A. ASSESSMENT OF OCEAN QUAHOGS [1]

1.0 TERMS OF REFERENCE (TOR)

1. Characterize the commercial and recreational catch including landings and discards.

Completed--Commercial landings were updated through 2005. Discards are negligible. However, a 5% allowance for incidental mortality due to contact with fishing gear is used in all assessment calculations.

2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years.

Completed--Fishing mortality, fishable and total stock biomass were estimated for 1978-2005. Confidence intervals were calculated to characterize uncertainty. Spawning biomass was calculated on an approximate basis after the SARC based on reviewers' suggestions.

3. Either update or re-estimate biological reference points (BRPs; proxies for B_{MSY} and F_{MSY}), as appropriate. Comment on the scientific adequacy of existing and redefined BRPs.

Partially completed—Biomass reference points B_{1978} (a proxy for virgin biomass), the management target $B_{MSY}=1/2\ B_{1978}$ and the management threshold $B_{Threshold}=1/4\ B_{1978}$ were updated based on new information. Fishing mortality reference points ($F_{Target}=F_{0.1}$ and $F_{Threshold}=F_{25\%}$) were updated using new information about fishery selectivity and maturity in a length based per recruit model. Problems with the scientific adequacy of the current existing $F_{Threshold}$ proxy for F_{MSY} are described. However, there was insufficient time to complete analyses required to recommend an optimum alternative. This work was deferred because fishing mortality rates are very low and there was no urgency.

4. Evaluate current stock status with respect to the existing BRPs, as well as with respect to new or re-estimated BRPs (from TOR 3).

Completed—Stock biomass and fishing mortality estimates for 2005 were compared to updated reference points.

5. Recommend what modeling approaches and data should be used for conducting single and multi-year stock projections, and for computing TACs or TALs.

Completed—A simple modeling approach and data were recommended for projecting biomass and fishing mortality of the ocean quahog stock through 2010.

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[1] This assessment was prepared by the Invertebrate Subcommittee. Contributing members are listed in INTRODUCTION TO SAW-44 ASSESSMENT REPORT.

6. If possible,

    a) provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and

    b) compare projected stock status to existing rebuilding schedules as appropriate.

Completed—Example calculations and projections through 2010 were carried out assuming three quota levels and at $F=F_{0.1}$.

7. Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in recent SARC-reviewed assessments.

Completed—Several key research recommendations were accomplished in this assessment. In particular: 1) a survey was completed, reference points were calculated and biomass and fishing mortality were estimated for ocean quahog in Maine waters; 2) field data collected during 2002 and new data collected during 2005 were examined to determine if survey and commercial dredge efficiency depends on depth, sediment type or clam density; 3) survey selectivity and fishery selectivity curves were used to better interpret survey data; and 4) reference points were revised in this assessment using a new length based model and new fishery selectivity and maturity at length curves.

2.0 EXECUTIVE SUMMARY

A) This assessment for ocean quahog in the US EEZ is based on fishery data landings and LPUE data for 1978-2005 and NEFSC survey data for 1982-2005. Based on assessment results, the ocean quahog population is a relatively unproductive stock which is being fished down slowly towards its B_{MSY} reference point (½ virgin biomass, estimated as 50% of biomass during 1978) gradually after about three decades of relatively low fishing mortality.

B) Ocean quahog in the US EEZ are not overfished and overfishing is not occurring. Stock biomass during 2005 was 3.039 million mt and above the revised management target of ½ virgin biomass = 1.987 million mt. The fishing mortality rate during 2005 for the exploitable region (all areas but GBK) was $F= 0.0077\ y^{-1}$ and below the revised management target level $F_{0.1} = 0.0278\ y^{-1}$.

C) Depletion experiments carried out during 1997-2005 on a cooperative basis with the fishing industry were used to estimate the efficiency of the NEFSC survey dredge, which is the basis for estimating biomass and fishing mortality. Based on all experiments to date, the NEFSC survey dredge has a capture efficiency of 16.5%, which is less than values used in the earlier assessments ($e = 0.269$ in SARC38, and 0.346 in SARC31).

D) Biomass and fishing mortality estimates were improved in this assessment using new information about size selectivity of survey and commercial clam dredges.

E) The estimates of biomass and fishing mortality in this assessment do not include biomass or landings from Maine waters. However, stock biomass is small (~1%) relative to the rest of the EEZ and calculations would not change appreciably if Maine were included. As described below, the Maine fishery and stock component were assessed separately (Russell 2006). Highlights from the Maine assessment are presented here but interested persons should consult the Maine stock assessment report.

F) Biological reference points based on per recruit models ($F_{0.1}$ and $F_{25\%}$) were recalculated based on new length based per recruit model, and new fishery selectivity and maturity curves (see below).

Reference Point	Old (SARC-38)	New
$F_{0.1}$ (target)	0.0275	0.0278
F_{MAX}	0.1810	0.0760
$F_{25\%}$ (threshold)	0.0800	0.0517
$F_{50\%}$	0.0200	0.0180

G) From a technical perspective, the current threshold reference point for fishing mortality $F_{25\%}=0.0517\ y^{-1}$ is a poor proxy for F_{MSY} in a long-lived species like ocean quahog with natural mortality rate $M=0.02\ y^{-1}$.

H) Proxies for virgin biomass and B_{MSY} in this assessment are substantially larger than in NEFSC (2003). In particular, the revised proxy in this assessment for B_{MSY} (½ virgin biomass) was 1.987 million mt compared to 1.5 million mt for B_{MSY} in the last assessment. The new estimates are different primarily because revised survey dredge efficiency estimates are smaller (e=0.165 instead of 0.269-0.346).

I) Biomass during 2005 was 76% of biomass during 1978 for the entire stock and 66% for the entire stock less GBK

J) Fishery LPUE, survey trends and assessment model estimates show substantial declines in stock biomass in southern regions (SVA, DMV and NJ) where the fishery has been continually active. In particular, biomass during 2005 was 5%, 34% and 44% of biomass during 1978 for SVA, DMV and NJ. Biomass trends in northern regions which did not support the fishery until recently (LI, SNE and GBK) are relatively flat and stable. Biomass during 2005 was 94%, 75% and 100% of biomass during 1978 for LI, SNE and GBK.

K) An increasingly large fraction of the stock (83% during 2005 compared to 70% during 1978) is in northern regions (LI, SNE) where fishing is relatively recent and in the GBK region, which is not fished due to risk of PSP contamination.

L) Fishing mortality rates for southern areas where the fishery has been continually active (SVA, DMV and NJ) peaked in the late 1980's and early 1990's then declined as fishing effort shifted towards the north. Fishing mortality rates in northern areas were nearly zero before 1990 and increased substantially afterwards as fishing effort shifted towards the north. Fishing mortality rates for the entire stock increased from near zero in 1978 to average about 0.006 y^{-1} (0.010 y^{-1} for the entire stock less GBK) during early 1990 through 2005.

M) Recruitment events appear to be regional and sporadic (i.e. often separated by decades). Survey length composition data show that recruitment occurs throughout the resource sporadically and at an apparently low rate. Based on survey length composition data and published studies, at least some recent recruitment (small ocean quahog) is evident in DMV, NJ, LI, SNE and GBK during recent years. The potential contribution of recent recruitment to stock biomass and productivity is unknown.

Maine waters

N) Ocean quahog in Maine waters are part of the unit stock covered by the FMP and support a small fishery that is managed under limited entry and quota systems that are separate from the individual transferable quota (ITQ) system used for ocean quahog in the rest of the EEZ.

O) The fishery and biological characteristics of ocean quahog in Maine waters are unique. In particular, the Maine fishery targets small ocean quahog for sale on the half shell market at prices roughly ten times the prices paid for larger ocean quahogs taken elsewhere in the EEZ. Management goals have for ocean quahog in Maine waters have not been described.

P) A survey and stock assessment were completed by the State of Maine for the portion of the ocean quahog stock occupying the major fishing grounds in Maine waters (Russell 2006). Most of the results presented here for the Maine fishery are from Russell (2006).

Q) Assessment results for Maine show relatively high levels of fishing effort and landings in recent years. LPUE levels have declined since the peak in 2002, but remain at relatively high levels overall.

R) Based on a per recruit model analysis, $F_{MAX} = 0.0561$, $F_{0.1} = 0.0247$ and $F_{50\%} = 0.013\ y^{-1}$ for ocean quahog in the major fishing grounds of Maine waters only. These reference points are provided only for comparison and do not have any special status as targets or thresholds.

S) Based on survey results and dredge efficiency estimates for Maine, the biomass of ocean quahog during 2005 that was available to the fishery in Maine waters was

22,493 mt meats. In comparison, catch (landings plus a 5% incidental mortality allowance) during 2005 was 505 mt meats.

T) Fishing mortality during 2005 in the areas surveyed and the principal fishing grounds in Maine waters was estimated to be $F = 505 \div 22{,}493 = 0.022\ y^{-1}$, which is almost equal to $F_{0.1} = 0.0247\ y^{-1}$, a reference point that would provide relatively high levels of yield while preserving some spawning stock.

3.0 INTRODUCTION

Ocean quahog (*Arctica islandica*) in the US Exclusive Economic Zone (EEZ) form a single stock for management purposes. With the exception of a relatively small component off the coast of Maine, the EEZ fishery is managed by under a single individual transferable quota (ITQ) system that was established for ocean quahog and Atlantic surfclam (*Spisula sodidissma*) in 1990. Murawski and Serchuk (1989) and Serchuk and Murawski (1997) provide detailed information about the history and operation of the fishery.

The ocean quahog fishery component off Maine is managed under a relatively small quota that is separate from the quota used to manage the ITQ fishery. The Maine component is of interest because of differences in biological, fishery, market and management characteristics. The ocean quahog assessment this year consists of two reports. The first (Russell 2006) estimates biomass, fishing mortality and per recruit reference points for the stock component in Maine waters based on a survey in 2005 and estimates of survey dredge efficiency. The second (this report) deals with the EEZ as a whole based on the NEFSC clam survey for 1982-2005 and summarized key aspects of the assessment for Maine waters.

Overfishing definitions and other management measures apply at the level of the entire stock although technical information is provided at the level of smaller stock assessment regions (Figure A1 and see below). Georges Bank (GBK) has been closed to ocean quahog harvesting since 1990 when Paralytic Shellfish Poison (PSP) was detected.

Stock Assessment Region	Abbreviation
Maine	MNE
Georges Bank	GBK
Southern New England	SNE
Long Island	LI
New Jersey	NJ
Delmarva	DMV
Southern Virginia and North Carolina	SVA

Categories and units used in this assessment are defined below.

Unit	**Equivalent**
Industry or Mid-Atlantic bushel (Industry bu)	1.88 ft^3
Maine (US standard) bushel (Maine bu)	1.2448 ft^3
Industry bushels x 10	Pounds meat wt
Industry bushels x 4.5359	Kilograms meat wt
Cage	32 Industry bushels
Vessel ton class 1	1-4 gross registered tons (GRT)
Vessel ton class 2	2-50 GRT
Vessel ton class 3	51-150 GRT
Vessel ton class 4	151-500 GRT
Vessel ton class 5	501-1000 GRT

Previous and current assessments

Stock assessments for ocean quahog in the EEZ were completed by NEFSC (1995; 1998; 2000; 2004). The last assessment (NEFSC 2004) concluded that the EEZ ocean quahog resource was not overfished and that overfishing was not occurring. This stock assessment arrives at the same conclusion.

The last assessment (NEFSC 2004) concluded that the qualitative condition of the stock off the coast of Maine was unknown and recommended that the Maine conduct a comprehensive survey and conduct experiments to estimate survey dredge efficiency. These recommendations were completed in this assessment and are presented in a separate report (Russell 2006).

Biological characteristics[2]

Ocean quahog are common around Iceland, in the eastern Atlantic as far south as Spain, and in the western Atlantic as far south as Cape Hatteras (Theroux and Wigley 1983; Thorarinsdottir and Einarsson 1996; Lewis et al. 2001). They are found at depths of 10-400 m, depending on latitude (Theroux and Wigley 1983; Thompson et al. 1980). The US stock is almost completely within the EEZ outside of state waters at depths of about 20-80 m. In a study of the mitochondrial cytochrome *b* gene, Dahlgren et al. (2000) did not find geographical differentiation between samples taken along the US coast from Maine to Virginia.

Ocean quahog are long-lived with some individuals aged at over 200 yrs (Jones 1983; Steingrimsson and Thorarinsdottir, 1995). Early studies of populations off New Jersey and Long Island (Thompson et al. 1980; Murawski et al. 1982) demonstrate that clams ranging in age from 50-100 years are common. In stock assessment work, adult ocean quahog are assumed to die from natural causes at the rate of about 2% annually (instantaneous rate of natural mortality M=0.02 y^{-1}).

Ocean quahog grow slowly after the first years of life (Lewis et al. 2001, Figure A56). Maximum size is typically about 110 mm in shell length (SL) although larger specimens are common. Individuals large enough to recruit to the fishery grow only 0.51-0.77% per year in meat weight and < 1 mm per year in shell length (NEFSC 2004).

Size and age at maturity are variable. Off Long Island, the smallest mature quahog found was a male 36 mm long and 6 years old; the smallest and youngest mature female was 41 mm long and 6 yr old (Ropes et al. 1984). Some clams in this region are still sexually immature at ages of 8-14 years (Thompson et al. 1980; Ropes et al. 1984).

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[2] See Cargnelli et al. (1999) for additional information.

Females are more common than males among the oldest and largest individuals in the population (Ropes et al. 1984; Fritz 1991). Recruitment events are regional and infrequent in ocean quahog with decadal periods of little or no recruitment (Powell and Mann 2005).

4.0 COMMERCIAL AND RECREATIONAL CATCH (TOR-1)

Landings and quotas for the ITQ segment of the EEZ fishery are reported in different bushel units than landings and quotas for the fishery off Maine (Russell 2006). In particular, "ITQ" bushels are used for the ITQ component and "standard" bushels are used for the Maine component. Biomass and landings from both fishery components are reported in this assessment as meat weights (the weight of marketable product after removal from the shell), unless otherwise noted, because meat weights are directly comparable.

Total EEZ landings (including the ITQ and Maine fishery components) were relatively high during 1987-1996 with a peak of 22.5 thousand mt meats (Tables A1-A2 and Figure A2) or 4.9 million ITQ bushels (Table A3) during 1992. After 1996, landings declined to a low of about 15,000 mt meats (3.3 million ITQ bushels) during 2000 and then increased to about 19,000 mt meats (4.2 million ITQ bushels) during 2003. Landings declined after 2003 to about 14,000 mt meats (3.2 million ITQ bushels) during 2005, which was the lowest level since 1981. Industry sources report that low landings during the most recent years were due to low market demand. The ITQ component accounted for almost all (≥98%) of total EEZ landings during 1990-2005. Landings from Maine waters are minor in comparison to EEZ landings (Tables A2-A3 and Figure A2).

Landings from Maine waters increased steadily after 1990 to relatively high levels (≥ 326 thousand mt meats annually) during 2000-2003 (Tables A2-A3). Landings in Maine waters decreased after 2003 to 294 thousand mt meats during 2005, which was the lowest level since 1999.

Landings by the ITQ component averaged 85% of the EEZ quota during 1990-2005 (Table A1). In contrast, the 100,000 Maine bushel quota allocated for ocean quahog in Maine waters was usually exhausted during 1999-2005 with vessels leasing ITQ shares in some years to harvest more than 100,000 mt meats from Maine waters (Tables A2-A3).

Landings of quahogs from state waters outside of Maine are near zero because ocean quahog are found offshore in relatively deep water. Landings in recreational fisheries are nil because commercial clam dredges are required to harvest ocean quahog and because ocean quahog are an industrial product with no recreational value.

4.1 Prices

Nominal exvessel prices for ITQ ocean quahog landings (expressed as dollars per ITQ bushel) decreased slightly during 2001-2004 (Table A4 and Figure A3). In real terms, prices during 2004 were about the average of real prices during 1994-2004. Prices for ocean quahog harvested in Maine waters (dollars per ITQ bushel) were roughly ten times higher than prices for ocean quahogs harvested in the rest of the EEZ (Table A4 and Figure A3).

4.2 Fishing effort

Total hours fished annually in the ITQ fishery component decreased from a peak of about 40,000 hr y^{-1} during 1991-1994 to about 30,000 hr y^{-1} during 1996-2004 and then decreased to about 20,000 hr y^{-1} during 2005 (Table A5 and Figure A4). The total number of trips in the ITQ fishery decreased steadily from about 3000 trip y^{-1} during 1991 to about 1000 trips y^{-1} during 2005 (Figure A5). In contrast, hours fished and trips increased in the Maine fishery component during 1991-2005. The number of active permits (vessels with landings) remained relatively constant during 1996-2004 but declined slightly during 2005 (Figure A6). Number of active permits, and fishing effort (hours fished and numbers of trips) is high in Maine waters relative to other stock assessment regions in the EEZ (Figure A4-A6).

4.3 Landings per unit effort (LPUE)

It is useful express trends in LPUE in terms of average catch rates for an actual vessel because industry sources report that fishing in the ITQ sector is profitable when LPUE is at least 110-120 bushels h^{-1} (D. Wallace, pers. comm.). The break-even LPUE reported in the last was assessment 80 bushels h^{-1} (NEFSC 2004). The new estimate is higher because of inflation, increased steaming time to relatively distant fishing grounds, operation of new larger vessels, and increased costs for food, fuel, insurance, etc. These estimates are not applicable to fishing in Maine waters.

LPUE (LPUE, bushels landed per hour fished) in the ocean quahog fishery may be a better measure of fishing success than a measure of stock abundance because changes in abundance or biomass for regions as a whole may be masked by concentration and movement of fishing effort between regions where ocean quahog density and catch rates are high (see below). In spite of these potential problems, LPUE and NEFSC clam survey data are highly correlated (see Section 5).

Trends in LPUE were not sensitive to the details of calculation (Table A6 and Figure A7). Three measures of LPUE were calculated for each stock assessment region based on vessel size classes 3-4 for the ITQ fishery and vessel size classes 1-2 for the Maine fishery. The size classes used in calculating LPUE accounted for almost all landings. "Nominal mean LPUE" was the average catch rates for individual trips in each region and year. "Total bushels/total hours" was the ratio of total landings and total hours fished. The "standardized index" for each region was calculated from the year effects estimated in a general linear model (described below).

General linear models (GLM) used to standardize LPUE data for ocean quahog were fit to trip-level log book data. A separate model was run for each stock assessment region because trends differed among regions. The dependent variable in GLM models was log LPUE (ITQ or Maine bushels per hour fished). There was no need to add a constant before taking logs because catch was greater than zero for all trips. The models included categorical year, month and vessel effects, which were statistically significant in every case. Other factors might have been included in GLM models but vessels and months were of special interest and other model formulations gave very similar trends in standardized LPUE.

The time series of standardized LPUE for each region was computed from the back-transformed year effects with adjustments so that the indices for each area were in units of LPUE for a single vessel that fished in each of the DMV, NJ, LI and SNE stock assessment regions. A different vessel was chosen for MNE.

GLM results show that standardized LPUE during 1985 declined in the DMV, NJ and LI stock assessment regions and fluctuated without trend in the SNE region (Table A6 and Figure A8). In the Maine fishery, standardized LPUE increased during 1991-2000, decreased afterwards but was still relatively high during 2005. Differences in trends among regions are discussed in detail below.

GLM results show that LPUE is slightly higher in the DMV, NJ, LI and SNE regions during February-April (Figure A9). LPUE in the Maine fishery peaks in June.

4.4 Spatial patterns in fishery data

Spatial patterns are important in interpreting fishery data and in managing fisheries for sessile and relatively unproductive organisms like ocean quahog. The ocean quahog stock is a complicated spatial mosaic with scattered productive and profitable fishing grounds where abundance is high and where fishing mortality tends to be concentrated. The size of productive fishing grounds for ocean quahog appears to be less than the size of ten minute squares (TNMS, 10' x 10' $\cong$ 100 nm^2), which are the smallest spatial strata consistently reported on logbooks and used in this stock assessment.

As described in NEFSC (2004), spatial patterns in cumulative landings, cumulative effort and LPUE are related. The spatial distribution of landings and fishing effort in the ITQ fishery component changed markedly over time. During the 1980s, nearly all of the landings (Figure A2) and fishing effort (Figure A4-A5) were from the southern DMV and NJ stock assessment regions. As LPUE declined in the southern DMV and NH stock assessment regions (Figure A8), fishing effort and landings shifted offshore and north to the LI and SNE stock assessment regions. During 2005, in particular, the southern DMV and NJ stock assessment regions accounted for less than 20% of landings and fishing effort while the bulk of landings and effort (outside of Maine waters) were from LI (Figures A2 and A4-A6).

Fishery data by ten-minute square (TNMS)

All vessels that fish for ocean quahog in the EEZ use logbooks to report landings and fishing effort by TNMS for each trip. TNMS are identified by six digit numbers. For example, TNMS 436523 is a ten-minute square that lies within the one-degree square with southeast corner at 43^o N and 65^o E. TNMS are formed by dividing one-degree squares further into six columns and six rows that are 10' wide. Columns are numbered 1-6 counting from west to east and the column number is given in the TNMS name before the row number. Rows are numbered 1-6 counting from north to south. Thus, TNMS 436523 is the ten-minute square whose southeast corner is at 43^o 30' N and 65^o 40' E.

Landings (Figure A10) during 1980-1990 were concentrated in relatively few TNMS that were primarily in the south and relatively inshore. Over time, TNMS with highest landings shifted offshore and north. Landings during 2001-2005 were concentrated in the LI stock assessment region.

Fishing effort (Figure A11) was concentrated in a few southern TNMS during 1980-1990 with three adjacent TNMS having effort levels higher than 1,000 h y^{-1} and appreciable fishing effort south of 38^o N. Fishing effort spread into additional offshore and northern TNMS during 1991-1995 and 1996-2000. After 1995, there were few or no TNMS with effort levels above 1000 h y^{-1}. During 2001-2005, there was a no fishing effort south of 38^o N.

LPUE (Figure A12) was relatively high inshore and south during 1980-1990 with ten TNMS that had LPUE ≥ 161 ITQ bushels h^{-1}. LPUE in the area below 40° S was generally high. LPUE declined in the south and fishing effort spread northward during 1991-1995 where LPUE was relatively high. During 1996-2000, LPUE declined in both the northern and southern areas. By 2001-2005, LPUE was often ≤ 80 ITQ bushels h^{-1} below 40° S.

Trends

Trends in landings and LPUE during 1980-2005 were plotted for individual TNMS that were important in the fishery (Figures A13-A15). Important TNMS were selected by sorting TNMS according to total landings during 1980-1990, 1991-1995, 1996-2000 and 2001-2005 and then selecting the top 20 TNMS during each time period. All of the TNMS selected in this manner were combined to form a single unique set of 79 TNMS that were important to the fishery at some time during 1980-2005.

Trends in LPUE for individual TNMS tend to be relatively high in during the first years of exploitation and then to subsequently decline as effort, annual landings and cumulative landings increase over time (Figures A13-A15). Decreasing trends in LPUE appear strongest in southern areas such as TNMS 377422 to 397326 with the longest history of exploitation. LPUE does not appear to increase in a TNMS once fishing effort decreases.

Unlike LPUE which is highest in the first years of exploitation, landings and fishing effort tend to peak after 5-10 years of exploitation while LPUE is still relatively high and then to decrease over a 5-10 y period as grounds are fished down (Figures A13-A15). In some TNMS with low recent LPUE levels (e.g. TNMS 387443-397316), fishing effort increased during 2001-2005 with some increase in landings.

4.5 Bycatch and discard

Landings and catch are almost equal in the ocean quahog fishery because discards are nil. Discard of ocean quahog in the ocean quahog fishery does not occur because undersize animals are automatically released by automatic sorting equipment. However, some incidental mortality occurs. Based on Murawski and Serchuk (1989), NEFSC (2004) assumed incidental mortality rates of ≤ 5% for ocean quahog damaged during fishing but not handled on deck. As in previous assessments, fishing mortality and other stock assessment calculations in this report assume 5% incidental mortality rates (i.e. landings x 1.05 = assumed catch).

Bycatch of ocean quahog probably occurs in fishing for Atlantic surfclam but has not been quantified and is certainly minor. Off DMV and SVA in the southern end of the ocean quahog's range, survey catches including both surfclam and ocean quahog have become more common in recent years as surfclam have shifted towards deeper water in response to warm water conditions (Weinberg et al. 2005). However, mixed loads of surfclam and ocean quahog are not acceptable to processors and it is not practical to sort catches at sea so that vessels would tend to avoid areas where both species might be caught.

Bycatch and discard of ocean quahogs in other fisheries is nil. Ocean quahogs are not vulnerable to bottom trawls, scallop dredges (because they are too deep in sediments), or hook and line gear.

4.6 Commercial size-composition data

Commercial length composition data (shell lengths, SL) for ocean quahogs collected by port agents from landings indicate that the size composition of ocean quahog captured in the DMV stock assessment region differed during 1987-1994, 1995-2000 and 2001-2005 (Figure A16). Lengths for DMV during 1987-1994 and 2001-2005 were similar.

Commercial length composition data for NJ were stable during 1982-2002 with smaller ocean quahog landed during 2003-2005 (Figure A17). Length data for LI include relatively high proportions of large individuals (11-12 cm SL) during 1997-1999 (Figure A18). Length data for SNE during 1998-2005 were generally stable but with smaller ocean quahog landed during 1997-2000 (Figure A19). According to NEFSC (2004), smaller sizes landed from SNE during 1997-2000 were due to vessels targeting specific beds with relatively small ocean quahogs that had relatively high meat yield.

4.7 Fishery selectivity

Commercial fishery selectivity estimates used in this assessment for ocean quahog are from Thorarinsdottir and Jacobson (2005) who estimated selectivity of commercial dredges that harvest ocean quahog off Iceland. The selectivity curve $s_L = 1/\left(1+e^{7.63-0.105L}\right)$, where L is shell length in mm, indicates that about 10%, 50% and 90% of ocean quahog are available to the fishery at 51, 72, and 93 mm SL (9, 28 and 86 y, based on the growth curve in Figure A59).

Dredges and towing speed in the US fishery are very similar to dredges and tow speed used in the selectivity experiments. The dredge used for selectivity experiments was 24 ft (7.35 m) in length, 5 ft (1.5 m) high and 12 ft (3.65 m) wide. The cutting blade was 10 ft (3.05 m) wide and set to penetrate sediments to a depth of 3 in (8 cm). The dredge was made of steel bars with intervening spaces of 1 ¼ in (3.5 cm) and was towed at about 2.1 knots (3.9 km h^{-1}). Water pressure supplied to jets on the dredge from a pump on the ship was about 109 psi (7.5 bars). Water pressure levels in the US fishery are usually lower (~80 psi) but water pressure probably has relatively little effect on size selectivity. Fishery selectivity curves are used in tracking trends in fishable biomass, estimating fishing mortality and in calculating biological reference points.

5.0 MORTALITY AND STOCK BIOMASS (TOR-2)

Mortality and stock biomass estimates for ocean quahog in the US EEZ are based on triennial NEFSC clam surveys, cooperative field studies used to measure survey dredge efficiency, and fishery data.

5.1 NEFSC Clam Surveys-Results

NEFSC clam surveys have been conducted since 1965 and are the main source of fishery-independent information about long term trends in abundance, biomass (Table A7, Figure A20), recruitment (Figure A21), stock distribution (Figures A22-A25 and Appendices A7-A8) and population length composition (Figure A26) for ocean quahog in the EEZ. The small area of coastal Maine waters is not covered by the NEFSC clam survey but it is minor in terms of stock biomass (20 vs. 2,700 thousand mt meats, Russell 2006) and landings (500 vs. 14,000 mt meats).

Based on survey data and in general terms (see below for details), fishable abundance (mean number per tow), stock biomass (mean kg tow) and spawning biomass (mean kg/tow) declined during 1982-2005 in southern areas (SVA, DMV and NJ) where the bulk of fishing has occurred while fishable biomass in northern areas (LI, SNE and GBK) remained relatively high and stable (with the exception of GBK in the 1999 survey). LI is the only area with clear evidence of strong recruitment after 1982 based on survey length and recruit trend data. In particular, length data from LI show ocean quahog at 65 mm SL during 1978 that grew slowly over time and became indistinguishable from the rest of the LI stock by about 1994 (Figure A26). Recruitment trend data for LI are higher prior to 1994 than afterwards and variable in other regions (Figure A21). Trends in spawning and stock biomass were nearly the same.

Survey methods

Survey data used in this assessment were from surveys during 1982-2005 by the *R/V Delaware II*, which were carried out during the summer (June-July), using the standard NEFSC survey hydraulic dredge with a submersible pump, 152 cm (60 in) blade 5.08 cm and small 5.08 cm (2 in) mesh liner. The survey dredge differs from commercial dredges in being smaller, using the small mesh liner, and in having the pump mounted on the dredge, rather than the deck of the vessel. The survey dredge used since 1982 catches ocean quahog as small as 50 mm SL with some reliability.

Surveys prior to 1982 were not used in this assessment because they were carried out during different seasons, used other sampling equipment or, in the case of 1981, have not been integrated into the clam survey database (Table A7 in NEFSC 2004). The last stock assessment for ocean quahog (NEFSC 2004) used survey data for 1978-1980 assuming that catchability was different during than in later surveys. In effect, the data for 1979-1980 were treated as a short separate survey time series that had little or no effects on stock assessment estimates. Catchability coefficients for earlier surveys were much different than for surveys since 1981 (NEFSC 2004).

NEFSC clam surveys are organized around NEFSC shellfish strata which are combined to define stock assessment areas (Figure A1). Most of ocean quahog landings originate from areas covered by the survey. The survey did not cover GBK and SVA completely in all years and strata in other areas are occasionally missed (Table A8). Strata not sampled during a particular survey are filled by borrowing data from the same stratum in the previous and/or next survey, if data are available (NEFSC 2004). Survey data are never borrowed from surveys behind the previous or beyond the next survey.

Surveys follow a stratified random sampling design, allocating a pre-determined number of tows to each stratum. Stations used to measure trends in ocean quahog abundance are either random or nearly random. A few nearly random tows were added in previous surveys to ensure that important areas were sampled. Other non-random stations are occupied for a variety of purposes but not used to estimate relative trends in ocean quahog abundance.

A standard tow is nominally 0.125 nm (m) in length (i.e. 5 minutes long at a speed of 1.5 knots). However, sensor data indicate that the actual tow lengths are greater (Weinberg et al. 2002 and see below).

Occasionally, randomly selected stations are found too rocky or rough to tow. In these cases during surveys since 1999, a search for fishable ground is made in the vicinity (0.5 nm) of the original station (NEFSC 2004). If no fishable ground is located, the station is given a special code (SHG=151) and the research vessel moves on to the next station. The proportion of random stations that cannot be fished is used to estimate the proportion of habitat in a stratum or region that is suitable habitat for ocean quahog, which is used in calculation of ocean quahog biomass from survey data (see below).

Following most survey tows, all ocean quahog and Atlantic surfclam in the survey dredge are counted and shell length is measured to the nearest mm. A few very large catches may be subsampled. Mean meat weight (kg) per tow is computed with shell length-meat weight (SLMW) equations from NEFSC (2004).

SLMW relationships used with survey data to track trends in survey meat weight per tow are region-specific. SLMW relationships used for survey data in this analysis (Table A9) were the same as in the last assessment (NEFSC 2004). They were derived by averaging SLMW curves from the 1997 and 2002 surveys, which were based on fresh tissue minus shell weighed at sea. Samples from earlier surveys were from frozen meats.

NEFSC clam survey require a great deal of additional adjustments after extraction from the database and before they are used in trend or swept-area biomass calculations (e.g. adjustments for tow distance and fishery or survey selectivity). Clam survey database parameters that would be required to replicate each analysis are listed in Table A10).

Survey gear selectivity

NEFSC (2004) estimated selectivity curves for ocean quahog in the NEFSC clam dredge based on catches by a commercial dredge with a small mesh liner during 2003 and survey catches in the same area during 2002. The selectivity curve $s_L = 1/\left(1 + e^{8.122-0.119L}\right)$ indicates that 50% of ocean quahog are fully available to the NEFSC clam dredge at about 68 mm SL, which can be compared to 73 mm for commercial dredges (Figure A27). The survey dredge tends to take smaller ocean quahogs than commercial dredges because of the relatively small 2 in liner in the survey dredge. Based on sizes retained by the survey dredge (NEFSC 2004), the survey dredge selectivity curve is reliable for ocean quahog $\geq$ 50 mm SL.

Survey, stock and fishable abundance and biomass

Catch and length composition data for ocean quahog $\geq$ 50 mm SL from the NEFSC clam survey were used to estimate abundance and length composition for the stock as a whole. In particular, $N_L = n_L / s_L$ where N_L is mean stock numbers or biomass per tow at length L, n_L is survey catch and s_L is survey selectivity.

Abundance and length composition for the fishable stock (i.e. available to the fishery) were estimated by correcting stock estimates for fishery selectivity. In particular, $\eta_L = \phi_L N_L$ where η_L is fishable abundance and ϕ_L is fishery selectivity. Fishable abundance can be estimated directly from survey data for ocean quahog $\geq$ 50 mm SL using $\eta_L = n_L \phi_L / s_L$ (Figure A27).

Calculation of stock abundance and biomass occasionally produces very large estimates for small sizes where selectivity is small (near zero) when ratios n_L / s_L become very large. Calculation of fishable abundance and biomass from survey data does not suffer from this problem because the adjustment of small sizes is relatively modest (Figure A27).

Spawning stock biomass

Trends in spawning stock biomass for ocean quahog were estimated based on survey data by applying a maturity at length relationship for ocean quahog from Thorarinsdottir and Jacobson (2005) to survey length composition for the stock as a whole (i.e. after correction for survey dredge selectivity). In particular, $S_L = m_L N_L w_L$ where S_L and w_L are spawning biomass and mean body weight (from a length-weight relationship) See Section 6 for more information about the maturity curve.

<u>2005 Survey</u>

The 2005 NEFSC clam survey was carried out during late May to early June. There were three legs (stations 1-182 during May 24-June 2, stations 183-250 during June 9-June 17, and stations 251-433 during June 22-29). Four hundred and thirty three stations were occupied. Sensor data used to monitor dredge performance were collected at 399 stations. Two hundred and eighty random and nearly random stations were used to calculate trends in ocean quahog abundance. The set of strata covered during the 2005 survey was similar to strata covered during previous surveys except that no stations were occupied in the most northern (GBK) and southern (SVA) stock assessment regions (Table A8).

Trends in survey, stock and fishable mean kg per tow were calculated for ocean quahog ≥ 50 mm SL in each region (Table A7 and Figure A20). Smaller ocean quahog taken in surveys were not included because catches of small individuals is very low and because selectivity curves used to calculate stock and fishable abundance are not valid below 50 mm SL. Trends in survey, stock and fishable numbers and weight per tow for the same region were generally similar.

The precision of survey trend data from the 2005 survey was typical but results for DMV were relatively imprecise with high coefficients of variation (CV) due to a single large tow in stratum 15 (Table A7). CVs for trend data from surveys during 1982-2005 averaged about 0.3, 0.2, 0.2 and 0.3 in the DMV, NJ, LI and SNE regions.

As described below, trends in NEFSC clam survey data are complicated by changes in survey dredge efficiency.[3] In particular, survey data for 1994 were judged not comparable to survey data from other surveys because power to the dredge used to run the submersible pump during 1994 was set to 480 instead of 460 volts and dredge efficiency was artificially increased during 1994.

Dredge performance

After the 1994 survey, sensors were used to monitor depth (ambient pressure), differential pressure, voltage, hertz and amperage of power supplied to the dredge, x-tilt (side to side), y-tilt (front to back) and ambient temperature during survey fishing operations. At the same time, sensors on board the ship monitor electrical frequency, GPS position, vessel bearing and vessel speed. All sensor data are recorded at 1 second intervals.

Good tows have characteristic sensor data patterns that are easy to interpret (Figure A28). Anomalous patterns indicate potential problems with the tow or sensors.

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[3] "Efficiency" of a clam dredge is the probability that an ocean quahog in the path of the dredge will be caught. Efficiency of capture may differ between quahog of difference size and the definition used here applies to quahog large enough to be fully available to the sampling gear. Efficiency estimates for the survey dredge are used with a variety of other information to estimate the "catchability" coefficients for NEFSC clam surveys that relate survey catches to stock abundance and biomass.

Differential pressure, amperage and y-tilt are particularly important. Differential pressure is one of the factors affecting the flow of water through the jets in front of the dredge blade. Amperage measures the work done by the pump in moving water through the jets. If water is blocked at the entrance to the pump, then both amperage and differential pressure will be low. If water is blocked downstream of the pump, then amperage will be low and differential pressure will be high. Y-tilt can be used to determine if the dredge is on the bottom with the blade in the sediment.

Differential pressure data collected during the 2005 clam survey show a spike early in the first leg (Figure A29) coinciding with a drop in amperage that was due to a faulty screen on the input to the dredge system that allowed rocks to enter and fill the manifold, which is downstream from the pump. The screen was repaired, rocks removed and the affected stations were reoccupied.

Differential pressure appeared to jump from about 40 to about 50 psi beginning at approximately station 221 during the second leg of the 2005 NEFSC clam survey at the same time that amperage might have declined (Figure A29). The timing of the change coincided with malfunction and repair of electrical equipment on the ship that supplies power to the pump on the dredge.

The apparent jump in differential pressure during the second leg of the 2005 survey triggered a careful analysis of survey sensor data and dredge performance (Appendix A1). The apparent problem with differential pressure was determined to stem from sensor drift. In particular, differential pressure measurements before and after the pump was turned on were generally biased high after station 220 to the same extent at each station. The difference between ambient measurements at the surface and during fishing for each tow (another way to estimate differential pressure) was usually about 40 psi and approximately equal to differential pressures measured in the normal manner during the first leg. The alternate estimates of differential pressure did show a slight but steady decline in differential pressure during the survey presumably due to wear on the pump (Appendix A1).

In the course of investigating the problems with differential pressure, a number of stations with poor dredge performance were identified based on problems with differential pressure, amperage, vessel speed, and y-tilt (Appendix A2). Four of the problematic stations (218, 225, 262 and 282) were in areas of typical ocean quahog habitat and would not have been omitted following standard survey procedures.[4] Stations 218, 225, 262 and 282 from omitted from further analysis. Similar problems may have occurred in earlier surveys but can not be detected or removed for lack of sensor data. Analysis of sensor data from the 2002 survey will be analyzed to determine if similar problems occurred during 2002.

Tow distance

Tow distance was estimated for each station in the 2005 NMFS clam survey based on speed over ground (SOG) data from the ship's GPS and dredge inclinometer data from the SSP. SOG was assumed to be the same for the ship and dredge.

Following NEFSC (2003), the dredge was assumed to be fishing effectively whenever the smoothed y-tilt was $\leq 5.16^{o}$ (see below). Based on the geometry of the

---

[4] Standard survey procedures omit stations with database Station Type-Haul Type-Gear Condition (SHG) codes greater than 136.

dredge, the blade penetrates the sediments to a depth of 1 inch when the y-tilt is 5.16°. Penetration increases as the y-tilt decreases.

Tow distance calculations for the 2005 survey were the same as in NEFSC (2003) except that missing values were interpolated as described below. The first step was to replace missing SOG and inclinometer data for each station with interpolated values from a cubic spline. The second step was to smooth the original plus interpolated SOG and inclinometer data with a centered seven point moving average (e.g. the smoothed value for $t = 3$ was the average for $t = 1$ to 7).[5] The final step was to compute the effective tow distance for each tow d_j using:

$$d = \frac{\sum_t \delta_t s_t}{3600}$$

where t was a one-second interval, δ_t was a dummy variable equal to one when the dredge was fishing effectively (smooth y-tilt $\leq 5.16^o$) and zero otherwise, s_t was SOG (knots) and 3600 is the number of seconds per hour. Tow distances calculated in this manner and used in this assessment for surveys during 1997-2002 (see below) were the same as in NEFSC (2003). The median tow distance for 2005 was consistent with median tow distances from the 1999 and 2002 surveys (see below). As pointed out in NEFSC (2003), the median tow distance for 1997 was 0.4-0.7 nm larger than median tow distances from other surveys because a slower winch was used to deploy the survey dredge (Table C7 in NEFSC 2003).

Year	Median Tow Distance (NM)
1997	0.26
1999	0.22
2002	0.19
2005	0.21

Tests showed that the new interpolation procedure had a negligible effect on tow distance estimates for the 2005 survey because missing values were rare. Similar results would likely be obtained for the 2002 survey, which also used the survey sensor package. Effects of interpolation on tow distance estimates were not investigated for 1997 and 1999 surveys but may be larger because sensor data from the 1997 and 1999 surveys were collected using less precise sensors with recording intervals that were sometimes longer than one second. This is a topic for future research.

---

[5] Steps 1-2 were done in SAS (note that interpolation precedes smoothing).

```
proc expand data=sdata1 out=sdata2 to=second;
    by station;
    ID TowTime;
   convert TiltY=SmoothAngle / transform=(cmovave 7);
    convert GPS1_SOG=SmoothSOG / transform=(cmovave 7);
  run;
```

Tow distance vs. depth

Tow distance is a key variable in estimating swept area biomass (see below). Weinberg et al. (2002) show that tow distance increases with depth for the NEFSC clam survey dredge when the dredge is deployed as in actual clam surveys. Regression analysis was used to determine if depth measurements could be used to infer tow length at survey stations when sensor data are not available. Based on graphical relationships (Figure A30), linear regression models were used, e.g. $d_j = \alpha + \beta D_j$ where d_j was tow distance in nm (calculated from sensor data assuming the dredge was fishing when the smoothed y-tilt was $\leq 5.16^{o}$), and D_j was average depth of the tow in meters as measured from the ship. Data used in the analysis were for random survey tows only (tows with database code RANDLIKE > 0). Tows with sensor-based tow distances < 0.125 nm were omitted from the analysis because they were likely aborted or test tows.

A stepwise regression procedure was used to select the best model from a range of models based on the AIC statistic. In the Splus programming language, the simplest model considered was:

```
Smallest <- lm(d~1)
```

where "~1" indicates that the model consists of the mean for the entire data set. The most complicated model was:

```
Biggest<- lm(d ~ CRUISE + D / CRUISE)
```

which is equivalent to a separate regression models relating tow distance and depth in each of the 1997, 1999, 2002 and 2005 surveys (Figure A30).

The most complicated model was selected as the best model by the stepwise procedure based on AIC. The best model was statistically significant (p<0.0001) and all parameters were statistically significant at the p=0.1 level (see below).

```
                                        Standard              p-
                          Estimate       Error     t-test    value
Survey effects (intercept parameters)
         Intercept           0.182       0.002    91.0098      0
            1997            -0.02        0.0028   -7.2647      0
            2002            -0.0093      0.0015   -6.1114      0
            2005            -0.0046      0.0013   -3.6898   0.0002
Depth effects (slope parameters)
           Depth             0.0009       0       20.0054      0
            1997             0.0001      0.0001    1.8697   0.0618
            2002            -0.0001       0       -2.7522   0.006
            2005             0.0001       0        2.5433   0.0111
Residual standard error: 0.02809 on 1179 degrees of freedom
Multiple R-Squared: 0.4634
F-statistic: 145.4 on 7 and 1179 degrees of freedom, the p-value is 0
```

Residual plots indicated reasonably good model fit although distributions of residuals were skewed either to the left or right for some surveys. Based on the regression analysis, tow distance increases by an average of about 0.0009 nm (1.7 m) per meter of depth.

Results show that missing tow distance data for NEFSC clam survey stations could be replaced with estimates based on depth from a survey-specific linear model. Unfortunately, differences among surveys were large enough to be important in estimating tow distance and should not be ignored. It does not appear that a single or average depth-tow distance relationship could be used to estimate tow distance for previous surveys with no sensor data for measurement of tow distances.

Commercial and survey dredge efficiency

Dredge efficiency is defined for this assessment as the probability of capture (i.e. of being handled on deck) for an ocean quahog that is in the path of the dredge and large enough (e.g. 83+ SL in a survey dredge or 90+ mm SL in commercial dredge, see below) to be fully selected by the dredge used in the experiment. Dredge efficiency for smaller ocean quahog is the product of the overall dredge efficiency for fully selected sizes and the selectivity for the particular size.

Collaborative "depletion" experiments were conducted following NEFSC clam surveys in 1997-2005 to estimate commercial and survey dredge efficiency (Figure A31). Commercial dredge efficiency estimates are of considerable interest but are most important in estimating efficiency of the survey dredge deployed from the *R/V Delaware II* during NEFSC clam surveys. Commercial dredges are inherently more efficient than the survey dredge (due to higher pressure water jets) and tend to select larger ocean quahog. In this assessment differences in the size of catches are accommodated by restricting analysis to sizes large enough to be fully selected by survey and commercial gear used in the experiment (see below).

Considerable progress has been made since the last assessment, but efficiency estimates for ocean quahog are still more uncertain and difficult than for Atlantic surfclam (NEFSC 2003). Dredge efficiency is harder to estimate for ocean quahog because they are found in deeper water (which makes dredge position data less reliable) and because they burrow deeper into sediments (and are probably sampled less efficiently) to a degree that depends on environmental conditions.

All depletion experiments for ocean quahog involve fishing repeatedly in the same area, usually until a significant decline in catch per tow is noted. Sensors and GPS equipment are have been used since 1999 to track the performance of the dredge and position of the vessel during each tow (vessel position is used as a proxy for dredge position). Experiments during 1997-1998 used loran positions noted by hand. The accuracy of position information is an important consideration (see below). Catch and position data are used in a statistical analysis (see below) to estimate the efficiency of the dredge used in the experiment.

In a "Delaware II" depletion experiment, the *R/V Delaware II* and NEFSC survey dredge are used to make depletion tows. The efficiency of the survey dredge is estimated from the depletion tow data directly using the "Patch" model (Rago et al., in press and see below). One Delaware II depletion experiment has been completed for ocean quahog (experiment OQ1999-01 DE2 in Table A11).

In "commercial" depletion experiments, a commercial vessel and dredge are used for depletion tows. The efficiency of the commercial dredge is estimated directly using the Patch model.

Commercial depletion experiments can be used to estimate survey dredge efficiency also if the *R/V Delaware II* conducts setup tows prior to the commercial depletion experiment in the same or immediately adjacent area (see below). About five non-overlapping setup tows are typically carried out. Sixteen commercial depletion experiments have been completed by commercial vessels of which thirteen included setup tows (Table A11 and Figure A31).

Patch model

The Patch model was used exclusively to estimate depletion experiment data in this assessment. It has become a standard approach used in NEFSC stock assessment work for a variety of shell- and sedentary demurral finfish including Atlantic sea scallops NEFSC (2004b), ocean quahog (NEFSC 2004), Atlantic surfclam (NEFSC 2003) and goosefish (NEFSC 2005). Other estimators used for ocean quahog in previous assessments were either *ad-hoc* or based on estimators involving assumptions that are tenuous for ocean quahog (e.g. complete mixing after each depletion tow). Now that a sufficient number of depletion experiments have been completed, it is possible to use Patch model estimates exclusively.

The Patch model was used to estimate three parameters for each depletion experiment (initial ocean quahog density, dredge efficiency, and a measure of dispersion) by maximizing the likelihood of the observed catches under the assumptions that the dredge path is known and that the catches are sampled from a negative binomial distribution. The key point is that it is not necessary to assume ocean quahogs mix randomly (except in relatively small cells) after every depletion tow. Ideally, GPS is used to monitor the position of the ship (a proxy for position of the dredge) at one second intervals during each tow (see below). In computing the likelihood for the catch in each tow, the model considers the number of times each grid sampled during the tow had been swept by the dredge in previous tows. Likelihood profiles are used to compute confidence intervals for all model estimates and residual plots (observed – predicted catches) can be used to judge model fit.

Revised estimators for survey dredge efficiency based on setup tows

Efficiency of the NEFSC clam survey dredge is estimated from commercial depletion experiment results by relating densities measured by the *Delaware II* in setup tows to initial density estimated from a commercial depletion experiment by the Patch model (Rago et al., in press). In particular:

$$e = \frac{d}{D}$$

where e is estimated efficiency of the NEFSC survey dredge, d is density (number ft^{-2}) estimated from setup tows by survey dredge, and D is density estimated by the Patch model. In this context, d is understood to measure survey catch rates while D is understood to measure the actual density of quahog on the bottom of the ocean within the boundaries of the depletion experiment site. Previous ocean quahog assessments (NEFSC 1998; NEFSC 2000; NEFSC 2004) used a different formula that is incorrect:

$$e = \frac{d}{D} E$$

where $E \leq 1$ is efficiency of the commercial dredge as estimated by the Patch model (note that this formula is correct if E=1, which is appropriate if D is absolute initial density). For this assessment, all depletion experiments were reanalyzed using the correct formula and other changes described below. All other things being equal, the corrected formula increases research survey dredge efficiency estimates (and decreases swept-area biomass estimates) because $E < 1$ so that $d/D \geq (d/D)E$.

Revised assumptions about dredge selectivity

It is important that data used in the Patch model include only length groups that are (or are nearly) fully selected. For survey efficiency estimates from setup tows and commercial depletion experiments, size groups fully selected by *both* the survey and commercial gear should be used. This restriction is important for two reasons. Firstly, the estimator $e=d/D$ requires that d and D be for the same fully recruited size groups. Secondly, Patch model estimates of E will be biased low if small size groups (with lower selectivity) are included.

Previous assessments (NEFSC 1998; NEFSC 2000; NEFSC 2004) assumed that Patch model estimates were valid as long as the survey dredge and commercial dredge used in the depletion experiment had “similar selectivity” for size groups included in the analysis. Commercial sampling equipment (dredge and shaker table) used in depletion experiments was usually adjusted prior to sampling so that the catch rates for small ocean quahog increased and the modified commercial and survey length composition data were made more similar. Decisions about which size groups to include in an analysis were made in previous assessment after experiments were completed based on length composition data from setup and depletion tows. In practice, length groups actually used in estimation varied from experiment to experiment (e.g. 71+ mm for the OQ2000-1, 76+ mm for the OQ2000-2, and all size groups for the OQ2002-1 to OQ2002-4 depletion studies). In experiments during 1997-1999 that used only one type of gear, all size groups were used.

Revised depletion study catch data

For this assessment, all depletion experiments during 1997-2005 were analyzed or reanalyzed using depletion experiment catch data (numbers of ocean quahog per tow) for size groups that were at least 85% selected by all gear used in the experiment. In particular, catches for commercial depletion experiments and setup tows were for ocean quahog 90+ mm SL and catches for Delaware II depletion experiments were for ocean quahog 83+ mm SL. Based on selectivity curves (Figure A27), 87% and 93% of ocean quahog are selected by commercial and survey dredges at 90 mm SL. As mentioned above, commercial equipment was usually adjusted prior to use in depletion experiments so that commercial selectivity at 90 mm SL was likely higher than 90%. Data analyzed from Delaware II depletion experiments were for ocean quahog 83+ mm SL because survey dredge selectivity is 85% at that size.

The decision to use the size at 85% selectivity as the cutoff was pragmatic. A higher selectivity cutoff level might be preferred on mathematical grounds but the variability of catch data decreased when fewer sizes were included. For example, data from the OQ2000-1 depletion experiment were used to estimate commercial dredge efficiency but could not be used to estimate survey dredge efficiency because relatively few ocean quahog 90+ mm were taken in setup tows. In OQ2000-1 setup tows, large ocean quahog comprised only 6% of the setup catch on average.

Calculation of catch of ocean quahog larger than a specified size (e.g. 90+ mm) requires information about the catch in bushels in each tow, the number of clams per bushel ("bushel counts"), and the proportion of clams larger than 90+ mm (from length measurements. Ideally:

$$n_{t,90+} = B_t n_t p_{t,90+}$$

where B_t is catch in bushels for tow t, n_t is the number of ocean quahogs in a sample bushel and $p_{t,90+}$, is the proportion of the length sample that was at least 90 mm SL.

Bushel counts and length data measurements were not collected from every tow during depletion experiments. During most experiments, one bushel of ocean quahog was counted and one bushel was measured at intervals of 3-5 tows, and occasionally at longer intervals (Table A11). In some cases, the number of broken clams was recorded so that the number measured plus broken provided additional information about numbers per bushel.

A convention was developed to objectively calculate the number of ocean quahog above a specific size for tows without bushel counts or length data. For example, if an experiment consisted of 10 tows with samples taken on tows 2, 6 and 9, then n_2 was used for tows 1-2. The average of n_2 and n_6 was used for tows 3-5. The average of n_6 and n_9 was used for tows 7-8. Finally, n_9 was used for tows 9-10. In previous assessments, a variety of conventions (including the one used in this assessment) was employed for different tows and different depletion experiments.

In theory, bushel counts should increase and proportions of large individuals in catches should decrease as a depletion study is carried out and large ocean quahog are preferentially removed from the study site. This pattern was not, however, consistently observed.

Length and bushel count data from depletion and setup tows appears more important than recognized in previous assessments. More detailed length data (e.g. 1 bushel per tow) should therefore be collected during future depletion experiments. Lengths and bushel counts were likely under-sampled in depletion experiments to date (Table A11)

Accuracy and precision of position data

Cell sizes used in Patch model runs for this assessment are 20-25 ft (Table A11). Previous assessments used 10-25 ft. Position data used in the Patch model for ocean quahog depletion experiments should be recorded at (or interpolated to) intervals $\leq$ 0.00001 degrees to avoid missing cells (see below). Position data recorded to 0.0001 degrees, for example, are too coarse, because the wrong cell would be assigned frequently due to imprecision in position measurements. This recommendation assumes that vessel position is an accurate proxy for dredge position. The accuracy of GPS data as information about dredge position likely deteriorates with depth. Problems with position information may be exaggerated to some extent for ocean quahog, which are found in relatively deep water. Potential effects of inaccurate position data should be evaluated by simulation analysis. Position data were smoothed prior to use in this assessment to account for imprecise position data from some depletion experiments (see below).

Distance in feet for a change in latitude or longitude at 40° N.

	Distance in Feet	
Degrees	Latitude	Longitude
1	364,560	279,269
0.1	36,456	27,927
0.01	3,646	2,793
0.001	365	279
0.0001	36.5	27.9
0.00001	4	3
0.000001	0.4	0.3

Position data used in the Patch model should be recorded at (or interpolated to) intervals ≤ 4 second intervals to avoid skipping cells too frequently between position observations. The target tow speed for the *R/V Delaware II* during depletion tows is 1.5 knots or 2.5 ft sec^{-1}. Commercial vessels probably average about 2 knots or 3.4 ft sec^{-1} during commercial operations tows (D. Wallace, Wallace and Associates, pers. comm.) and about 3 knots or 5 ft sec^{-1} during depletion tows (E. Powell, Rutgers University, pers. comm..). Thus, sampling (or interplation) at intervals of 1-3 seconds is recommended because the *R/V Delaware II* crosses a 20 ft cell in 8 seconds and a commercial vessel crosses a 20 ft cell in 4 seconds (see below). Smaller cell sizes require more frequent sampling or interpolation. Position data were interpolated in this assessment to account for relatively long sampling intervals in some depletion experiments (se below).

Time in seconds required to cross Patch model cells 15-25 ft wide at vessel speeds of 1.5 and 2 knots.

	Vessel speed (knots)	
Feet	1.5	3
15	5.9	2.9
20	7.9	3.9
25	9.9	4.9

Smoothed position data for depletion experiments

Position data for 1997-2005 depletion experiments were from original Loran or GPS records. Start and stop times for GPS data were the same as used in the last assessment).

Position data from depletion studies during 2000-2005 were recorded to 10^{-6} degrees at one second intervals based on differential GPS or the equivalent (Table A11). However, position data from the 1999 Delaware II depletion study from GPS were recorded to only 0.0001 degrees and position data from loran readings in depletion studies during 1998-1998 were recorded to an accuracy of about 0.0001 degrees.

To avoid problems with erratic "stair pattern" tow tracks from coarse position data, original position data from all depletion experiments were smoothed prior to further analysis (Appendix A3). The smoother was a cubic spline when the number of observations $n \geq 15$, a quadratic polynomial when the number of observations was $5 \leq n < 15$ or a straight line when $2 \leq n < 5$. Smooth lines were fit using latitude or longitude as the dependent variable and order of collection (a crude measure of time) as the independent variable. Smoothed values were used in subsequent calculations, instead of the original data. Decisions about smoothing were ad-hoc but consistently applied and seemed to result in plausible tow paths for further analysis (Appendix A3). Fortunately, survey dredge efficiency estimates were from recent depletion studies with generally accurate position data sampled at relatively frequent intervals. With accurate data at frequent intervals, smoothing had very little effect of tow path data.

No position data were available for 2 out of 60 tows in the 1999 Delaware II depletion experiment. Crude estimates of the start and stop locations for these tows from previous assessments from a previous assessment were used instead.

Before analysis in the patch model, original or smoothed position data were interpolated along straight lines to a distance of 5 ft (~ 1- 2 second intervals) to ensure that all cells that were crossed by the dredge would be recorded as "hits" in the Patch model program. This was apparently not done for all depletion experiments in previous assessments and it is possible that not all hits were included in previous estimates. In future assessments, interpolation should be based on the model (e.g. cubic spline) used to smooth the original position data, rather than by linear interpolation.

Assumptions about cell size

All depletion studies were analyzed or reanalyzed using consistent and updated assumptions about cell size and indirect effects, which are closely related. Rago et al. (in press) suggested that the cell size be set at twice the width of the dredge used in the depletion experiment. They point out that decisions about cell size reflect a compromise between the accuracy of position data and the tenability of the assumption that animals mix within cells after each tow. Dredges used in depletion experiments were mostly ≥ 10 ft wide with the exception of the commercial dredge in the OQ1997-1 commercial depletion experiment and the 5 ft dredge used in the OQ1999-1 (DE-2) Delaware II depletion experiment (Table A11).

In this assessment, the cell size in Patch model analyses was set at twice the dredge width or 20 ft, whichever was larger. This approach basically follows the advice in Rago et al. (in press) for all experiments during 2000-2005 while assuming that positional accuracy (particularly for experiments during 1997-2005) was never better than 20 ft. Patch model estimates for ocean quahog were moderately sensitive to the assumed cell size (Figure A32). In particular, efficiency estimates tend to increase and density estimates tend to decrease as the cell size assumed in the Patch model increase.

Indirect effects

The "gamma" parameter in the Patch model is used to measure indirect effects (ocean quahog lost from the study site without being counted on deck). In this assessment gamma was fixed at the ratio of the dredge width and cell width (γ=0.5) so that no indirect effects were assumed to occur. The gamma parameter is theoretically estimable but estimation has proven difficult in practice because the estimate for gamma is correlated with other estimates in the model and dependent on assumptions about cell size (Rago et al., in press). The previous assessment assumed indirect effects (γ=0.75) in depletion experiments during 1997-2000 and no indirect effects (γ=0.5) in depletion experiments during 2002. As shown in Rago et al. (in press) efficiency and density estimates from the Patch model tend to decrease as the assumed level of γ increases.

Sensitivity to initial parameter estimates

Patch model estimates were not sensitive to the starting values for parameter estimates. After an initial Patch model run for each experiment was completed, the model was rerun several times to determine if results were sensitive to starting parameter values. In particular, the model was rerun at least four times with HD/LE, LD/HE, HD/HE and LD/LE where HD, LD, HE and LE stand for higher and lower starting density values and higher and lower starting efficiency values. In general, higher starting values were 2-3 times higher than the initial estimate and lower starting values were one-half to one-third of the initial estimate. The estimate providing the best fit to the catch data (smallest negative log-likelihood) was the best estimate.

2005 Depletion experiments

In 2005, five new commercial depletion experiments were completed with five setup tows and 17-21 depletion tows per site (Figures A33-A37). No Delaware II depletion studies were carried out for ocean quahog during 2005. Details about depletion studies during 2002 are described in NEFSC 2004, experiments during 1998 and 1999 are described in NEFSC (2000) and experiments during 1997-1998 are described in NEFSC (1998).

Survey sensor package equipment (with the exception of GPS and a backup depth sensor) did not function during ocean quahog depletion tows by the commercial vessel during 2005 due to battery failure, with the exception of initial tows at the OQ2005-6 depletion site.

The survey data that are available for 2005 commercial depletion tows (Figure A38) indicate that the commercial dredge was not always horizontal and hard on bottom at the OQ2005-06 depletion site due to the combined effect of low scope and choppy seas. The estimated efficiency for OQ2005-06 may have been reduced by these factors. The OQ2005-06 site was in the deepest water (65 m, Table A11) and conducted in choppy seas. The commercial dredge was deployed at this site with lower scope because the hose used to supply water to the dredge was relatively short. The sea was calmer and shallower at towing scope was greater at other relatively shallow depletion sites for ocean quahog during 2005. Although no sensor data are available, it is likely that the commercial dredge towed well at the other 2005 ocean quahog depletion sites.

As in previous years, commercial sampling equipment (dredge and shaker table) used in 2005 was adjusted to increase catch of relatively small ocean quahog. However, length composition data for the setup and depletion tows at each site during 2005 indicate that the selectivity of the two dredges differed (Figure A39). Confidence intervals and residual plots (Appendix A4) indicate that efficiency and density estimates from experiments during 2005 were reasonably precise.

Depletion study results

For this assessment, all depletion experiments for ocean quahog during 1997-2005 were analyzed or reanalyzed using the Patch model based on revised data, assumptions and procedures described above. All of the underlying data, with the exception of the raw GPS position information collected during depletion studies during 1999-2005, were reevaluated. Residuals and confidence intervals for Patch model parameters are shown for each depletion experiment in Appendix A4. Estimates and model fit are summarized in Tables A11-A12. To build a bridge between new and old results, differences between efficiency and density estimates in this and previous assessments are summarized in Table A13.

Estimates from commercial depletion experiments during 1997-1998 and the Delaware II depletion experiment during 1999 are probably less reliable than estimates from experiments during 2000-2005. Position data were relatively imprecise in depletion experiments prior to 2000 (Table A11). Goodness of fit to depletion catch data was poor for the OQ1998-1 and OQ1999-1 (DE-2) experiments (Appendix A4). Average annual commercial efficiency estimates from experiments during 1997 (*E*=0.592) and 1998 (*E*=0.860) were outside the range of average annual estimates for later years (i.e. *E*=0.615, 0.588 and 0.559 during 2000-2005). The OQ1999-1 (DE-2) survey dredge efficiency estimate was anomalously high and the corresponding density estimate was anomalously low, relative to estimates from later commercial depletions with setup tows.

There were no clear relationships between dredge efficiency and density or depth (Figure A40). There is, however, a suggestion of a negative correlation between survey dredge efficiency and sediment size.

Revised Patch model estimates of commercial and survey dredge efficiency from historical depletion experiments were smaller than previous estimates with a few exceptions (Table A13). Revised density estimates were always smaller but the revised and previous density estimates are not comparable because they are for different size groups.

The seventeen commercial dredge efficiency estimates indicate that efficiency of commercial dredges is highly variable with *E* = 0.15 to 1.00 (Tables A11-A12 and Figure A42). The average and median of estimates of commercial efficiency were 0.60 (CV=24%) and 0.66 (CV=14%).

Twelve survey dredge efficiency estimates were available, eleven from commercial depletion experiments with setup tows and one from a depletion study by the *R/V Delaware II* (Tables A11-A12). Survey dredge efficiency estimates were also variable (*e* = 0.098 to 0.990, Figure A43). Omitting the estimate from the OQ1999-1 (DE-2) experiment, which was anomalously high, survey dredge efficiency estimates ranged 0.098-0.297. The average and median of estimates of survey efficiency were 0.248 (CV=29%) and 0.165 (CV=18%). The ratio of median commercial efficiency and median survey dredge efficiency indicates that the NEFSC survey dredge is about one-quarter as efficient as commercial dredges (Table A12). Survey dredge efficiency estimates did not appear correlated with commercial dredge efficiency estimates (Figure A41).

Density estimates for ocean quahog 90 mm SL (Table A11-A13 and Figure A42) ranged 0.007-0.295 ft^{-2}. The smallest density estimate (0.007 ft^{-2}) was from the OQ1999-1 (DE-2) survey depletion experiment, which gave an anomalously small survey dredge efficiency estimate. The highest density estimates (0.226-0.295 ft^{-2}) were the OQ2002-1 and OQ2002-2 depletion experiments.

Best survey dredge efficiency estimate

The "best" estimates for survey dredge efficiency (*e*=0.165, CV=18%), commercial dredge efficiency (*E*=0.66, CV=14%) and ocean quahog density (*D*=0.082 ocean quahog ft^{-2}, CV=13%) were the medians of all available estimates from ocean quahog depletion experiments during 1999-2005 (Table A12). Medians were used because they are robust to anomalous estimates, such as the high estimate for survey dredge efficiency from the OQ1999-1 (DE-2) experiment and the low estimate of commercial dredge efficiency from the OQ1997-3 experiment (Table A11).

The new best estimate of survey dredge efficiency (*e*=0.165) is smaller than the estimates used in the last assessment NEFSC (2004) for the 1997 survey (*e*=0.346) and for the 1999-2000 surveys (*e*=0.269).

Ideally, efficiency estimates would be survey specific because differences in sampling efficiency are possible. However it is not possible at present to estimate dredge efficiency for each survey with sufficient precision.

Depletion experiments-building a bridge

As described above, factors that contribute to the differences between the previous and revised estimates are:

1) Revised computer programs
2) Corrected formula for survey dredge efficiency based on setup tows.
3) Cell size assumed in the Patch model set to the larger of 20 ft or twice the dredge width (affects OQ1997-01 and OQ1999-1 DE-2 only);
4) Depletion and setup catch data for ocean quahog 90+ mm SL (affects all depletion studies during 1997-2002);
5) Revised position data (new smoothing and interpolation, affects all studies during 1997-2002);
6) No indirect effects, i.e. γ = ratio of dredge width and cell size (affects all depletion studies during 1997-2000);

Not all changes apply to each depletion experiment.

To build a bridge between old and new results, effects on efficiency and density estimates due to individual factors for the OQ1998-1 and OQ2002-1 depletion experiments are shown in Table A14. In the OQ2002-1 experiment, estimates were most sensitive to using the correct formula, revised position data, and revised catch data while the density estimate was most sensitive to using catch data for ocean quahog 90+ mm SL only. In the OQ1998-1 experiment, estimates were most sensitive to using the revised position and catch data.

Repeat stations

Stations from previous and the current survey are repeated during each survey to help detect potential changes in sampling efficiency. Catch data for stations sampled twice during the 2005 survey and during both the 2002 and 2005 surveys were analyzed for this assessment but results are not presented here because the repeat stations were in Atlantic surfclam habitat where ocean quahog catches were very low.

5.2 Efficiency corrected swept area biomass

Efficiency corrected swept area biomass (ESB) estimates were for years (1997, 1999, 2002 and 2005) when NEFSC clam surveys collected sensor data for each tow. Sensor data are important because ESB calculations require accurate measurements of tow distance. Differences in ESB estimates between this assessment and NEFSC (2004) for 1997-2002 are described in detail below under the heading “Building a bridge”.

ESB estimates (Table A15) for ocean quahog were calculated:

$$B = \frac{B'}{e}$$

where:

$$B' = \frac{\overline{\chi} A'}{a}(1+\phi)u$$

In ESB calculations, *e* is the best estimate of survey dredge efficiency for ocean quahogs, $\overline{\chi}$ is mean catch of fishable ocean quahog per standard tow based on sensor data (kg tow^{-1}, see below), *A'* is habitat area (nm^2), $a= 0.0008225\ \text{nm}^2\ \text{tow}^{-1}$ is the area that would be covered by the 5 ft wide survey dredge during a standard tow of 0.15 nm, and $u=10^{-6}$ converts kilograms to thousand metric tons. *B'* is the minimum swept-area biomass prior to correction for survey dredge efficiency.

The term ϕ used in ESB calculations is new in this assessment. It is the fraction of total biomass in deep water strata off LI (strata 32 and 36), SNE (strata 40, 44, 48) and GBK (strata 56, 58, 60 and 62) that were sampled only during 1999. According to NEFSC (2000), deep water strata accounted for 0%, 2% and 13% of total biomass in the LI, SNE and GBK regions during 2005. Data for deep water strata sampled only during 1999 are otherwise omitted in calculations and, in particular, calculation of mean catch per tow $\overline{\chi}$. NEFSC (2004) used a slightly different approach for GBK in the last assessment which gave essentially the same results.

Habitat area for ocean quahogs in each region was estimated:

$$A' = Au$$

where $\underline{u}$ is the proportion of random tows in the region not precluded by rocky or rough ground (ocean quahogs occupy smooth sandy habitats), and *A* is the total area computed by summing GIS area estimates for each survey stratum in the region. Mean catch per standard tow ($\overline{\chi}$) is the stratified mean catch of fishable ocean quahog for individual tows after adjustment to standard tow distance based on tow distance measurements from sensor data (d_s):

$$\chi_i = \frac{C_i d}{d_s}$$

Only random tows were used in calculations of ESB. Tows without sensor data, with gear damage or poor pump performance were excluded from ESB calculations.

Following NEFSC (2004), and as described above, tow distance was measured for each station assuming that the dredge was fishing when the blade penetrated the sediments to a depth of at least one inch. Thus, the tow distance at each station was the sum of the distance covered while the dredge angle was $\leq 5.2^{\circ}$.

ESB estimates for the entire ocean quahog stock during 1997-2005 (Table A15) were computed using a formula that facilitated variance calculations (see below):

$$B_{total} = \frac{B'_{total}}{e} = \frac{\sum_r B'_r}{e}$$

The 80% confidence intervals for efficiency corrected total fishable biomass during 1997, 1999, 2002 and 2005 overlapped suggesting that the estimates were not significantly different (Table A15).

Catch-ESB Mortality estimates

Fishing mortality rates were estimated directly from the ratio of catch (landings plus an assumed 5% incidental mortality allowance) and ESB data for each region and year (Table A16). Biomass levels change slowly in ocean quahog, fishing and natural mortality rates are low for ocean quahog, and the survey during June provides a good approximation to average biomass. It was advantageous to use the ratio estimator because the surveys occur in June and because it was easy to include a wide range of uncertainties in variance calculations (see below).

Uncertainty in ESB and mortality estimates

Variance estimates for ESB and related mortality estimates were important in using and interpreting results (Tables A15 and A16). Formulas for estimating ESB and mortality for a single stock assessment region are products and ratios of constants and random variables. Random variables in calculations are typically non-zero (or at least non-negative) and can be assumed to be approximately log normal. Therefore, we estimated uncertainty in ESB and related mortality estimates using a formula for independent log normal variables in products and ratios (Deming 1960):

$$CV\left(\frac{ab}{c}\right)=\sqrt{CV^2(a)+CV^2(b)+CV^2(c)}$$

where $ln(ab/c)$, $ln(a)$, $ln(b)$ and $ln(c)$ are normally distributed. The accuracy of Deming's formula for ESB estimates was checked by comparison to simulated estimates (NEFSC 2002). CV's by the two methods were similar as long as variables in the calculation were log normally distributed. In addition, distributions of the simulated products and ratios were skewed to the right and appeared lognormal.

CV estimates for terms used in ESB and related estimates (Tables A15-A16 and Figures A44-A45) were from a variety of sources and were sometimes just educated guesses. The CV for best estimate of survey dredge efficiency (e) was CV=0.177 calculated by bootstrapping the median (15,000 bootstrap iterations) (Table A12). For lack of better information, CVs for sensor tow distances (d), area swept per standard tow (a), total area of region (A), percent suitable habitat (u), and catch were all assumed to be 10%. The CV for area swept (a) is understood to include variance due to Doppler distance measurements and variability in fishing power during the tow due, for example, to rocky or muddy ground.

Uncertainty in estimates for combined assessment regions

ESB for combined stock assessment areas was estimated as described above. Variance calculations accommodated covariance among regional estimates due to using a single estimate of survey dredge efficiency:

$$CV^2(B_{total})=CV^2(e)+CV^2(B'_{total})$$

Previous assessments used the formula:

$$Var(B_{total}) = \sum_r Var(B_r)$$

where $Var(x)$ is the variance of x. The formula used previously was incorrect because it assumed that efficiency and biomass estiamtes for each region were independent. The new formula makes the estimated confidence intervals for ESB and fishing mortality wider.

Building a bridge

Efficiency corrected swept-area biomass estimates in this assessment are almost double the estimates in the previous assessment (Table A19). For example, total stock biomass during 2002 was 2.1 million mt in NEFSC (2004) while the revised estimate in this assessment is 3.8 million mt. Several factors are responsible for this change in the estimates for 2002: 1) changes to spreadsheet software used in computations, 2) an error in the survey data for 2002 (but not for other years); 3) accounting for ocean quahogs on GBK that are too deep to be taken in the survey (13% of total stock biomass); 4) use of fishable biomass rather than 70+ mm biomass, and 5) new estimates of survey dredge efficiency. Of all the factors, the revised survey dredge efficiency (followed by the corrected survey data for 2002) was the most important factor contributing to higher ESB estimates in this assessment (Table A19).

5.3 “VPA” estimates

VPA estimates of biomass and fishing mortality are useful for stock assessment regions where the KLAMZ model (see below) is not applicable. Assuming no recruitment and that growth exactly balances natural mortality, ocean quahog biomass on January 1st and annual fishing mortality rates (Figure A46-A50) can be estimated for each stock assessment region using a simple virtual population analysis or “VPA” approach (NEFSC 2004). Efficiency corrected swept-area biomass estimates for 1999, 2002 and 2005 are averaged and used to anchor the calculations. Averages for 1999-2005 are used because the estimates for individual years are less precise (Table A15).

The VPA biomass estimate for January 1, 2002 is:

$$b_{2002} = \frac{B_{1999} + B_{2002} + B_{2005}}{3} - \frac{C_{2002}}{2}$$

where b_y is the VPA biomass estimate for January 1 in year y, B_y is the efficiency corrected swept area biomass for June in year y, C_{2002} is total catch weight (landings plus a 5% allowance for incidental mortality). The first ratio on the right-hand side is average efficiency corrected swept-area biomass during 1999-2005 and used as an estimate of biomass in June of 2002. Catch for 2002 is divided by two prior to subtraction because NEFSC clam surveys occur during June, when the year is half over.

Biomass estimates for years prior to 2002 were calculated:

$$b_{y<2002} = b_{2002} + \sum_{i=y}^{2001} C_i$$

Biomass estimates for years after 2002 were calculated:

$$b_{y>2002} = b_{2002} - \sum_{i=2002}^{y} C_i$$

Fishing mortality rates from VPA estimates were calculated by solving the catch equation with instantaneous rates for natural mortality and somatic growth both zero.

5.4 KLAMZ Model

KLAMZ (see Appendix A5 for a complete technical description) is a forward projecting stock assessment model based on the Deriso-Schnute delay-difference equation (Deriso 1980; Schnute 1985; Quinn and Deriso 1999). The delay-difference equation is an implicitly age structured population dynamics model that is mathematically identical to explicitly age-structured models if fishery selectivity is "knife-edged", somatic growth follows the von Bertalanffy equation, and natural mortality is the same for all age groups in each year. Knife-edge selectivity means that all individuals alive in the model during the same year experience the same fishing mortality rate. Natural mortality rates and growth parameters can change from year to year in the KLAMZ model but are assumed to be the same for all individuals alive during the same year. The model is implemented in AD Model Builder and Excel but only the AD Model Builder version was used in this assessment.

The main assumptions in the KLAMZ model for ocean quahog are: recruitment is constant over time, fishery selectivity is knife-edged; the natural mortality rate is low or constant, and growth in weight can be described by a von Bertalanffy growth curve. Recruitment is assumed constant (at levels always estimated to be very low) because no recruitment index is available. The assumption of constant recruitment is used for ocean quahog because no reliable recruitment index current exists, recruitment levels are apparently very low, and trends in stock dynamics are appear due primarily to fishing mortality.

KLAMZ model runs for ocean quahog that linked virgin biomass calculations with estimated biomass during 1978 were explored during the SARC review for this assessment. NEFSC (2000) used an equvilent virgin biomass approach. NEFSC (2004) compared several approaches and ultimately rejected the virgin biomass approach due to poor fit to survey data. As shown during the review for this assessment, models for ocean quahog that linked initial and virgin biomass in this assessment did not yield plausible results in some cases and fit to survey data was substantially reduced.

Recruitment to the ocean quahog fishery is not knife-edged but occurs at sizes of 51-86 mm SL (Figure A27). Under these circumstances, KLAMZ is an approximate model can be use to track trends in fishable (instead of total) biomass. Fishable biomass is dominated by relatively large individual ocean quahogs that are readily captured (see research recommendations).

Despite the assumption of knife-edge selectivity, KLAMZ is a relatively robust model (i.e. with little or no retrospective bias) that has been used successfully in previous assessments for ocean quahog (NEFSC 2004) and other species. It provides useful estimates of long-term biomass and fishing mortality, performs relatively well with very limited information about age and growth and when explicitly age-structured models are difficult to apply. One of the chief reasons for the utility of the KLAMZ model is statistical simplicity. The models used for ocean quahog in this assessment, for example, estimates only 2-3 parameters.

Model configurations

Configurations of the KLAMZ model for ocean quahog in each region were similar to the "best" configurations identified in the last assessment (NEFSC 2004) following a thorough analysis of a wide range of alternate configurations. Changes are highlighted in the descriptions below.

KLAMZ model estimates were for ocean quahog in the DMV, NJ, LI and SNE regions during 1977-2005. The model was not used for SVA because survey data for SVA are noisy and incomplete. The KLAMZ model was fit to data for GBK for sensitivity analysis. Following NEFSC (2004), the KLAMZ model was not used to make best estimates for GBK because no fishing occurs there, the survey time series is short (1986-2002) and because apparent trends in stock biomass are not clear (see "GBK at virgin biomass?" below).

Data used in KLAMZ models for ocean quahog in this assessment were: NEFSC clam survey biomass trends and associated CV's for 1982-2005; efficiency corrected swept-area biomass estimates for 1997-2005 (see below); and catch during 1977-2005 (landings plus a 5% allowance for incidental mortality). LPUE data are included in the model but only for comparative purposes (i.e. they had nil effect on model estimates).

NEFSC (2004) chose to omit LPUE data entirely but the decision was unnecessary because it is useful to compare model trends with LPUE data and because the LPUE data have no effect on model estimates. LPUE data did not affect estimates in this assessment because the likelihood component for trends in LPUE data was set to a very low level (10^{-6}) and the survey scaling parameter Q for LPUE was calculated using a closed form maximum likelihood estimator (i.e. Q was not estimated as a formal parameter). LPUE data did not affect variances estimates because LPUE data did not affect goodness of fit to other data.

Catch data for ocean quahog were assumed accurate and not estimated in the model. NEFSC clam survey data were used to measure trends in biomass. NEFSC clam survey data for 1994 were omitted because electrical voltage supplied to the pump on the survey dredge was set to 480 v, rather than 460 v, artificially increasing dredge efficiency during the 1994 survey (NEFSC 2004). Efficiency corrected swept-area biomass estimates for 1997-2005 are used to measure the scale of recent biomass levels but are not used to measure trends. Recruitment is assumed to be constant at some low level or zero. The natural mortality rate was M=0.02 y^{-1}, except in DMV (see below).

As described above, the KLAMZ model in this assessment estimates trends in fishable biomass. In contrast NEFSC (2004) modeled biomass of ocean quahog 70+ mm SL. Survey data used in the model are trends in mean fishable biomass while survey data used by NEFSC (2004) were trends in ocean quahog 70+ mm SL. Based on the fishery selectivity curve for ocean quahog, 50% of ocean quahog are selected by commercial dredges at about 73 mm SL. Thus, the previous and current assumptions about recruitment to the fishable stock are reasonably compatible.

Assumptions about growth are the same as in the last assessment. In particular, the growth parameters $\rho=e^K$ (where K=0.0176 is the von Bertalanffy growth parameter for weight), $J_t= w_{k-1}/w_k$ = 0.9693 (where w_j is predicted weight at age j) are constant and the same for all regions (NEFSC 2004). These growth parameters mean that quahogs in the model are slow growing, and that quahog recruit to the fishery (reach 70 mm SL) at age k=26 (Figure A59). Growth patterns differ among regions (Lewis et al. 2001 and Figure A56) but ocean quahog are difficult to age and there is too little information available to use region-specific growth curves (NEFSC 2000). The growth curve used in KLAMZ models for all areas but GBK was estimated from data collected in the Mid-Atlantic Bight where fishing occurs. Lewis et al.'s (2001) growth curve was used for GBK sensitivity analysis runs.

An assumed level of variance in instantaneous somatic growth rates (IGR) for old recruits is used to help estimate the initial age structure of ocean quahogs in the initial years of the model (Appendix A5). For ocean quahog in each region, IGR values during 1979-1980 were estimated assuming a lognormal distribution with arithmetic mean equal to the estimated IGR for 1981 and an arithmetic CV for years 1981-2005 estimated in a preliminary run. For ocean quahog, this constraint is unimportant because estimated age structures were stable due to assumptions about recruitment and low mortality rates.

ESB data are very important in KLAMZ models for ocean quahog as a source of information about biomass scale. Trends in ESB data during 1997-2005 were ignored in modeling because the time series is short (four years) and because information about trends from the NEFSC clam survey is already provided by the clam survey biomass index for 1982-2005. To use ESB data as a measure of scale while ignoring trend (see Appendix A5), the likelihood component for trends in ESB data were set to 10^{-6} so that the survey scaling parameter Q was calculated but the trend was ignored. Information in ESB data about biomass scale is contained in the estimated survey scaling parameter Q.

As described in Appendix A5, the likelihood of the survey scaling factor is calculated assuming that estimates of Q are from a lognormal prior distribution:

$$L = 0.5\left[\frac{\ln(Q)-\tau}{\varphi}\right]^2$$

where L is the negative log likelihood, $\varphi = \sqrt{\ln(1+CV)}$ and $\tau = \ln(\overline{q}) - \frac{\varphi^2}{2}$ is the mean of the log normal distribution. For ocean quahog ESB data, the mean of the prior $\overline{q}$ = $ln(1) = 0$ if ESB data measure stock biomass accurately and CV=0.177 is the bootstrap coefficient of variation (standard deviation / mean) for the median survey dredge efficiency used in calculating ESB (Table A12).

Parameters estimated

KLAMZ models for ocean quahog in this assessment estimate either two or three parameters by maximum likelihood and numerical optimization. The three parameters potentially estimated are logarithms of: 1) biomass at the beginning of 1977, 2) escapement biomass (total biomass less biomass of new recruits) at the beginning of 1978, and 3) annual recruitment biomass (which is assumed constant over time for each region). In models where recruitment estimates were very low, recruitment was fixed at an assumed value that was nearly zero (1 kg y^{-1}) and the other two parameters were estimated.

Fishing mortality rates are calculated solving the catch equation numerically. Survey scaling parameters were calculated using a closed form maximum likelihood estimator.

