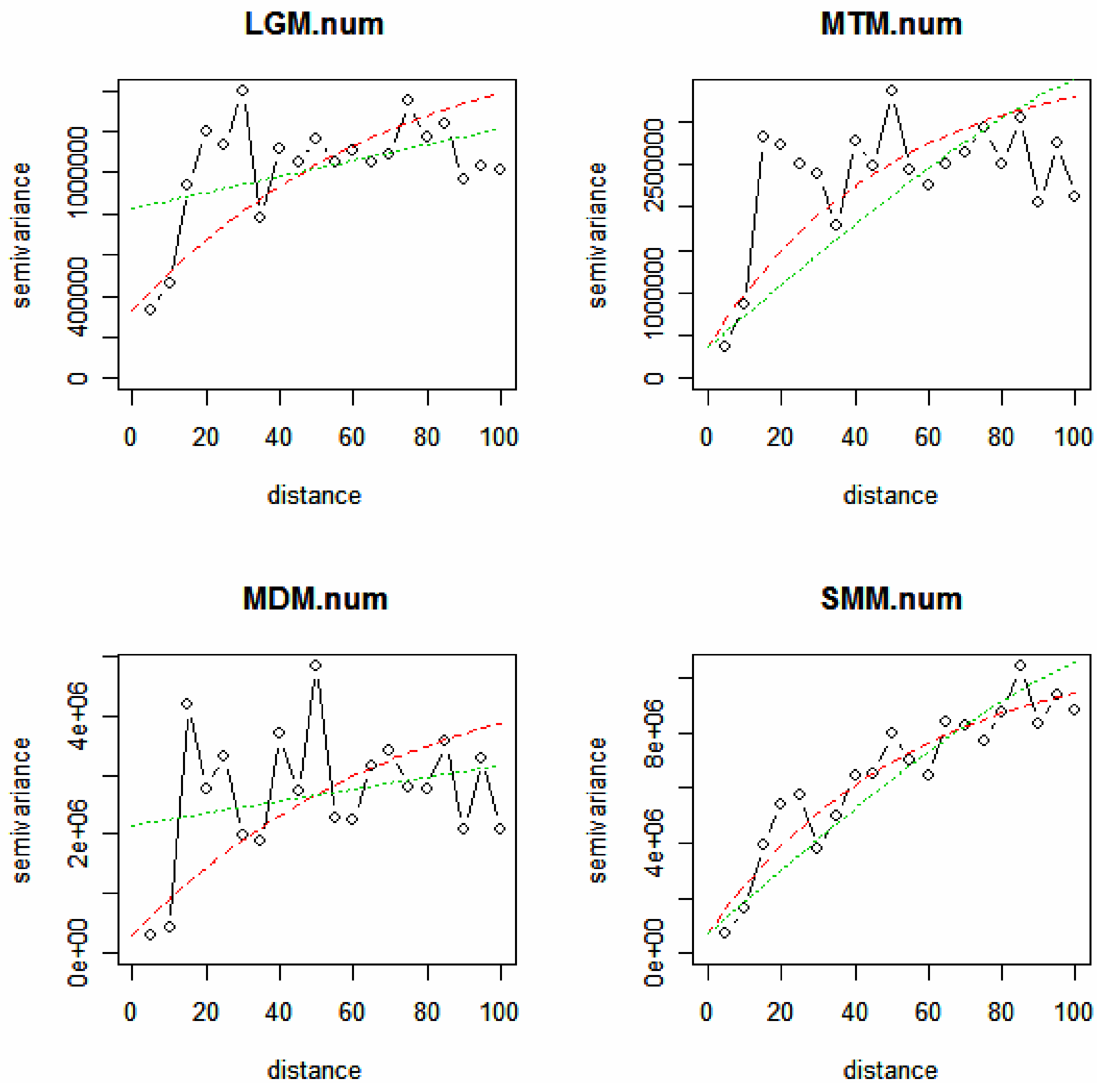


Figure 2. Example non-directional (top panels) and directional (4 directions; bottom panels) variograms for total female and mature male biomass. These are typical of all other sex/size classes.

Variogram Fitting: Comparison of Exponential and Circular Models

I produced variograms for all sex and size classes including numbers and pounds. Variograms were for a maximum distance of 100 km and 21 bins; although both of these can be changed in the program (they are parameters). I fit the variograms, using maximum likelihood (nonlinear least squares) fits to both exponential and circular distributions. The weighting function used was equal weights for each bin. This was done so that the small distance numbers wouldn't get downplayed in the fit (they are comprised of fewer points and would suffer if weighted least squares weighted by the number of points in that bin [points being all distances between pairs of sample locations that are within the distance range of that bin] were used). In all cases the exponential distributions gave more visually appealing fits than the circular distributions. Here are the fits (exponential fit in red, circular in green; Figure 4). Parameter values from these fits are given in Table 2.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SMM.num
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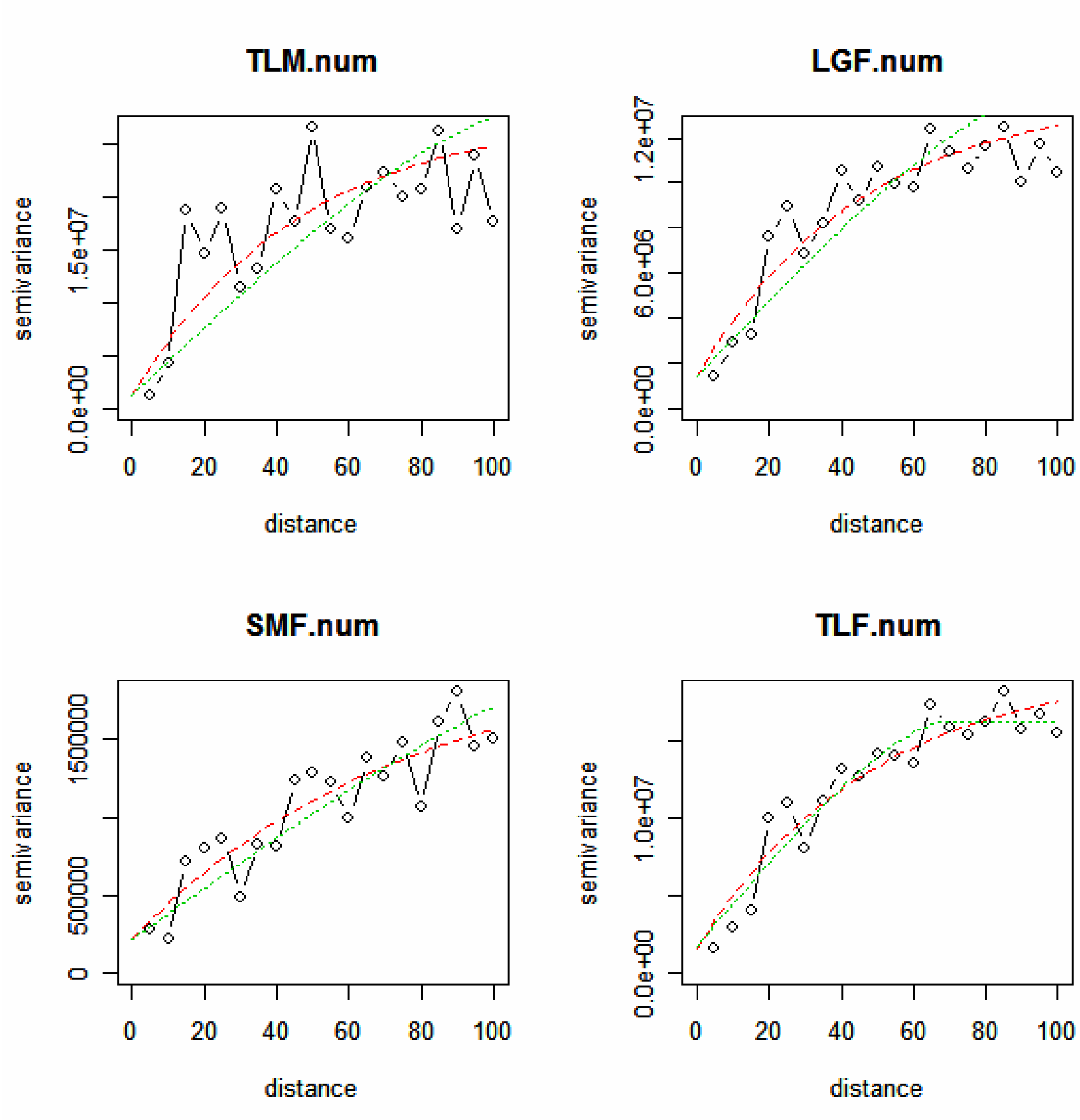
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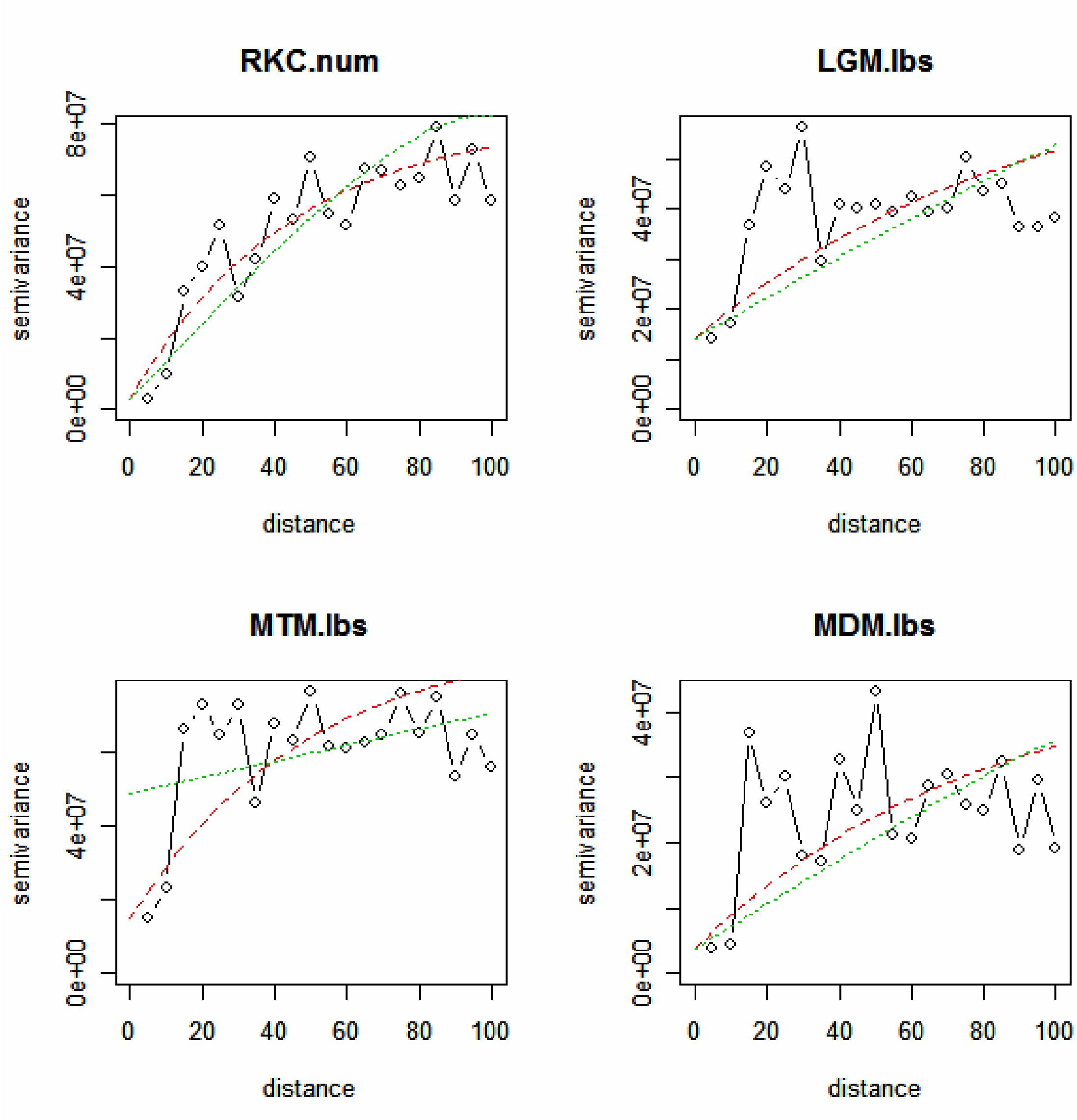
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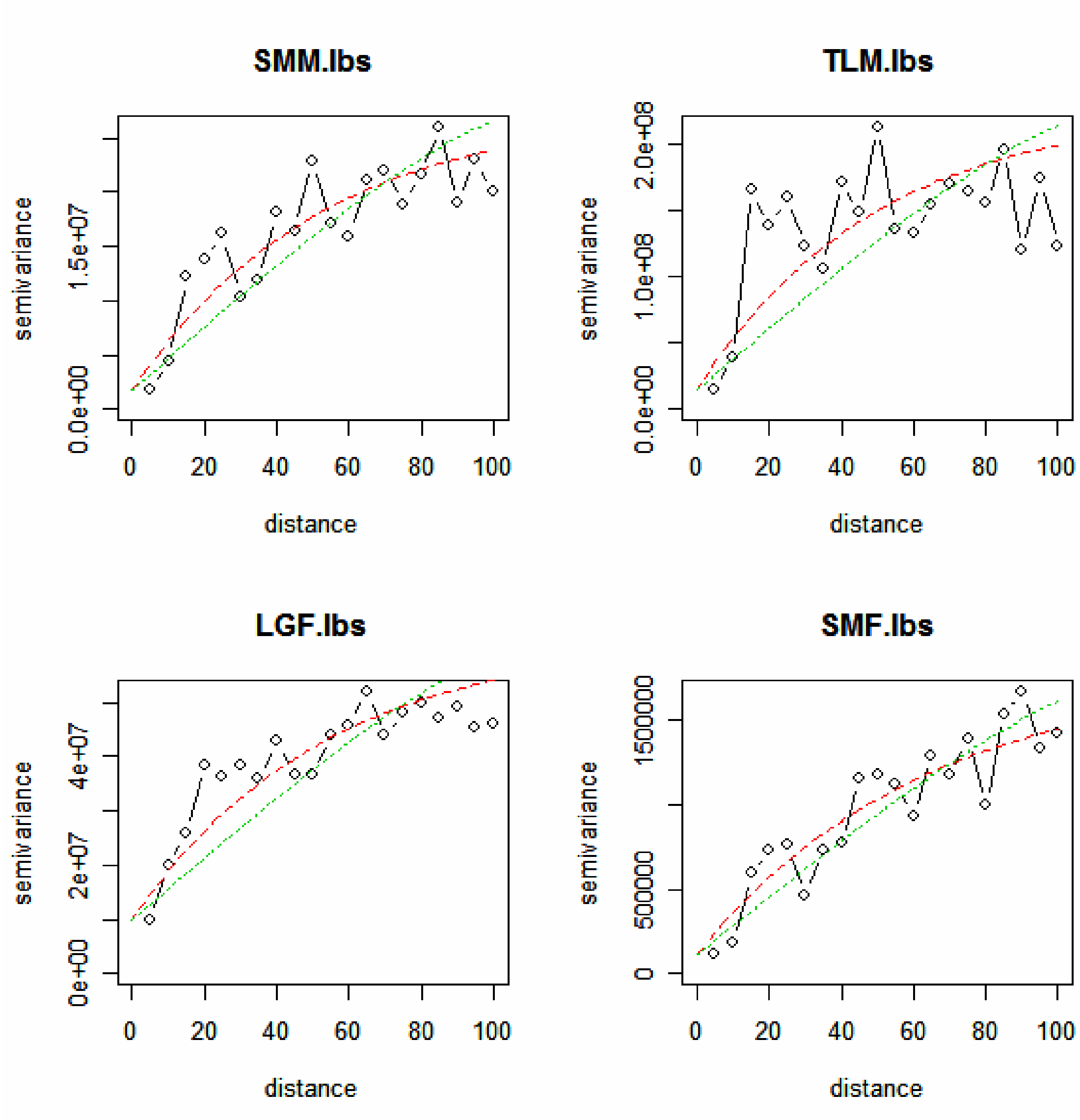
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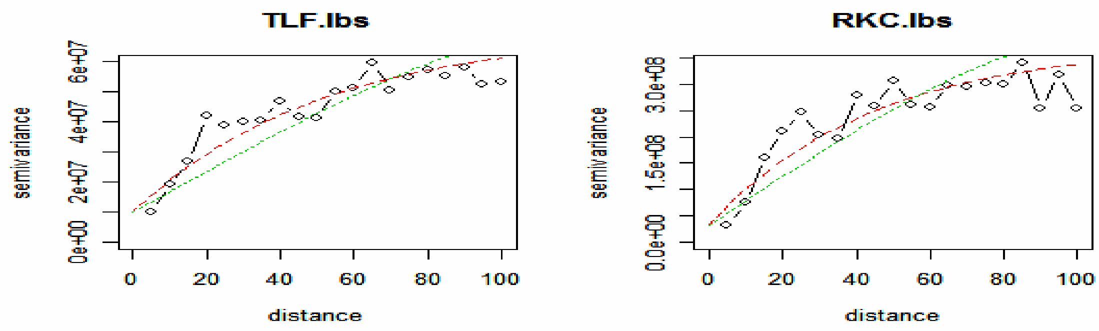


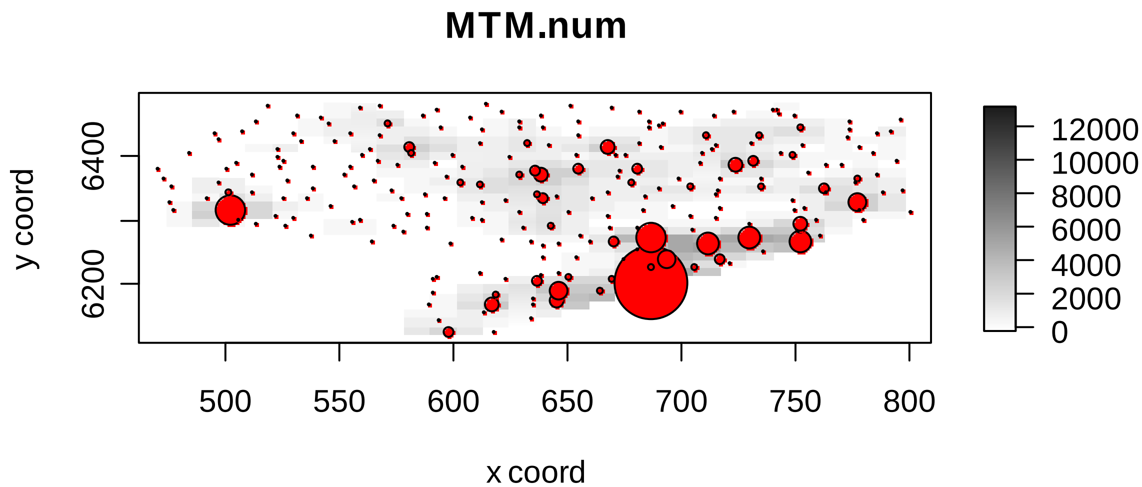
Figure 4. Empirical variograms for all size/sex classes of crab with likelihood fits for an exponential model (red) and circular model (green). In all cases the exponential model gave more appealing overall fits by eye.