Variance estimates

Variances for biomass and fishing mortality estimates and for model parameters can be estimated by the delta method using exact derivatives calculated by AD Model Builder libraries or by bootstrapping (Appendix A5). Estimates in this assessment were from the delta method.

KLAMZ Results-DMV

As in the previous assessment (NEFSC 2004), estimated recruitment was near zero and hard to estimate in preliminary runs for DMV. The annual recruitment level was therefore fixed at very low value (1 kg y^{-1}) in final runs.

The KLAMZ model for ocean quahog in the DMV area (Figure A48) fit NEFSC survey and LPUE data well (LPUE data did not affect model estimates). The CV of arithmetic scale residuals (26%) for NEFSC survey data was smaller than the mean CV (32%) for mean kg/tow survey data but within the range of observed values (21%-53%). The estimated survey scaling parameter for ESB data was Q=0.98 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2005 using the catch data and trends in NEFSC survey data.

Biomass estimates for DMV declined steadily after 1978. Estimated fishable biomass during 2005 was 34% of the estimate for 1978 (Figure A48). During 2005, fishable biomass was 101,000 mt (CV 18%) and mean fishing mortality was 0.0094 y^{-1} (CV 18%).

KLAMZ Results-NJ

The KLAMZ model for ocean quahog in the NJ area (Figure A49) fit NEFSC survey and LPUE data well (LPUE data did not affect model estimates). The CV of arithmetic scale residuals (32%) for NEFSC survey data was larger than the mean (19%) and range (14%-24%) of CV values for mean kg/tow survey data. The estimated survey scaling parameter for ESB data was Q=0.95 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2005 using the catch data and trends in NEFSC survey data.

Biomass estimates for NJ declined steadily after 1978. Estimated fishable biomass in NJ during 2005 was 44% of the estimate for 1978. During 2005, fishable biomass was 401,000 mt (CV 17%) and mean fishing mortality was 0.0017 y^{-1} (CV 17%).

KLAMZ Results-LI

The KLAMZ model for ocean quahog in the LI area (Figure A50) fit NEFSC survey data well. The model fit LPUE data well (Figure A50) except during early years (1986-1993) when the fishery was becoming established and LPUE was relatively high but falling rapidly reflecting, perhaps, fishing down on the very best ocean quahog beds (LPUE data did not affect model estimates). The CV of arithmetic scale residuals (28%) for NEFSC survey data was larger than the mean (19%) and at the upper bound of the range (14%-28%) of CV values for mean kg/tow survey data. The estimated survey scaling parameter for ESB data was Q=1.0 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2005 using the catch data and trends in NEFSC survey data.

Biomass estimates for LI increased steadily after 1978 until 1992 when fishing mortality increased to maximum levels. Estimated fishable biomass in LI during 2005 was 94% of the estimate for 1978 and 90% of the maximum estimated biomass during 1992. During 2005, fishable biomass was 678,000 mt (CV 18%) and mean fishing mortality was 0.016 y^{-1} (CV 18%).

KLAMZ Results-SNE

The KLAMZ model for ocean quahog in the SNE area (Figure A51) did not fit NEFSC survey data or LPUE data as well as for other areas (LPUE data did not affect model estimates). Predicted survey values from the KLAMZ model decreased slowly in all years. Trends is fishable biomass based on mean survey kg/tow and LPUE data suggest an increasing trend in biomass before 1994 and a decreasing trend afterwards. These patterns are discussed in detail below.

The CV of arithmetic scale residuals (24%) for NEFSC survey data was smaller than the mean 29%) but within the range (18%-47%) of CV values for mean kg/tow survey data. The estimated survey scaling parameter for ESB data was Q=0.99 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2005 using the catch data and trends in NEFSC survey data.

Biomass estimates for SNE decreased steadily after 1978 until 1996 when landings and fishing mortality increased to peak levels. After 1996, biomass decreased at a slightly faster rate. Estimated fishable biomass in SNE during 2005 was 75% of the estimate for 1978. During 2005, fishable biomass was 595,000 mt (CV 18%) and mean fishing mortality was 0.003 y^{-1} (CV 18%).

Uncertainty about historical estimates and hypotheses about lack of fit

The apparent lack of fit to survey trend and LPUE data for SNE contributes uncertainty to historical biomass estimates but has little effect on estimates for recent years which were anchored by efficiency corrected swept area biomass data. However, future assessments should consider more complicated models that address hypotheses described below that might explain upward trends in fishable biomass prior to 1994 and decreasing trends afterwards.

It is possible that the upward trend in LPUE during 1984-1993 reflects an exploration phase during which the fishery searched for and located prime fishing grounds. However, this explanation does not apply to survey trend data.

Changes in recruitment patterns and the assumption of constant recruitment in the KLAMZ model might explain the difference between trends in KLAMZ model estimates and survey trend and LPUE data. However, survey trends in fishable biomass are not consistent with survey length and recruit trend data. In particular, survey length data (Figure A26) and survey recruit abundance data (Figure A21) do not suggest strong recruitment prior to 1994 and weak recruitment afterwards. Survey length data for 1980-1994 do not show a mode of small ocean quahog recruiting to fishable size while survey trend data and LPUE were increasing. Survey length data after 1994 do not show reductions in recruits while survey trend and LPUE data were decreasing. Survey recruit abundance data seem, in particular, to suggest higher recruitment after 1994.

Changes in landings and fishing mortality may explain the trends in survey trend and LPUE data. Annual landings were low (0 to 1,000 mt) during 1978-1994 while the survey trend and LPUE data were increasing. After 1994, landings increased dramatically (2,000 to 9,000 mt) during while survey trend and LPUE data were decreasing.

KLAMZ–methods for GBK trial and sensitivity runs

For the first time, the KLAMZ model was applied to GBK on a trial basis and to conduct sensitivity analyses. The trial run indicated increasing biomass in GBK since 1986. Rapidly increasing biomass estimates were due to the short and noisy survey trend data for GBK (Figure A20) and in particular the relatively low 1990 survey observation. The sensitivity analysis consisted of a run with the 1990 survey observation omitted.

The KLAMZ model for GBK covered 1986-2002 using NEFSC clam survey data for the same period when sampling was relatively consistent in all strata (Table A8). Survey data for 1994 were excluded due to problems with the pump voltage. Catches were zero in all years. In other respects, the configuration of the KLAMZ model for GBK was identical to the configuration used for ocean quahog in other stock assessment areas.

Based on Lewis et al. (2001), ocean quahog growth is faster on Georges Bank than in southern areas. A von Bertalanffy growth curve was therefore fit to weight at age information for ocean quahog in GBK to obtain growth parameters used in the KLAMZ model. The weight at age information was obtained by converting Lewis et al.'s (2001) growth curve for length to meat weight at age using length-weight parameters for GBK (Table A9). The resulting von Bertalanffy curve for growth in weight ($W_a = 41.07\left(1-e^{-0.04525(\text{a-0.3695})}\right)$ where W_a was meat weight (g) at age *a* years) closely approximated the weight at age information. The growth parameters used in the KLAMZ model were $\rho = e^{-0.04525} = 0.9558$ and $J = {}^{w_{k-1}}\!/_{w_k}$ = 15.59/16.66 = 0.9362 where w_k was the meat weight at age 13 which is approximately when ocean quahog reach 70 mm SL and become available to fishing (if fishing occurs).

Confidence intervals for estimated biomass on GBK were computed assuming that errors were from a lognormal distribution. In particular, the 95% bounds for the biomass estimate *B* were computed $Be^{\pm 1.96\sigma}$ where $\sigma = \sqrt{\left(1+CV^2\right)}$ and CV is the arithmetic scale coefficient of variation. The CV was the ratio of the biomass estimate and arithmetic standard deviation estimated in the KLAMZ model using AD-Model builder libraries and the delta method.

Recruitment and surplus production rates from the KLAMZ model for GBK were compared to results from the LI region where a strong recruitment event occurred and where biomass appears to have increased at least slightly during some years (Figure A50). Recruitment estimates (assumed constant) in the two regions were divided by the area (nm^2) of each region to make estimates for the two regions comparable on a per unit area basis. The annual instantaneous surplus production rate for each region is $\overline{P} = \overline{G} + \overline{r} - M$ where $\overline{G}$ and $\overline{r}$ are average rates for somatic growth and recruitment. The average growth rate is the mean of annual rates which are computed automatically in KLAMZ (Appendix A5). The average recruitment rate is the mean of annual recruitment rates which were computed $r_t = R_t / \overline{B}_t$ with the average biomass during each year $\overline{B}_t$ computed automatically in KLAMZ (Appendix A5).

KLAMZ–results for GBK trial and sensitivity runs

The estimated trends from KLAMZ model runs for GBK (Figures A52-A53) were judged implausible and not used for GBK because of the short survey time series (six observations during 1986 to 2002), frequency of survey strata that were not sampled

(Table A8), lack of catch data due to no fishing on GBK, no contrast in biomass levels due to catch that are usually used in stock assessment modeling to measure stock productivity, interannual variability and lack of consistent trend in survey data over time, statistically insignificant trend in survey data (see below under the heading "GBK at virgin biomass?"), lack of LPUE data to serve as corroboration, lack of evidence for recruitment in survey length data, and lack of historical biomass estimates for 1978 that might be used to calculate historical biomass. In addition, KLAMZ model estimates for GBK seemed implausible because the average surplus production rate and average recruitment per unit area for GBK were substantially higher than estimates for LI where a strong recruitment trend occurred and where biomass levels may have increased.

The trial model fit NEFSC clam survey data after 1994 better than before 1994 (Figure A52). With the 1998 survey observation omitted, the model fit was much better (Figure A53). The estimated survey scaling parameter for ESB data was Q=0.98 in both runs indicating that the model was able to match the observed ESB biomass levels during 1995-2005.

In the trial run (Figure A52), estimated biomass increased by about 99% from 735,000 mt during 1985 to 1,466,000 mt during 2002 (5% per year). Means for annual recruitment and surplus production rates on GBK during 1985-2002 were 2.3 and 8.8 times larger than for LI. Mean recruitment per unit area on GBK (Figure A52) was twice as high as on LI. The 95% confidence interval for trends in estimated biomass (Figure A52) was broad and, at the extremes, included scenarios with stable trends.

In the sensitivity run omitting the 1989 survey (Figure A53), the increasing trend in biomass was not as steep. In particular, estimated biomass increased by about 48% from 940,000 mt during 1985 to 1,389,000 mt during 2002 (2.4% per year). Means for annual recruitment and surplus production rates on GBK during 1985-2002 were 1.6 and 5 times larger than for LI. Mean recruitment per unit area on GBK (Figure A54b) was 1.5 times as high as on LI. The 95% confidence interval for trends in estimated biomass (Figure 56) was broad and largely compatible with scenarios with stable trend.

"Best" Estimates

KLAMZ model estimates were used at the best source of information about DMV, NJ, LI, and SNE during 1977-2005. VPA estimates were used for SVA and efficiency correct swept area biomass estimates were used for GBK (VPA and efficiency corrected swept-area biomass estimates for GBK are the same because no fishing has occurred there). NEFSC (2004) used VPA estimates for LI instead of KLAMZ model estimates. However, KLAMZ model estimates appear useful with addition of the 2005 survey data.

Biomass of ocean quahog and the entire stock less GBK during 1978-2005 was estimated by summing best estimates for each stock assessment area. Fishing mortality in large areas was computed by solving the catch equation with total catch, total biomass and M=0.02 y^{-1}. CV's were not calculated for whole stock biomass or fishing mortality estimates because of difficulties accommodating covariance in the estimates for individual area that was due to using the same survey efficiency estimates as prior information.

Best estimates (Table A20 and Figure A54) show declines in ocean quahog biomass for southern regions (SVA, DMV and NJ) where the fishery has been continually active. In particular, biomass during 2005 was 5%, 34% and 44% of biomass during 1978 for SVA, DMV and NJ (Table A21).

Best estimates of biomass in northern regions, which did not support the fishery until recently (LI, SNE and GBK), are relatively flat and stable. LI biomass actually increased during 1978-1992 before fishing occurred. Biomass during 2005 was 94%, 75% and 100% of biomass during 1978 for LI, SNE and GBK (Table A21). Biomass during 2005 was 76% and 66% of biomass during 1978 for the entire stock and the entire stock less GBK (Table A21).

Best estimates of fishing mortality rates (Figure A55) for southern areas where the fishery has been continually active (SVA, DMV and NJ) peaked during the late 1980's and early 1990's then declined as fishing effort shifted towards the north (Figures A4-A6 and A11). Fishing mortality rates in northern areas (Figure A55) were nearly zero before 1990 and increased substantially in later years as fishing effort shifted towards the north. Fishing mortality rates for the entire stock increased from about 0.003 y^{-1} during 1978 to an average of about 0.006 y^{-1} (0.010 y^{-1} for the entire stock less GBK) during the early 1990s through 2005.

Proportions of total fishable biomass at various density levels

Best biomass estimates and survey data were combined to partition best biomass estimates into components found in areas with a range of biomass density levels. Biomass density is important to profitability of the ocean quahog fishery because it determines commercial catch rates. Biomass density was measured as survey catch per tow (fishable kg/tow) because commercial catch rate data for random locations and the entire stock area were not available. The analysis used random NEFSC clam survey tows during 1980-2005 (1994 excluded) that were in areas deep enough (≥20 m) to be ocean quahog habitat. All survey data was from random stations so that the survey data would measure survey catch rates across the study area on average.

Survey data for stock assessment regions other than GBK were grouped into ten-year time intervals to increase sample size. Five surveys during 1980-1989, three surveys during 1990-1999 (excluding 1994), and two surveys during 2000-2005 were used in the analysis. Survey data for GBK were grouped into two intervals 1966-1992 and 1997-2002 and analyzed as a single group (1966-2002) because GBK was covered in fewer surveys and sample size was lower. The 1994 survey was excluded from all analyses because of problems with survey dredge efficiency and electrical voltage of current supplied to the pump.

Survey tow data were grouped by 5 kg/tow biomass density categories (e.g. catches of 0-4.9 kg/tow were assigned to the same biomass density category). The grouped data were used to calculate the proportion of fishing grounds occupied by ocean quahog at each biomass density level, as well as the proportion of fishable biomass on fishing grounds at each biomass density level (see below).

Proportions of fishable biomass in one region during a single time period were calculated:

$$X_L = \frac{p_L K_L}{\sum_j p_j K_j}$$

where p_L is the proportion of random survey tows in biomass density category L, K_L is mean survey fishable kg/tow for random stations in the same biomass density category, and the summation in the denominator is over all biomass density categories. The percentage of random tows in each biomass density category p_L is an estimate of the proportion of fishing grounds in each biomass density category. Total biomass at each density level during 2005 was calculated by multiplying the proportions X_L for each region by the best estimate of total biomass in each region.

Results (Table A17) show reductions in the proportions of areas with high catch rates (p_L) and the proportion of total stock biomass in areas of high catch rates (X_L) within the southern DMV and NJ stock assessment regions where the most of the fishing for ocean quahog occurred historically. Proportions were variable in LI and SNE where less fishing has occurred.

During 2005 (Table A18), the largest component (19% or 575 thousand mt meats) of total fishable stock biomass was on GBK in the highest (25+ kg/tow) biomass density category. In contrast, stock biomass levels in density categories larger than 10 kg/tow were low for other regions.

Building a bridge

Best estimates in this assessment are higher than in the previous assessment (NEFSC 2004) due mostly to the change in estimated survey dredge efficiency (Table 21). As expected, the ratios between current and previous biomass estimates were similar to ratios for efficiency corrected swept area biomass levels (Table A19).

GBK at virgin biomass?

This section describes a hypothesis that fishable biomass on GBK has increased substantially since 1978 due to relatively fast growth and recruitment. The hypothesis is new and untested for GBK which has never been fished and is usually assumed to be at a high "virgin" level. The hypothesis is important because it affects estimates of stock productivity, decisions about biomass reference points (i.e. virgin biomass) and stock status determinations. No fishing occurs on GBK due to potential for PSP contamination, but experimental ocean quahog fisheries in the area are planned. Reviewer's comments and suggestions are important and will be considered in the next assessment. However, they will not affect choice of the best biomass estimates for this assessment.

Best estimates for GBK in this and recent assessments assume a flat biomass trend since 1978 at an equilibrium "virgin" level (NEFSC 2000; NEFSC 2004). In particular, averages of efficiency corrected swept area biomass estimates during 1997-2002 were used as estimates of average biomass over longer time periods. As described above, preliminary KLAMZ model runs for GBK are not suitable for estimating long term trends in ocean quahog biomass at this time primarily due to limited prior to 1986.

Analysis of NEFSC survey data for GBK is complicated because survey coverage tends to be spotty on GBK (Table A8). During 1986-2002, survey coverage was relatively complete but 14% (18 out of 126) strata had no tows in a given year (Table A8). Only five strata (55, 57, 59, 71 and 73) were sampled during all seven years. As described above, the survey during 1994 is not comparable to other surveys during 1986-2002 because of voltage problems. Thus, only six survey observations are available for analyzing trends in ocean quahog recruitment and biomass on GBK.

Lewis et al. (2001) carried out a spatially detailed analysis of NEFSC survey data for GBK focusing on growth, spatial patterns in length composition and trends in abundance by size. The major finding was that small ocean quahog were present and that recruitment was apparently occurring on GBK during the 1990s. Lewis et al. (2001) noted that size distributions from the 1980s had a single mode and were dominated by large individuals, 75-90 mm SL. In contrast, bimodal size distributions were observed and small individuals (< 70 mm SL) often represented 20-50% of the catch in numbers at stations during the 1990s along the southeast flank of GBK. The small individuals were attributed to spawning during the 1980s. Lewis et al. (2001) did not evaluate the potential contribution of small ocean quahog to the fishable biomass for the stock as a whole.

Lewis et al. (2001) estimated a a von Bertalanffy growth curve for GBK that showed faster growth to maximum size than the growth curve for ocean quahog in the Mid-Atlantic Bight (Figure A56). Faster growth should result in higher productivity on GBK. Based on both growth curves, ocean quahog growth is relatively rapid during the first years of life and much slower in older individuals as they grow large enough to enter the fishery. The size at 50% selectivity to the commercial fishery (72 mm SL) is a reference point that separates recruits and the fishable stock. At 72 mm SL, ocean quahog on GBK grow about 1.5 mm SL per year while ocean quahog in other areas grow about 0.8 mm SL per year (Figure A56). The corresponding percentage increase in meat weight growth at 72 mm is 6% per year for GBK and 3% per year for other areas (Figure A56).

Survey length data

The survey length composition data presented in this assessment and used by Lewis et al. (2001) show that small ocean quahog and presumably recruitment occurs throughout the range of the ocean quahog stock (Figure A26 and see Section 7). The clearest example is in LI where length compositions during the 1970s and 1980s have an obvious mode due to recruitment of small individuals. As pointed out by Lewis et al. (2001), small ocean quahog were more common on GBK after 1990 and this pattern is evident in length composition data used in this assessment (Figure A26). Compared to other areas, however, length composition data for GBK are stable with relatively few small individuals and little apparent recruitment (Figure A26).

It is unlikely that ocean quahog in GBK too small to be taken in the survey (< 50 mm SL) are escaping detection by growing to fishable size during the time between surveys. Annual growth increments in GBK are 3 mm for ocean quahog 50 mm SL and increments decrease with size. Thus, a small 50 mm SL ocean quahog would be expected to growth to no more than 59 mm SL during the three year interval between surveys. Moreover, based on the growth curve for TBK, ocean quahog 50 mm SL are about age 4 y and recruits to the fishable stock at 70 mm SL are about age 14 y so that at least 10 y would be required to grow to fishable size from 50 mm SL.

Trends

Survey trends were computed for 1986-2002 (excluding 1994) using data (uncorrected for survey gear selectivity, Table A23) for ocean quahog < 70 mm SH (mean numbers per tow to measure recruitment) and ≥ 70+ mm (mean weight per tow to measure recruited stock biomass). Strata with no tows were filled by borrowing (see above), which is the standard procedure for ocean quahog.

The time series of mean weight per tow biomass indices for GBK are short (6 data points, Figure A57) but seem to suggest increasing trends. Regression lines fit to the two time series seem to indicate that biomass of ocean quahog 70+ increased rapidly and that biomass of smaller ocean quahog <70 mm increased slowly during 1986-2002. Neither regression was statistically significant (*p-value*=0.43 for ocean quahog < 70 mm SL and *p-value*=0.21 for ocean quahog 70+ mm). The apparently increasing trends were due largely to relatively low mean kg/tow in the 1989 survey (Figure A57).

6.0 BIOLOGICAL REFERENCE POINTS (TOR-3)

The Atlantic Surfclam and Ocean Quahog Fishery Management Plan (FMP, Amendment 12) defines biological reference points used as management targets and thresholds for stock biomass and fishing mortality. Targets are intended to represent desirable stock conditions. Thresholds are intended to identify overfishing (fishing mortality too high) and overfished (stock biomass too low) stock conditions.

Biological reference points used in managing US fisheries including the fishery for ocean quahog are linked in policy and law to maximum sustained yield (MSY) concepts. In particular, the overfishing threshold is meant to be smaller than or equal to F_{MSY}, the fishing mortality rate that provides MSY. Fishing mortality levels higher than F_{MSY} constitute overfishing.

The biomass and fishing mortality targets specified in the FMP for ocean quahogs are $B_{Target} = B_{MSY}$, which is assumed be one-half of the virgin biomass *for the whole stock*, and $F_{Target} = F_{0.1}$ *for the exploited region* (whole stock less GBK) The biomass and fishing mortality thresholds are $B_{Threshold} = ½ B_{MSY}$ and $F_{Threshold}$=$F_{25\%}$ (the fishing mortality rate that reduces life time egg production for an average female to 25% of the level with no fishing). The FMP does not specify whether the thresholds apply to the whole stock or exploited region only.

Biological reference points for ocean quahog defined in the FMP were recalculated for this assessment resulting in substantial changes to $F_{25\%}$ and F_{MAX} (the fishing mortality rate that maximizes yield per recruit). The new and old estimates for $F_{0.1}$ are similar (Table A24 and Figure A58). Sensitivity analysis indicates that assumptions about natural mortality had substantial effect on estimated reference points (Table A24).

In recalculating biological reference points, the Invertebrate Subcommittee noted that the current threshold reference point for fishing mortality (new estimate $F_{25\%}$=0.0517 y^{-1}, Table A24) is a poor proxy for F_{MSY} in a long-lived species like ocean quahog with natural mortality rate M=0.02 y^{-1} (Clark 2002; Thorarinsdottir and Jacobson 2005). From a purely technical perspective, it would be advantageous to reconsider biological reference points in the FMP for ocean quahog and their application to the entire or exploited portions of the stock.

Simulation analyses in Clark (2002) show that the highest sustainable catches for long lived stocks like ocean quahog are achieved when lower fishing mortality rates are applied at relatively high stock biomass levels. The same simulations show that fishing at $F_{25\%}$ would eventually depress stock spawning stock biomass to less than 25% of the virgin level, a level likely far below B_{MSY}. In the simulations, long-term yield from unproductive stocks was maximized at fishing mortality rates lower than $F_{50\%}$ (Clark 2002). Fortunately, the ocean quahog fishery is currently managed under an individual ITQ system with a quota on landings that keeps fishing mortality rates lower than both $F_{0.01}$ and $F_{25\%}$. The current quota is based on market demand and other economic factors.

Revised biomass reference points (building a bridge)

New proxies for virgin biomass and B_{MSY} in this assessment are substantially larger than in NEFSC (2003). The proxy for virgin ocean quahog biomass was recalculated using the best estimates of stock biomass during 1978 for each region (3.973 million mt including GBK, Table A20). The proxy for B_{MSY} (½ virgin biomass) in this assessment 1.987 million mt including GBK. Proxies for virgin biomass and B_{MSY} in NEFSC (2004) were smaller (3.3 and 1.5 million mt). The new estimates are larger mainly because of changes in survey dredge efficiency estimates (e=0.165 instead of 0.269-0.346). In addition, the new reference points are fishable biomass rather than biomass 70+ mm SL.

Fishing mortality reference points (building a bridge)

Biological reference points for fishing mortality were calculated for ocean quahog in this assessment using a length-based per-recruit model that is part of the NEFSC Stock Assessment Toolbox.[6] The length-based model is similar to the Thompson and Bell (1934) age-based model except that selectivity, maturity and growth are specified in terms of length, rather than age. The length-based approach is advantageous for ocean quahog because fishery selectivity and maturity are better known in terms of length than age (Figure A59).

Biological assumptions for reference point calculations in this assessment were generally comparable to assumptions in the last assessment (Figure A60). The ascending logistic fishery selectivity curve in per recruit model calculations was the same as in calculation of fishable survey biomass trends. The von Bertalanffy growth curve for length at age was the same as used earlier in this assessment for the MAB (Figure A59). Length-weight parameters ($ln(\alpha)$ = -9.242, β= 2.821) were averages for the stock as a whole.

Maturity at length was from Thorarinsdottir and Jacobson (2005) for ocean quahog in Icelandic waters with 10%, 50% and 90% of female ocean quahog mature at 40, 64, and 88 mm SL (2, 19, and 61 y, based on the growth curve in Figure A59). Based on the size range of samples (G. Thorarinsdottir, pers. comm..), the maturity curve is probably valid for ocean quahog in the size range used to estimate fishing mortality.

Maturity information for ocean quahog in the US EEZ is scant (see review in Cargnelli et al. 1999) but all available information and age-based per-recruit model calculations in the last assessment are compatible with the maturity at length estimates for ocean quahog in Icelandic waters (Figure A60).

7.0 STOCK STATUS (TOR-4)

Ocean quahog in the US EEZ are not overfished and overfishing is not occurring. Stock biomass during 2005 was 3.039 million mt (Table A20) and above the revised management target of ½ virgin biomass = 1.987 million mt (Figure A61). The fishing mortality rate during 2005 (all areas but GBK) was F= 0.0077 y^{-1} (Table A20), which is below the revised management target level $F_{0.1}$ = 0.0278 y^{-1} (Figure A61)

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[6] Contact Alan Seaver (Alan.Seaver@noaa.gov), Northeast Fisheries Science Center, Woods Hole, MA, USA for information and access to the Stock Assessment Toolbox.

Biological condition of the entire EEZ stock

The ocean quahog population is a relatively unproductive with total biomass gradually approaching the B_{MSY} reference point (½ virgin biomass, estimated as 50% of biomass during 1978) gradually after about three decades of relatively low fishing mortality (Table A20 and Figures A54-A55).

Based on survey data (Figure A20), LPUE data (Figure A8) and best estimates for 1977-2005 (Figure A54), declines in stock biomass are most pronounced in southern regions (SVA, DMV and NJ) where the fishery has been active longest. In particular, stock biomass was below the ½ virgin level during 2005 in SVA, DMV and NJ (Table A21).

An increasingly large fraction of the stock (42% during 2005 compared to 38% during 1978, Table A25) is in northern regions (LI and SNE) where fishing is relatively recent and in the GBK region, which is not fished due to risk of PSP contamination (Figure A54).

Fishing effort and mortality

Fishing effort has shifted to offshore and northern grounds over time as catch rates and abundance in the south declined (Figures A2, A4, A8 and A54). Analysis of LPUE data for individual 10' squares indicates considerable fishing down on fishing grounds that historically supplied the bulk of landings (Figures A13-A15). There is no clear indication that LPUE increased on historical grounds after fishing effort was reduced.

Fishing mortality rates during 2005 are relatively low for the entire stock (F=0.0045 y^{-1}) and for the fishable stock (F=0.0077 y^{-1}), which excludes GBK (Figure A55). Fishing mortality rates in the south where biomass was relatively low during 2005 decreased substantially over the last decade to low levels (F = 0.0, 0.0094 and 0.0017 y^{-1} for SVA, DMV and NJ) during 2005. Fishing mortality rates for LI increased abruptly during 1992 as effort increased, declined and then increased to F=0.0145 y^{-1} in 2005. The fishing mortality rate in LI during 2005 is comparable to fishing mortality rates in southern areas as they were fished down to relatively low biomass levels.

Productivity under fishing

Questions about the potential productivity of ocean quahog are becoming important as the stock is fished down from high virgin levels to B_{MSY}. Uncertainties about productivity are close related to choice of an accurate F_{MSY} proxy and other decisions that affect sustainability and fishery profitability.

Ocean quahog in the EEZ do not currently show a clear increase in stock productivity, due to higher recruitment and increased growth rates, that would be expected as biomass declines to B_{MSY} levels. Given the long periods between settlement and recruitment and slow growth once ocean quahog reach fishable size, any increase in stock productivity may be delayed (Powell and Mann 2005).

Recruitment events appear to be regional and sporadic (i.e. often separated by decades). Survey length composition data show that recruitment occurs throughout the resource sporadically and at an apparently low rate. Based on survey length composition data, some recent recruitment is evident in DMV, NJ, LI, SNE and GBK during recent years (Figure A26). Lewis et al. (2001) describe recruitment on GBK during the 1990s. Powell and Mann (2005) used a lined commercial dredge on a directed survey during 2002 and detected recruitment in some regions across the Mid-Atlantic Bight. Slow growth at sizes large enough to recruit to the fishery probably reduces the contribution of new recruits to fishery productivity (A62).

Information about growth of ocean quahog is sparse (Lewis et al. 2001). It is not possible to detect potential changes in growth at this time or to detect differences among regions (other than in GBK).

Biological condition of ocean quahog in Maine waters

The State of Maine carried out a survey and a stock assessment was completed for a portion of the ocean quahog stock in Maine waters (Russell 2006). The survey and assessment cover the principal fishing grounds in Maine waters. The fishery and biological characteristics of ocean quahog in Maine coastal waters are unique. In particular, the fishery targets small ocean quahogs for sale on the half shell market at prices roughly ten times the price paid in the rest of the EEZ. Most of the information in this section is from the assessment report for Maine waters (Russell 2006).

Biological and fishery information for Maine waters were used in the length based per recruit model (also used for the rest of the EEZ, see Section 6) to estimate conventional biological reference points for *Maine waters* only. In particular, F_{MAX} = 0.0561, $F_{0.1}$ = 0.0247 and $F_{50\%}$ = 0.013 y^{-1} for ocean quahog in Maine waters.

Assessment results for Maine show relatively high levels of fishing effort (Figure A4) and landings in recent years (Figure A2). LPUE levels have declined since the peak in 2002, but remain at relatively high levels overall (Figure A8).

Based on survey results and dredge efficiency estimates, stock biomass available to the fishery during 2005 was about 22,493 mt meats. In comparison, catch (landings plus a 5% incidental mortality allowance) during 2005 was 505 mt meats. The biomass estimate and catch data are for the area surveyed which includes the main areas of commercial fishing in Maine waters. Biomass in Maine waters is underestimated to the extent that it excludes ocean quahog outside the area where fishing occurs and the survey was carried out.

Fishing mortality during 2005 the assessed was estimated to be $F = 505 \div 22{,}493 = 0.022$ y^{-1}, which is almost equal to $F_{0.1} = 0.0247^{-1}$ calculated from a per recruit model for ocean quahog in Maine waters. The $F_{0.1}$ estimate for Maine waters has no special significance in policy because, based on the FMP, biological reference points used in defining management targets and thresholds are estimated for and applied to the entire stock.

Management goals have not been described for ocean quahog in Maine waters but maximization of long term catch is a likely candidate. Based on simulation analyses for long-lived and unproductive fish species (Clark 2002), fishing mortality rates as low as $F_{50\%}$ =0.013 y^{-1} may be required if spawning stock must be conserved to maximize long term catch levels.

The importance of maintaining spawning stock in Maine waters may be low if the bulk of recruits originate in the EEZ outside of the relatively small Maine fishing grounds. In that case, $F_{0.1}$=0.0247 y^{-1} might be useful reference point for maximizing long term catch because it would probably provide relatively high levels of yield while preserving some spawning potential. If spawning biomass in Maine waters is completely irrelevant, then long term catch might be maximized by fishing at F_{MAX} = 0.0561 y^{-1}. However, F_{MAX} is likely to require high levels of fishing effort and the estimate of F_{MAX} is sensitive to small changes in growth and fishery selectivity parameters.

8.0 TAL and PROJECTIONS (TOR-5 & 6)

Under current quota regulations, annual total allowable landings (TAL) for ocean quahog during 2007 is 24,190 mt meats (5.333 million bushels). The quota and TAL will result in a fishing mortality rate of approximately $F = 24{,}190 \div 1{,}775{,}000 = 0.014$ y^{-1} for the exploitable portion of the stock (excluding GBK) and $F = 24{,}190 \div 3{,}039{,}000 = 0.008$ y^{-1} for the stock as a whole if biomass during 2007 is similar to biomass during 2005 (1,775 and 2,698 million mt). TAL levels for longer time periods and for constant levels of fishing mortality can be calculated by projection, as described below.

Projections

A simple method for making short term projections for ocean quahog biomass, catch and fishing mortality is demonstrated in this section with example calculations. Example calculations assume either: 1) constant regional catch at 4, 5.33 and 6 million bushels; 2) constant fishing mortality at the manager's target level, $F_{0.1} = 0.0275$ y $^{-1}$. In the calculations wit $F_{0.1}$, for example, predicted landings could be used as TAL.

All projection calculations use the following equations to represent biomass dynamics:

$$X = G + r - M - F$$

$$B_{t+1} = B_t e^X$$

$$F = \frac{C}{B} \quad or \quad C = FB$$

where X is the net instantaneous annual rate of change, G is the instantaneous rate for somatic growth in weight, r is the rate for recruitment, $M = 0.02$ y^{-1} is the natural mortality rate, C is catch (e.g. quota for landings + 5%), and B is fishable biomass.

When catch is assumed known, the fishing mortality rate F can be calculated iteratively (e.g. Solver in Excel). When F is known, catch can be calculated directly.

Input data for projections are summarized in Table A26. Estimates of initial biomass (in 2005) and fishing mortality during 2005 were best estimates from Table A15. Catches (landings + 5%) in 2006 are assumed to be the same as in 2005. In projections with constant $F = F_{0.01} = 0.0278$ y^{-1} for exploited regions (excluding GBK) the proportions of catch in each region during 2006-2010 are assumed to be the same as in 2005. In projections for GBK, which is virgin and normally assumed to be at equilibrium carrying capacity in stock assessment work, rates for fishing mortality, natural mortality, growth and recruitment were zero so that stock biomass in GBK did not change over time. All of the projections suggest that the stock as a whole will continue to decline gradually over time (Table A27-A30). The decline is relatively rapid with $F = F_{0.01}$ (Table A31).

The method for ocean quahog is deterministic and does not consider natural variability in recruitment, growth or natural mortality. However, uncertainty in short term projections is primarily due to uncertainty in initial biomass estimates. Recruitment, natural mortality and growth of ocean quahog occur at low rates that have little effect on short term projections. Thus, CVs for efficiency corrected swept area biomass during 2005 (see below) can serve as reasonable measures of uncertainty in projections.

CVs for projected biomass levels from Table A15.							
SVA	DMV	NJ	LI	SNE	GBK	Total less GBK	Total
104%	55%	30%	31%	36%	32%	24%	24%

If uncertainty in short-term biomass projections is lognormal, then bounds for an asymmetric 95% confidence interval around projected biomass can be computed $Be^{\pm 1.96\sigma}$ where $\sigma = \sqrt{\ln\left(CV^2 + 1\right)}$.

9.0 RESEARCH RECOMMENDATIONS (TOR-7)

Recommendations from the previous assessment and new research recommendations are described sequentially.

Recommendations from last assessment

- A complete survey and a valid survey dredge efficiency estimate are needed by the State of Maine to assess ocean quahogs off the coast of Maine.

A directed survey for ocean quahog that covered the main fishing grounds in Maine waters was completed by the Maine Department of Marine Resources during 2005 (Russell 2006). Data from box core and dredge sampling during 2006 were used to estimate survey dredge efficiency. The 2005 survey and efficiency estimate were used to estimate fishing mortality and biomass for ocean quahog in Maine waters (Russell 2006).

- Explore whether efficiency of the DE-II dredge and commercial dredges are affected by depth, sediment type, and clam density. This could be examined experimentally, or by having an efficient commercial dredge repeat stations sampled by the RV DE-II. Also, evaluate non-extractive methods to estimate dredge efficiency and survey the resource.

Data collected during 2002 and new data collected during 2005 were examined in this assessment to determine if dredge efficiency depends on depth, sediment type or clam density. Additional data and analysis are required, however, to address this research recommendation. Non-extractive methods for estimating dredge efficiency were not investigated.

- Identify whether there are major differences in life histories and population dynamics between regions, and consider treating the EEZ stock as metapopulations.

A review of life history characteristics and analysis of population dynamics of ocean quahog in Maine waters was completed (Russell 2006). Alternate spatial based management approaches were not addressed in this assessment.

- Consider using ecological estimates of carrying capacity (based on available food, maximum size, predation, amount of suitable habitat) to evaluate/validate model estimates of virgin biomass.

Ecological estimates of carrying capacity were not addressed in this assessment. However, information suggesting that ocean quahog biomass on GBK (a virgin area) is increasing was examined and presented for review.

- Re-examine the rate of incidental mortality to ocean quahogs caused by commercial dredges.

No new field work or data analysis were carried out to address the research recommendation.

- Consider applying the relative selectivity function to the entire survey time series.

A survey selectivity curve was estimated for ocean quahog in the EEZ and a fishery selectivity curve estimated for ocean quahog off Iceland were used to better interpret survey data.

- Consider whether future stock assessment models should be based on age and abundance, rather than shell length and weight.

No progress.

- There is little information regarding F_{MSY} and B_{MSY} or suitable proxies for long lived species like ocean quahog. Traditional proxies (e.g., $F_{MSY} = F_{25\%\ MSP}$, $F_{MSY} = M$, $F_{MSY} = F_{0.1}$ and B_{MSY} at one-half virgin biomass) may be inappropriate for long lived organisms. The question of F_{MSY} and B_{MSY} proxies should be considered.

Traditional reference points from per recruit calculations were revised in this assessment using a new length based model and new estimates of fishery selectivity and maturity at length. Recent simulation work for long-lived rockfish and results for Icelandic ocean quahog were reviewed. The simulation results indicate that $F_{0.1}$ and $F_{25\%}$ are likely poor proxies for F_{MSY} in a long-lived organism like ocean quahog. Based on the simulations $F_{50\%}$ may be a better proxy. These issues could be taken up the next time the fishery management plan is revised.

- Survey coverage of Georges Bank needs to be a priority in NMFS EEZ survey. Strata along the Hague line may need to be re-stratified and biomass estimates recalculated to include only US areas.

GBK was not surveyed during 2005 due to competing priorities for sampling in southern areas. However, this remains an important issue, particularly in view of hypotheses that stock biomass is increasing on GBK. Different stratification schemes were not investigated.

- If the management system requires accurate position information (e.g. VMS) from fishery vessels, evaluate the possible improvements to assessments using catch and location information from this source.

The working group discussed this topic but it is not mentioned in the report because the discussions were preliminary.

- Investigate the use of survey data collected prior to 1978.

No progress.

New Recommendations (not prioritized)

- The *R/V Delaware II* may not be available for use on NEFSC clam surveys after 1998 and it appears likely that the clam survey will become a cooperative effort with sampling from a commercial vessel. Both the *R/V Delaware II* and commercial vessel should be used during 1998 so that catch rates, efficiency and selectivity patterns for the two vessels can be compared and calibrated. Planning should commence immediately.
- Fishing mortality and biomass reference points used as proxies for F_{MSY} and B_{MSY} should be reevaluated in the next assessment.
- Additional estimates of survey dredge efficiency from cooperative depletion studies are required.
- Develop a length (and possibly age) structured stock assessment model for ocean quahog that makes better use of survey and fishery length composition data which may provide better estimates of recruitment trends.
- Conduct further experimental work to determine the relationship between dredge efficiency, depth, substrate and clam density. A comprehensive study coincident with the next NEFSC clam survey would be most useful. The experimental design should include sufficient contrast in variables that may affect dredge efficiency.
- Cover GBK in the next NEFSC clam survey.
- Investigate the survey data from GBK during the 1989 survey to determine why it is low relative to survey observations during earlier years. This may be important in determining if biomass is increasing in GBK.
- Survey strata with no tows are a particular problem in the GBK region. The current procedure for filling holes in survey data involves borrowing data from adjacent surveys. This may not be optimal for ocean quahog surveys and GBK in particular. In the next assessment, consider filling holes in the GBK survey data using a model with stratum and year effects.
- Evaluate possible increasing trends in biomass for ocean quahog on GBK.
- Evaluate effects and contribution of recruitment to stock productivity.
- Improve estimates of biological parameters for age, growth (particularly of small individuals), and maturity for ocean quahog in both the EEZ and in Maine waters.
- Survey dredge and commercial dredge efficiency estimates should be reevaluated by field work during the next NEFSC clam survey. The next survey may be the last opportunity to estimate survey dredge selectivity. The commercial dredge selectivity curve was used in this assessment was estimated from field studies done off Iceland

where conditions may differ. Repeat tow experiments (i.e. survey stations reoccupied by commercial vessels) may be useful for this purpose.

- In the next assessment, projection calculations should be carried out using a model that is basically the same as the primary stock assessment model used to estimate biomass and fishing mortality (e.g. delay-difference population model in KLAMZ).
- Recommendations for future depletion studies.
    - It was difficult to find areas with high concentrations of ocean quahog for depletion experiment sites during 2005. However, areas with lower densities of ocean quahog can be used if depletion tow distance is increased.
    - Revised estimators for survey dredge efficiency based on commercial depletion experiments and setup tows use data for relatively large ocean quahog (i.e. 90+ mm) only. Future depletion sites should contain reasonably high densities of large individuals.
    - In future, every effort must be made to collect and record precise location data at short time intervals during depletion studies.
    - Collect length and bushel count data from survey and depletion tows more frequently (e.g. every 1-2 tows). It might be advantageous to measure fewer individuals sampled from more tows.
    - Analyze results from previous depletion studies to determine if differences between bushel counts and length composition data from different tows in the same depletion experiment are significantly different. Use the results to modify sampling protocols as appropriate.
    - Changes in length composition during a depletion experiment might be incorporated into efficiency estimation by, for example, including selectivity parameters in the Patch model. Efficiency estimates (and commercial selectivity) might be more precise because more size groups would be included in catch data.
    - It would be useful to analyze efficiency estimates in terms of season because ocean quahog are believed to change their depth in sediments on a seasonal basis.
- The next stock assessment should review the M=0.02 y-1 assumption for ocean quahog.
- In the next assessment, KLAMZ model runs with two recruitment parameters should be explored for LI and SNE. Survey length composition show more recruitment prior to 1994 than afterwards. Model fit was not as good for SNE as other stock assessment regions.
- KLAMZ model runs for GBK should be explored further in the next assessment.

10.0 ACKNOWLEDGMENTS

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OCEAN QUAHOG TABLES

Table A1. Landings (1,000 mt meats) for ocean quahog during 1967-2005 from dealer data (state + EEZ waters) and logbooks (EEZ only). Landings from state waters are calculated approximately by subtracting logbook landings from dealer landings. The EEZ quota and ratio of EEZ landings and EEZ quota are shown for comparison. Data for 2005 are preliminary and may be incomplete.

Year	Dealer Database	EEZ (Logbook)	State Waters (Logbook - Dealer)	Percent Landings in EEZ	EEZ Quota	EEZ Landings / Quota (%)
1967[a]	0.020	0.000	0.020	0.000		
1968	0.102	0.000	0.102	0.000		
1969	0.290	0.000	0.290	0.000		
1970	0.792	0.000	0.792	0.000		
1971	0.921	0.000	0.921	0.000		
1972	0.634	0.000	0.634	0.000		
1973	0.661	0.000	0.661	0.000		
1974	0.365	0.000	0.365	0.000		
1975	0.569	0.000	0.569	0.000		
1976	2.510	1.854	0.656	0.739		
1977	8.411	7.293	1.118	0.867		
1978	10.415	9.197	1.218	0.883		
1979	15.748	14.344	1.404	0.911	13.608	105%
1980[b,c]	11.623	13.407	-1.784	1.153	15.876	84%
1981	11.202	13.101	-1.899	1.170	18.144	72%
1982	16.478	14.234	2.244	0.864	18.144	78%
1983	16.200	14.586	1.615	0.900	18.144	80%
1984	17.939	17.974	-0.035	1.002	18.144	99%
1985	22.035	20.726	1.310	0.941	22.226	93%
1986	20.585	18.902	1.683	0.918	27.215	69%
1987	22.709	21.514	1.195	0.947	27.215	79%
1988	21.007	20.273	0.734	0.965	27.215	74%
1989	23.147	22.359	0.788	0.966	23.587	95%
1990	21.235	20.965	0.270	0.987	24.040	87%
1991	22.119	22.063	0.056	0.997	24.040	92%
1992	22.871	22.476	0.395	0.983	24.040	93%
1993	24.843	21.876	2.968	0.881	24.494	89%
1994	21.159	20.985	0.174	0.992	24.494	86%
1995	23.253	21.107	2.145	0.908	22.226	95%
1996	21.122	20.061	1.062	0.950	20.185	99%
1997	19.930	19.628	0.302	0.985	19.581	100%
1998	18.098	17.896	0.201	0.989	18.144	99%
1999	17.557	17.381	0.175	0.990	20.412	85%
2000	14.899	14.722	0.176	0.988	20.412	72%
2001	17.234	17.068	0.165	0.990	20.412	84%
2002	18.144	17.947	0.198	0.989	20.412	88%
2003	18.997	18.815	0.182	0.990	20.412	92%
2004	17.788	17.650	0.138	0.992	22.680	78%
2005		13.629	-13.629		24.190	56%

[a] Landings for 1967-1979 are from NEFSC (1990)

[b] Landings for 1980-1993 from NEFSC (2003).

[c] For 1980-2005, "Dealer Database Total" landings are from commercial landings databases (CFDETS or CFDERS), EEZ landings are from logbooks (Maine included), and "State Waters (Dealer-Logbook)" landings are the difference. Logbook landings are more accurate. In some years, logbook landings exceeded dealer database totals slightly.

Table A2. Ocean quahog landings (mt meats) by stock assessment region reported in logbooks for the US EEZ. Data for 1980-2003 are from logbooks and differ from the previous assessment (NEFSC 2004) because additional landings from other/unknown regions ("UNK") were allocated to regions in this assessment and because NEFSC (2004) treated Maine landings as other/unknown. Landings for 1978-1979 are not from logbooks and less reliable. Data for 2005 are preliminary and may be incomplete. Based on Maine reports, UNK amounts during 2002 were probably from Maine waters.

YEAR	SVA	DMV	NJ	LI	SNE	GBK	MNE	UNK	Grand Total
1978		1,290	6,350					2,775	10,415
1979		5,450	6,030					4,268	15,748
1980	0	4,230	7,750	6	0			1,421	13,407
1981	56	3,637	8,402	3	0			1,003	13,101
1982	6	4,598	8,538	0	0			1,092	14,234
1983	0	5,396	8,249	21	629	0	0	291	14,586
1984	6	7,164	8,857	0	822	0	0	1,125	17,974
1985	160	7,200	10,676	40	693	0	0	1,956	20,726
1986	0	8,236	9,053	396	568	0	0	649	18,902
1987	0	10,533	9,077	1,180	696	0	0	27	21,514
1988	42	11,715	7,014	640	841	0	0	20	20,273
1989	0	6,439	14,100	605	1,196	0	0	20	22,359
1990	14	3,685	15,590	739	934	0	3	0	20,965
1991	0	4,839	14,575	1,674	865	0	110	0	22,063
1992	0	2,378	6,942	11,939	1,143	0	75	0	22,476
1993	0	1,953	10,205	8,642	1,020	0	56	0	21,876
1994	0	992	6,938	12,014	954	0	65	22	20,985
1995	0	699	5,356	9,526	5,412	0	114	0	21,107
1996	0	736	4,864	5,943	8,350	0	142	26	20,061
1997	0	1,072	4,229	5,141	8,968	0	218	0	19,628
1998	0	1,365	2,684	6,856	6,736	0	218	39	17,896
1999	0	1,090	3,038	6,329	6,618	0	279	27	17,381
2000	0	1,048	3,318	4,745	5,083	49	357	123	14,722
2001	0	894	4,560	5,692	4,694	13	326	889	17,068
2002	0	1,732	2,781	9,113	3,884	0	387	51	17,947
2003	0	896	3,692	11,617	2,177	0	359	73	18,815
2004	0	634	2,795	10,631	3,283	0	307	0	17,650
2005	0	932	664	9,688	2,015	0	294	35	13,629

Table A3. Ocean quahog landings by stock assessment region as reported in logbooks for the US EEZ. Figures are 1000 ITQ bushels except for Maine, which are reported as both ITQ and Maine bushels. Data for 2005 are preliminary and may be incomplete. Based on Maine reports, UNK amounts during 2002 were probably from Maine waters.

YEAR	SVA	DMV	NJ	LI	SNE	GBK	MNE	MNE (Maine bushels)	UNK	Grand Total
1980	0	933	1,709	1	0	0	0		313	2,956
1981	12	802	1,852	1	0	0	0		221	2,888
1982	1	1,014	1,882	0	0	0	0		241	3,138
1983	0	1,190	1,819	5	139	64	0	0	64	3,280
1984	1	1,580	1,953	0	181	248	0	0	248	4,211
1985	35	1,587	2,354	9	153	431	0	0	431	5,001
1986	0	1,816	1,996	87	125	143	0	0	143	4,310
1987	0	2,322	2,001	260	153	6	0	0	6	4,749
1988	9	2,583	1,546	141	185	4	0	0	4	4,474
1989	0	1,420	3,108	133	264	4	0	0	4	4,934
1990	3	812	3,437	163	206	0	1	1	0	4,623
1991	0	1,067	3,213	369	191	0	24	37	0	4,901
1992	0	524	1,530	2,632	252	0	16	25	0	4,980
1993	0	431	2,250	1,905	225	0	12	19	0	4,841
1994	0	219	1,530	2,649	210	5	14	21	5	4,653
1995	0	154	1,181	2,100	1,193	0	25	38	0	4,691
1996	0	162	1,072	1,310	1,841	6	31	47	6	4,476
1997	0	236	932	1,133	1,977	0	48	73	0	4,400
1998	0	301	592	1,511	1,485	9	48	72	9	4,026
1999	0	240	670	1,395	1,459	6	62	93	6	3,931
2000	0	231	732	1,046	1,121	27	79	119	27	3,381
2001	0	197	1,005	1,255	1,035	196	72	109	196	4,065
2002	0	382	613	2,009	856	11	85	129	11	4,097
2003	0	198	814	2,561	480	16	79	120	16	4,284
2004	0	140	616	2,344	724	0	68	102	0	3,993
2005	0	206	146	2,136	444	8	65	98	8	3,110

Table A4. Real and nominal prices (dollars per ITQ bushel) for ocean quahogs landed by ITQ and Maine vessels. Real prices are 1991 dollars. Information for ITQ vessels from dealer data. Information for Maine vessels from MAFMC (2005). Price data for Maine vessels (originally prices for Maine bushel) were converted to prices per ITQ bushel). Adjustments for inflation from the US Bureau of Labor Statistics for unprocessed shellfish.[a]

	ITQ		Maine	
Year	Nominal	Real	Nominal	Real
1994	$4.44	$4.20		
1995	$4.30	$3.56		
1996	$4.12	$3.40		
1997	$4.13	$2.39		
1998	$4.23	$2.41		
1999	$4.24	$2.53		
2000	$4.35	$2.55		
2001	$5.54	$3.23		
2002	$5.47	$3.33		
2003	$5.37	$3.08	$61.73	$35.43
2004	$5.26	$3.02	$59.55	$34.17

Table A5. Ocean quahog fishing effort (hours fished) by stock assessment region in the US EEZ based on logbook data. Figures for 1983-2003 differ from NEFSC (2003) because additional other/unknown ("UNK") trips were allocated to region and because data for subtrips (deliveries from the same trip to different dealers) were counted only once. Data for 2005 are preliminary and may be incomplete. Based on Maine reports, UNK amounts during 2002 were probably from Maine waters.

YEAR	SVA	DMV	NJ	LI	SNE	GBK	MNE	UNK	Grand Total
1983	0	7,131	13,932	50	1,535	0	0	56	22,704
1984	15	11,096	15,488	0	2,523	0	0	1,231	30,353
1985	204	10,058	17,890	87	2,066	0	0	2,955	33,260
1986	0	12,260	14,350	361	1,145	0	0	1,012	29,127
1987	0	15,812	14,704	806	1,340	0	0	49	32,711
1988	64	19,100	11,598	615	1,639	0	0	64	33,079
1989	0	12,124	24,262	797	2,327	0	0	50	39,560
1990	25	8,166	29,327	1,283	1,838	0	286	0	40,924
1991	0	12,048	30,397	1,844	1,433	0	17,110	0	62,832
1992	0	5,513	15,998	13,148	1,964	0	13,424	0	50,047
1993	0	4,622	25,457	12,883	1,783	0	5,720	0	50,465
1994	0	2,260	20,543	19,165	2,082	0	5,056	57	49,162
1995	0	1,621	13,598	16,015	8,561	0	5,731	0	45,526
1996	0	1,521	9,340	10,238	11,866	0	8,404	54	41,422
1997	0	2,742	9,382	8,295	13,515	0	11,734	0	45,669
1998	0	3,225	6,983	10,509	10,639	0	11,631	79	43,066
1999	0	2,595	7,623	9,132	12,258	0	10,821	90	42,518
2000	0	2,517	7,966	7,071	10,542	63	12,215	612	40,986
2001	0	2,170	10,844	7,813	11,404	22	13,113	1,454	46,820
2002	0	4,290	6,683	11,605	7,797	0	16,779	85	47,240
2003	0	2,617	10,764	16,099	4,596	0	17,832	108	52,016
2004	0	2,476	7,953	14,478	6,665	0	19,013	0	50,586
2005	0	3,500	1,935	12,437	4,019	0	16,572	129	38,591

Table A6. Commercial landings per unit effort (LPUE) for ocean quahog by region. Figures for Maine are for vessels in ton class groups 1-2 (1-50 GRT). Figures for all other regions are for vessels in ton class groups 3-4 (51-500 GRT). "Nominal Mean LPUE" is the simple average of LPUE for each trip in the region during the year. "Total Bushels / Total Hours" is total landings divided by total hours fished. "Standardized Index" is back-transformed year effects from a general linear model with year, month and vessel effects. The standardized indices are adjusted to the LPUE level of a single randomly chosen vessel (ton class 4 for the EEZ and ton class 1 for Maine) during June of each year. Data for 2005 are preliminary and may be incomplete.

	DMV				NJ			
Year	Nominal Mean LPUE	Total Bushels / Total Hours	Standardized Index	CV	Nominal Mean LPUE	Total Bushels / Total Hours	Standardized Index	CV
1980	153	139	165	0.15	119	118	113	0.19
1981	149	140	159	0.15	122	118	113	0.19
1982	151	143	176	0.15	135	130	120	0.19
1983	175	167	201	0.15	138	131	124	0.19
1984	154	142	181	0.15	133	126	119	0.19
1985	167	158	192	0.15	140	132	124	0.19
1986	157	148	169	0.15	144	139	125	0.19
1987	159	147	158	0.15	136	136	116	0.19
1988	144	135	141	0.15	137	133	110	0.19
1989	127	117	131	0.15	133	128	105	0.19
1990	106	99	118	0.15	123	117	95	0.19
1991	94	89	102	0.15	110	106	82	0.19
1992	100	95	104	0.15	101	96	84	0.19
1993	105	93	105	0.15	95	88	75	0.19
1994	104	97	97	0.15	80	74	68	0.19
1995	102	95	91	0.16	93	87	79	0.19
1996	119	107	101	0.16	121	115	100	0.19
1997	93	86	90	0.15	105	99	86	0.19
1998	100	93	92	0.15	109	85	75	0.19
1999	96	93	88	0.15	95	88	80	0.19
2000	98	92	86	0.15	96	92	82	0.19
2001	90	91	76	0.16	98	93	80	0.19
2002	93	88	83	0.15	94	91	77	0.19
2003	77	74	68	0.15	79	74	63	0.19
2004	66	56	60	0.16	88	77	67	0.19
2005	61	59	56	0.15	80	76	64	0.18

Table A6 (continued).

	LI				SNE			
Year	Nominal Mean LPUE	Total Bushels / Total Hours	Standardized Index	CV	Nominal Mean LPUE	Total Bushels / Total Hours	Standardized Index	CV
1980								
1981	123	123						
1982								
1983	91	93			91	90		
1984					73	72	73	0.17
1985	106	102			75	74	79	0.18
1986	262	242	267	0.23	115	109	114	0.17
1987	322	323	319	0.20	122	115	117	0.17
1988	232	230	210	0.22	114	113	113	0.17
1989	176	167	190	0.21	127	113	118	0.17
1990	180	127	221	0.23	129	112	136	0.17
1991	205	200	212	0.18	135	133	134	0.17
1992	207	200	227	0.15	119	128	164	0.17
1993	159	148	174	0.15	115	126	179	0.17
1994	152	138	161	0.15	100	101	142	0.17
1995	145	131	159	0.15	145	139	119	0.17
1996	136	128	149	0.16	164	155	137	0.17
1997	144	137	157	0.16	156	146	126	0.17
1998	155	144	160	0.16	147	140	120	0.17
1999	165	153	172	0.16	126	119	106	0.17
2000	156	148	163	0.16	109	106	99	0.17
2001	165	161	177	0.16	93	91	88	0.17
2002	182	173	178	0.15	122	110	122	0.17
2003	169	160	168	0.15	116	104	106	0.17
2004	179	162	166	0.15	115	109	106	0.17
2005	177	172	151	0.06	113	111	108	0.17

Table A6 (continued).

	MNE			
Year	Nominal Mean LPUE	Total Bushels / Total Hours	Standardized Index	CV
1980				
1981				
1982				
1983				
1984				
1985				
1986				
1987				
1988				
1989				
1990	3.50	3.56		
1991	2.06	2.15	2.09	0.031
1992	1.89	1.85	1.89	0.031
1993	3.18	3.00	2.52	0.033
1994	4.95	4.25	3.95	0.032
1995	6.98	6.62	6.18	0.032
1996	5.92	5.61	5.55	0.031
1997	6.64	6.20	5.86	0.030
1998	6.73	6.23	5.55	0.030
1999	9.66	8.60	7.58	0.030
2000	10.05	9.73	8.30	0.030
2001	8.45	8.28	7.28	0.030
2002	8.02	7.67	7.14	0.030
2003	7.06	6.71	6.01	0.029
2004	5.58	5.37	4.76	0.029
2005	6.14	5.91	5.03	0.027

Table A7. Trends in survey, stock and fishable abundance and biomass for ocean quahog ≥ 50 mm SL during 1982-2005 based on NEFSC clam survey data. Mean numbers per tow (N/Tow) and mean meat weight per tow (KG/Tow) are for a standard 0.15 nm tow with adjustments for tow distance based on Doppler data. Figures include original plus borrowed tows. For example, "Number Strata" for a particular year includes strata sampled by the survey during the same year plus strata sampled by tows borrowed from the previous and subsequent surveys. Survey data for 1994 are excluded because of gear problems that artificially boosted sampling efficiency. Survey coverage was incomplete on GBK prior to 1986 and GBK was not sampled during 2005.

		Survey				Stock				Fishable						
Region	Year	N/Tow	CV	KG/Tow	CV	N/Tow	CV	KG/Tow	CV	N/Tow	CV	KG/Tow	CV	Number Tows	Number Positive Tows	Number Strata With Data
SVA	1982	0.039	0.00	0.002	0.00	0.039	0.00	0.002	0.00	0.038	0.00	0.002	0.00	5	1	2
SVA	1983	1.892	0.58	0.099	0.58	1.917	0.58	0.101	0.58	1.854	0.58	0.097	0.58	10	3	2
SVA	1984	0.189	0.85	0.010	0.87	0.191	0.84	0.010	0.87	0.185	0.85	0.010	0.87	14	2	2
SVA	1986	0.285	0.00	0.013	0.00	0.294	0.00	0.013	0.00	0.275	0.00	0.012	0.00	9	1	2
SVA	1989	0.392	0.00	0.018	0.00	0.401	0.00	0.019	0.00	0.380	0.00	0.018	0.00	9	1	2
SVA	1992	0.000	.	0.000	.	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	9	0	2
SVA	1997	0.154	0.00	0.004	0.00	0.282	0.00	0.006	0.00	0.132	0.00	0.003	0.00	9	1	2
SVA	1999	0.081	0.55	0.002	0.61	0.182	0.50	0.003	0.54	0.069	0.56	0.002	0.61	19	2	2
SVA	2002	0.045	1.00	0.001	1.00	0.133	1.00	0.002	1.00	0.037	1.00	0.001	1.00	10	1	2
SVA	2005	0.000	.	0.000	.	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	9	0	2
DMV	1982	79.162	0.32	2.956	0.34	86.645	0.31	3.156	0.33	73.837	0.32	2.786	0.34	59	24	6
DMV	1983	86.228	0.49	2.549	0.42	106.611	0.52	2.988	0.45	76.158	0.48	2.301	0.41	54	28	6
DMV	1984	52.011	0.35	1.667	0.30	63.193	0.36	1.904	0.31	46.650	0.34	1.530	0.30	78	34	6
DMV	1986	75.681	0.23	2.532	0.22	86.737	0.24	2.800	0.22	68.939	0.23	2.342	0.22	61	28	6
DMV	1989	64.366	0.58	1.801	0.46	82.482	0.62	2.179	0.51	55.961	0.55	1.606	0.44	69	31	6
DMV	1992	71.982	0.36	2.285	0.31	85.405	0.40	2.589	0.33	64.676	0.35	2.093	0.30	69	25	6
DMV	1997	47.743	0.21	1.669	0.21	56.440	0.22	1.847	0.21	43.721	0.21	1.557	0.21	73	28	6
DMV	1999	28.359	0.29	0.948	0.27	33.388	0.29	1.056	0.27	25.821	0.29	0.878	0.26	70	23	6
DMV	2002	31.814	0.25	1.106	0.23	38.774	0.26	1.232	0.23	29.139	0.24	1.032	0.22	71	19	6
DMV	2005	19.407	0.49	0.694	0.53	24.842	0.45	0.776	0.50	17.906	0.50	0.652	0.53	66	21	6

Table A7 (cont.)

Region	Year	Survey				Stock				Fishable				Number Tows	Number Positive Tows	Number Strata With Data
		N/Tow	CV	KG/Tow	CV	N/Tow	CV	KG/Tow	CV	N/Tow	CV	KG/Tow	CV			
NJ	1982	112.339	0.20	3.555	0.20	129.333	0.20	3.918	0.20	102.545	0.20	3.302	0.20	100	50	13
NJ	1983	86.092	0.21	2.832	0.21	98.417	0.21	3.090	0.21	79.201	0.21	2.649	0.21	98	55	13
NJ	1984	143.533	0.24	4.531	0.24	165.861	0.24	4.998	0.24	131.075	0.24	4.208	0.24	153	80	13
NJ	1986	142.520	0.23	4.847	0.23	158.243	0.24	5.213	0.23	132.170	0.23	4.555	0.22	103	52	13
NJ	1989	73.510	0.22	2.193	0.21	90.578	0.21	2.491	0.21	66.320	0.22	2.020	0.21	110	52	13
NJ	1992	88.043	0.18	3.023	0.17	97.822	0.18	3.246	0.17	81.725	0.18	2.843	0.17	110	52	13
NJ	1997	122.262	0.15	4.273	0.15	135.780	0.16	4.576	0.15	113.720	0.15	4.028	0.15	124	59	13
NJ	1999	59.480	0.15	2.019	0.14	72.266	0.15	2.221	0.14	54.889	0.15	1.900	0.14	132	61	13
NJ	2002	89.793	0.23	3.229	0.24	101.123	0.22	3.456	0.23	83.825	0.24	3.059	0.24	127	60	13
NJ	2005	47.076	0.16	1.568	0.15	62.364	0.15	1.769	0.15	43.117	0.15	1.473	0.14	103	54	13
LI	1982	278.856	0.15	7.021	0.16	434.976	0.16	9.325	0.15	239.652	0.15	6.258	0.16	43	37	9
LI	1983	185.877	0.21	5.232	0.21	253.508	0.22	6.355	0.21	163.619	0.21	4.742	0.21	38	36	9
LI	1984	235.154	0.17	6.536	0.16	318.987	0.18	7.967	0.17	206.330	0.17	5.906	0.16	71	63	9
LI	1986	311.430	0.22	8.625	0.21	416.390	0.23	10.480	0.21	273.066	0.22	7.782	0.21	36	31	9
LI	1989	226.213	0.34	5.062	0.29	367.492	0.38	7.152	0.33	190.104	0.33	4.384	0.28	40	36	9
LI	1992	323.335	0.18	8.313	0.16	465.234	0.20	10.625	0.17	279.032	0.17	7.401	0.16	42	36	9
LI	1997	401.643	0.16	11.156	0.16	518.847	0.17	13.351	0.16	353.149	0.16	10.049	0.16	42	35	9
LI	1999	232.273	0.17	6.280	0.15	310.519	0.19	7.671	0.16	202.716	0.17	5.628	0.14	45	41	9
LI	2002	253.059	0.21	6.969	0.20	330.414	0.21	8.385	0.20	222.209	0.21	6.268	0.20	43	40	9
LI	2005	151.233	0.18	4.122	0.19	218.396	0.19	5.121	0.18	132.758	0.18	3.717	0.19	45	39	9

Table A7 (cont.)

Region	Year	Survey				Stock				Fishable				Number Tows	Number Positive Tows	Number Strata With Data
		N/Tow	CV	KG/Tow	CV	N/Tow	CV	KG/Tow	CV	N/Tow	CV	KG/Tow	CV			
SNE	1982	277.607	0.27	6.981	0.25	345.845	0.28	8.222	0.26	245.458	0.27	6.283	0.25	48	30	10
SNE	1983	173.213	0.29	4.163	0.30	237.689	0.31	5.149	0.29	151.399	0.29	3.727	0.30	58	37	10
SNE	1984	188.458	0.27	4.753	0.29	234.355	0.26	5.588	0.28	166.802	0.27	4.280	0.29	69	38	10
SNE	1986	289.151	0.31	6.961	0.31	394.360	0.35	8.561	0.32	253.117	0.31	6.226	0.31	27	23	9
SNE	1989	274.664	0.19	6.707	0.18	353.181	0.21	8.050	0.19	241.358	0.19	6.003	0.18	34	29	10
SNE	1992	333.079	0.19	8.634	0.19	400.104	0.19	9.947	0.19	297.003	0.19	7.814	0.20	36	31	10
SNE	1997	292.893	0.54	6.128	0.45	447.963	0.61	8.405	0.52	246.944	0.52	5.335	0.43	39	27	10
SNE	1999	252.431	0.54	6.169	0.48	312.910	0.56	7.316	0.51	221.840	0.53	5.510	0.47	39	30	10
SNE	2002	180.674	0.22	5.103	0.22	206.737	0.22	5.663	0.22	164.245	0.22	4.697	0.22	29	28	9
SNE	2005	178.281	0.28	3.944	0.24	395.499	0.44	5.882	0.29	154.795	0.27	3.547	0.24	29	25	7
GBK	1986	276.488	0.19	6.207	0.18	427.632	0.23	8.633	0.20	232.206	0.19	5.313	0.18	48	21	16
GBK	1989	90.805	0.26	2.371	0.26	124.548	0.25	2.950	0.25	78.933	0.26	2.098	0.26	79	38	16
GBK	1992	346.253	0.21	9.225	0.21	485.713	0.19	11.427	0.20	302.841	0.21	8.208	0.21	74	41	16
GBK	1997	269.762	0.19	7.058	0.19	389.377	0.19	8.969	0.18	234.251	0.19	6.274	0.19	83	44	18
GBK	1999	273.398	0.17	7.806	0.19	365.971	0.16	9.391	0.18	241.903	0.17	7.060	0.19	77	47	18
GBK	2002	328.367	0.18	9.059	0.19	478.136	0.15	11.247	0.18	288.963	0.18	8.149	0.19	61	38	15

Table A8. Number of random and nearly random NEFSC survey tows used to estimate trends in abundance of ocean quahog. Figures in each cell are the number of tows in calculations for each combination of stratum and cruise. Figures in plain text are the number of original tows (without borrowing). Bold and outlined figures are for cells with zero tows originally that were filled by borrowing tows from the same strata during previous and/or subsequent cruises. Black cells are for cells with zero tows that could not be filled by borrowing. Note that there were too few tows in GBK during 1982-1984 and 2005 to calculate abundance indices for GBK during these years.

		Survey Year										
Region	**Stratum**	**1982**	**1983**	**1984**	**1986**	**1989**	**1992**	**1994**	**1997**	**1999**	**2002**	**2005**
SVA	5	4	9	13	8	8	8	8	8	**16**	8	8
	6	1	1	1	1	1	1	1	1	**3**	2	2
DMV	9	30	26	35	29	37	37	39	39	38	39	39
	10	2	2	3	3	3	3	3	3	3	3	3
	11	2	2	**4**	2	2	2	2	2	2	2	2
	13	19	18	25	20	20	20	21	22	19	20	20
	14	2	2	3	3	3	3	5	3	3	3	3
	15	4	4	**8**	4	4	4	5	4	5	4	4
NJ	17	11	11	18	12	12	12	12	14	12	12	12
	18	3	3	**6**	3	3	3	3	3	3	3	3
	19	3	3	**6**	3	3	3	3	3	3	3	3
	21	18	18	22	19	20	20	23	26	39	29	29
	22	3	3	**6**	3	3	3	5	3	3	3	3
	23	7	6	**11**	5	4	5	5	5	5	5	5
	25	9	9	13	8	9	9	9	12	8	9	9
	26	2	2	**5**	3	3	3	3	3	3	3	3
	27	4	4	**8**	4	4	4	4	4	4	4	4
	87	8	7	10	9	9	9	9	9	9	16	16
	88	15	15	24	17	20	20	20	21	22	20	20
	89	15	15	21	15	18	17	17	19	18	18	18
	90	2	2	3	2	2	2	2	2	2	2	2
LI	29	11	10	**20**	10	10	10	10	10	11	10	10
	30	7	8	**14**	6	6	6	6	6	7	6	6
	31	9	7	**12**	5	7	8	8	8	9	8	8
	33	4	4	**8**	4	4	4	5	4	4	4	4
	34	2	2	**4**	2	2	2	5	2	2	2	2
	35	4	2	**4**	2	5	6	6	6	6	6	6
	91	3	2	4	4	3	3	3	3	3	3	3
	92	2	2	3	2	2	2	2	2	2	2	2
	93	1	1	2	1	1	1	1	1	1	2	2

Table A8 (continued).

		Survey Year										
Region	**Stratum**	**1982**	**1983**	**1984**	**1986**	**1989**	**1992**	**1994**	**1997**	**1999**	**2002**	**2005**
SNE	37	7	4	**7**	3	**6**	3	5	4	4	3	3
	38	3	2	**5**	3	3	3	5	3	3	3	3
	39	6	4	**6**	2	5	5	5	5	5	5	5
	41	6	5	7	5	6	6	6	6	5	6	6
	45	3	7	9	4	4	4	4	4	4	3	3
	46	2	5	5	3	2	3	5	3	3	2	2
	47	4	3	4	2	2	4	5	4	3	1	1
	94	1	2	**2**	■	**1**	1	2	2	**4**	2	2
	95	4	14	11	4	4	4	4	4	4	4	4
	96	**12**	12	**13**	1	1	3	2	4	**4**	■	■
GBK	54	■	**3**	3	3	**6**	3	3	3	**3**	0	0
	55	3	**3**	**3**	3	1	3	3	3	2	2	**2**
	56	■	■	■	■	■	■	■	**4**	4	**4**	■
	57	■	■	**2**	2	1	2	5	2	2	2	**2**
	58	■	■	■	■	■	■	■	**5**	5	**5**	■
	59	1	4	**5**	1	2	6	5	5	4	5	**5**
	60	■	■	**2**	2	2	**4**	2	5	5	5	**5**
	61	8	1	**6**	5	**12**	*7*	6	6	6	6	**6**
	62	■	■	**1**	1	**1**	**4**	4	4	4	4	**4**
	65	■	■	**3**	3	**5**	2	2	3	**4**	1	**1**
	67	■	**5**	5	5	7	7	7	7	**7**	■	■
	68	1	**8**	7	3	6	6	5	5	**5**	■	■
	69	2	5	**11**	6	6	6	7	6	7	**7**	■
	70	1	2	**6**	4	**8**	4	4	4	3	2	**2**
	71	■	**2**	2	3	1	2	3	3	1	2	**2**
	72	2	**10**	8	1	8	8	8	8	6	**6**	■
	73	1	1	**4**	3	6	6	6	6	5	6	**6**
	74	3	**4**	1	3	**7**	4	4	4	3	3	**3**

Table A9. Parameter estimates for the relationship between shell length (*L*, mm) and drained (fresh, not frozen) meat weight (*W*, g) in ocean quahog (NEFSC 2004). The equation for the relationship is $W=e^{\alpha}L^{\beta}$.

Region	Alpha	Beta
SVA	-9.042313	2.787987
DMV	-9.042313	2.787987
NJ	-9.847183	2.949540
LI	-9.233646	2.822474
SNE	-9.124283	2.774989
GBK	-8.969073	2.767282

Table A10. Clam survey database parameters used to extract survey data for ocean quahog in this assessment. Parameters were the same for all regions. Negative parameter values are ignored in database calculations.

Database Parameter	**Survey length composition**	**Trends < 70 mm SL**	**Trends in survey, stock and fishable biomass**	**Efficiency corrected swept-area biomass**
DISTANCE_TYPE	TREND	TREND	TREND	SENSORS
USEINCHESDOWN	1	1	1	1
LENGTH_BIN_SIZE_MM	10	1000	1000	1000
FIRST_LENGTH_MM	1	0	50	50
FIRST_BIN_IS_PLUSGROUP	-1	-1	-1	-1
LAST_LENGTH_MM	250	69	250	250
LAST_BIN_IS_PLUSGROUP	-1	-1	-1	-1
SVSPP_TO_USE	409	409	409	409
AREAKIND	GIS	GIS	GIS	GIS
REV_DATE_FOR_AREAS	2002	2002	2002	2002
REV_DATE_FOR_LW	2000	2000	2000	2000
FIRST_JWSTCODE	-1	-1	-1	-1
LAST_JWSTCODE	-1	-1	-1	-1
FIRST_RANDLIKE	1	1	1	1
LAST_RANDLIKE	2	2	2	2
FIRST_STATION	-1	-1	-1	-1
LAST_STATION	-1	-1	-1	-1
FIRST_HAUL	1	1	1	1
LAST_HAUL	3	3	3	3
FIRST_GEARCOND	1	1	1	1
LAST_GEARCOND	6	6	6	6
FIRST_STRATUM	-1	-1	-1	-1
LAST_STRATUM	-96	-96	-96	-96
FIRST_REGION_CODE	1	1	1	1
LAST_REGION_CODE	6	6	6	6
WRITE_TOW_DATA	1	1	1	1
WRITE_STRATUM_DATA	1	1	1	1
FIRST_CRUISE	-199700	-199700	-199700	199700
LAST_CRUISE	-200509	-200509	-200509	200509
SurvSelxAlpha	8.122	8.122	8.122	8.122
SurvSelxBeta		-0.119	-0.119	-0.119
FisherySelxAlpha		7.63	7.63	7.63
FisherySelxBeta		-0.105	-0.105	-0.105
NOMINAL_TOW_DISTANCE_NM		0.15	0.15	0.15
MINVALIDDOPPLER		0.04	0.04	0.04
MAXVALIDDOPPLER		0.3	0.3	0.3
FILLHOLZ		1	1	1

Table A11. Patch model estimates of efficiency for commercial and NEFSC survey clam dredges based on depletion experiments during 1997-2005. "NA" means not available.

Study area						Depletion Tows						Patch Model							Setup Tows (if applicable)				
Experiment	Region	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth (m)	Mean Sediment Size (microns)	Depletion Study Vessel	Depletion Date	Ship Position Data (source / nominal accuracy / time interval)	N tows used	N Bushel Counts / Length samples	Depletion Vessel Blade Width (ft)	Cell Size (ft)	Density (N ft^{-2})	Depletion Vessel Efficiency	*k*	γ	Neg. Log likelihood	Fit to Catch Data (R2s)	Setup Date	Setup or RV Depletion Stations	Density (N ft^{-2})	NEFSC Dredge Efficiency	Foornotes
OQ2005-1	LI	40.5190	72.0762	57	536	F/V Lisa Kim	Sep-05	GPS / 6 ft / 6 sec	20	4 / 4	10	20	0.073	0.183	1.97	0.50	127.0	Ok	Jun-05	165, 231-234	0.0120	0.165	1
OQ2005-2	LI	40.3896	72.3895	53	438	F/V Lisa Kim	Sep-05	GPS / 6 ft / 6 sec	21	4 / 4	10	20	0.047	0.402	8.57	0.50	131.8	Ok	Jun-05	162, 235-238	0.0080	0.169	1
OQ2005-3	LI	40.6422	72.6517	35	267	F/V Lisa Kim	Sep-05	GPS / 6 ft / 6 sec	20	4 / 4	10	20	0.085	0.733	9.57	0.50	125.9	Ok	Jun-05	3, 239-242	0.0101	0.119	1
OQ2005-4	LI	40.6882	72.1815	46	308	F/V Lisa Kim	Sep-05	GPS / 6 ft / 6 sec	17	4 / 4	10	20	0.027	0.815	12.31	0.50	89.4	Ok	Jun-05	168, 243-246	0.0042	0.154	1
OQ2005-6	LI	40.0555	72.4167	65	554	F/V Lisa Kim	Sep-05	GPS / 6 ft / 6 sec	20	4 / 4	10	20	0.137	0.660	2.55	0.50	146.3	Ok	Jun-05	252-256	0.0210	0.153	1
Mean				*51*	*421*				*19.6*				*0.074*	*0.559*	*6.99*						*0.0110*	*0.152*	
CV for Mean				*10%*	*14%*				*3%*				*25%*	*21%*	*29%*						*25%*	*6%*	
OQ2002-1 (LK-1)	LI	40.7276	71.7373	60	331	F/V Lisa Kim	Mar-02	GPS / 1 ft / 6 sec	24	5 / 5	10	20	0.295	0.489	6.56	0.50	173.1	Ok	Jun-02	5 - 9	0.0290	0.098	1, 2, 5
OQ2002-2 (LK-2)	LI	40.1031	73.1911	48	277	F/V Lisa Kim	Mar-02	GPS / 1 ft / 6 sec	22	4 / 4	10	20	0.165	0.785	10.57	0.50	149.7	Ok	Jun-02	25- 29	0.0245	0.149	1, 2
OQ2002-3 (LK-3)	NJ	38.8149	73.8133	50	195	F/V Lisa Kim	Mar-02	GPS / 1 ft / 6 sec	20	4 / 4	10	20	0.081	0.777	11.57	0.50	133.4	Ok	Jun-02	213 - 217	0.0239	0.297	1, 2
OQ2002-4 (LK-4)	DMV	37.8876	74.6449	48	135	F/V Lisa Kim	Mar-02	GPS / 1 ft / 6 sec	24	5 / 5	10	20	0.073	0.254	12.46	0.50	136.0	Ok	Jun-02	272 - 276	0.0210	0.287	1, 2,9, 16
Mean				*52*	*235*				*22.5*				*0.153*	*0.576*	*10.29*						*0.0704*	*0.178*	
CV for Mean				*6%*	*18%*				*4%*				*34%*	*22%*	*13%*						*65%*	*0.274*	
OQ2000-1 (JN-1)	LI	40.6022	71.9875	58	N/A	F/V John N	Mar-00	GPS / 1 ft / 30 sec	22	5 / 5	12.5	25	0.100	0.730	5.55	0.50	157.4	Ok	Jun-99	194 - 199	NA	NA	1, 2,6
OQ2000-2 (JN-2)	LI	40.3945	72.5430	48	N/A	F/V John N	Mar-00	GPS / 1 ft / 30 sec	16	4 / 3	12.5	25	0.062	0.554	15.10	0.50	98.1	Ok	Jun-99	178 - 180	0.0145	0.234	1, 2,7,11,12, 17
OQ2000-3 (DM-1)	LI	40.5830	72.7968	40	N/A	F/V Danielle Maria	May-00	GPS / 1 ft / 30 sec	27	6 / 6	10	20	0.089	0.560	4.57	0.50	184.2	Ok	Jun-99	3 - 8	0.0147	0.165	1, 2,8,10,12, 18
Mean									*21.7*				*0.084*	*0.615*	*8.405*						*0.0146*	*0.199*	
CV for Mean									*15%*				*14%*	*9%*	*40%*						*1%*	*17%*	
OQ1999-01 DE2	LI	40.6023	71.9848	57	N/A	R/V Delaware II	Jun-99	GPS / 36 ft / 1 sec	60	8 / 8	5	10	0.007	0.990	4.05	0.25	253.1	Poor		N/A		0.990	14, 15
OQ1998-1 (SH-3)	LI (Shinnecock)	40.7665	72.1795	41	N/A	F/V Cape Fear	3/1/11998 8	Loran / 40 ft / 30 sec.	14	3 / 3	10	20	0.017	1.000	3.48	0.50	76.5	Poor		NA		NA	1, 13
OQ1998-2 (SH-2)	LI (Shinnecock)	40.7220	72.0075	45	N/A	F/V Cape Fear	Mar-98	Loran / 40 ft / 30 sec.	23	5 / 5	10	20	0.067	0.869	10.57	0.50	140.3	Ok					15
OQ1998-3 (NS-1)	SNE (Nantucket Shoals)	40.4670	69.4830	63	N/A	F/V Cape Fear	Apr-98	Loran / 40 ft / 30 sec.	24	5 / 5	10	20	0.255	0.710	7.56	0.50	195.5	Ok					15
Mean									*20.3*				*0.113*	*0.860*	*7.204*								
CV for Mean									*16%*				*64%*	*10%*	*29%*								
OQ1997-1 (SH-1)	LI (Shinnecock)	40.2695	72.2985	58	N/A	F/V Laura Ann	Jul-97	Loran / 40 ft / 30 sec.	28	7 / 7	7.75	20	0.083	0.458	10.57	0.39	164.2	Ok		NA		NA	1,3
OQ1997-2 (WW-1)	NJ (Wildwood)	38.5095	74.1115	49	N/A	F/V Agitator	Aug-97	Loran / 40 ft / 30 sec.	28	13 / 6	10	20	0.084	0.150	2.37	0.50	176.0	Ok					1,4
Mean				*51*					*19.6*				*0.180*	*0.592*	*6.01*								
CV for Mean				*8%*					*19%*				*45%*	*23%*	*25%*								

SEE FOOTNOTES ON NEXT PAGE

[1] NA

[2] NA

[3] Depletion tows 1, 2, 12 & 18 omitted per NEFSC 1998, Figure E18

[4] Depletion tows 1, 19, 23 & 27 omitted per NEFSC 1998, Figure E21

[5] Setup station 5 dropped because sensor tow distance < 0.04 nm

[6] Length composition data collected at setup tow 194 only for OQ2000-1 (indicated 6% of catch >= 90 mm SL), setup data not useable.