Here are the parameter values from the exponential fits:

Variable	NUGGET	SILL	RANGE
LGM.num	177690	1525041	39.0
MTM.num	177691	4269028	47.8
MDM.num	0	6634806	71.8
SMM.num	462127	8835244	40.0
TLM.num	1122740	34587215	63.3
LGF.num	283447	12678616	34.4
SMF.num	126414	1513675	47.6
TLF.num	872258	15933434	35.0
RKC.num	1286317	87319920	49.5
LGM.lbs	13444969	59840776	60.8
MTM.lbs	13444937	99147737	53.5
MDM.lbs	0	57591856	67.0
SMM.lbs	1381819	26965594	52.6
TLM.lbs	10053476	286641434	61.0
LGF.lbs	2439864.6	48324463	24.5
SMF.lbs	69517	1435659	46.1
TLF.lbs	3003419	53130419	25.6
RKC.lbs	22787111	393502817	48.5

Table 2. Parameters for likelihood fit exponential distributions to empirical variograms.

Graphing the abundance and variance estimates



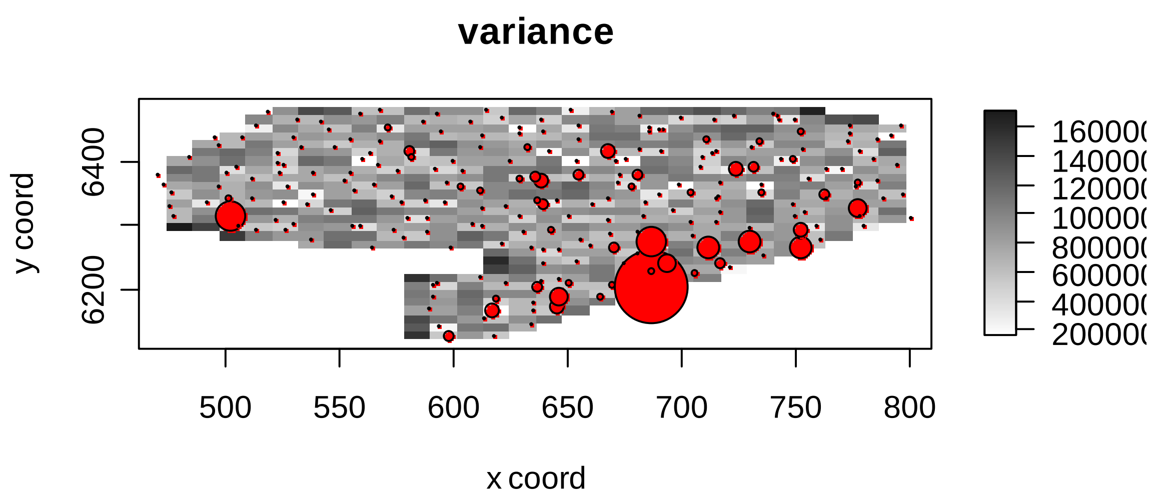


Figure 5. Kriged estimates for mature male crab numbers (upper panel) and variance (lower panel) based on data values (shown by red circles) and an exponential model for the variogram. Kriged estimates for all size classes are shown in Appendix 0.

In examining the fits to the variograms, the least squares (likelihood) fits are clearly the optimal fits over the entire distance range (Figure 4). However, it is conceivable that these fits are 'forced' by the larger distance values and do not fit the lower distance values as well. These might be fit better if the range were made quite a bit smaller. The argument for smaller ranges are the apparent increase in the variogram from fairly low values (i.e. high spatial autocorrelation) up to a distance of about 20 km and then large increases in the variogram (drop off in spatial autocorrelation) at distances larger than this, with generally greater variability in the variogram (though apparently having increasing average variogram levels with increasing distance). Another possibility is that the higher variogram values for larger distances are due to trend and not autocorrelation, though I don't have ancillary variable information to see what the trend might be. This point is well made in the literature by Petitgas (2001) in a review of geostatistical applications in fisheries [Petitgas, P. 2001. Geostatistics in fisheries survey design and stock assessment: models, variances and applications. Fish and Fisheries. 2:231-249].

Trend and autocorrelation are alternative factors that can affect the variogram at larger distances. A possible way of distinguishing the two would be the existence of more accurate data along with the abundance estimates (such as bottom depth or temperature) which could be highly correlated with abundance and could be used as a covariate via cokriging, but these data are not (yet) available for this analysis.

It is possible that fitting by eye can produce more realistic estimates for variance, based on better fits in the small distance range, where empirical variograms are clearly low (Appendix 2). My major concern is that fitting by eye depends a great deal on the individual and, given the implications for abundance estimation (sensitivity analysis recommended), the results should, I think, be subject to some algorithm. As such, I compared the 'best' estimate fits to each of the variograms with fits having parameter values at ½, 2/3 and ¾ of the fitted values for sill and range (in tandem) and either having a 0 nugget or making the same change on the nugget (i.e. 2/3 of the nugget for the 2/3 case). Then, based on eye estimation I chose the best of these for each variable. My criterion was providing the best fit in the low distance range (where the variogram is increasing consistently in almost every case) yet having the variogram at least in the range of values for the higher distances. This omitted fitting very large values (which frequently occurred) for larger distances. This resulted in lower values in all cases for both the range and the sill. I justify this by the (I think) dramatically improved fits in the lower distance range. These plots are shown in Appendix 2.

The by-eye parameter values were either half, 2/3 or ¾ of the parameter estimates in Table 2. The values chosen for each group were:

LGM.num	MTM.num	MDM.num	SMM.num	TLM.num	LGF.num	SMF.num
0.67	0.67	0.50	0.67	0.67	0.75	0.67
TLF.num	RKC.num	LGM.lbs	MTM.lbs	MDM.lbs	SMM.lbs	TLM.lbs
0.75	0.50	0.67	0.67	0.50	0.67	0.50
LGF.lbs	SMF.lbs	TLF.lbs	RKC.lbs			
0.75	0.67	0.75	0.67			

For the nugget, only 3 groups appeared to have a non-zero nugget and these all had the nugget at 2/3 of the estimated nugget. These groups were large male numbers, large male biomass and mature male biomass.

The estimates for abundance (the same as earlier) and standard deviation of abundance for the fit-by-eye variograms are:

Abundance estimation

Table 3. Best estimates for total abundance, standard deviations and 95% confidence limits generated from kriging using the likelihood estimated variogram model (fit) and the constrained by eye estimation.

Total Abundance:

LGM.num	MTM.num	MDM.num	SMM.num	TLM.num	LGF.num	SMF.num
14968954	22317833	13807874	24590907	53373495	43815690	6003414 fit
14991155	22331277	13856222	24564888	53296245	43943148	6013999 eye

TLF.num	RKC.num	LGM.lbs	MTM.lbs	MDM.lbs	SMM.lbs	TLM.lbs
49802915	103054970	89144667	115588766	42571069	37204788	169442494 fit
49961517 eye	103495284	89333304	115749540	42719757	37073457	169536203

LGF.lbs	SMF.lbs	TLF.lbs	RKC.lbs
100012568	5718392	105714006	274839335 fit
100368588	5745238	106099474	275113680 eye

Standard Deviations:

LGM.num	MTM.num	MDM.num	SMM.num	TLM.num	LGF.num	SMF.num
1039410	1513257	1500723	2356595	3810644	2912068	941052 fit
973349	1387086	1428558	2134706	3525855	2743836	827672 eye

TLF.num	RKC.num	LGM.lbs	MTM.lbs	MDM.lbs	SMM.lbs	TLM.lbs
3333499	6540048	6169544	7666232	4559283	3705312	11174331 fit
3054855	5964775	5627581	7141752	4324598	3358440	10006265 eye

LGF.lbs	SMF.lbs	TLF.lbs	RKC.lbs
6607722	896811	6842996	14695628 likelihood fit
5989606	816177	6197210	13241486 by eye (corrected)

95% Confidence Interval as percentage of total abundance:

LGM.num	MTM.num	MDM.num	SMM.num	TLM.num	LGF.num	SMF.num
13.9	13.6	21.7	19.2	14.3	13.3	31.4 fit
13.0	12.4	20.6	17.4	13.2	12.5	27.5 eye

TLF.num	RKC.num	LGM.lbs	MTM.lbs	MDM.lbs	SMM.lbs	TLM.lbs
13.4	12.7	13.8	13.3	21.	19.9	13.2 fit
12.2	11.5	12.6	12.3	20.2	18.1	11.8 eye

LGF.lbs	SMF.lbs	TLF.lbs	RKC.lbs
13.2	31.4	12.9	10.7 likelihood fit
11.9	28.5	11.7	9.6 by eye

My best estimate standard deviations are those based on the fits by eye, as supported by the graphs in Appendix 2. However, the likelihood algorithm is arguably the least dependent on possible human error. Apparently, there is little change in the variance (standard deviation) estimates due to differences in the variograms (within the constraints used in this work). As such, I recommend that future analysis use only the likelihood estimated parameters for the variograms, because they offer a more repeatable estimation procedure.

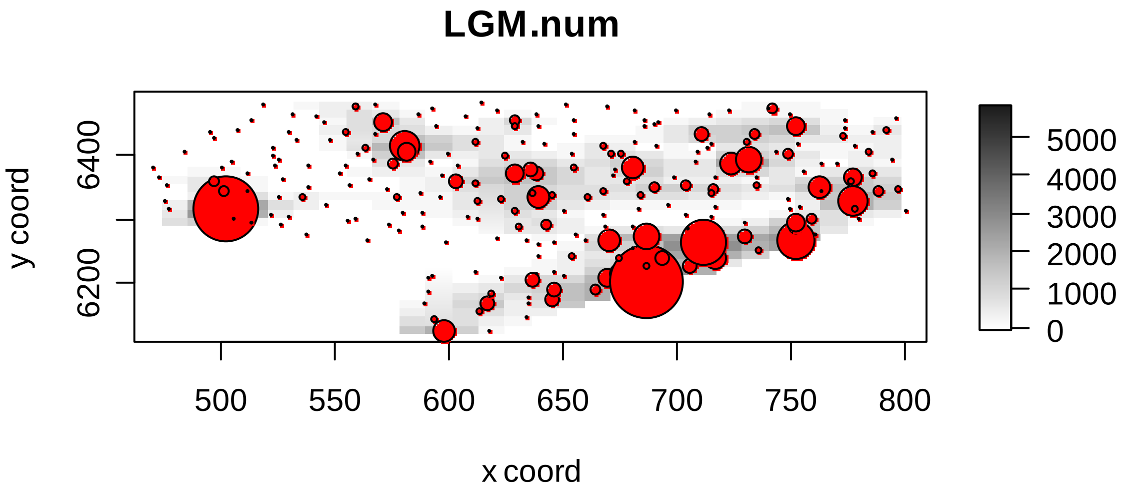
Recommendation for survey design.

The survey design had the advantage of having distances between the survey points at a variety of distances (rather than a limited set of distances that would result in regular grid sampling protocols). However, there were considerably fewer points at small distances. It seems important to examine, as much as possible covariates that might influence the patchiness seen at high abundance, such as abrupt changes in bottom type or depth. I recommend bottom surveying for bottom type along with the crab survey. There are acoustic systems (multibeam systems) that quite effectively characterize bottom types acoustically.

Overall Recommendations:

1. The best estimate overall variances are based on the eye-fitted exponential parameters, starting with and in comparison to the likelihood estimated parameter fits to the empirical variograms. However, given the similarity in variances between the likelihood and by eye fitted variograms I suggest using the likelihood estimates directly in the variance estimation.
2. Ancillary data should be explored to look for possibilities for trends in the data and to possibly explain the patchiness in high abundance areas.
3. If small-distance patchiness is a regular feature of crab distributions another survey method such as strong stratification (with some covariate) and possibly adaptive sampling (with a HIGH threshold to prevent non-completion of the survey) is appropriate.
4. Software to conduct future stock assessments using kriging has been provided and can be used directly (after training). However, I suggest some checking with an experienced practitioner to validate results and procedures. . Also, I suggest a sensitivity analysis of the effect of several model assumptions and parameter values on the abundance and variance prediction. These include the maximum distance used for the variogram, the number of bins for the variogram, the grid size for estimation, the use of exponential versus a circular model for the variogram likelihood estimation, and the initial guesses for the sill, nugget and range for the variogram. Also, in fitting the variogram I used equal weighting for all bins, independent of the number of observations in each bin. Alternatives, to be considered for the sensitivity analysis include weighting by the number of observations in each bin or inversely by the standard deviation for observations in each bin.

Appendix 0. KRIG PLOTS for all sex / size categories of crab, showing abundance and variance estimated on a grid over the study region in the Eastern Bering Sea.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x coord
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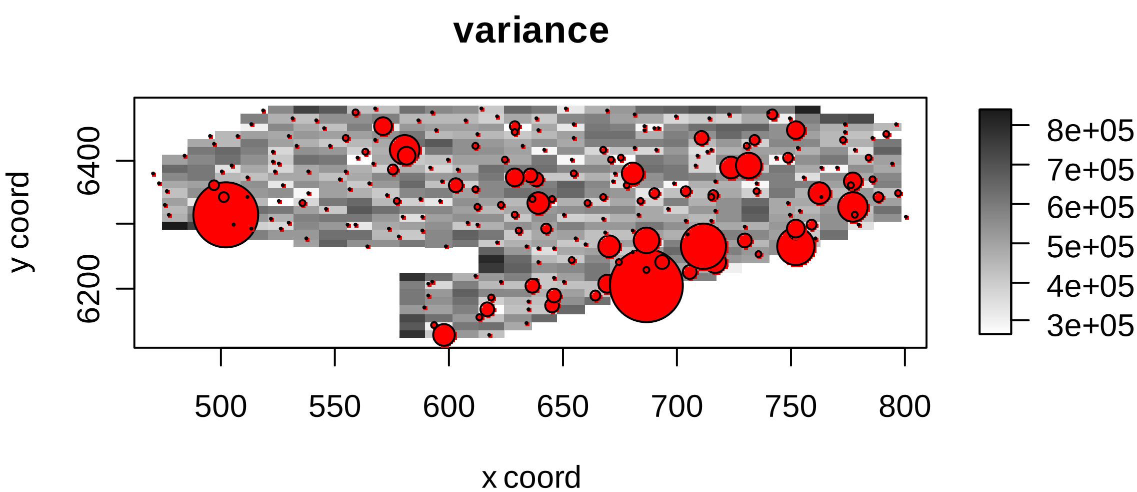
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700
750
800
x coord
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4e+05
5e+05
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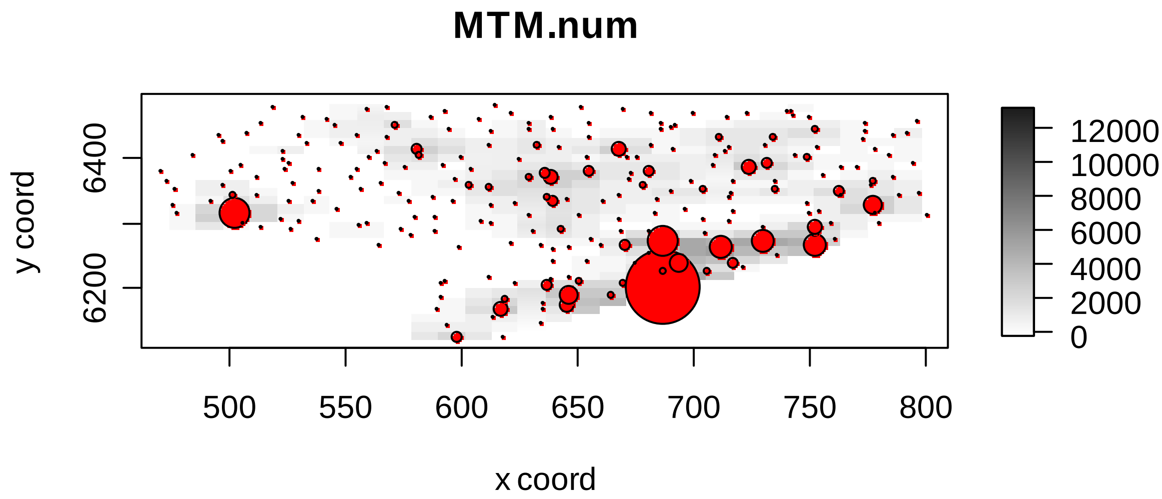
7e+05
8e+05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6000
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2000
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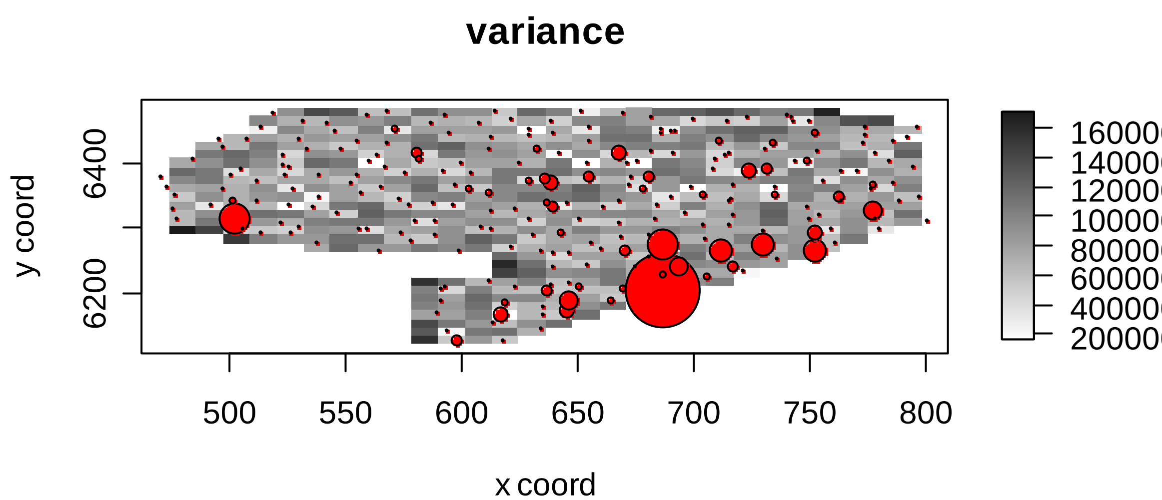
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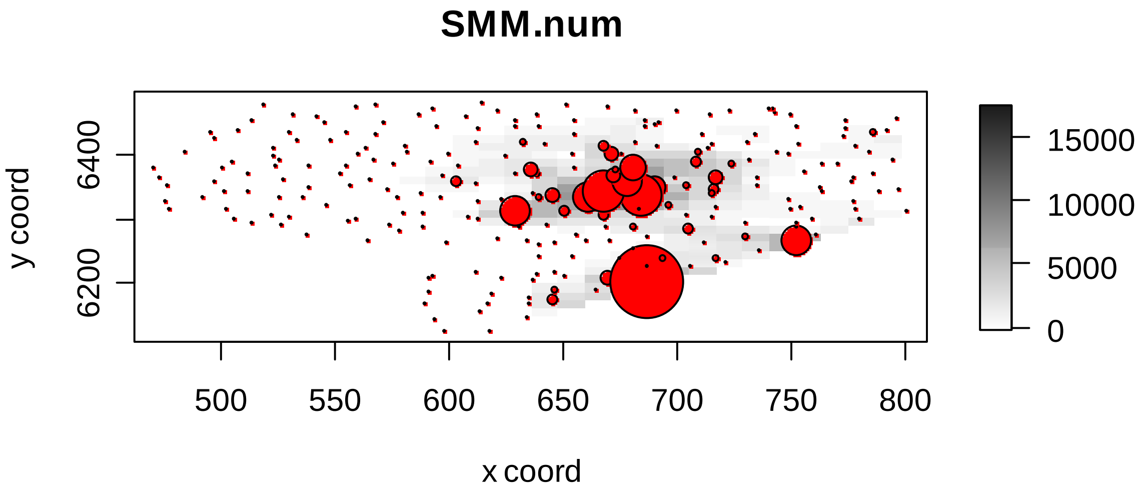
700
750
800
x coord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x coord
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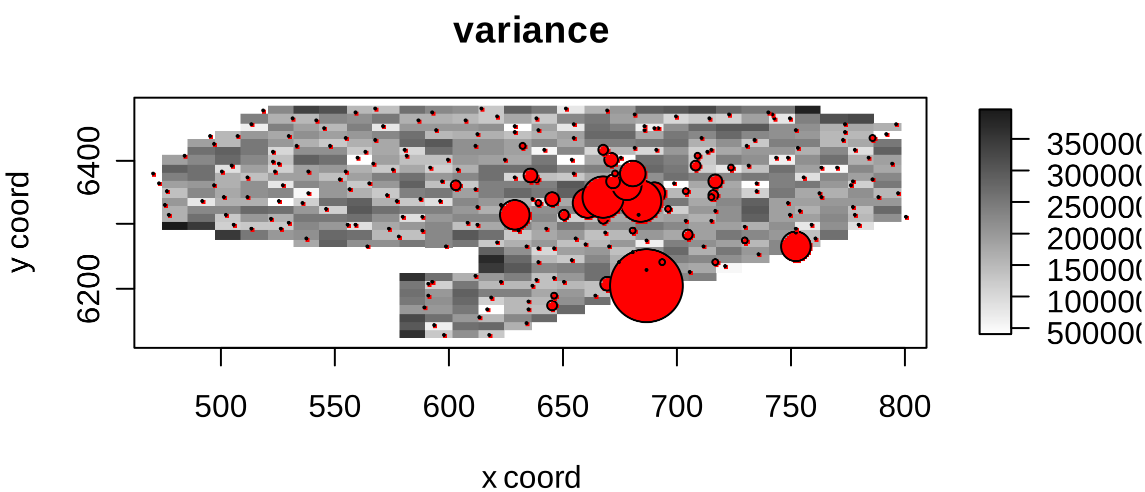
10000
15000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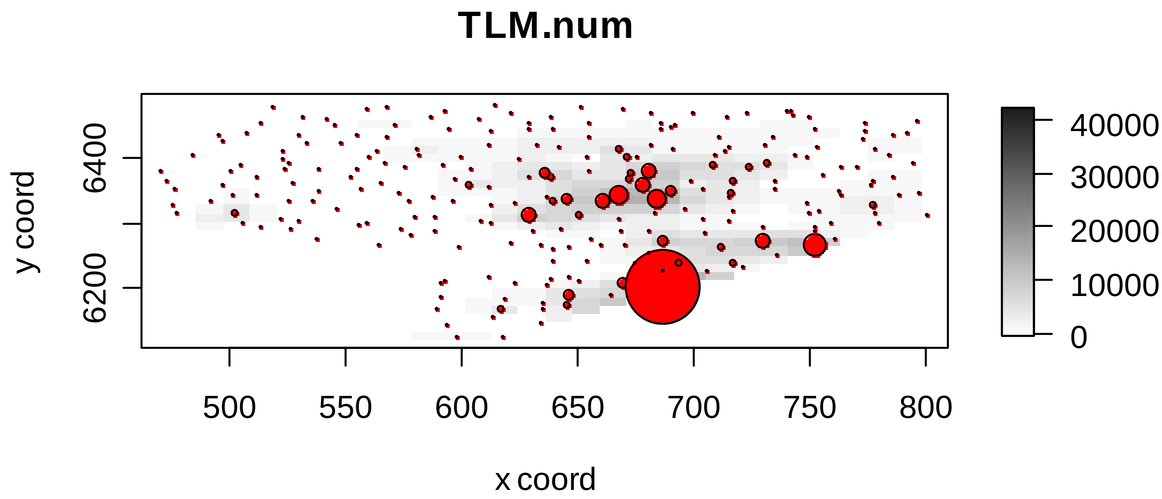
300000
350000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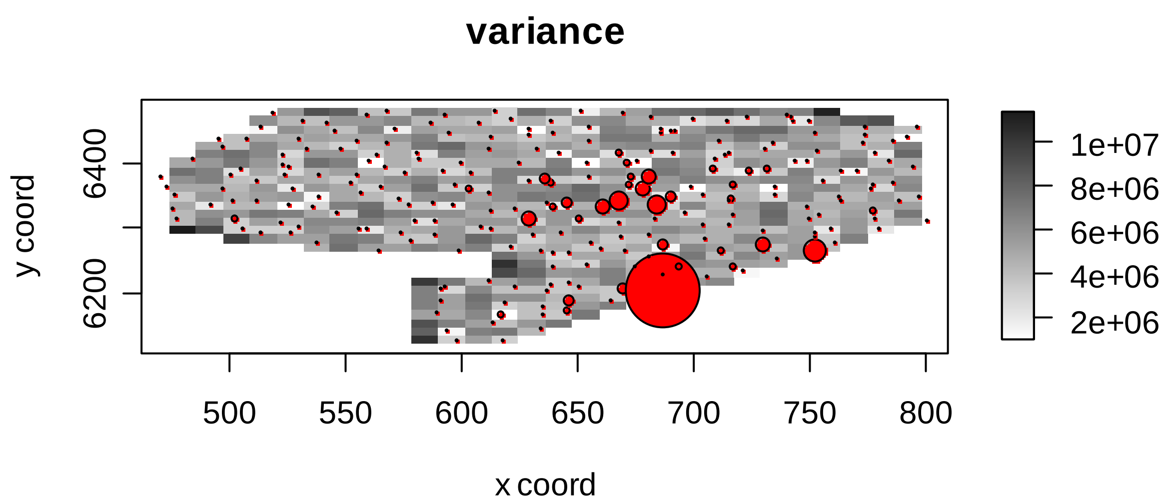
30000
40000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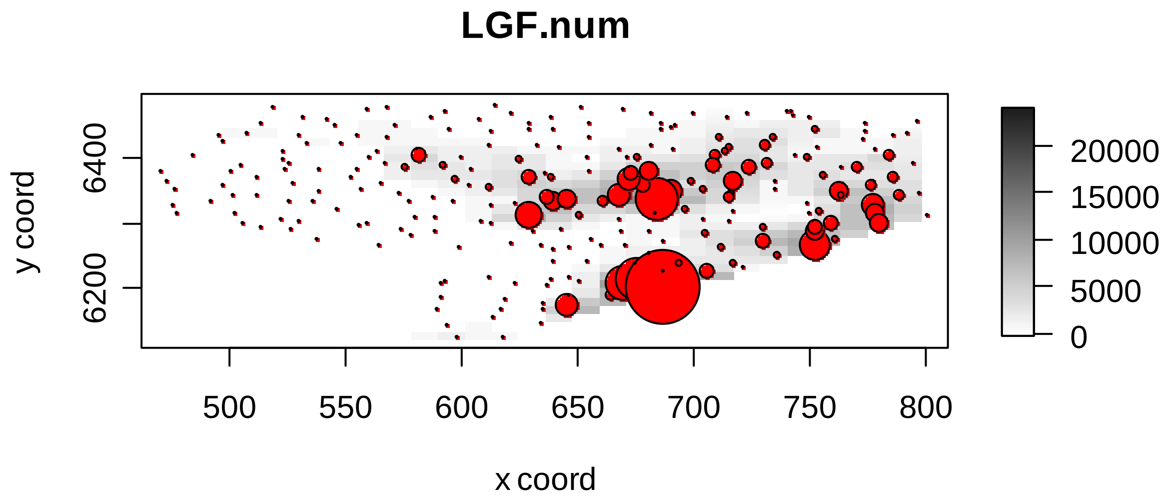
1e+07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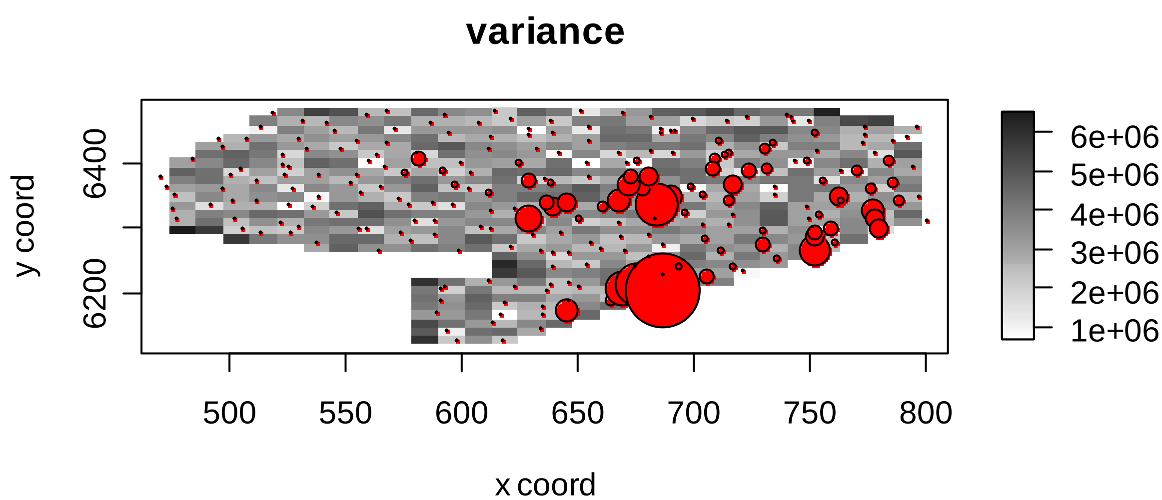
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700
750
800
x coord
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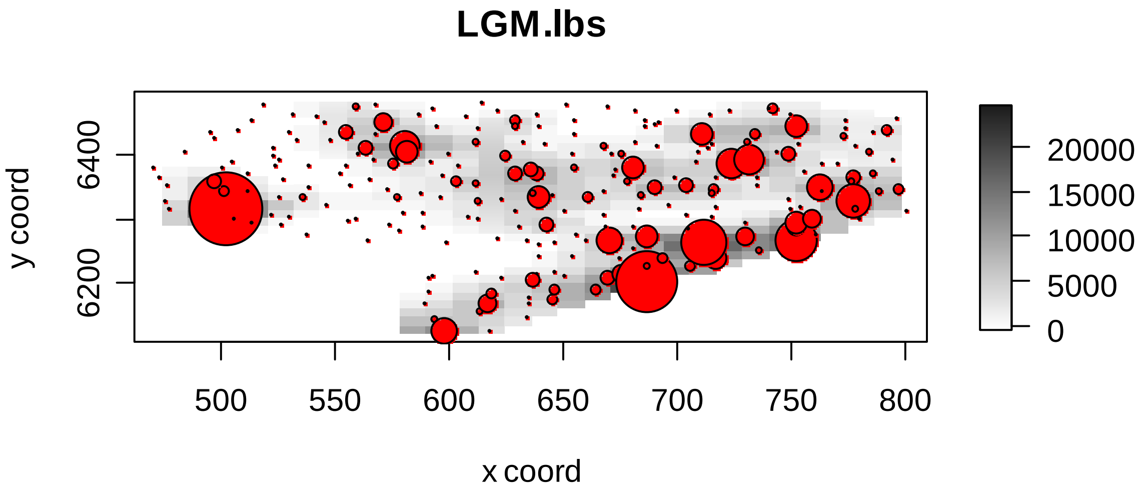
2e+06
1e+06



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x coord
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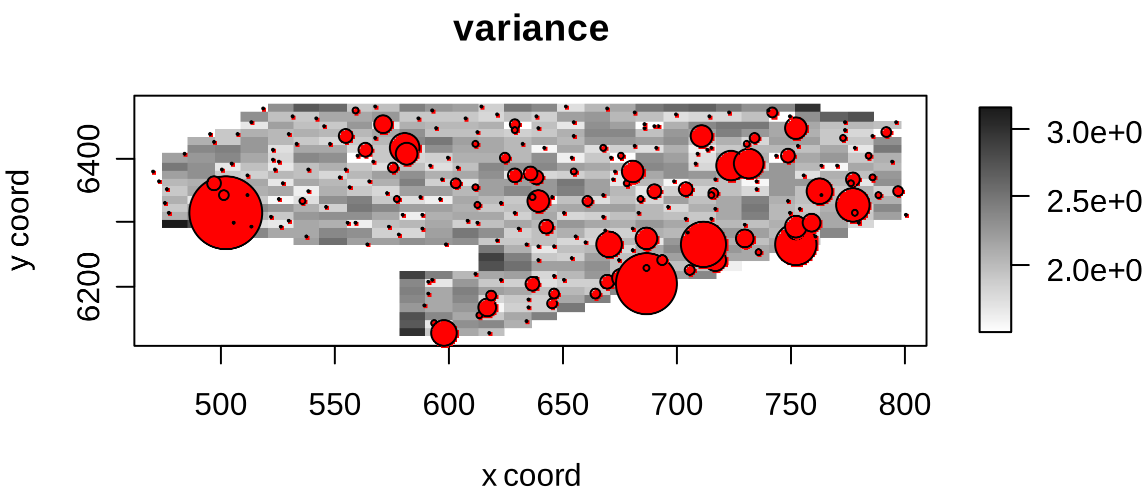
10000
15000
20000



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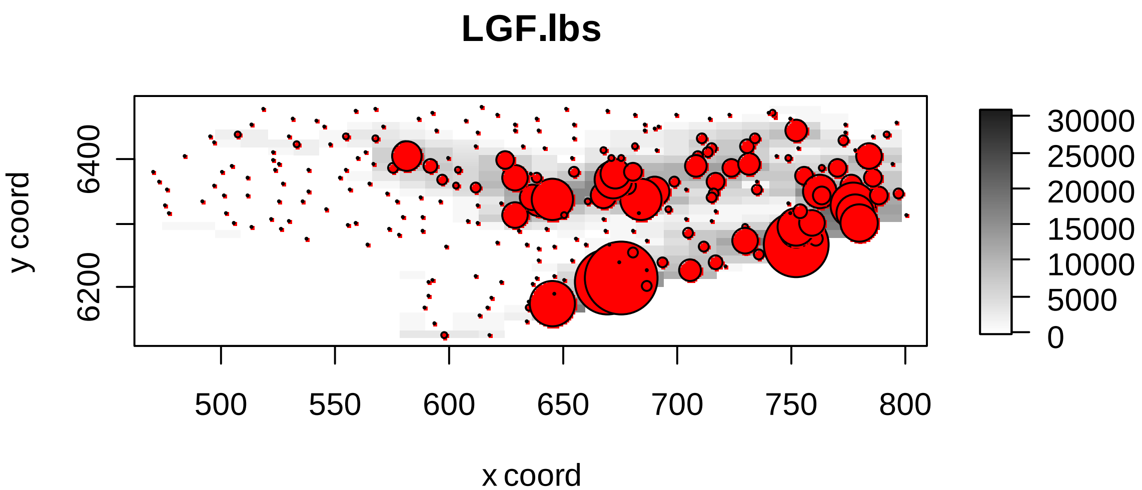
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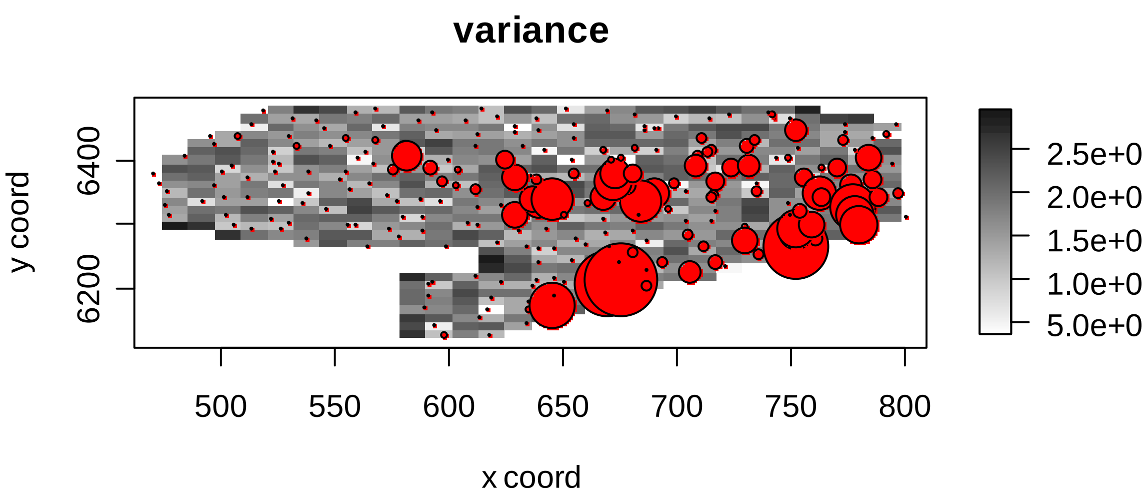
5000
0


variance
y coord
6200
6400
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550
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650
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750
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x coord
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2.0e+0
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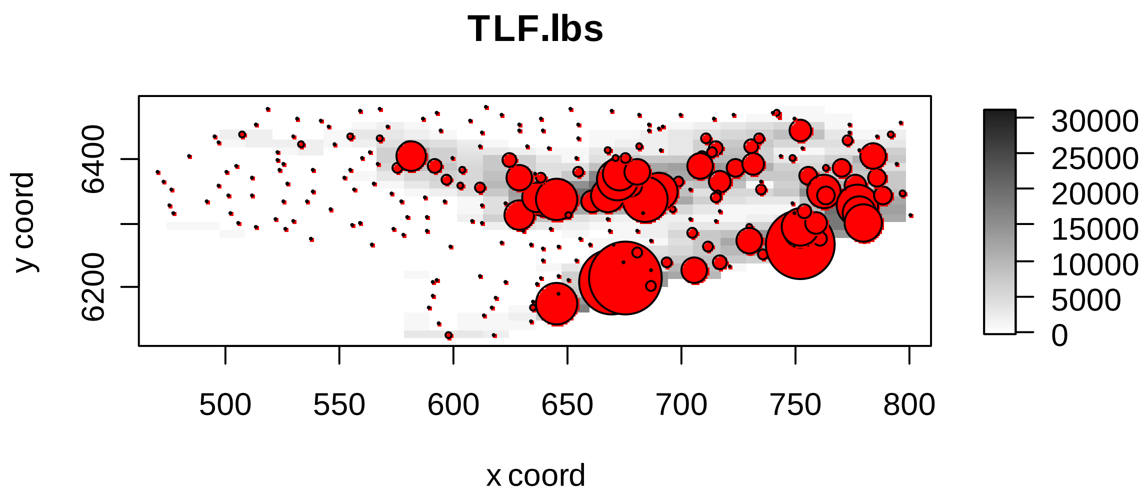
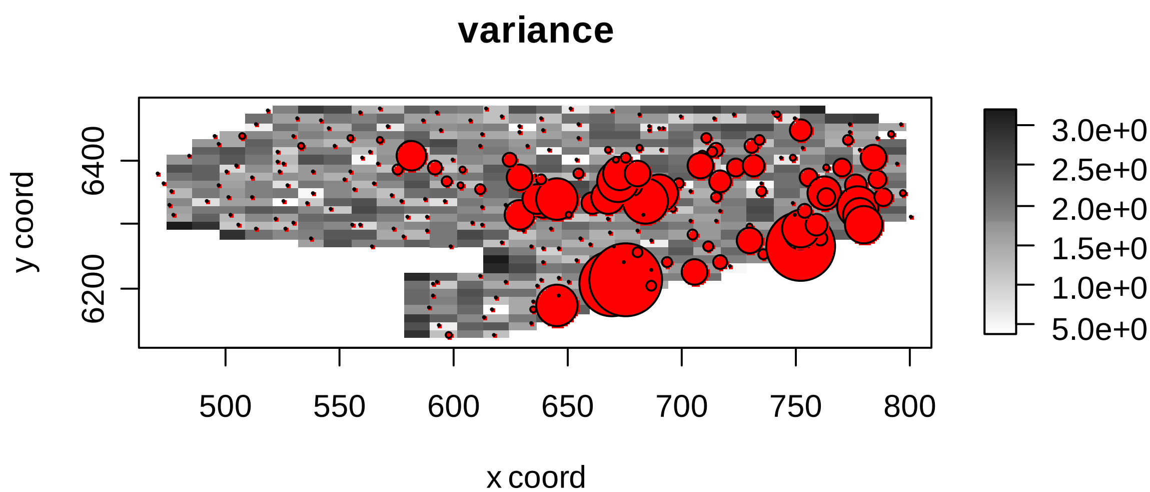
1.0e+0
5.0e+0





Appendix 1. Equations for variance estimation for overall crab abundance

We estimated abundance of crab from geostatistics by multiplying the mean density of crab (• km^{-2}) in a grid cell by the area of each grid cell and then summing over all grid cells in each lake area.