[7] Length composition data collected at setup tow 178 only for OQ2000-2 (indicated 28% of catch >= 90 mm SL), used for all setup tows.

[8] Length composition data collected at setup tows 3 and 6 only for OQ2000-3 (average 33% and 28% of catch >= 90 mm SL), used for all setup tows.

[9] Length composition data collected at setup tow 272 only for OQ2000-4 (33% of catch >= 90 mm SL), used for all setup tows.

[10] Sensor tow distance missing for setup station 4, average tow distance at stations 3, 5, 6, 7, 8 used instead.

[11] Depletion tow 1 omitted because it was outside the study area.

[12] Adjustments for apparent trends in numbers per bushel during depletion experiment.

[13] Original estimates appear to have used incorrect mean number per bushel in depletion tows

[14] Missing GPS location data at survey stations 198 and 216 (depletion tows 5 and 23) replaced by approximate start/stop locations and interpolation.

[15] Anomalously high bushel count and length data at station 200 not used.

[16] One setup tow with length data for OQ2002-4.

[17] One setup tow with length data for OQ2000-2.

[18] Two setup tows with length data for OQ2000-3.

Table A12. Summary of new and revised density, commercial dredge efficiency, and survey dredge efficiency estimates for ocean quahog 90+ mm SL from the Patch model and setup tows.

Statistic	Density (N ft^{-2})	Commercial Vessel Efficiency	NEFSC Dredge Efficiency
N experiments	18	17	12
Minimum	0.007	0.150	0.098
Maximum	0.295	1.000	0.990
Median	0.082	0.660	0.165
Mean	0.097	0.596	0.248
Distribution of point estimates[1]			
sd	0.141	0.267	0.241
CV (sd/mean)	1.453	0.448	0.972
Lo 95%	0.000	0.073	0.000
Hi 95%	0.373	1.000	0.722
Distribution of average estimates[1]			
se	0.033	0.065	0.070
CV (se/mean)	0.236	0.243	0.289
Lo 95%	0.032	0.469	0.112
Hi 95%	0.162	0.723	0.385
Distribution of median estimates[2]			
se	0.011	0.091	0.029
Robust CV (se/median)	0.132	0.138	0.177
Lo 95%	0.047	0.402	0.136
Hi 95%	0.089	0.733	0.261

[1] Parametric statistics.

[2] Bootstrap statistics (15,000 iterations).

Table A13. Original (used in the last assessment, NEFSC 2004) and revised ocean quahog density and efficiency estimates from the Patch model based on depletion experiments during 1997-2002. Percent change is (Revised-Previous).Previous x 100. "NA" means not available. Previous and revised density estimates are shown but are not directly comparable because they are based on different size groups.

Experiment	Density (*D*, n ft^{-2})[a]			Commercial efficiency (*E*)			Setup Density (*d,n* ft^{-2})			Survey efficiency (*e*)		
	Previous	Revised	% Change	Previous	Revised	% Change[c]	Previous	Revised	% Change[c]	Previous	Revised	% Change[c]
OQ2002-1	0.550	0.295	-46%	0.653	0.489	-25%	0.068	0.029	-57%	0.081	0.098	21%
OQ2002-2	0.345	0.165	-52%	0.810	0.785	-3%	0.067	0.024	-64%	0.158	0.149	-6%
OQ2002-3	0.111	0.081	-27%	0.816	0.777	-5%	0.037	0.024	-36%	0.275	0.297	8%
OQ2002-4	0.101	0.073	-27%	0.599	0.254	-58%	0.080	0.021	-74%	0.474	0.287	-39%
OQ2000-1[b]	0.413	0.100	-76%	0.950	0.730	-23%	0.169	NA	NA	0.389	NA	NA
OQ2000-2[b]	0.095	0.062	-35%	0.922	0.554	-40%	0.054	0.015	-73%	0.524	0.234	-55%
OQ2000-3[b]	0.180	0.089	-51%	0.734	0.560	-24%	0.053	0.015	-72%	0.216	0.165	-24%
OQ1999-01 DE2	0.306	0.007	NA	NA	NA	NA	NA	NA	NA	0.470	0.990	111%
OQ1998-1	0.105	0.017	-84%	0.950	1.000	5%	NA	NA	NA	NA	NA	NA
OQ1998-2	0.242	0.067	-73%	0.401	0.869	117%	NA	NA	NA	NA	NA	NA
OQ1998-3	0.570	0.255	-55%	0.950	0.710	-25%	NA	NA	NA	NA	NA	NA
OQ1997-1	0.440	0.083	-81%	0.488	0.458	-6%	NA	NA	NA	NA	NA	NA
OQ1997-2	0.060	0.084	39%	0.256	0.150	-41%	NA	NA	NA	NA	NA	NA

[a] Previous and revised density estimates are shown for completeness but are not comparable because they are based on different size groups.

[b] Survey efficiencies calcuated based on information in NEFSC (2000, Tables C12 and C13) using e=d/D*E.

[c] Percent change is (Revised - Previous) / Previous.

Table A14. Effects of new data and methods on efficiency and density estimates for ocean quahog from the Patch model and setup tows (where available).

Data and methods	**Density (*D*, n/ft^2)**	**Commercial Efficiency (*E*)**	**Setup Tow Density (*d*, n/ft^2)**	**Survey Efficiency (*e*)**
		OQ1998-2		
Original[1]	0.242	0.401	NA	
Step 1[2]	0.253	0.383		
Step 2[3]	NA	NA		
Step 3[4]	0.109	0.489		
New[5]	0.067	0.869		
		OQ2002-1		
Original[6]	0.550	0.653	0.068	0.081
Step 1[2]	0.550	0.653	0.068	0.081
Step 2[3]	0.550	0.653	0.068	0.124
Step 3[4]	0.255	0.553	0.029	0.114
New[5]	0.295	0.489	0.029	0.098

[1] From Table A10 in NEFSC (2004)
[2] Step 1 uses new programs and original data
[3] Step 2 is like step 1 but with correct formula for survey dredge efficiency
[4] Step 3 is like step 2 but with new catch data for 90+ mm SL
[5] New estimates are the current best estimates and like step 3 but with revised position data
[6] From Tables C11-C12 in NEFSC (2000)

Table A15. Efficiency corrected swept-area biomass estimates (1,000 mt) and CVs for the fishable stock of ocean quahog during 1997, 2000, 2002 and 2005 by stock assessment region. Figures for SVA and GBK during 2005 were taken from 2003 because no data were available for 2005.

	Estimate	CV
INPUT: Nominal tow distance (d_n, *nm*)	0.15	
INPUT: Dredge width (nm)	0.0008225	
Area swept per standard tow (a, nm^2)	1.23375E-04	10%

Area of assessment region (A, nm^2) - no correction for stations with unsuitable clam habitat

	Estimate	CV
S. Virginia and N. Carolina (SVA)	712	10%
Delmarva (DMV)	4,071	10%
New Jersey (NJ)	6,510	10%
Long Island (LI)	4,463	10%
Southern New England (SNE)	4,922	10%
Georges Bank (GBK)	7,821	10%
Total	28,499	

INPUT: Fraction suitable habitat (u)

	Estimate	CV
S. Virginia and N. Carolina (SVA)	100%	10%
Delmarva (DMV)	100%	10%
New Jersey (NJ)	100%	10%
Long Island (LI)	100%	10%
Southern New England (SNE)	96%	10%
Georges Bank (GBK)	90%	10%

Habitat area in assessment region (A', nm2)

	Estimate	CV
S. Virginia and N. Carolina (SVA)	712	14%
Delmarva (DMV)	4,071	14%
New Jersey (NJ)	6,510	14%
Long Island (LI)	4,463	14%
Southern New England (SNE)	4,714	14%
Georges Bank (GBK)	7,039	14%

INPUT: Biomass fraction in unsurveyd deep water

	Estimate	CV
S. Virginia and N. Carolina (SVA)	0%	10%
Delmarva (DMV)	0%	10%
New Jersey (NJ)	0%	10%
Long Island (LI)	0%	10%
Southern New England (SNE)	2%	10%
Georges Bank (GBK)	13%	10%

INPUT: Original survey mean catch from fishable stock (kg/tow, for tows adjusted to nominal tow distance using sensors)

	Estimates for 1997	CV	Estimates for 1999	CV	Estimates for 2002	CV	Estimates for 2005	CV
S. Virginia and N. Carolina (SVA)	0.0013	100%	0.0007	55%	0.0004	100%	0.0004	100%
Delmarva (DMV)	0.6528	23%	0.4449	26%	0.6863	24%	0.4221	48%
New Jersey (NJ)	1.7341	15%	0.9728	14%	1.8614	23%	1.0441	14%
Long Island (LI)	4.5648	17%	3.0065	14%	3.4414	17%	2.1812	16%
Southern New England (SNE)	2.2252	37%	2.6964	45%	3.2654	26%	2.2555	24%
Georges Bank (GBK)	2.6710	16%	3.1454	18%	3.8760	17%	3.8760	17%

Swept-area biomass without efficiency correction (B', 1000 mt):

	Estimates for 1997	CV	Estimates for 1999	CV	Estimates for 2002	CV	Estimates for 2005	CV
S. Virginia and N. Carolina (SVA)	0.0076	102%	0.0040	59%	0.0022	102%	0.0022	102%
Delmarva (DMV)	21.5388	30%	14.6803	33%	22.6452	31%	13.9280	52%
New Jersey (NJ)	91.4993	25%	51.3297	24%	98.2159	30%	55.0929	24%
Long Island (LI)	165.1265	26%	108.7572	24%	124.4894	26%	78.9022	26%
Southern New England (SNE)	86.7210	42%	105.0878	49%	127.2624	33%	87.9046	31%
Georges Bank (GBK)	172.2007	26%	202.7813	27%	249.8861	26%	249.8861	26%
Total fishable biomass less GBK	365	17%	280	21%	373	16%	236	16%
Total fishable biomass	537	14%	483	17%	623	14%	486	16%

	Estimates for 1997	CV	Estimates for 1999	CV	Estimates for 2002	CV	Estimates for 2005	CV
INPUT: Survey dredge efficiency (e)	0.165	18%	0.165	18%	0.165	18%	0.165	18%

Efficiency adjusted swept area fishable biomass (B, 1000 mt)

	Estimates for 1997	CV	Estimates for 1999	CV	Estimates for 2002	CV	Estimates for 2005	CV
S. Virginia and N. Carolina (SVA)	0.046	104%	0.024	61%	0.013	104%	0.013	104%
Delmarva (DMV)	131	35%	89	37%	137	36%	84	55%
New Jersey (NJ)	555	31%	311	30%	596	35%	334	30%
Long Island (LI)	1,002	32%	660	30%	755	32%	479	31%
Southern New England (SNE)	526	46%	638	52%	772	37%	533	36%
Georges Bank (GBK)	1,045	31%	1,230	32%	1,516	32%	1,516	32%
Total fishable biomass less GBK	2,214	24%	1,698	28%	2,261	24%	1,431	24%
Total fishable biomass	3,258	23%	2,928	24%	3,776	23%	2,947	24%

Lower bound for 80% confidence intervals on fishable biomass (1000 mt, for lognormal distribution with no bias correction)

	Estimates for 1997	Estimates for 1999	Estimates for 2002	Estimates for 2005
S. Virginia and N. Carolina (SVA)	0.015	0.012	0.004	0.004
Delmarva (DMV)	84	56	88	44
New Jersey (NJ)	378	213	385	229
Long Island (LI)	675	452	509	324
Southern New England (SNE)	302	340	487	342
Georges Bank (GBK)	708	823	1,021	1,021
Total fishable biomass less GBK	1,627	1,199	1,667	1,060
Total fishable biomass	2,448	2,153	2,830	2,189

Upperbound for 80% confidence intervals on fishable biomass (1000 mt, for lognormal distribution with no bias correction)

	Estimates for 1997	Estimates for 1999	Estimates for 2002	Estimates for 2005
S. Virginia and N. Carolina (SVA)	0.137	0.050	0.040	0.040
Delmarva (DMV)	202	141	215	163
New Jersey (NJ)	814	454	923	488
Long Island (LI)	1,488	962	1,122	706
Southern New England (SNE)	918	1,197	1,225	833
Georges Bank (GBK)	1,542	1,839	2,251	2,251
Total fishable biomass less GBK	3,012	2,405	3,066	1,931
Total fishable biomass	4,336	3,982	5,039	3,967

Table A16. Ocean quahog fishing mortality estimates based on catch and efficiency corrected swept-area biomass for fishable ocean quahog during 1997, 1999, 2002 and 2005. CV's are based on analytical variance calculations assuming log normality, and include uncertainty in catch, survey data, swept-area, amount of suitable habitat, and survey dredge efficiency.

INPUT: Upper bound incidental mortality allowance	5%
INPUT: Assumed CV for catch	10%

INPUT: Landings (1000 mt, discard ~ 0)	**Estimates for 1997**	**Estimates for 1999**	**Estimates for 2002**	**Estimates for 2005**
S. Virginia and N. Carolina (SVA)	0.000	0.000	0.000	0.000
Delmarva (DMV)	1.072	1.092	1.737	0.935
New Jersey (NJ)	4.229	3.043	2.788	0.665
Long Island (LI)	5.141	6.338	9.139	9.713
Southern New England (SNE)	8.968	6.628	3.895	2.021
Georges Bank (GBK)	0.000	0.000	0.000	0.000
Total	19.409	17.102	17.559	13.334
Catch (1000 mt, landings + upper bound incidental mortality allowance)				
S. Virginia and N. Carolina (SVA)	0.000	0.000	0.000	0.000
Delmarva (DMV)	1.126	1.146	1.824	0.981
New Jersey (NJ)	4.441	3.195	2.928	0.699
Long Island (LI)	5.398	6.655	9.596	10.199
Southern New England (SNE)	9.416	6.960	4.090	2.122
Georges Bank (GBK)	0.000	0.000	0.000	0.000
Total	20.380	17.957	18.437	14.001

INPUT: Efficiency Corrected Swept Area Biomass for Fishable Stock (1000 mt)	**Estimates for 1997**	**CV**	**Estimates for 1999**	**CV**	**Estimates for 2002**	**CV**	**Estimates for 2005**	**CV**
S. Virginia and N. Carolina (SVA)	0	104%	0	61%	0	104%	0	104%
Delmarva (DMV)	131	35%	89	37%	137	36%	84	55%
New Jersey (NJ)	555	31%	311	30%	596	35%	334	30%
Long Island (LI)	1,002	32%	660	30%	755	32%	479	31%
Southern New England (SNE)	526	46%	638	52%	772	37%	533	36%
Georges Bank (GBK)	1,045	31%	1,230	32%	1,516	32%	1,516	32%
Total fishable biomass less GBK	2,214	24%	1,698	28%	2,261	24%	1,431	24%
Total fishable biomass	3,258	23%	2,928	24%	3,776	23%	2,947	24%
Fishing mortality (y^{-1})								
S. Virginia and N. Carolina (SVA)	0.000	104%	0.000	62%	0.000	104%	0.000	104%
Delmarva (DMV)	0.009	37%	0.013	39%	0.013	37%	0.012	56%
New Jersey (NJ)	0.008	32%	0.010	32%	0.005	37%	0.002	32%
Long Island (LI)	0.005	NA	0.010	NA	0.013	33%	0.021	33%
Southern New England (SNE)	0.018	47%	0.011	53%	0.005	39%	0.004	37%
Georges Bank (GBK)	0.000	NA	0.000	NA	0.000	NA	0.000	NA
Total fishable biomass less GBK	0.009	26%	0.011	29%	0.008	26%	0.010	26%
Total fishable biomass	0.006	25%	0.006	26%	0.005	25%	0.005	26%

Lower bound for 80% confidence intervals for fishing mortality (y^{-1}, for lognormal distribution with no bias correction)	**Estimates for 1997**	**Estimates for 1999**	**Estimates for 2002**	**Estimates for 2005**
S. Virginia and N. Carolina (SVA)	NA	NA	NA	NA
Delmarva (DMV)	0.005	0.008	0.008	0.006
New Jersey (NJ)	0.005	0.007	0.003	0.001
Long Island (LI)	NA	NA	0.008	0.014
Southern New England (SNE)	0.010	0.006	0.003	0.003
Georges Bank (GBK)	NA	NA	NA	NA
Total fishable biomass less GBK	0.007	0.007	0.006	0.007
Total fishable biomass	0.005	0.004	0.004	0.003
Upper bound for 80% confidence intervals for fishing mortality (y^{-1}, for lognormal distribution with no bias correction)				
S. Virginia and N. Carolina (SVA)	NA	NA	NA	NA
Delmarva (DMV)	0.014	0.021	0.021	0.023
New Jersey (NJ)	0.012	0.015	0.008	0.003
Long Island (LI)	NA	NA	0.019	0.032
Southern New England (SNE)	0.032	0.021	0.009	0.006
Georges Bank (GBK)	NA	NA	NA	NA
Total fishable biomass less GBK	0.013	0.015	0.011	0.014
Total fishable biomass	0.009	0.009	0.007	0.007

Table A17. Proportions of total fishable ocean quahog biomass during 1980-2005 at a range of survey biomass density levels, by region.

Years	Fishable biomass density levels (kg/tow) from survey data						Sum of Proportions (check)	Total Number of Tows	Total Number of Surveys
	0 to 4	5 to 9	10 to 14	15 to 19	20 to 24	25+			
Proportions of tows (and stock area) at each survey catch rate level:									
Southern Virgina (SVA)									
1980-1989	1.00						1.00	47	5
1990-1999	1.00						1.00	37	3
2000-2005	1.00						1.00	19	2
Delmarva (DMV)									
1980-1989	0.90	0.04	0.03	0.01	0.01	0.02	1.00	317	5
1990-1999	0.92	0.05	0.01	0.01	0.00		1.00	207	3
2000-2005	0.96	0.02	0.01	0.01			1.00	131	2
New Jersy (NJ)									
1980-1989	0.84	0.07	0.03	0.02	0.02	0.03	1.00	458	5
1990-1999	0.82	0.11	0.04	0.02	0.01		1.00	307	3
2000-2005	0.92	0.05	0.02			0.01	1.00	183	2
Long Island (LI)									
1980-1989	0.57	0.21	0.12	0.06	0.01	0.04	1.00	218	5
1990-1999	0.49	0.19	0.12	0.10	0.02	0.07	1.00	121	3
2000-2005	0.64	0.24	0.06	0.02	0.01	0.02	1.00	84	2
Southern New England (SNE)									
1980-1989	0.75	0.09	0.08	0.03	0.02	0.03	1.00	245	5
1990-1999	0.67	0.16	0.08	0.04	0.01	0.04	1.00	114	3
2000-2005	0.65	0.23	0.07	0.04	0.02		1.00	57	2
Georges Bank (GBK)									
1986-1992	0.82	0.06	0.03	0.01	0.01	0.06	1.00	201	3
1997-2002	0.68	0.10	0.07	0.03	0.05	0.07	1.00	219	3
All years	0.75	0.08	0.05	0.02	0.03	0.07	1.00	420	6
Mean survey catch rate (kg/tow) at each survey catch rate level (p_L):									
Southern Virgina (SVA)									
1980-1989	0.054								
1990-1999	0.007								
2000-2005	0.002								
Delmarva (DMV)									
1980-1989	0.490	5.856	11.604	18.761	21.994	31.082			
1990-1999	0.413	7.133	13.556	17.734	21.847				
2000-2005	0.307	7.888	11.960	15.524					
New Jersy (NJ)									
1980-1989	0.848	7.115	12.577	17.033	20.956	35.668			
1990-1999	0.647	6.845	11.748	17.546	23.198				
2000-2005	0.938	6.166	12.707			29.972			
Long Island (LI)									
1980-1989	1.703	7.100	12.281	17.431	20.781	38.945			
1990-1999	1.252	7.523	12.508	16.974	22.793	30.846			
2000-2005	1.779	6.894	12.780	16.666	20.087	39.638			
Southern New England (SNE)									
1980-1989	1.002	7.084	12.200	17.286	21.627	33.942			
1990-1999	1.001	7.461	11.993	17.384	20.904	36.563			
2000-2005	1.387	7.238	12.077	16.226	21.845				
Georges Bank (GBK)									
1986-1992	0.627	6.874	12.945	16.049	23.225	44.962			
1997-2002	0.626	7.681	12.370	16.595	23.386	40.787			
All years	0.627	7.381	12.535	16.413	23.349	42.576			
Proportions of stock biomass at each survey catch rate level (X_L):									
Southern Virgina (SVA)									
1980-1989	1.00						1.00		
1990-1999	1.00						1.00		
2000-2005	1.00						1.00		
Delmarva (DMV)									
1980-1989	0.23	0.12	0.15	0.12	0.07	0.31	1.00		
1990-1999	0.30	0.27	0.15	0.20	0.08		1.00		
2000-2005	0.43	0.26	0.13	0.17			1.00		
New Jersy (NJ)									
1980-1989	0.22	0.15	0.14	0.09	0.10	0.29	1.00		
1990-1999	0.23	0.34	0.20	0.17	0.07		1.00		
2000-2005	0.49	0.17	0.16			0.19	1.00		
Long Island (LI)									
1980-1989	0.15	0.22	0.23	0.15	0.03	0.22	1.00		
1990-1999	0.08	0.18	0.19	0.21	0.07	0.28	1.00		
2000-2005	0.22	0.32	0.15	0.08	0.05	0.18	1.00		
Southern New England (SNE)									
1980-1989	0.18	0.16	0.22	0.13	0.08	0.23	1.00		
1990-1999	0.12	0.22	0.18	0.14	0.03	0.30	1.00		
2000-2005	0.21	0.38	0.19	0.13	0.09	0.00	1.00		
Georges Bank (GBK)									
1986-1992	0.11	0.10	0.08	0.05	0.08	0.58	1.00		
1997-2002	0.07	0.12	0.13	0.07	0.16	0.45	1.00		
All years	0.08	0.11	0.11	0.06	0.13	0.50	1.00		

Table A18. Proportions of total 2005 stock biomass at a range of survey density levels, by region.

	Survey catch rate level (kg/tow)						
Region	**0 to 4**	**5 to 9**	**10 to 14**	**15 to 19**	**20 to 24**	**25+**	**Total**
	Total 2005 biomass (mt meats)						
Southern Virgina (SVA)	17	0	0	0	0	0	17
Delmarva (DMV)	43,532	26,628	13,459	17,470	0	0	101,089
New Jersy (NJ)	195,400	68,833	63,047	0	0	74,354	401,634
Long Island (LI)	151,198	217,001	100,560	52,457	31,612	124,762	677,590
Southern New England (SNE)	123,098	225,647	115,846	77,824	52,388	0	594,802
Georges Bank (GBK)	82,714	148,850	163,456	87,709	206,009	574,872	1,263,610
Total	595,959	686,960	456,369	235,460	290,008	773,987	3,038,741
	Total 2005 biomass (bushels)						
Southern Virgina (SVA)	3,731	0	0	0	0	0	3,731
Delmarva (DMV)	9,597,036	5,870,504	2,967,208	3,851,373	0	0	22,286,120
New Jersy (NJ)	43,077,930	15,174,947	13,899,368	0	0	16,391,987	88,544,232
Long Island (LI)	33,333,071	47,840,106	22,169,510	11,564,629	6,969,113	27,504,966	149,381,395
Southern New England (SNE)	27,138,182	49,746,067	25,539,371	17,157,064	11,549,366	0	131,130,049
Georges Bank (GBK)	18,235,073	32,815,497	36,035,560	19,336,384	45,416,674	126,736,217	278,575,405
Total	131,385,021	151,447,120	100,611,016	51,909,450	63,935,154	170,633,170	669,920,932
	Percent of total 2005 biomass						
Southern Virgina (SVA)	0.001%	0.000%	0.000%	0.000%	0.000%	0.000%	0.001%
Delmarva (DMV)	1.43%	0.88%	0.44%	0.57%	0.00%	0.00%	3.33%
New Jersy (NJ)	6.43%	2.27%	2.07%	0.00%	0.00%	2.45%	13.22%
Long Island (LI)	4.98%	7.14%	3.31%	1.73%	1.04%	4.11%	22.30%
Southern New England (SNE)	4.05%	7.43%	3.81%	2.56%	1.72%	0.00%	19.57%
Georges Bank (GBK)	2.72%	4.90%	5.38%	2.89%	6.78%	18.92%	41.58%
Total	19.61%	22.61%	15.02%	7.75%	9.54%	25.47%	100.00%

Table A19. Calculations to build a bridge between efficiency corrected swept area biomass estimates for ocean quahog during 2002 in NEFSC (2004) and new estimates in this assessment. Columns show cumulative effects from each change in data and methods starting with NEFSC's (2004) estimates on the left and ending with the new estimates on the right.

Region	NEFSC (2004)	Step 1 (New spread sheet)	Step 2 (Correct survey data)	Step 3 (Add biomass in deep water)	Step 4 (Use fishable biomass)	This assessment (New efficiency estimate	Ratio (New / NEFSC(2004)
Data and configuration							
Efficiency	0.269	0.269	0.269	0.269	0.269	0.165	0.61
Size groups in Patch model	70+	70+	70+	70+	Fishable	Fishable	NA
Deep water percentage	0%	0%	0%	13%	13%	13%	NA
Survey data	Erroneous	Erroneous	Correct	Correct	Correct	Correct	NA
2002 efficiency corrected swept-area biomass estimates (1000 mt)							
SVA	0.01	0.01	0.01	0.01	0.01	0.01	1.93
DMV	71	71	89	89	84	137	1.93
NJ	330	330	383	383	365	596	1.81
LI	454	454	498	498	463	755	1.66
SNE	428	437	511	511	473	772	1.80
GBK	833	833	875	989	929	1,516	1.82
Total less GBK	1,283	1,292	1,481	1,481	1,385	2,261	1.76
Total	2,116	2,125	2,356	2,470	2,314	3,776	1.78

Table A20. "Best" fishable biomass and fishing mortality estimates for ocean quahog during 1978-2005, by stock assessment region and for the entire EEZ stock (with and without GBK).

	SVA	DMV		NJ		LI		SNE		GBK		Entire stock less GBK	Entire Stock
Model	VPA	KLAMZ		KLAMZ		KLAMZ		KLAMZ		Mean ESB 1997-2002 (Same as VPA)		NA	NA
	Estimate	**Estimate**	**CV**	**Estimate**	**CV**	**Estimate**	**CV**	**Estimate**	**CV**	**Estimate**	**CV**	**Estimate**	**Estimate**
Scaling parameter for swept area biomass	1 (assumed)	0.99	NA	0.95	NA	1.00	NA	0.99	NA	1 (assumed)	NA	NA	NA
Recruitment (1000 mt)	NA	0 (assumed)		0.541	0.43	9.860	0.34	4.799	1.06	NA		15.199 (excludes SVA)	15.199 (excludes SVA & GBK)
Fishable Stock Biomass (1000 mt)													
1978	0.338	299	0.10	904	0.22	718	0.26	788	0.32	1,264	0.19	2,710	3,973
1979	0.338	292	0.10	879	0.22	721	0.25	782	0.31	1,264	0.19	2,674	3,938
1980	0.338	280	0.10	855	0.21	723	0.24	777	0.30	1,264	0.19	2,636	3,900
1981	0.338	270	0.11	831	0.21	726	0.24	771	0.29	1,264	0.19	2,599	3,862
1982	0.275	261	0.11	807	0.21	729	0.23	765	0.28	1,264	0.19	2,562	3,826
1983	0.268	251	0.11	783	0.20	732	0.22	759	0.27	1,264	0.19	2,525	3,789
1984	0.268	240	0.11	761	0.20	734	0.22	753	0.26	1,264	0.19	2,489	3,753
1985	0.261	228	0.12	738	0.20	737	0.21	747	0.25	1,264	0.19	2,450	3,714
1986	0.075	216	0.12	713	0.20	739	0.20	741	0.24	1,264	0.19	2,409	3,672
1987	0.075	203	0.12	691	0.19	742	0.20	735	0.24	1,264	0.19	2,370	3,634
1988	0.075	189	0.13	669	0.19	743	0.20	729	0.23	1,264	0.19	2,330	3,594
1989	0.031	173	0.14	650	0.19	745	0.19	723	0.22	1,264	0.19	2,291	3,555
1990	0.031	163	0.15	625	0.19	747	0.19	717	0.21	1,264	0.19	2,252	3,515
1991	0.017	157	0.15	598	0.19	749	0.18	711	0.21	1,264	0.19	2,214	3,478
1992	0.017	149	0.15	573	0.19	749	0.18	705	0.20	1,264	0.19	2,176	3,440
1993	0.017	143	0.16	556	0.18	740	0.18	699	0.20	1,264	0.19	2,139	3,402
1994	0.017	139	0.16	536	0.18	734	0.18	693	0.19	1,264	0.19	2,102	3,366
1995	0.017	135	0.16	520	0.18	724	0.18	688	0.18	1,264	0.19	2,067	3,331
1996	0.017	131	0.16	505	0.18	718	0.18	678	0.18	1,264	0.19	2,033	3,296
1997	0.017	128	0.16	492	0.18	714	0.18	665	0.18	1,264	0.19	2,000	3,263
1998	0.017	125	0.16	479	0.18	712	0.18	652	0.18	1,264	0.19	1,968	3,231
1999	0.017	121	0.17	468	0.17	708	0.18	642	0.18	1,264	0.19	1,938	3,202
2000	0.017	117	0.17	457	0.17	705	0.18	631	0.18	1,264	0.19	1,910	3,173
2001	0.017	114	0.17	445	0.17	703	0.18	622	0.18	1,264	0.19	1,884	3,148
2002	0.017	111	0.17	433	0.17	700	0.18	614	0.18	1,264	0.19	1,857	3,121
2003	0.017	107	0.17	422	0.17	694	0.18	607	0.18	1,264	0.19	1,830	3,093
2004	0.017	104	0.17	412	0.17	685	0.18	601	0.18	1,264	0.19	1,802	3,065
2005	0.017	101	0.18	402	0.17	678	0.18	595	0.18	1,264	0.19	1,775	3,039

Table A20 (continued).

Fishing mortality rate													
1978	0.0000	0.0044	0.10	0.0097	0.22	0.00000	NA	0.0000	NA	0.0000	0.00	0.0039	0.0026
1979	0.0000	0.0191	0.10	0.0095	0.22	0.00000	NA	0.0000	NA	0.0000	0.00	0.0059	0.0040
1980	0.0000	0.0172	0.10	0.0103	0.21	0.00001	0.24	0.0000	NA	0.0000	0.00	0.0051	0.0034
1981	0.2085	0.0148	0.11	0.0111	0.21	0.00000	0.24	0.0000	NA	0.0000	0.00	0.0051	0.0034
1982	0.0252	0.0195	0.11	0.0116	0.21	0.00000	NA	0.0000	NA	0.0000	0.00	0.0056	0.0037
1983	0.0000	0.0224	0.11	0.0109	0.20	0.00003	0.22	0.0009	0.27	0.0000	0.00	0.0058	0.0039
1984	0.0257	0.0326	0.11	0.0126	0.20	0.00000	NA	0.0012	0.26	0.0000	0.00	0.0072	0.0048
1985	1.2454	0.0358	0.12	0.0163	0.20	0.0001	0.21	0.0010	0.25	0.0000	0.00	0.0085	0.0056
1986	0.0000	0.0407	0.12	0.0134	0.20	0.0006	0.20	0.0008	0.24	0.0000	0.00	0.0079	0.0052
1987	0.0000	0.0539	0.13	0.0134	0.19	0.0016	0.20	0.0010	0.24	0.0000	0.00	0.0091	0.0059
1988	0.8817	0.0649	0.14	0.0106	0.19	0.0009	0.20	0.0012	0.23	0.0000	0.00	0.0087	0.0057
1989	0.0000	0.0383	0.14	0.0221	0.19	0.0008	0.19	0.0017	0.22	0.0000	0.00	0.0098	0.0063
1990	0.6092	0.0230	0.15	0.0255	0.19	0.0010	0.19	0.0013	0.21	0.0000	0.00	0.0094	0.0060
1991	0.0000	0.0317	0.15	0.0249	0.19	0.0023	0.18	0.0012	0.21	0.0000	0.00	0.0100	0.0064
1992	0.0000	0.0163	0.16	0.0123	0.19	0.0161	0.18	0.0016	0.20	0.0000	0.00	0.0104	0.0066
1993	0.0000	0.0139	0.16	0.0187	0.19	0.0118	0.18	0.0015	0.20	0.0000	0.00	0.0103	0.0065
1994	0.0000	0.0073	0.16	0.0132	0.18	0.0166	0.18	0.0014	0.19	0.0000	0.00	0.0100	0.0063
1995	0.0000	0.0053	0.16	0.0105	0.18	0.0133	0.18	0.0080	0.19	0.0000	0.00	0.0103	0.0064
1996	0.0000	0.0057	0.16	0.0098	0.18	0.0084	0.18	0.0125	0.18	0.0000	0.00	0.0099	0.0061
1997	0.0000	0.0085	0.16	0.0087	0.18	0.0073	0.18	0.0137	0.18	0.0000	0.00	0.0099	0.0060
1998	0.0000	0.0112	0.16	0.0057	0.18	0.0097	0.18	0.0105	0.18	0.0000	0.00	0.0091	0.0056
1999	0.0000	0.0092	0.17	0.0066	0.17	0.0090	0.18	0.0105	0.18	0.0000	0.00	0.0090	0.0054
2000	0.0000	0.0091	0.17	0.0074	0.17	0.0068	0.18	0.0082	0.18	0.0000	0.00	0.0077	0.0047
2001	0.0000	0.0084	0.17	0.0110	0.17	0.0086	0.18	0.0080	0.18	0.0000	0.00	0.0091	0.0054
2002	0.0000	0.0160	0.17	0.0065	0.17	0.0132	0.18	0.0064	0.18	0.0000	0.00	0.0097	0.0058
2003	0.0000	0.0085	0.17	0.0089	0.17	0.0170	0.18	0.0036	0.18	0.0000	0.00	0.0103	0.0061
2004	0.0000	0.0062	0.17	0.0069	0.17	0.0157	0.18	0.0055	0.18	0.0000	0.00	0.0098	0.0058
2005	0.0000	0.0094	0.18	0.0017	0.17	0.0145	0.18	0.0034	0.18	0.0000	0.00	0.0077	0.0045

Table A21. Ocean quahog biomass in 2005 as a percentage of biomass in 1978, based on best estimates.

SVA	DMV	NJ	LI	SNE	GBK	Entire stock less GBK	Entire Stock
5%	34%	44%	94%	75%	100%	66%	76%

Table A22. Comparison of best estimates for ocean quahog biomass during 2004 from the previous (NEFSC 2004) and current assessments.

Assessment	SVA	DMV	NJ	LI	SNE	GBK	Entire stock less GBK	Entire Stock
1978 Biomass Estimates (Virgin Biomass)								
This assessment	0.338	299	904	718	788	1,264	2,710	3,973
NEFSC (2004)	0.297	298	455	534	386	655	1,674	2,329
Ratio (new/old)	1.1	1.0	2.0	1.3	2.0	1.9	1.6	1.7
2004 Biomass Estimates								
This assessment	0.0169	103.8	411.5	685	601.3	1264	1801.603121	3065
NEFSC (2004)	0.013	91	284	478	349	655	1,201	1,856
Ratio (new/old)	1.3	1.1	1.5	1.4	1.7	1.9	1.5	1.7

Table A23. Mean numbers per tow for ocean quahog < 70 mm SL and mean weight per tow for ocean quahog 70+ mm SL in NEFSC clam surveys on GBK during 1986-2002 (1994 omitted due to high pump voltage).

Year	< 70 mm SL (N tow^{-1})	CV	70+ mm SL (KG tow^{-1})	CV
1986	40.5	0.60	5.7	0.17
1989	7.0	0.32	2.3	0.26
1992	31.7	0.35	9.0	0.21
1997	62.0	0.35	6.6	0.19
1999	35.3	0.34	7.5	0.19
2002	39.7	0.18	8.7	0.20

Table A24. Biological reference points for ocean quahog from a length based per-recruit model with sensitivity analyses. Biological reference points from an age based per-recruit model in the last assessment (NEFSC 2004) are shown for comparison.

			Natural Mortality (M)		Fishery selectivity L50%		Growth parameter K		Maturity L50%	
Reference Point	Old (SARC-38)	New basecase[A]	Half basecase (M_{LO}=0.01 y^{-1})	Double basecase (M_{HI}=0.04 y^{-1})	Basecase - 5 mm ($L50_{LO}$ = 73 - 5 = 67 mm)	Basecase - 5 mm ($L50_{HI}$ = 73 + 5 = 78 mm)	Basecase - 30% (K_{LO} = 0.0311 * 0.7 = 0.0218 y^{-1})	Basecase + 30% (K = 0.0311 * 1.3 = 0.0404 y^{-1})	Basecase - 5 mm ($L50_{LO}$ = 64 - 5 = 59 mm)	Basecase + 5 mm ($L50_{HI}$ = 64 + 5 = 69 mm)
$F_{0.1}$ (target)	0.0275	0.0278	0.0160	0.0618	0.0254	0.0300	0.0288	0.0277	0.0278	0.0278
F_{MAX}	0.1810	0.0760	0.0361	0.2300	0.0632	0.0896	0.0882	0.0722	0.0760	0.0760
$F_{25\%}$ (threshold)	0.0800	0.0517	0.0291	0.1249	0.0429	0.0617	0.0564	0.0501	0.0561	0.0478
$F_{50\%}$	0.0200	0.0180	0.0110	0.0402	0.0158	0.0205	0.0192	0.0177	0.0190	0.0171

[A] In the basecase run: M=0.02 y^{-1}, growth parameters (L_{max}=97.28 mm; K=0.0311 y^{-1}) are from NEFSC (2002); maturity (α=-5.92; b=0.0927) and fishery selectivity (a=-7.63; b=0.1054) parameters are from Thorarinsdottir and Jacobson (2005); and length-weight parameters (ln a=-9.242; b=2.821) are from an average length-weight curve for all stock assessment areas.

Table A25. Percentage of ocean quahog biomass in each stock assessment region during 1978 and 2005. Percentages for SVA, DMV, NJ, LI, SNE and GBK in the same row sum to 100%.

Year	SVA	DMV	NJ	LI	SNE	GBK	Entire stock less GBK
1978	0.009%	8%	23%	18%	20%	32%	68%
2005	0.001%	3%	13%	22%	20%	42%	58%

Table A26. Input data for ocean quahog projections.

Year	**SVA**	**DMV**	**NJ**	**LI**	**SNE**	**GBK**	**Total Less GBK**	**Total**
Somatic growth rate (G y^{-1})								
2005	0.0045	1.0600E-07	0.0013	0.0101	0.0066	0	0.0064	0.0037
Recruitment rate (r = Recruitment / Average Biomass in 2005 y^{-1})								
2005	0.0060	1.0038E-08	0.0014	0.0146	0.0081	0.0000	0.0086	0.0050
Natural mortality (M y^{-1})								
2005	0.0200	0.0200	0.0200	0.0200	0.0200	0	0.0200	0.0117
Initial Biomass								
2005	0.017	101	402	678	595	1,264	1,775	3,039
Landings (mt y^{-1})								
2005	0.000	0.890	0.634	9.251	1.924	0	12.6990	12.6990
Catch (landings + 5% allowance for incidental mortality, mt y^{-1})								
2005	0.000	0.935	0.665	9.713	2.021	0	13.3340	13.3340
Fishing mortality (F y^{-1})								
2005	0.0000	0.0094	0.0017	0.0145	0.0034	0	0.0077	0.0045

Table A27. Projected biomass and fishing mortality for ocean quahog during 2005-2010 based on a 4 million bushel (18,144 mt meats) annual quota during 2007-2010. Landings during 2006 are assumed the same as in 2005. Proportions of total catch in each year for each region are the same as in 2005.

Year	SVA	DMV	NJ	LI	SNE	GBK	Total Less GBK	Total
Somatic growth rate (G y^{-1})								
2005	0.0045	0.0000	0.0013	0.0101	0.0066	0.0000	0.0064	0.0037
Recruitment rate (r = Recruitment / Average Biomass in 2002 y^{-1})								
2005	0.0060	0.0000	0.0014	0.0146	0.0081	0.0000	0.0086	0.0050
Natural mortality (M y^{-1})								
2005	0.0200	0.0200	0.0200	0.0200	0.0200	0.0000	0.0200	0.0117
Net instantaneous rate of change, less fishing (X - F = G + r - M y^{-1})								
2005	-0.0095	-0.0200	-0.0174	0.0047	-0.0052	0.0000	-0.0050	-0.0029
Fishing mortality first year (F y^{-1})								
2005	0.0000	0.0094	0.0017	0.0145	0.0034	0.0000	0.0077	0.0045
Landings (mt meats y^{-1})								
2005-2006	0	1	1	9	2	0	13	13
2007-2010	0	1	1	13	3	0	18	18
Catch (mt meats y^{-1}, landings+ 5% allowance for incidental mortality)								
2005-2006	0	1	1	10	2	0	13	13
2007-2010	0	1	1	14	3	0	19	19
Initial Biomass								
2005-2006	0	101	402	678	595	1,264	1,775	3,039
Projected biomass (mt meats)								
2006	0	98	394	671	590	1,264	1,753	3,016
2007	0	95	387	664	585	1,264	1,731	2,995
2008	0	92	379	654	579	1,264	1,703	2,967
2009	0	89	372	643	573	1,264	1,676	2,940
2010	0	86	364	632	567	1,264	1,649	2,912
Projected fishing mortality rate (F y^{-1})								
2006	0.000	0.010	0.002	0.015	0.003	0.000	0.008	0.004
2007	0.000	0.014	0.002	0.021	0.005	0.000	0.011	0.006
2008	0.000	0.015	0.003	0.021	0.005	0.000	0.011	0.006
2009	0.000	0.015	0.003	0.022	0.005	0.000	0.011	0.007
2010	0.000	0.016	0.003	0.022	0.005	0.000	0.012	0.007

Table A28. Projected biomass and fishing mortality for ocean quahog during 2005-2010 based on a 5.333 million bushel (24,189 mt meats) annual quota during 2007-2010. Landings during 2006 are assumed the same as in 2005. Proportions of total catch in each year for each region are the same as in 2005.

Year	SVA	DMV	NJ	LI	SNE	GBK	Total Less GBK	Total
Somatic growth rate (G y^{-1})								
2005	0.0045	0.0000	0.0013	0.0101	0.0066	0.0000	0.0064	0.0037
Recruitment rate (r = Recruitment / Average Biomass in 2002 y^{-1})								
2005	0.0060	0.0000	0.0014	0.0146	0.0081	0.0000	0.0086	0.0050
Natural mortality (M y^{-1})								
2005	0.0200	0.0200	0.0200	0.0200	0.0200	0.0000	0.0200	0.0117
Net instantaneous rate of change, less fishing (X - F = G + r - M y^{-1})								
2005	-0.0095	-0.0200	-0.0174	0.0047	-0.0052	0.0000	-0.0050	-0.0029
Fishing mortality first year (F y^{-1})								
2005	0.0000	0.0094	0.0017	0.0145	0.0034	0.0000	0.0077	0.0045
Landings (mt meats y^{-1})								
2005-2006	0	1	1	9	2	0	13	13
2007-2010	0	2	1	18	4	0	24	24
Catch (mt meats y^{-1}, landings+ 5% allowance for incidental mortality)								
2005-2006	0	1	1	10	2	0	13	13
2007-2010	0	2	1	19	4	0	25	25
Initial Biomass								
2005-2006	0	101	402	678	595	1,264	1,775	3,039
Projected biomass (mt meats)								
2006	0	98	394	671	590	1,264	1,753	3,016
2007	0	95	387	664	585	1,264	1,731	2,995
2008	0	92	379	649	578	1,264	1,697	2,961
2009	0	88	371	633	571	1,264	1,663	2,927
2010	0	85	363	618	564	1,264	1,630	2,893
Projected fishing mortality rate (F y^{-1})								
2006	0.000	0.010	0.002	0.015	0.003	0.000	0.008	0.004
2007	0.000	0.019	0.003	0.028	0.007	0.000	0.015	0.009
2008	0.000	0.020	0.003	0.029	0.007	0.000	0.015	0.009
2009	0.000	0.021	0.003	0.030	0.007	0.000	0.015	0.009
2010	0.000	0.021	0.004	0.030	0.007	0.000	0.016	0.009

Table A29. Projected biomass and fishing mortality for ocean quahog during 2005-2010 based on a 6 million bushel (27,215 mt meats) annual quota during 2007-2010. Landings during 2006 are assumed the same as in 2005. Proportions of total catch in each year for each region are the same as in 2005.

Year	SVA	DMV	NJ	LI	SNE	GBK	Total Less GBK	Total
				Somatic growth rate (G y^{-1})				
2005	0.0045	0.0000	0.0013	0.0101	0.0066	0.0000	0.0064	0.0037
				Recruitment rate (r = Recruitment / Average Biomass in 2002 y^{-1})				
2005	0.0060	0.0000	0.0014	0.0146	0.0081	0.0000	0.0086	0.0050
				Natural mortality (M y^{-1})				
2005	0.0200	0.0200	0.0200	0.0200	0.0200	0.0000	0.0200	0.0117
				Net instantaneous rate of change, less fishing (X - F = G + r - M y^{-1})				
2005	-0.0095	-0.0200	-0.0174	0.0047	-0.0052	0.0000	-0.0050	-0.0029
				Fishing mortality first year (F y^{-1})				
2005	0.0000	0.0094	0.0017	0.0145	0.0034	0.0000	0.0077	0.0045
				Landings (mt meats y^{-1})				
2005-2006	0	1	1	9	2	0	13	13
2007-2010	0	2	1	20	4	0	27	27
				Catch (mt meats y^{-1}, landings+ 5% allowance for incidental mortality)				
2005-2006	0	1	1	10	2	0	13	13
2007-2010	0	2	1	21	4	0	29	29
				Initial Biomass				
2005-2006	0	101	402	678	595	1,264	1,775	3,039
				Projected biomass (mt meats)				
2006	0	98	394	671	590	1,264	1,753	3,016
2007	0	95	387	664	585	1,264	1,731	2,995
2008	0	91	379	647	577	1,264	1,694	2,957
2009	0	88	371	629	570	1,264	1,657	2,921
2010	0	84	363	611	563	1,264	1,620	2,884
				Projected fishing mortality rate (F y^{-1})				
2006	0.000	0.010	0.002	0.015	0.003	0.000	0.008	0.004
2007	0.000	0.021	0.004	0.032	0.007	0.000	0.017	0.010
2008	0.000	0.022	0.004	0.033	0.008	0.000	0.017	0.010
2009	0.000	0.023	0.004	0.034	0.008	0.000	0.017	0.010
2010	0.000	0.024	0.004	0.035	0.008	0.000	0.018	0.010

Table A30. Projected biomass and fishing mortality for ocean quahog during 2005-2010 based on $F=F_{0.1}=0.0278\ y^{-1}$ for exploitable region (total area less GBK) during 2007-2010. Landings during 2006 are assumed the same as in 2005. Proportions of total catch in each year for each region are the same as in 2005.

Year	SVA	DMV	NJ	LI	SNE	GBK	Total Less GBK	Total
Somatic growth rate ($G\ y^{-1}$)								
2005	0.0045	0.0000	0.0013	0.0101	0.0066	0.0000	0.0064	0.0037
Recruitment rate (r = Recruitment / Average Biomass in 2002 y^{-1})								
2005	0.0060	0.0000	0.0014	0.0146	0.0081	0.0000	0.0086	0.0050
Natural mortality ($M\ y^{-1}$)								
2005	0.0200	0.0200	0.0200	0.0200	0.0200	0.0000	0.0200	0.0117
Fishing mortality ($F\ y^{-1}$)								
2005-2006	0.0000	0.0094	0.0017	0.0145	0.0034	0.0000	0.0077	0.0045
2007-2010	0.0278	0.0278	0.0278	0.0278	0.0278	0.0000	NA	NA
Net instantaneous rate of change $X = G + r - F - M\ y^{-1}$)								
2005-2006	-0.0095	-0.0294	-0.0190	-0.0098	-0.0086	0.0000	-0.0127	-0.0074
2007-2010	-0.0373	-0.0478	-0.0452	-0.0231	-0.0330	0.0000	NA	NA
Initial Biomass								
2005	0.017	101	402	678	595	1,264	1,775	3,039
Projected biomass (mt meats)								
2006	0.017	98	394	671	590	1,264	1,753	3,016
2007	0.016	94	377	656	571	1,264	1,696	2,960
2008	0.016	89	360	641	552	1,264	1,642	2,905
2009	0.015	85	344	626	534	1,264	1,589	2,853
2010	0.014	81	329	612	517	1,264	1,538	2,802
Catch (landings + 5% allowance for incidental mortality, mt y^{-1})								
2006	0.0	0.9	0.7	9.7	2.0	0.0	13.3	13.3
2007	0.0	3.2	2.3	33.8	7.0	0.0	46.4	46.4
2008	0.0	3.1	2.2	32.1	6.7	0.0	44.1	44.1
2009	0.0	3.0	2.1	30.8	6.4	0.0	42.3	42.3
2010	0.0	2.9	2.0	29.7	6.2	0.0	40.8	40.8
Landings (95% of catch, mt y^{-1})								
2006	0.0	0.9	0.6	9.2	1.9	0.0	12.7	12.7
2007	0.0	3.1	2.2	32.1	6.7	0.0	44.0	44.0
2008	0.0	2.9	2.1	30.5	6.4	0.0	41.9	41.9
2009	0.0	2.8	2.0	29.2	6.1	0.0	40.1	40.1
2010	0.0	2.7	1.9	28.2	5.9	0.0	38.7	38.7
Projected fishing mortality rate ($F\ y^{-1}$)								
2006	0.000	0.009	0.002	0.014	0.003	0.000	0.008	0.004
2007	0.000	0.035	0.006	0.052	0.012	0.000	0.027	0.016
2008	0.000	0.035	0.006	0.051	0.012	0.000	0.027	0.015
2009	0.000	0.035	0.006	0.050	0.012	0.000	0.027	0.015
2010	0.000	0.036	0.006	0.049	0.012	0.000	0.027	0.015

Table A31. Summary of example projections.

Year	Biomass All Regions (1000 mt)	Biomass less GBK (1000 mt)	Landings (1000 mt)	*F* All Regions (y^{-1})	*F* less GBK (y^{-1})
Quota = 4 million bushels (18,144 mt meats)					
2006	3,016	1,753	13	0.004	0.008
2007	2,995	1,731	18	0.006	0.011
2008	2,967	1,703	18	0.006	0.011
2009	2,940	1,676	18	0.007	0.011
2010	2,912	1,649	18	0.007	0.012
Quota = 5.333 million bushels (24,189 mt meats)					
2006	3,016	1,753	13	0.004	0.008
2007	2,995	1,731	24	0.009	0.015
2008	2,961	1,697	24	0.009	0.015
2009	2,927	1,663	24	0.009	0.015
2010	2,893	1,630	24	0.009	0.016
Quota = 6 million bushels (27,215 mt meats)					
2006	3,016	1,753	13	0.004	0.008
2007	2,995	1,731	27	0.010	0.017
2008	2,957	1,694	27	0.010	0.017
2009	2,921	1,657	27	0.010	0.017
2010	2,884	1,620	27	0.010	0.018
$F = F_{0.1}=0.028\ y^{-1}$ in exploited regions (F=0 for GBK)					
2006	3,016	1,753	13	0.004	0.028
2007	2,960	1,696	44	0.016	0.028
2008	2,905	1,642	42	0.015	0.028
2009	2,853	1,589	40	0.015	0.028
2010	2,802	1,538	39	0.015	0.028

OCEAN QUAHOG FIGURES

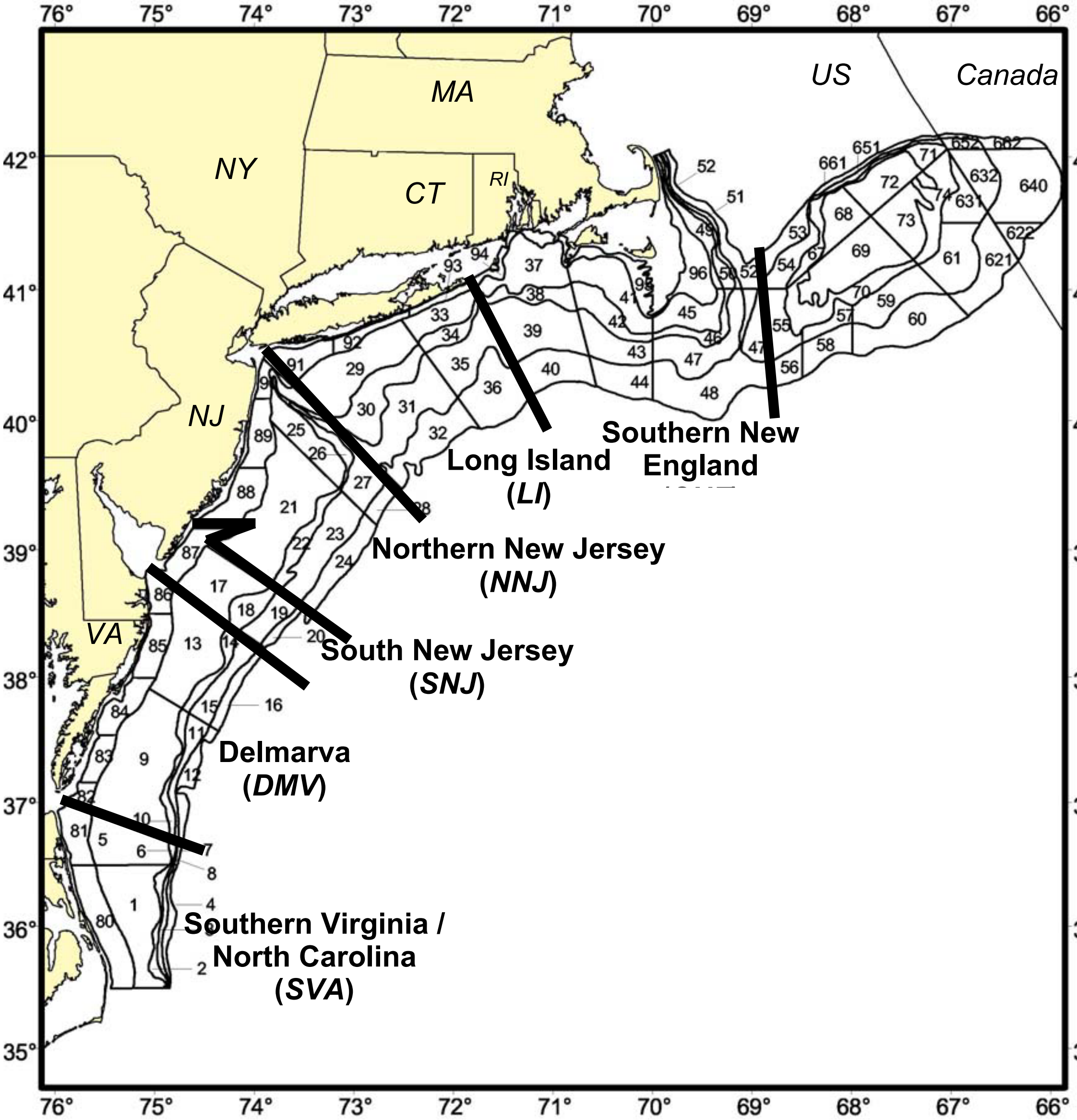


Figure A1. Stock assessment regions for ocean quahog in the US EEZ, with NEFSC shellfish survey strata numbers and boundaries.

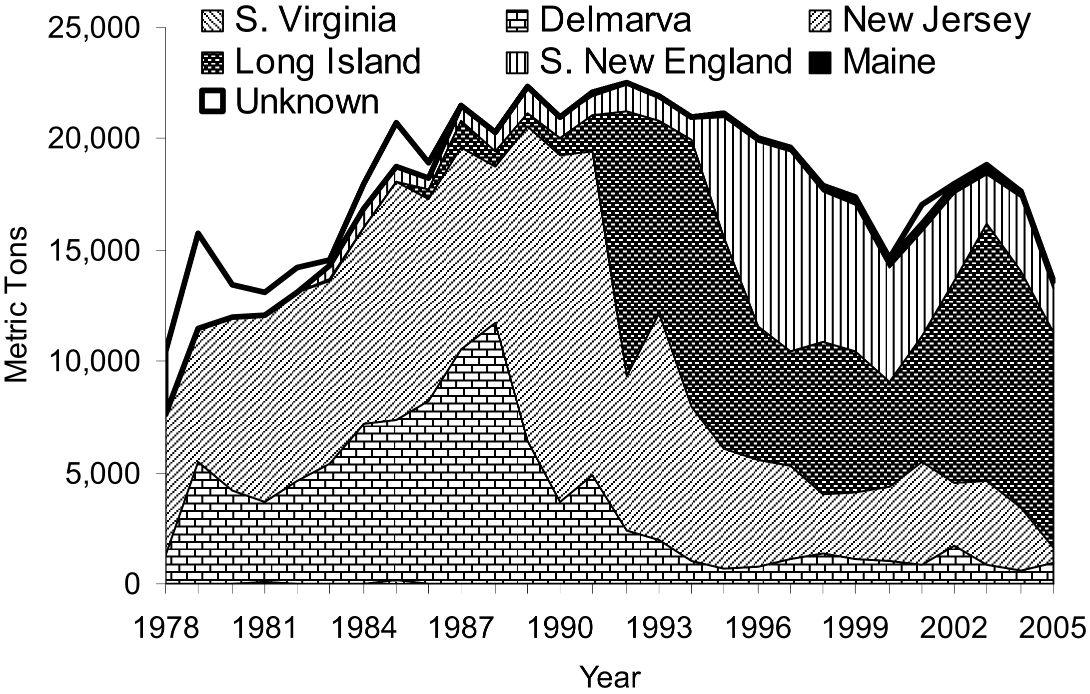
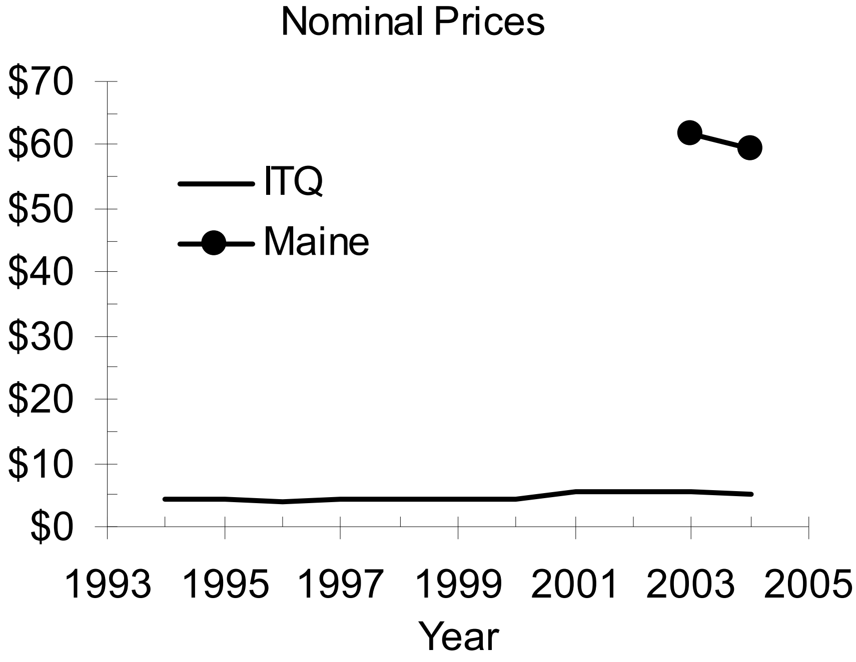


Figure A2. Ocean quahog commercial landings (meat weights) from the US EEZ during 1978-2005. Data for 2005 are preliminary and may be incomplete.



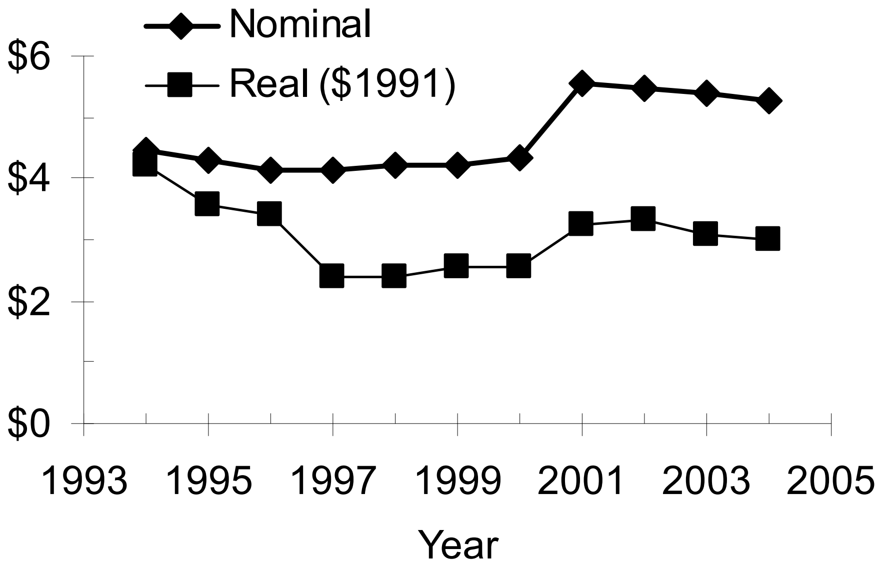


Figure A3. Real and nominal exvessel prices for ocean quahog in the ITQ and Maine fishery components.

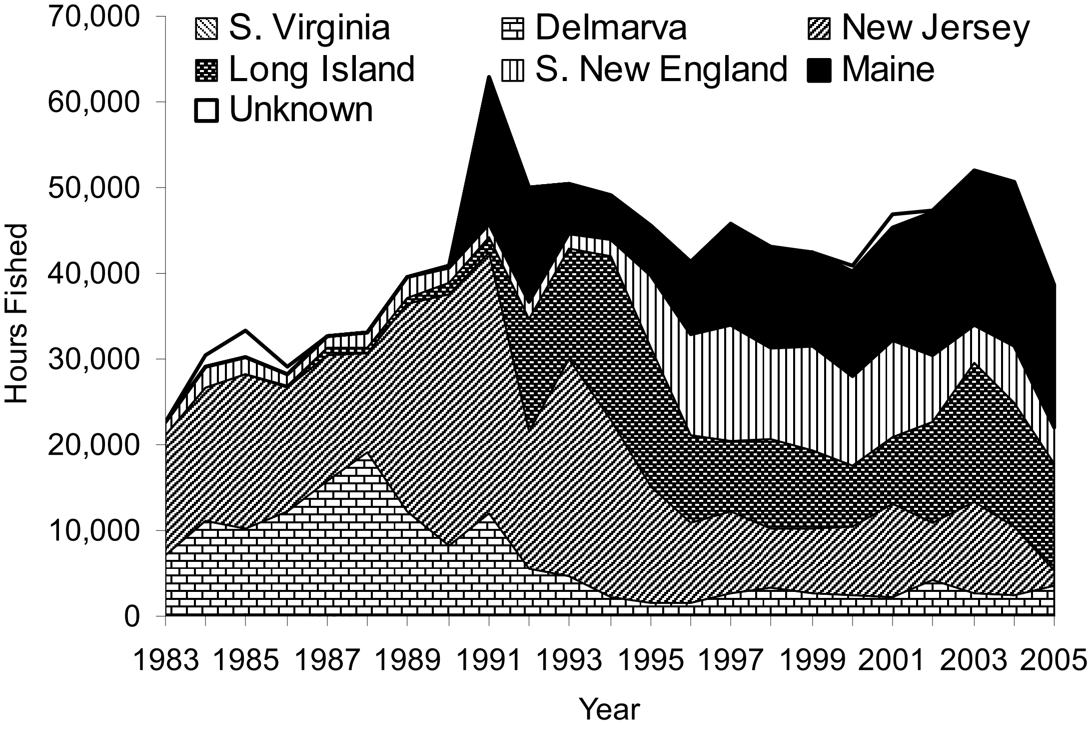


Figure A4. Hours fished for ocean quahog in the US EEZ during 1983-2005 based on logbook records.

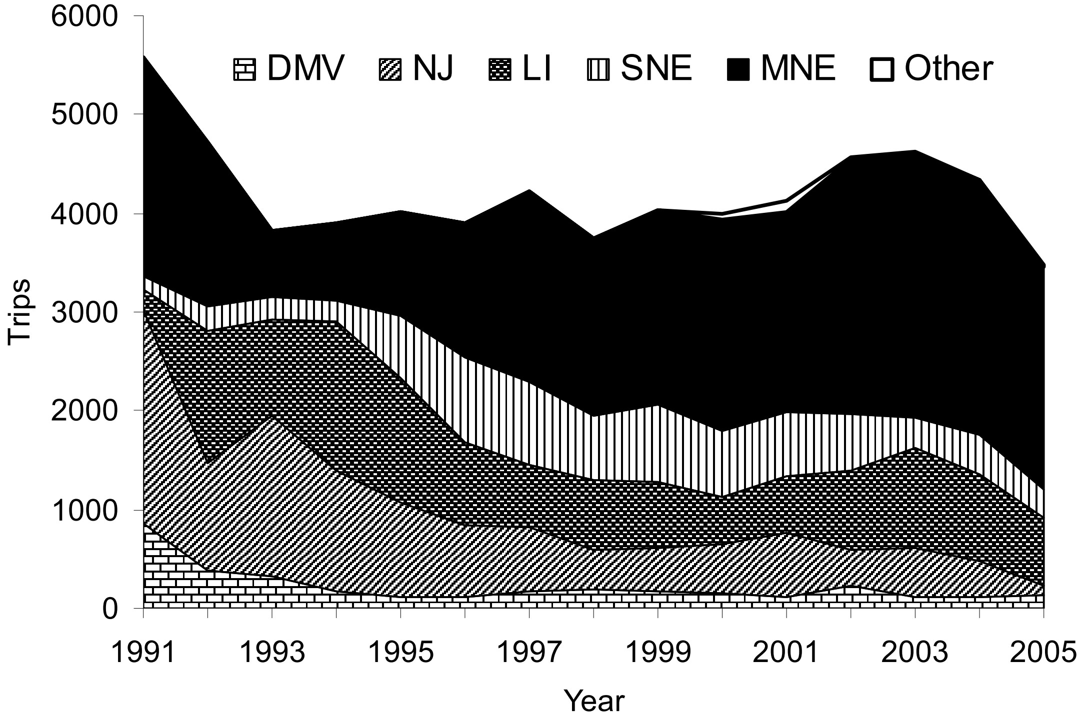


Figure A5. Number of trips for ocean quahog in the US EEZ during 1991-2004 based on logbook records.

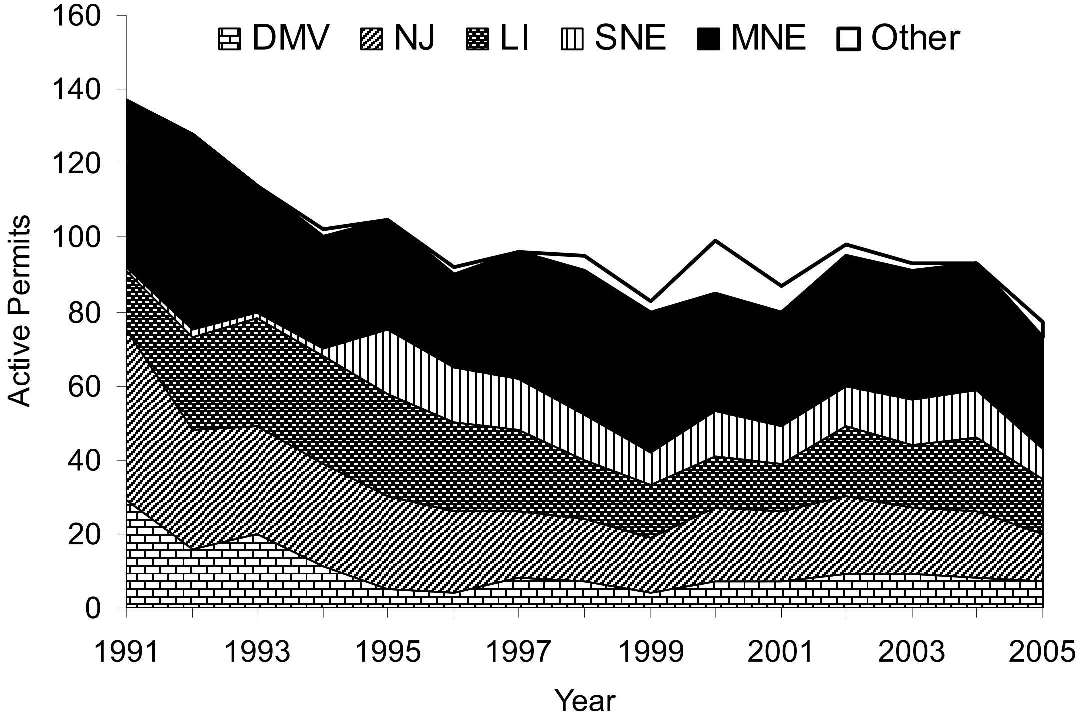


Figure A6. Number of active permits (fishing vessels) for ocean quahog in the US EEZ during 19910-2004 based on logbook records. The total number of permits in the graph for any year may exceed the total number of active permits in the fishery because some vessels fished in more than one area.

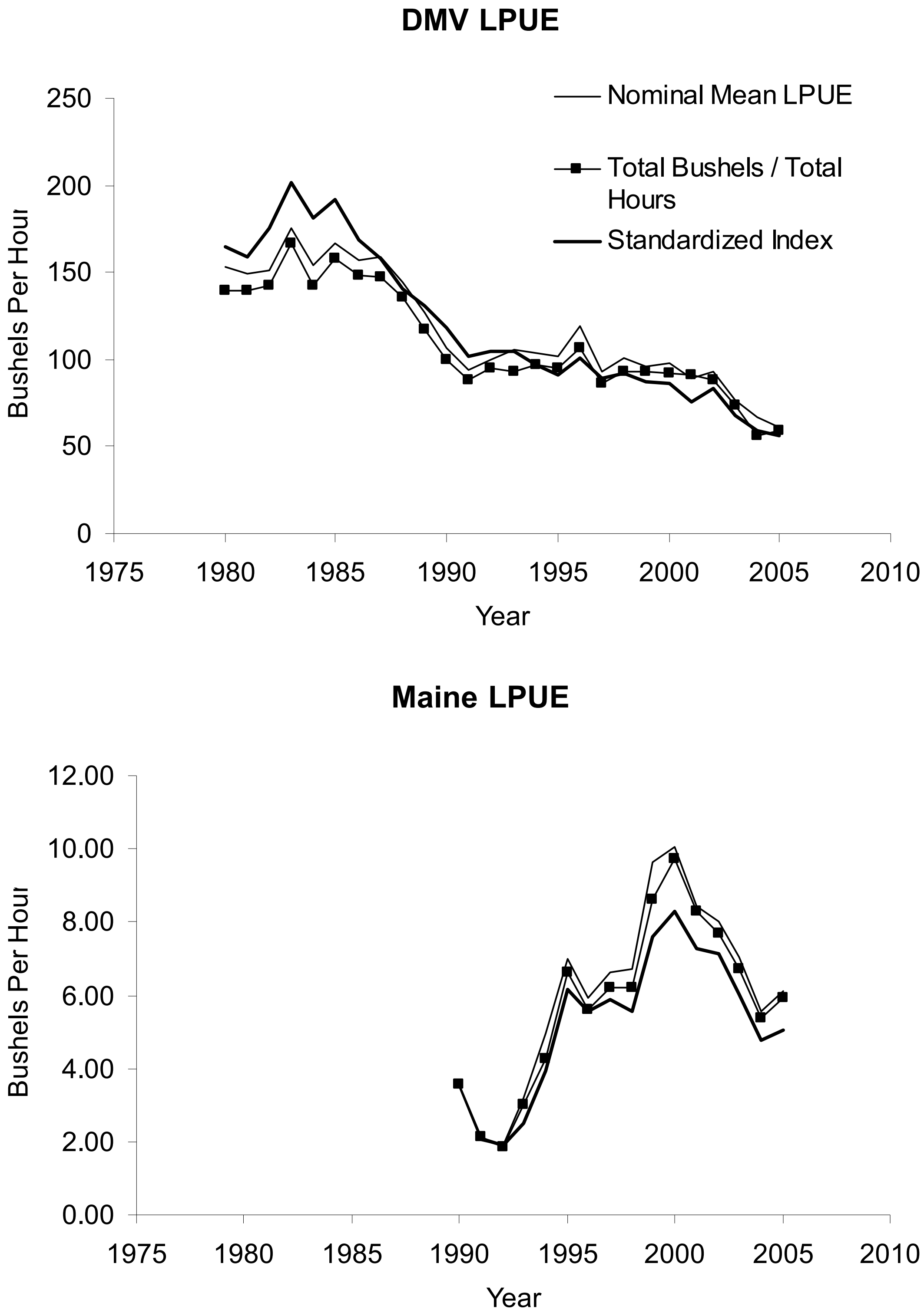


Figure A7. Trends in three measures of LPUE for ocean quahog in the DMV (ITQ bushels per hour) and MNE (Maine bushels per hour) stock assessment regions.

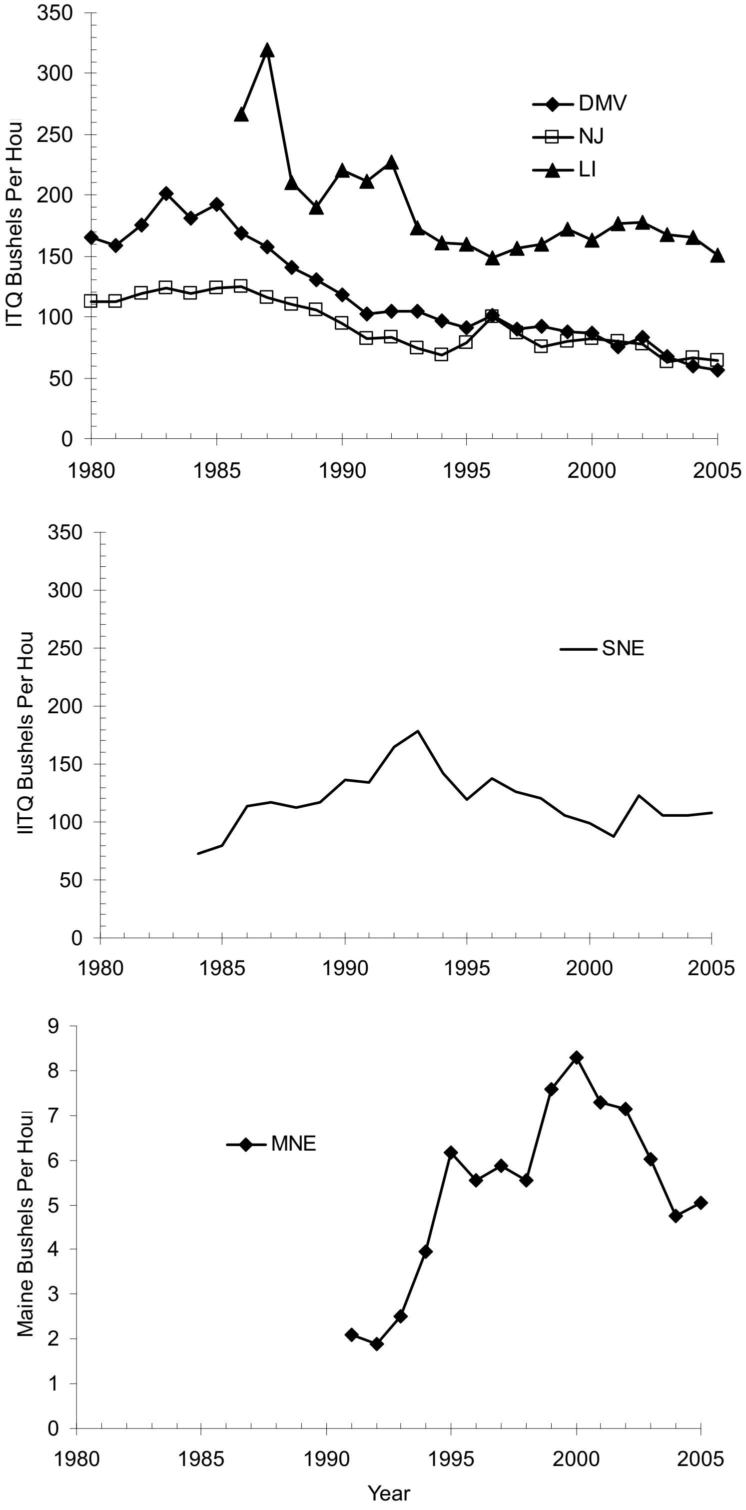


Figure A8. Trends in standardized LPUE for ocean quahog during 1980-2005 by stock assessment region.

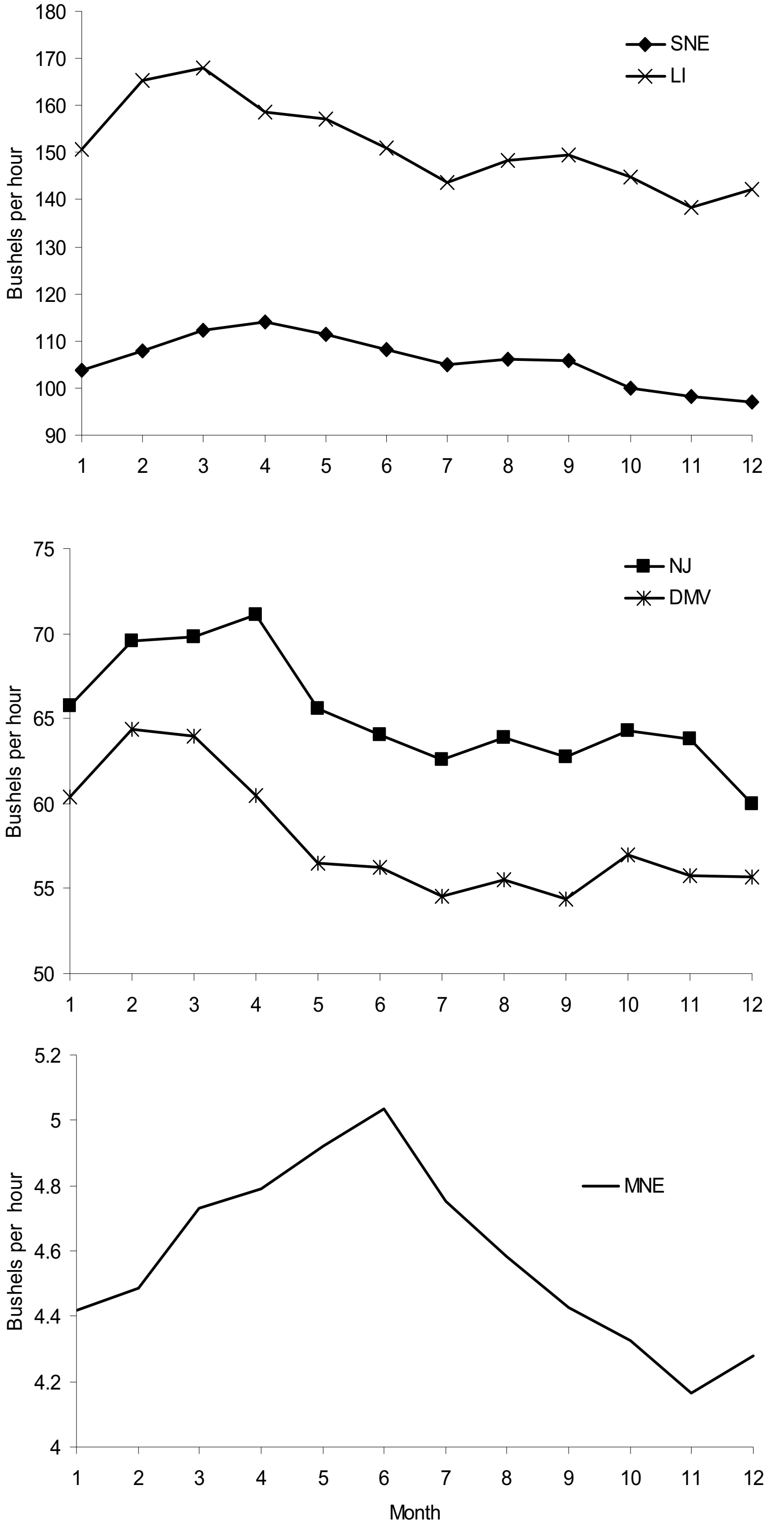


Figure A9. Trends in standardized LPUE month effects for ocean quahog during 1980-2005 by stock assessment region.