Global variance estimates were also made for each dataset. These estimates were calculated as:

$$V(\hat{W}_{Total}) = \sum_{m} V(\hat{W}(x_m)) + 2\sum_{n,m} C(\hat{W}(x_m), \hat{W}(x_n))$$

Where:

$V(\hat{W}(x_m))$ is the variance associated with each prediction at location x_m as calculated by the universal kriging procedure, and

$C(\hat{W}(x_m), \hat{W}(x_n))$ is the covariance between predictions at locations x_m and x_n and is calculated as:

$$C(\hat{W}(x_m), \hat{W}(x_n)) = \sigma^2(x_m, x_n) - \lambda_m k(x_n) - \lambda_n k(x_m) + \lambda_{m_i} K \lambda_{n_j}$$

where:

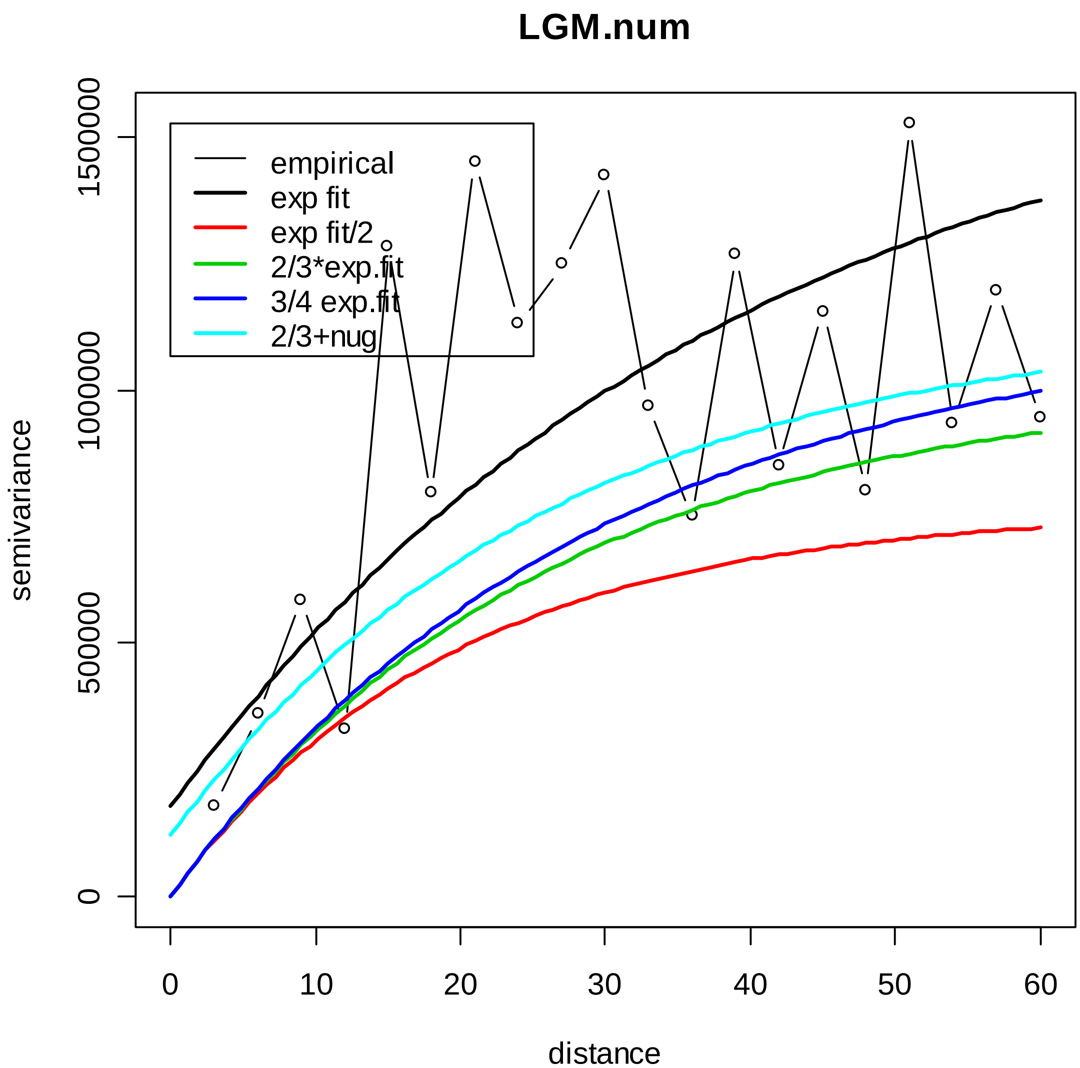
σ^2 is the estimation variation,

λ is the vector of weights used in the predictions,

K is the spatial covariance between observation locations, and

k is the spatial covariance between observation locations and the prediction location

Appendix 2. Comparison of variograms with 'likelihood fits' and different fractions of these parameters. The labels on the different plots are empirical for the empirical variogram, exp.fit for the likelihood fits (automatic), and exp fit/2, 2/3 exp fit and ¾ exp fit for curves having parameter values for sill and range (in tandem) being that fraction of the likelihood estimated parameter values with nugget effect set to 0. The 2/3 + nug case is the same as the 2/3 exp fit case except the nugget effect is set to 2/3 of the likelihood fit nugget value.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exp fit
exp fit/2
2/3*exp.fit
3/4 exp.fit
2/3+nug
semivariance
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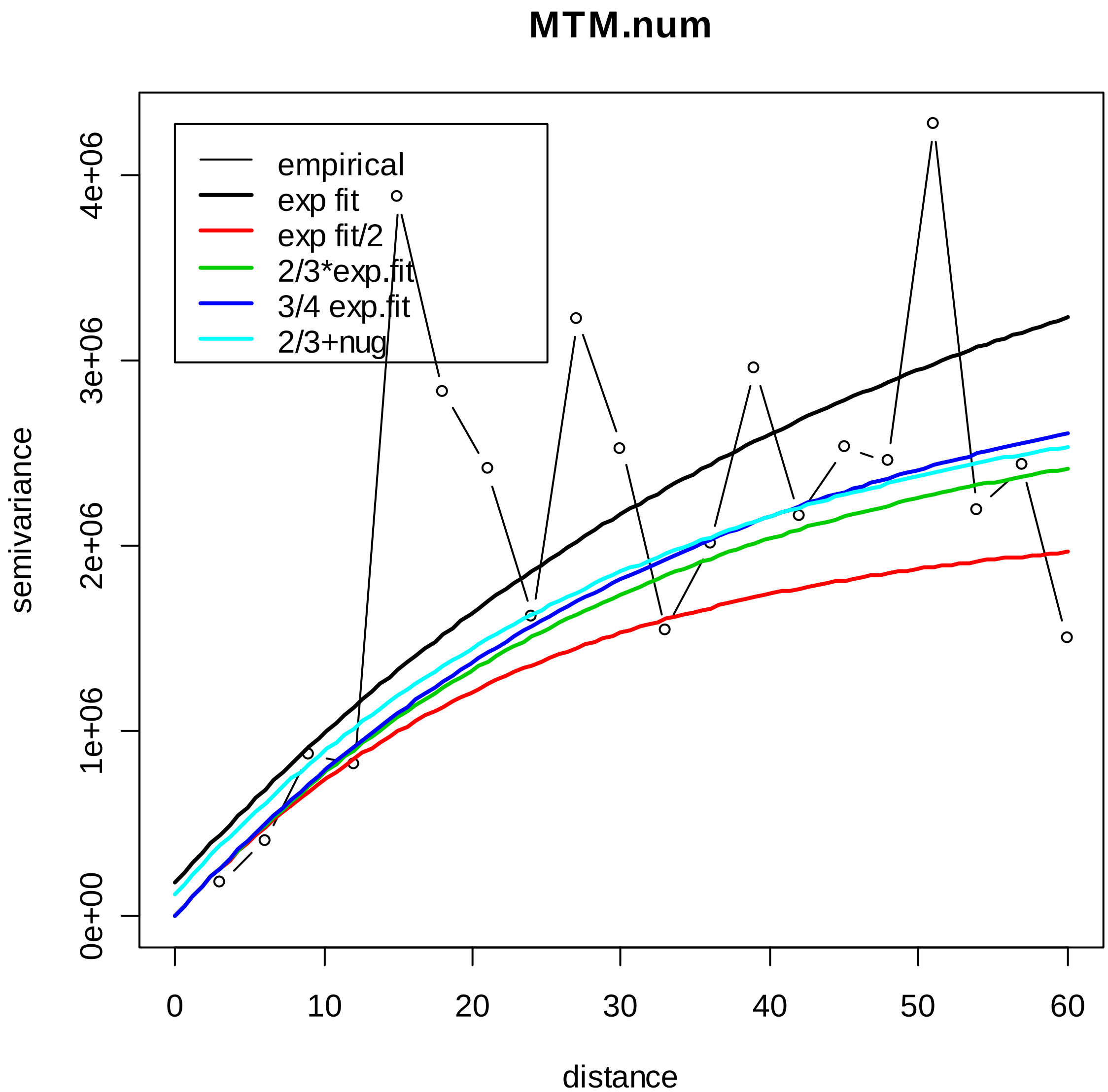
1000000
1500000
0
10
20
30
40
50
60
distance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exp fit
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3/4 exp.fit
2/3+nug
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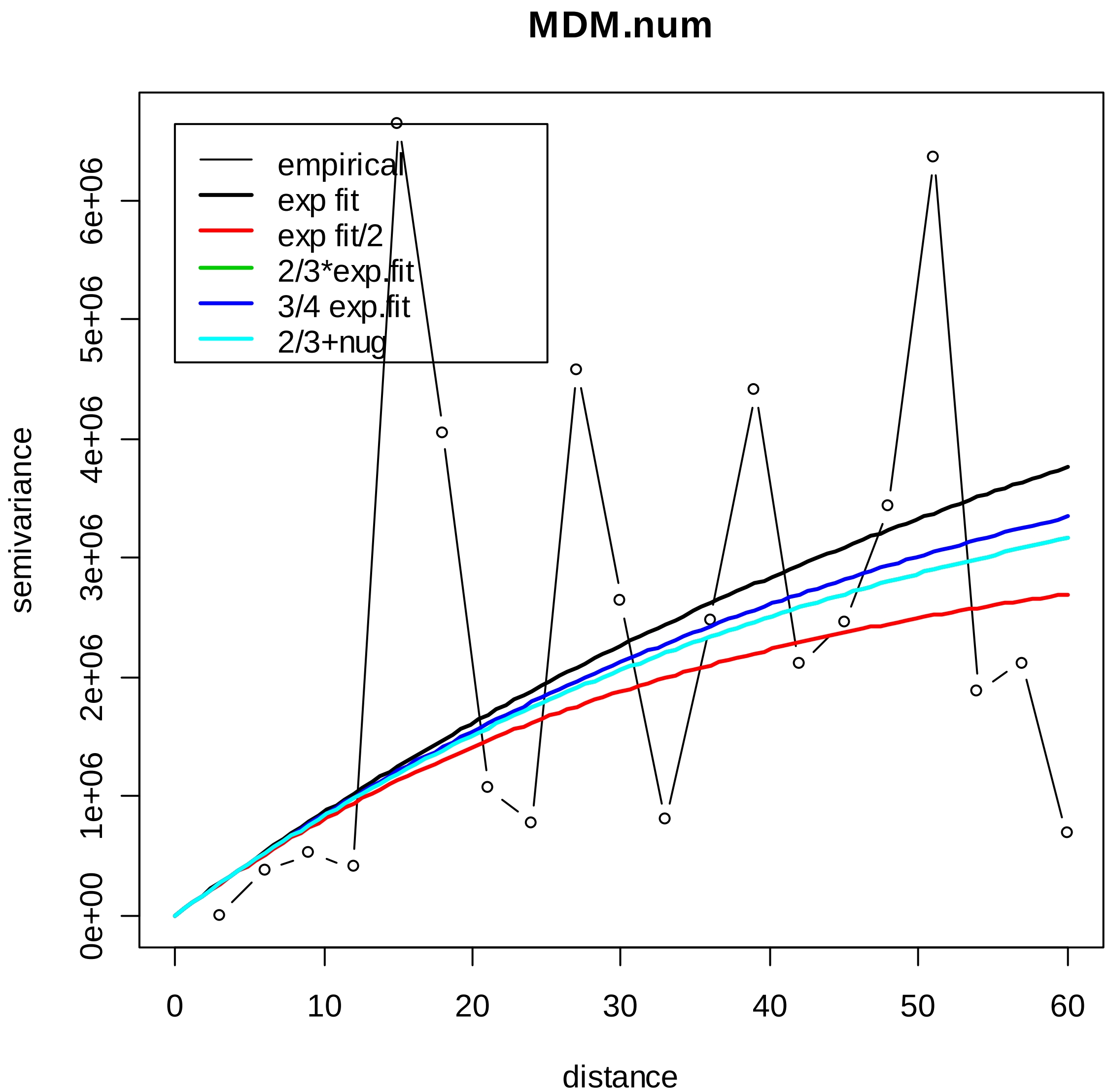
distance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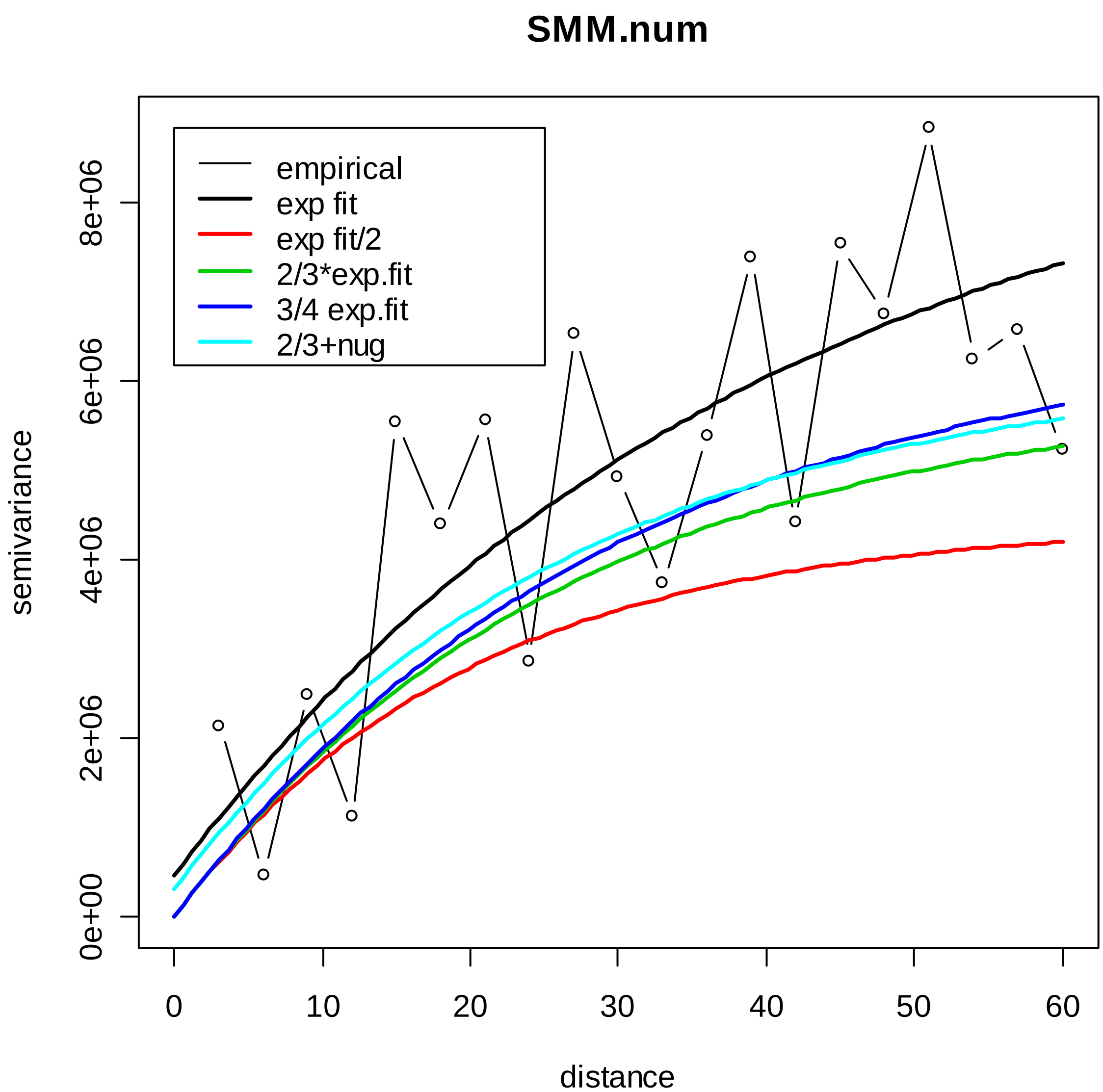
distance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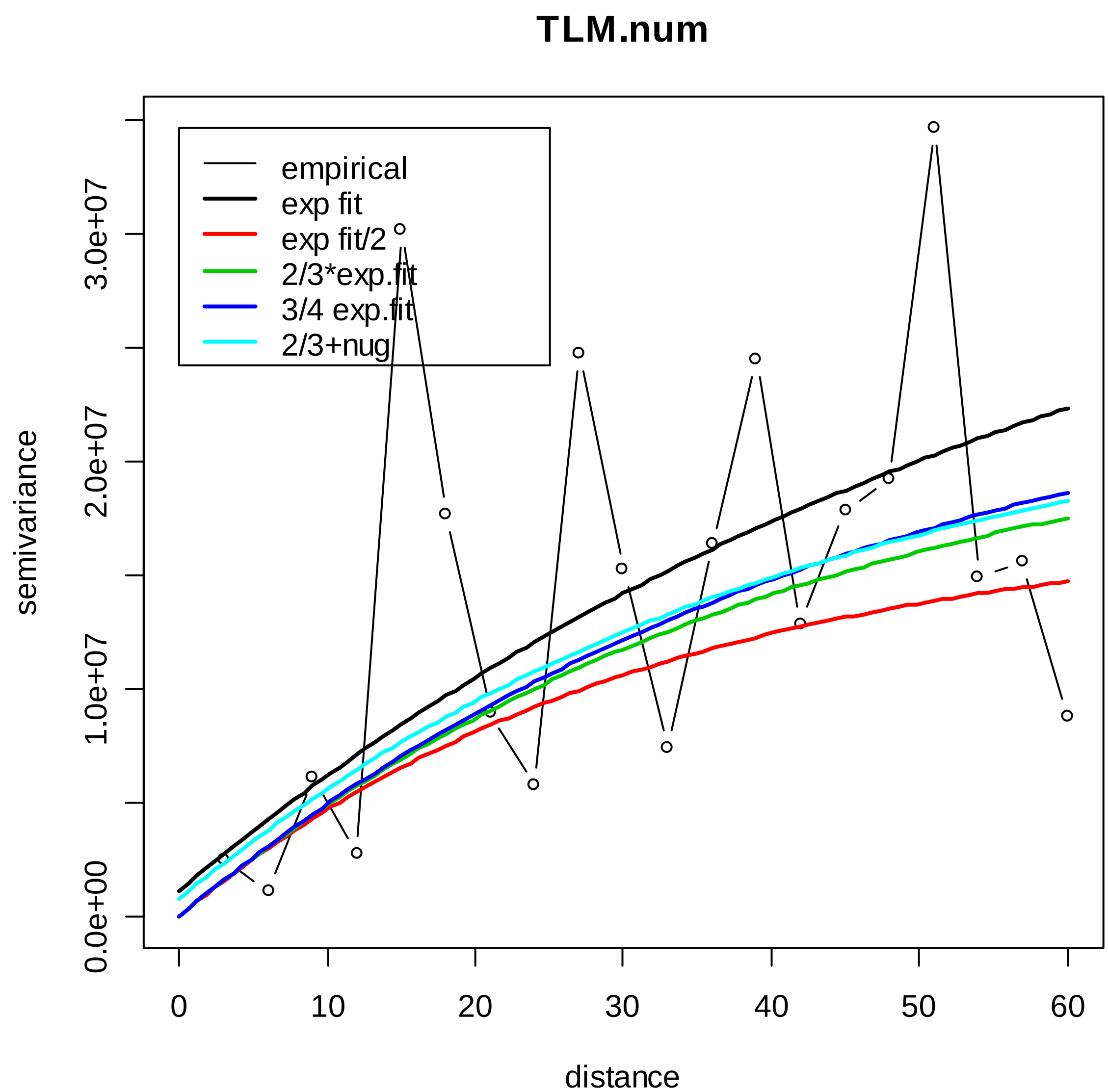

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2/3+nug
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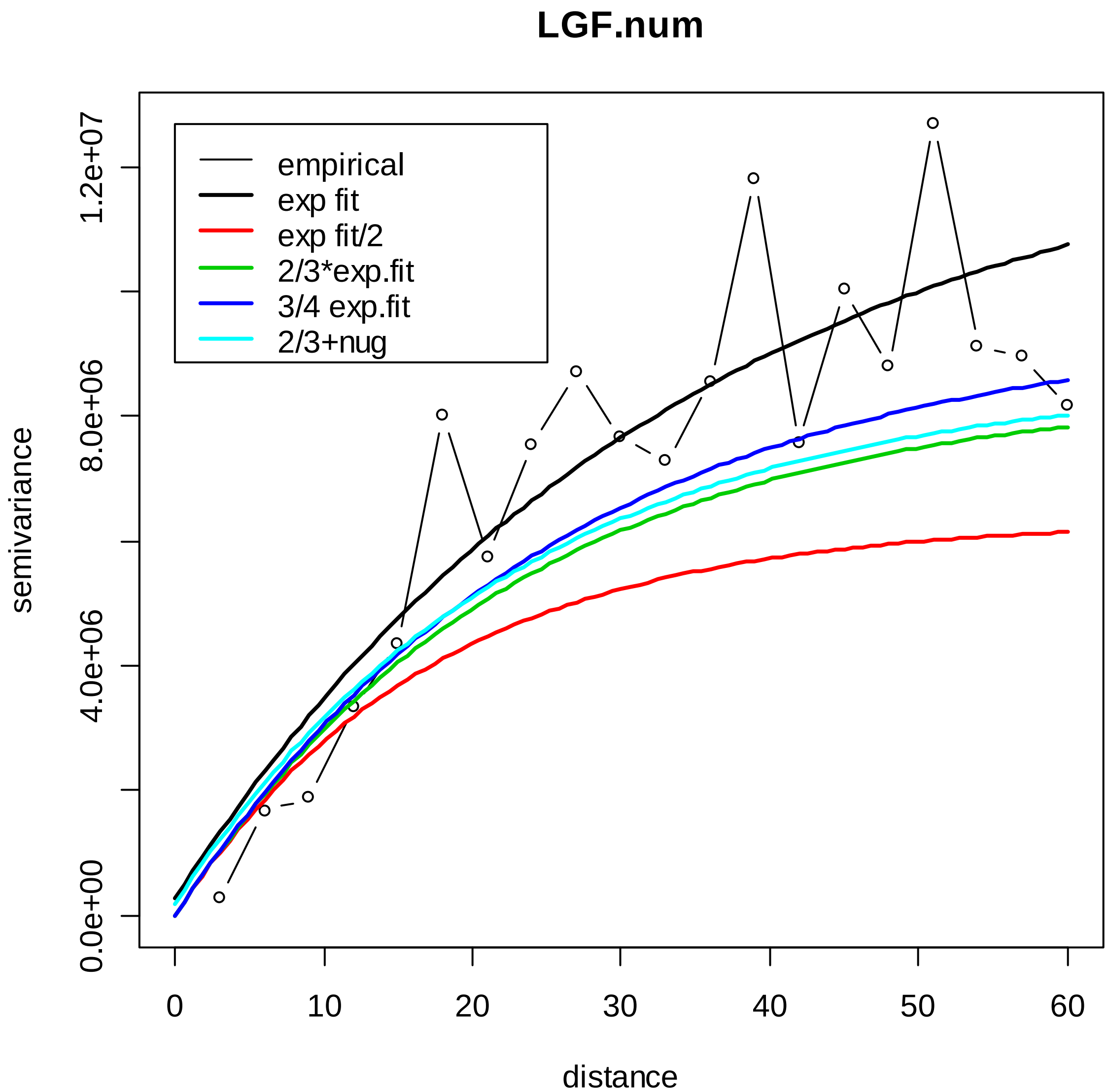
60
distance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50
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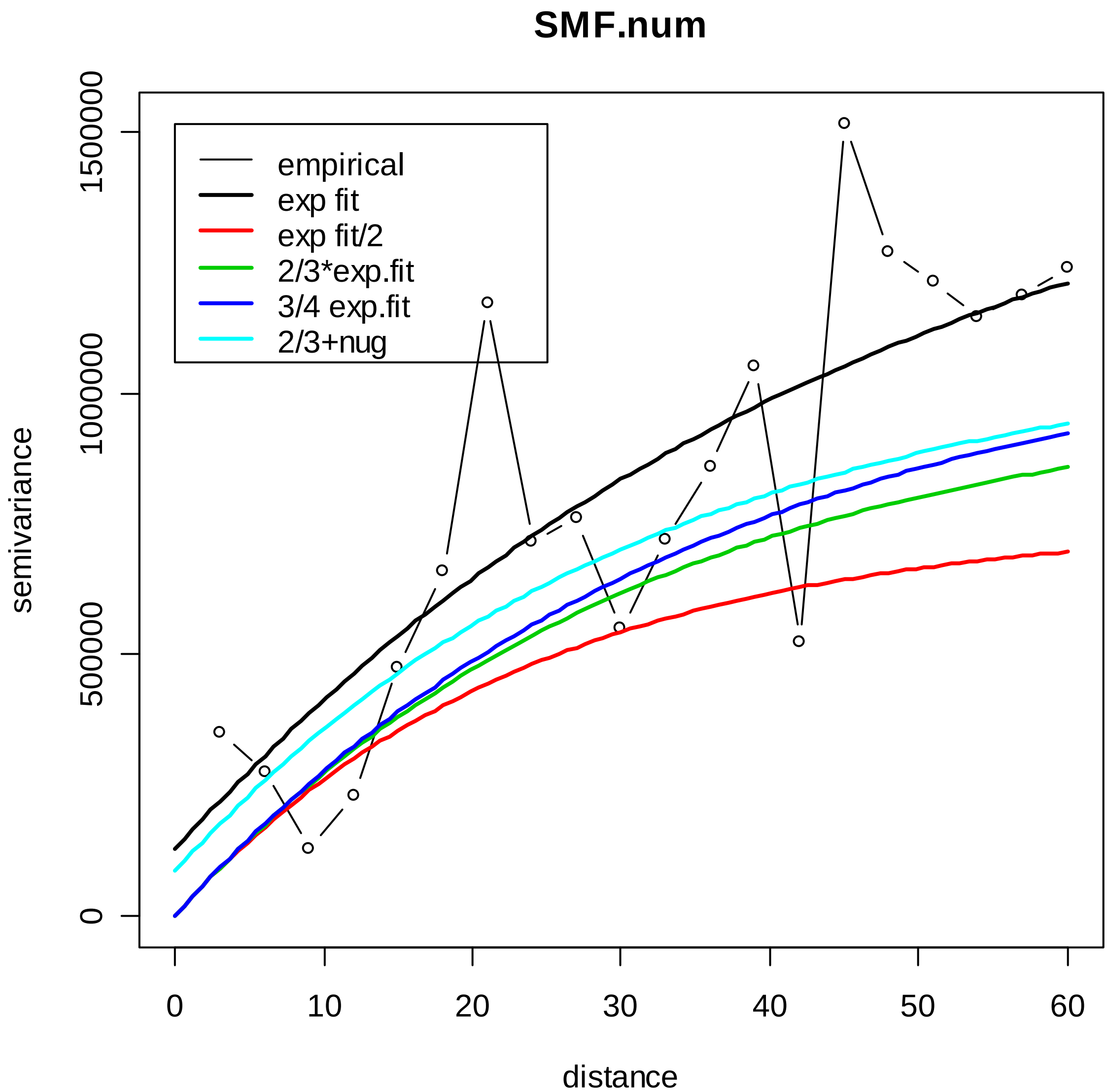
distance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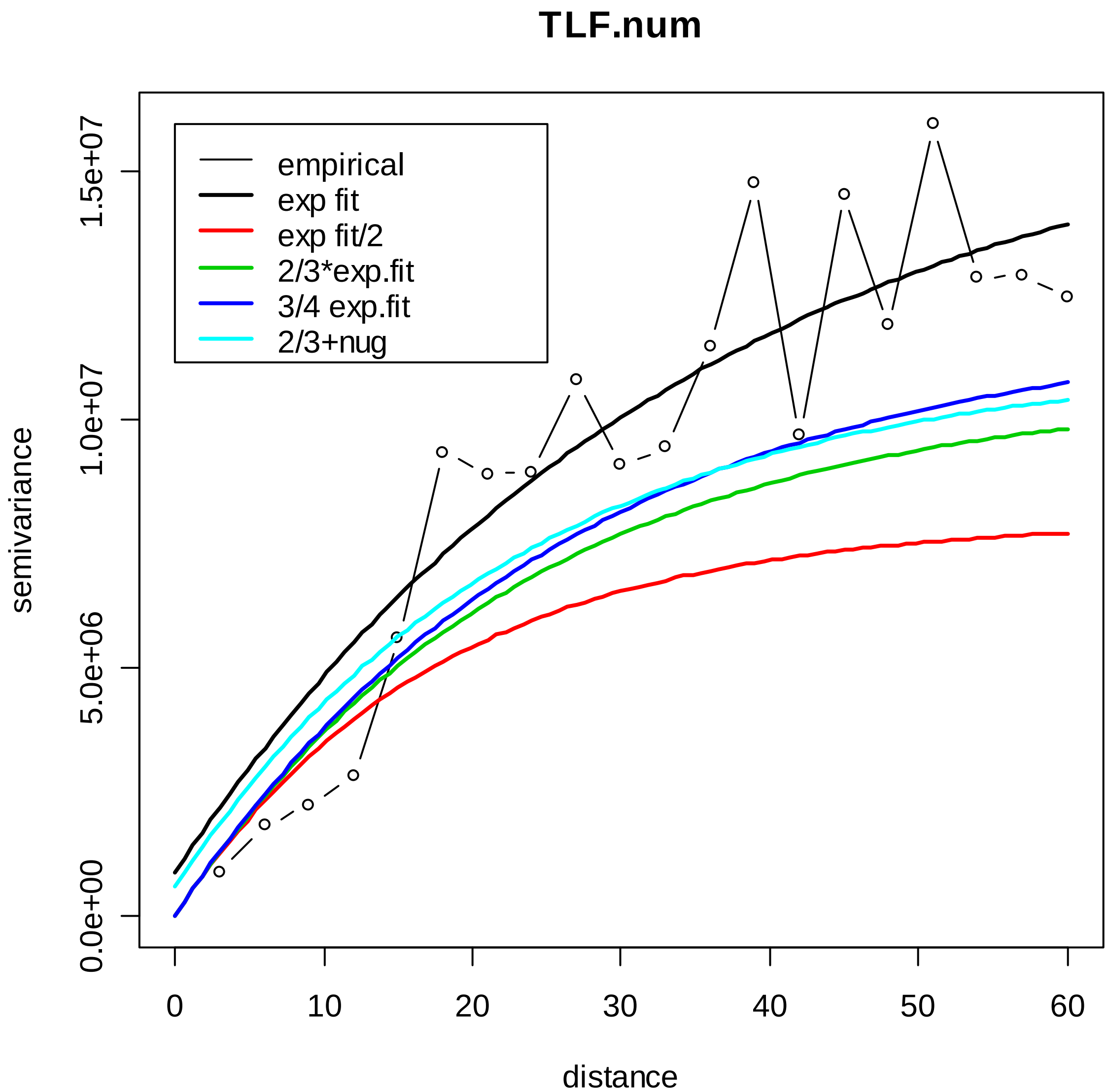
distance



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3/4 exp.fit
2/3+nug
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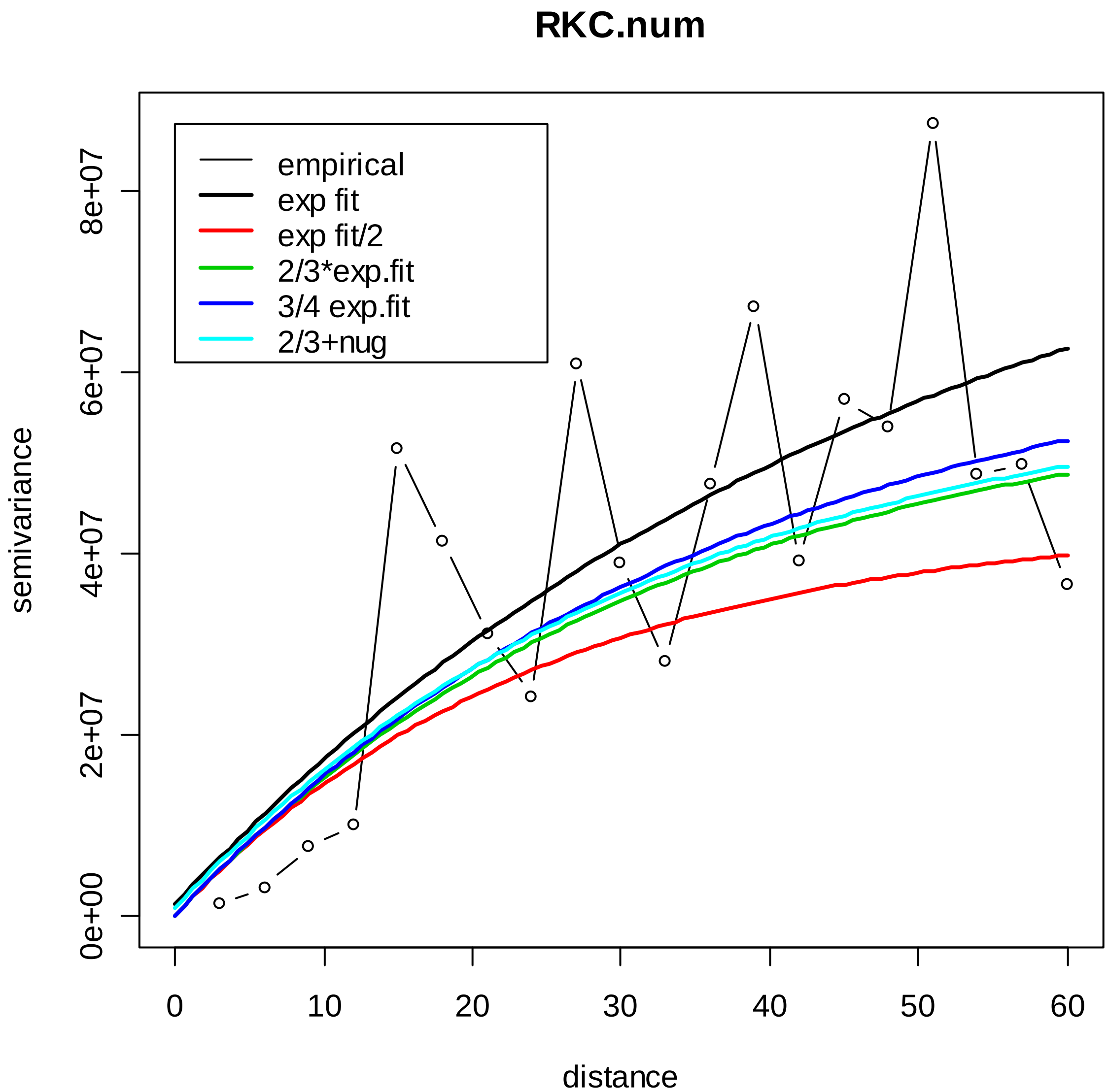
distance