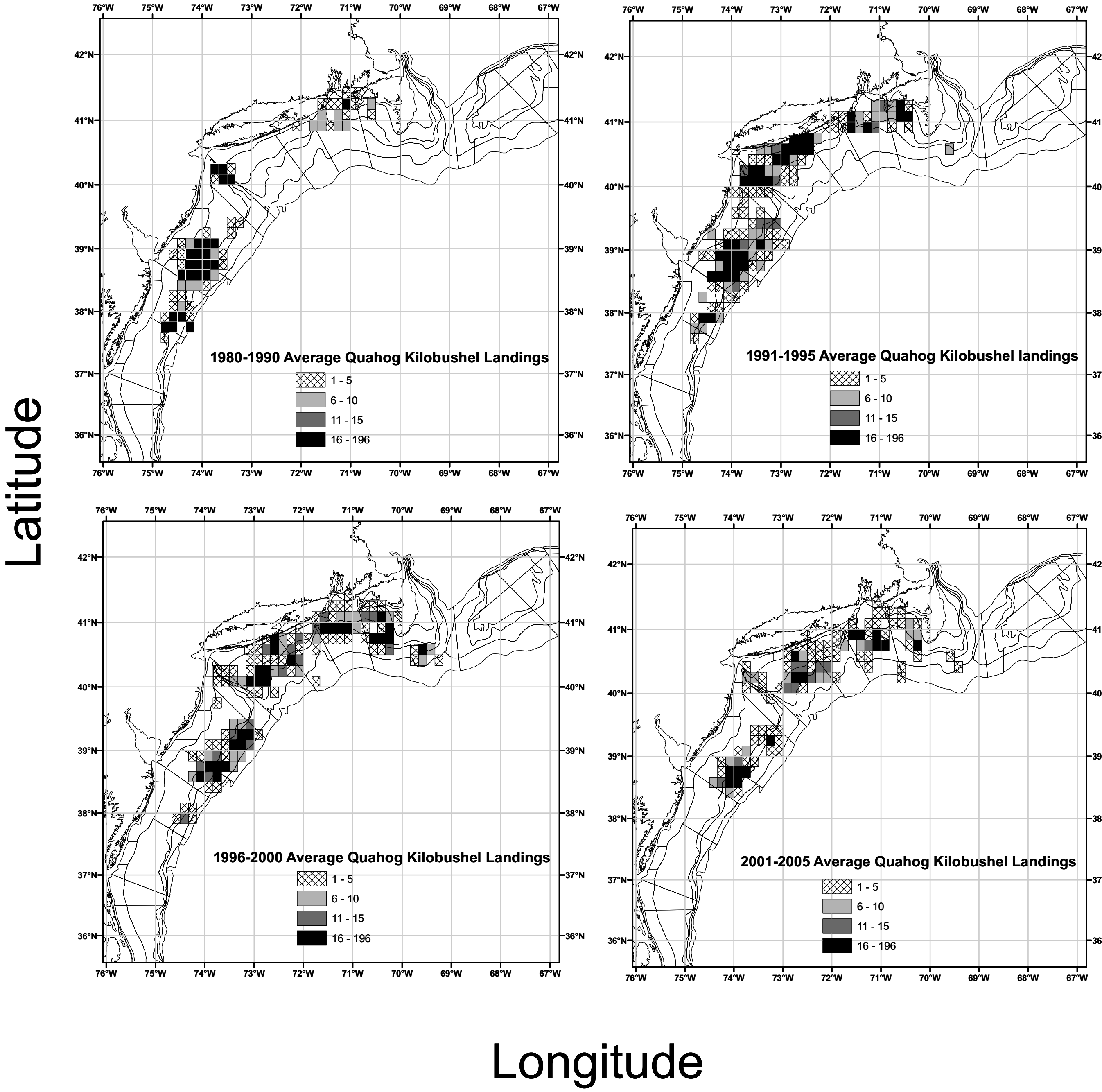
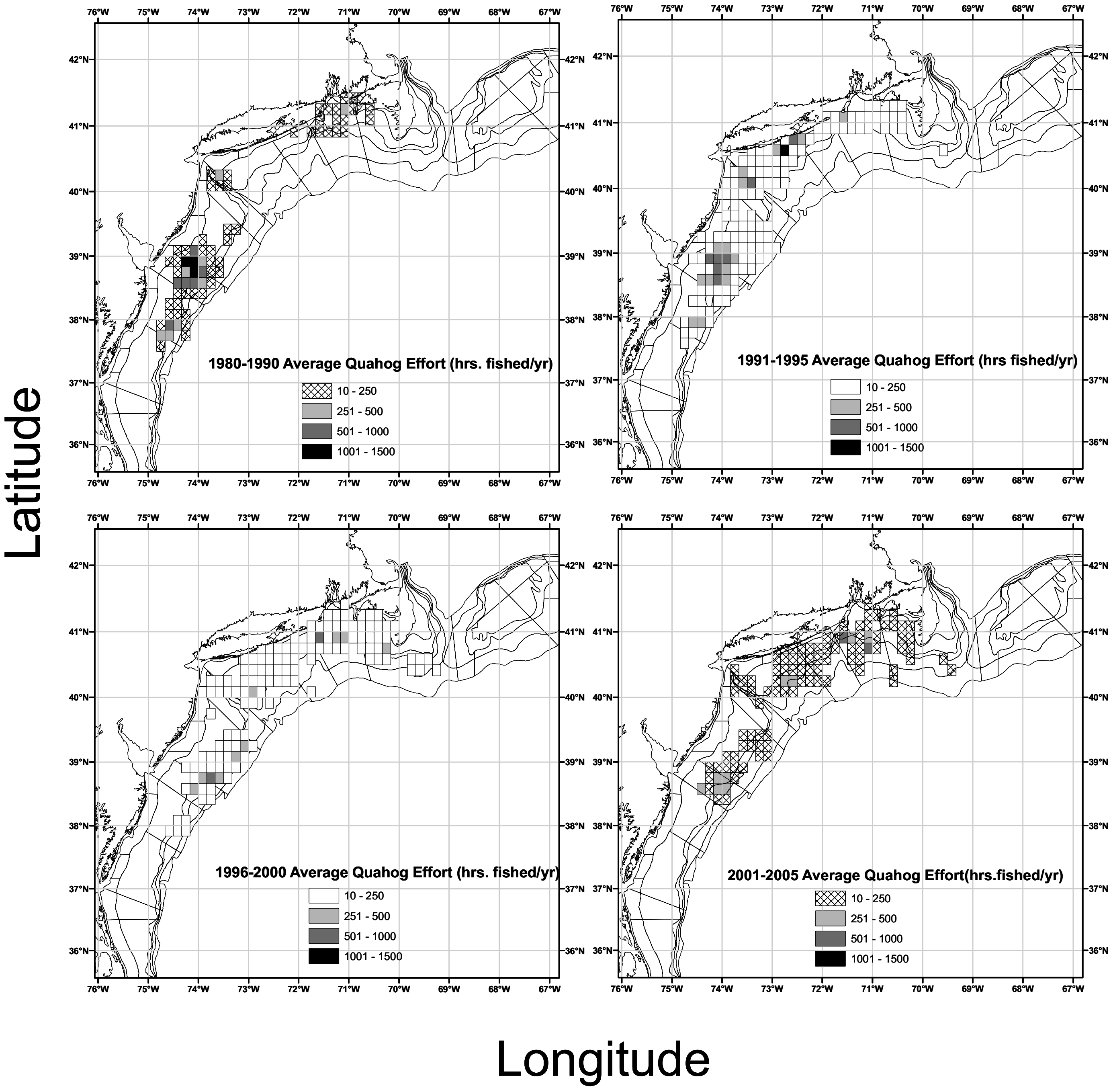


Figure A10. Spatial patterns in average annual landings (1000 ITQ bushels y^{-1}) for ocean quahog from logbook records. Data in TNMS far offshore reflect errors in logbook data.


1980-1990 Average Quahog Effort (hrs. fished/yr)

1991-1995 Average Quahog Effort (hrs fished/yr)

1996-2000 Average Quahog Effort (hrs. fished/yr)

2001-2005 Average Quahog Effort(hrs.fished/yr)

Figure A11. Spatial patterns in average annual fishing effort (hours fished y^{-1}) for ocean quahog from logbook records. Data in TNMS far offshore reflect errors in logbook data.

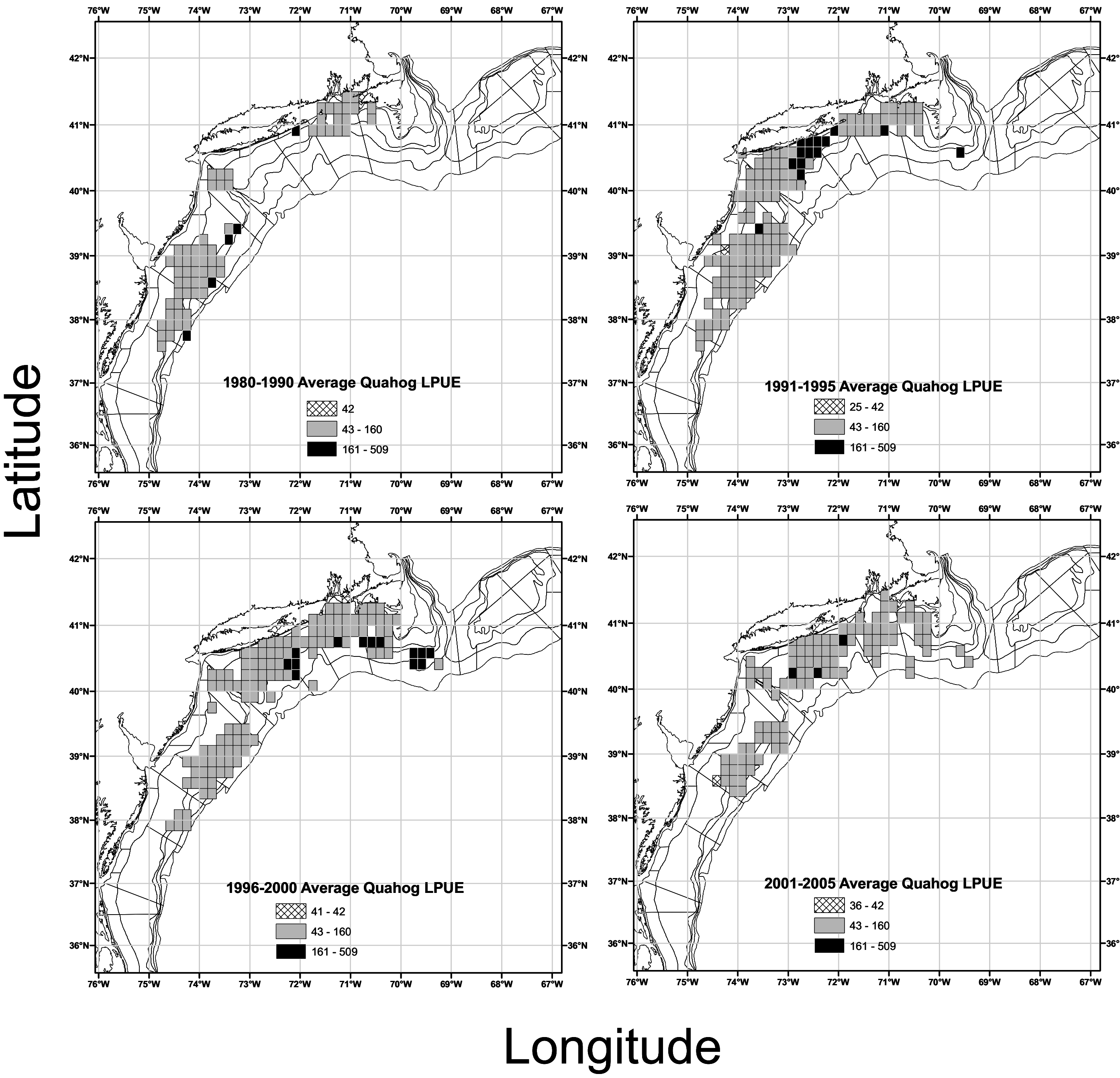


Figure A12. Spatial patterns in average LPUE (ITQ bushels per hours fished) for ocean quahog from logbook records. Data in TNMS far offshore reflect errors in logbook data.

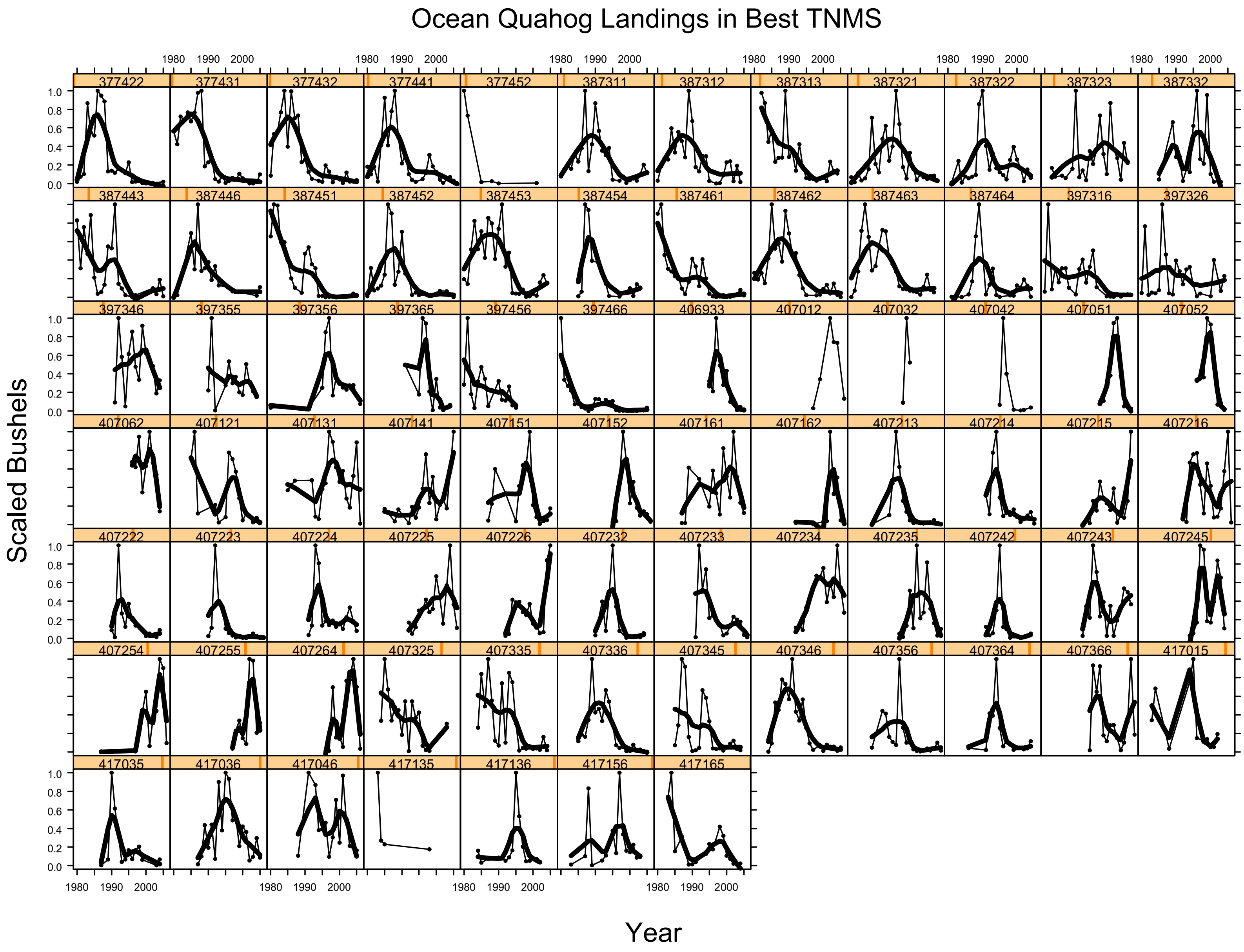


Figure A13. Trends in total annual landings (ITQ bu y^{-1}, vessel ton class 3-4) for ocean quahog in important TNMS during 1980-2005.

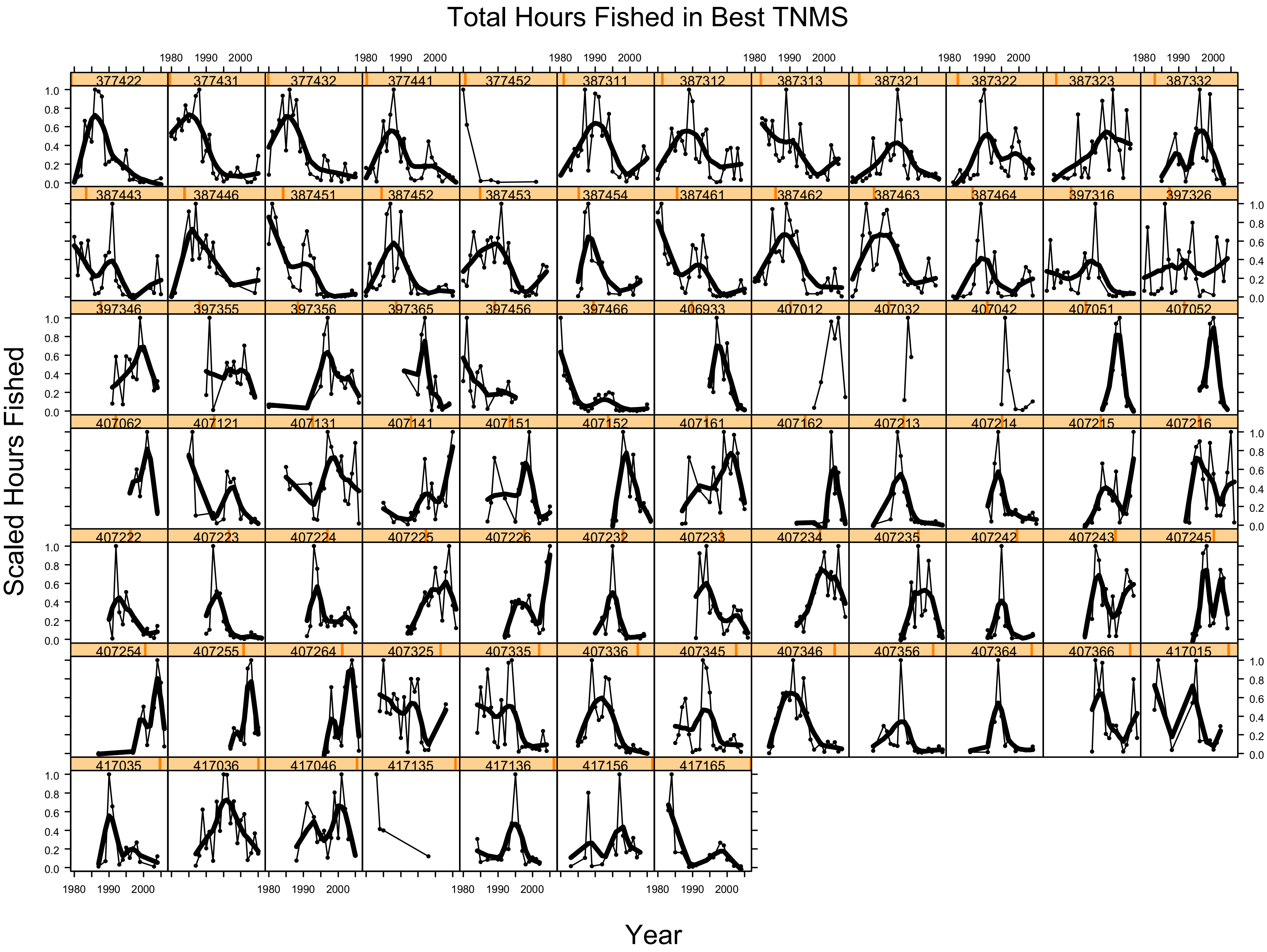


Figure A14. Trends in total annual fishing effort (hours fished y^{-1}, vessel ton class 3-4) for ocean quahog in important TNMS during 1980-2005.

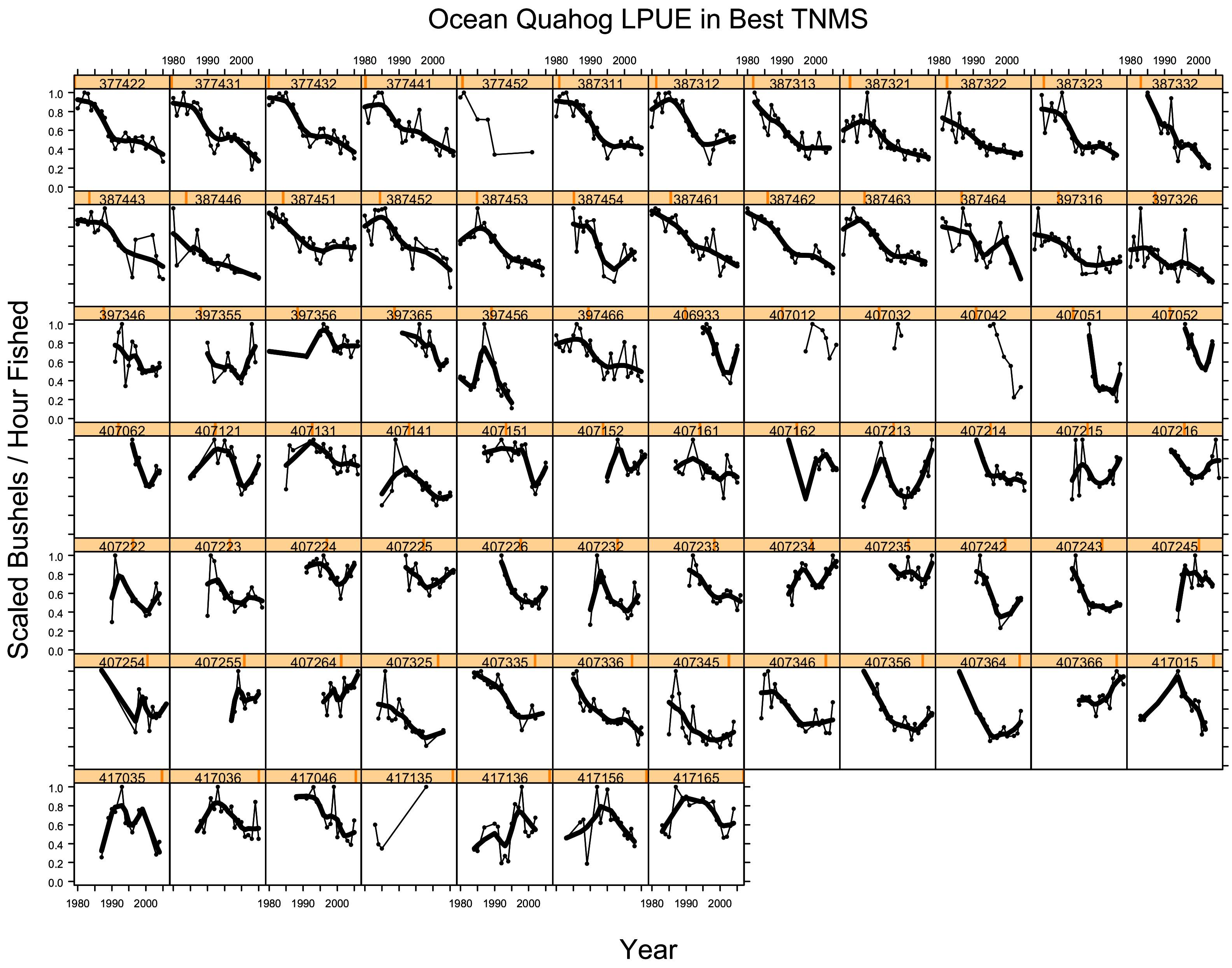


Figure A15. Trends in annual LPUE (ITQ bushels per hours fished, vessel ton class 3-4) for ocean quahog in important TNMS during 1980-2005.

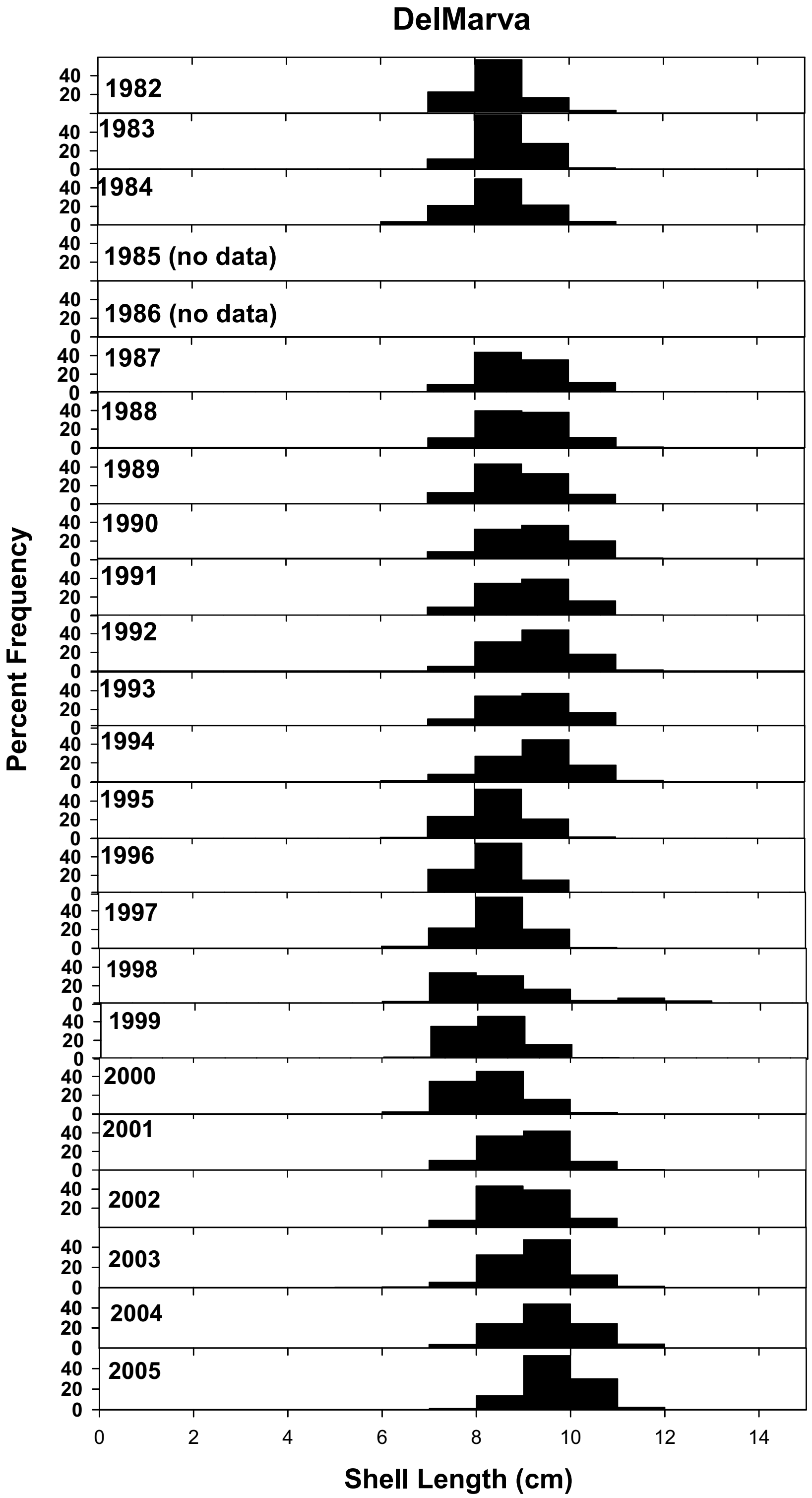


Figure A16. Commercial length composition data for ocean quahog landed in the DMV stock assessment region.

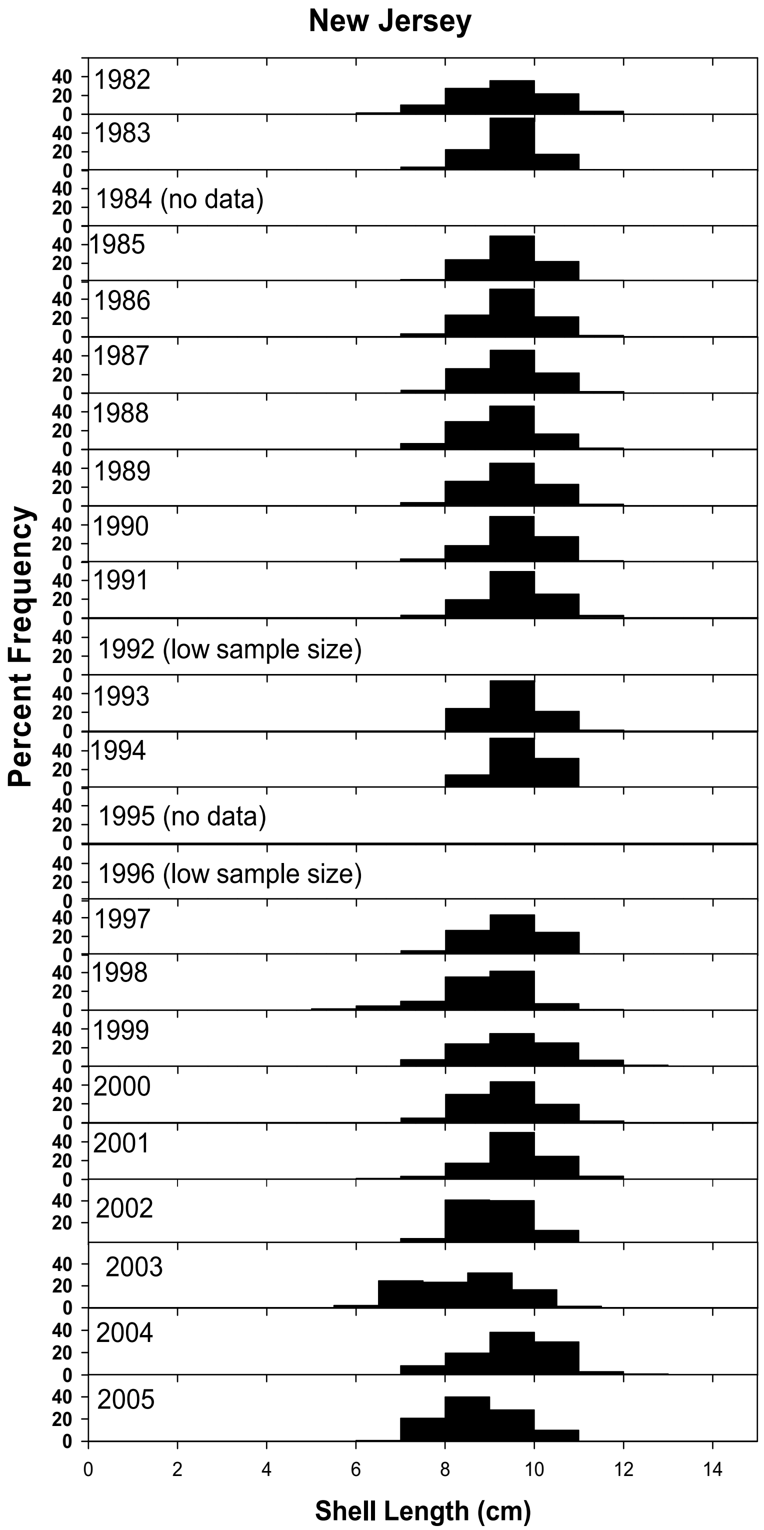


Figure A17. Commercial length composition data for ocean quahog landed in the NJ stock assessment region.

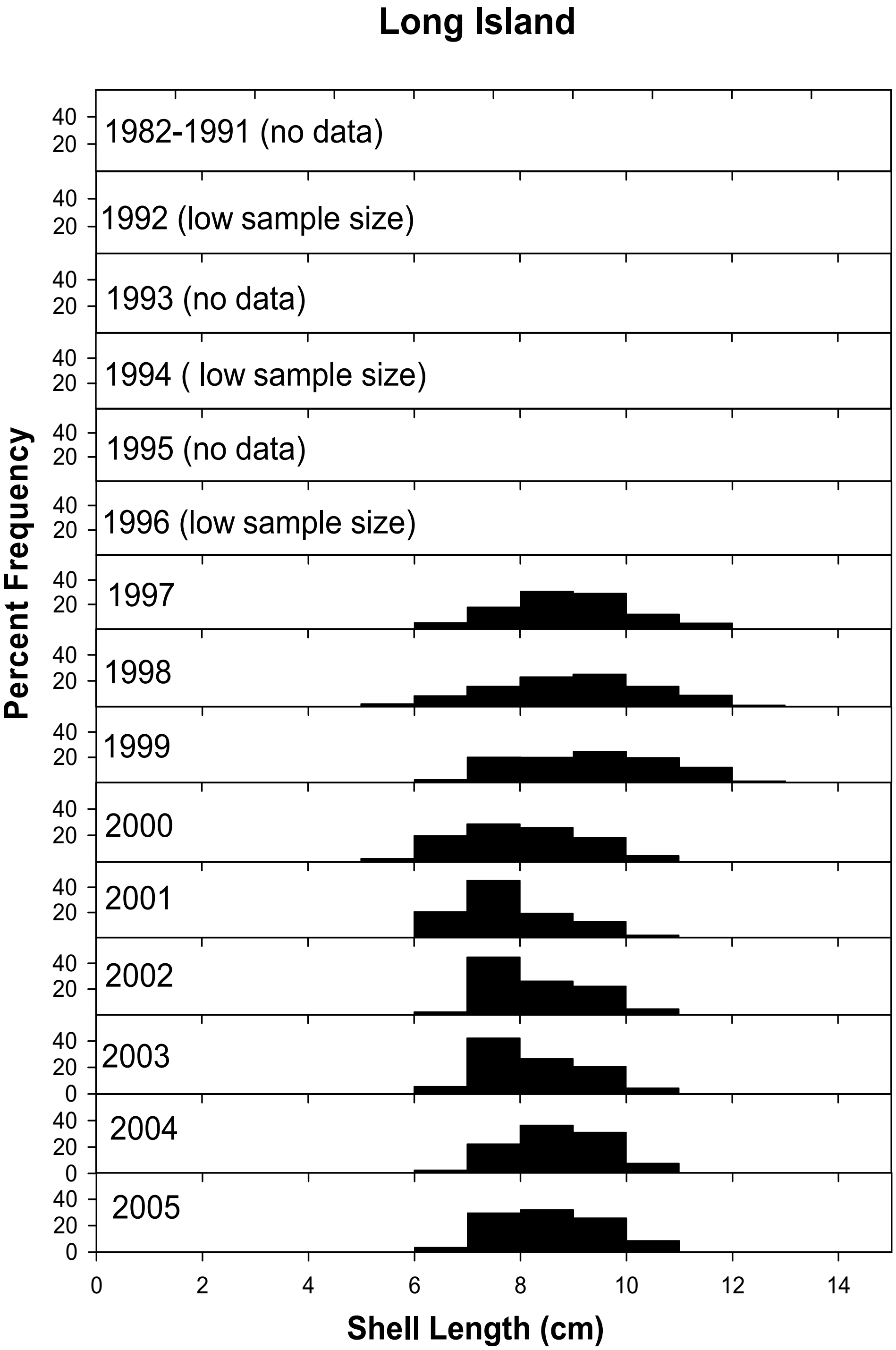


Figure A18. Commercial length composition data for ocean quahog landed in the LI stock assessment region.

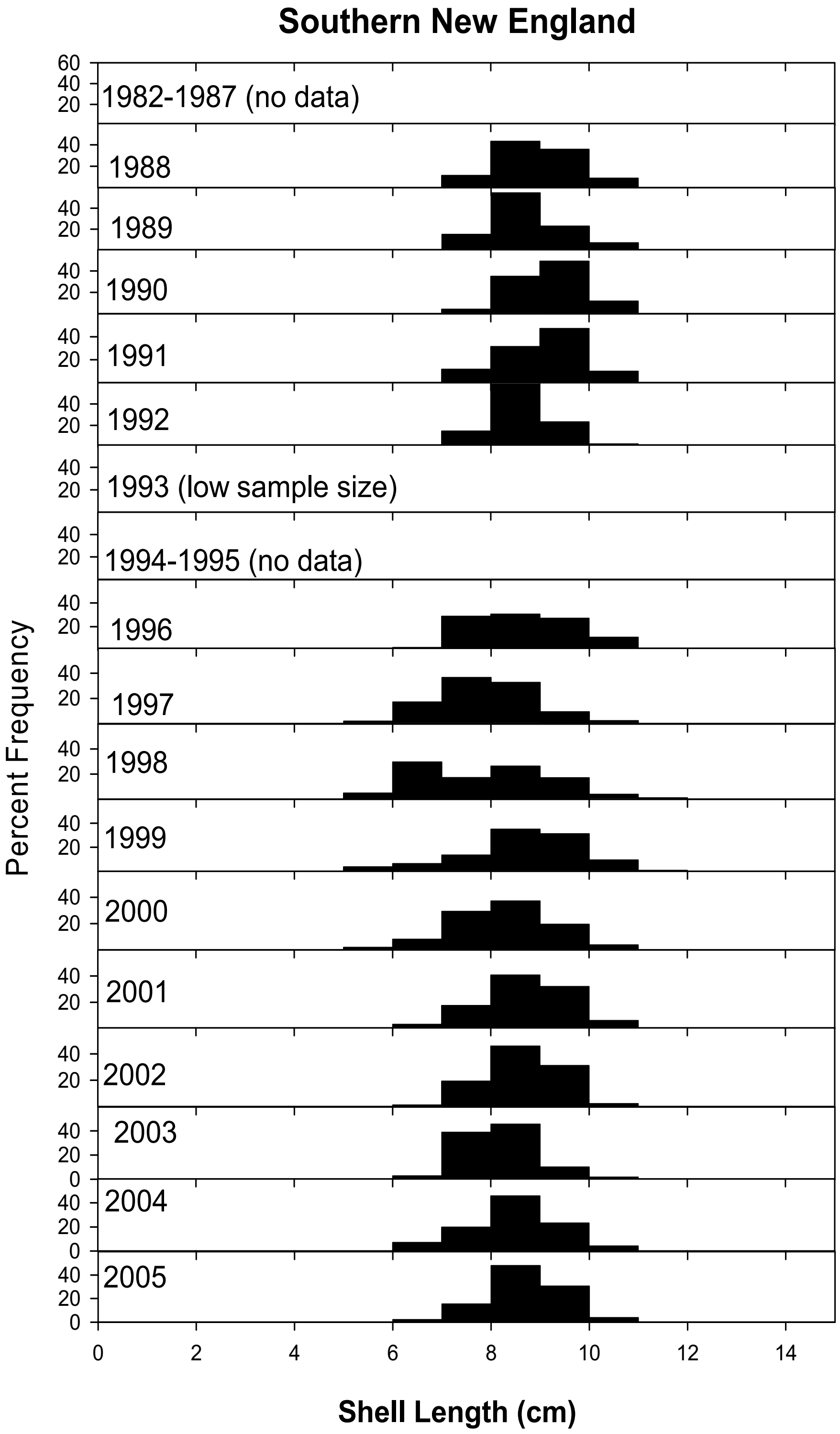


Figure A19. Commercial length composition data for ocean quahog landed in the SNE stock assessment region.

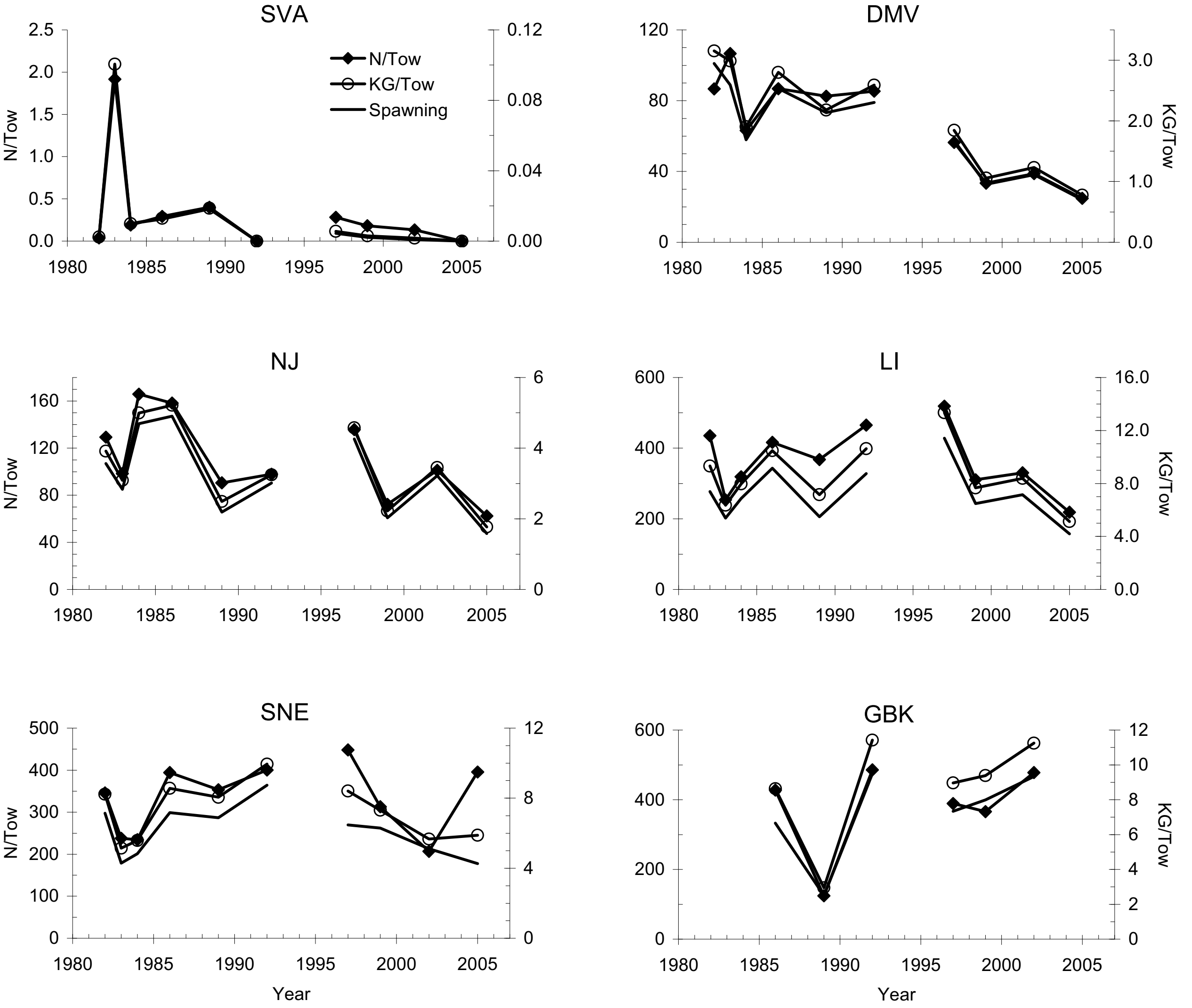


Figure A20. NEFSC clam survey trends for ocean quahog stock abundance (mean n/tow), biomass (mean kg/tow), and spawning biomass (mean kg/tow) during 1982-2005. Data for 1994 are omitted because of electrical problems with pump voltage that artificially increased dredge efficiency. Survey data shown in graphs were adjusted based on survey selectivity to estimate trends for the entire stock.

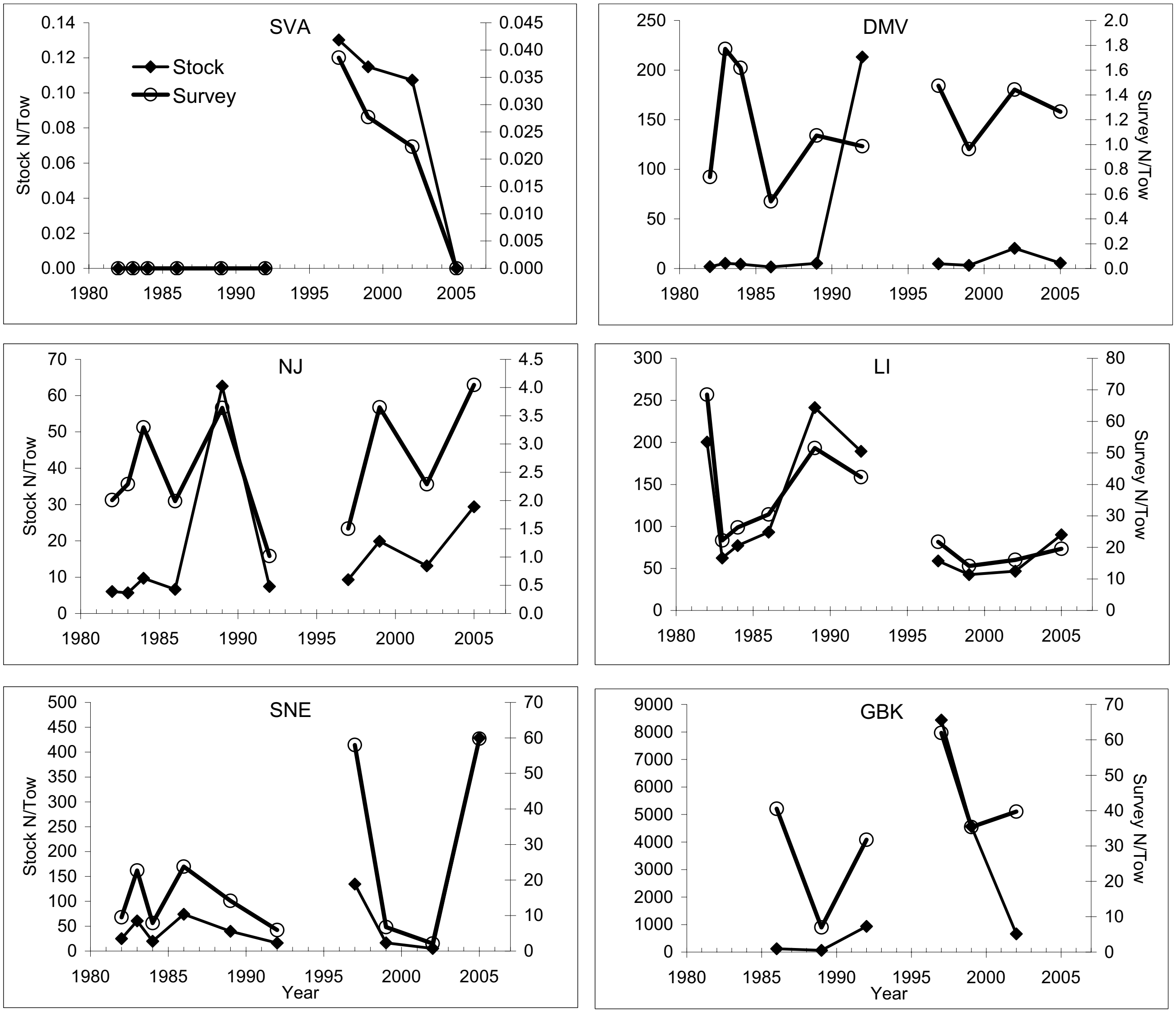


Figure A21. NEFSC clam survey trends for ocean quahog recruit (<70 mm SL) abundance (mean n/tow) during 1982-2005. Trends are shown with ("Stock") and without ("Survey") corrections for survey dredge selectivity. Data for 1994 are omitted because of electrical problems with pump voltage that artificially increased dredge efficiency. The apparent outlier for stock n/tow in DMV during 1992 is due to a relatively large catch of small ocean quahog which was increased substantially when adjusted for survey dredge selectivity.

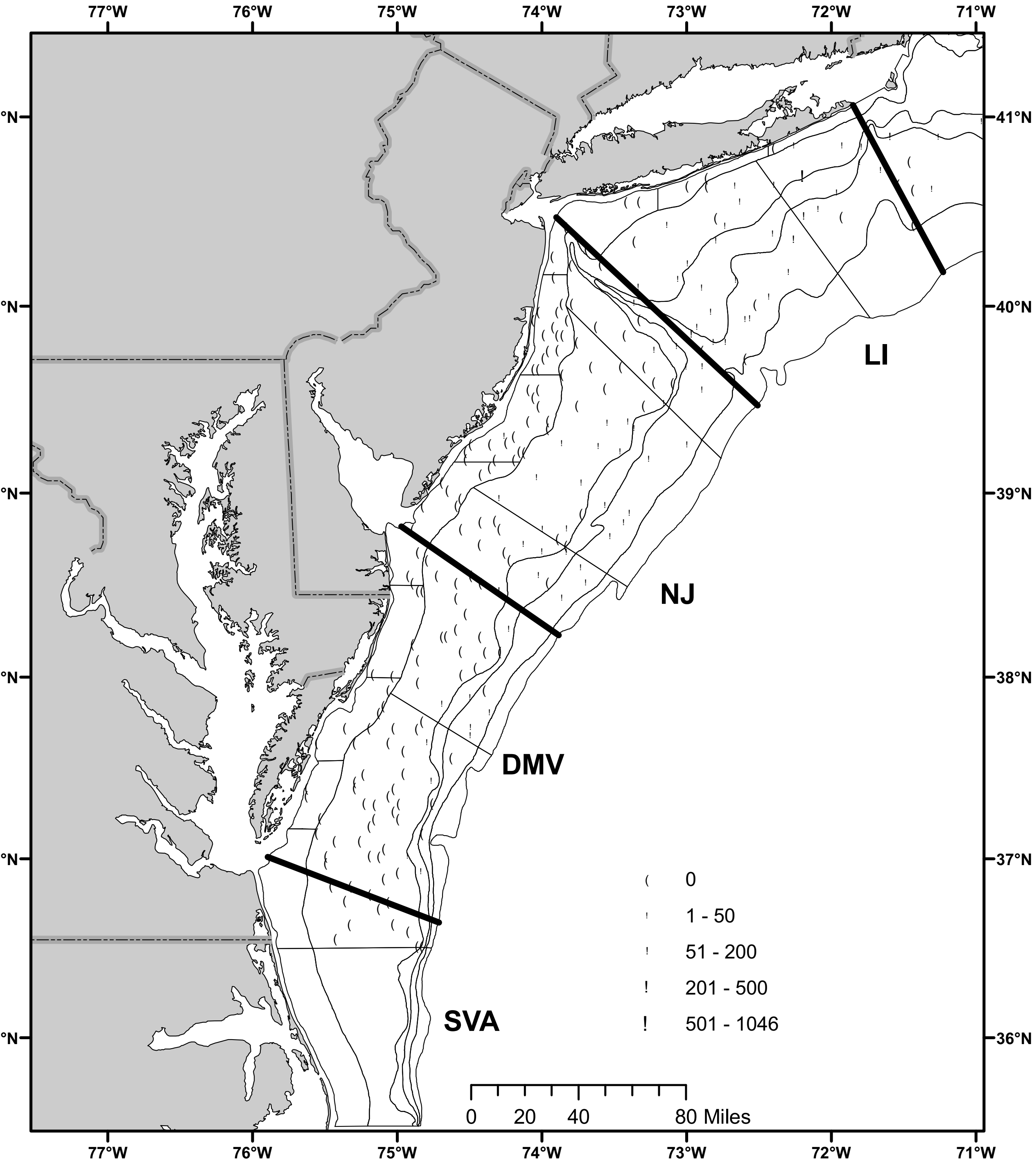


Figure A22. Location and size of recruit ocean quahog (<70 mm) catches in 2005 NEFSC clam survey, between Long Island and Cape Hatteras.

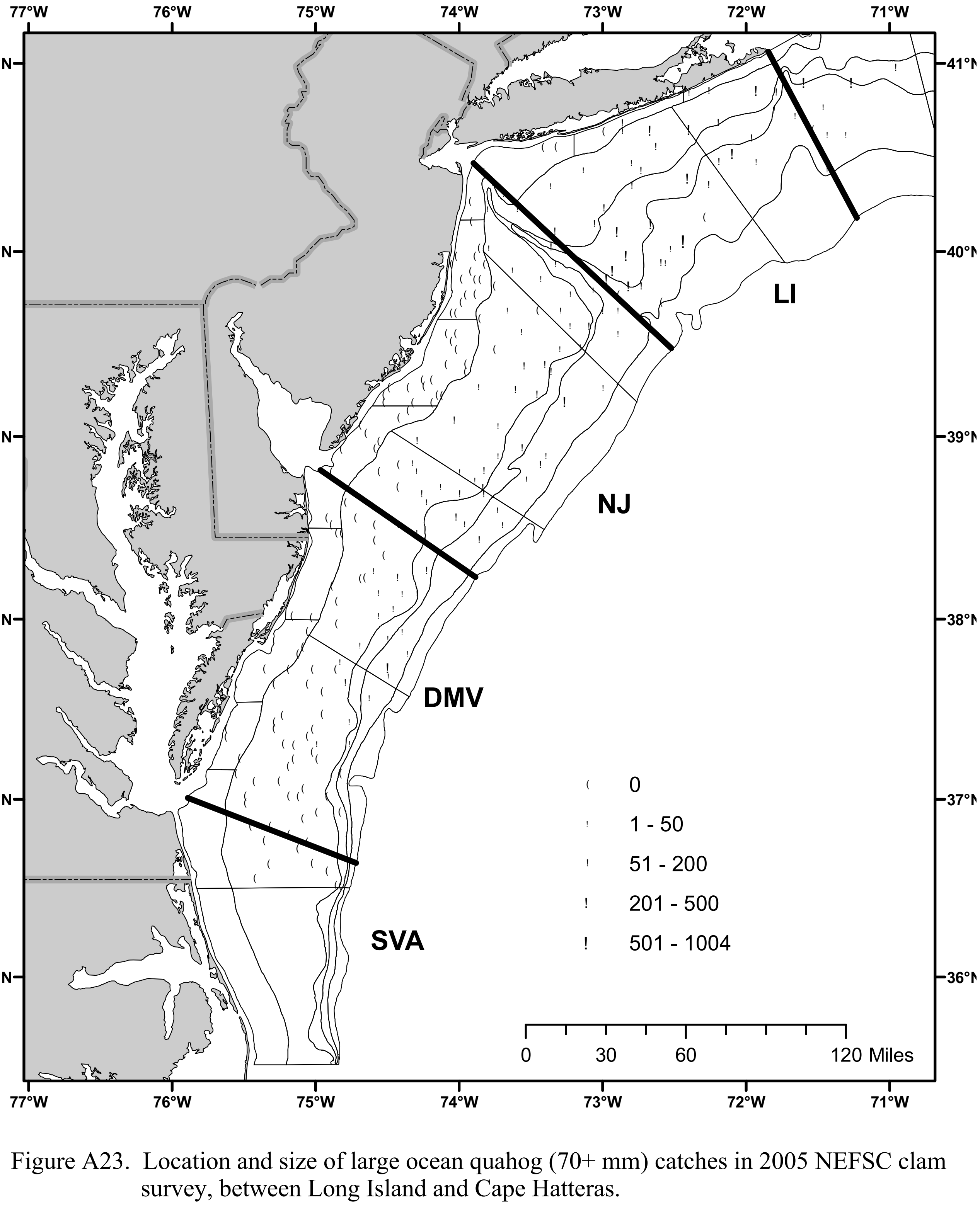


Figure A23. Location and size of large ocean quahog (70+ mm) catches in 2005 NEFSC clam survey, between Long Island and Cape Hatteras.

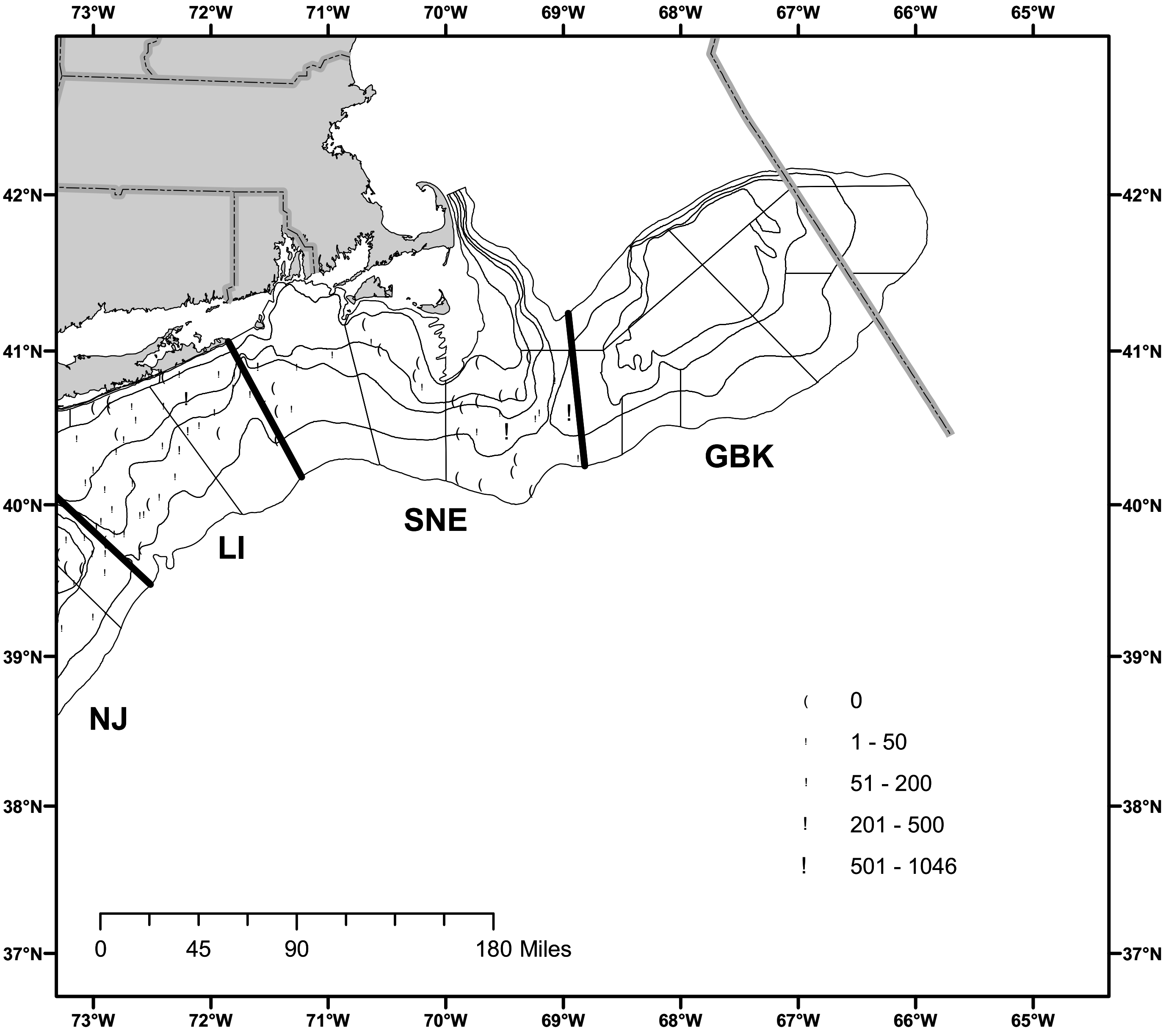


Figure A24. Location and size of recruit ocean quahog (<70 mm) catches in 2005 NEFSC clam survey, between Georges Banks and Long Island.

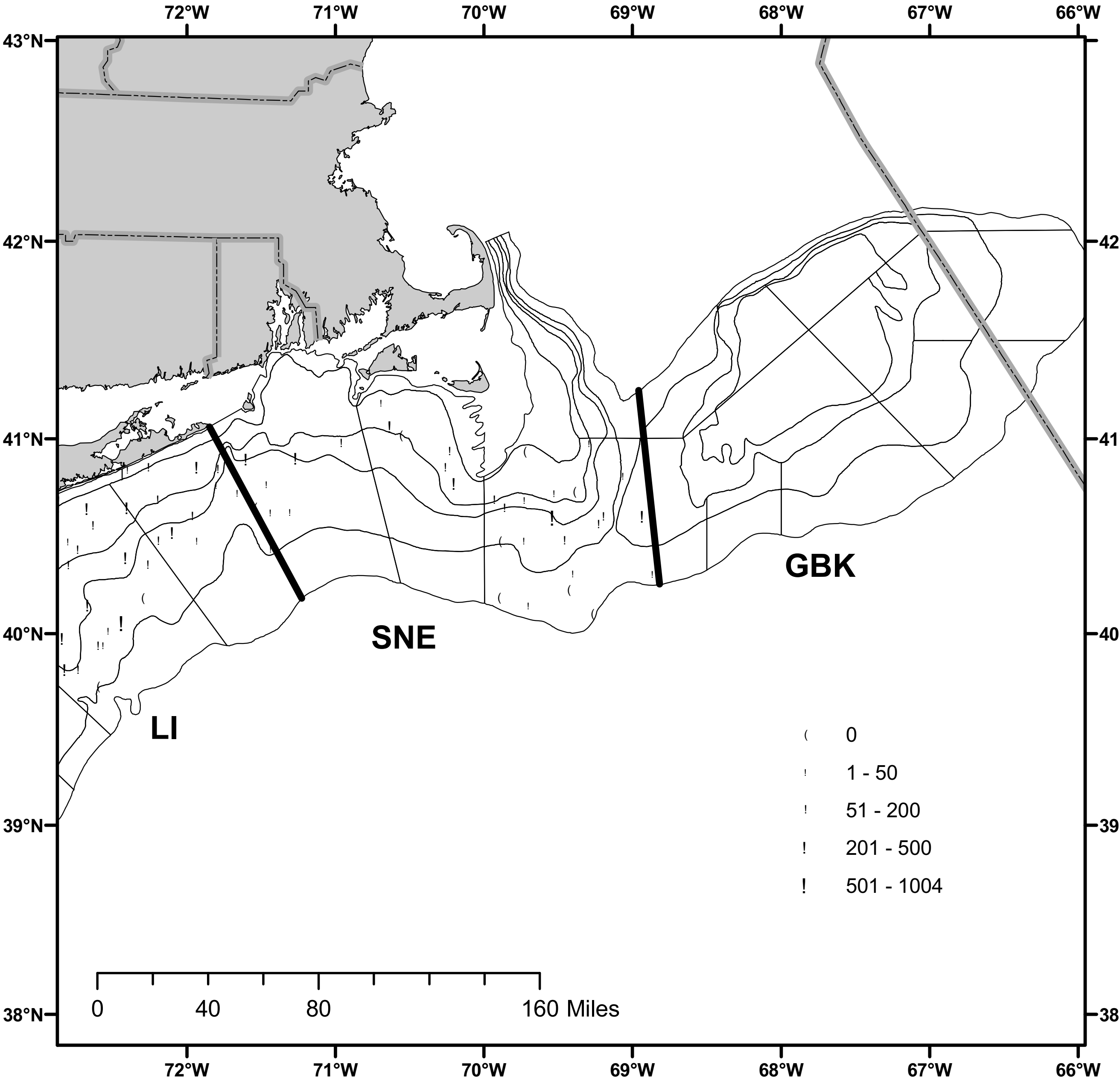


Figure A25. Location and size of large ocean quahog (70+ mm) catches in 2005 NEFSC clam survey, between Georges Bank and Long Island.

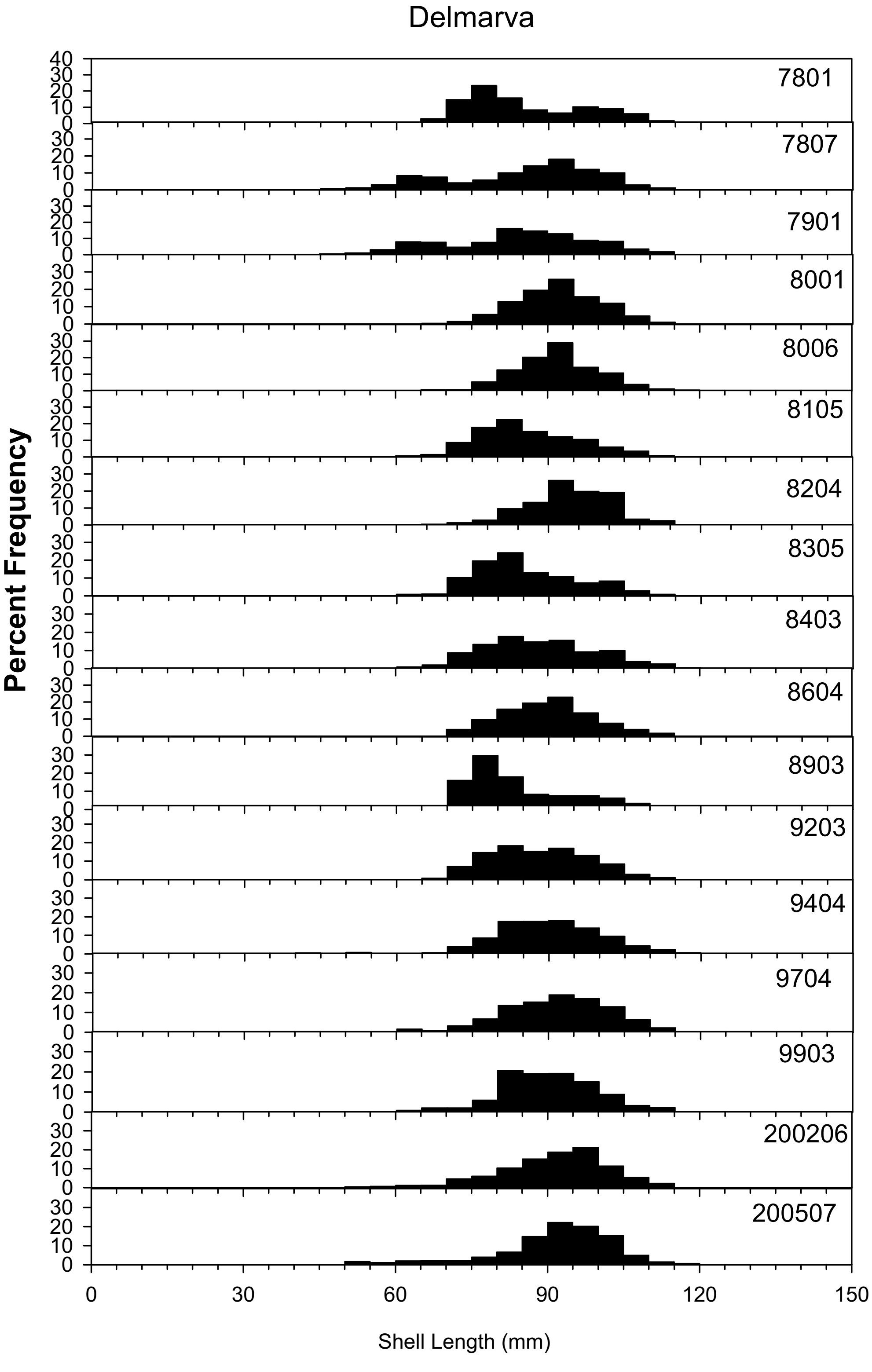


Figure A26. Length composition for ocean quahog in NEFSC clam surveys, by region. Frequencies are proportional to mean numbers per tow at length, without adjustment for survey dredge selectivity.

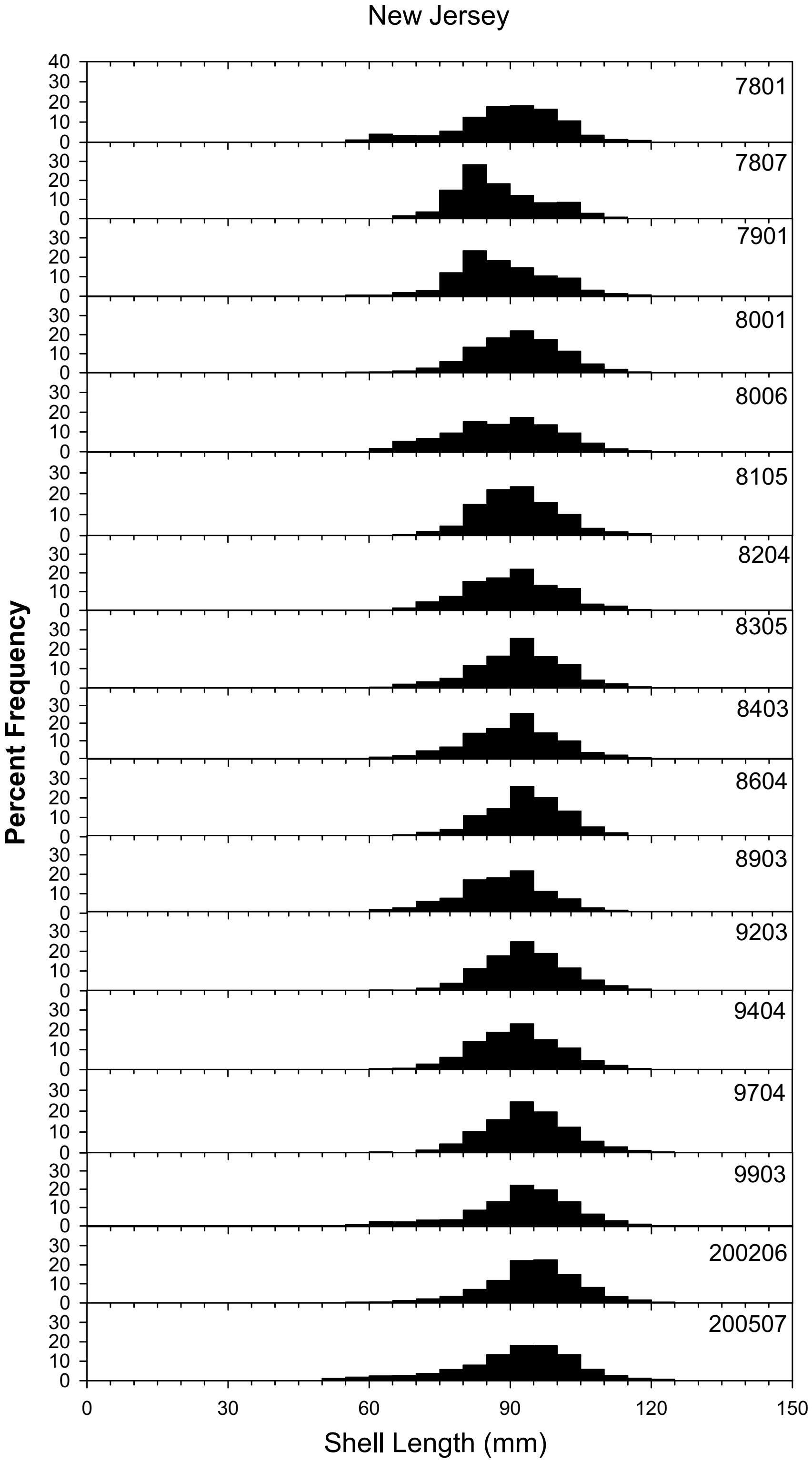
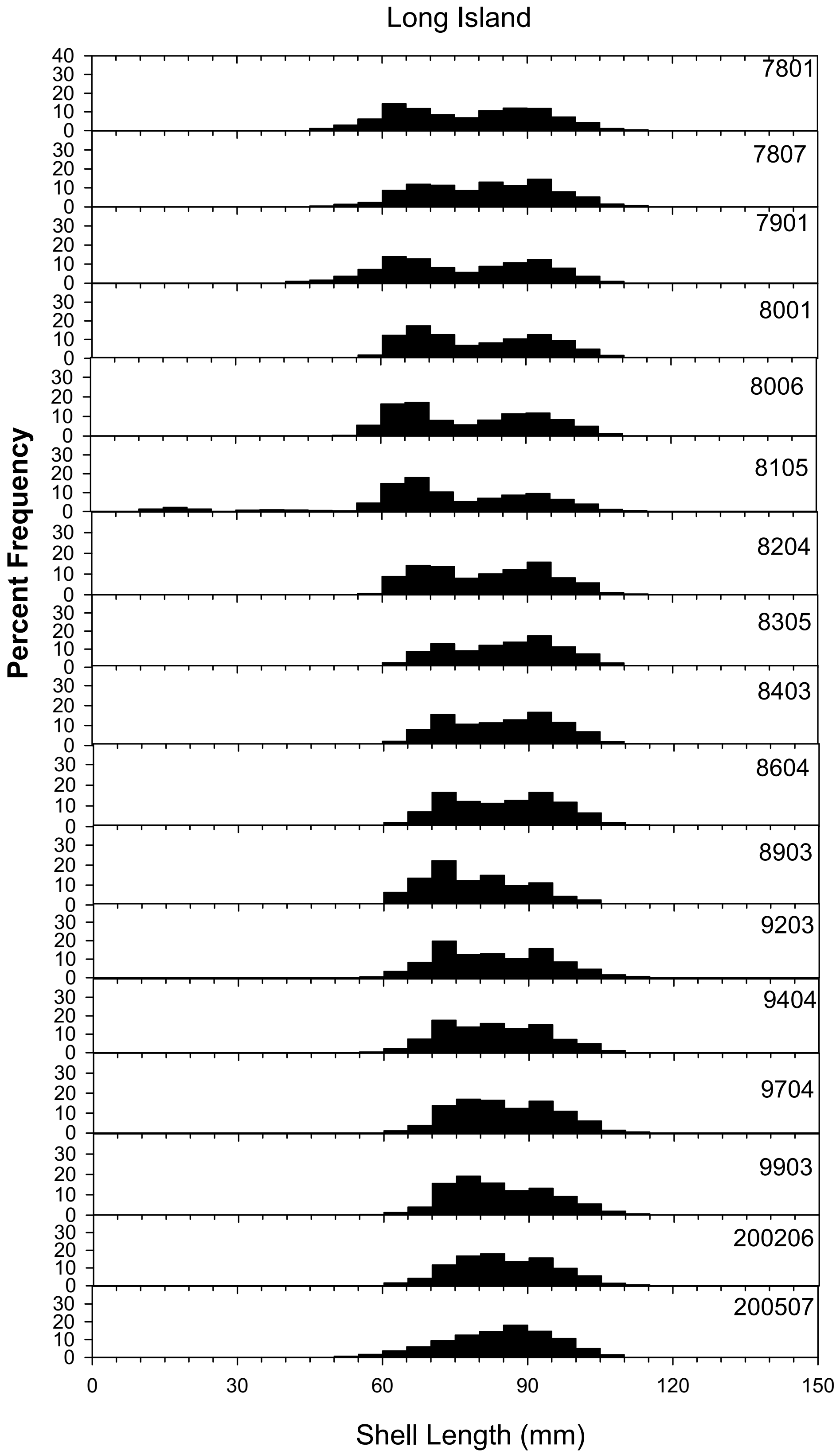


Figure A26 (continued)



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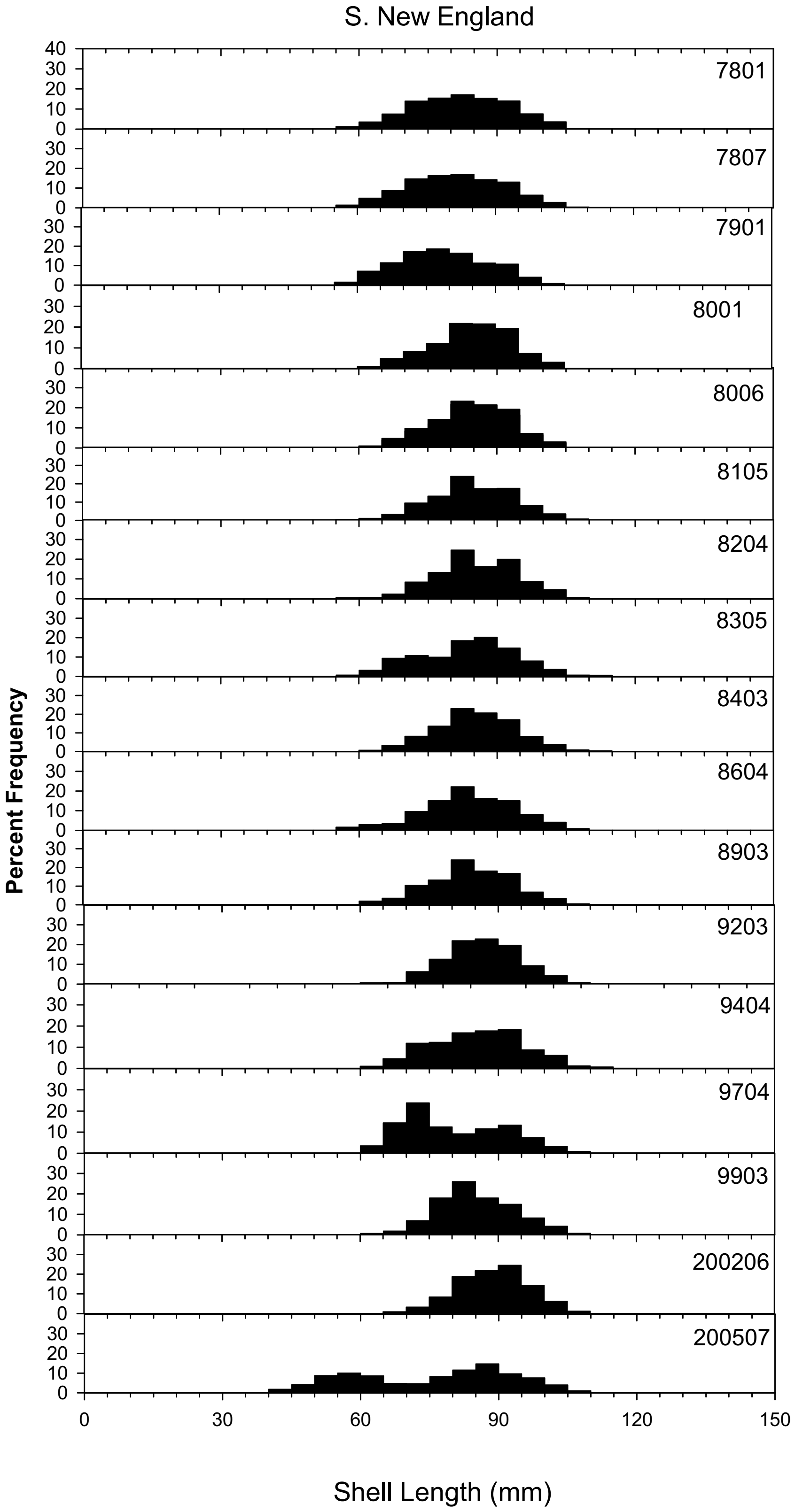

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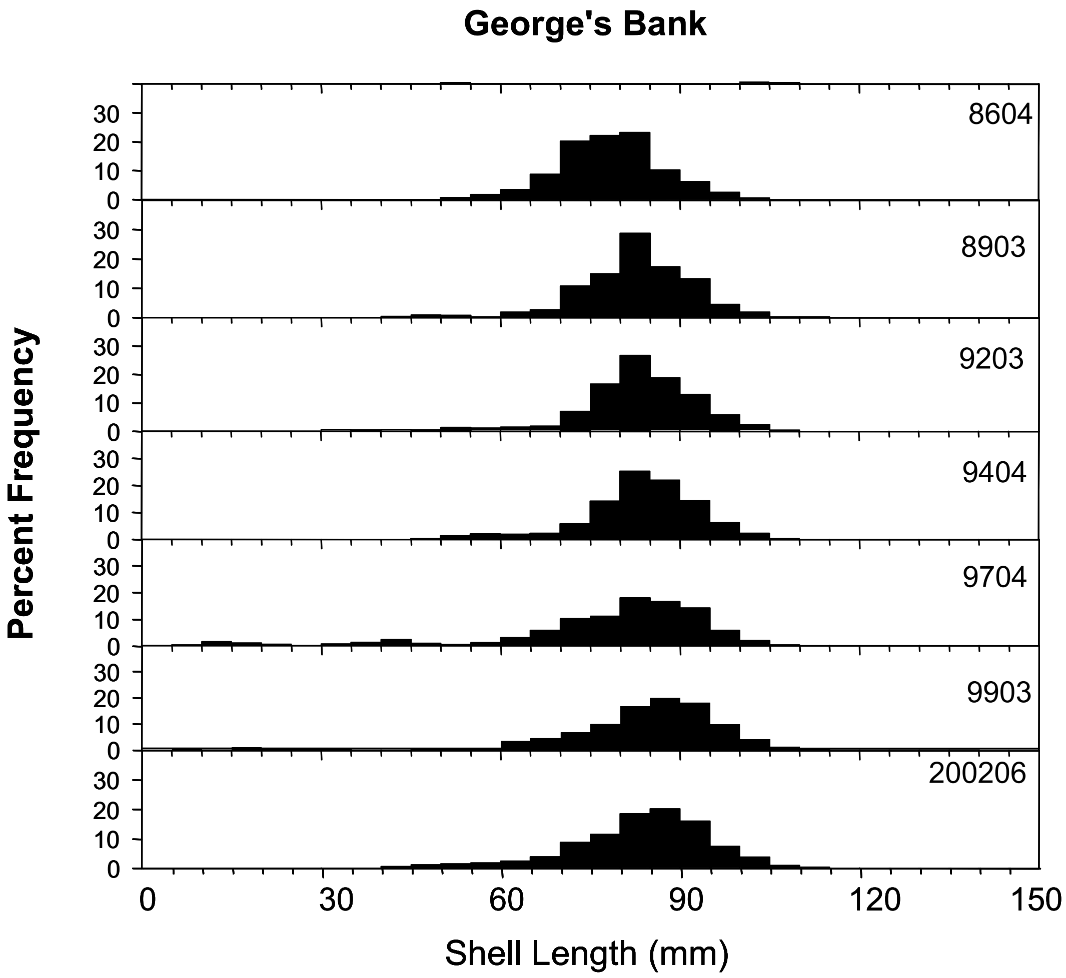


Figure A26 (continued)

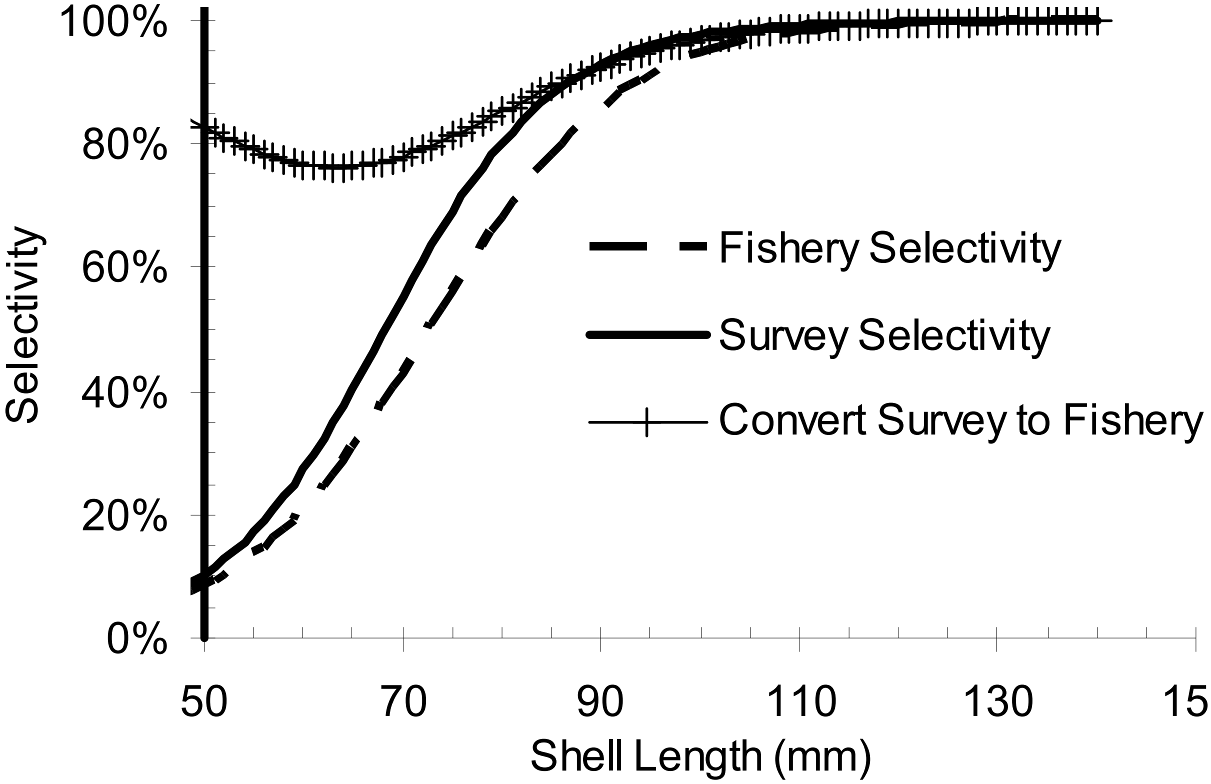


Figure A27. Fishery and survey selectivity curves for ocean quahog. The ratio of the fishery and survey selectivity curves, which can be used to convert survey abundance at size directly to fishable abundance at size, is also shown.