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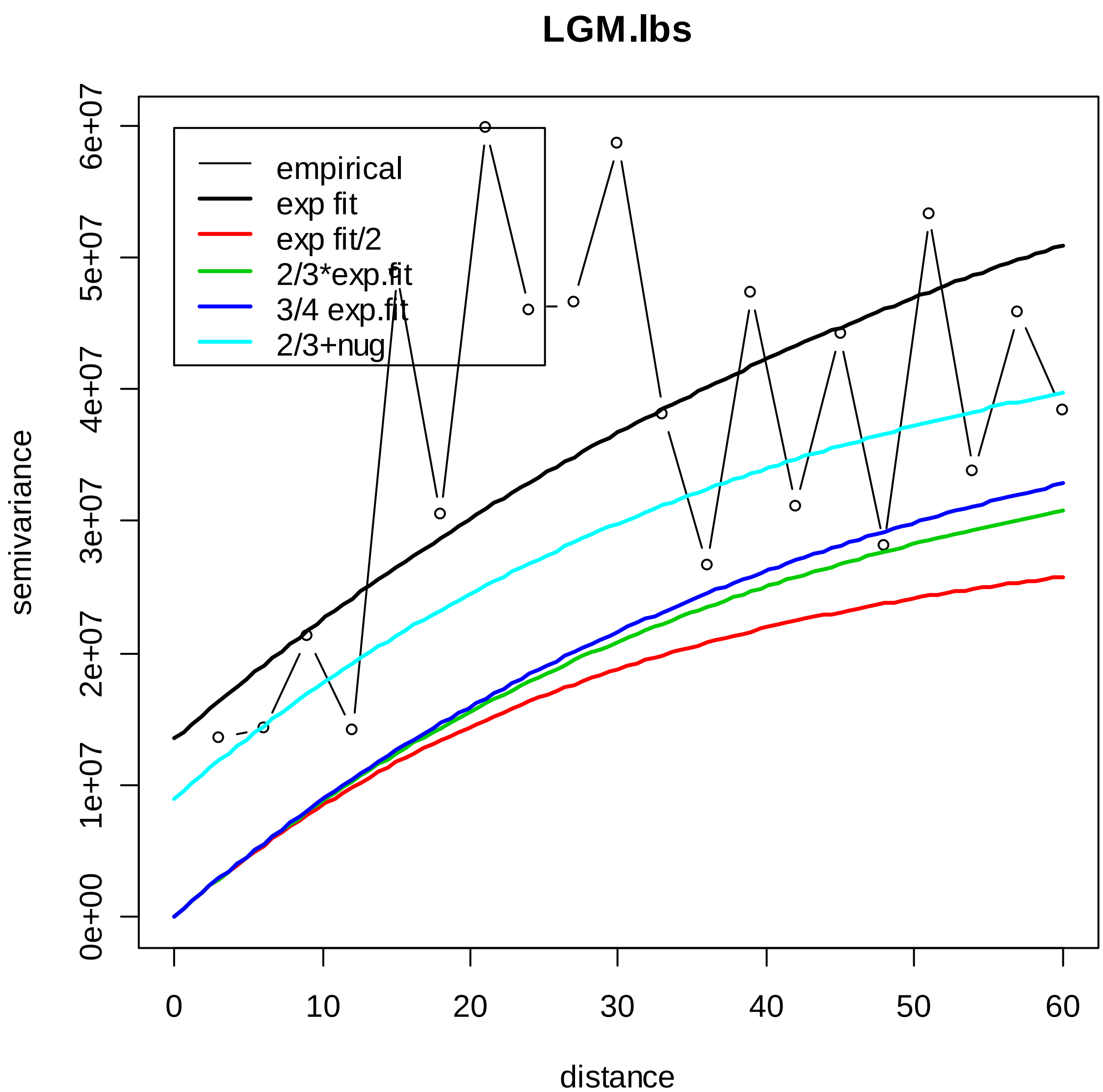
distance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semivariance
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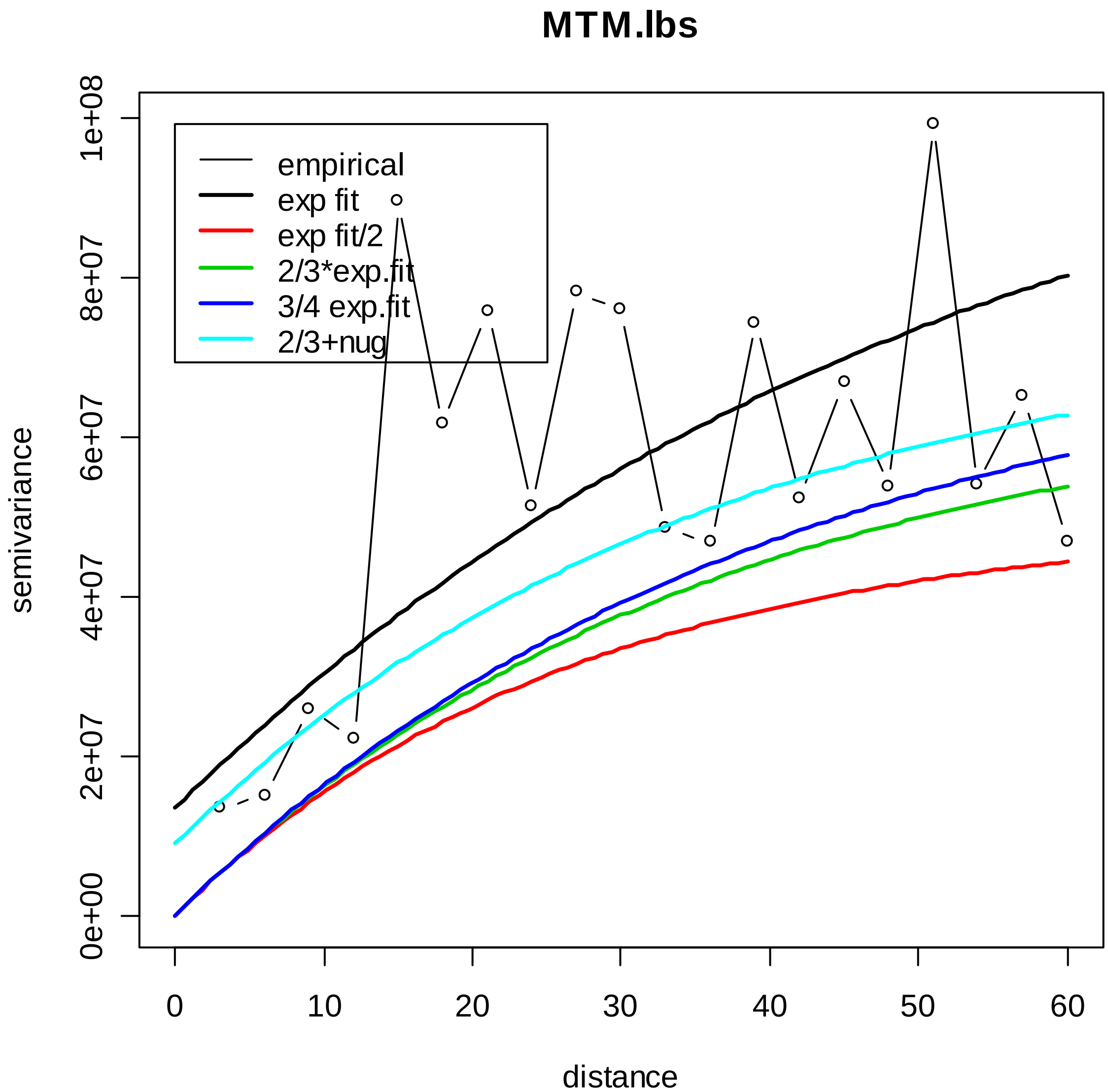

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3/4 exp.fit
2/3+nug
semivariance
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20
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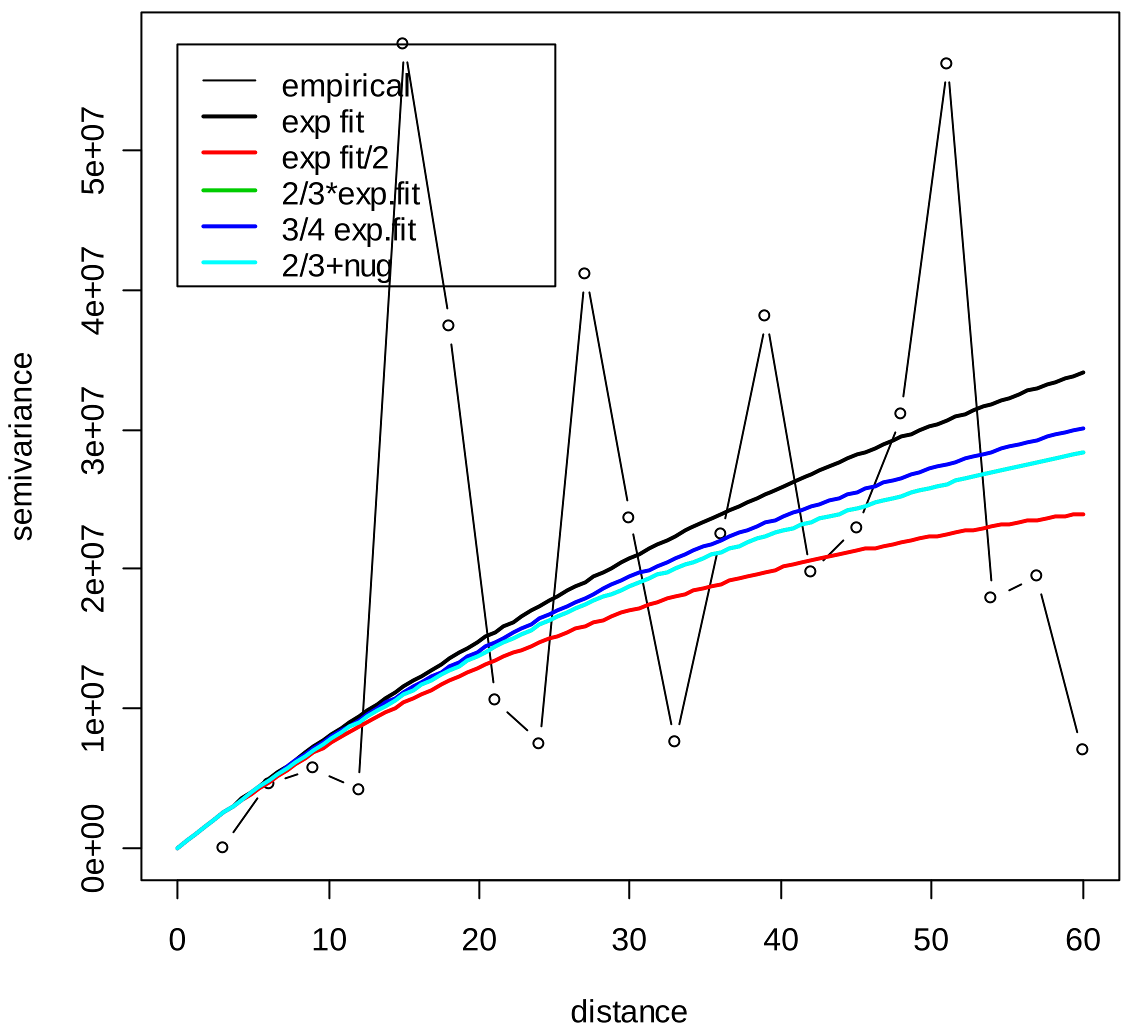
50
60
distance

MDM.lbs



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2/3+nug
semivariance
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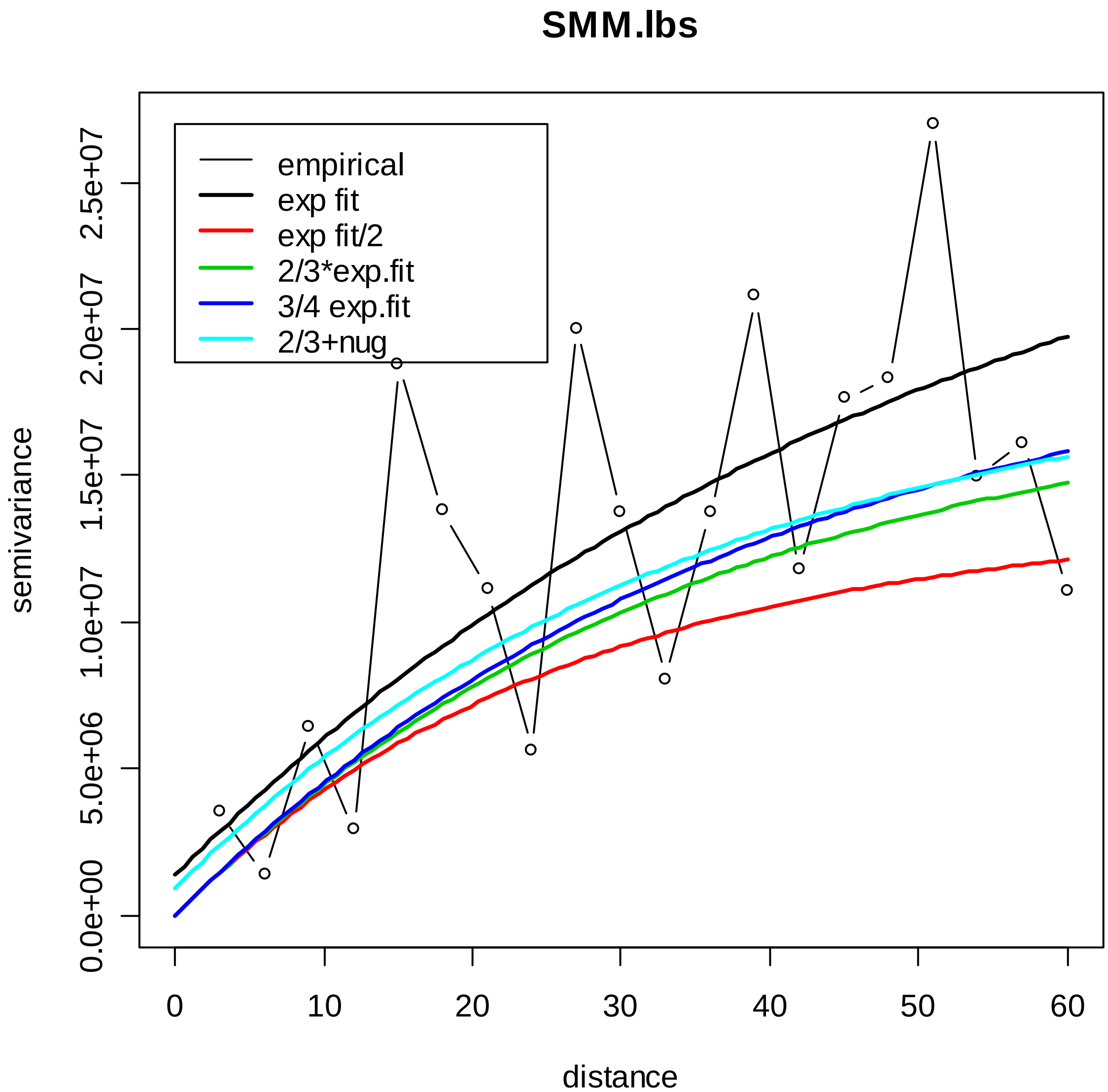
distance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2/3+nug
semivariance
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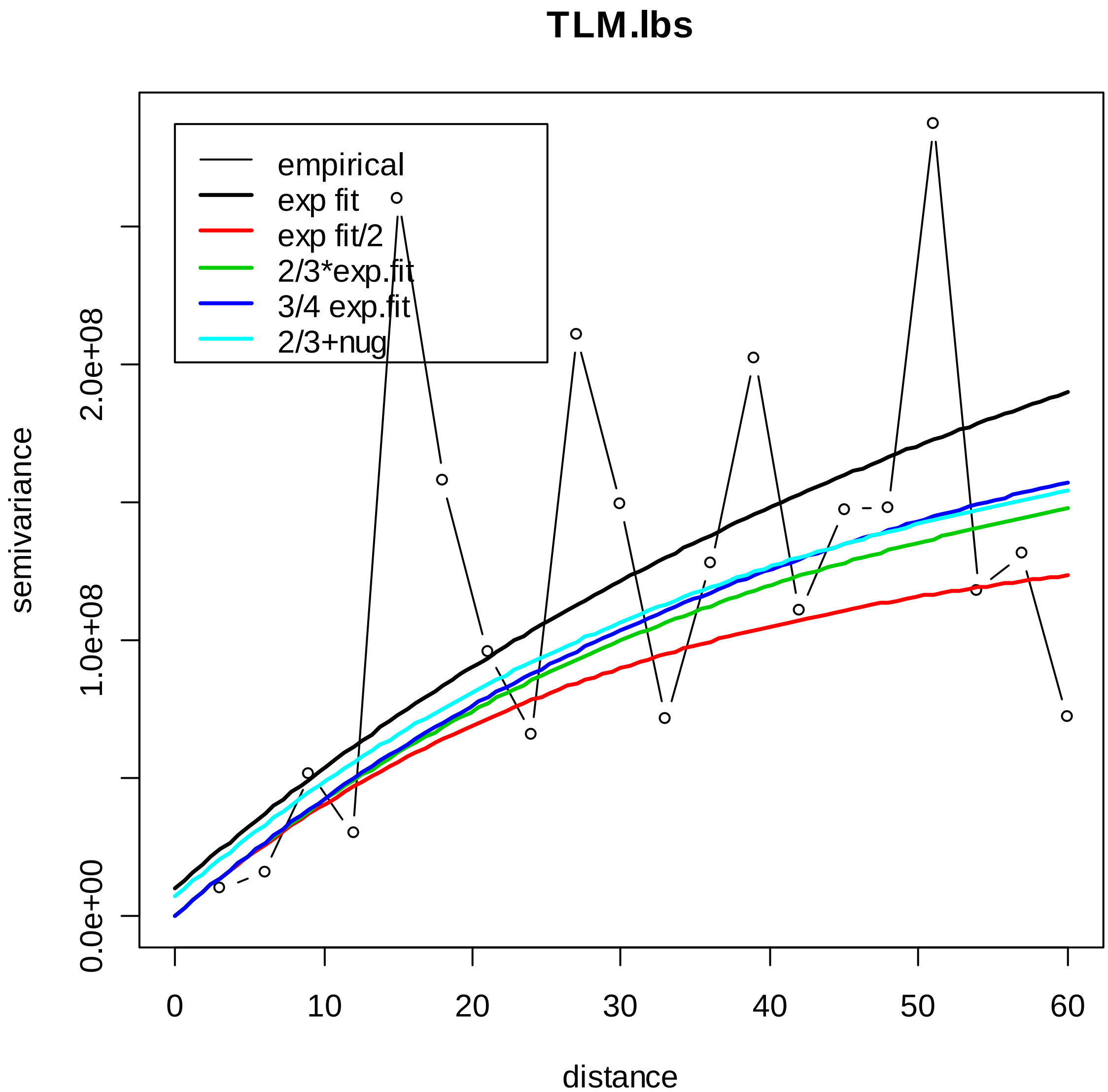
distance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10
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40
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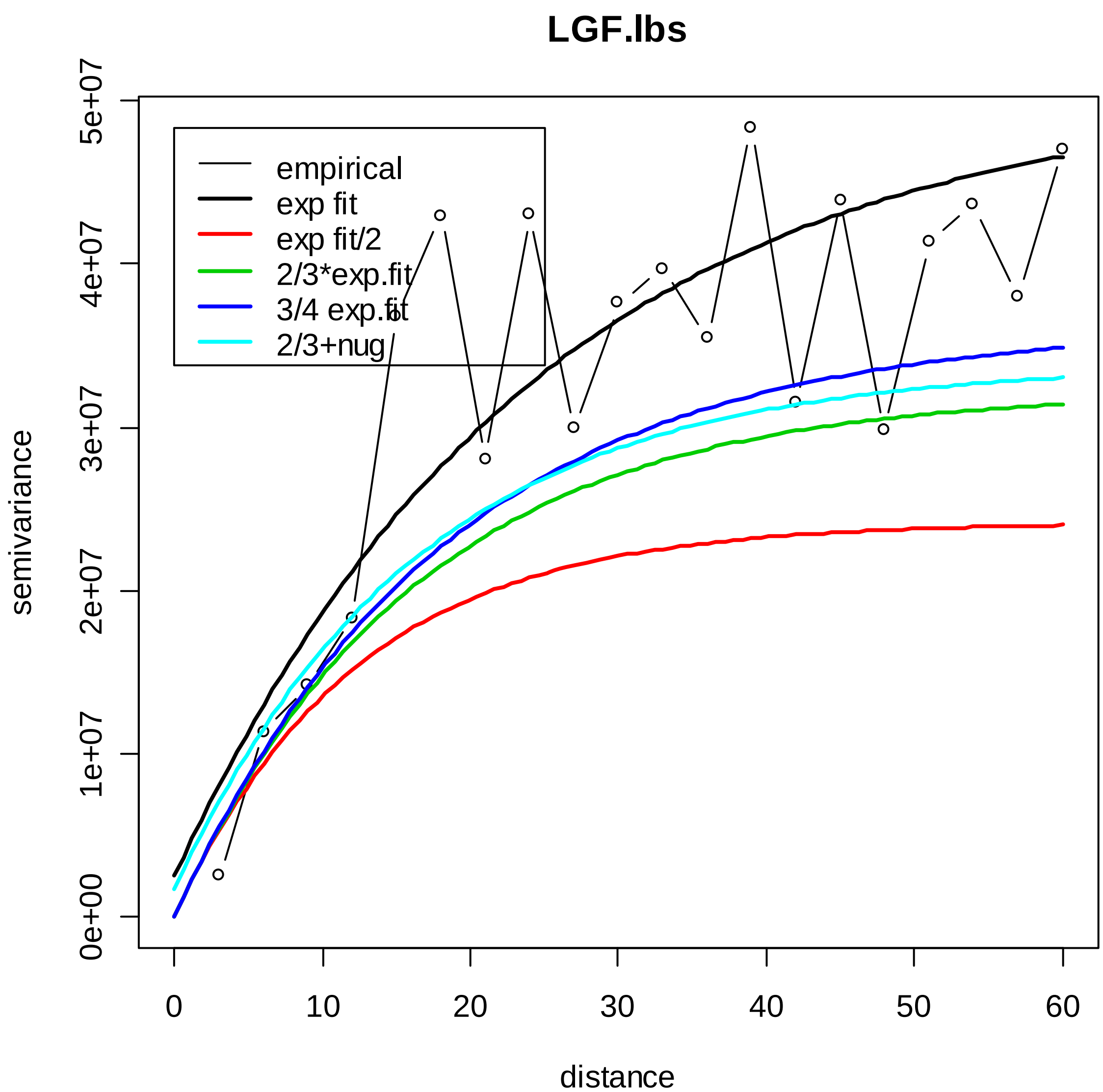
60
distance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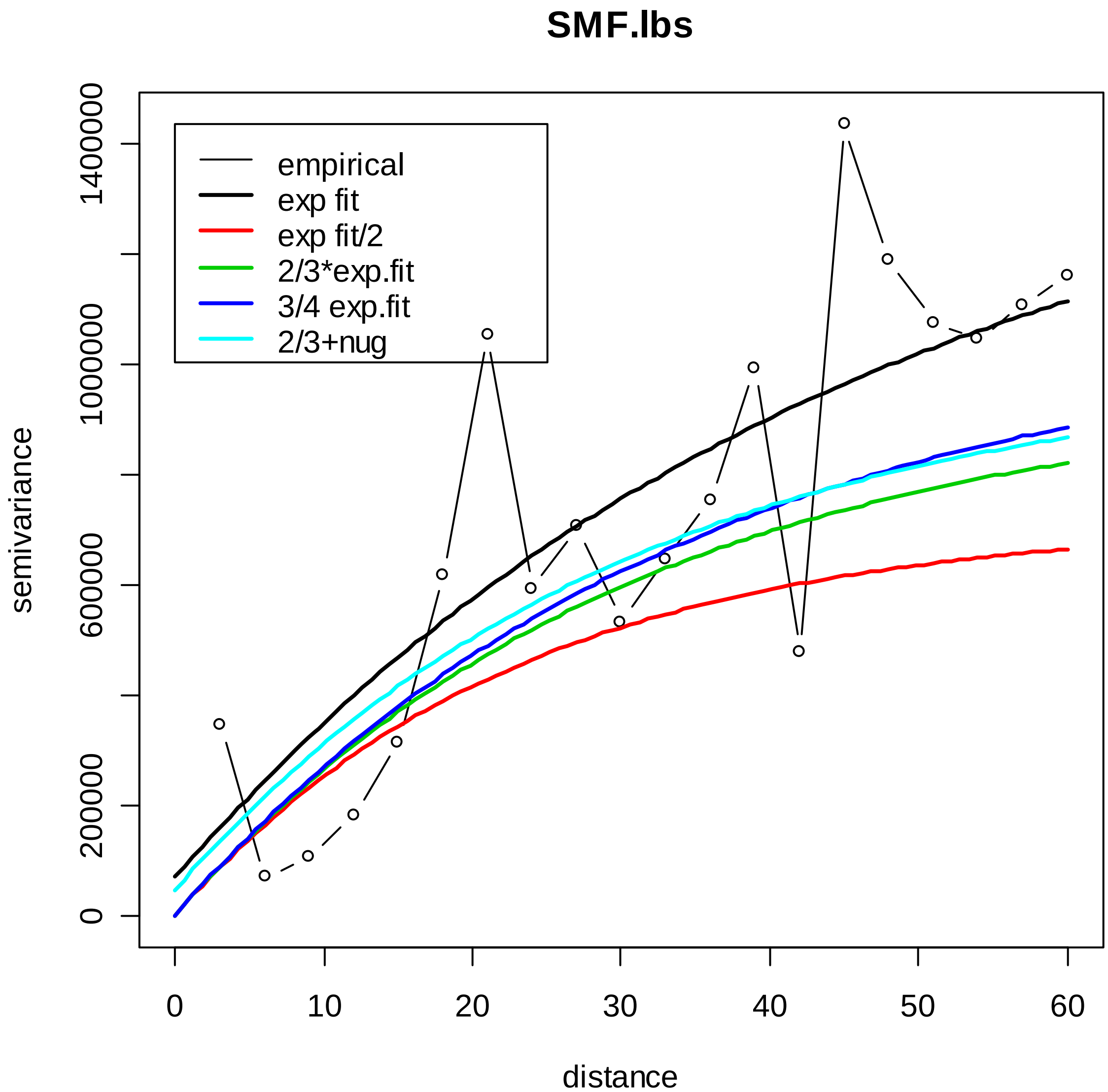
distance