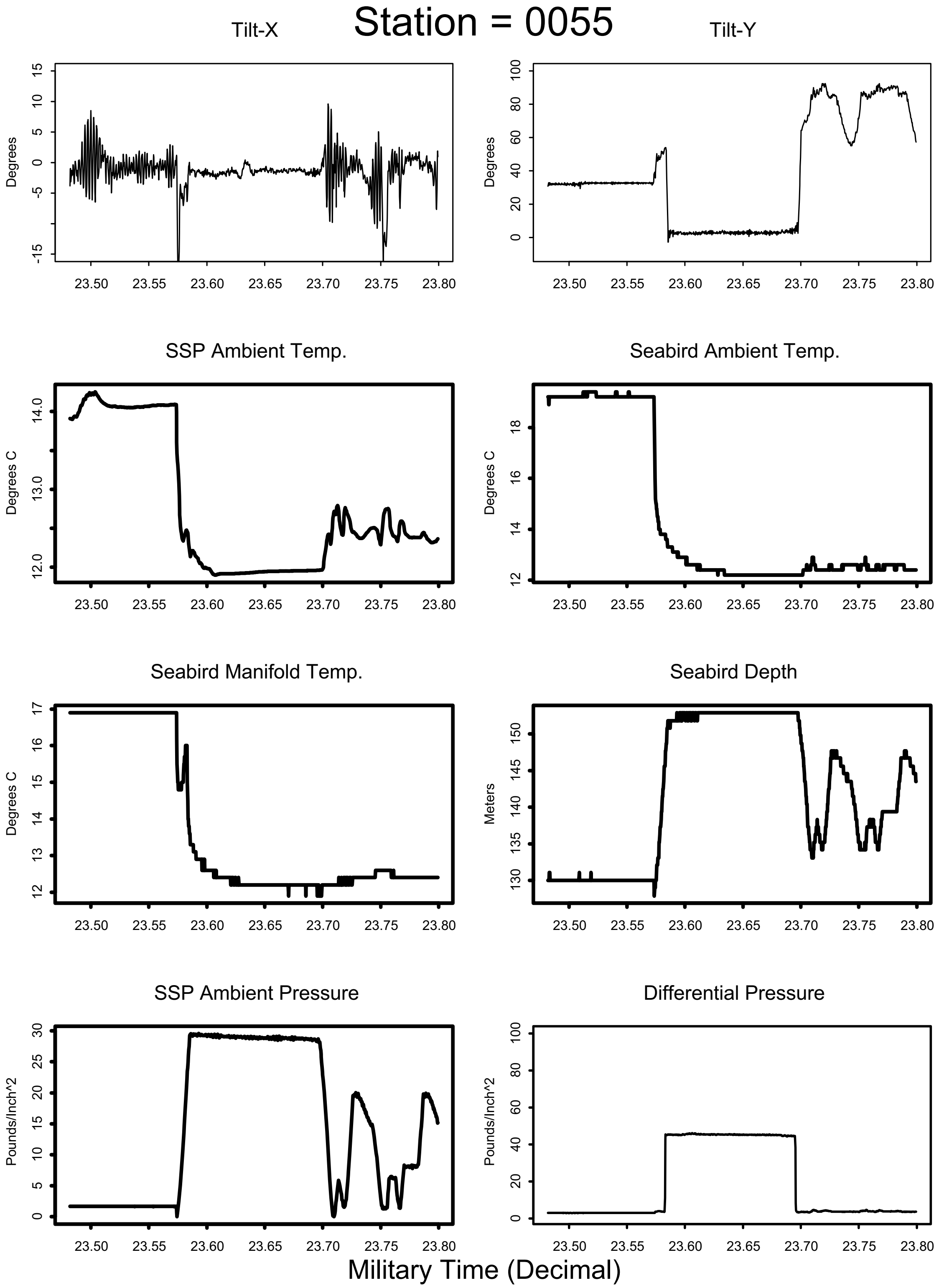


Figure A28. Survey sensor package data for an NEFSC clam survey tow with acceptable dredge performance.

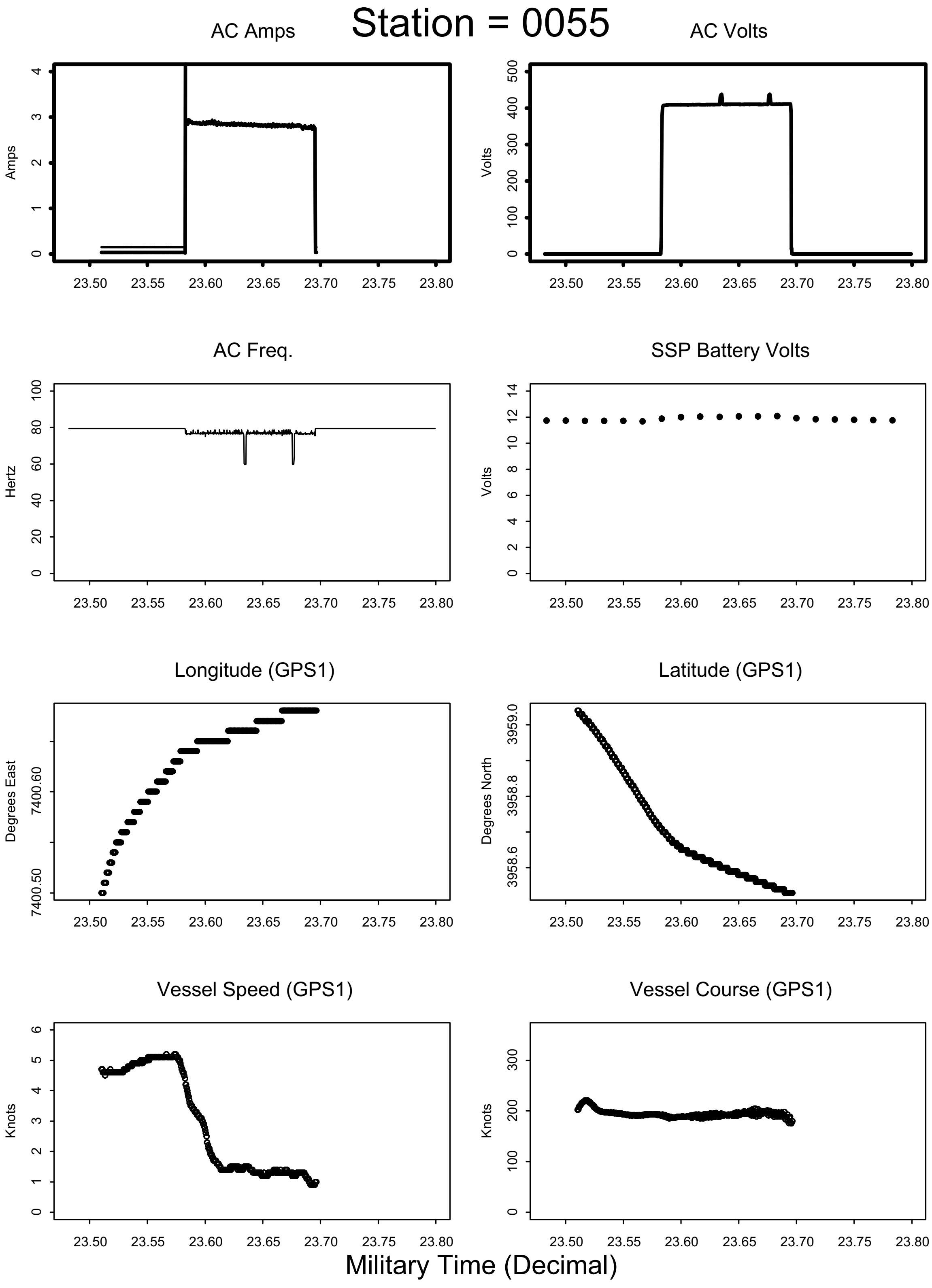


Figure A28. (continued)

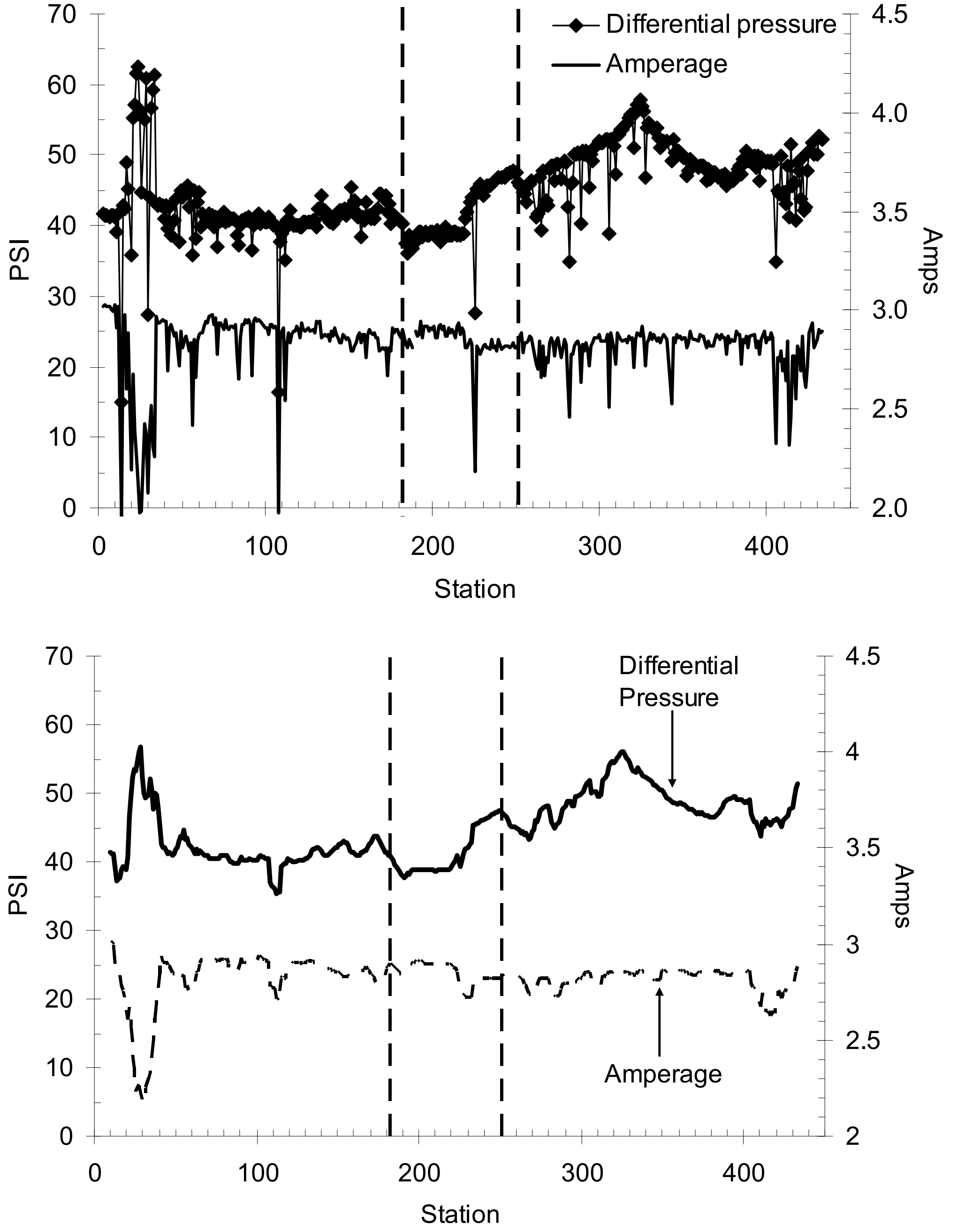


Figure A29. Differential pressure and amperage measured by sensors on the survey dredge during the 2005 NEFSC clam survey. Vertical lines separate the first, second and third legs. *Top*: Mean values for each station. *Bottom*: Mean values for each station smoothed by a seven point moving average.

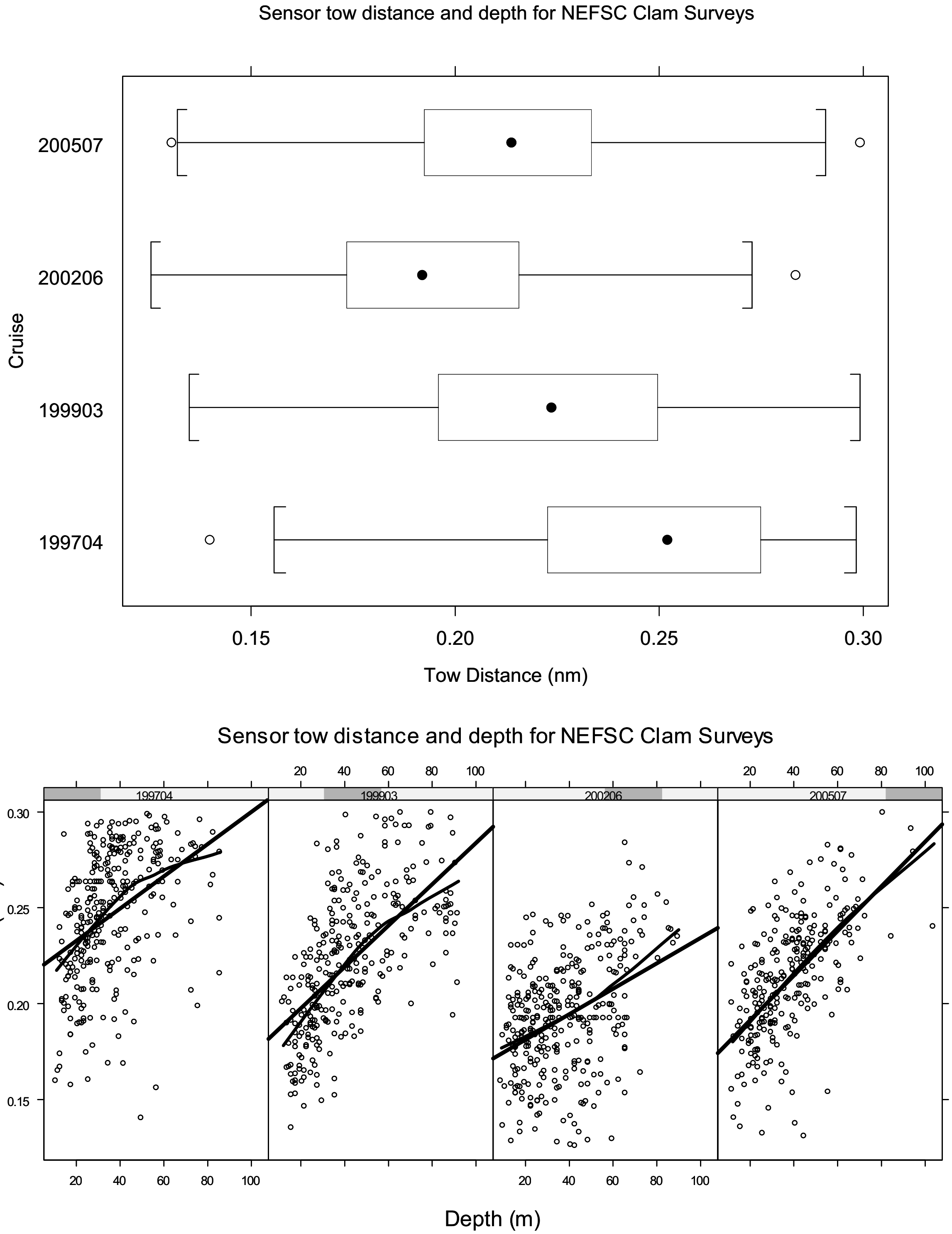


Figure A30. Tow distance measurements for NEFSC clam surveys from sensor data (top) and tow distance as a function of depth (bottom). Straight lines in the bottom panel show the best regression model. Curved lines are from loess regression and are intended to show trends.

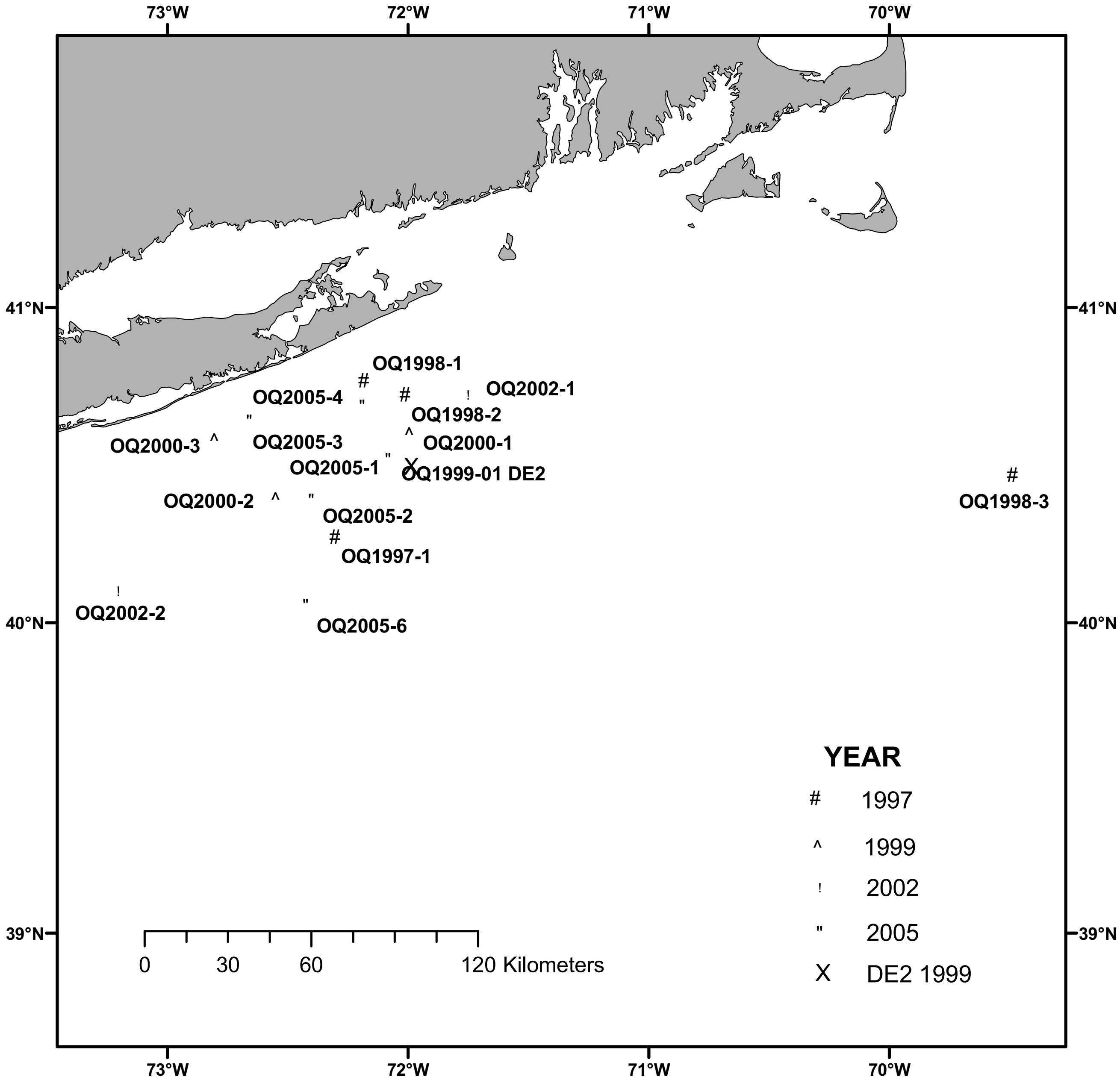


Figure A31a. Locations of ocean quahog depletion experiments off the Long Island area, 1997-2005.

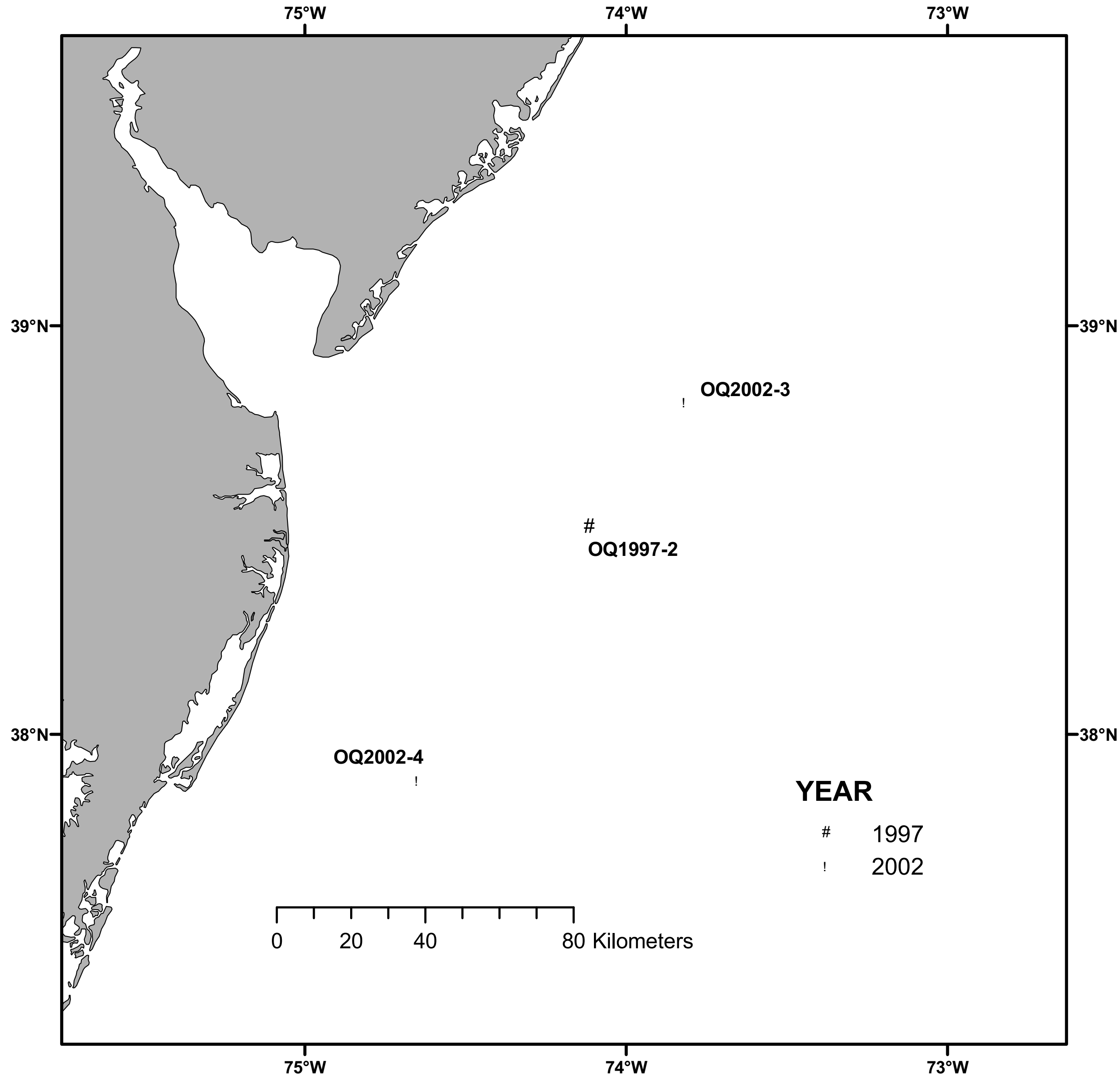


Figure A31b. Locations of ocean quahog depletion experiments off the New Jersey-Delmarva area, 1997-2005.

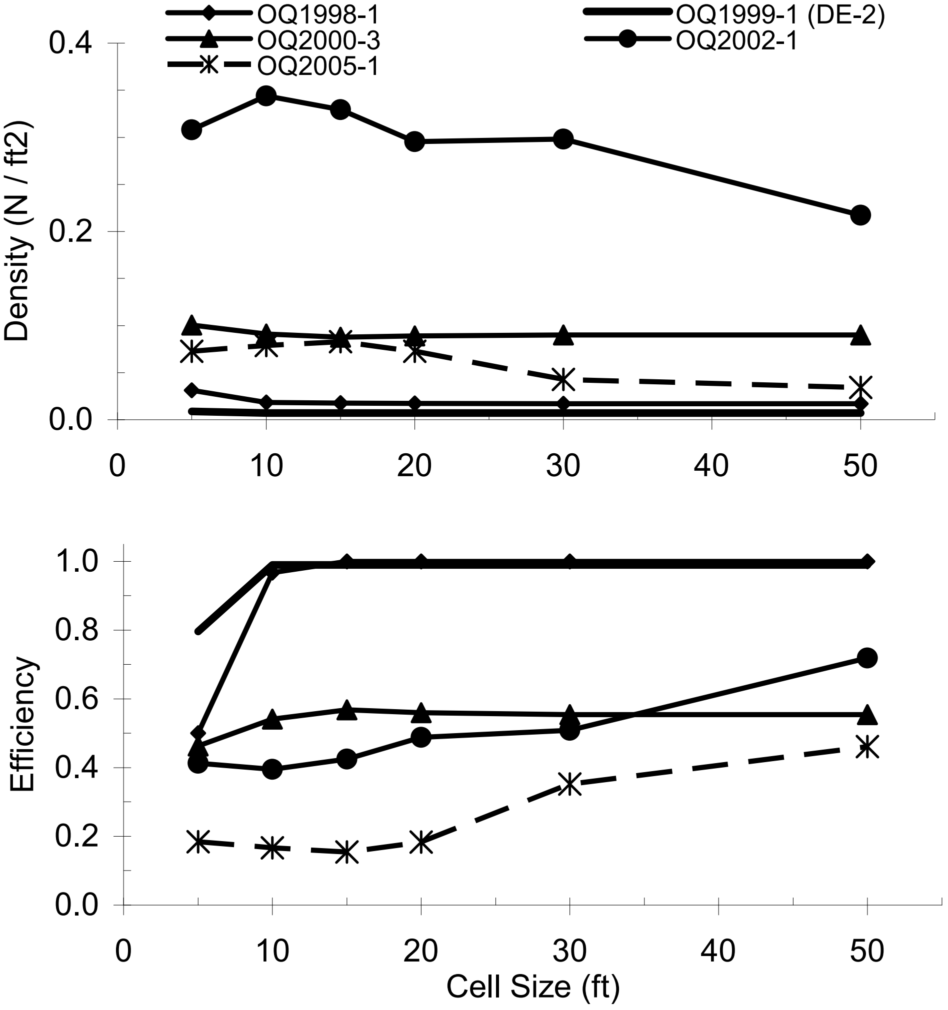


Figure A32. Sensitivity of Patch model estimates of ocean quahog density and dredge efficiency from depletion experiments and the Patch model. All of the experiments shown in the figure except OQ1999-1 (DE-2) were commercial experiments with a 10 ft dredge. The OQ1999-1 (DE-2) experiment was a Delaware II depletion experiment using a 5 ft dredge. The default cell size for Patch model analysis was 20 ft in all cases.

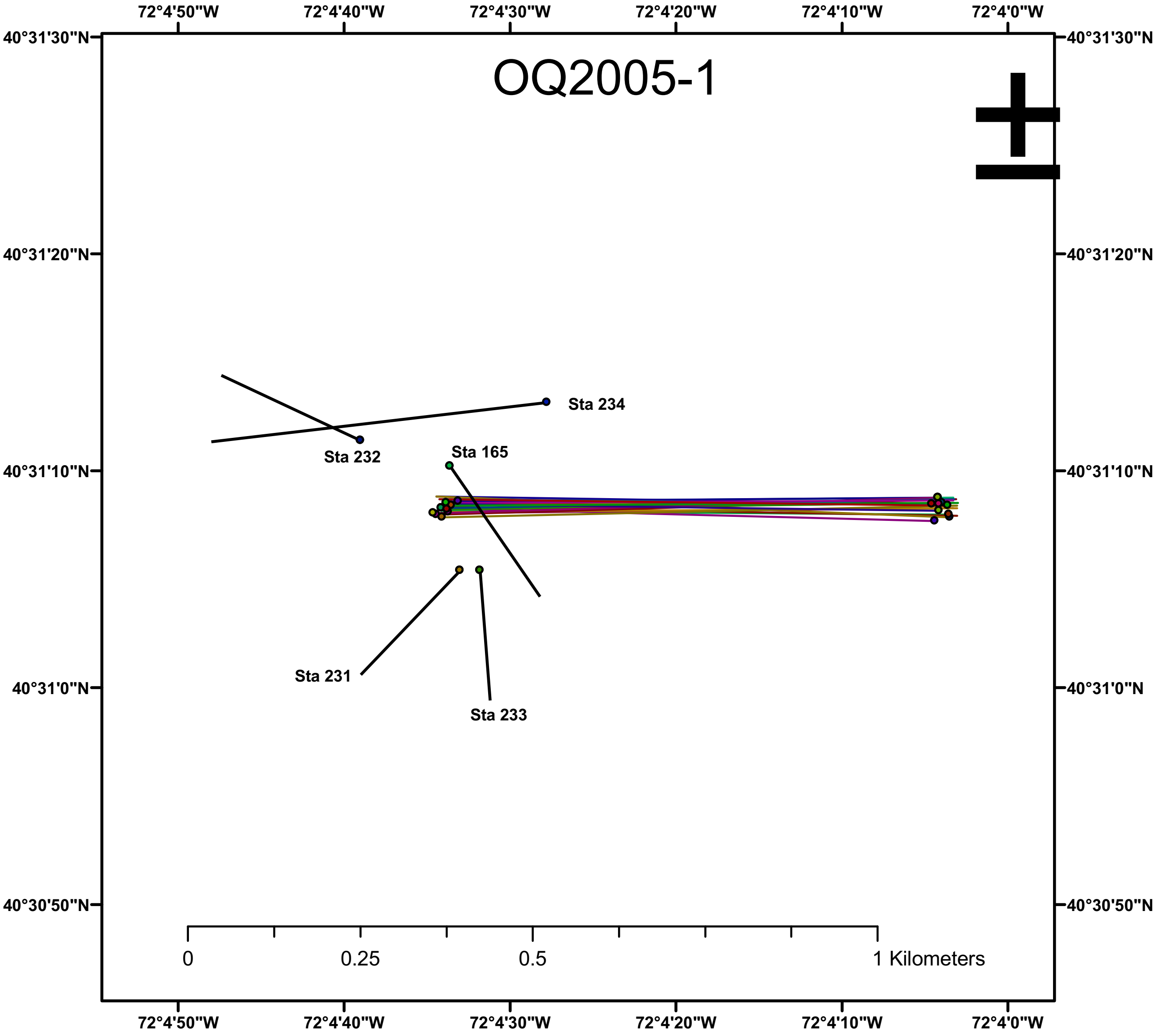


Figure A33. Setup and depletion tows for the OQ2005-1 ocean quahog depletion study. Setup tows by the *R/V Delaware II* are identified by station numbers. Depletion tows by the *F/V Lisa Kim* are tightly clustered along parallel tracks. Tow paths appear straight because they are shown as straight lines between start and stop points.

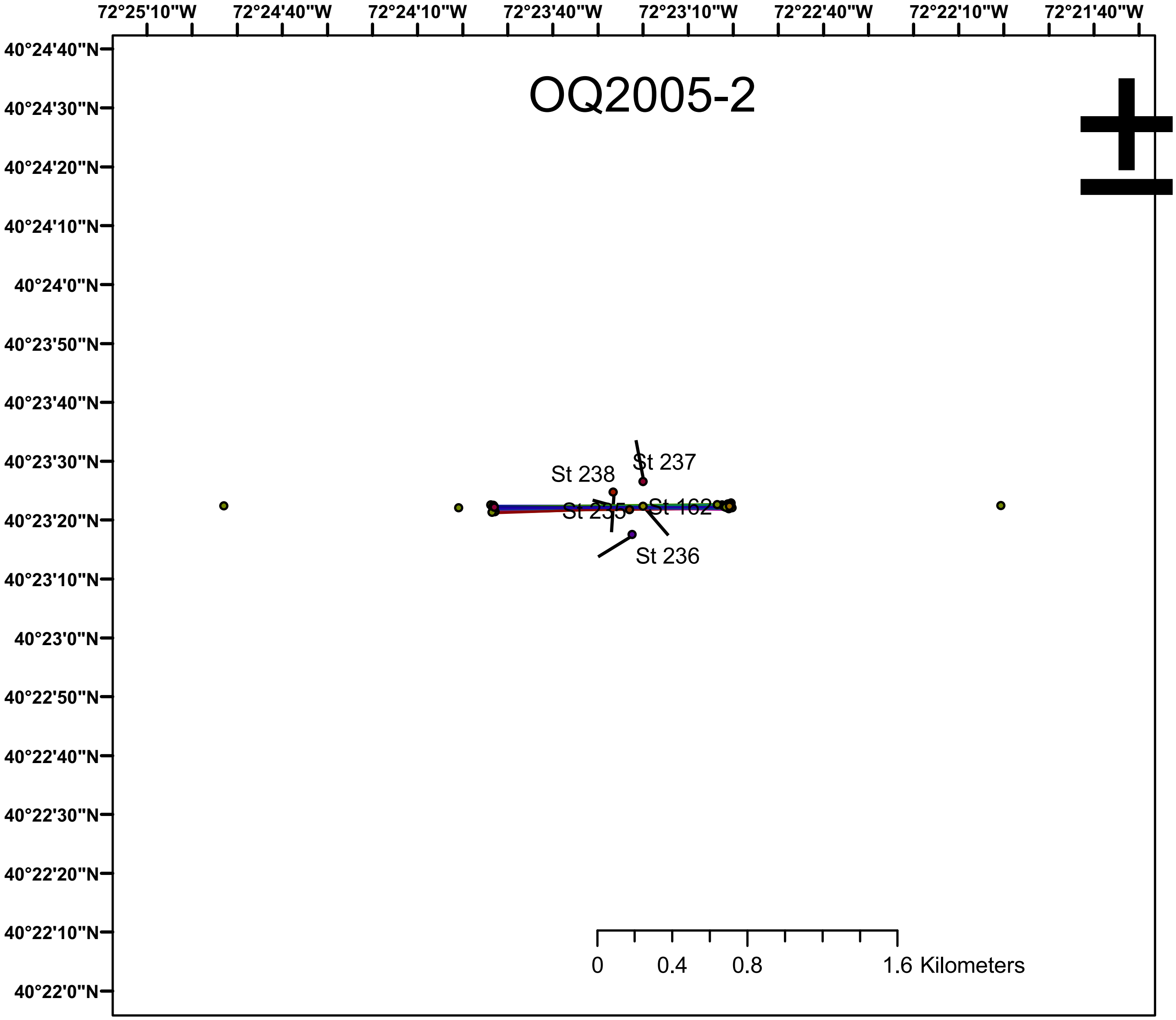


Figure A34. Setup and depletion tows for the OQ2005-2 ocean quahog depletion study. Setup tows by the *R/V Delaware II* are identified by station numbers. Depletion tows by the *F/V Lisa Kim* are tightly clustered along parallel tracks. Tow paths appear straight because they are shown as straight lines between start and stop points.

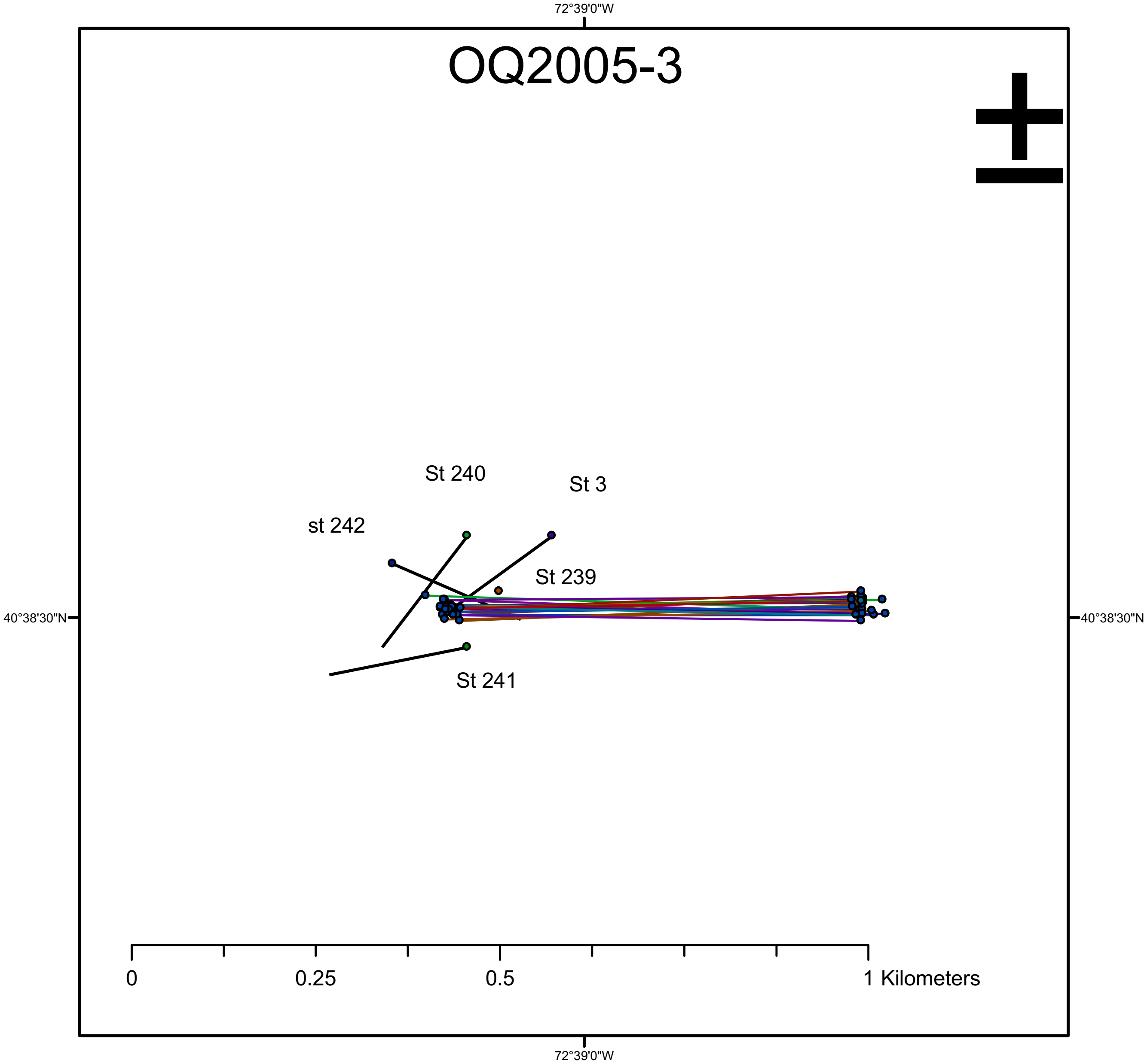


Figure A35. Setup and depletion tows for the OQ2005-3 ocean quahog depletion study. Setup tows by the *R/V Delaware II* are identified by station numbers. Depletion tows by the *F/V Lisa Kim* are tightly clustered along parallel tracks. Tow paths appear straight because they are shown as straight lines between start and stop points.

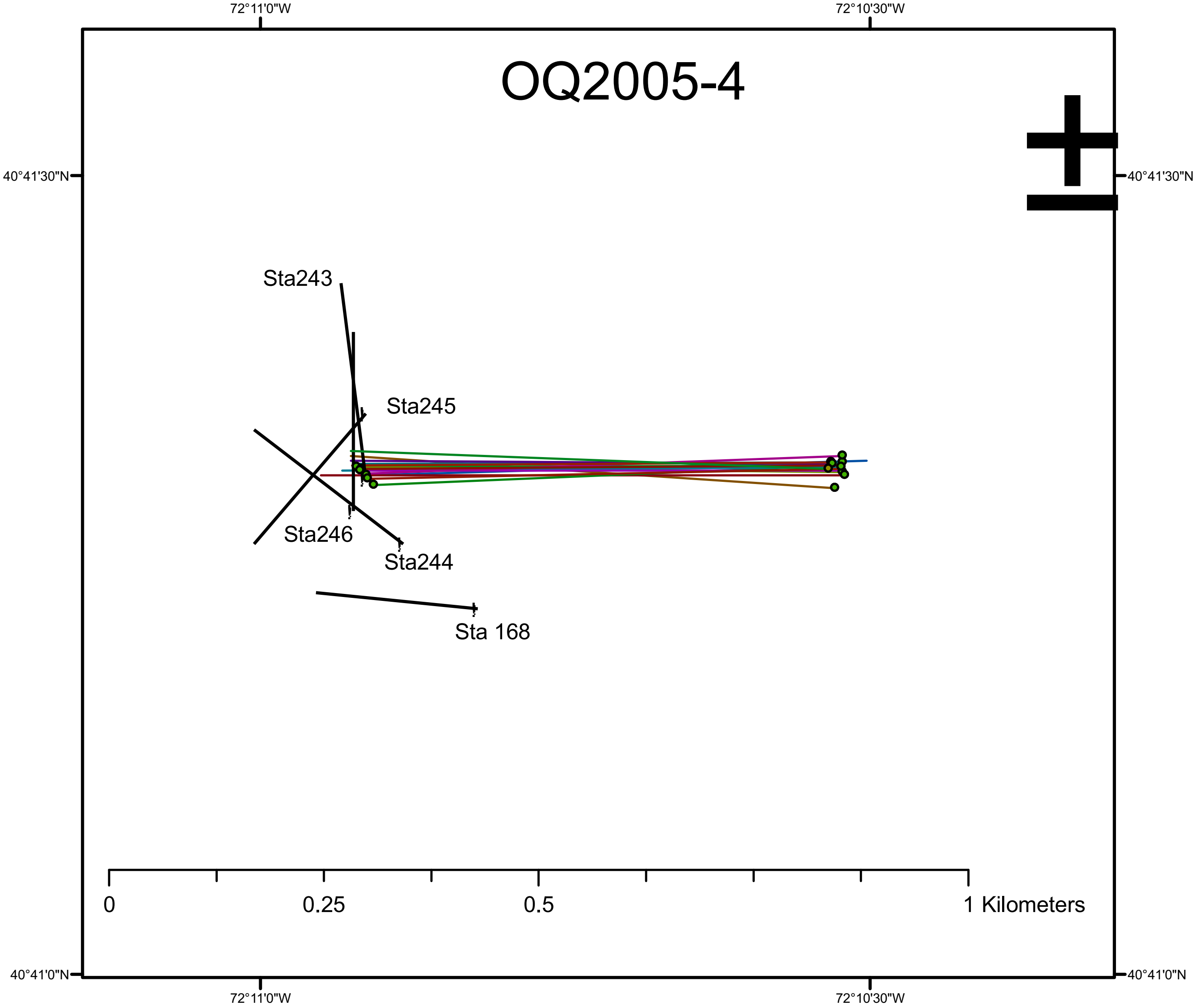


Figure A36. Setup and depletion tows for the OQ2005-4 ocean quahog depletion study. Setup tows by the *R/V Delaware II* are identified by station numbers. Depletion tows by the *F/V Lisa Kim* are tightly clustered along parallel tracks. Tow paths appear straight because they are shown as straight lines between start and stop points.

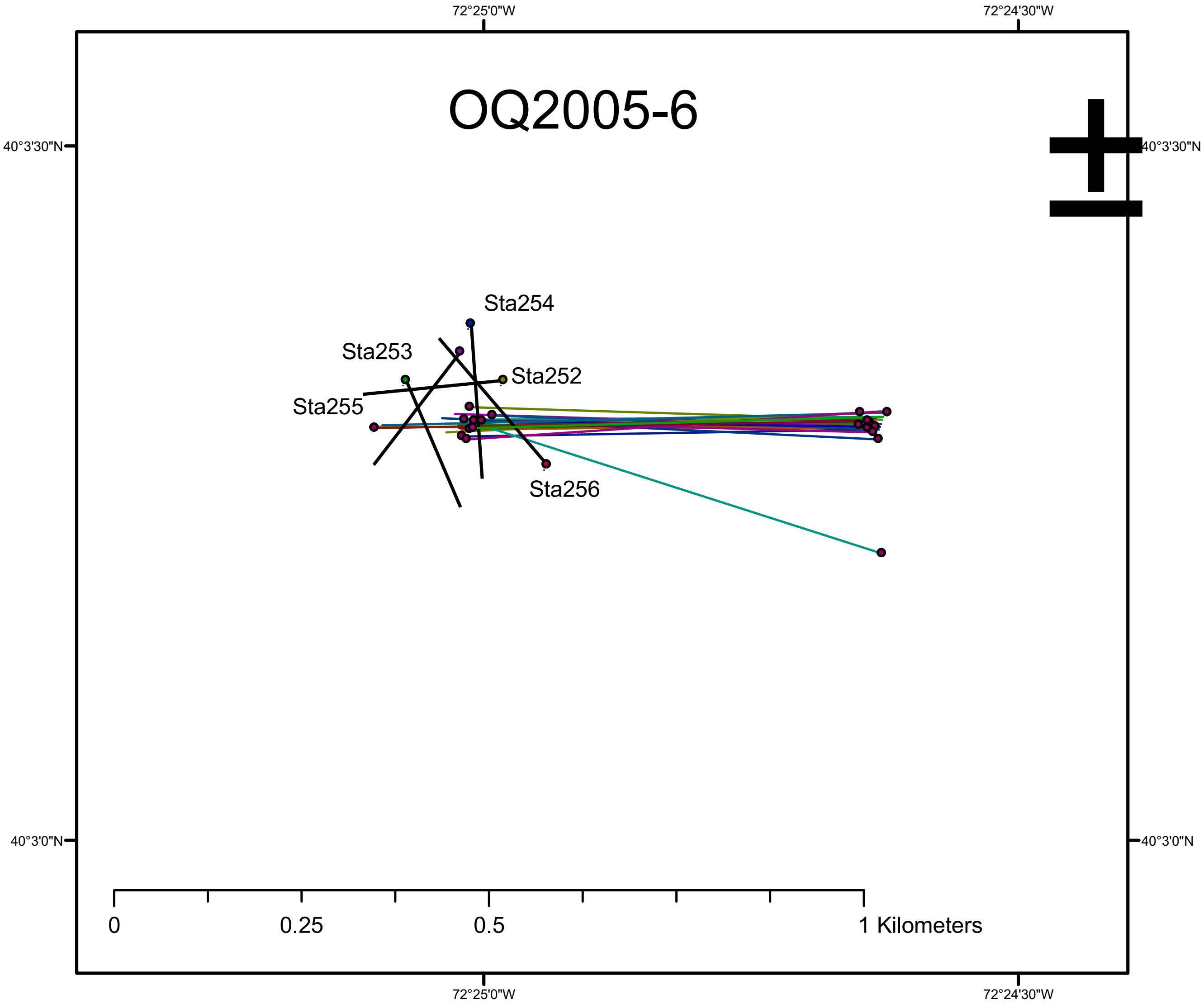


Figure A37. Setup and depletion tows for the OQ2005-6 ocean quahog depletion study. Setup tows by the *R/V Delaware II* are identified by station numbers. Depletion tows by the *F/V Lisa Kim* are tightly clustered along parallel tracks. Tow paths appear straight because they are shown as straight lines between start and stop points.

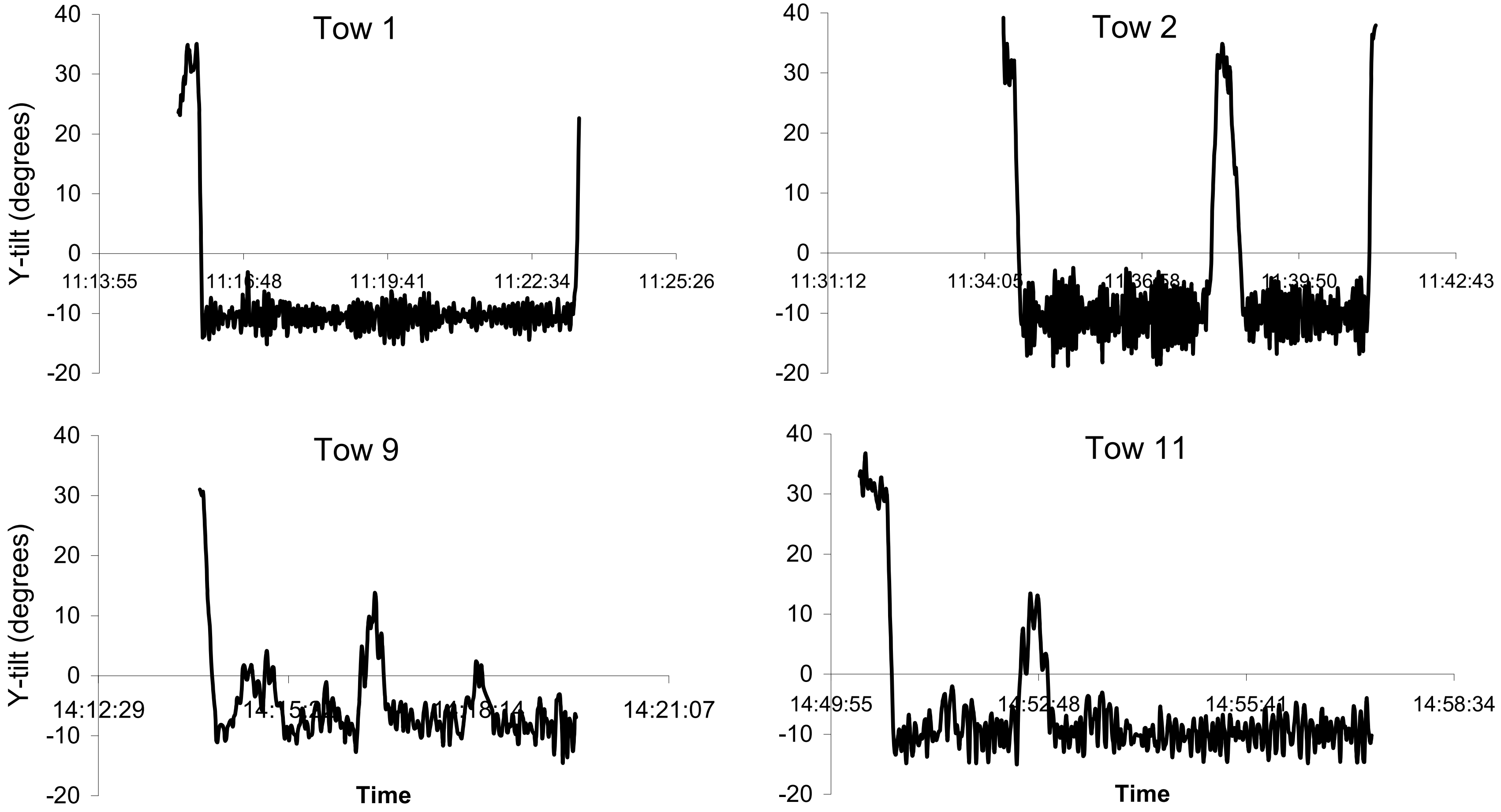


Figure A38. Inclinometer data for selected tows by a commercial dredge at depletion experiment site OQ2005-06, which was carried out in relatively deep water with a short pump hose and under choppy conditions. Data missing at end of tows 9-11 because of low sensor batteries.

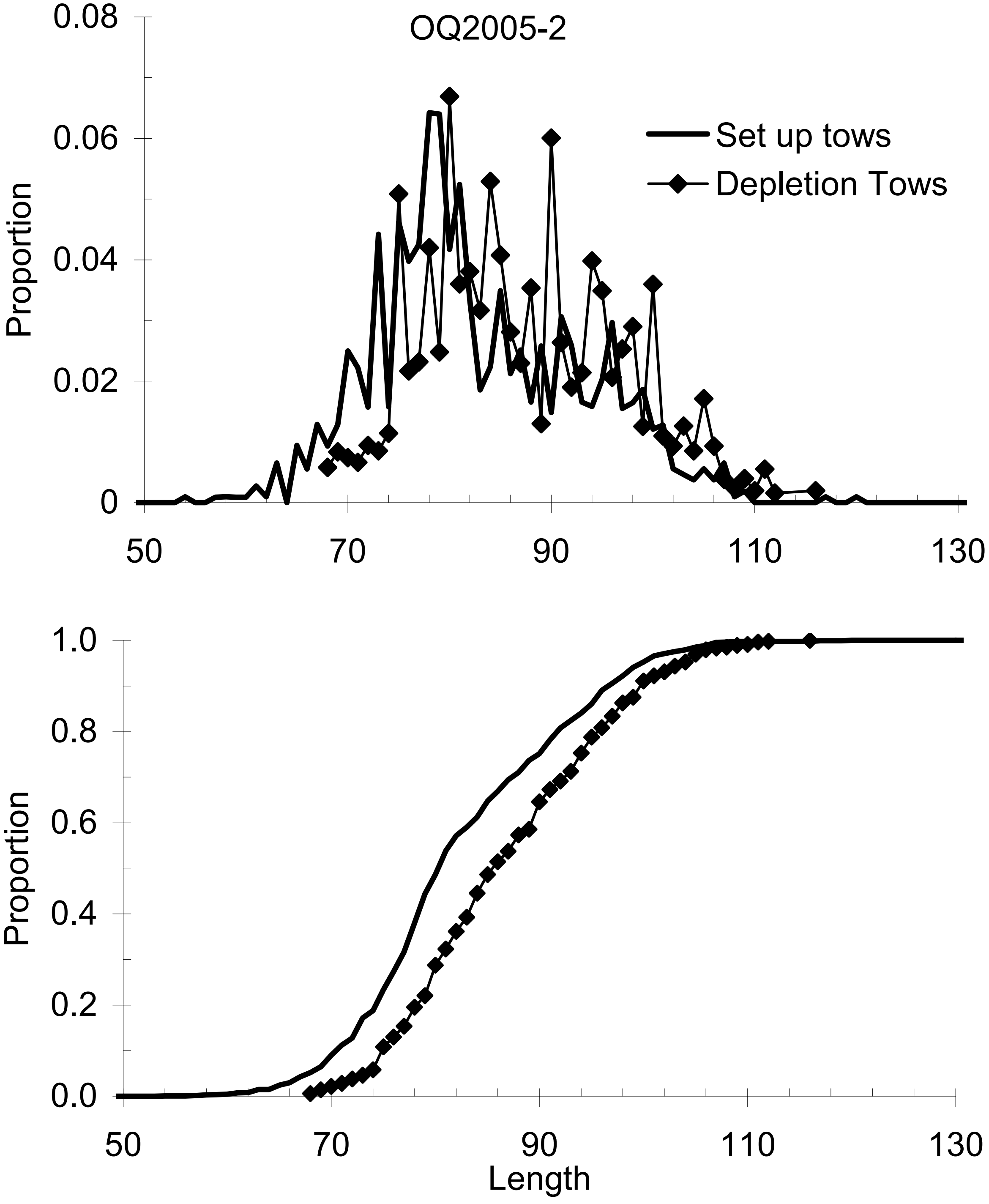


Figure A39. Length composition data from setup and depletion tows at a typical 2005 depletion site for ocean quahog (OQ2005-02).

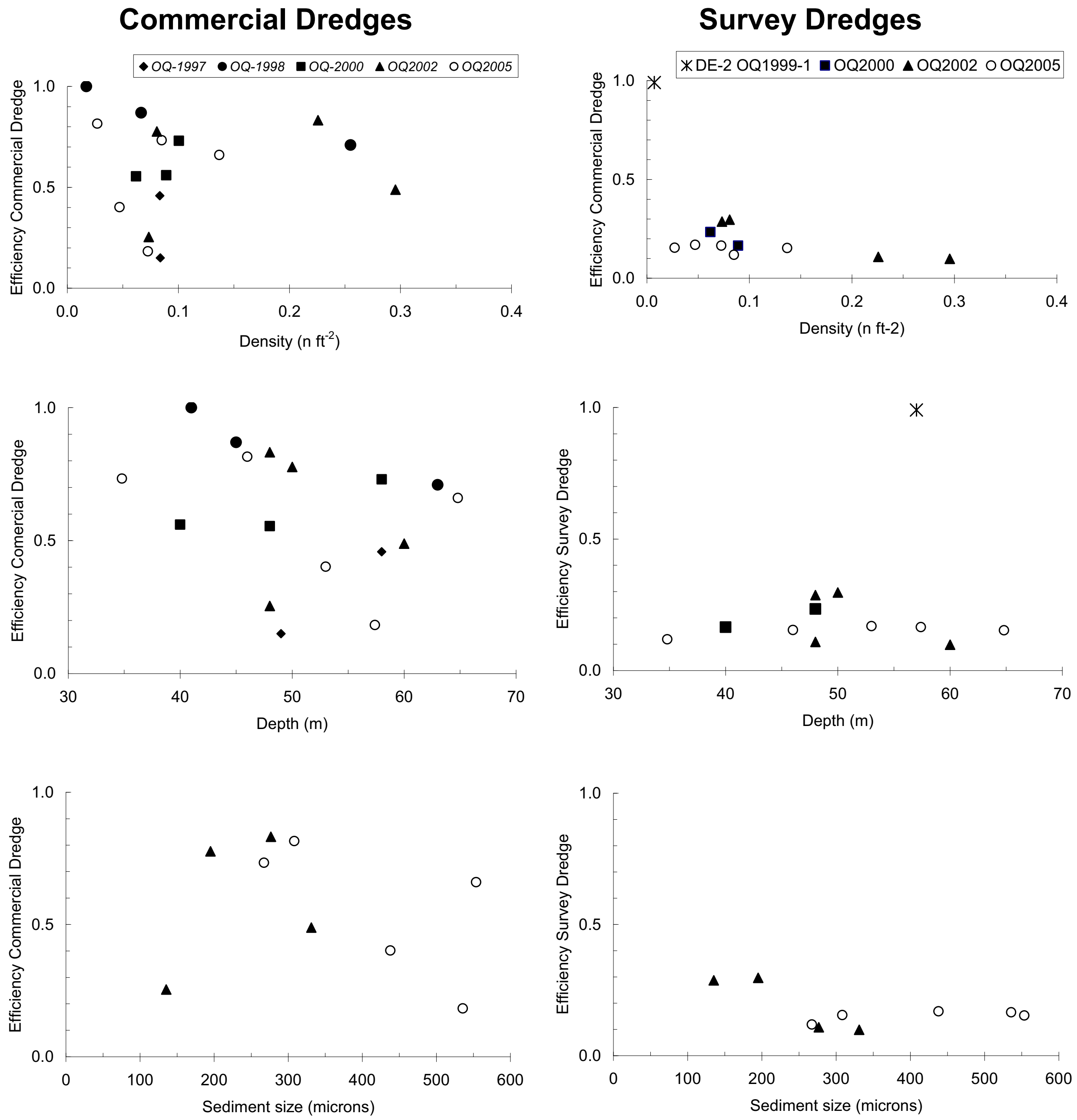


Figure A40. Patch model dredge efficiency estimates vs. depth, estimated density from the Patch model and mean sediment size for ocean quahog in hydraulic dredges used on commercial vessels during depletion studies and the hydraulic dredge used during research surveys by the *F/V Delaware II*. All data shown in plots on the left hand side are efficiency estimates for commercial vessels used in depletion studies. All data shown in plots on the right hand side are efficiency estimates for the R/V Delaware II based on commercial depletion estimates with setup tows by the Delaware II or, in the case of "DE-2 OQ1999-1", a depletion study carried out directly by the R/V Delaware II.

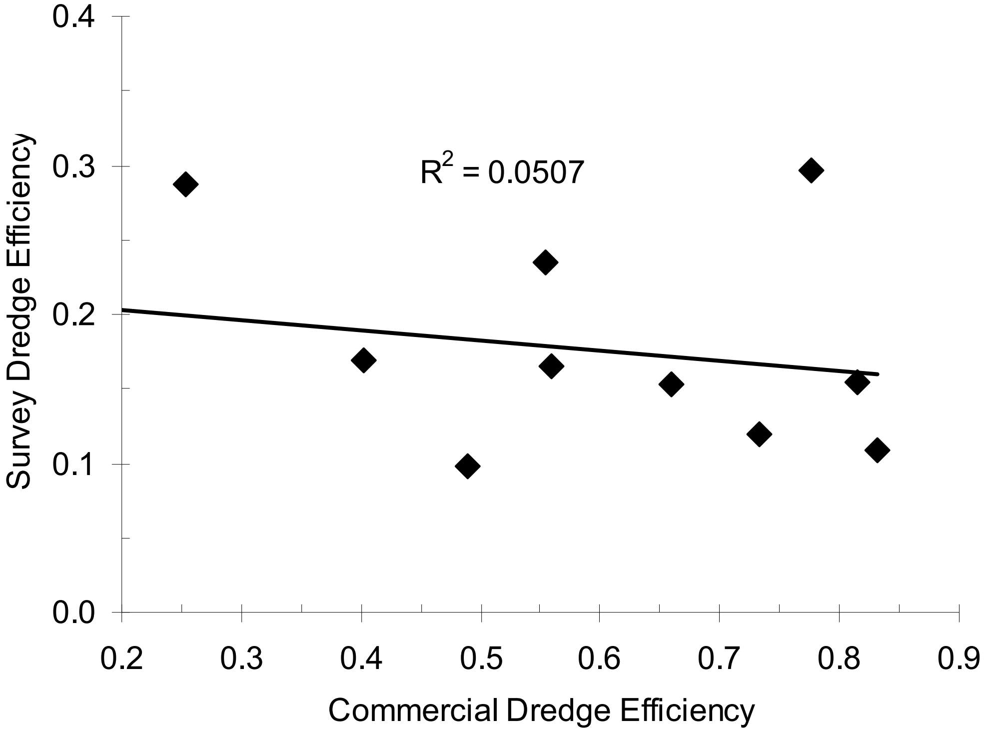


Figure A41. Survey dredge efficiency estimates for ocean quahog from depletions studies by commercial vessels and by the R/V Delaware II.

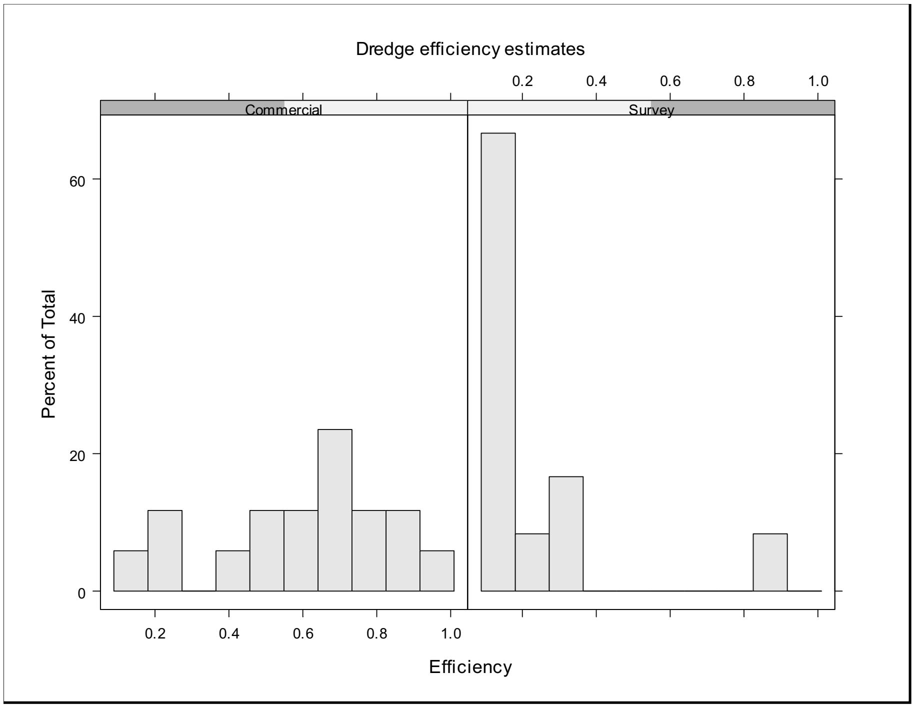


Figure A42. Distribution of survey dredge efficiency estimates for ocean quahog from depletion studies by commercial vessels and by the survey vessel (*R/V Delaware II*).

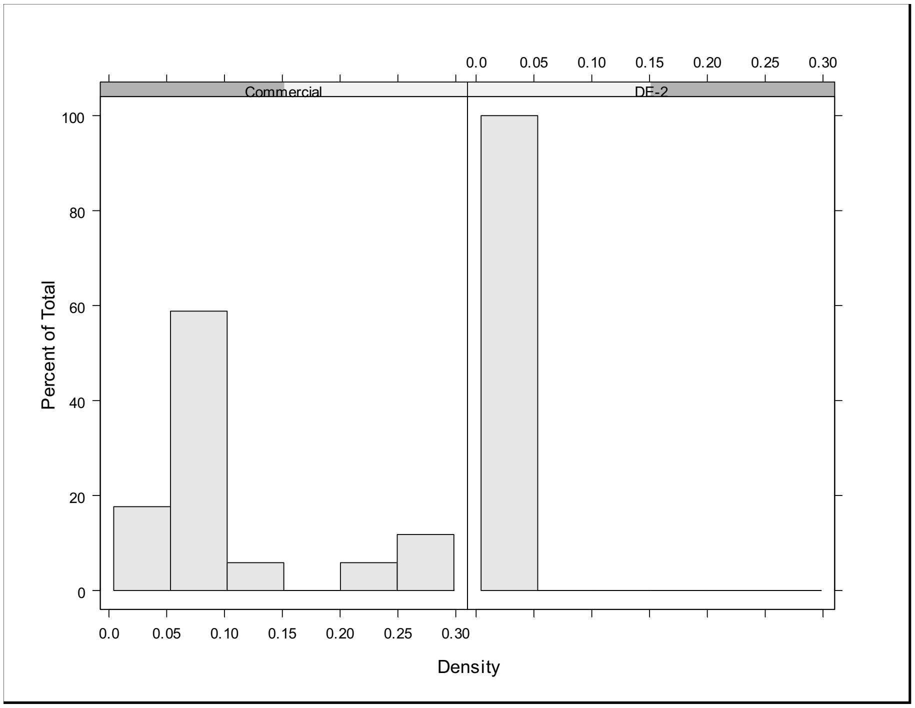


Figure A43. Distribution of ocean quahog density estimates (n ft^{-2}) for ocean quahog 90+ mm SL from depletion studies by commercial vessels and by the survey vessel (*R/V Delaware II*).

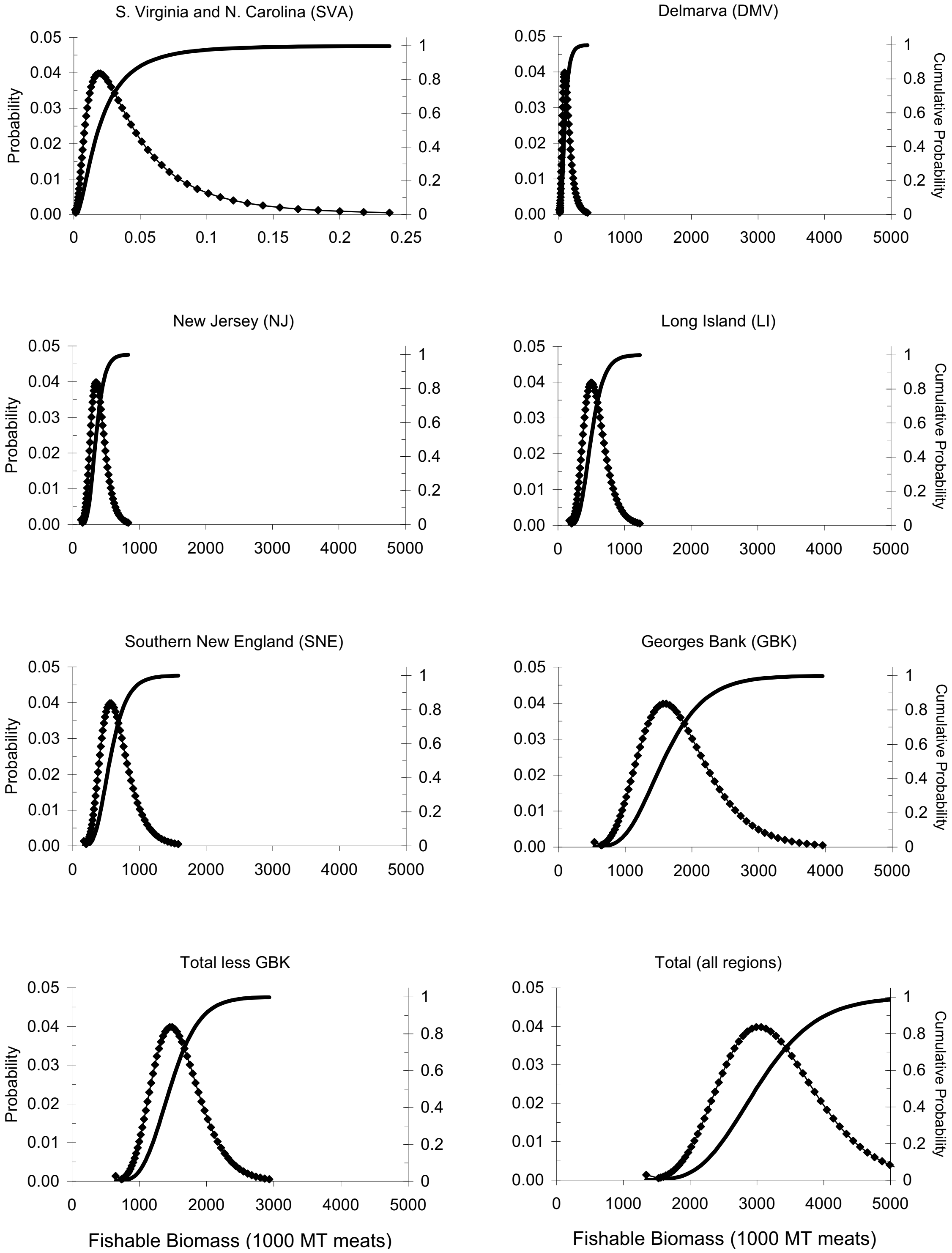


Figure A44. Uncertainty in efficiency corrected swept area biomass estimates for fishable ocean quahog during 2005. Note that the x-axis differs in the panel for SVA but is the same in all other panels to facilitate comparisons.

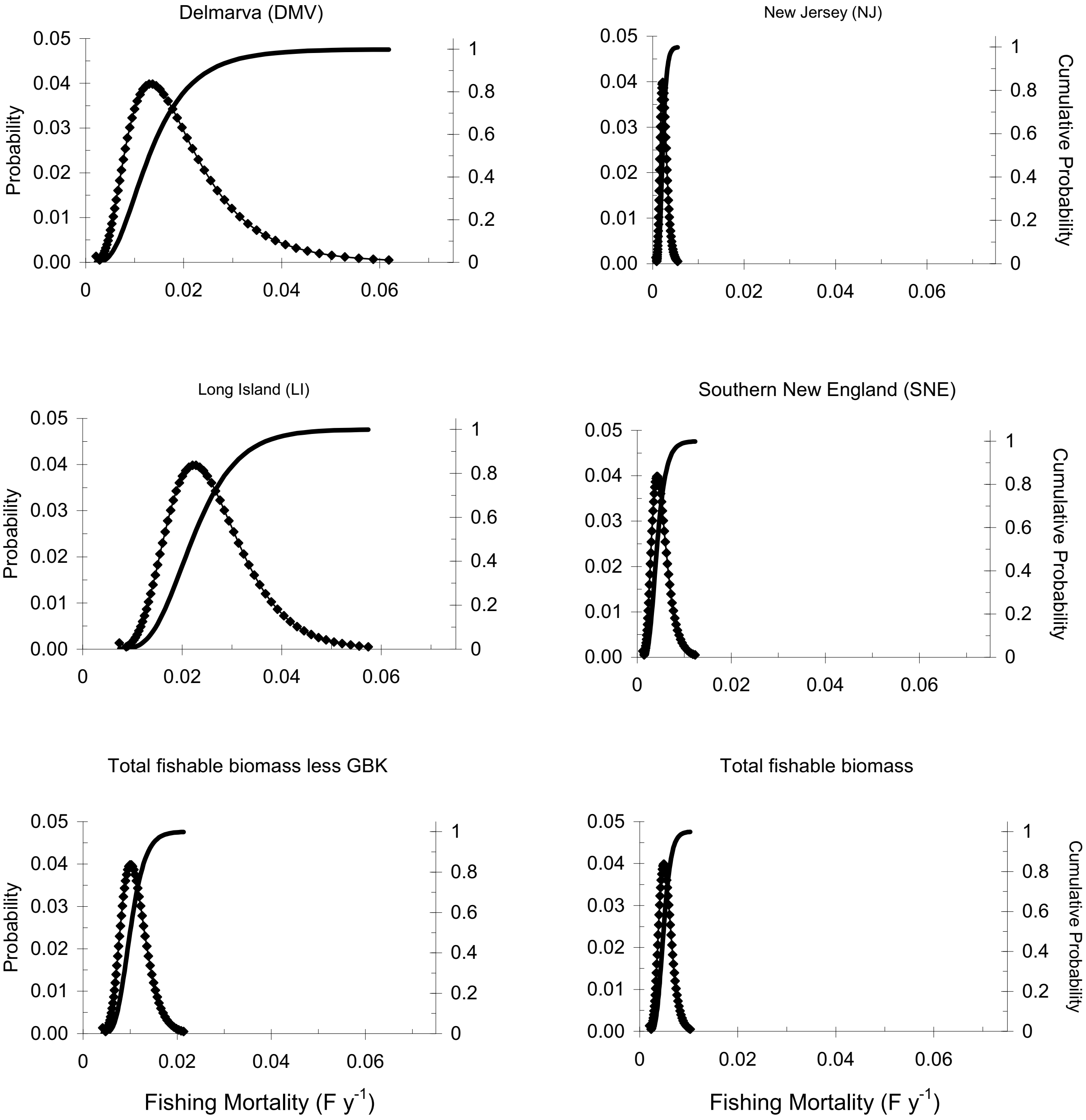
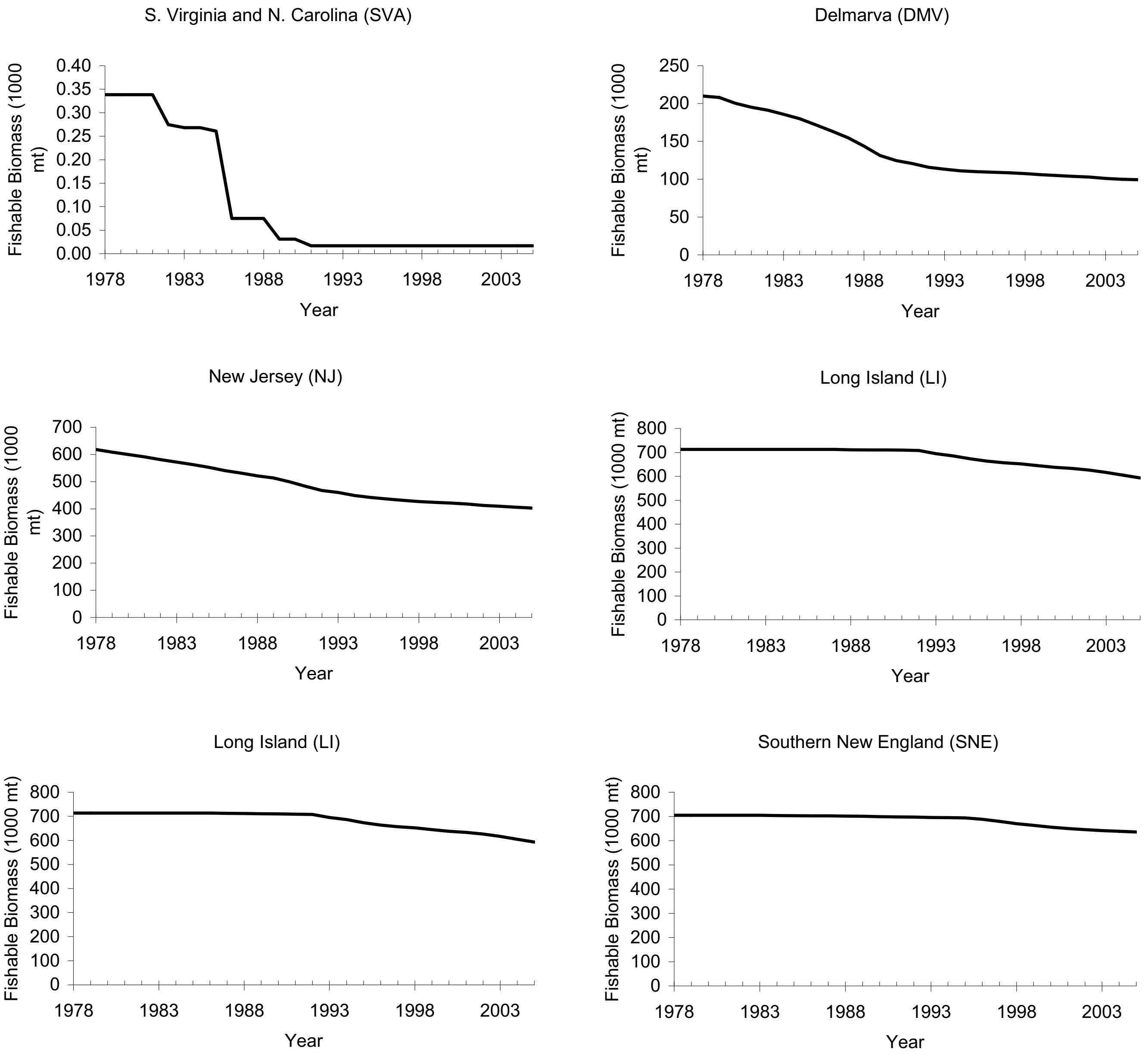


Figure A45. Uncertainty in fishing mortality estimates for ocean quahog during 2005 based on catch data and efficiency corrected swept-area biomass. X-axes are scaled to the same maximum to facilitate comparisons.



S. Virginia and N. Carolina (SVA)

Delmarva (DMV)

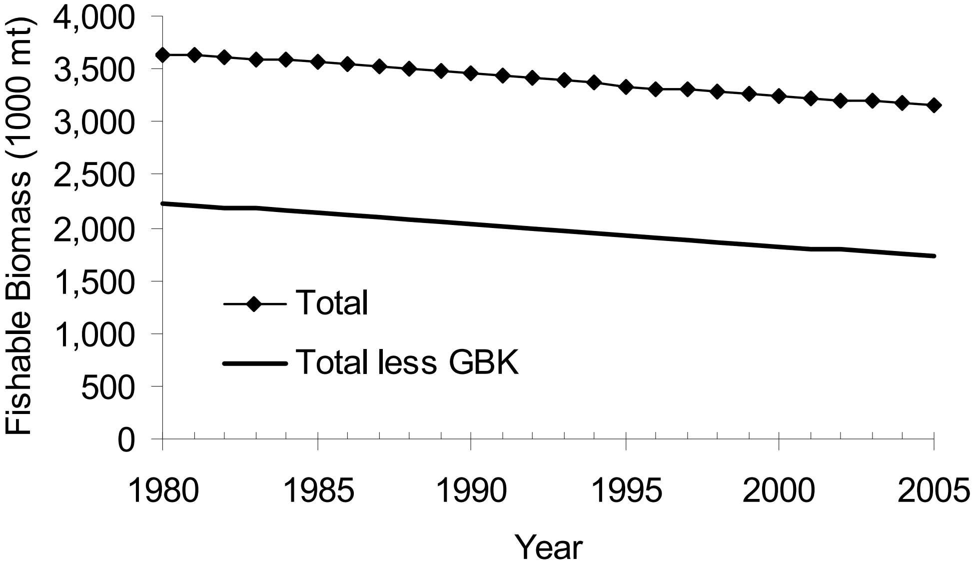
New Jersey (NJ)

Long Island (LI)

Long Island (LI)

Southern New England (SNE)

Figure A46. Trends in fishable biomass for ocean quahog from the "VPA" model, by region.



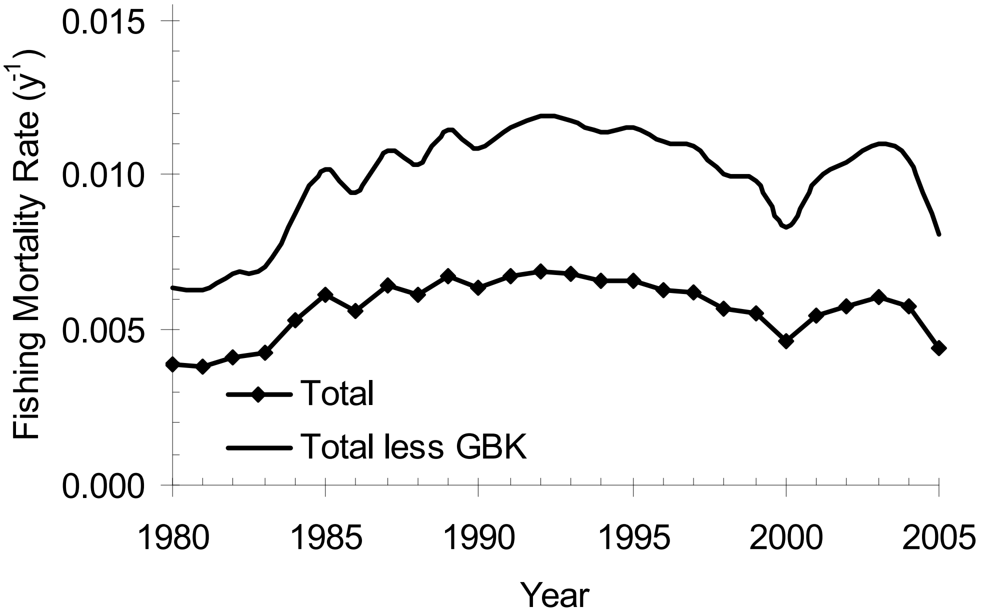


Figure A47. Trends in fishable biomass and fishing mortality for ocean quahog from the "VPA" model.

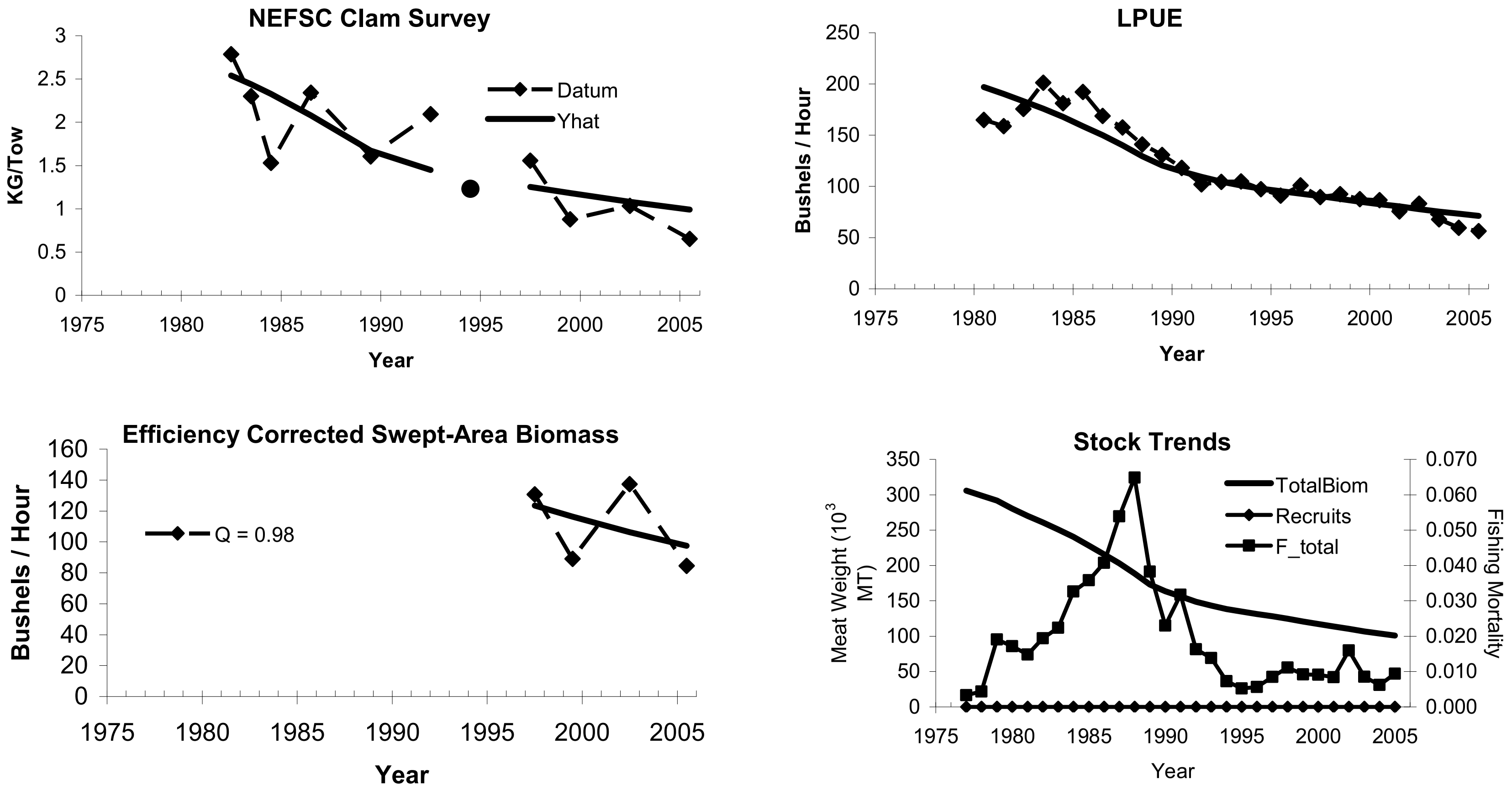


Figure A48. KLAMZ model results for ocean quahog in the DMV stock assessment region. The bottom right panel shows population estimates. Other panels show goodness of fit to trend data. The survey scaling parameter estimate for efficiency corrected swept-area biomass data used as prior information is shown in the bottom left panel. Trends in efficiency corrected swept area biomass and LPUE data did not affect model estimates and are shown for comparison only.

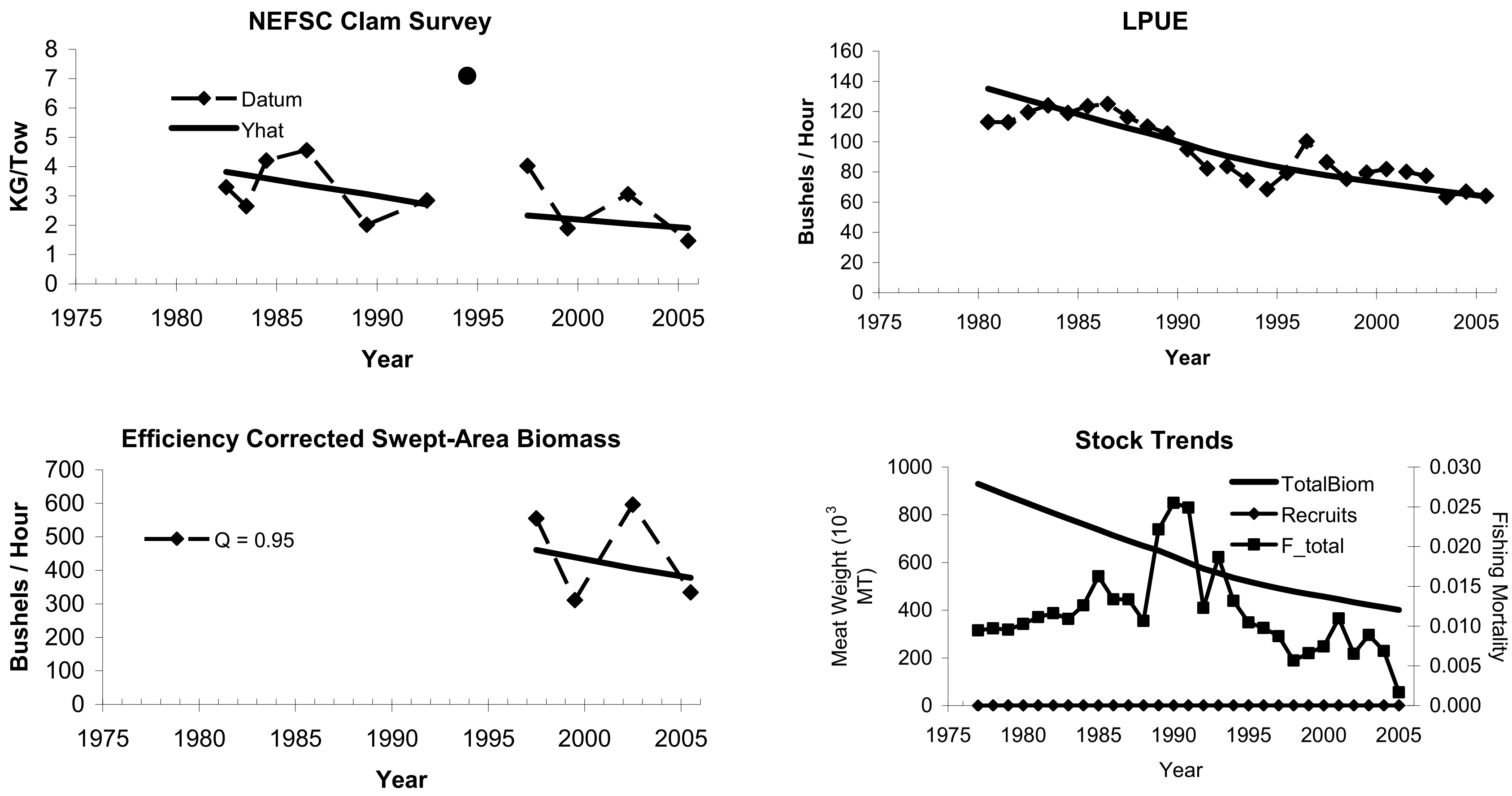


Figure A49. KLAMZ model results for ocean quahog in the NJ stock assessment region. The bottom right panel shows population estimates. Other panels show goodness of fit to trend data. The survey scaling parameter estimate for efficiency corrected swept-area biomass data used as prior information is shown in the bottom left panel. Trends in efficiency corrected swept area biomass and LPUE data did not affect model estimates and are shown for comparison only.

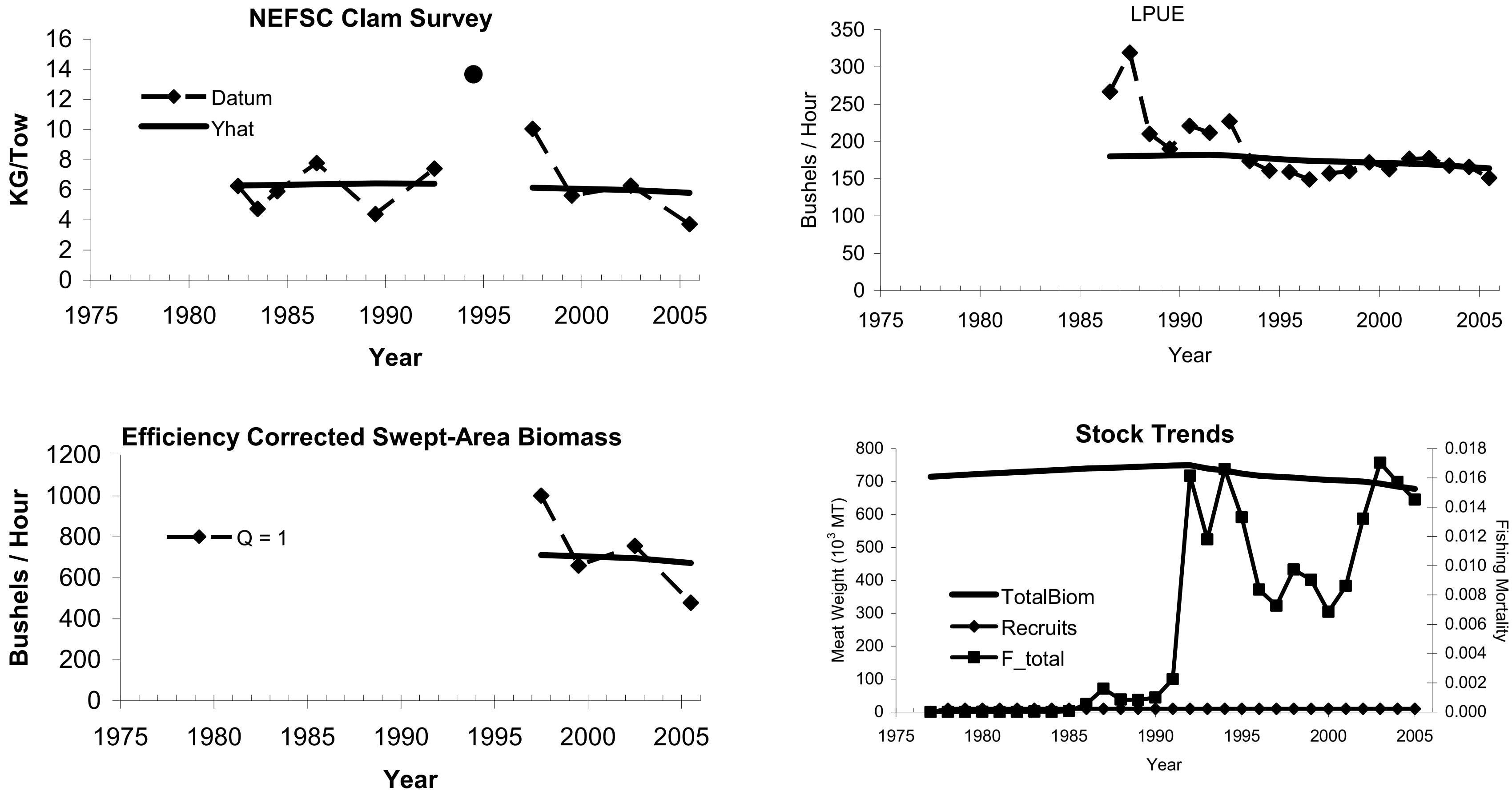


Figure A50. KLAMZ model results for ocean quahog in the LI stock assessment region. The bottom right panel shows population estimates. Other panels show goodness of fit to trend data. The survey scaling parameter estimate for efficiency corrected swept-area biomass data used as prior information is shown in the bottom left panel. Trends in efficiency corrected swept area biomass and LPUE data did not affect model estimates and are shown for comparison only.

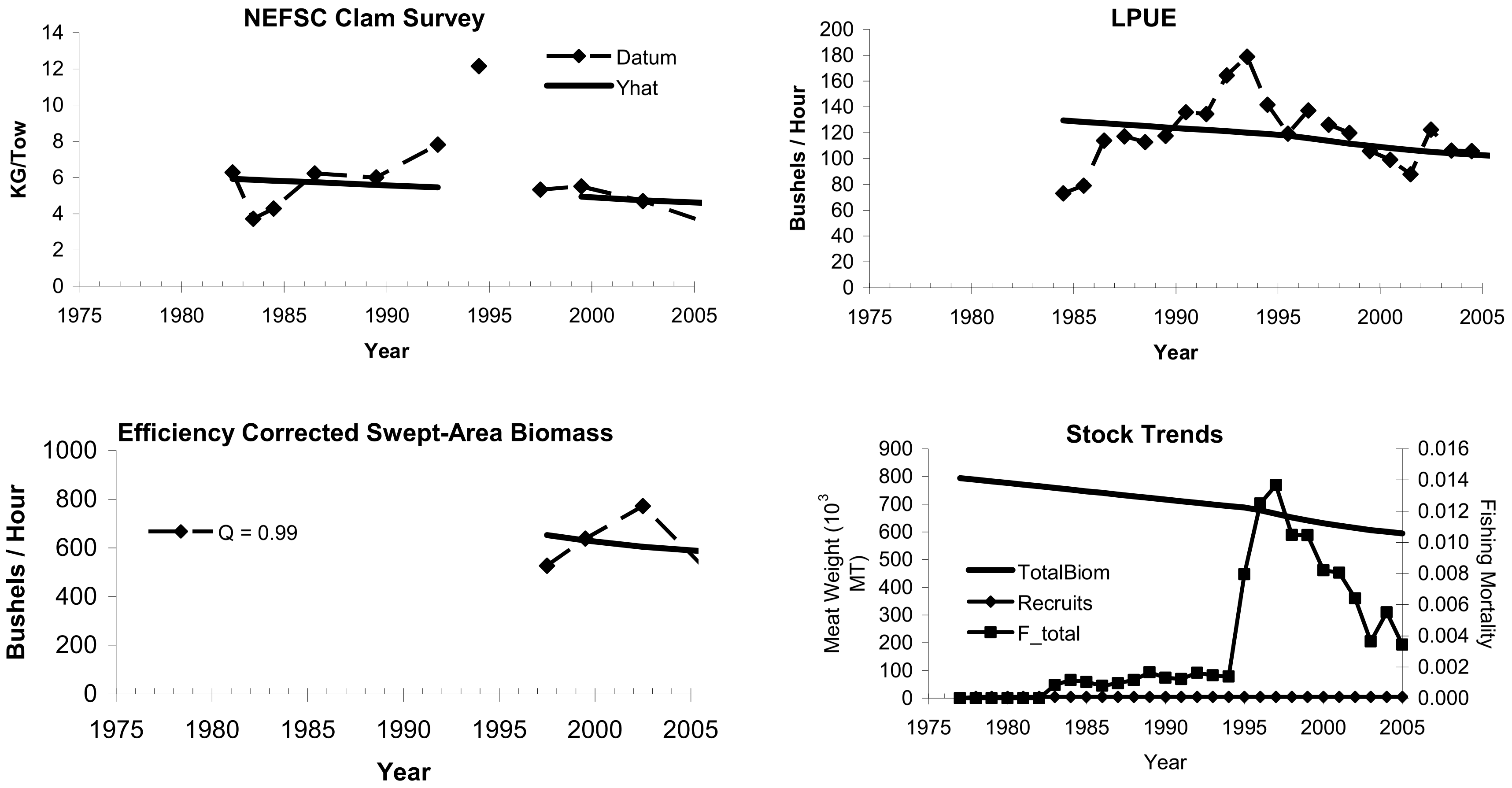
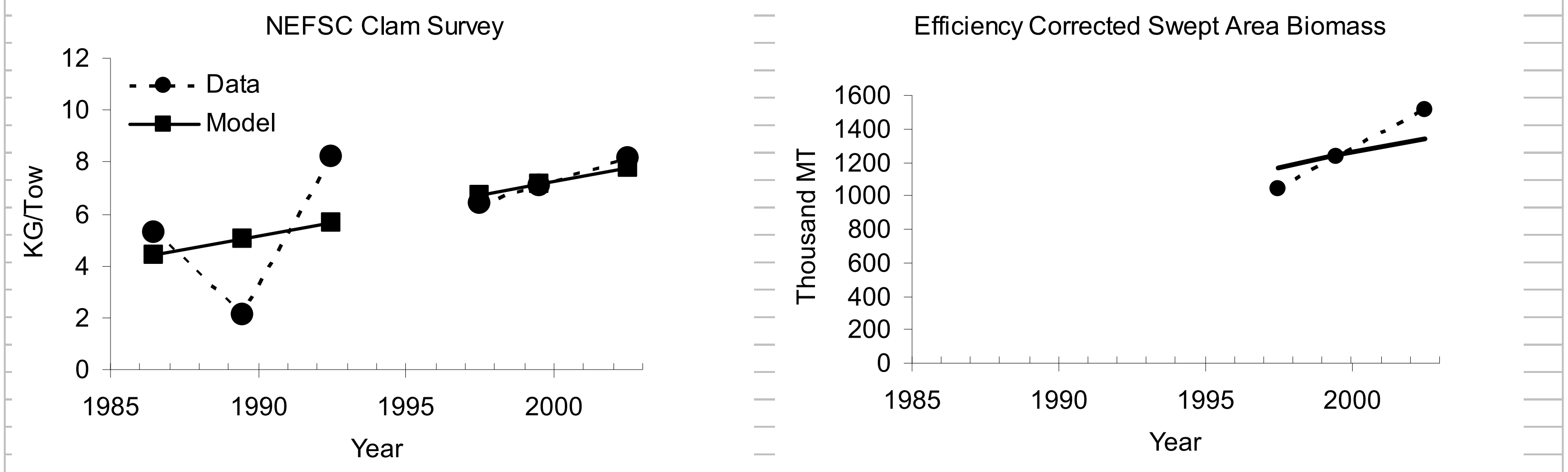
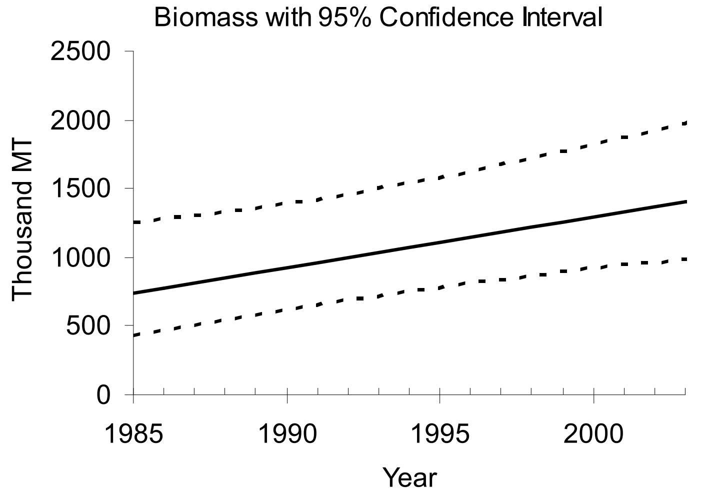


Figure A51. KLAMZ model results for ocean quahog in the SNE stock assessment region. The bottom right panel shows population estimates. Other panels show goodness of fit to trend data. The survey scaling parameter estimate for efficiency corrected swept-area biomass data used as prior information is shown in the bottom left panel. Trends in efficiency corrected swept area biomass and LPUE data did not affect model estimates and are shown for comparison only.



Q for efficiency corrected swept area biomass = 0.98



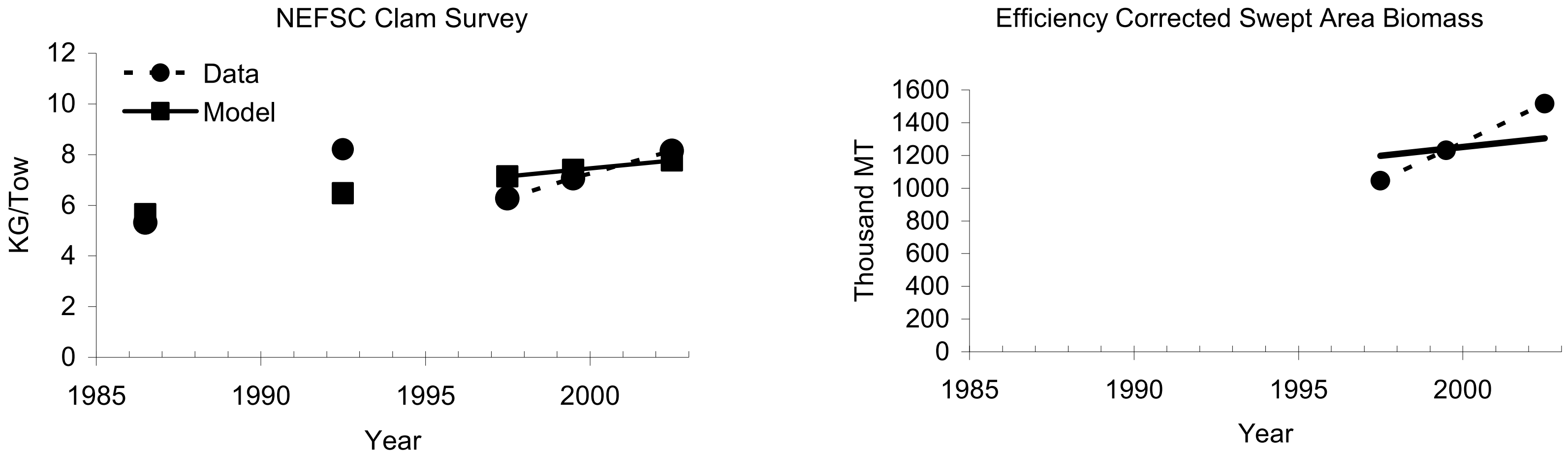
Mean instantaneous rates

Rate	GBK	LI	GBK/LI
M=	-0.020	-0.020	1.0
G=	0.022	0.010	2.2
R=	0.031	0.014	2.3
Surplus prod. rate	0.034	0.004	8.8

Mean recruits per unit area

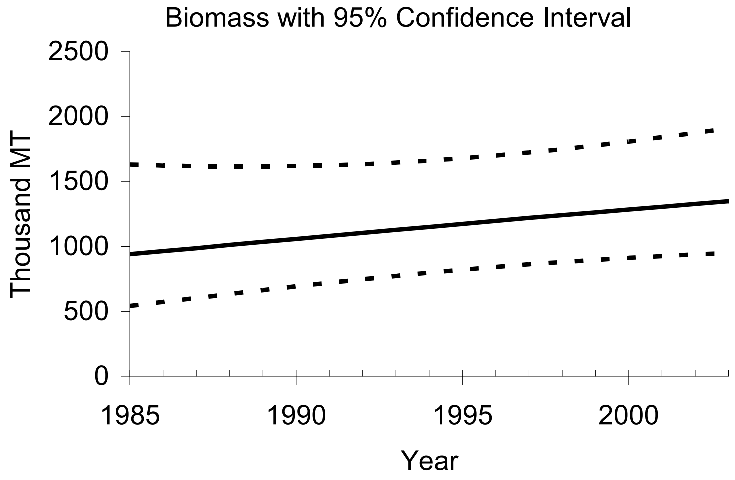
	GBK	LI	GBK/LI
Recruits (MT / year)	34.2	9.9	3.5
Area (nm^2)	7821	4463	1.8
Recruits/Area	0.0044	0.0022	2.0

Figure A52. Results from a trial run of the KLAMZ model for ocean quahog in the GBK stock assessment region during 1986-2002 with all survey data in the model.


NEFSC Clam Survey

Efficiency Corrected Swept Area Biomass

Q for efficiency corrected swept area biomass = 0.98


Biomass with 95% Confidence Interval

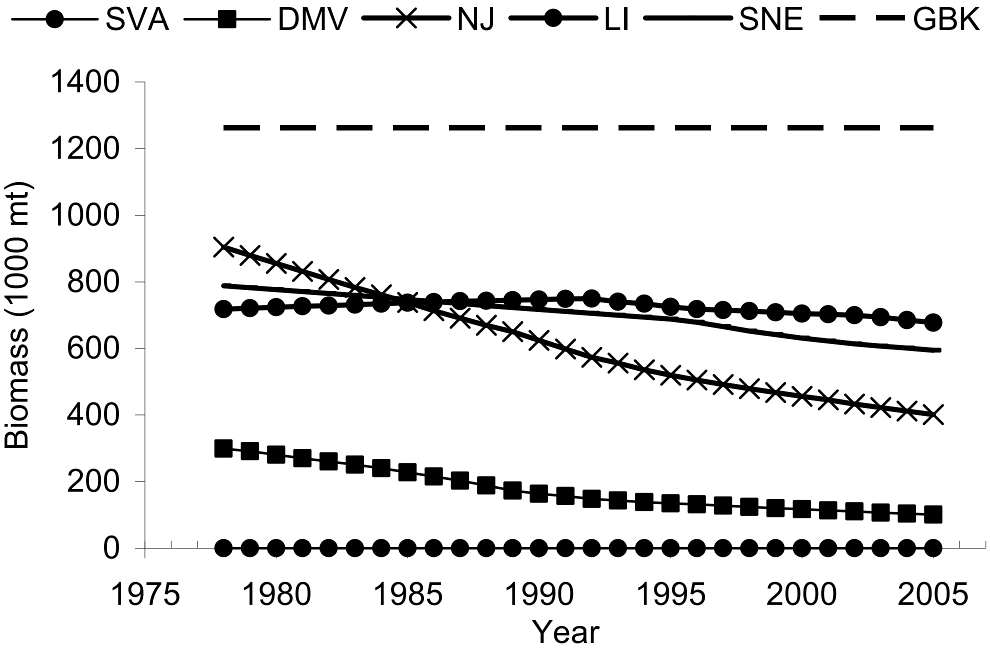
Mean instantaneous rates

Rate	GBK	LI	GBK/LI
M=	-0.020	-0.020	1.0
G=	0.017	0.010	1.7
R=	0.022	0.014	1.6
Surplus prod. rate	0.019	0.004	5.0

Mean recruits per unit area

	GBK	LI	GBK/LI
Recruits (MT / year)	25.4	9.9	2.6
Area (nm^2)	7821	4463	1.8
Recruits/Area	0.0033	0.0022	1.5

Figure A53. Results from a sensitivity run of the KLAMZ model for ocean quahog in the GBK stock assessment region with survey data for 1989 removed.



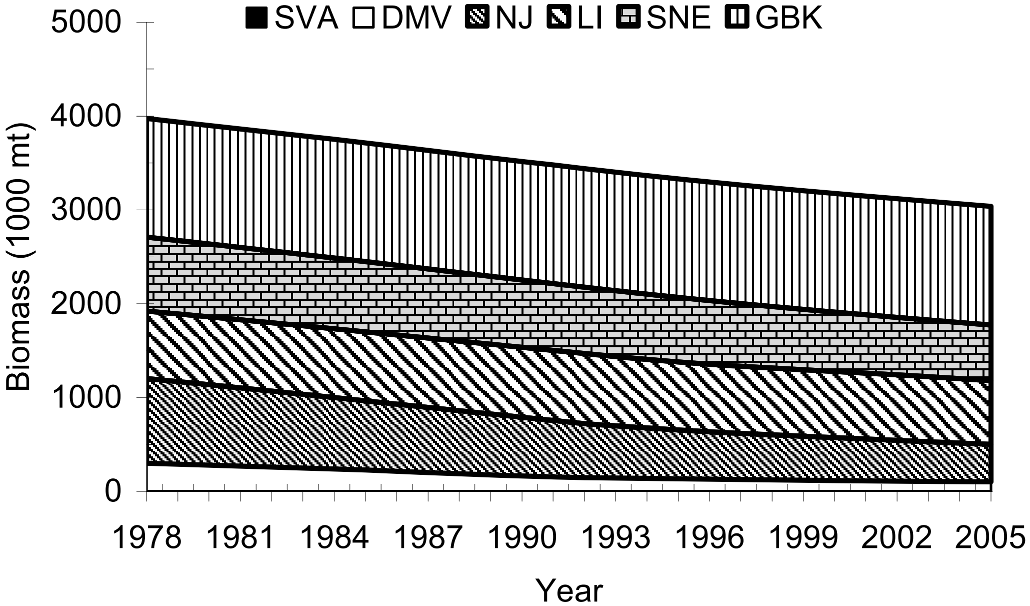


Figure A54. Best biomass estimates for ocean quahog in the US EEZ.

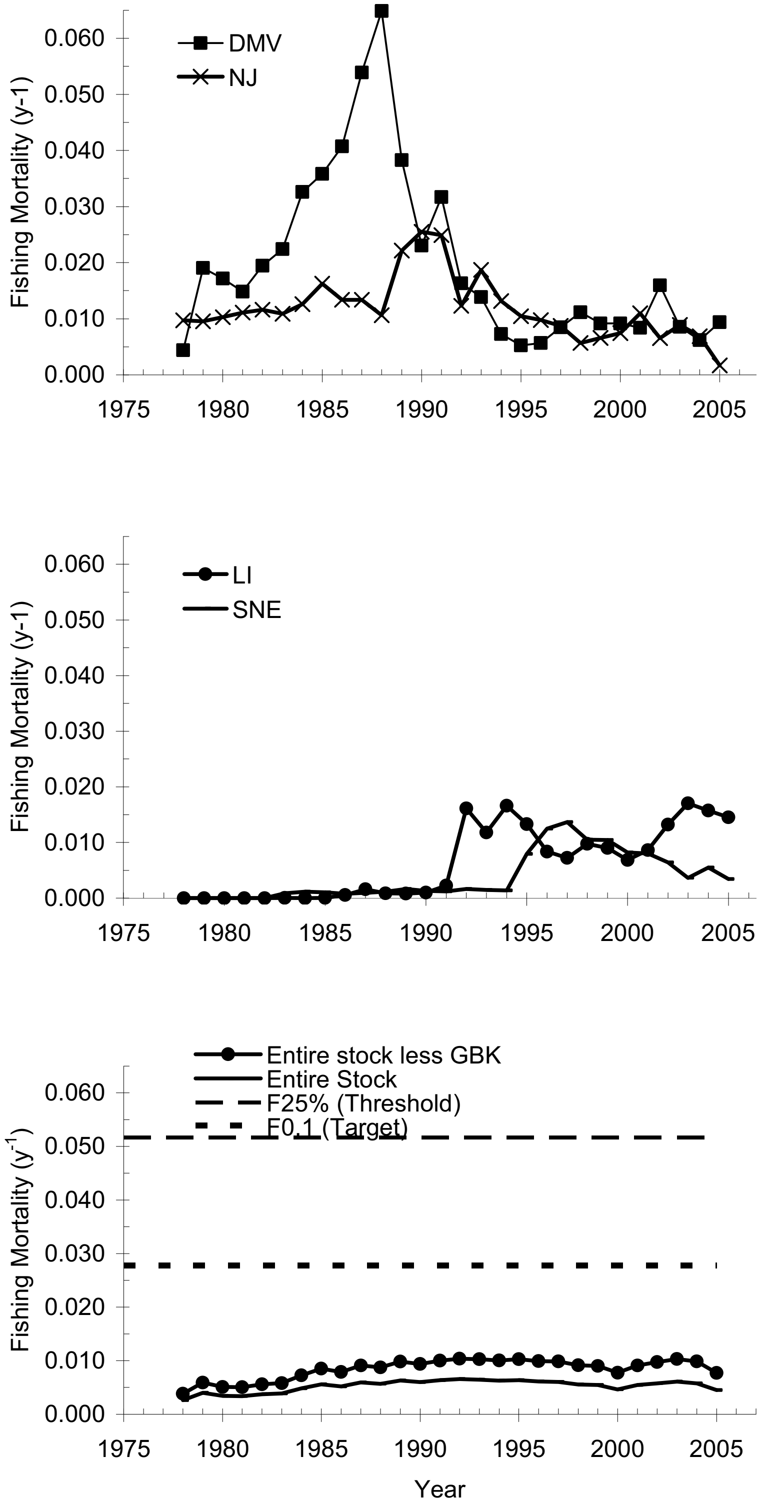


Figure A55. Best fishing mortality estimates for the ocean quahog stock in the US EEZ and the total stock less GBK.

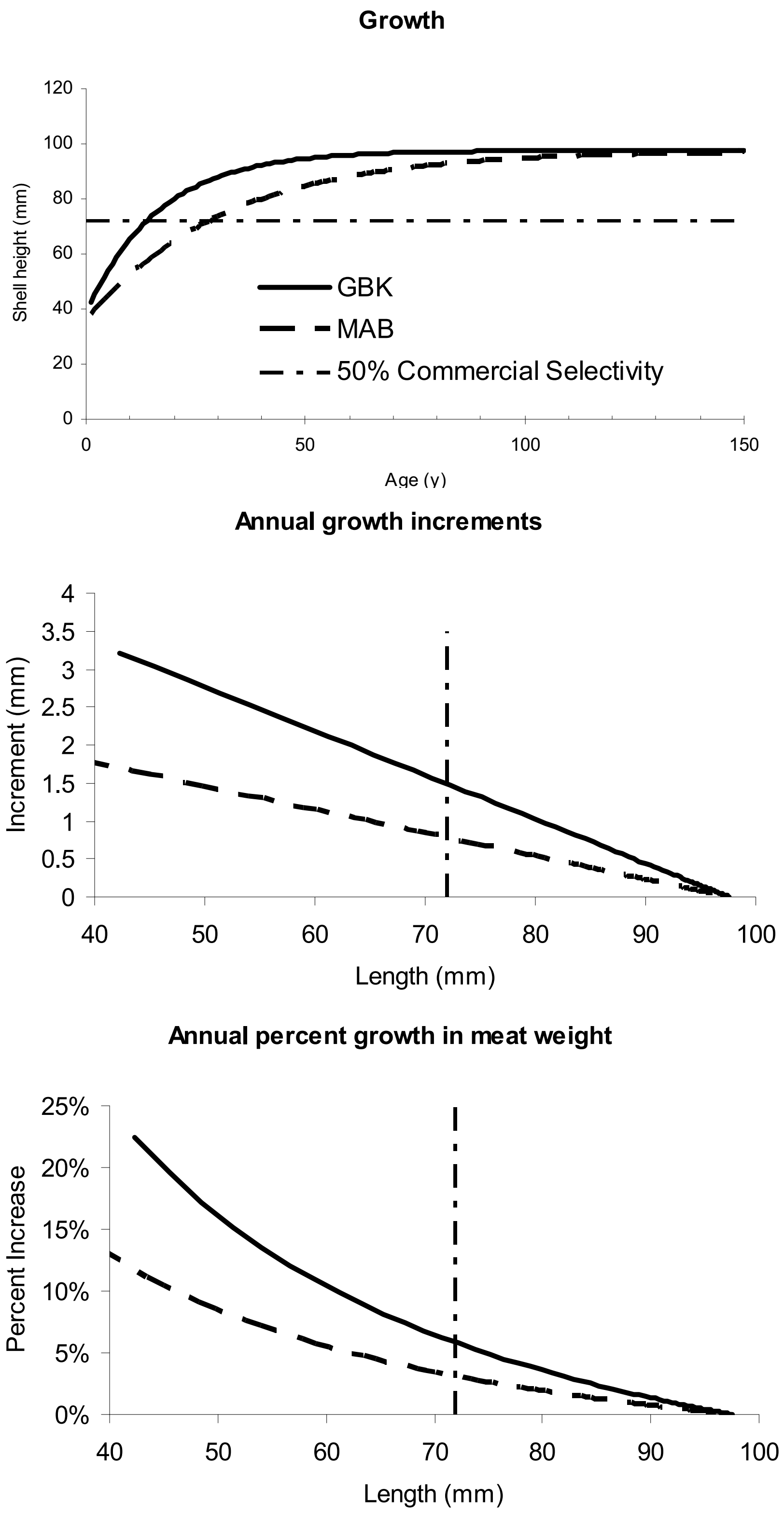


Figure A56. Growth, annual growth increments and percent annual change in meat weights for ocean quahog in GBK and in the Mid-Atlantic Bight (MAB) based on von Bertalanffy growth curves. The growth curve for GBK is from Lewis et al. (2001). The growth curve for MAB is used in this assessment for the fishable ocean quahog stock (which excludes GBK).

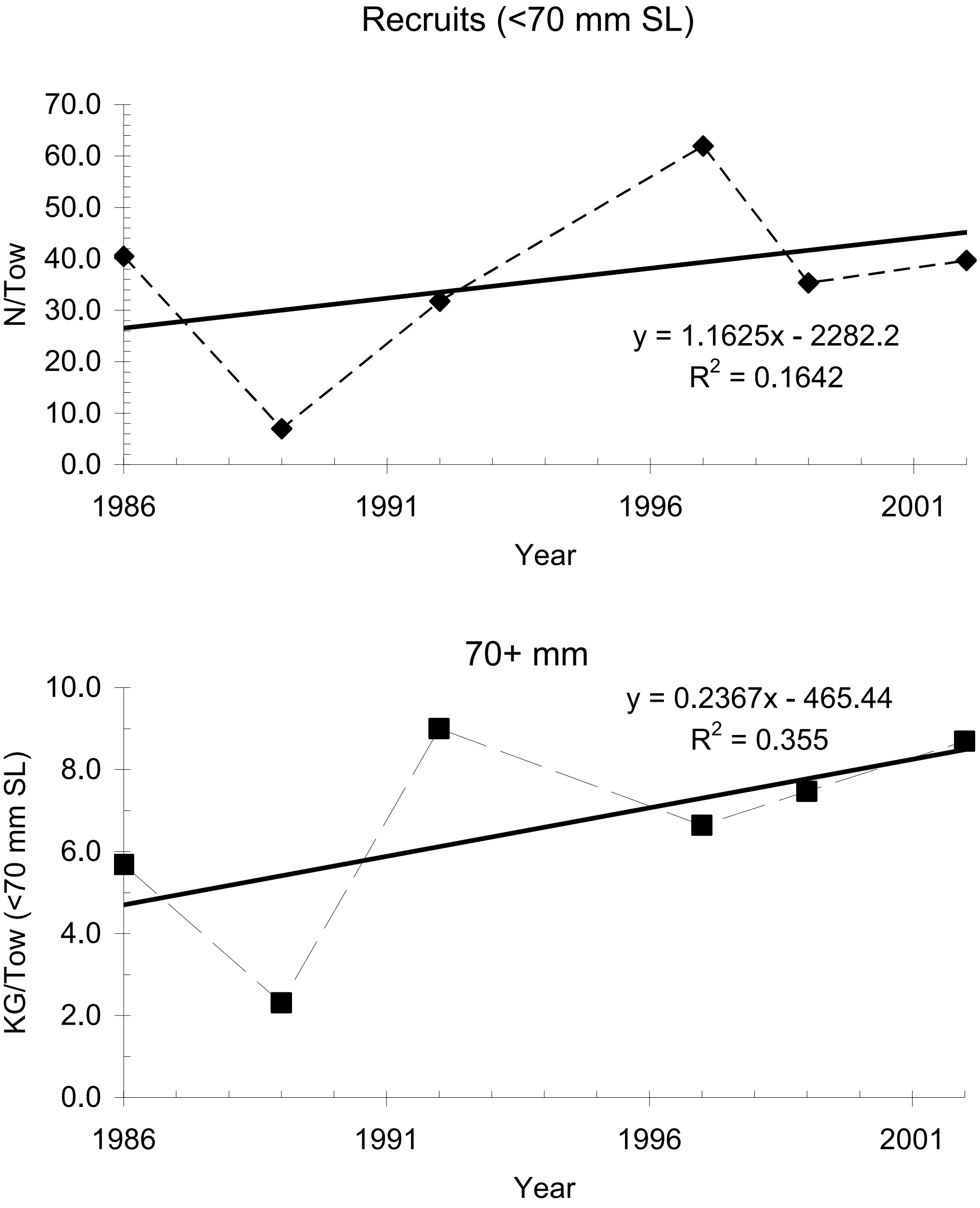


Figure A57. Trends in survey biomass (no correction for selectivity) for ocean quahog from NEFSC clam surveys during 1986-2002 (1994 omitted due to high pump voltage).

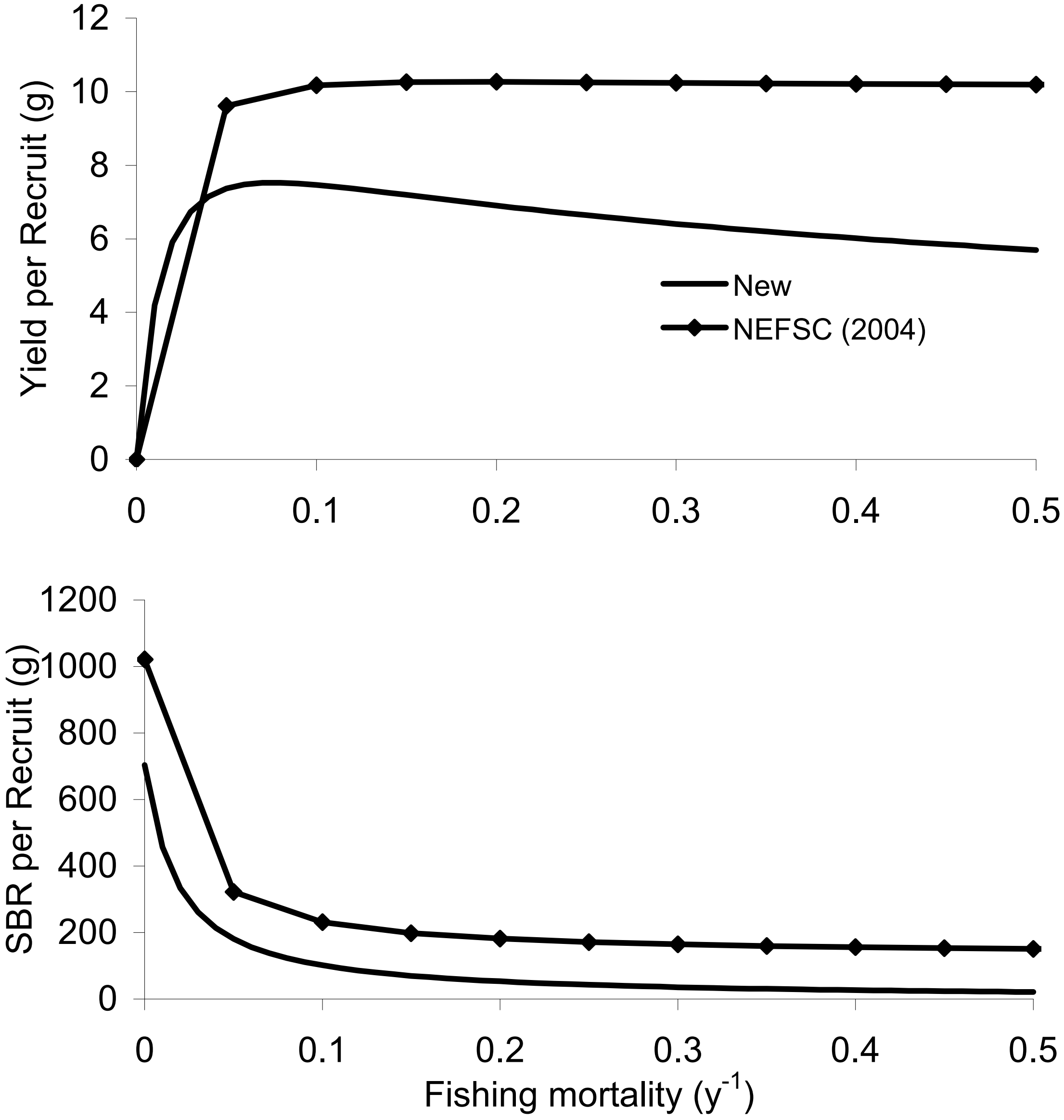


Figure A58. Per recruit model results from a new length based per recruit model and from NEFSC (2004).

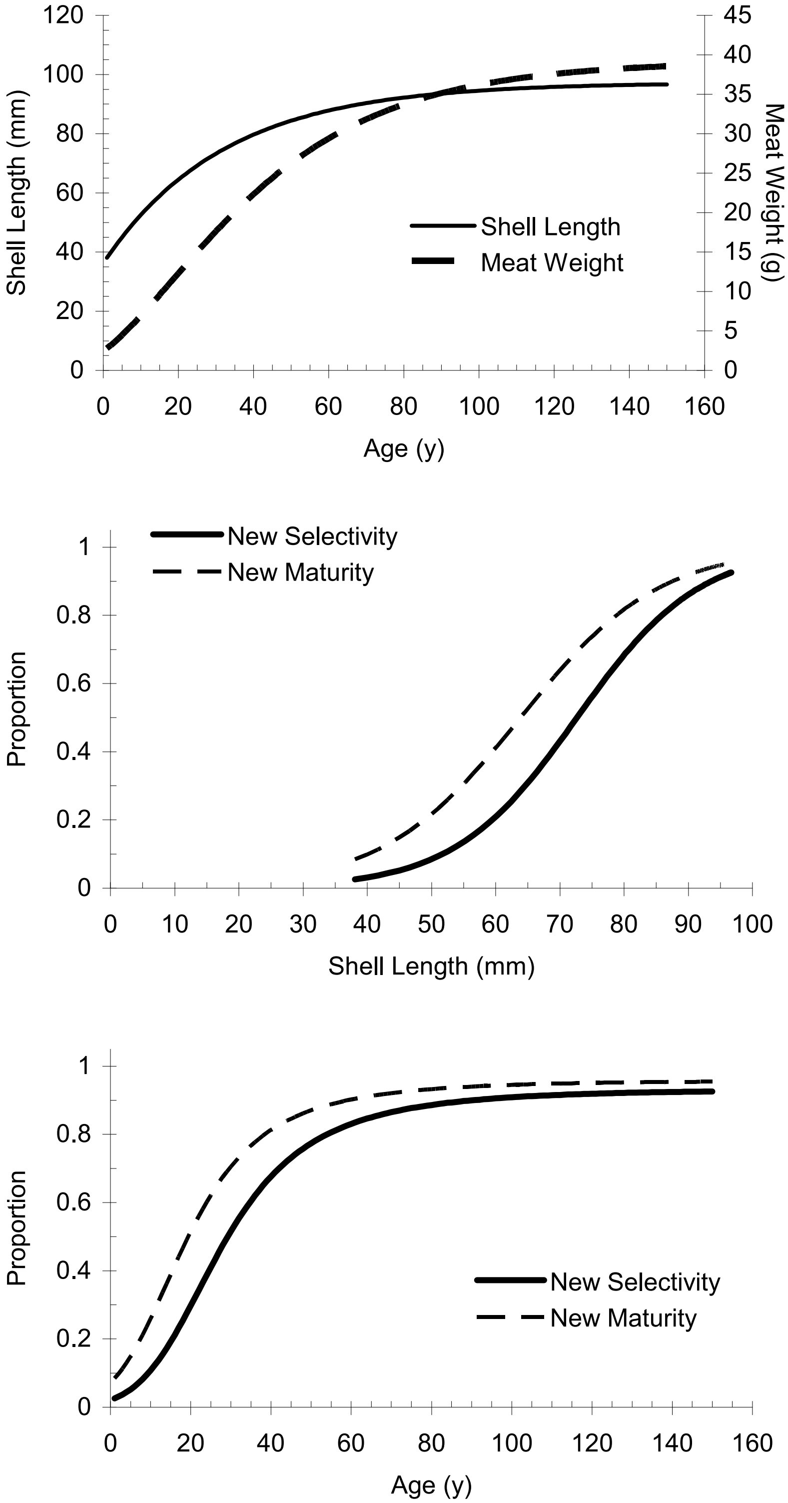


Figure A59. Growth, maturity and fishery selectivity curves used in length-based per recruit model used to calculate biological reference points for ocean quahog. Maturity and selectivity (originally functions of length, middle panel) were expressed as functions of age (bottom panel) by inverting the growth curve.

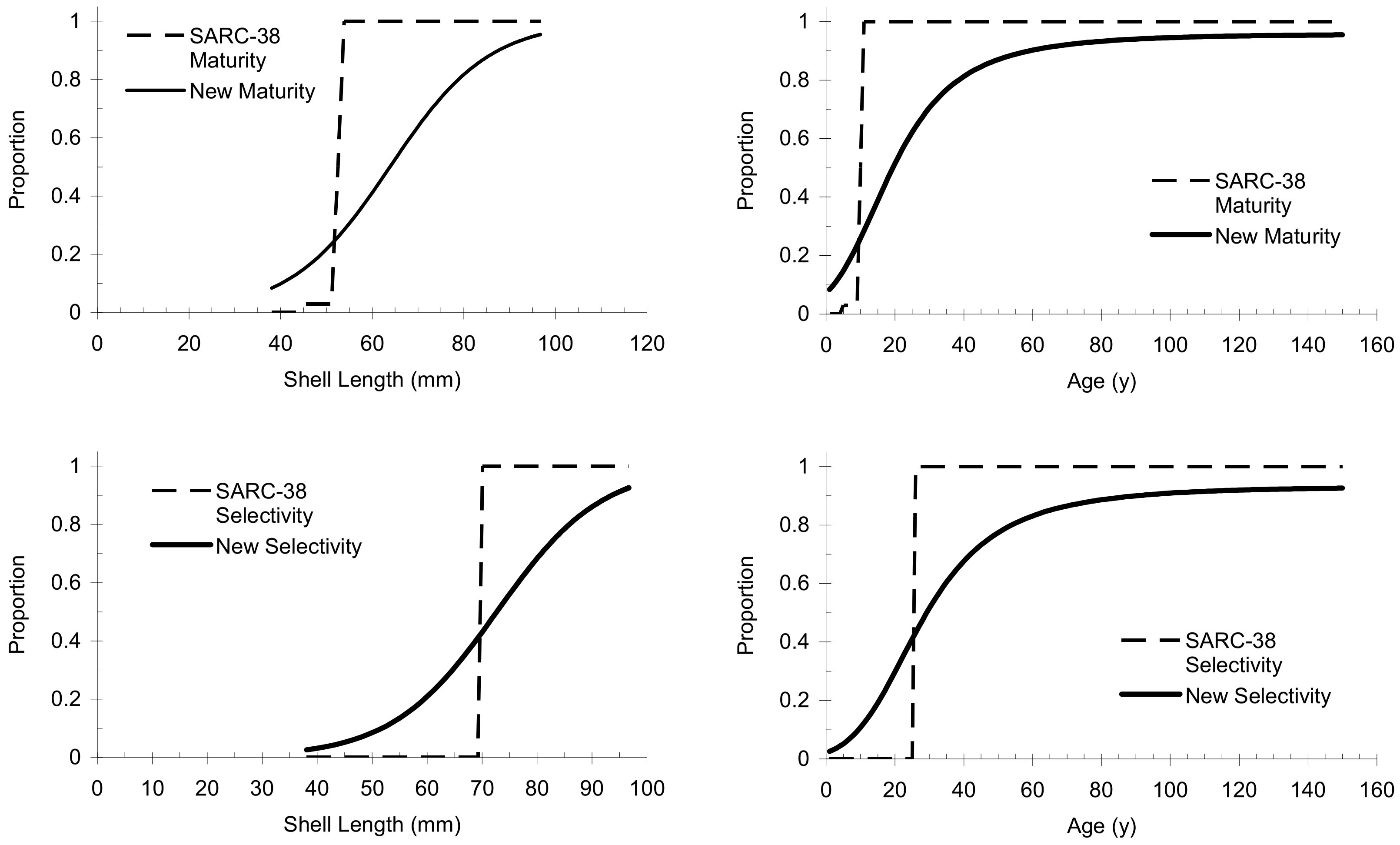
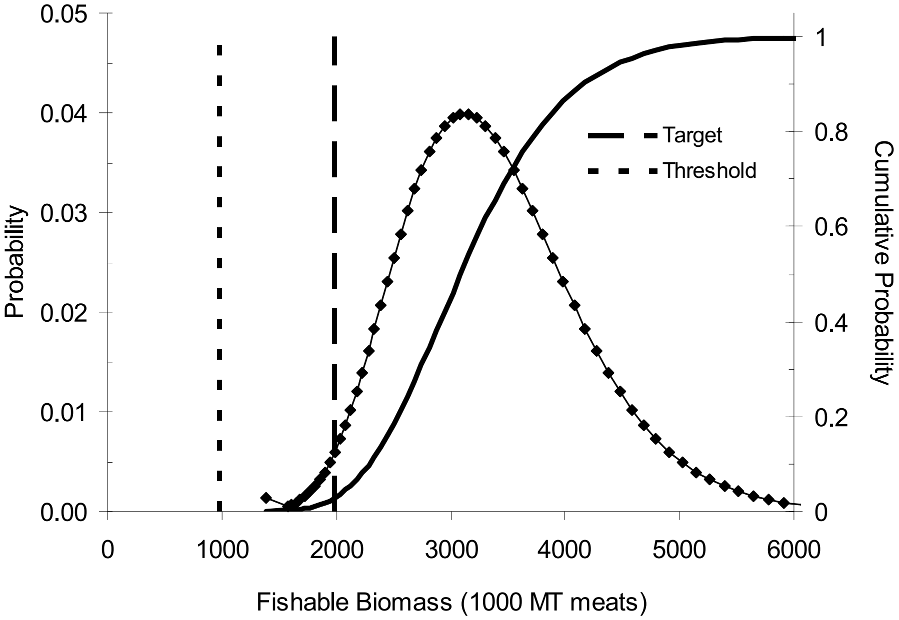


Figure A60. New and old (SARC-38 in NEFSC 2004) maturity and fishery selectivity curves used in per recruit models for ocean quahog.



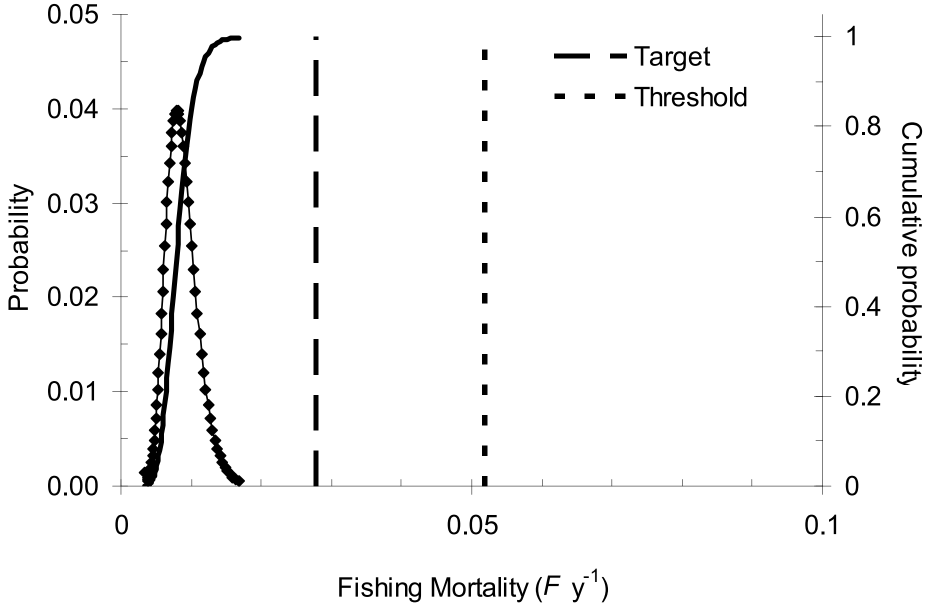


Figure A61. Best estimates of fishable ocean quahog biomass for the entire ocean quahog stock (top) and fishing mortality for the exploitable stock (excluding GBK) during 2005, with confidence intervals and reference points. The confidence intervals are approximate and based on the CV for the efficiency corrected swept-area biomass estimates for 2005.

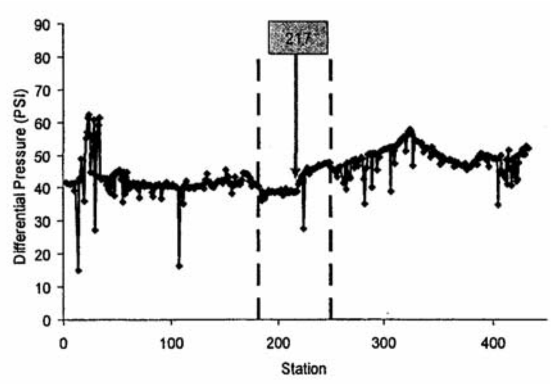
OCEAN QUAHOG APPENDICES

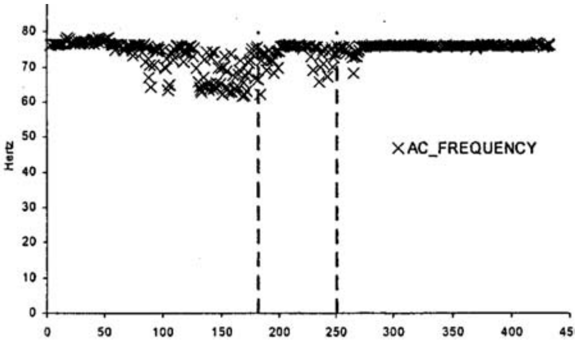
APPENDIX A1. Survey sensor package data from the 2005 NEFSC clam survey. Differential pressure and other data were analyzed to determine if the pump on the survey dredge performed as expected.

R/V Delaware II Clam Dredge Pump Performance[7]

Introduction

From an initial review of the Survey Sensor Pack (SSP) data, the dredge pump manifold differential pressure showed a significant variation over the course of the survey's three cruise legs (See Figure 1). This variation was sporadic during the first survey leg with the pressure spikes being attributed to blocked manifold nozzles from visual inspections at the dredge's retrieval. This however, can not explain the consistent upward trend in the manifold differential pressure starting in the middle of the 2nd survey cruise leg which continued to the middle of the 3rd leg with a then subsequent small falling trend towards the end of the survey. The numerous and sporadic pressure drop spikes that were also noted were not readily explainable by any events that occurred during the survey cruise.





Appendix A1. Figure 1 - SSP Manifold Differential Pressure   Figure 2 - AC Pump Frequency

It was also noted that the frequency recorded also showed a large variation during the ends of the 1st and 2nd survey legs and was consistently higher than the 60 hertz that should have been expected (See Figure 2).

An overheated wire connection on the clam survey package's main breaker was discovered during station 217's tow and temporarily repaired for the remainder of the 2nd survey leg. The clam survey package's main breaker was replaced at the completion of the 2nd survey leg.

To first investigate these anomalies, a visual inspection of the clam survey sensor data plots for all of the survey tows was done. In particular the Y-Tilt (dredge angle), Manifold Differential Pressure, Pump AC Amps/Volts/Frequency, and Vessel Speed were reviewed. Each tow was graded in an Excel worksheet to summarize the basic characteristics as noted below.

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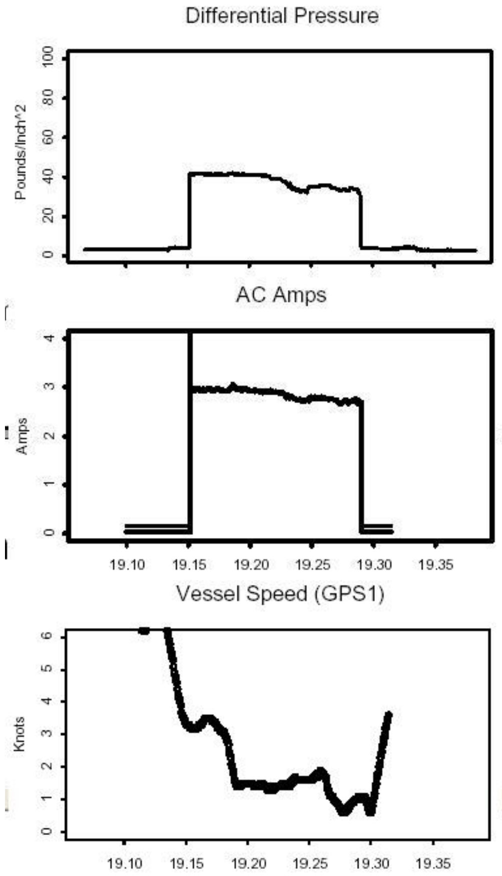
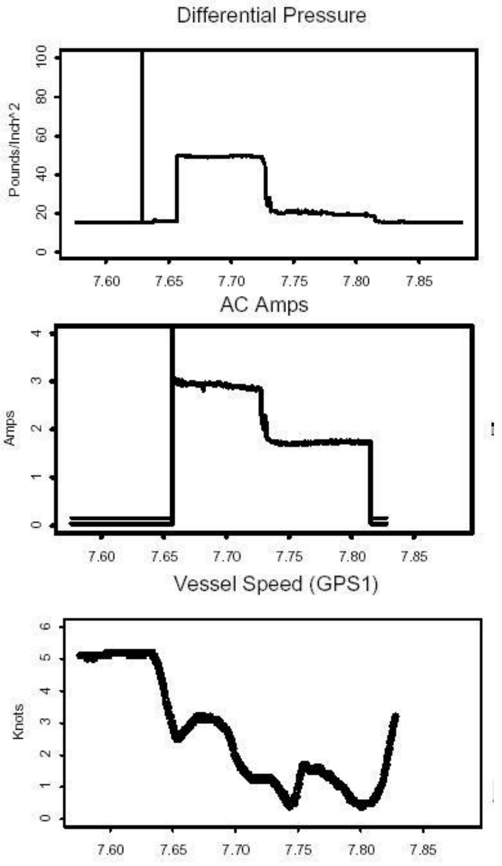
[7] Prepared by John Womack, Wallace and Associates, Ltd.

- Good/Bad Tow or Missing Sensor Data
- Approximate Manifold Differential Pressure
- Manifold Clogging or Pump Intake Blockage
- Erratic Dredge Angle (Y-Tilt); Front Middle, and End of Tow
- Dredge Pump Frequency; Front Middle, and End of Tow
- Tow Speed; Front Middle, and End of Tow
- Did a Low Speed Spike Occur (Tow speed < ½ knot)?

The first discovery is the explanation the sporadic pressure drop spikes in the manifold differential pressure. These pressure drop spikes are likely being caused by a temporary blockage of the pumps intake or the pump ingesting the discharge from the dredge manifold which somehow disrupts the pump's intake flow.





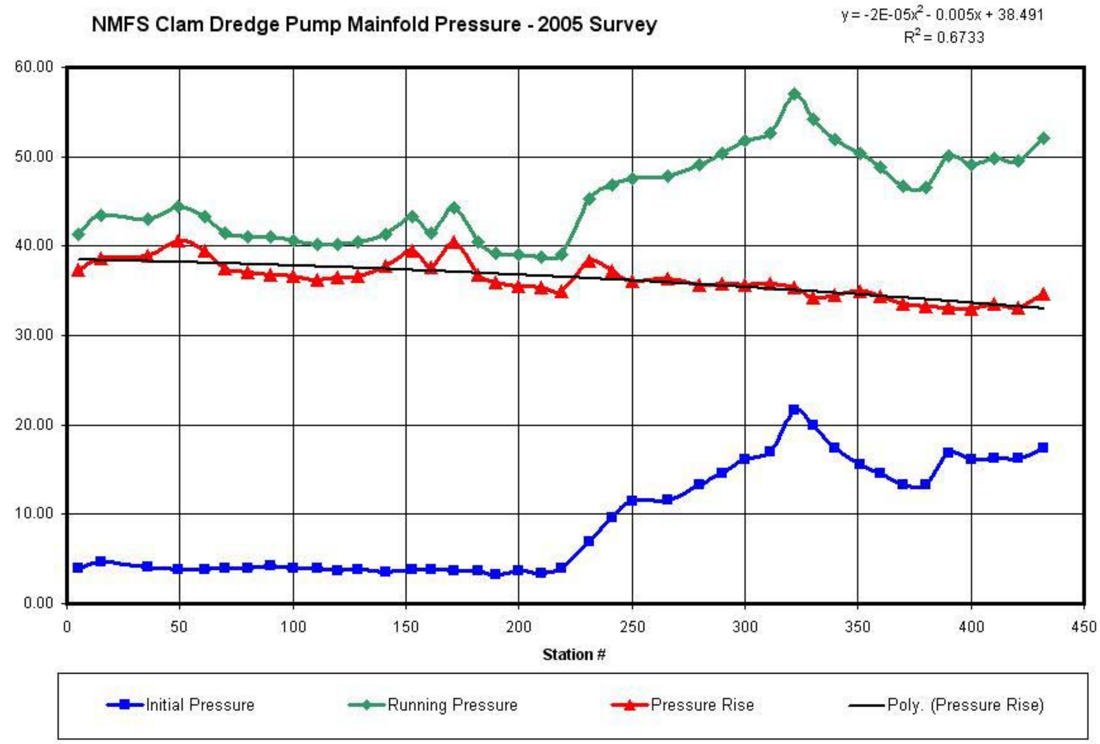
Appendix A1. Figure 3 - Station #71 Tow

Figure 4 - Station #405 Tow

Figure 3 shows a typical tow where this pump intake blockage has likely occurred. Note that there is a corresponding drop in the dredge pump's amps draw as the manifold pressure drops. This is typical for a centrifugal style pump such as is on the clam dredge. The drop in pressure could be minor as in Figure 3 or very substantial as shown in Figure 4. Figure 4 is likely an example of the pump ingesting the manifold discharge as it occurred when a very low speed spike, less than 1/2 knots, also occurred.

The visual inspection of the senor plots also revealed the likely cause for the variation in the general trend of the pump manifold pressure. Using Figures 3 and 4, note that the differential pressures recorded before the pump was started were significantly different. For Figure 3 the starting value is about 5 PSI and for Figure 4 the value is about 15 PSI, a significant difference. Based on this, the following sensor values were graphed on a 10 station interval (those stations with obvious problems were ignored and the next nearest good station was selected, see Figure 5).

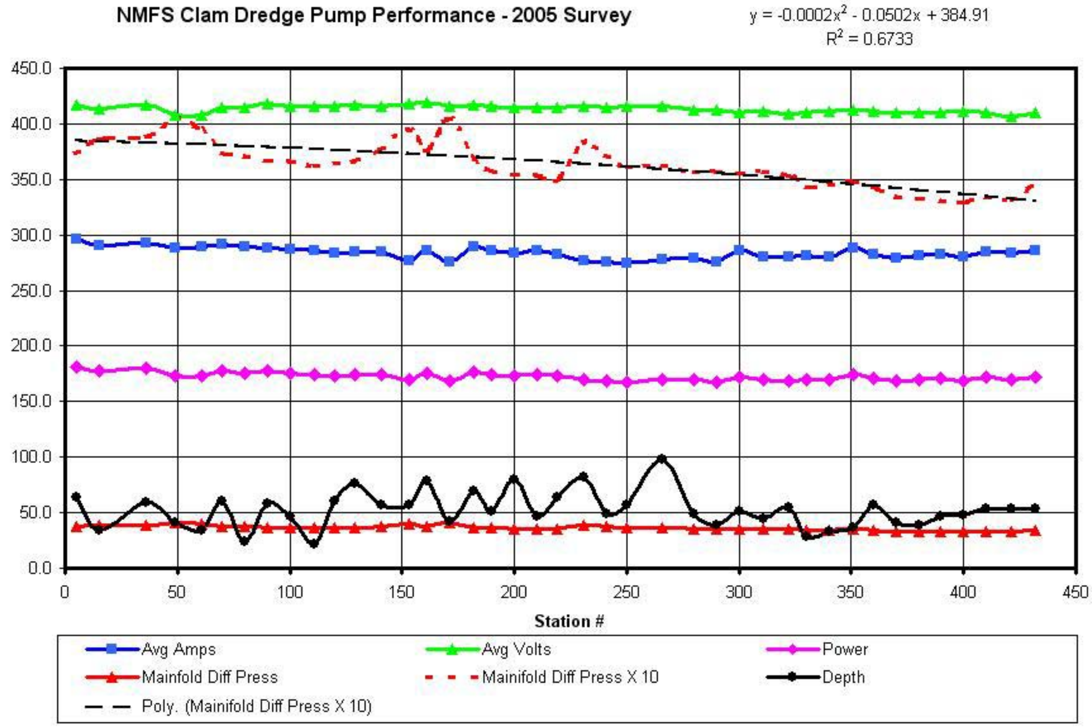
Manifold Differential Pressure Before Starting the Dredge Pump.
Manifold Differential Pressure After Starting the Dredge Pump.
Difference Between the After and Before Starting Values (Pump Pressure Rise)



Appendix A1. Figure 5

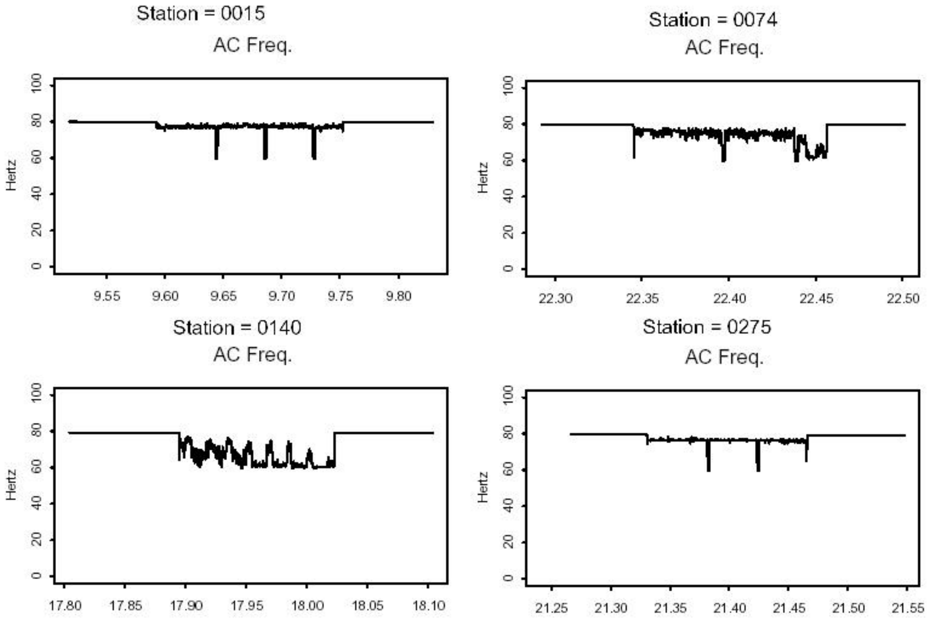
From Figure 5 the pressure rise in the dredge pump manifold is fairly steady with a consistent downward trend that is typical of a centrifugal pump becoming worn from sand/silt ingestion over the survey. The spikes at stations 49, 153, 171, and 231 are likely due to minor clogging of the manifold nozzles as there is a corresponding drop in the amps draw from the pump. This is shown in Figure 6 which also graphs the amps draw, AC voltage, pump power, and tow depth.

Based on this the conclusion is the general performance of the clam dredge pump was fairly uniform over the entire survey and the previous noted variations in the manifold differential pressure are likely due to a calibration drift in the SSP sensor. Interestingly this drift starts to occur at about station 217, which is when the problem with the main clam package breaker was noticed and repaired. How the breaker problem could cause a sensor drift is not known as the SSP package uses an internal DC battery completely separate from the AC system containing the clam package breaker.



Appendix A1. Figure 6

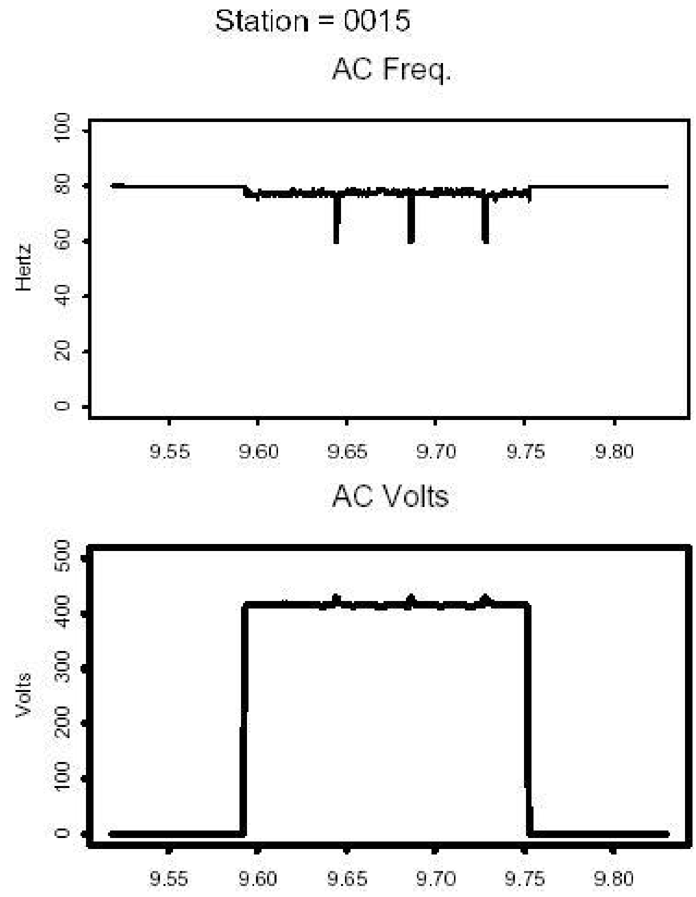
The variation that occurred in the recorded frequency remains a mystery even after the review of the sensor plots and conversations with the ship's engineer. The value should be very steady and between 59 and 61 hertz which is the output from the ship's generator. Figure 7 shows the typical variation in frequency that occurred during the survey.



Appendix A1. Figure 7

The frequency was fairly steady at the start of the survey, and then started a gradual degradation during the last half of the survey's first leg. This degradation in recorded values was not consistent with wide variations between tows. Shortly after the start of the 3rd leg at about station 271, the problem appears to have cleared itself and the frequency was very steady for the remainder of the survey. While there is no direct explanation for this change, it does not to appear to have had any effect on the performance of the clam dredge. The hertz values seen by the pump during the survey are likely have to been the steady standard 59 to 61 hertz values shown on the ship's main switchboard. The changes are likely a problem is in the calibration of the sensor for the frequency not being at 60 hertz and some type of sensor interference for the variations experienced.

The last observation from the sensor plots and data is the occurrence of a rhythmic spike in the AC frequency and volts sensor plots. This occurred throughout the entire survey and a typical example is shown in Figure 8. As with the frequency variation discussed above this appears to be a sensor problem. First it is impossible for a generator to vary its speed as would be shown in the frequency plot. In addition there is no corresponding spikes in the amps or pump pressure that should occur if the volts were truly spiking.



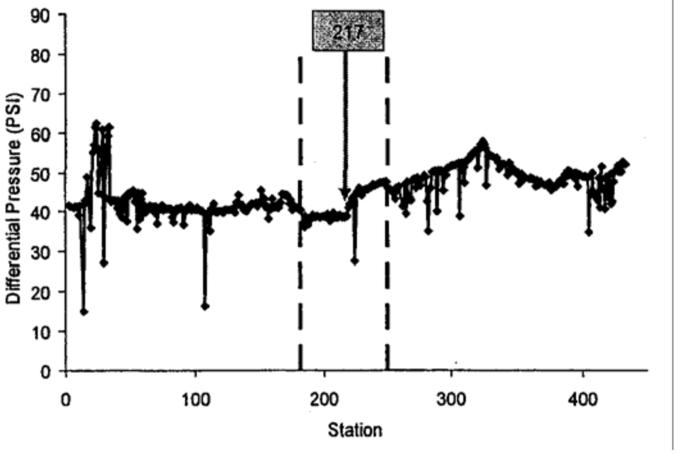
Appendix A1. Figure 8

APPENDIX A2. Clam survey tows with poor performance. This appendix describes a proposal for using sensor data to identify NEFSC clam survey tows with poor performance. Current criteria for identifying tows with poor performance are based on data recorded on deck by the watch chief after each tow. In particular, the survey variable "HAUL" can be used to describe problems with tow duration, and the survey variable "GEARCOND" describes the condition of the dredge after a tow. The proposal described below uses sensor data collected on the dredge and on board the ship. Sensor based criteria could not be applied to data for surveys before 1997 because sensors were not used on the ship. The proposal is for discussion and review and does not represent a recommendation by the Invertebrate Subcommittee.

NMFS R/V Delaware II Clam Survey Dredge Development of Good/Bad Tow Selection Criteria[8]

Introduction

From a review of the Survey Sensor Pack (SSP) data from the NMFS 2005 Surf Clam and Ocean Quahog survey, the survey dredge's basic parameters showed a significant variation in the over the course of the survey's three cruise legs. This was primarily both a general upward trend in the manifold's differential pressure and sporadic pressure spikes over the survey (see figure 1). In addition there were occasionally tows that experienced significant variations in the dredge's fore and aft towing angle.



Appendix A2. Figure 1 - Average Survey Dredge Manifold Pressure vs. Survey Station Number

From a previous report (Appendix A2), these parameter variations were explored and their potential effect on the survey dredge's sampling efficiency reviewed. The general upward manifold pressure trend was attributed to a sensor calibration drift, not a true change in manifold pressure, and thus had no likely affect on the dredge's efficiency. The survey tows with manifold pressure spikes and the variations in the dredge's towing angle however were likely causing a significant change in the dredge's sampling efficiency, with the most extreme cases probably preventing the dredge from fishing at all.

Since these survey tows with the manifold pressure spikes and the towing angle variations have a significantly different, and unknown, sampling efficiency than the survey's overall efficiency determined by the depletion studies and other methods,

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[8] Prepared by John Womack, Wallace and Associates, Inc.

inclusion of them in the survey will likely create a bias in the final survey results. Because of this, those survey tows that have some of their key parameters that differ significantly from the normal values should be excluded from the survey as “bad” tows.

Key Dredge Performance Parameters

The following general parameters are recorded from the SSP and onboard ship sensors for each of the NMFS clam dredge’s survey tows.

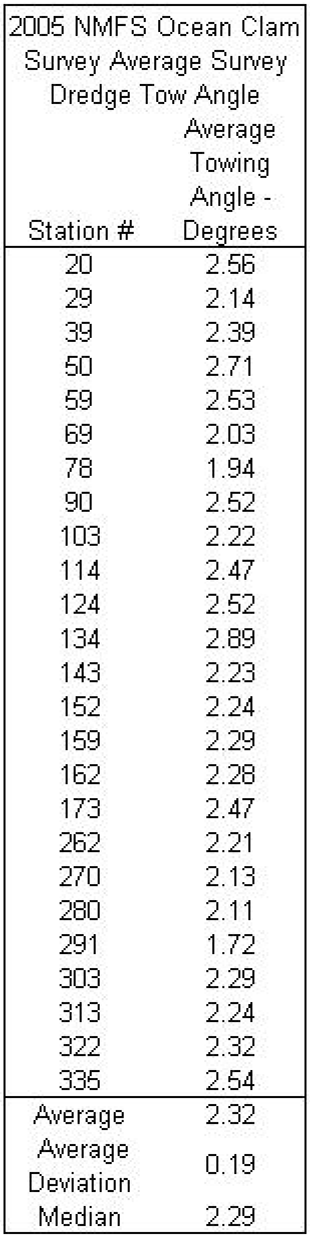
Tilt-X - Side to side dredge angle.
Tilt-Y - Fore and aft dredge towing angle.
SSP Ambient Temperature - Sea water temperature at the dredge.
SSP Ambient Pressure - Ambient sea water pressure at the dredge (depth).
Differential Pressure - Dredge’s water manifold deferential pressure.
AC Amps - Dredge pump’s amperage draw.
AC Volts - Dredge pump’s voltage.
AC Freq - Dredge pump’s frequency.
Vessel Speed - Speed of the DEII

Of these parameters, the two key ones for the dredge’s sampling efficiency are;

Tilt-Y - Fore and aft dredge towing angle.
Differential Pressure - Dredge’s water manifold differential pressure.

Both of these are the parameters that are directly associated with how the dredge fishes. The Tilt-Y parameter will indicate if the dredge’s knife is in sufficient contact with the sea bottom to be in a fishing position. The Differential Pressure indicates if sufficient water is being forced through the dredge’s manifold to adequately liquefy the sea bottom.

The AC Amps, AC Volts, and AC Freq are not key parameters as any changes in them will be reflected in the manifold Differential Pressure values. Similarly, Vessel Speed is also not a key parameter in determining a good or bad tow. In this case any vessel speed variations (and thus the survey dredge) are handled in the standardization of each tow to a set “standard” tow distance. SSP Ambient Temperature and Pressure are not key parameters, as they have no effect on overall dredge performance.



2005 NMFS Ocean Clam Survey Average Survey Dredge Tow Angle

Station #	Average Towing Angle - Degrees
20	2.56
29	2.14
39	2.39
50	2.71
59	2.53
69	2.03
78	1.94
90	2.52
103	2.22
114	2.47
124	2.52
134	2.89
143	2.23
152	2.24
159	2.29
162	2.28
173	2.47
262	2.21
270	2.13
280	2.11
291	1.72
303	2.29
313	2.24
322	2.32
335	2.54
Average	2.32
Average Deviation	0.19
Median	2.29

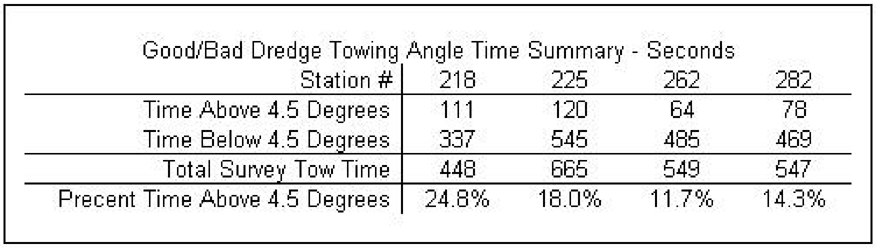
The Tilt-Y and Manifold Pressure parameters will each be handled separately, but with a similar method, in determining a good or bad survey tow. A bad tow would then occur when either parameter varies by a specified difference from their normal values.

Good/Bad Tow Tilt-Y Selection Criteria

The Tilt-Y parameter is a fixed fishing, not fishing (i.e. pass/fail) situation. From previous studies of the NMFS survey dredge the knife theoretically makes contact with the bottom at 4.4 degrees and is fully down at 0 degrees, referenced to the dredge side runners. For the selection criteria the pass/fail cutout was set at the mid point of 2.2 degrees when the knife is at its half fishing depth in the sea bottom.

The dredge however does not tow with the side runners level as the aft end of the dredge will settle into the trough created in the ocean bottom by the water manifold while the forward dredge end rides on the bottom surface. From the table above this angle is approximately 2.3 degrees. This angle needs to be added to the 2.2 degree pass/fail point above to adjust for the dredge towing angle from the SSP data, which gives an adjusted pass/fail point of 4.5 degrees.

To use this set point, the SSP data will be evaluated by first calculating the total time the dredge Tilt-Y towing angle is above the 4.5 degree set point versus the total time the dredge was on the bottom. The tow will be deemed a bad tow if this time equals or exceeds 20% of the total towing time. For the four quahog strata survey stations deemed as a bad tow, the resultant time values using the 4.5 degree set point are tabulated below. Based on these Tilt-Y criteria, Station 218 is considered to be a bad tow and should be removed from the survey.