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2/3+nug
semivariance
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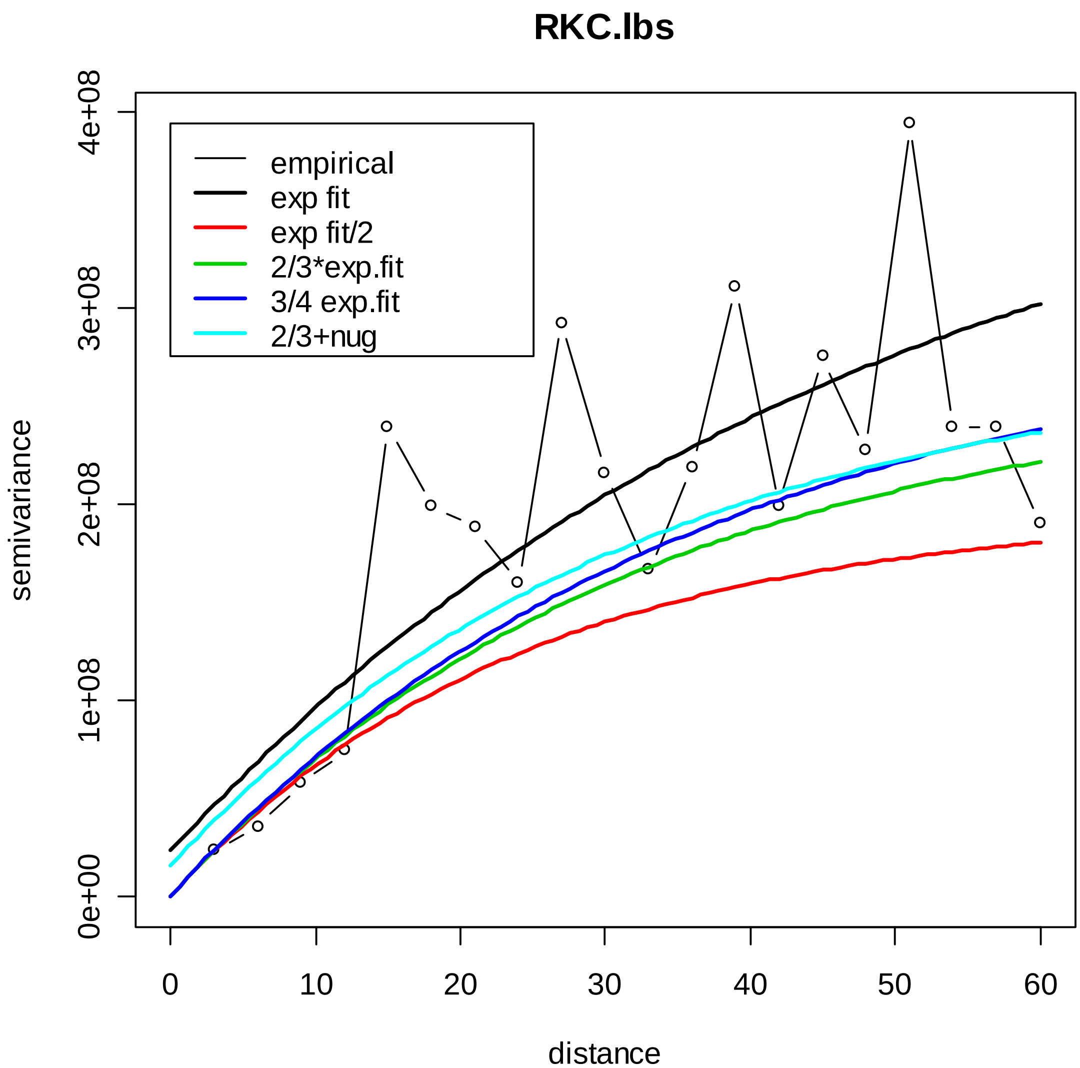
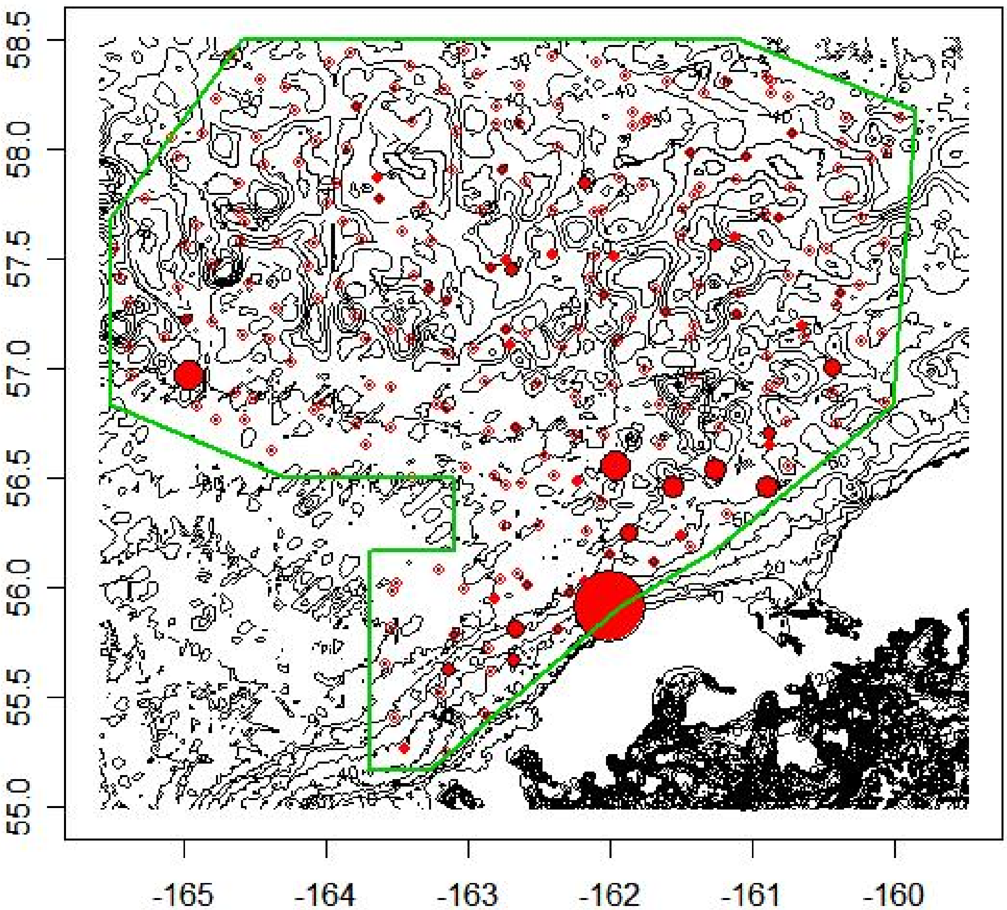
50
60
distance



Appendix 3. Depth contours over the survey region (region outlined in green). Mature male samples are shown with red circles

2007 RKC survey mature male numbers in defined region



Appendix 6

Area swept densities of BBRKC from BSFRF 2007 survey for 241 station tows

Appendix 6. Area swept densities of red king crab within BSFRF 241 survey station survey area by size and sex category in both numbers of crab and pounds of crab per square nautical mile. (Page 1 of 5).

				Density (# Red King Crab per nm^2) - [size categories are carapace length (CL) in mm]								
				MALES					FEMALES			RKC
Stn	NMFS	Tow ≈ Midpoint		Large	Mature	Medium	Small	Total	Large	Small	Total	Total
Tow	BOX	Latitude	Longitude	(≥134)	(≥120)	(110-134)	(<110)	All	(≥90)	(<90)	All	All
1x	G-05	56.9626	-165.3657	0	0	0	0	0	0	0	0	0
2x	G-05	57.1391	-165.1324	0	0	0	0	0	0	0	0	0
3x	G-05	56.9646	-164.9592	7,591	0	0	0	7,591	0	0	0	7,591
4x	F-05	56.8232	-164.9066	0	0	0	0	0	0	0	0	0
5x	F-06	56.7651	-164.7705	0	0	0	0	0	0	0	0	0
6x	G-06	56.8882	-164.6376	0	0	0	0	0	0	0	0	0
7x	G-06	56.8538	-164.5126	0	0	0	0	0	0	0	0	0
8x	F-06	56.7582	-164.5676	0	0	0	0	0	0	0	0	0
9x	F-06	56.6187	-164.3837	0	0	0	0	0	0	0	0	0
10x	F-07	56.8028	-164.0820	0	1,228	1,228	0	1,228	0	0	0	1,228
11x	F-07	56.8284	-164.0246	0	0	0	0	0	0	0	0	0
12x	F-07	56.5196	-163.9483	0	0	0	0	0	0	0	0	0
13x	F-07	56.6509	-163.7206	0	0	0	0	0	0	0	0	0
14x	F-07	56.7439	-163.7853	0	0	0	0	0	0	0	0	0
15x	G-07	56.9184	-163.6901	0	0	0	0	0	0	0	0	0
16x	G-08	56.9117	-163.5437	0	0	0	0	0	0	0	0	0
17x	F-08	56.7233	-163.5461	0	0	0	0	0	0	0	0	0
18x	F-08	56.4968	-163.3889	0	0	0	0	0	0	0	0	0
19	G-08	56.8360	-163.2199	607	0	0	0	607	607	0	607	1,214
20	F-08	56.8127	-163.1456	0	0	0	0	0	0	0	0	0
21	G-08	57.0611	-163.1360	935	0	0	0	935	935	0	935	1,870
22	G-09	57.0897	-162.9597	880	0	880	0	1,759	880	880	1,759	3,518
23	G-09	56.9374	-162.8792	760	0	0	10,645	11,406	11,406	2,281	13,687	25,092
24	G-09	57.1032	-162.7006	2,697	674	2,023	2,697	7,417	7,417	1,349	8,765	16,182
25	H-09	57.1713	-162.7343	750	750	750	1,500	3,000	6,001	1,500	7,501	10,502
26	G-09	57.1515	-162.5926	684	684	2,735	4,786	8,204	8,204	684	8,888	17,093
27	G-09	56.9239	-162.5172	0	1,366	2,050	4,099	6,149	2,733	0	2,733	8,881
28	F-09	56.7303	-162.6663	1,393	697	697	697	2,787	697	0	697	3,483
29	F-09	56.7073	-162.8539	717	717	717	0	1,434	0	0	0	1,434
30	F-09	56.5439	-163.0208	0	0	0	0	0	0	0	0	0
31	F-09	56.5054	-162.8141	0	0	0	0	0	0	0	0	0
32	E-09	56.4627	-162.7343	0	0	0	0	0	0	0	0	0
33	E-09	56.4750	-162.6189	0	0	0	0	0	0	0	0	0
34	E-09	56.2804	-162.7469	0	0	0	0	0	593	0	593	593
35	E-10	56.2844	-162.5034	698	0	698	0	1,395	0	0	0	1,395
36	D-09	56.0060	-162.5766	628	1,256	1,256	0	1,884	0	0	0	1,884
37	D-09	56.0624	-162.6499	0	0	0	0	0	0	0	0	0
38	D-09	56.0380	-162.7736	616	0	0	0	616	0	0	0	616
39	D-09	55.9436	-162.8055	1,666	833	833	0	2,498	0	0	0	2,498
40	D-09	55.9879	-163.0229	0	0	0	0	0	0	0	0	0
41	D-08	56.0819	-163.2049	0	0	0	0	0	0	0	0	0
42	D-08	56.0173	-163.5007	0	0	0	0	0	0	0	0	0
43	D-08	55.9817	-163.5332	0	0	0	0	0	0	0	0	0
44	C-08	55.8133	-163.5470	0	0	0	0	0	0	0	0	0
45	C-08	55.6476	-163.5809	0	0	0	0	0	0	0	0	0
46	B-08	55.4061	-163.5152	727	0	0	0	727	0	0	0	727
47	B-08	55.2611	-163.4518	2,649	0	0	0	2,649	1,766	0	1,766	4,415
48	B-08	55.2460	-163.1451	0	0	0	0	0	1,098	0	1,098	1,098
49	C-08	55.5184	-163.1935	822	0	0	0	822	822	0	822	1,643
50	C-08	55.6257	-163.1332	1,993	1,993	2,990	0	4,984	0	0	0	4,984

Appendix 6. Area swept densities of red king crab within BSFRF 241 survey station survey area by size and sex category in both numbers of crab and pounds of crab per square nautical mile. (Page 2 of 5).