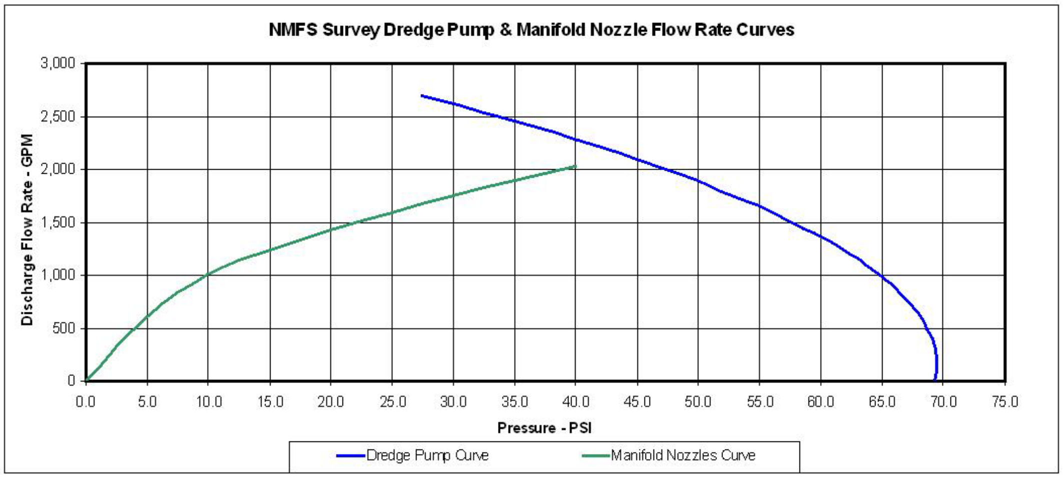
Good/Bad Dredge Towing Angle Time Summary - Seconds

Station #	218	225	262	282
Time Above 4.5 Degrees	111	120	64	78
Time Below 4.5 Degrees	337	545	485	469
Total Survey Tow Time	448	665	549	547
Precent Time Above 4.5 Degrees	24.8%	18.0%	11.7%	14.3%

Good/Bad Tow Manifold Pressure Selection Criteria

While the Tilt-Y parameter could be handled as a “Knife Edged” pass/fail selection criteria, this will not work for the Manifold Pressure parameter. First there are two different problem modes that can occur, a manifold pressure above or below the normal value. In addition a linear variation in the pressure doesn’t correspond into a linear variation in the water flow through the nozzles.

When the manifold pressure drops below the normal value (37-39 PSI), this is indicating a blocked pump intake which is restricting water flow through the manifold nozzles. A manifold pressure increase on the hand is indicating a blockage in the manifold and/or nozzles. This blockage though is also restricting the water flow through the manifold nozzles. These variations in water flow versus manifold pressure are shown in the graph below.



Because of this non-linearity, the good/bad selection criteria for the Manifold Pressure parameter will need to take into account the magnitude of the difference from normal values. That is the farther the Manifold Pressure value at a given time is from the normal value, the larger the influence that time period will have on the tow being declared a bad tow. This will allow for several different bad tow scenarios to be designated. They are.

1) A small increase or decrease in pressure over the entire tow period.
2) A large increase or decrease in pressure over a short portion of a tow.
3) A combination of small or large pressure variations during a tow.

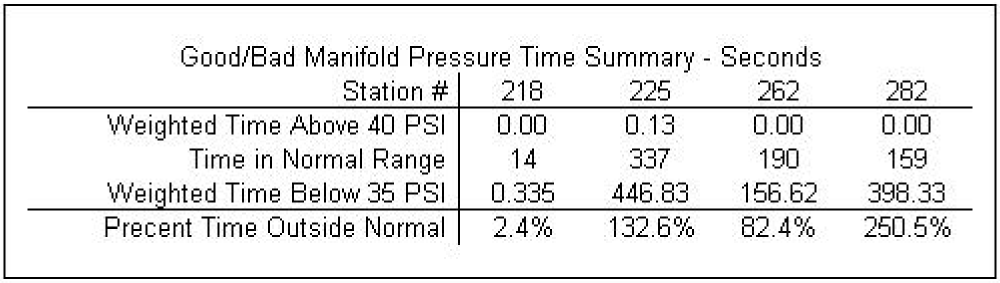
The selection criteria time period weighting factor (WF) for the Manifold Pressure parameter will be formatted using the following formulas.

$WF = 2 \times (MP-40)/40$ when the Manifold Pressure is Higher than Normal or
$WF = 1$ when the Manifold Pressure is in the Normal range or
$WF = 2 \times ((35-MP)/35 \times 0.83)$ when the Manifold Pressure is Lower than Normal
where MP = SSP measured Manifold Pressure in PSI.

The "0.83" is used to bring the potential below value range (0 to 35 PSI) into same magnitude as the potential above value range (40 to 69 PSI or 29 PSI range). An average normal Manifold Pressure value of 35-40 PSI was selected based on previous analysis of the 2005 SSP survey data in "R/V Delaware II Clam Dredge Pump Performance" which showed a range in manifold pressure from 39 PSI at the start to 36 PSI at the end of the survey. The doubling of the difference is used to account for the non-linearity by increasing the weighting factor disproportionably for Manifold Pressures farther from the normal value.

For the SSP data the weighting factor will be calculated for each data point which represents a one second time interval. The weighting factors for each second period will then be added to get a total weighted towing time. A bad tow will be declared when this weighted towing time exceeds the actual towing time that was within the normal range by more then 25%. See sample table below for examples.

Based on these Manifold Pressure criteria, Stations 225, 262, and 282 are considered to be a bad tow and should be removed from the survey.



Good/Bad Manifold Pressure Time Summary - Seconds

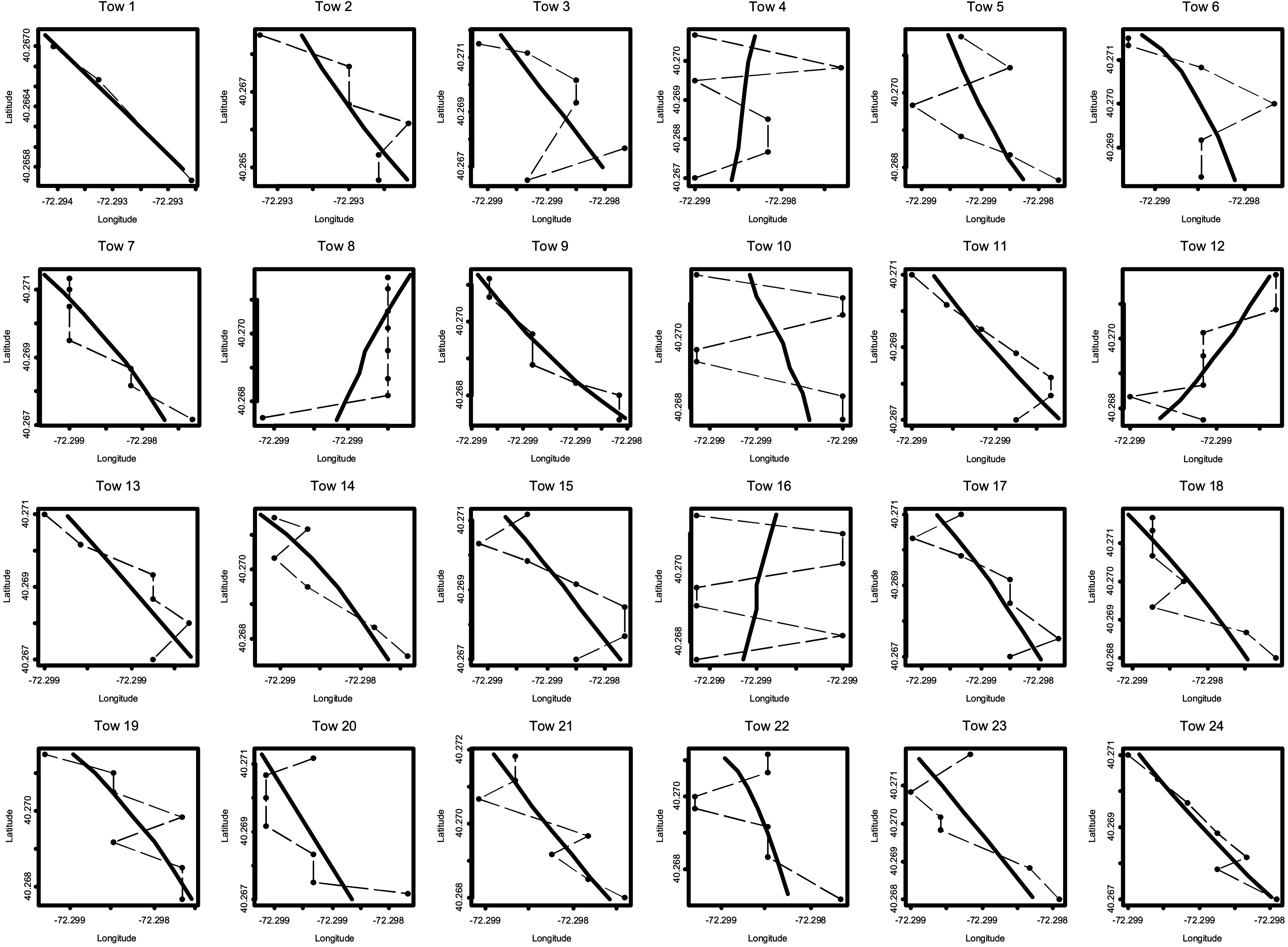
Station #	218	225	262	282
Weighted Time Above 40 PSI	0.00	0.13	0.00	0.00
Time in Normal Range	14	337	190	159
Weighted Time Below 35 PSI	0.335	446.83	156.62	398.33
Precent Time Outside Normal	2.4%	132.6%	82.4%	250.5%

NMFS Clam Survey Dredge - Manifold Pressure Good/Bad Tow Selection Criteria Examples

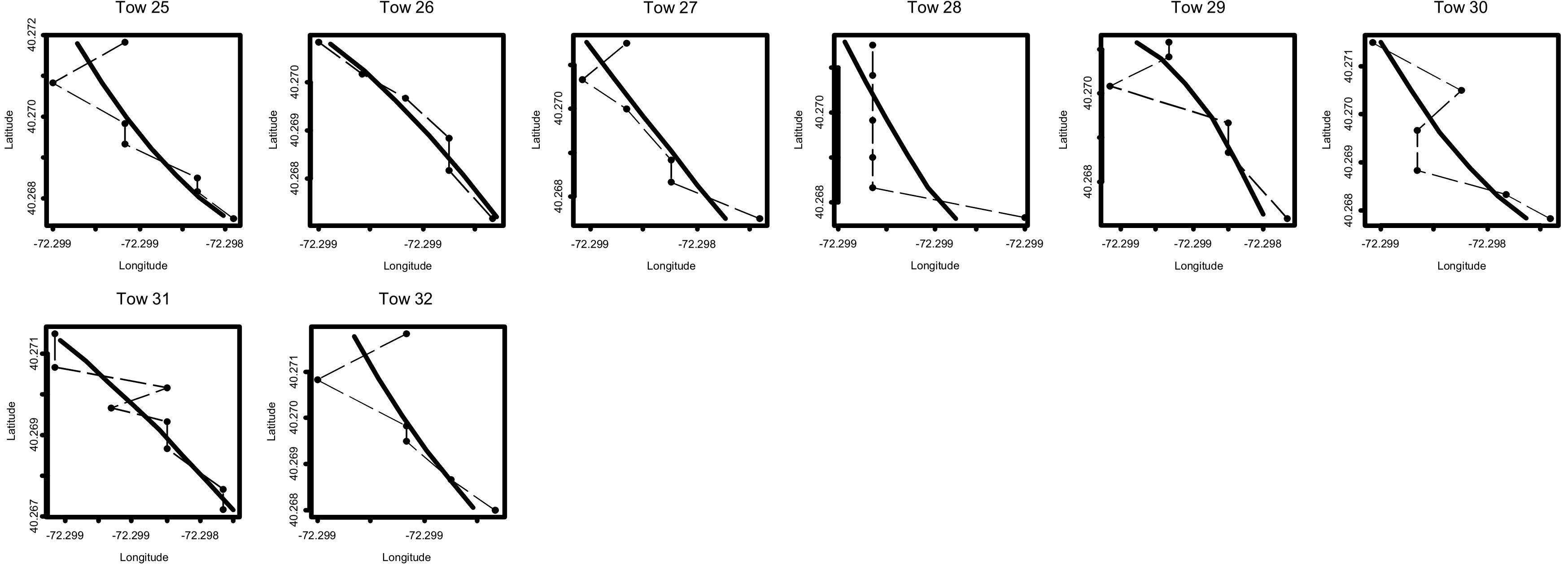
	Good Survey Tow				Bad Tow - Pressure Slightly Abv Normal				Bad Tow - Pressure Slightly Abv Normal				Bad Tow - Pressure Moderatly Abv Normal				Bad Survey Tow - Exterme Pressure Spikes			
Time	Manifold Pressure PSI	Over Range Weighting Factor	In Normal Weighting Factor	Under Range Weighting Factor	Manifold Pressure PSI	Over Range Weighting Factor	In Normal Weighting Factor	Under Range Weighting Factor	Manifold Pressure PSI	Over Range Weighting Factor	In Normal Weighting Factor	Under Range Weighting Factor	Manifold Pressure PSI	Over Range Weighting Factor	In Normal Weighting Factor	Under Range Weighting Factor	Manifold Pressure PSI	Over Range Weighting Factor	In Normal Weighting Factor	Under Range Weighting Factor
1	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
2	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
3	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
4	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	62	1.10	0.00	0.00
5	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	62	1.10	0.00	0.00
6	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	62	1.10	0.00	0.00
7	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	62	1.10	0.00	0.00
8	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	62	1.10	0.00	0.00
9	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	12	0.00	0.00	1.09
10	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	12	0.00	0.00	1.09
11	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	12	0.00	0.00	1.09
12	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	12	0.00	0.00	1.09
13	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	12	0.00	0.00	1.09
14	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	12	0.00	0.00	1.09
15	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
16	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
17	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
18	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
19	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
20	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
21	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
22	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
23	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
24	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
25	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
26	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
27	40	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
28	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
29	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
30	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
31	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
32	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
33	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	45	0.25	0.00	0.00	38	0.00	1.00	0.00
34	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
35	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
36	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
37	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
38	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
39	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
40	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
41	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
42	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
43	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
44	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
45	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
46	38	0.00	1.00	0.00	41	0.05	0.00	0.00	42	0.10	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
47	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
48	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
49	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
50	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
51	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
52	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
53	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
54	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
55	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
56	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
57	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
58	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
59	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
60	38	0.00	1.00	0.00	41	0.05	0.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00	38	0.00	1.00	0.00
60	WF Sums	0.0	60.0	0.0	WF Sums	3.0	0.0	0.0	WF Sums	4.3	17.0	0.0	WF Sums	7.5	30.0	0.0	WF Sums	5.5	49.0	6.5
	% Over+Under of All		0%		% Over+Under of All		100%		% Over+Under of All		25%		% Over+Under of All		25%		% Over+Under of All		25%	

APPENDIX A3. Original and smoothed position data for ocean quahog depletion experiments, during 1997-2005 by tow.

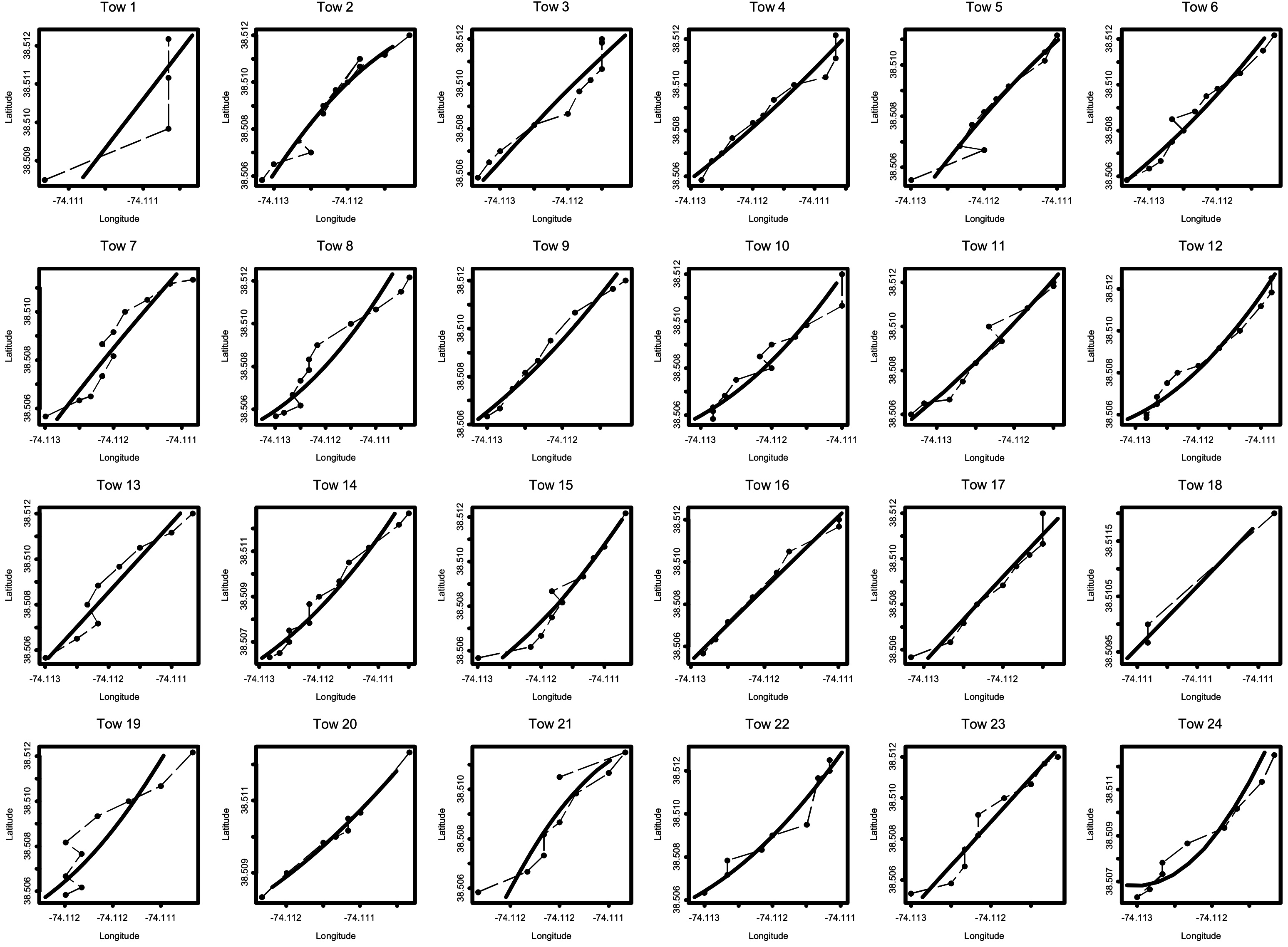
Smoothed Position Data OQ1997-1 (SH-1)



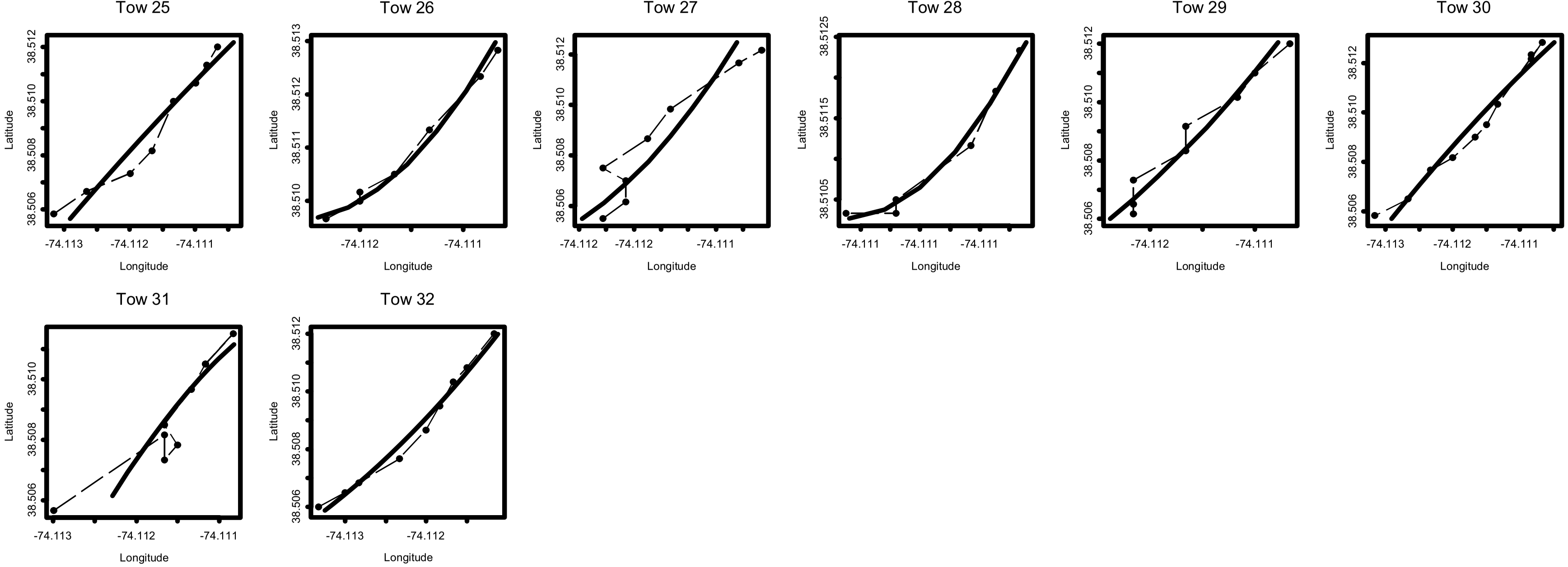
Smoothed Position Data OQ1997-1 (SH-1)



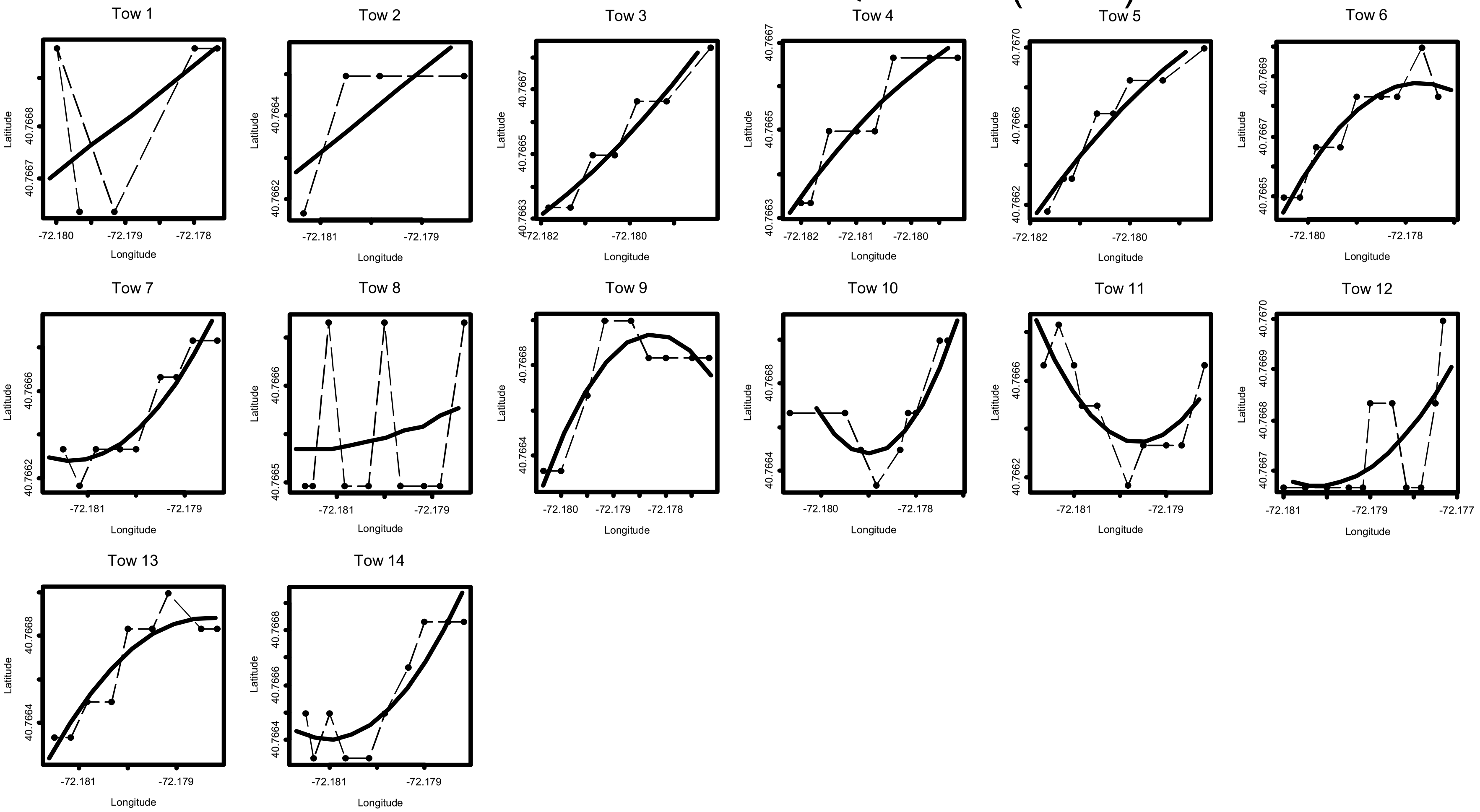
Smoothed Position Data OQ1997-2 (WW-1)



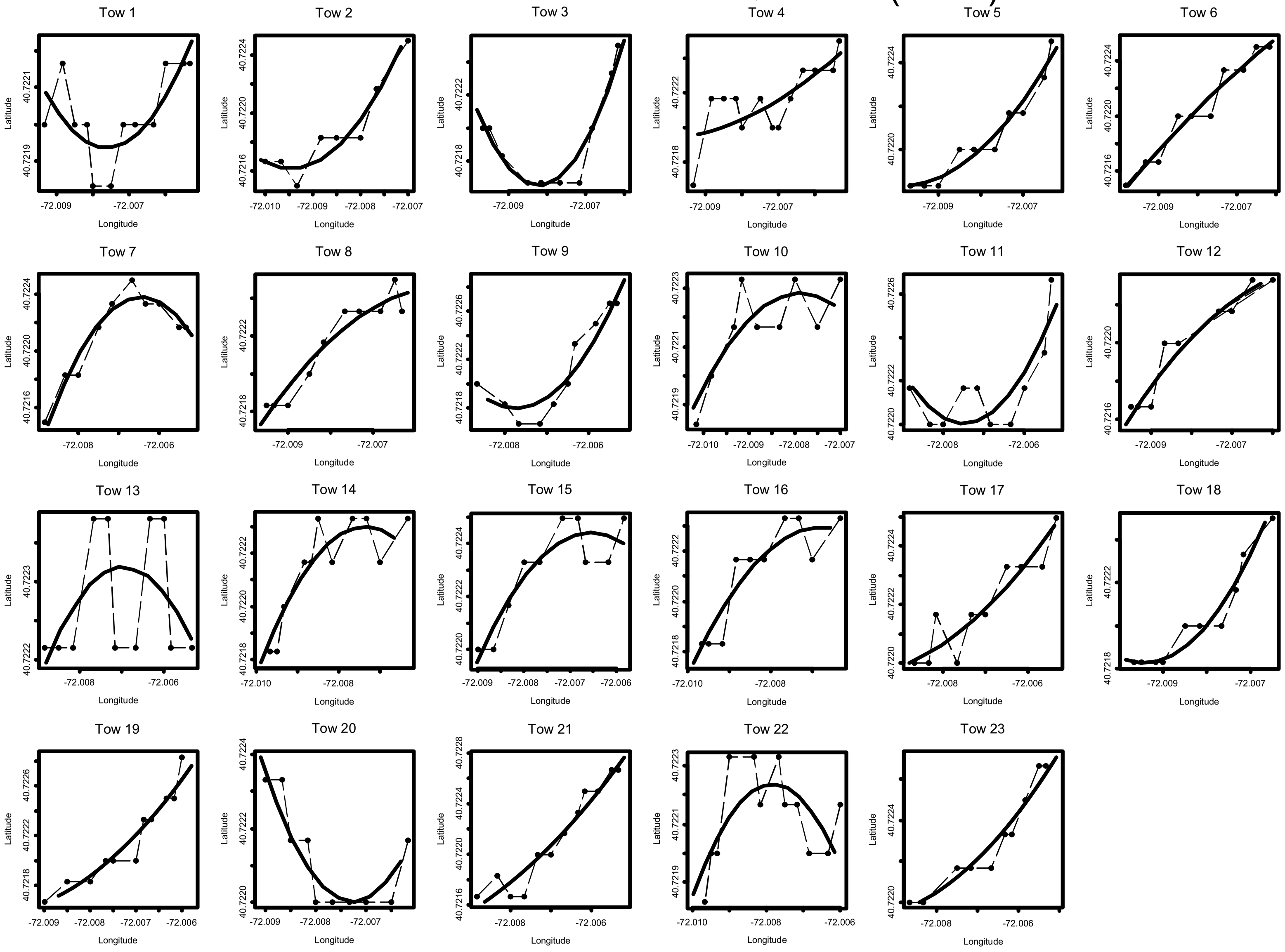
Smoothed Position Data OQ1997-2 (WW-1)


Tow 25
Tow 26
Tow 27
Tow 28
Tow 29
Tow 30
Tow 31
Tow 32

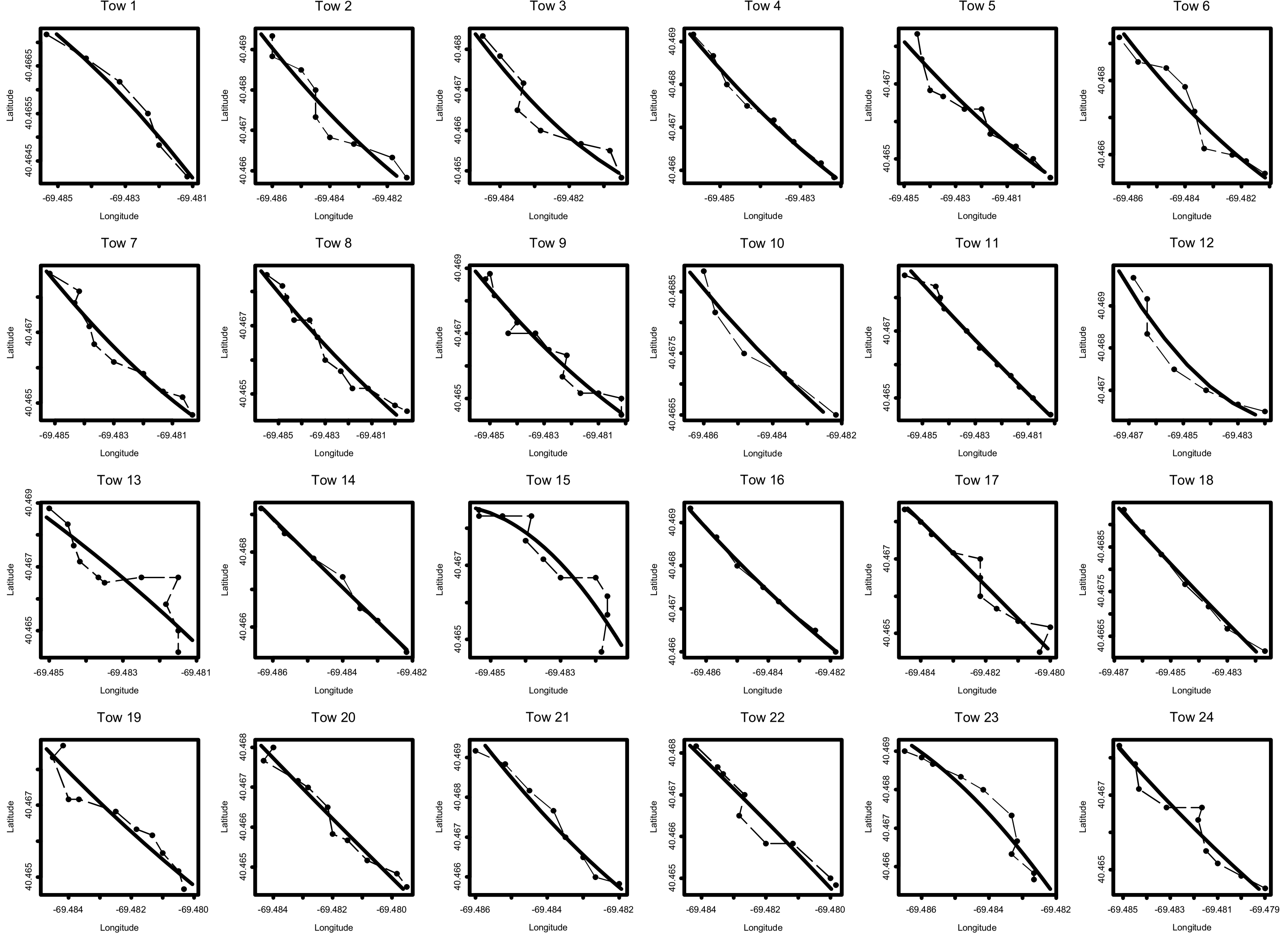
Smoothed Position Data OQ1998-1 (SH-3)



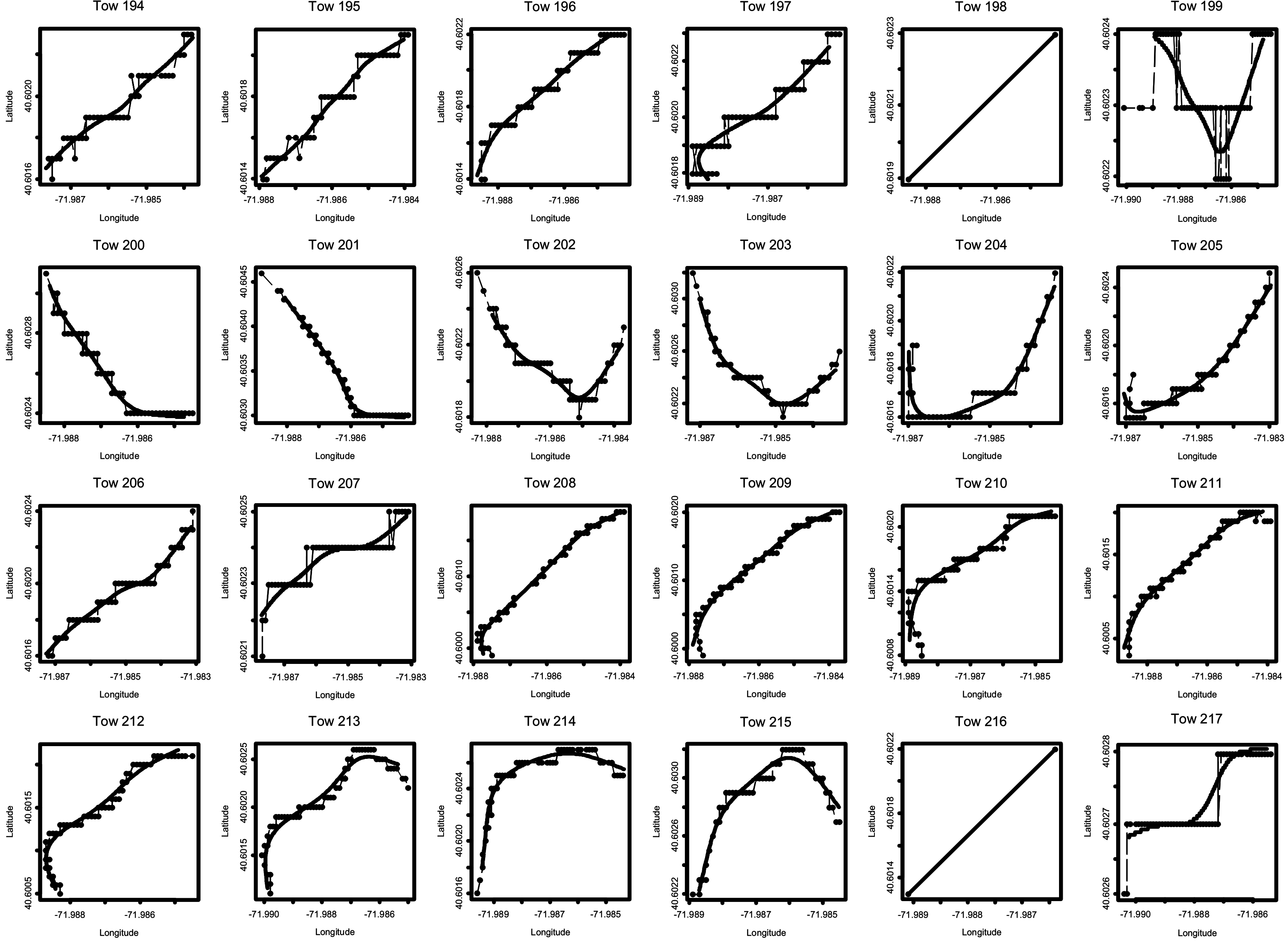
Smoothed Position Data OQ1998-2 (SH-2)



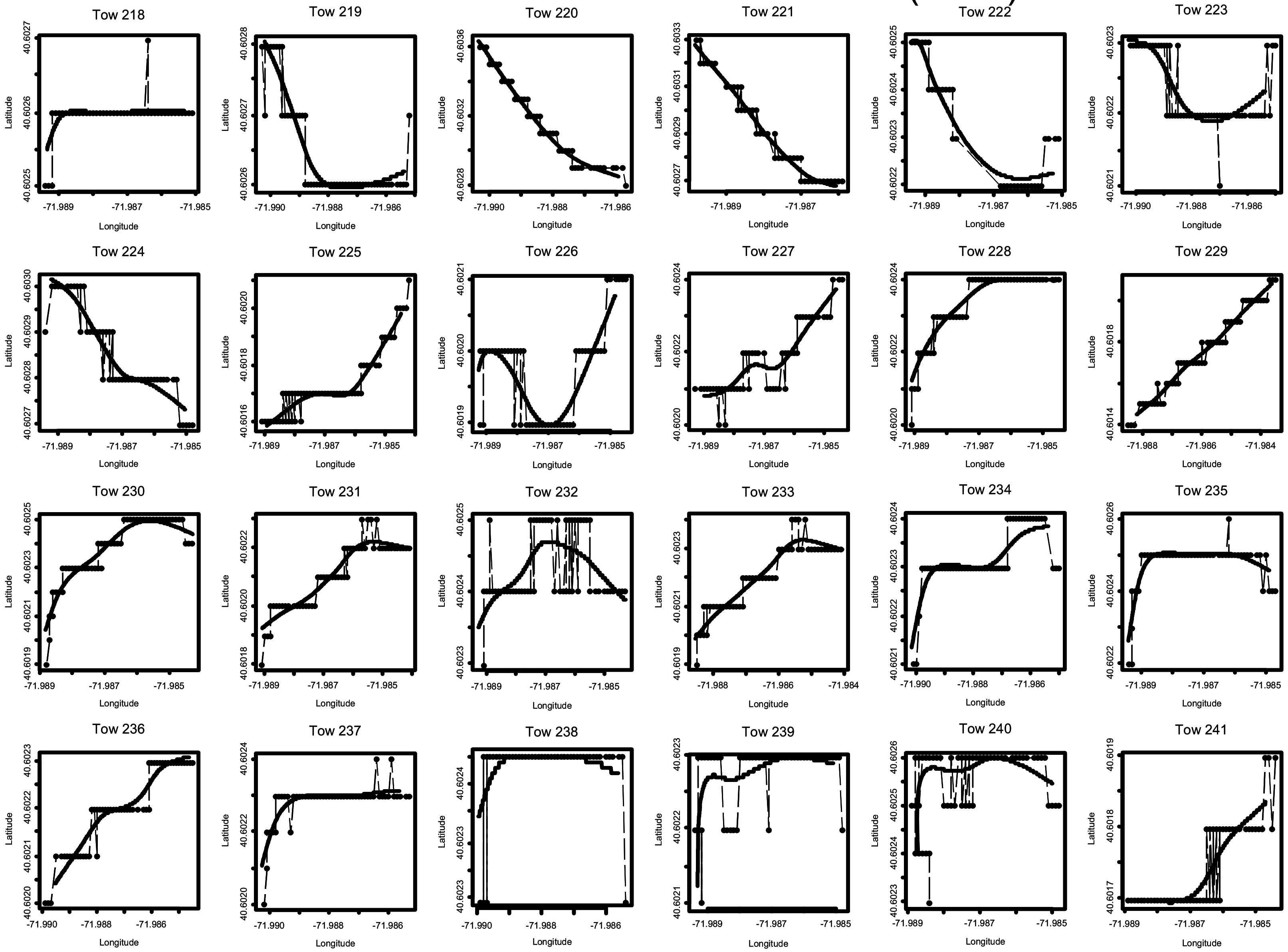
Smoothed Position Data OQ1998-3 (NS-1)



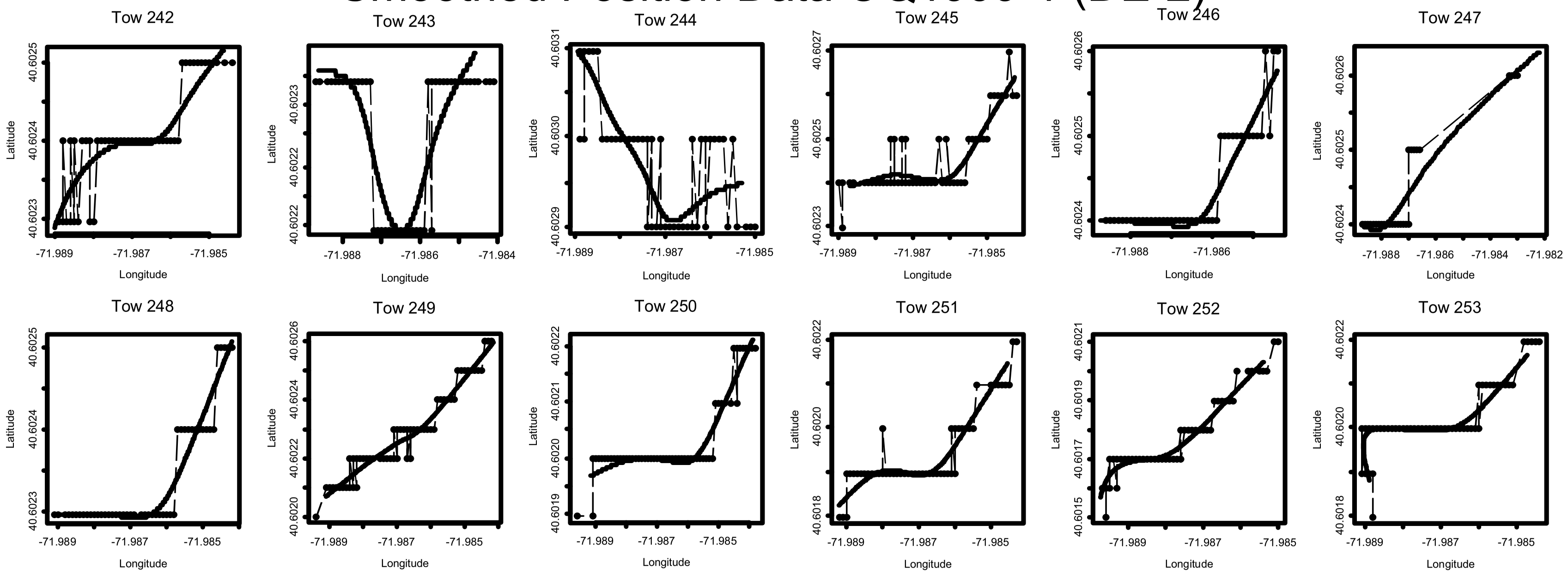
Smoothed Position Data OQ1999-1 (DE-2)



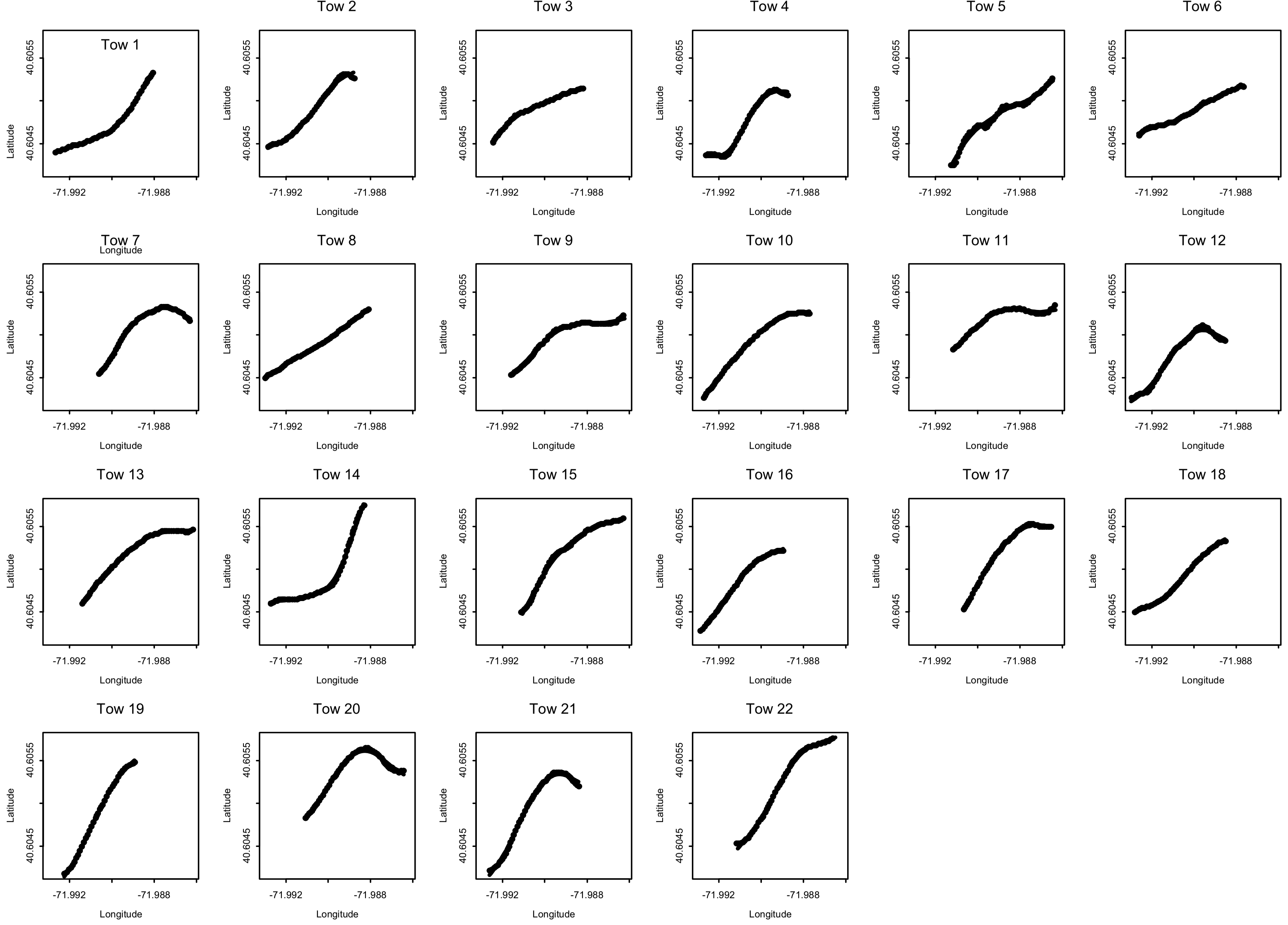
Smoothed Position Data OQ1999-1 (DE-2)



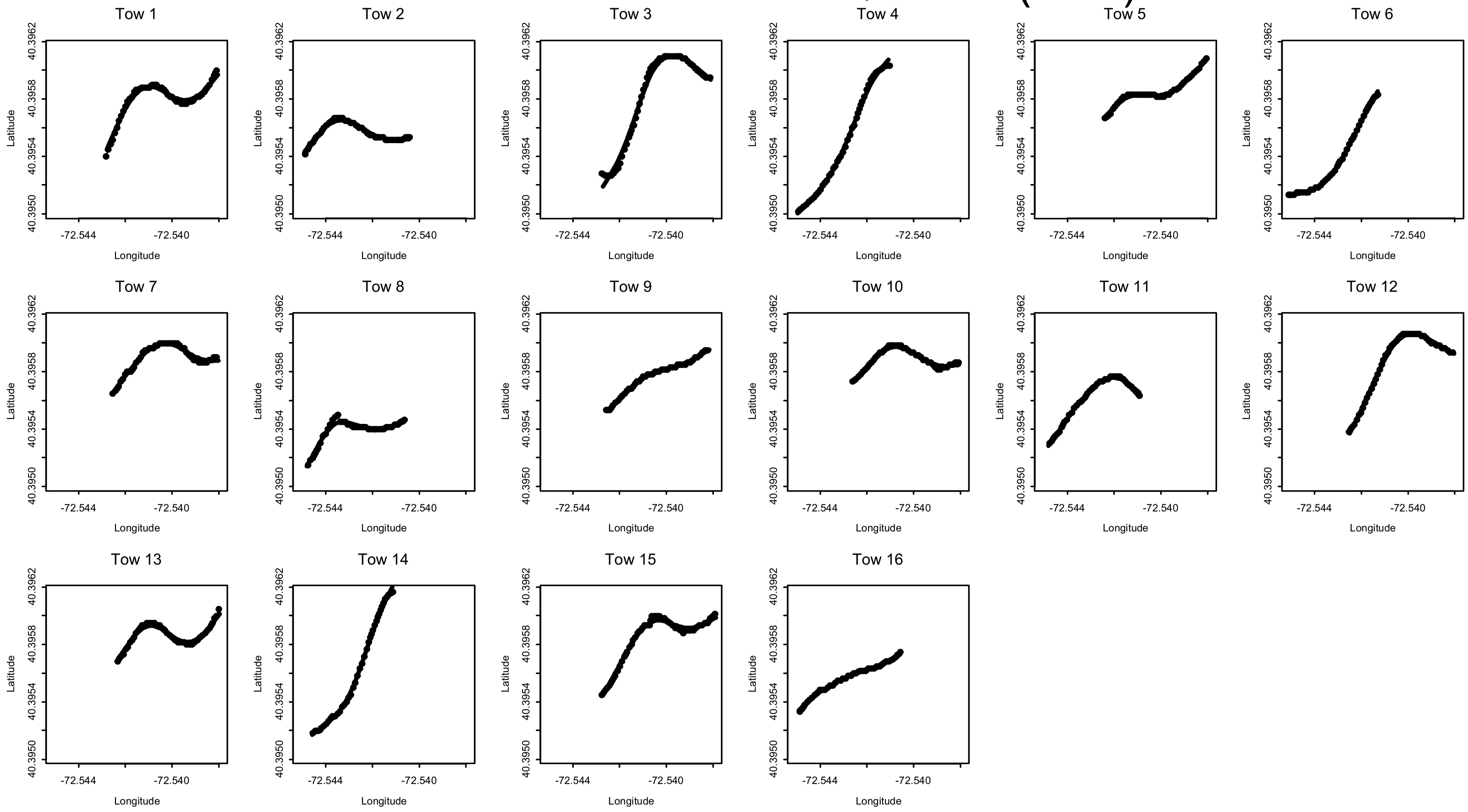
Smoothed Position Data OQ1999-1 (DE-2)



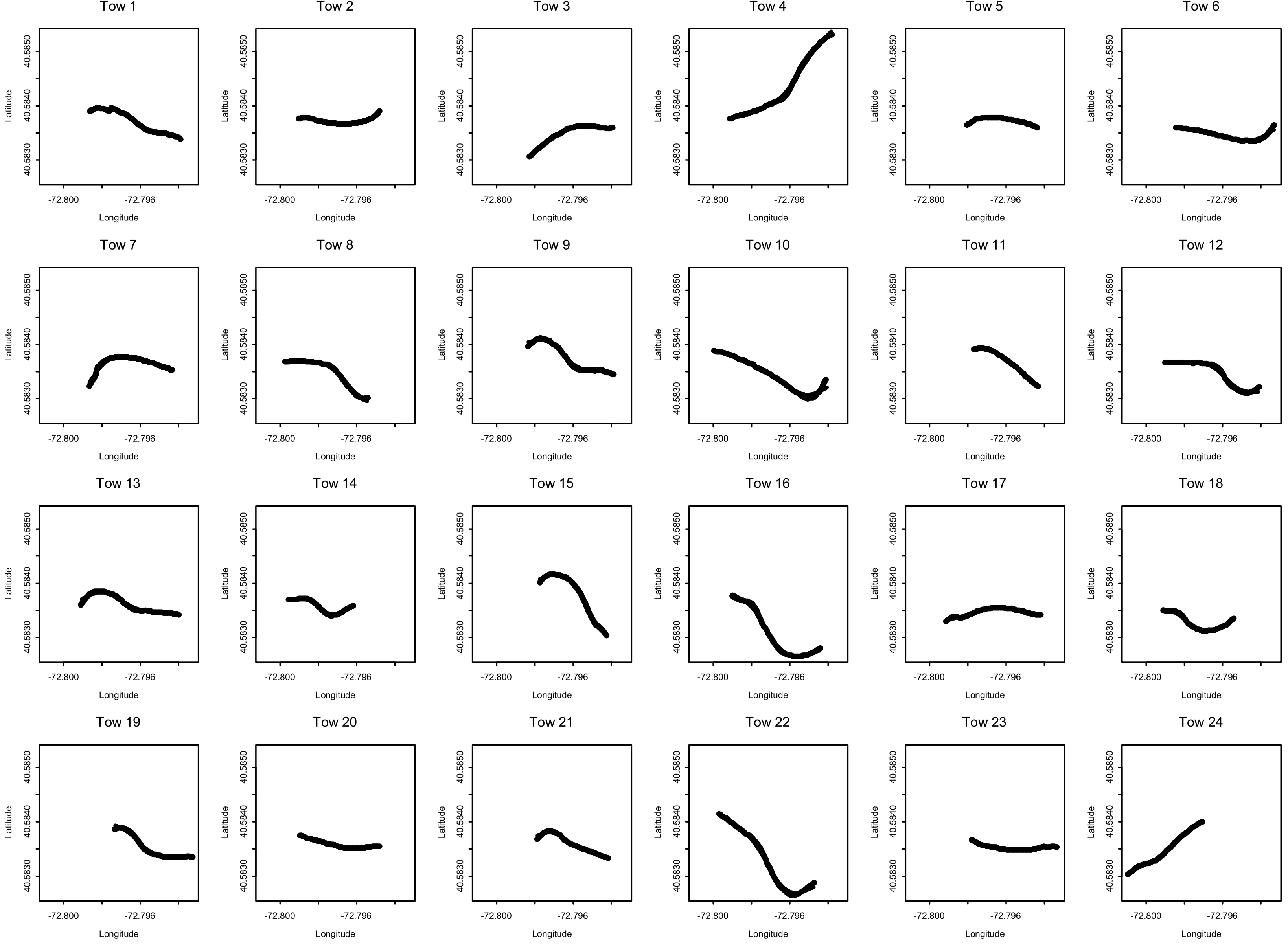
Smoothed Position Data OQ2000-1 (JN-1)



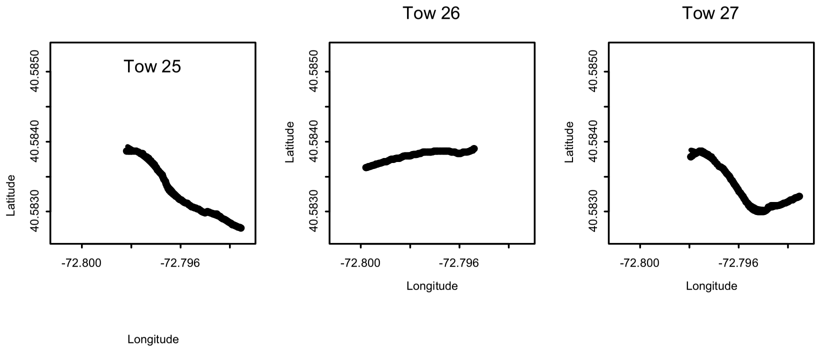
Smoothed Position Data OQ2000-2 (JN-2)



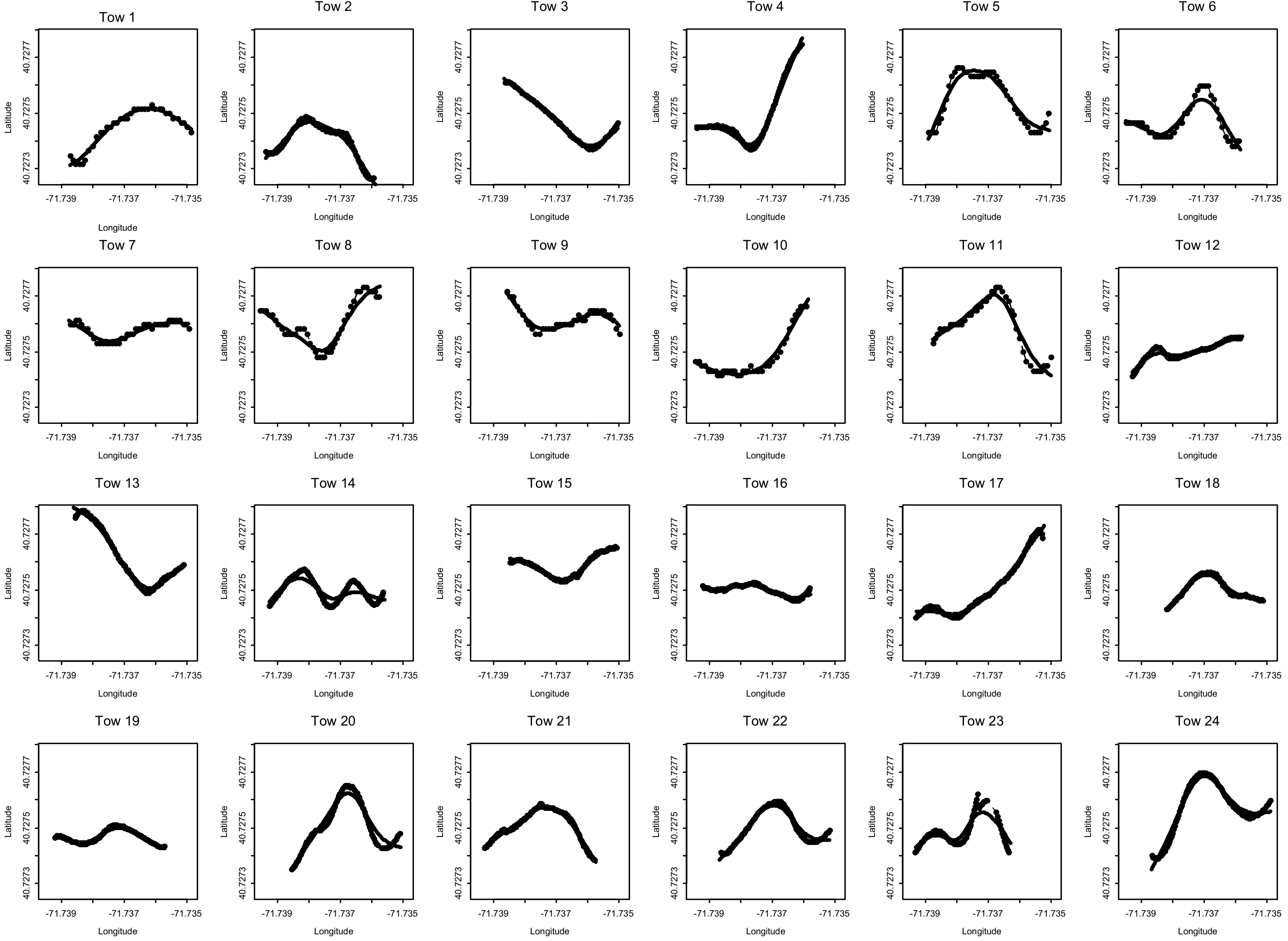
Smoothed Position Data OQ2000-3 (DM-1)



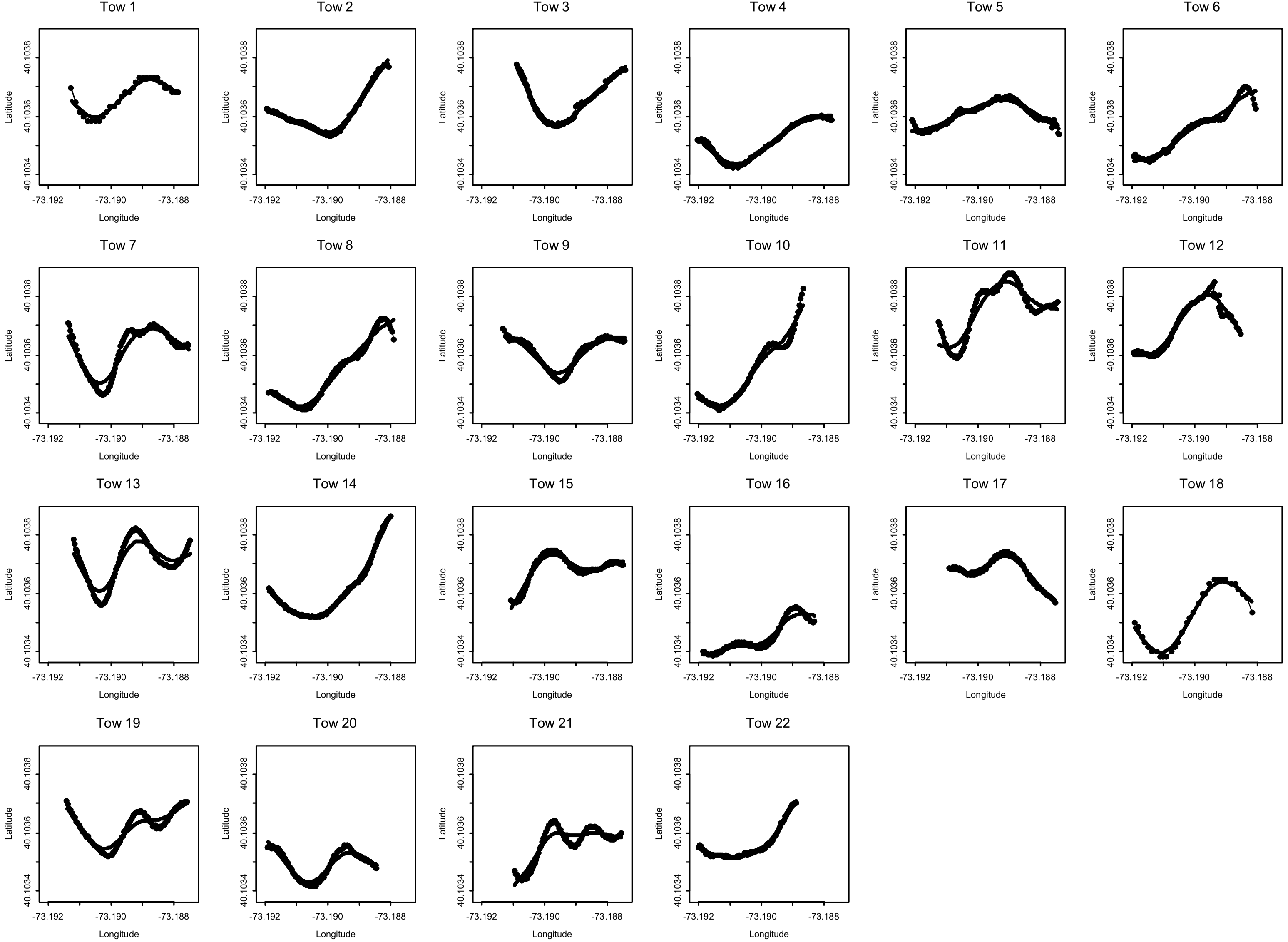
Smoothed Position Data OQ2000-3 (DM-1)



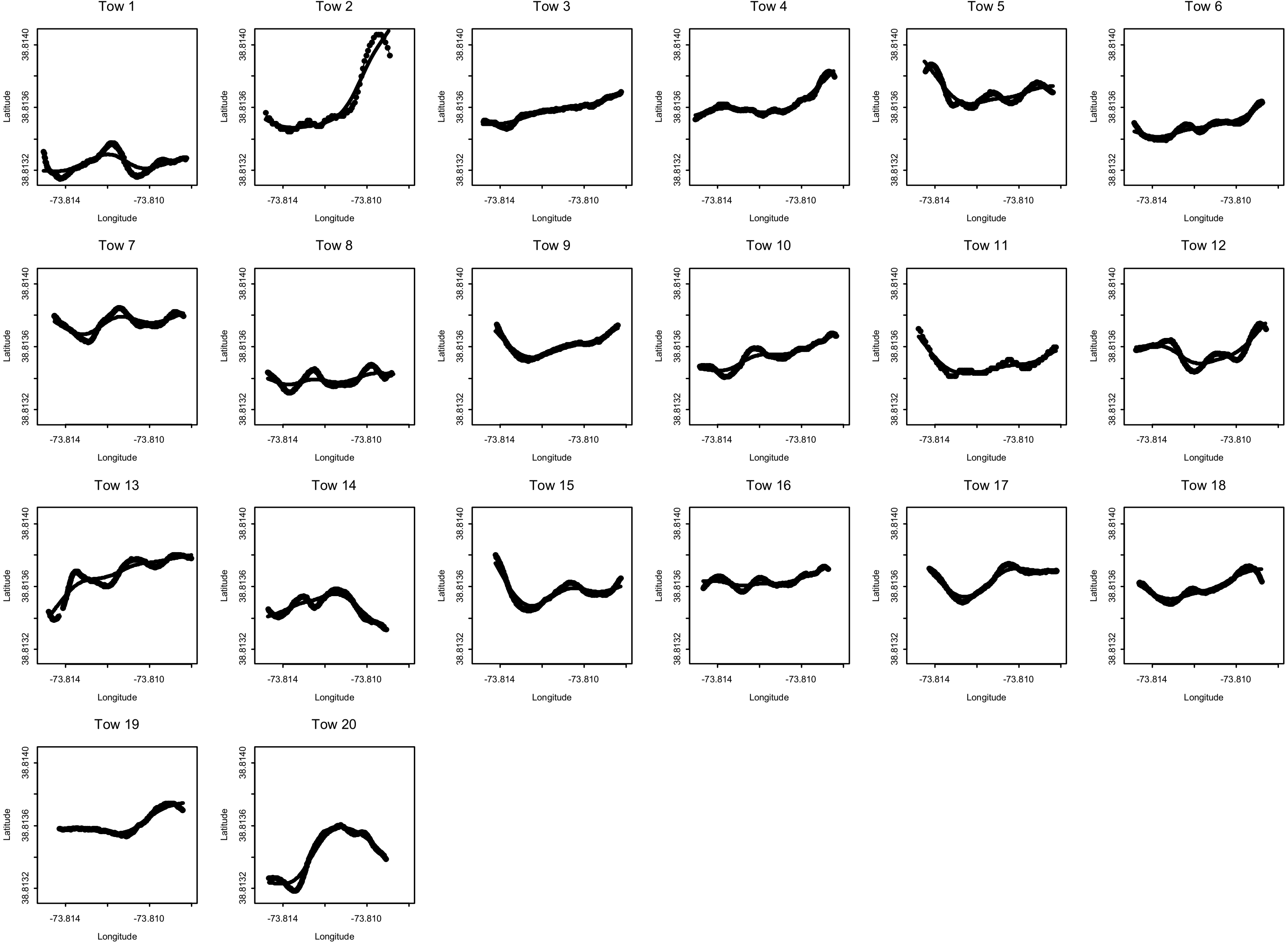
Smoothed Position Data OQ2002-1 (LK-1)



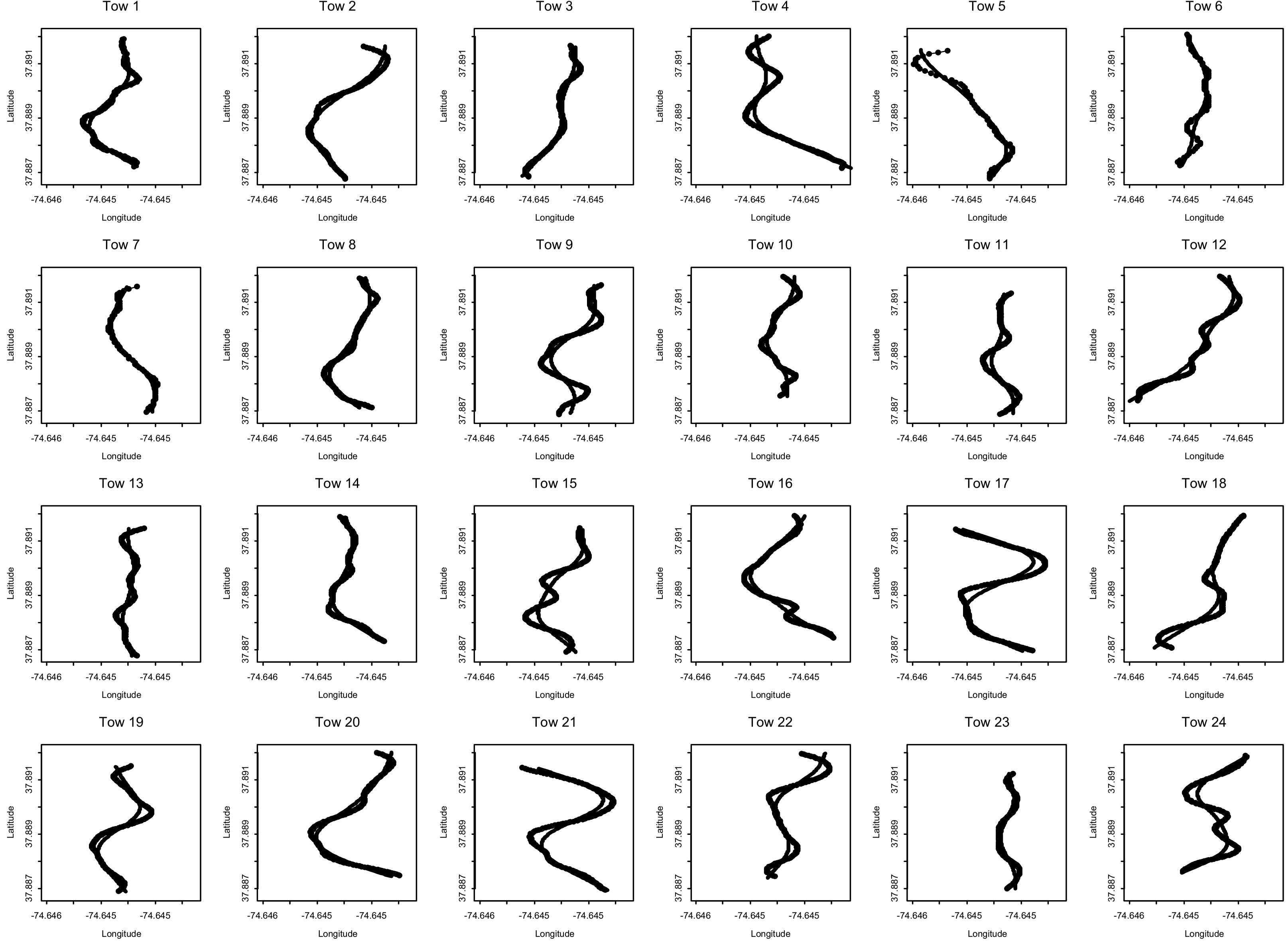
Smoothed Position Data OQ2002-2 (LK-2)



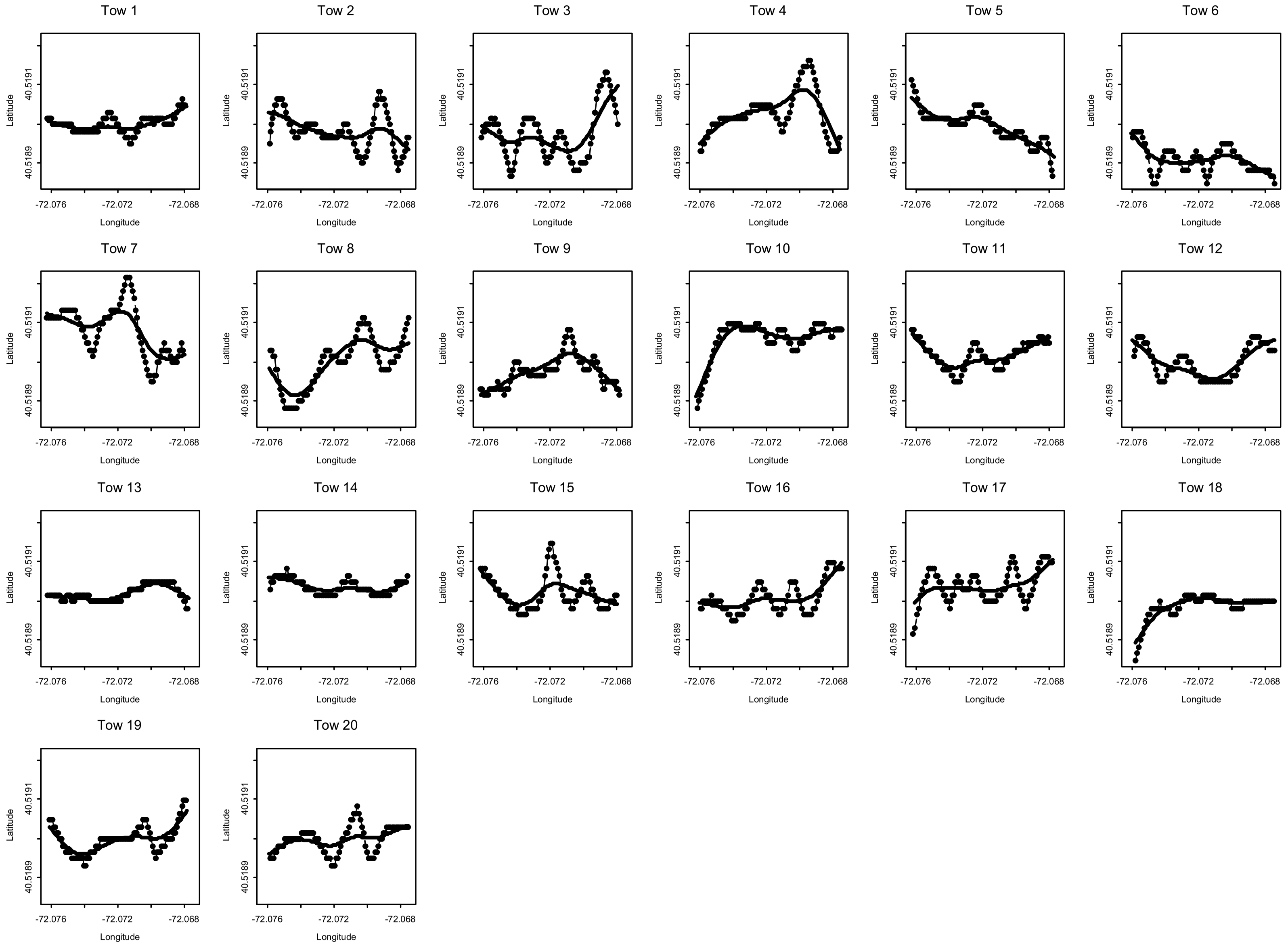
Smoothed Position Data OQ2002-3 (LK-3)



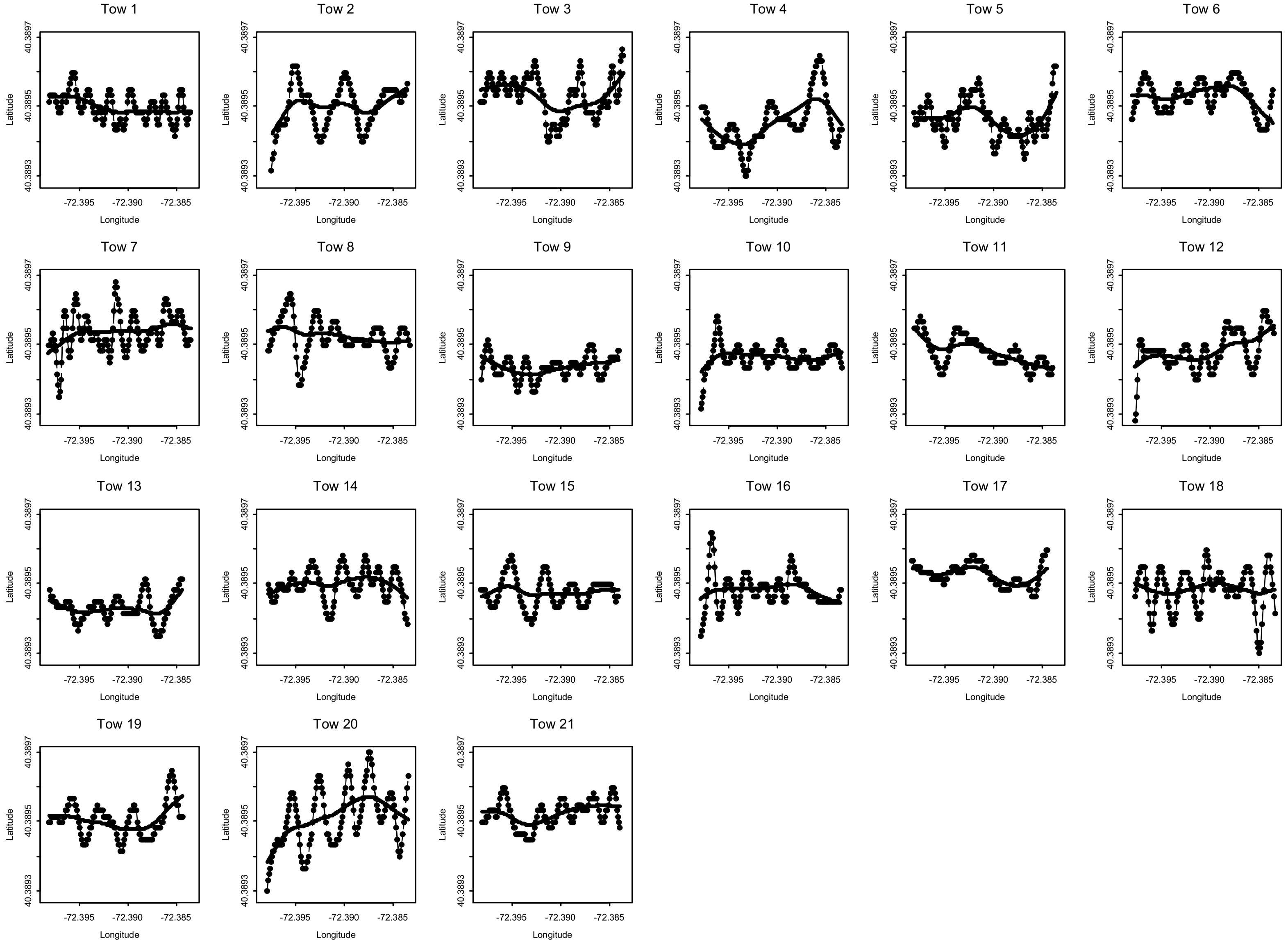
Smoothed Position Data OQ2002-4 (LK-4)