				Density (# Red King Crab per nm^2) - [size categories are carapace length (CL) in mm]								
				MALES					FEMALES			RKC
Stn	NMFS	Tow ≈ Midpoint		Large	Mature	Medium	Small	Total	Large	Small	Total	Total
Tow	BOX	Latitude	Longitude	(≥134)	(≥120)	(110-134)	(<110)	All	(≥90)	(<90)	All	All
51	C-09	55.7773	-163.0992	1,100	1,100	1,100	0	2,200	0	0	0	2,200
52	C-09	55.7154	-162.8504	0	0	0	0	0	0	0	0	0
53	C-09	55.6181	-162.8445	0	0	0	0	0	790	0	790	790
54	C-09	55.4216	-162.8816	0	0	0	0	0	0	0	0	0
55	C-09	55.6656	-162.6790	1,777	1,777	2,666	3,554	7,997	9,774	0	9,774	17,770
56	C-09	55.8115	-162.6583	1,584	3,167	4,751	2,376	8,710	792	0	792	9,502
57	D-10	55.8091	-162.3688	1,558	519	2,077	0	3,635	5,192	0	5,192	8,827
58	D-10	55.9700	-162.2837	2,199	0	733	5,131	8,064	13,928	0	13,928	21,992
59	D-10	56.0252	-162.1768	2,495	0	0	3,326	5,821	17,464	832	18,296	24,117
60	D-10	55.9134	-162.0052	8,587	10,304	27,478	25,760	61,824	30,054	0	30,054	91,878
61	D-10	56.1465	-161.9944	1,113	1,113	1,113	1,113	3,340	1,113	0	1,113	4,453
62	E-11	56.2445	-161.8695	1,842	2,763	2,763	2,763	7,368	2,763	0	2,763	10,131
63	E-11	56.1128	-161.6915	1,739	0	0	0	1,739	6,955	1,739	8,694	10,433
64	E-11	56.1818	-161.4280	0	0	0	0	0	0	0	0	0
65	E-11	56.2391	-161.4978	2,531	0	1,266	3,164	6,961	3,164	633	3,797	10,758
66	E-11	56.4551	-161.5614	5,342	890	890	890	7,123	2,671	0	2,671	9,794
67	F-11	56.6436	-161.6513	0	0	0	3,805	3,805	3,044	0	3,044	6,850
68	G-11	56.8324	-161.6488	0	0	0	897	897	1,795	0	1,795	2,692
69	G-11	56.9873	-161.7610	0	0	816	3,263	4,079	2,447	816	3,263	7,342
70	H-11	57.2549	-161.6114	1,529	0	765	2,294	4,588	3,823	0	3,823	8,411
71	H-11	57.3607	-161.6819	0	0	837	1,675	2,512	3,349	0	3,349	5,861
72	H-10	#N/A	#N/A	1,349	0	1,349	8,094	10,791	9,442	4,047	13,489	24,281
73	G-10	57.1194	-161.9491	743	0	743	14,867	16,354	17,841	2,230	20,071	36,424
74	G-10	56.9238	-161.9863	0	665	1,331	1,331	2,662	665	665	1,331	3,992
75	F-10	56.6949	-162.0418	0	793	2,379	2,379	4,758	1,586	0	1,586	6,344
76	F-10	56.5497	-161.9583	2,954	5,170	6,647	0	9,602	0	0	0	9,602
77	E-10	56.3969	-162.0712	0	0	2,124	0	2,124	2,124	0	2,124	4,248
78	E-10	56.2526	-162.1699	772	0	0	772	1,545	1,545	0	1,545	3,090
79	E-10	56.4847	-162.2317	2,711	678	1,355	0	4,066	1,355	0	1,355	5,422
80	F-10	56.5065	-162.3890	0	0	0	0	0	0	0	0	0
81	F-10	56.5954	-162.4540	0	806	806	806	1,612	806	0	806	2,419
82	F-10	56.6913	-162.2473	0	0	0	0	0	0	0	0	0
83	G-10	56.8708	-162.2425	0	0	0	3,935	3,935	787	787	1,574	5,509
84	G-10	57.0964	-162.3328	810	0	0	10,527	11,337	4,049	9,718	13,767	25,104
85	H-10	57.1769	-162.2234	758	0	0	14,411	15,169	9,860	5,309	15,169	30,339
86	H-10	57.3326	-162.0353	850	850	850	11,049	12,748	5,949	3,400	9,349	22,097
87	H-10	57.4059	-162.1361	0	0	0	5,968	5,968	8,952	3,979	12,931	18,899
88	I-10	57.5036	-162.1145	627	0	1,255	3,137	5,019	6,274	3,137	9,410	14,429
89	I-10	57.5086	-161.9765	2,540	0	2,540	9,313	14,394	7,620	5,080	12,700	27,094
90	I-10	57.7156	-162.0504	836	0	0	1,672	2,508	2,508	1,672	4,180	6,689
91	I-10	57.7114	-162.1147	968	0	0	5,808	6,776	1,936	0	1,936	8,712
92	J-10	57.8346	-162.1722	1,005	3,014	3,014	4,019	8,038	2,010	0	2,010	10,048
93	J-10	57.8651	-161.9398	0	897	897	897	1,794	897	0	897	2,692
94	I-11	57.8265	-161.7757	0	0	955	955	1,910	0	0	0	1,910
95	J-11	57.9756	-161.4329	1,971	0	0	0	1,971	2,957	0	2,957	4,928
96	I-11	57.8187	-161.3670	0	1,050	1,050	0	1,050	3,151	1,050	4,201	5,252
97	I-11	57.7832	-161.4033	0	884	884	884	1,768	3,536	0	3,536	5,304
98	I-11	57.7237	-161.4857	0	1,325	1,325	2,650	3,974	3,974	1,325	5,299	9,273
99	I-11	57.5996	-161.5015	0	928	1,855	4,639	6,494	5,566	928	6,494	12,988
100	H-11	57.3735	-161.3800	0	0	0	4,837	4,837	7,255	1,209	8,464	13,301

Appendix 6. Area swept densities of red king crab within BSFRF 241 survey station survey area by size and sex category in both numbers of crab and pounds of crab per square nautical mile. (Page 3 of 5).

				Density (# Red King Crab per nm^2) - [size categories are carapace length (CL) in mm]								
				MALES					FEMALES			RKC
Stn	NMFS	Tow ≈ Midpoint		Large	Mature	Medium	Small	Total	Large	Small	Total	Total
Tow	BOX	Latitude	Longitude	(≥134)	(≥120)	(110-134)	(<110)	All	(≥90)	(<90)	All	All
101	H-11	57.1881	-161.4115	1,229	0	0	3,687	4,916	3,687	0	3,687	8,603
102	G-11	57.1417	-161.4361	721	0	721	2,886	4,329	4,329	721	5,050	9,379
103	G-11	56.9503	-161.4224	0	0	0	1,009	1,009	0	0	0	1,009
104	F-11	56.8132	-161.4700	0	873	873	873	1,745	873	0	873	2,618
105	F-12	56.7247	-161.2302	0	0	0	0	0	2,479	0	2,479	2,479
106	F-12	56.5341	-161.2613	1,993	3,986	6,975	2,989	11,958	6,975	0	6,975	18,933
107	E-12	56.3359	-161.1712	799	0	799	799	2,398	2,398	0	2,398	4,797
108	E-12	56.4536	-160.8989	4,387	1,755	3,509	10,528	18,424	13,160	3,509	16,669	35,093
109	F-12	56.5514	-160.7463	0	0	850	1,699	2,549	3,399	0	3,399	5,947
110	F-12	56.6505	-160.8751	1,911	955	955	0	2,866	8,599	0	8,599	11,465
111	F-12	56.6998	-160.8745	2,171	2,171	2,171	0	4,341	6,512	0	6,512	10,854
112	F-12	56.7558	-160.7552	1,416	0	0	0	1,416	5,663	0	5,663	7,079
113	G-12	56.9306	-160.8189	0	1,061	1,061	1,061	2,122	3,183	0	3,183	5,305
114	G-12	56.8982	-160.8874	0	0	0	1,047	1,047	0	0	0	1,047
115	G-12	57.0481	-160.8894	0	0	0	1,001	1,001	0	0	0	1,001
116	H-12	57.2421	-161.1030	752	752	752	752	2,257	2,257	0	2,257	4,514
117	H-12	57.3418	-161.0918	0	0	0	0	0	0	0	0	0
118	I-11	57.5557	-161.2527	2,815	938	938	2,815	6,568	5,629	0	5,629	12,197
119	I-12	57.5945	-161.1224	2,936	0	0	1,957	4,893	4,893	0	4,893	9,786
120	J-12	57.8576	-161.1082	1,055	0	1,055	0	2,110	4,220	0	4,220	6,329
121	J-12	57.9588	-161.0394	1,527	0	0	1,527	3,054	3,054	0	3,054	6,107
122	I-12	57.6963	-160.9052	0	0	0	0	0	0	0	0	0
123	I-12	57.6769	-160.8175	1,528	0	0	764	2,293	3,057	0	3,057	5,349
124	H-12	57.4191	-160.7414	0	0	0	0	0	3,898	0	3,898	3,898
125	I-12	57.5318	-160.5903	0	0	0	0	0	1,550	0	1,550	1,550
126	I-13	57.5387	-160.4725	0	0	0	0	0	4,009	0	4,009	4,009
127	H-13	57.3373	-160.3804	2,058	0	0	0	2,058	1,029	0	1,029	3,086
128	H-13	57.2840	-160.4104	991	0	0	0	991	4,955	0	4,955	5,946
129	H-12	57.1922	-160.6469	2,904	0	0	0	2,904	7,745	0	7,745	10,649
130	G-12	57.1376	-160.6393	0	756	2,267	0	2,267	3,779	0	3,779	6,047
131	G-13	56.9940	-160.4325	3,638	910	910	910	5,458	9,096	0	9,096	14,554
132	G-13	56.8864	-160.4312	755	0	755	755	2,264	8,302	0	8,302	10,566
133	F-13	56.7450	-160.4116	0	0	0	1,887	1,887	7,550	944	8,493	10,381
134	G-13	56.8445	-160.0662	0	0	0	0	0	836	0	836	836
135	G-13	57.1568	-160.0851	1,007	0	1,007	0	2,014	2,014	0	2,014	4,028
136	G-13	57.1215	-160.2291	1,212	0	0	0	1,212	4,849	0	4,849	6,061
137	H-13	57.3767	-160.2378	1,000	0	1,000	0	2,001	4,002	0	4,002	6,002
138	I-13	57.5714	-160.0637	0	0	0	0	0	1,073	0	1,073	1,073
139	I-13	57.6821	-160.2256	890	0	0	890	1,779	5,338	890	6,228	8,007
140	I-13	57.7741	-160.3209	0	0	0	1,036	1,036	0	1,036	1,036	2,072
141	J-13	57.9491	-160.1572	0	0	1,051	2,102	3,154	0	3,154	3,154	6,307
142	J-13	57.9876	-160.0554	1,012	0	0	0	1,012	1,012	0	1,012	2,025
143	J-13	58.1342	-159.9552	0	0	0	0	0	0	0	0	0
144	J-13	58.1387	-160.3362	0	0	0	0	0	0	0	0	0
145	J-13	58.0258	-160.3593	0	0	0	0	0	0	0	0	0
146	J-13	57.9121	-160.3858	903	0	0	0	903	1,806	0	1,806	2,709
147	I-12	57.8230	-160.7244	0	0	0	0	0	0	0	0	0
148	J-12	58.0643	-160.7189	2,327	0	0	0	2,327	3,491	0	3,491	5,818
149	K-12	58.2303	-160.7414	0	0	0	0	0	0	0	0	0
150	K-12	58.2537	-160.8594	0	0	0	0	0	0	0	0	0

Appendix 6. Area swept densities of red king crab within BSFRF 241 survey station survey area by size and sex category in both numbers of crab and pounds of crab per square nautical mile. (Page 4 of 5).

				Density (# Red King Crab per nm^2) - [size categories are carapace length (CL) in mm]								
				MALES					FEMALES			RKC
Stn	NMFS	Tow ≈ Midpoint		Large	Mature	Medium	Small	Total	Large	Small	Total	Total
Tow	BOX	Latitude	Longitude	(≥134)	(≥120)	(110-134)	(<110)	All	(≥90)	(<90)	All	All
151	K-12	58.3033	-160.8626	1,185	0	0	0	1,185	1,185	0	1,185	2,370
152	K-12	58.3245	-160.8893	0	0	0	0	0	0	0	0	0
153	K-11	58.3030	-161.1889	0	0	0	0	0	0	0	0	0
154	K-11	58.2538	-161.3401	0	0	0	0	0	0	0	0	0
155	K-11	58.3060	-161.5915	0	0	0	0	0	0	0	0	0
156	J-11	58.1405	-161.7371	0	0	0	732	732	732	0	732	1,464
157	J-11	58.1227	-161.7631	0	0	0	701	701	0	0	0	701
158	J-10	58.1001	-161.8432	0	0	996	996	1,991	996	0	996	2,987
159	J-10	58.1628	-161.8377	0	0	0	1,508	1,508	0	0	0	1,508
160	K-10	58.3255	-161.8924	0	0	0	0	0	0	0	0	0
161	K-10	58.3866	-162.0984	0	0	0	0	0	0	0	0	0
162	K-09	58.4167	-162.4084	0	0	0	0	0	0	0	0	0
163	K-10	58.1953	-162.3627	0	0	0	0	0	0	0	0	0
164	J-10	58.0018	-162.3702	0	0	1,611	805	2,416	0	0	0	2,416
165	J-09	58.1146	-162.6327	0	0	744	744	1,488	0	0	0	1,488
166	K-09	58.2882	-162.6365	0	0	0	0	0	0	0	0	0
167	K-09	58.1892	-162.8017	1,296	0	0	0	1,296	0	0	0	1,296
168	J-09	58.1123	-162.8021	999	0	0	0	999	0	0	0	999
169	J-09	57.9030	-162.7640	0	2,020	2,020	2,020	4,041	0	0	0	4,041
170	J-09	57.8475	-162.6013	0	960	1,919	960	2,879	960	0	960	3,839
171	I-10	57.7137	-162.4071	0	0	0	0	0	0	1,171	1,171	1,171
172	I-10	57.5108	-162.4032	945	1,890	1,890	945	3,780	1,890	0	1,890	5,670
173	H-09	57.4426	-162.6906	1,750	1,750	1,750	2,626	6,127	2,626	0	2,626	8,752
174	H-09	57.4895	-162.7288	1,714	857	3,428	5,999	11,141	857	0	857	11,998
175	H-09	57.4578	-162.8448	2,289	0	763	0	3,052	6,104	0	6,104	9,157
176	I-09	57.7129	-162.9017	756	0	756	756	2,268	3,779	0	3,779	6,047
177	J-08	57.9021	-163.1075	1,076	0	0	1,076	2,152	1,076	0	1,076	3,228
178	J-08	58.0772	-163.0861	0	0	0	0	0	0	0	0	0
179	K-09	58.3354	-162.9294	0	0	0	0	0	0	0	0	0
180	K-09	58.4391	-163.0311	0	0	0	0	0	0	0	0	0
181	K-08	58.2659	-163.1681	0	0	0	0	0	0	0	0	0
182	J-08	58.1221	-163.3950	0	0	0	0	0	0	0	0	0
183	K-08	58.3726	-163.4135	0	0	0	0	0	0	0	0	0
184	K-08	58.2758	-163.5134	0	0	0	0	0	0	0	0	0
185	K-07	58.1874	-163.7866	2,093	0	0	0	2,093	1,047	0	1,047	3,140
186	K-07	58.4349	-163.8287	0	0	0	0	0	0	0	0	0
187	K-07	58.3923	-163.9763	963	0	0	0	963	0	0	0	963
188	K-07	58.1736	-164.2203	0	1,026	1,026	0	1,026	0	0	0	1,026
189	J-07	57.9315	-164.1848	0	0	0	0	0	0	0	0	0
190	J-07	58.0320	-164.0645	1,050	0	0	0	1,050	1,050	0	1,050	2,099
191	J-07	58.0043	-163.8546	0	0	0	0	0	1,018	0	1,018	1,018
192	J-07	57.8365	-163.9242	1,057	0	0	0	1,057	0	0	0	1,057
193	I-07	57.7481	-163.9929	0	0	0	0	0	0	0	0	0
194	I-07	57.6679	-163.8791	0	0	0	0	0	0	0	0	0
195	I-07	57.5869	-163.7386	1,359	0	0	0	1,359	2,717	0	2,717	4,076
196	J-08	57.8617	-163.6327	3,425	0	0	0	3,425	2,284	0	2,284	5,709
197	I-08	57.7681	-163.6258	2,331	0	1,166	0	3,497	5,828	0	5,828	9,325
198	I-08	57.6178	-163.4625	0	0	0	0	0	3,094	0	3,094	3,094
199	I-08	57.7310	-163.3185	0	885	885	0	885	885	0	885	1,770
200	I-08	57.5779	-163.2594	0	0	0	1,173	1,173	1,173	0	1,173	2,346

Appendix 6. Area swept densities of red king crab within BSFRF 241 survey station survey area by size and sex category in both numbers of crab and pounds of crab per square nautical mile. (Page 5 of 5).

				Density (# Red King Crab per nm^2) - [size categories are carapace length (CL) in mm]								
				MALES					FEMALES			RKC
Stn	NMFS	Tow ≈ Midpoint		Large	Mature	Medium	Small	Total	Large	Small	Total	Total
Tow	BOX	Latitude	Longitude	(≥134)	(≥120)	(110-134)	(<110)	All	(≥90)	(<90)	All	All
201	H-08	57.4203	-163.3818	0	802	802	802	1,604	2,405	0	2,405	4,009
202	H-08	57.3589	-163.2743	1,683	0	841	3,365	5,889	841	0	841	6,730
203	H-08	57.3087	-163.1457	960	960	960	0	1,921	2,881	0	2,881	4,801
204	G-08	57.1270	-163.4074	0	0	0	0	0	0	0	0	0
205	H-08	57.1772	-163.5400	0	0	0	0	0	0	0	0	0
206	G-07	57.1309	-163.7204	732	0	0	0	732	0	0	0	732
207	H-07	57.2360	-163.7933	0	0	0	0	0	0	0	0	0
208	H-07	57.3869	-163.9095	0	0	0	0	0	0	0	0	0
209	H-07	57.3103	-164.0545	0	0	872	0	872	0	0	0	872
210	H-07	57.4627	-164.1293	0	0	0	0	0	0	0	0	0
211	I-07	57.5677	-164.0836	0	0	0	0	0	0	0	0	0
212	I-06	57.5658	-164.3456	0	0	0	0	0	0	0	0	0
213	H-06	57.3802	-164.5376	0	0	0	0	0	0	0	0	0
214	H-06	57.2727	-164.3512	0	0	0	0	0	0	0	0	0
215	G-07	57.0287	-164.2396	0	0	0	0	0	0	0	0	0
216	G-06	57.1292	-164.3995	692	0	0	0	692	0	0	0	692
217	G-06	57.1497	-164.5792	0	0	0	0	0	0	0	0	0
218	H-06	57.2069	-164.7957	0	0	0	0	0	0	0	0	0
219	H-05	57.2144	-164.9682	1,287	643	643	0	1,930	0	0	0	1,930
220	H-05	57.3683	-165.0409	1,313	0	0	0	1,313	0	0	0	1,313
221	I-05	57.5624	-164.9862	0	0	0	0	0	0	0	0	0
222	I-06	57.6426	-164.9088	0	0	0	0	0	0	0	0	0
223	H-06	57.4727	-164.8018	0	0	0	0	0	0	0	0	0
224	I-06	57.5741	-164.5961	0	0	0	0	0	0	0	0	0
225	I-06	57.6679	-164.5634	0	0	0	0	0	0	0	0	0
226	I-06	57.7097	-164.6112	0	0	0	0	0	0	0	0	0
227	J-06	57.8389	-164.6032	0	1,166	1,166	0	1,166	0	0	0	1,166
228	J-06	57.9256	-164.4340	0	0	0	0	0	1,126	0	1,126	1,126
229	J-06	58.0524	-164.4939	0	0	0	0	0	0	0	0	0
230	K-06	58.2734	-164.2803	0	0	0	0	0	0	0	0	0
231	K-06	58.3088	-164.4591	0	0	0	0	0	0	0	0	0
232	K-06	58.4216	-164.6698	0	0	0	0	0	0	0	0	0
233	K-06	58.2213	-164.7695	0	0	0	0	0	0	0	0	0
234	J-06	58.0635	-164.8707	0	0	0	0	0	1,176	0	1,176	1,176
235	J-05	58.0520	-165.0786	0	0	0	0	0	0	0	0	0
236	J-05	57.9628	-165.0416	0	0	0	0	0	0	0	0	0
237	I-05	57.7722	-165.2672	0	0	0	0	0	0	0	0	0
238	I-05	57.5408	-165.4857	0	0	0	0	0	0	0	0	0
239	H-05	57.4101	-165.4521	0	0	0	0	0	0	0	0	0
240	H-05	57.2982	-165.3893	0	0	0	0	0	0	0	0	0
241	G-05	57.0928	-165.3960	0	0	0	0	0	0	0	0	0