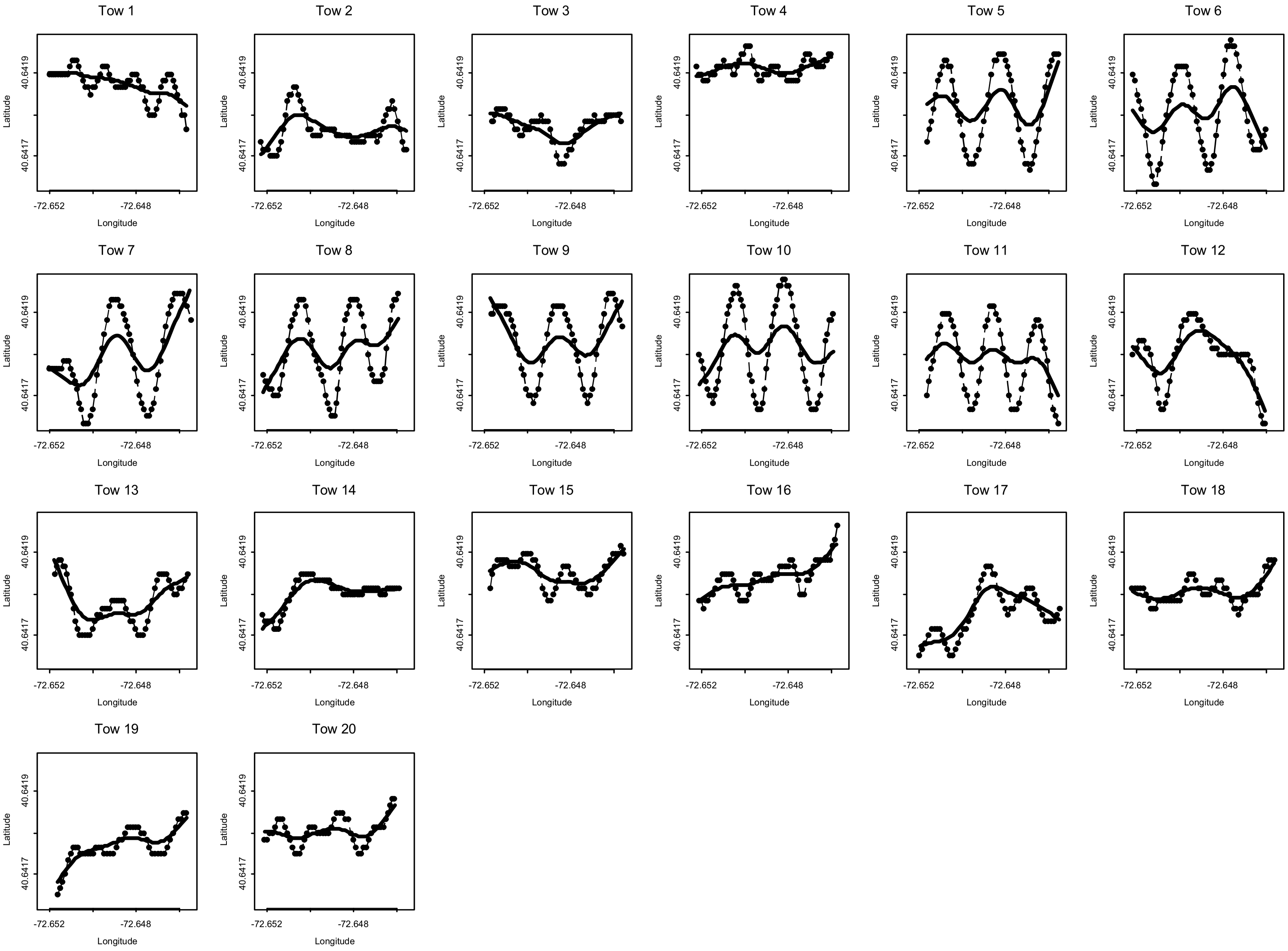
Smoothed Position Data OQ2005-1



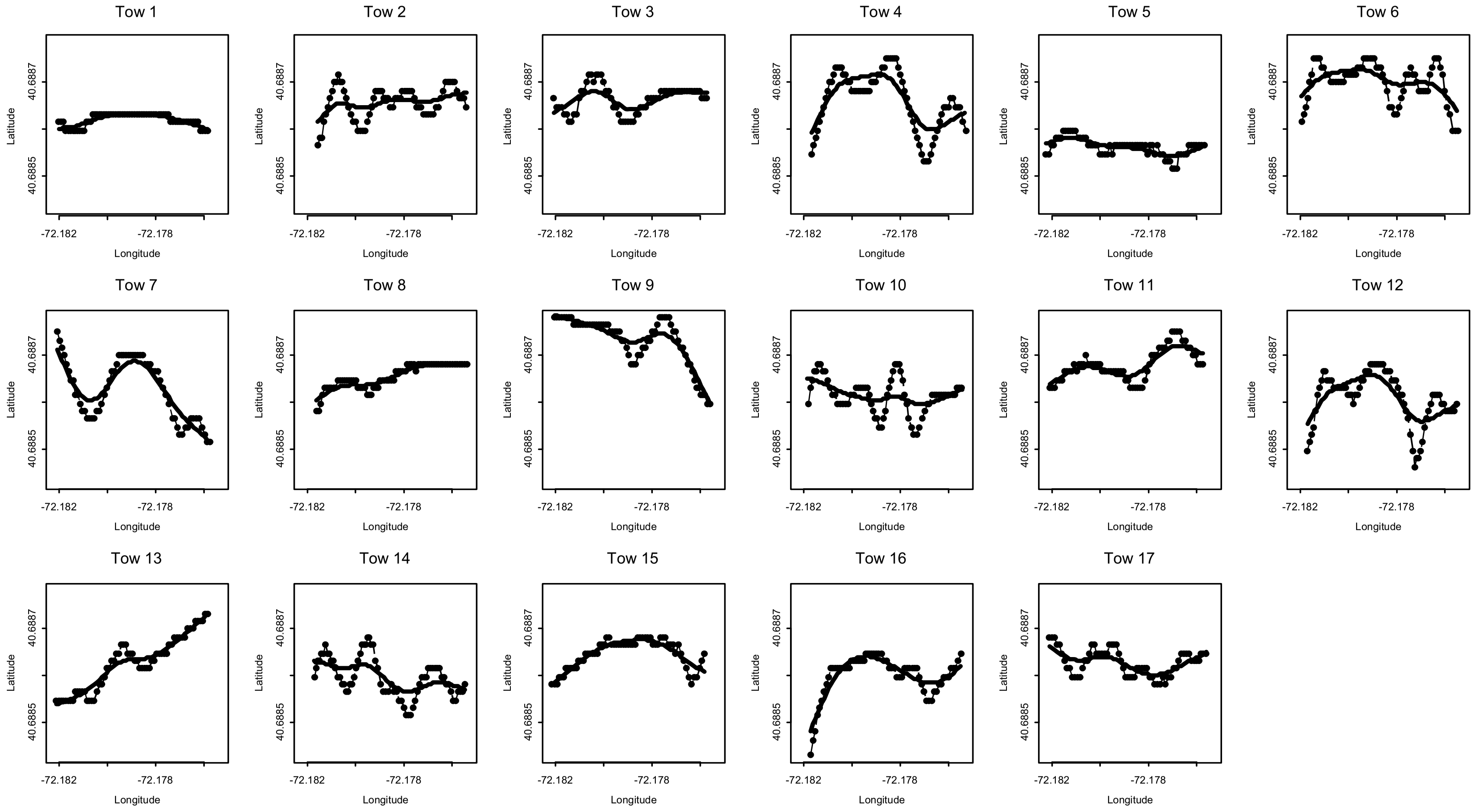
Smoothed Position Data OQ2005-2



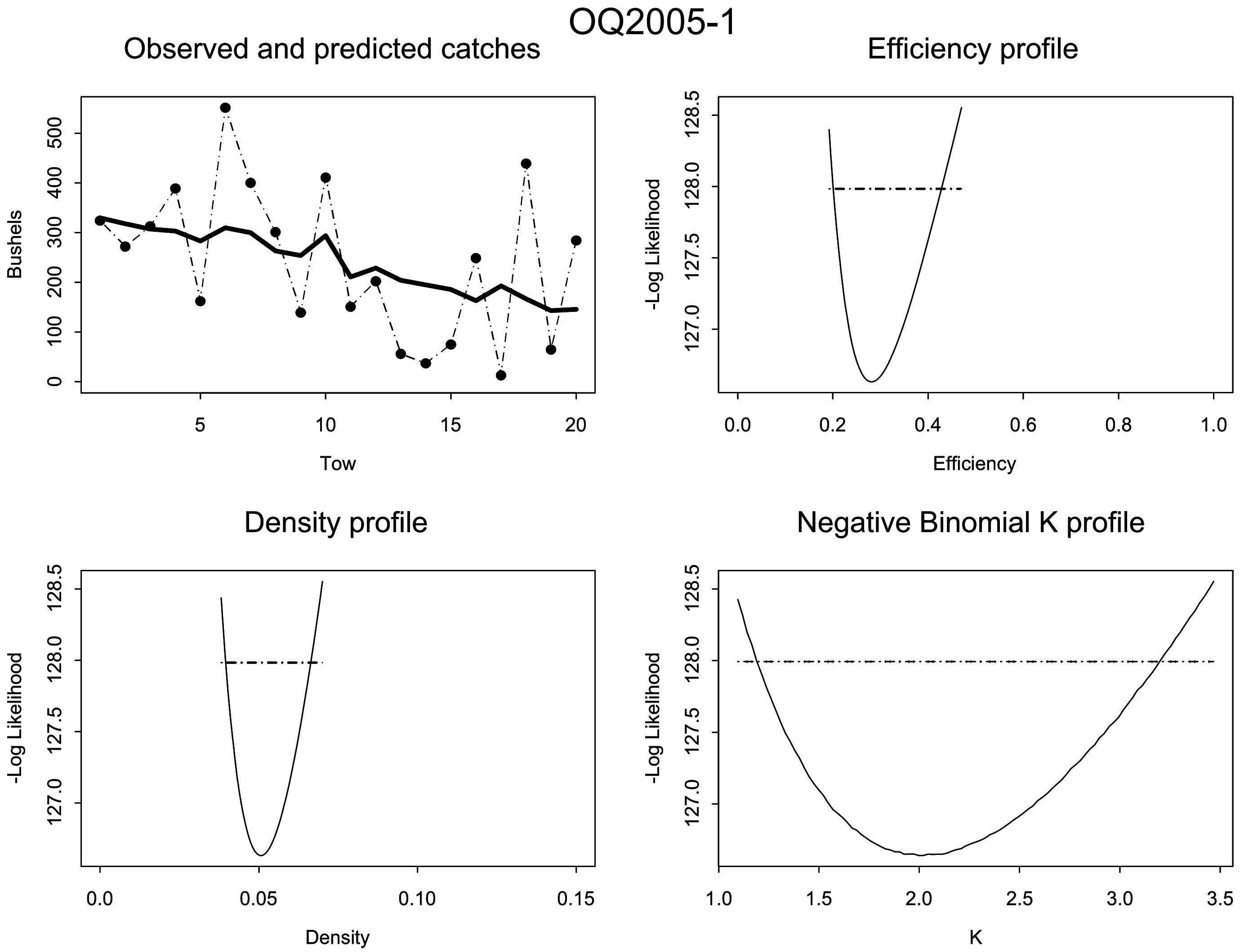
Smoothed Position Data OQ2005-3

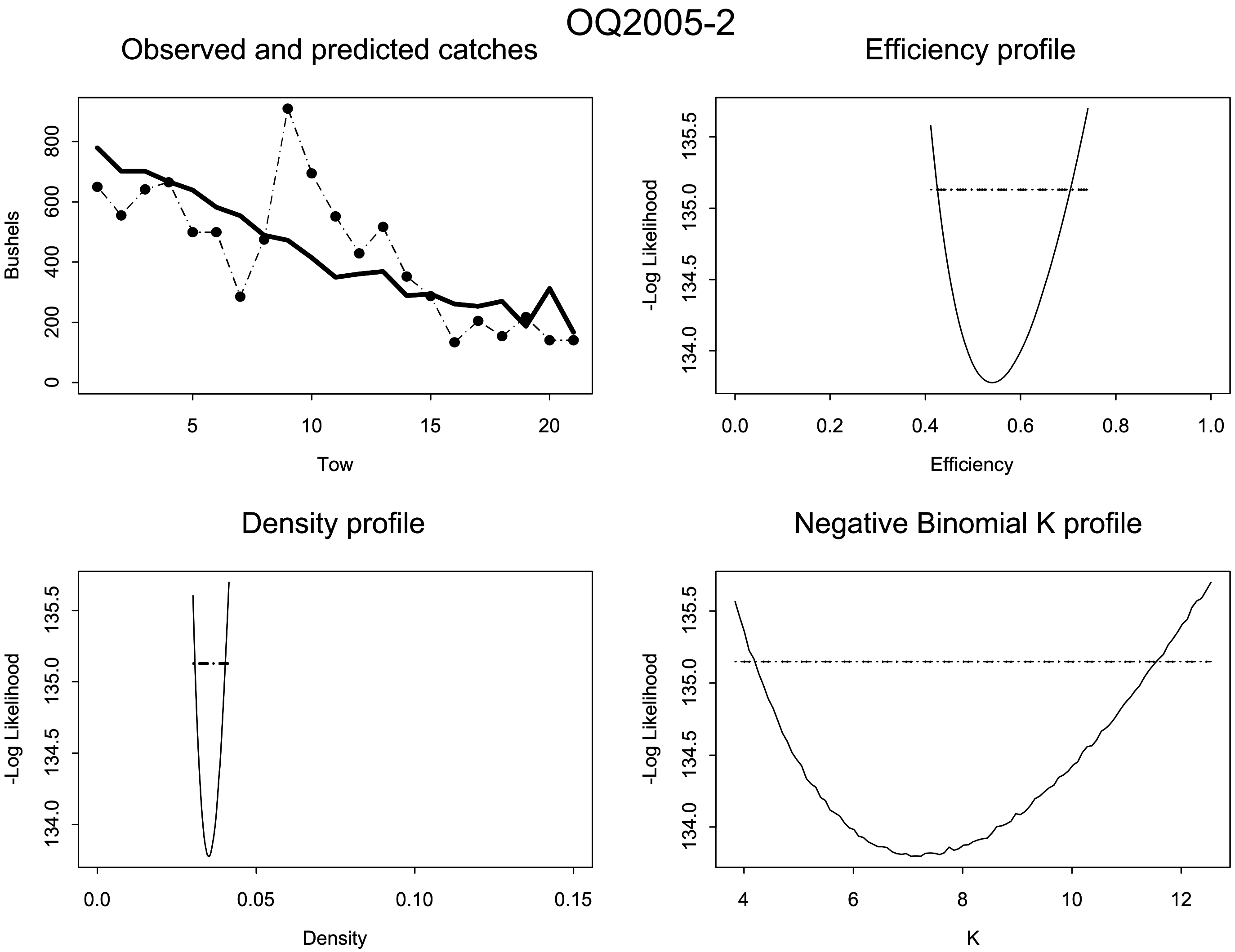


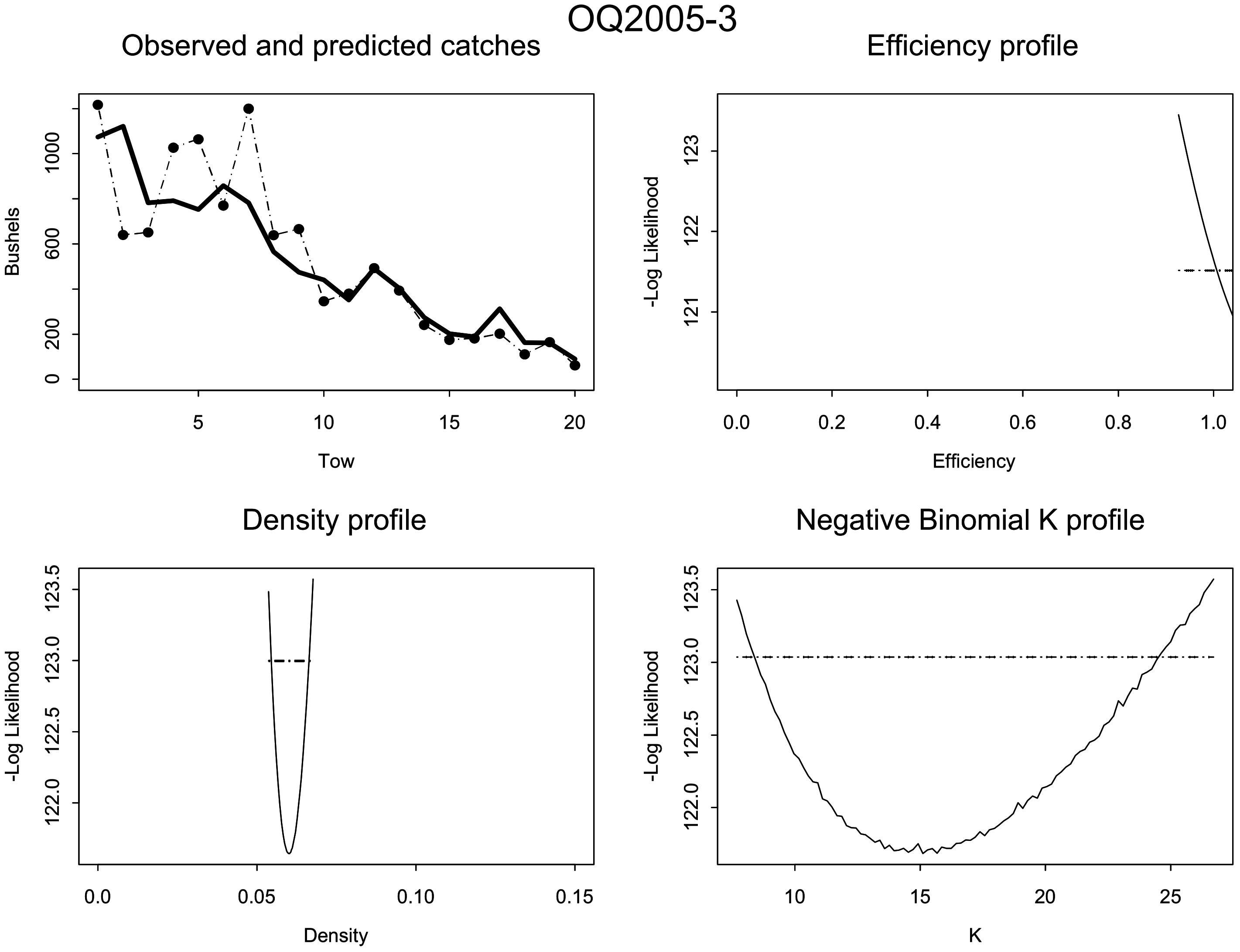
Smoothed Position Data OQ2005-4



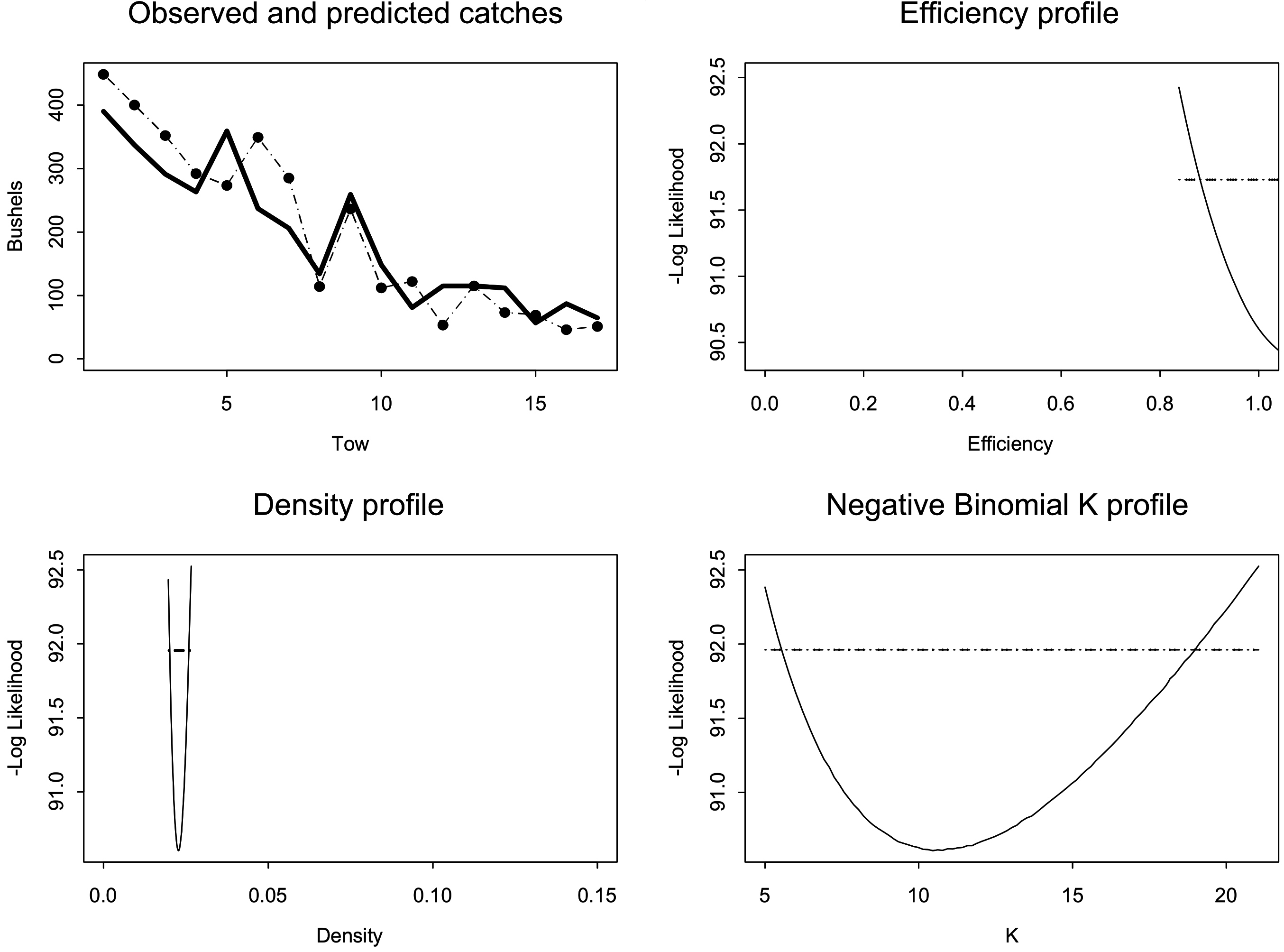
APPENDIX A4. Goodness of fit and likelihood profile plots for ocean quahog depletion experiments with 95% confidence intervals.

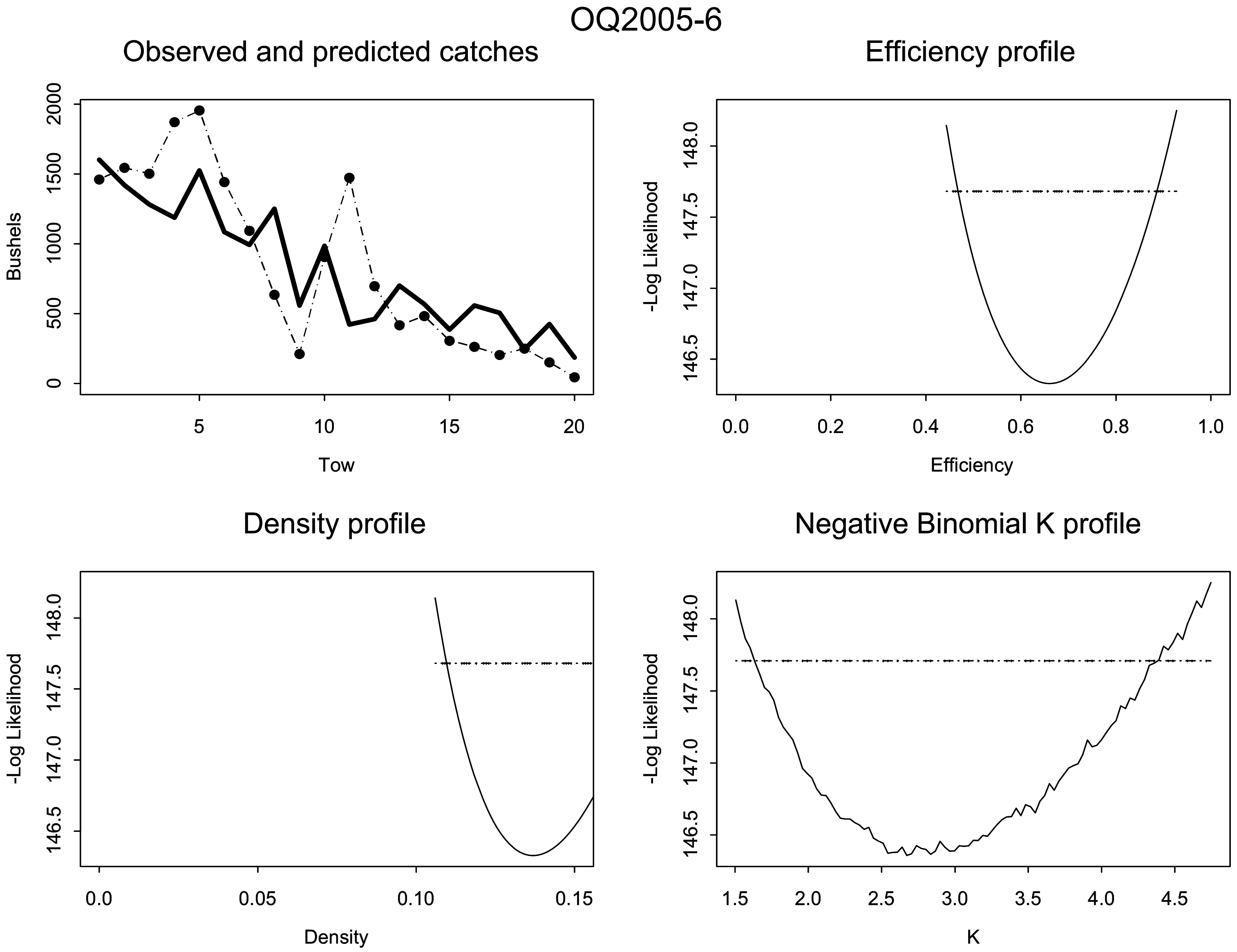

OQ2005-1
Observed and predicted catches
Bushels
0
100
200
300
400
500
5
10
15
20
Tow
Efficiency profile
-Log Likelihood
127.0
127.5
128.0
128.5
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
127.0
127.5
128.0
128.5
0.0
0.05
0.10
0.15
Density
Negative Binomial K profile
-Log Likelihood
127.0
127.5
128.0
128.5
1.0
1.5
2.0
2.5
3.0
3.5
K

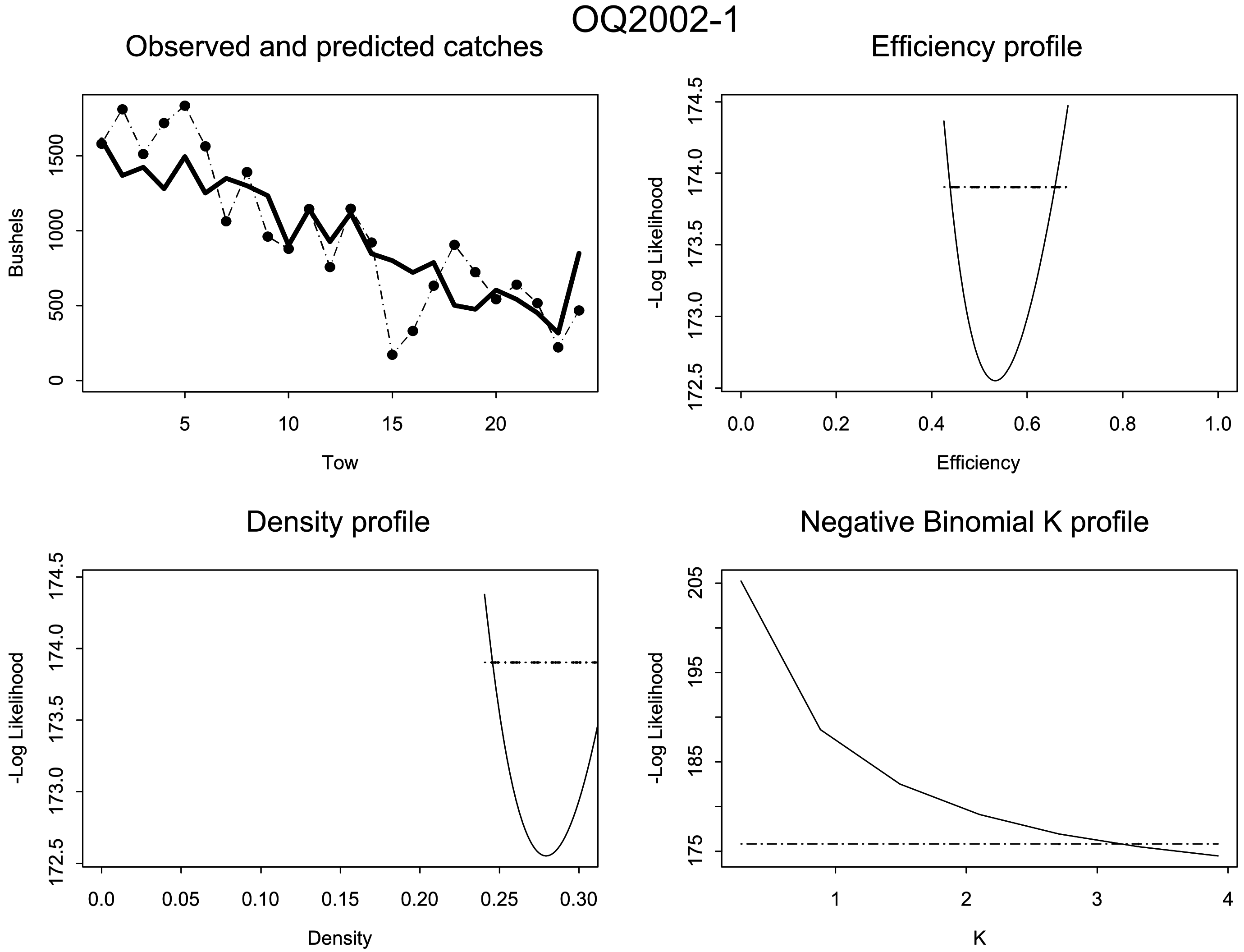

OQ2005-2
Observed and predicted catches
Bushels
0
200
400
600
800
5
10
15
20
Tow
Efficiency profile
-Log Likelihood
134.0
134.5
135.0
135.5
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
134.0
134.5
135.0
135.5
0.0
0.05
0.10
0.15
Density
Negative Binomial K profile
-Log Likelihood
134.0
134.5
135.0
135.5
4
6
8
10
12
K

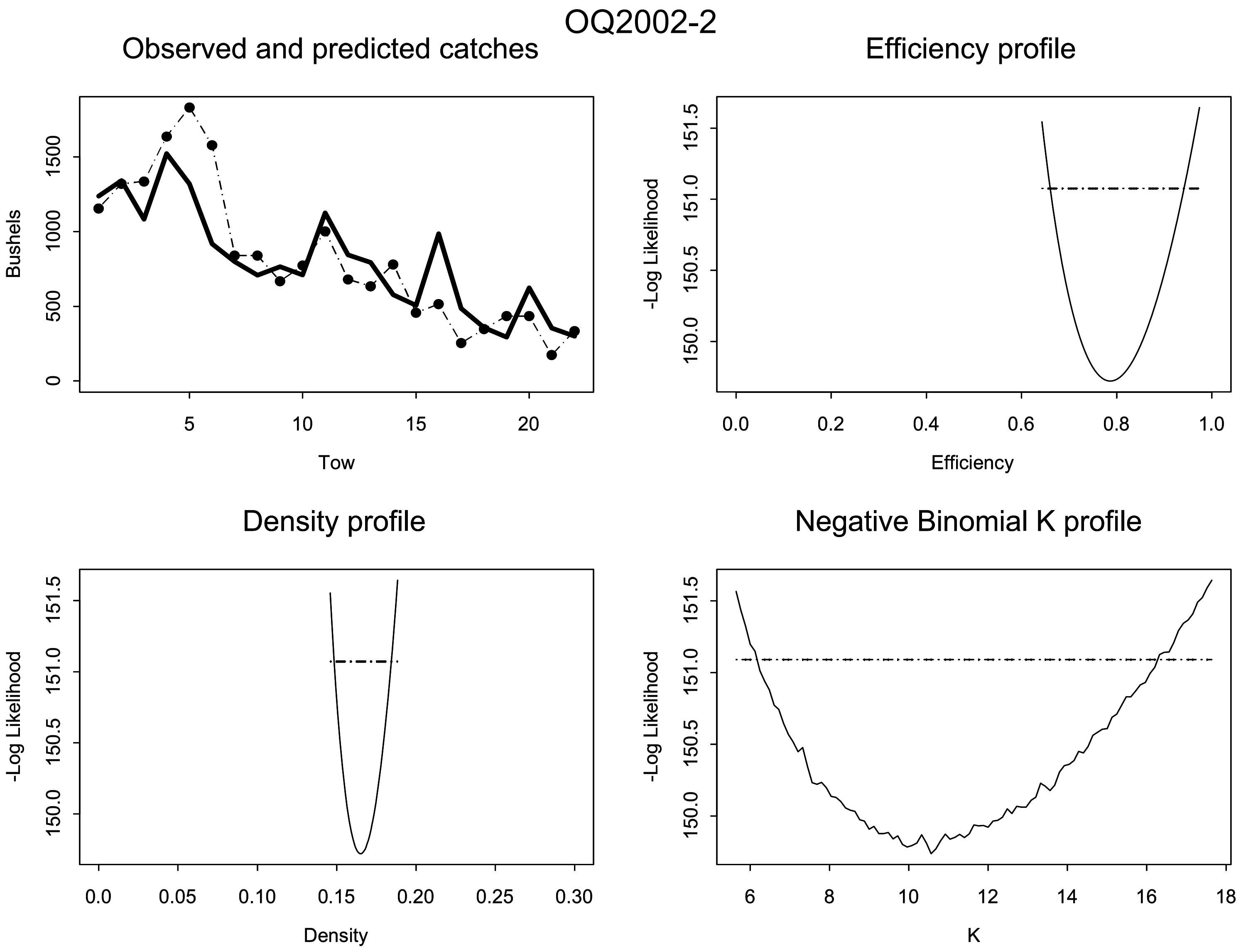

OQ2005-3
Observed and predicted catches
Bushels
0
200
600
1000
Tow
5
10
15
20
Efficiency profile
-Log Likelihood
121
122
123
Efficiency
0.0
0.2
0.4
0.6
0.8
1.0
Density profile
-Log Likelihood
122.0
122.5
123.0
123.5
Density
0.0
0.05
0.10
0.15
Negative Binomial K profile
-Log Likelihood
122.0
122.5
123.0
123.5
K
10
15
20
25

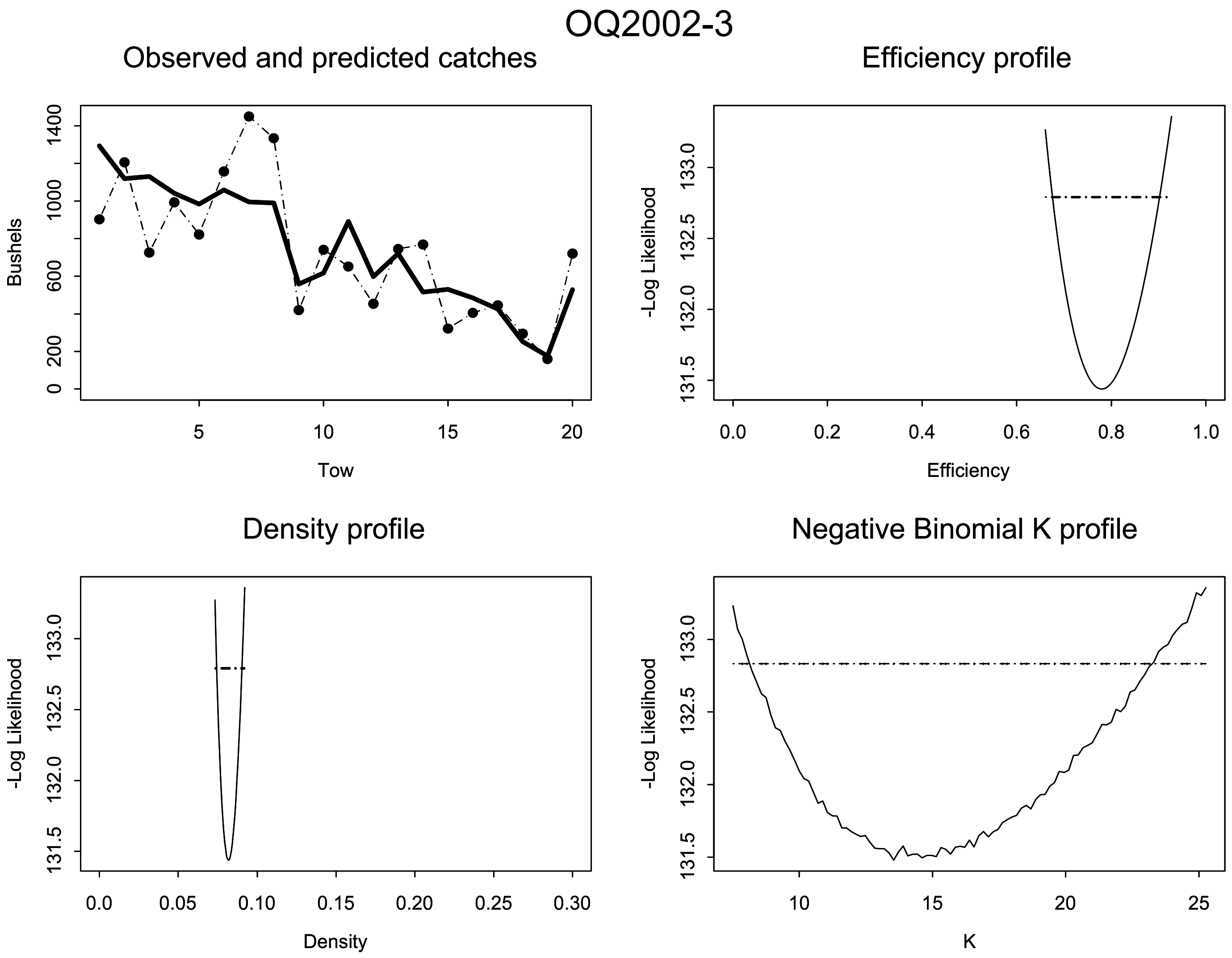
OQ2005-4

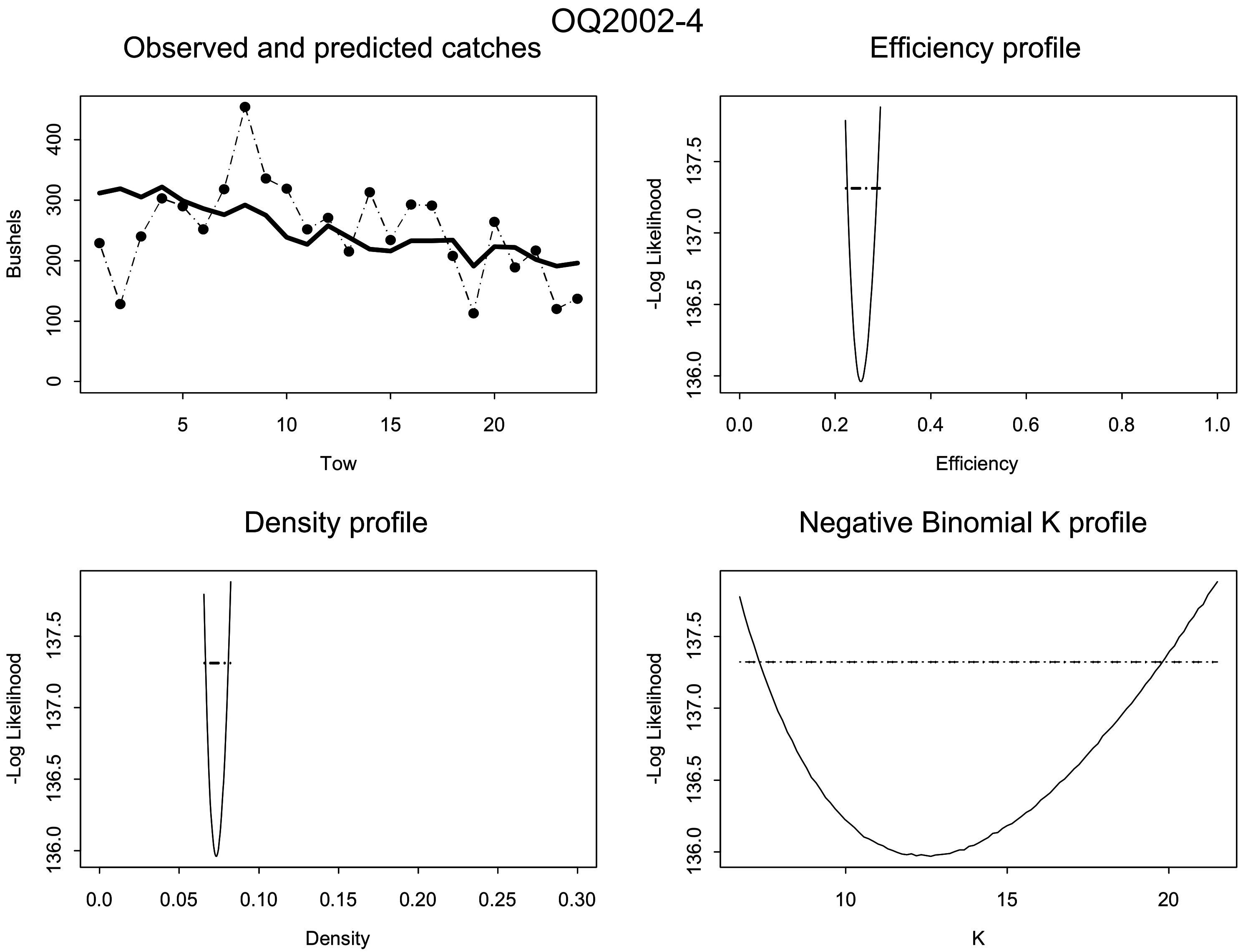

Observed and predicted catches
Bushels
0
100
200
300
400
5
10
15
Tow
Efficiency profile
-Log Likelihood
90.5
91.0
91.5
92.0
92.5
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
91.0
91.5
92.0
92.5
0.0
0.05
0.10
0.15
Density
Negative Binomial K profile
-Log Likelihood
91.0
91.5
92.0
92.5
5
10
15
20
K

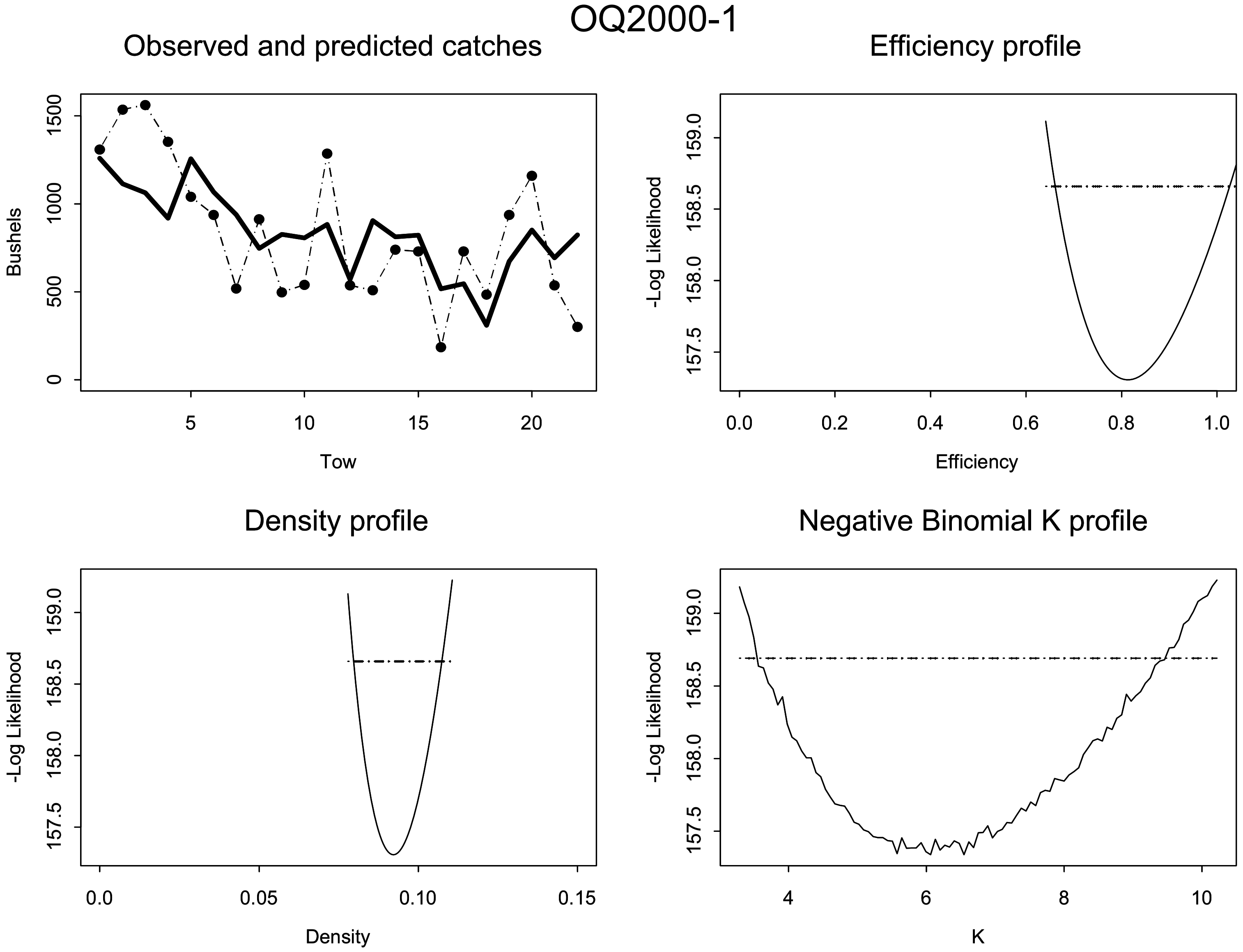

OQ2005-6
Observed and predicted catches
Bushels
0
500
1000
1500
2000
5
10
15
20
Tow
Efficiency profile
-Log Likelihood
146.5
147.0
147.5
148.0
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
146.5
147.0
147.5
148.0
0.0
0.05
0.10
0.15
Density
Negative Binomial K profile
-Log Likelihood
146.5
147.0
147.5
148.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
K


OQ2002-1
Observed and predicted catches
Bushels
0
500
1000
1500
5
10
15
20
Tow
Efficiency profile
-Log Likelihood
172.5
173.0
173.5
174.0
174.5
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
172.5
173.0
173.5
174.0
174.5
0.0
0.05
0.10
0.15
0.20
0.25
0.30
Density
Negative Binomial K profile
-Log Likelihood
175
185
195
205
1
2
3
4
K

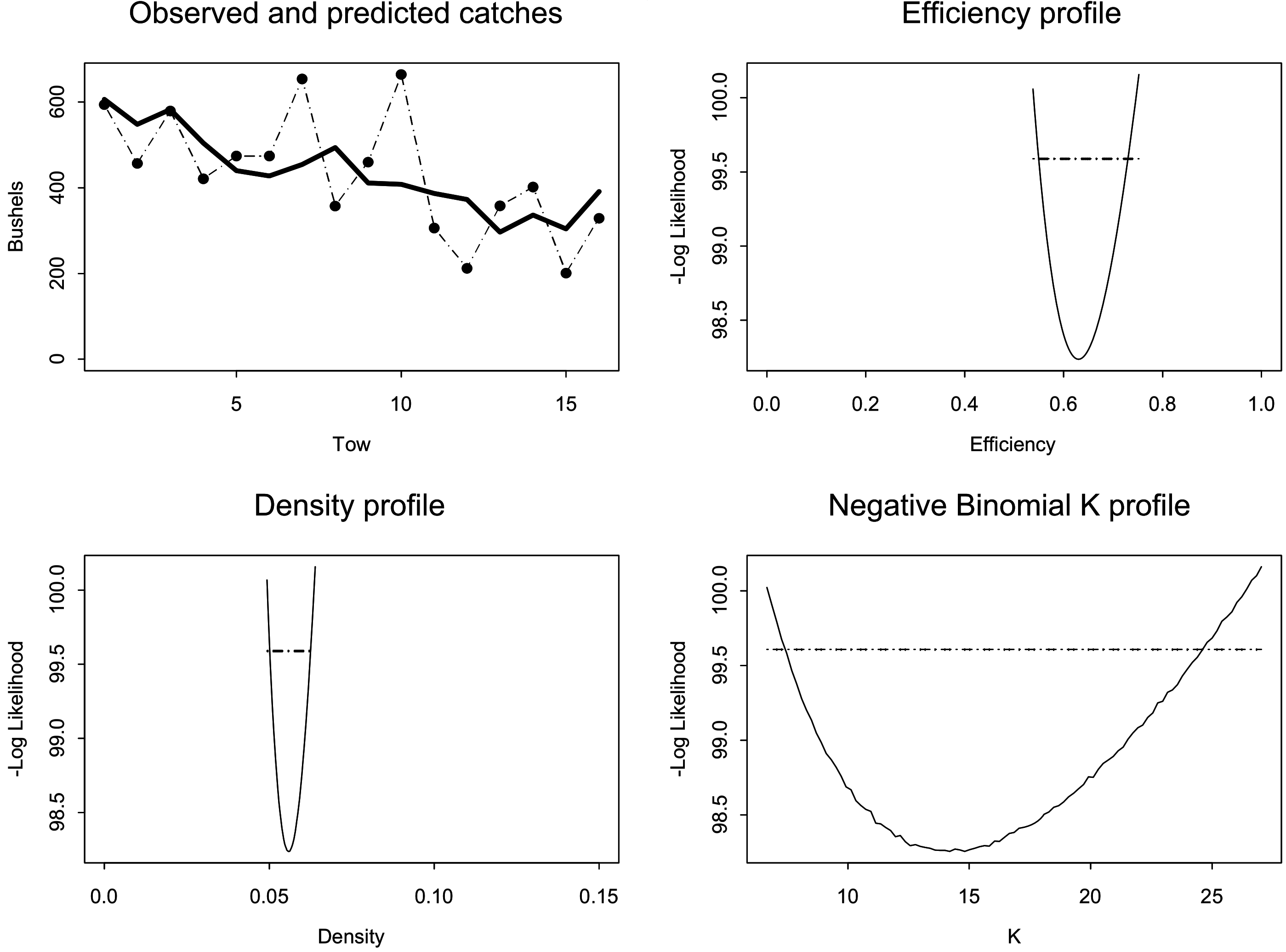

OQ2002-2
Observed and predicted catches
Bushels
0
500
1000
1500
5
10
15
20
Tow
Efficiency profile
-Log Likelihood
150.0
150.5
151.0
151.5
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
150.0
150.5
151.0
151.5
0.0
0.05
0.10
0.15
0.20
0.25
0.30
Density
Negative Binomial K profile
-Log Likelihood
150.0
150.5
151.0
151.5
6
8
10
12
14
16
18
K


OQ2002-3
Observed and predicted catches
Bushels
0
200
600
1000
1400
Tow
5
10
15
20
Efficiency profile
-Log Likelihood
131.5
132.0
132.5
133.0
Efficiency
0.0
0.2
0.4
0.6
0.8
1.0
Density profile
-Log Likelihood
131.5
132.0
132.5
133.0
Density
0.0
0.05
0.10
0.15
0.20
0.25
0.30
Negative Binomial K profile
-Log Likelihood
131.5
132.0
132.5
133.0
K
10
15
20
25


OQ2002-4
Observed and predicted catches
Bushels
0
100
200
300
400
5
10
15
20
Tow
Efficiency profile
-Log Likelihood
136.0
136.5
137.0
137.5
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
136.0
136.5
137.0
137.5
0.0
0.05
0.10
0.15
0.20
0.25
0.30
Density
Negative Binomial K profile
-Log Likelihood
136.0
136.5
137.0
137.5
10
15
20
K


OQ2000-1
Observed and predicted catches
Bushels
0
500
1000
1500
5
10
15
20
Tow
Efficiency profile
-Log Likelihood
157.5
158.0
158.5
159.0
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
157.5
158.0
158.5
159.0
0.0
0.05
0.10
0.15
Density
Negative Binomial K profile
-Log Likelihood
157.5
158.0
158.5
159.0
4
6
8
10
K

OQ2000-2

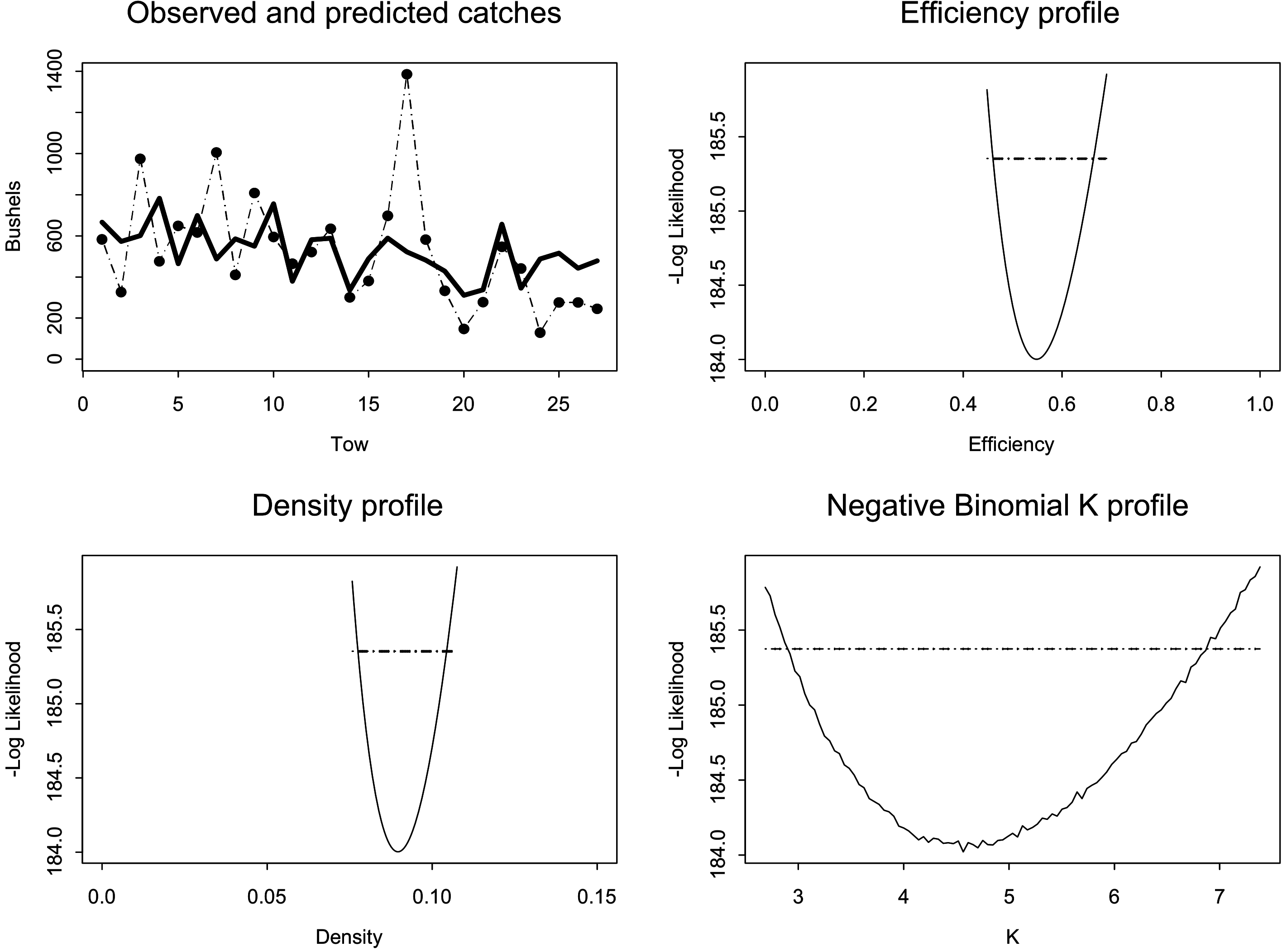

Observed and predicted catches

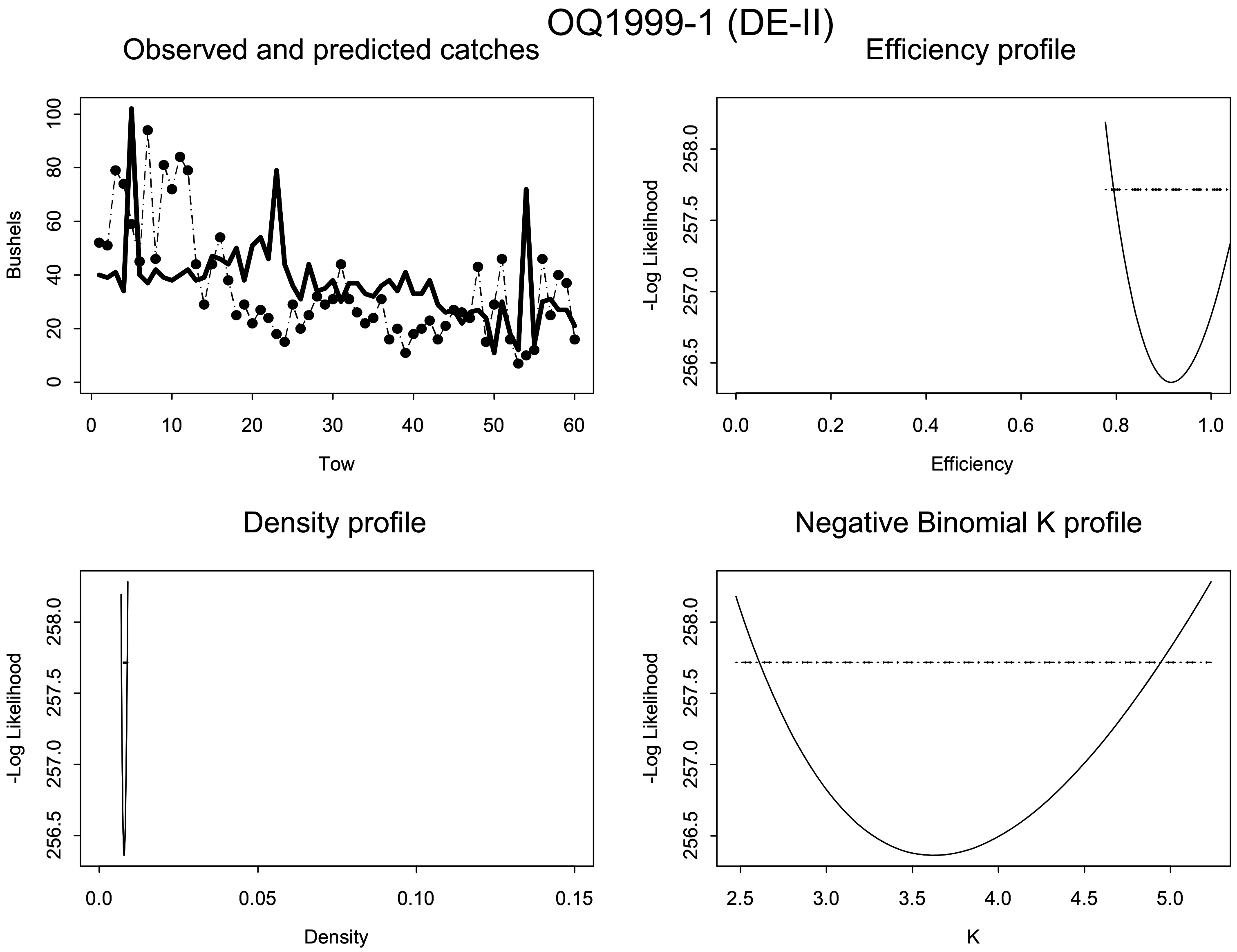
Efficiency profile

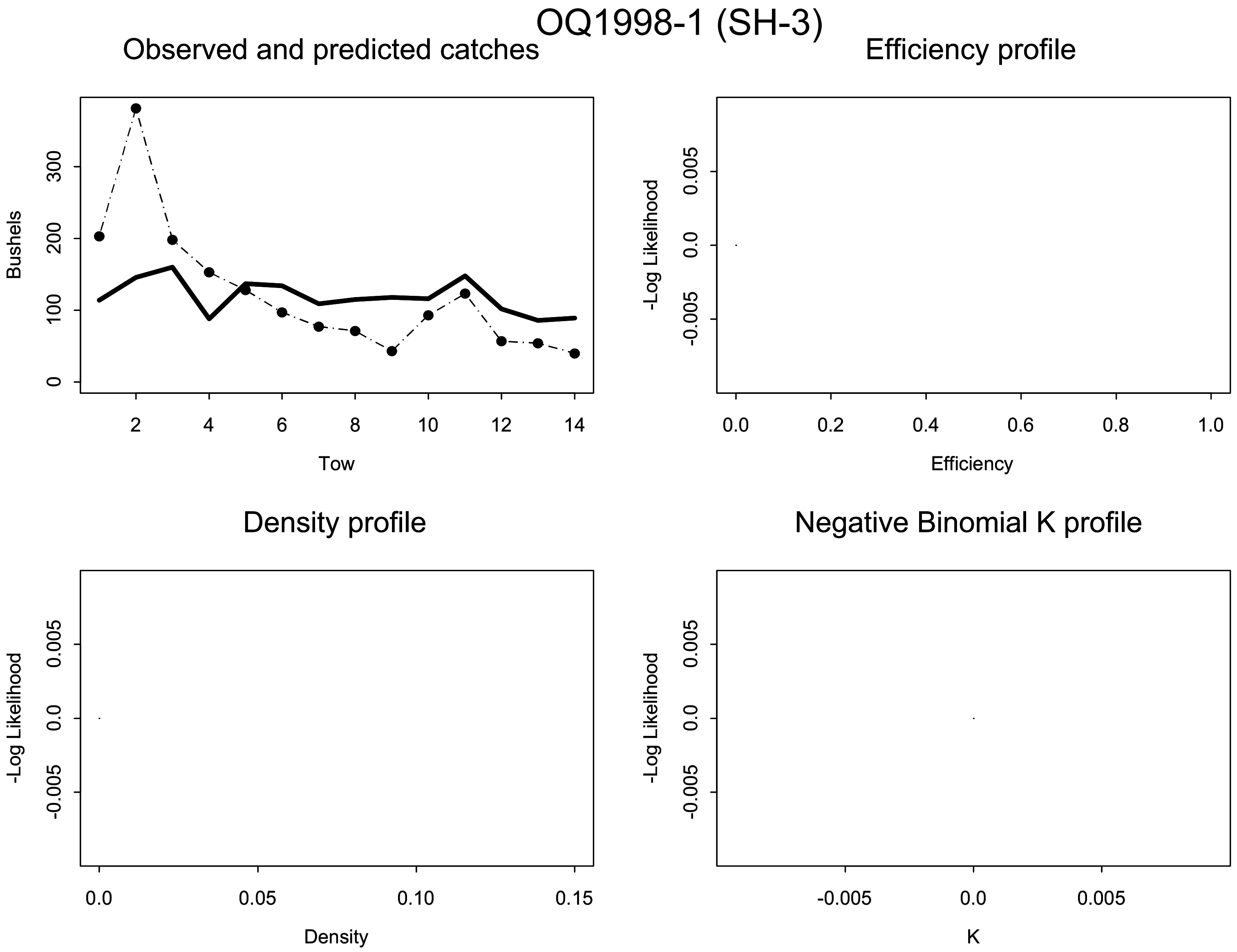
Density profile

Negative Binomial K profile

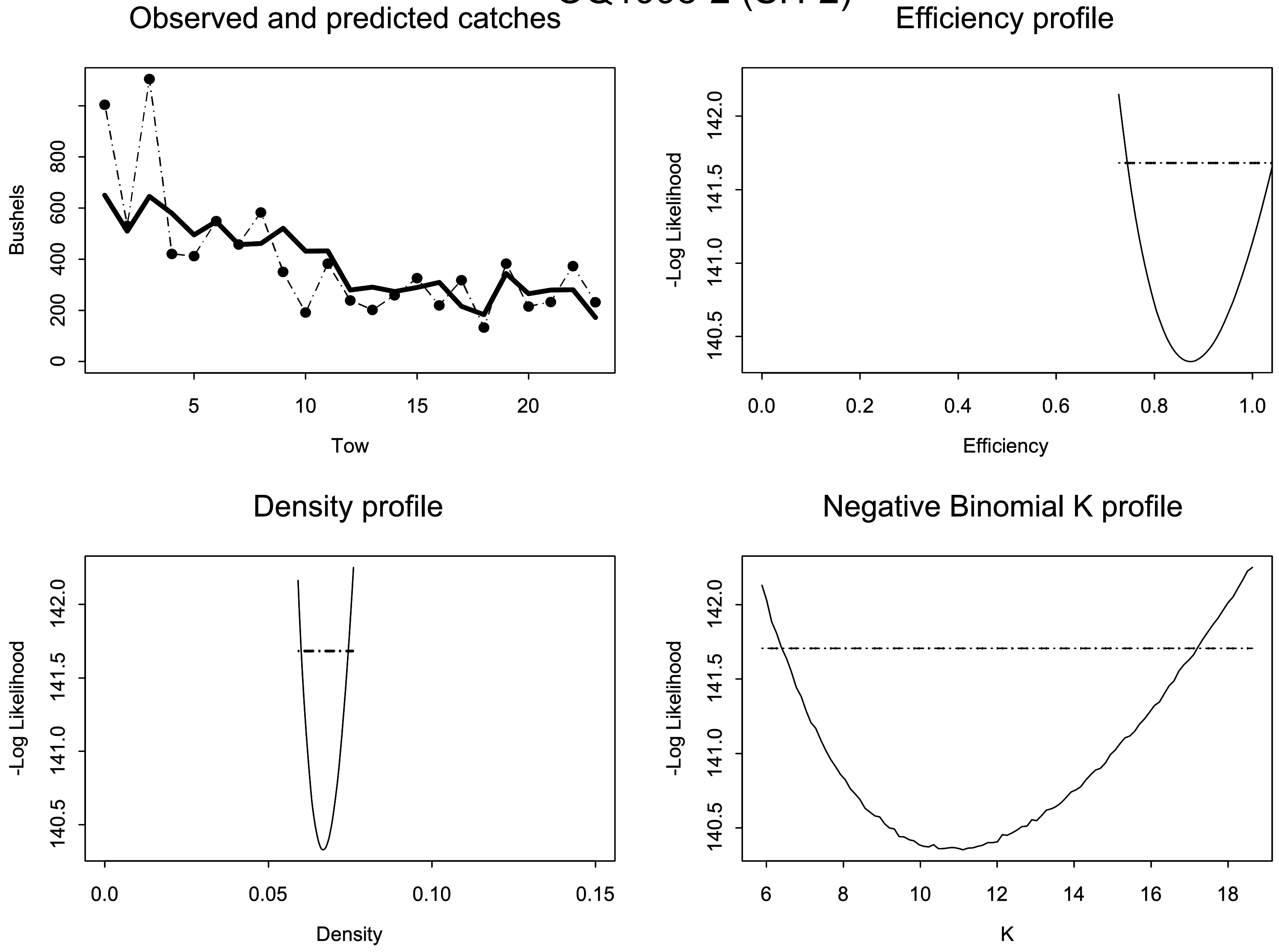
OQ2000-3


Observed and predicted catches
Bushels
0
200
600
1000
1400
Tow
0
5
10
15
20
25
Efficiency profile
-Log Likelihood
184.0
184.5
185.0
185.5
Efficiency
0.0
0.2
0.4
0.6
0.8
1.0
Density profile
-Log Likelihood
184.0
184.5
185.0
185.5
Density
0.0
0.05
0.10
0.15
Negative Binomial K profile
-Log Likelihood
184.0
184.5
185.0
185.5
K
3
4
5
6
7

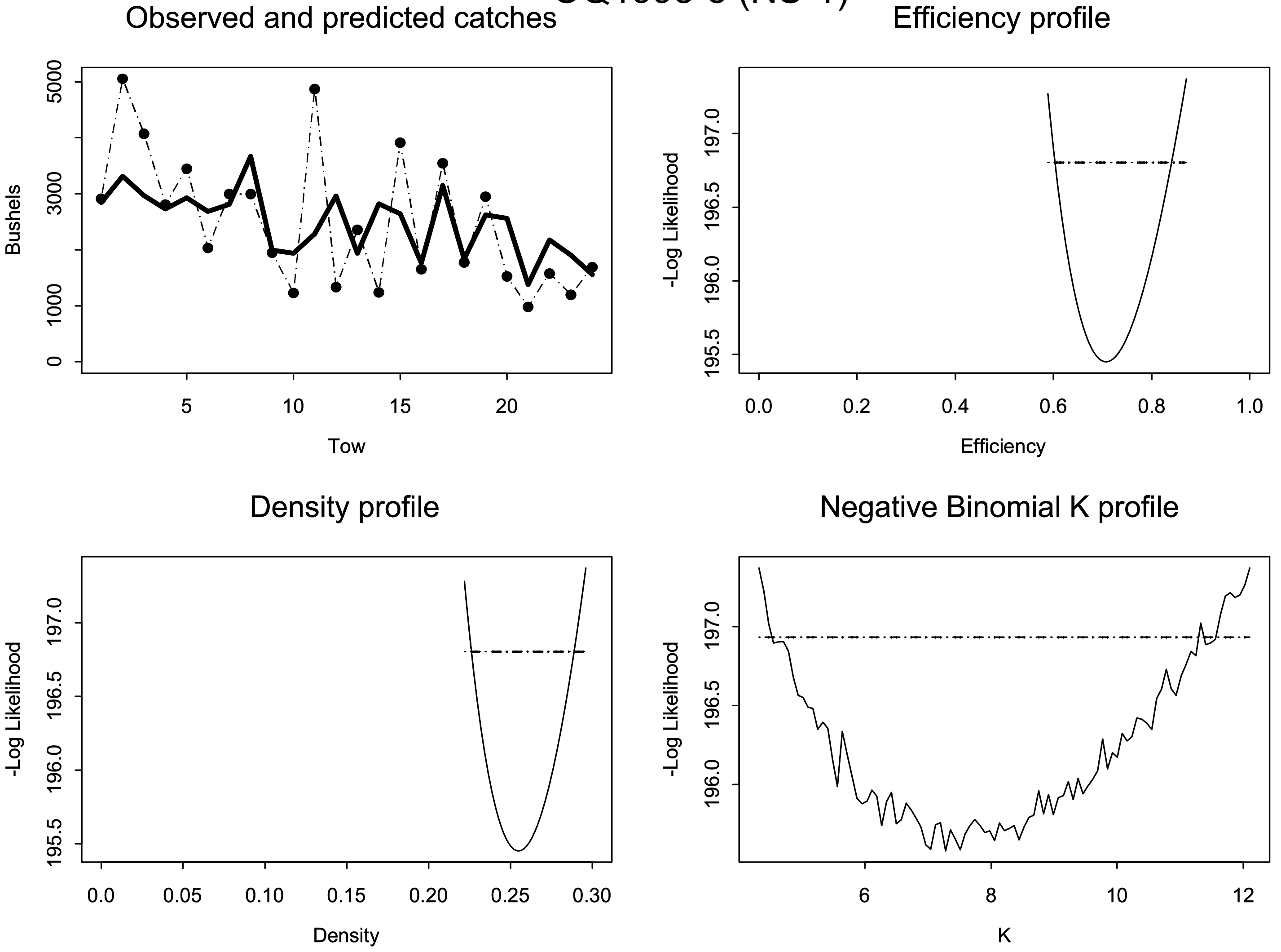

OQ1999-1 (DE-II)
Observed and predicted catches
Bushels
0
20
40
60
80
100
Tow
0
10
20
30
40
50
60
Efficiency profile
-Log Likelihood
256.5
257.0
257.5
258.0
Efficiency
0.0
0.2
0.4
0.6
0.8
1.0
Density profile
-Log Likelihood
256.5
257.0
257.5
258.0
Density
0.0
0.05
0.10
0.15
Negative Binomial K profile
-Log Likelihood
256.5
257.0
257.5
258.0
K
2.5
3.0
3.5
4.0
4.5
5.0


OQ1998-1 (SH-3)
Observed and predicted catches
Bushels
0
100
200
300
2
4
6
8
10
12
14
Tow
Efficiency profile
-Log Likelihood
-0.005
0.0
0.005
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
-0.005
0.0
0.005
0.0
0.05
0.10
0.15
Density
Negative Binomial K profile
-Log Likelihood
-0.005
0.0
0.005
-0.005
0.0
0.005
K

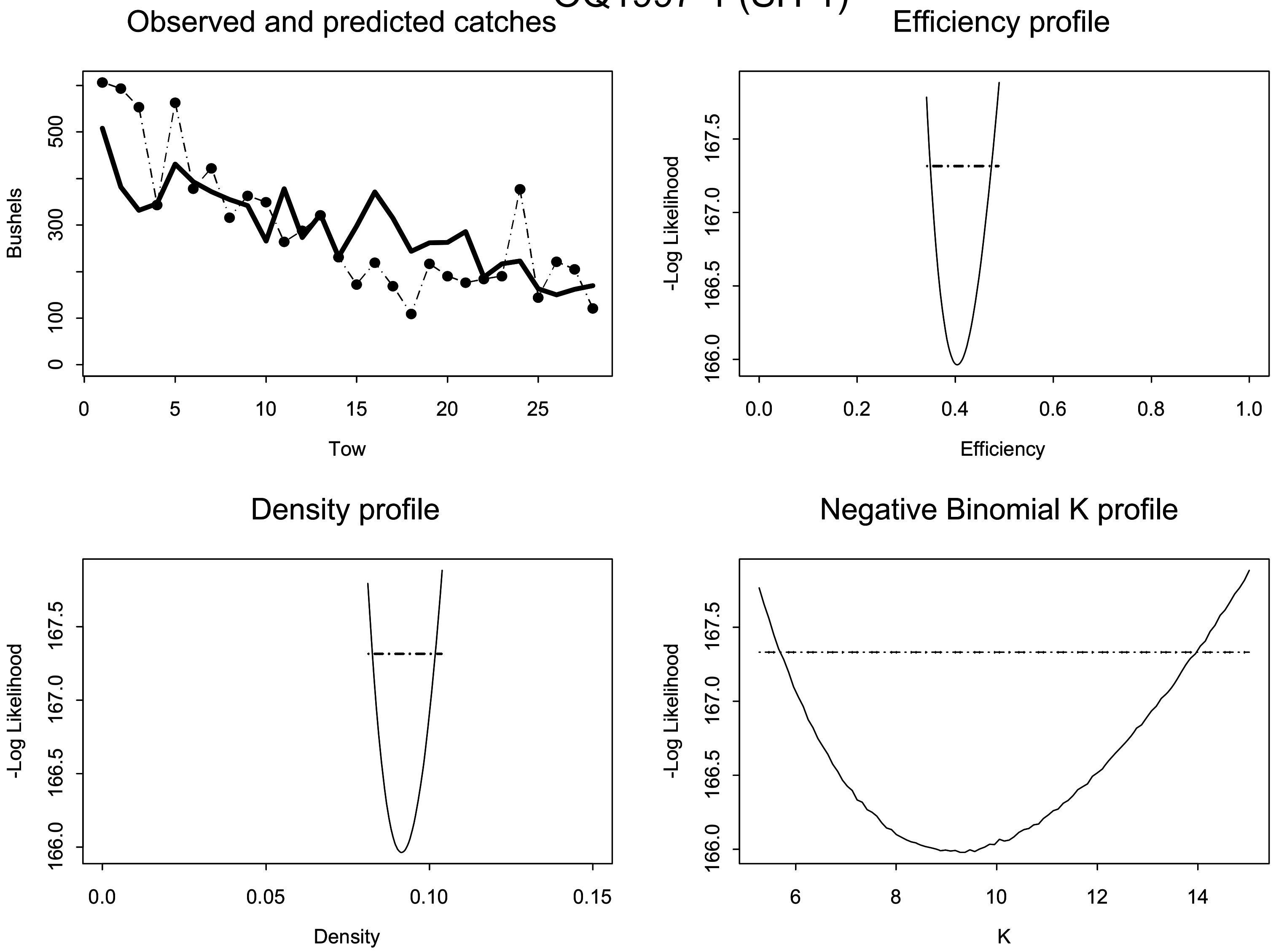
OQ1998-2 (SH-2)


Observed and predicted catches
Bushels
0
200
400
600
800
5
10
15
20
Tow
Efficiency profile
-Log Likelihood
140.5
141.0
141.5
142.0
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
140.5
141.0
141.5
142.0
0.0
0.05
0.10
0.15
Density
Negative Binomial K profile
-Log Likelihood
140.5
141.0
141.5
142.0
6
8
10
12
14
16
18
K

OQ1998-3 (NS-1)


Observed and predicted catches
Bushels
0
1000
3000
5000
Tow
5
10
15
20
Efficiency profile
-Log Likelihood
195.5
196.0
196.5
197.0
Efficiency
0.0
0.2
0.4
0.6
0.8
1.0
Density profile
-Log Likelihood
195.5
196.0
196.5
197.0
Density
0.0
0.05
0.10
0.15
0.20
0.25
0.30
Negative Binomial K profile
-Log Likelihood
196.0
196.5
197.0
K
6
8
10
12

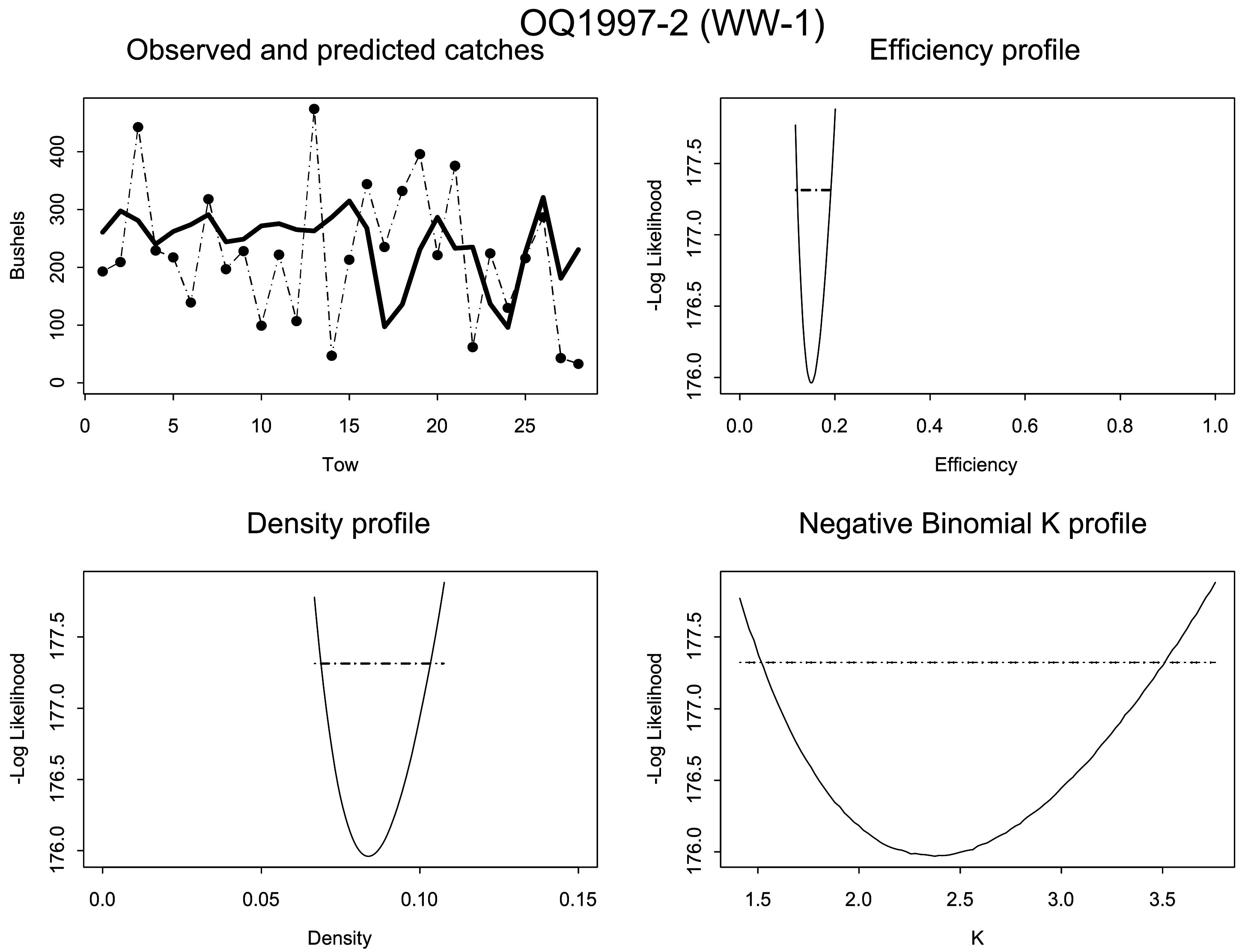
OQ1997-1 (SH-1)


Observed and predicted catches

Efficiency profile

Density profile

Negative Binomial K profile



OQ1997-2 (WW-1)

Observed and predicted catches
Bushels
0
100
200
300
400
0
5
10
15
20
25
Tow
Efficiency profile
-Log Likelihood
176.0
176.5
177.0
177.5
0.0
0.2
0.4
0.6
0.8
1.0
Efficiency
Density profile
-Log Likelihood
176.0
176.5
177.0
177.5
0.0
0.05
0.10
0.15
Density
Negative Binomial K profile
-Log Likelihood
176.0
176.5
177.0
177.5
1.5
2.0
2.5
3.0
3.5
K

APPENDIX A5. Technical description of the KLAMZ stock assessment model.

Larry Jacobson
NEFSC, Woods Hole
May 25, 2007

The KLAMZ assessment model is based on the Deriso-Schnute delay-difference equation (Deriso 1980; Schnute 1985; Quinn and Deriso 1999). The delay-difference equation is a relatively simple and implicitly age structured approach to counting fish in either numerical or biomass units. It gives the same results as explicitly age-structured models (e.g. Leslie matrix model) if fishery selectivity is "knife-edged", if somatic growth follows the von Bertalanffy equation, and if natural mortality is the same for all age groups in each year. Knife-edge selectivity means that all individuals alive in the model during the same year experience the same fishing mortality rate.[9] Natural and fishing mortality rates, growth parameters and recruitment may change from year to year, but delay-difference calculations assume that all individuals share the same mortality and growth parameters within each year. The KLAMZ model includes simple numerical models (e.g. Conser 1995) as special cases because growth can be turned off so that all calculations are in numerical units (see below).

As in many other simple models, the delay difference equation explicitly distinguishes between two age groups. In KLAMZ, the two age groups are called "new" recruits (R_t in biomass or numerical units at the beginning of year *t*) and "old" recruits (S_t) that together comprise the whole stock (B_t). New recruits are individuals that recruited at the beginning of the current year (at nominal age *k)*.[10] Old recruits are all older individuals in the stock (nominal ages *k*+1 and older, survivors from the previous year). As described above, KLAMZ assumes that new and old recruits are fully vulnerable to the fishery. The most important differences between the delay-difference and other simple models (e.g. Prager 1994; Conser 1995; Jacobson et al. 1994) are that von Bertalanffy growth is used to calculate biomass dynamics and that the delay-difference model captures transient age structure effects due to variation in recruitment, growth and mortality exactly. Transient effects on population dynamics are captured exactly because, as described above, the delay-difference equation is algebraically equivalent to an explicitly age-structured model with von Bertalanffy growth.

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[9] In applications, assumptions about knife-edge selectivity can be relaxed by assuming the model tracks "fishable", rather that total, biomass (NEFSC 2000a; 2000b). An analogous approach assigns pseudo-ages based on recruitment to the fishery so that new recruits in the model are all pseudo-age *k*. The synthetic cohort of fish pseudo-age *k* may consist of more than one biological cohort. The first pseudo-age (*k*) can be the predicted age at first, 50% or full recruitment based a von Bertalanffy curve and size composition data (Butler et al. 2002). The "incomplete recruitment" approach (Deriso 1980) calculates recruitment to the model in each year R_t as the weighted sum of contributions from two or more biological cohorts (year-classes) from spawning during successive years (i.e. $R_t = \sum_{a=1}^{k} r_a \Pi_{t-a}$ where k is the age at full recruitment to the fishery, r_a is the contribution of fish age *k-a* to the fishable stock, and Π_{t-a} is the number or biomass of fish age *k-a* during year *t*).

[10] In some applications, and more generally, new recruits might be defined as individuals recruiting at the beginning or at any time during the current time step (e.g. NEFSC 1996).

The KLAMZ model incorporates a few extensions to Schnute's (1985) revision of Deriso's (1980) original delay difference model. Most of the extensions facilitate tuning to a wider variety of data that anticipated in Schnute (1985). The KLAMZ model is programmed in both Excel and in C++ using AD Model Builder[11] libraries. The AD Model Builder version is faster, more reliable and probably better for producing "official" stock assessment results. The Excel version is slower and implements fewer features, but the Excel version remains useful in developing prototype assessment models, teaching and for checking calculations.

The most significant disadvantage in using the KLAMZ model and other delay-difference approaches, beyond the assumption of knife-edge selectivity, is that age and length composition data are not used in tuning. However, one can argue that age composition data are used indirectly to the extent they are used to estimate growth parameters or if survey survival ratios (e.g. based on the Heinke method) are used in tuning (see below).

Population dynamics

The assumed birth date and first day of the year are assumed the same in derivation of the delay-difference equation. It is therefore natural (but not strictly necessary) to tabulate catch and other data using annual accounting periods that start on the assumed biological birthday of cohorts.

Biomass dynamics

As implemented in the KLAMZ model, Schnute's (1985) delay-difference equation is:

$$B_{t+1} = (1+\rho)\,\tau_t\,B_t - \rho\,\tau_t\,\tau_{t-1}\,B_{t-1} + R_{t+1} - \rho\,\tau_t\,J_t\,R_t$$

where B_t is total biomass of individuals at the beginning of year t; ρ is Ford's growth coefficient (see below); $\tau_t=exp(-Z_t)=exp[-(F_t+M_t)]$ is the fraction of the stock that survived in year t, Z_t, F_t, and M_t are instantaneous rates for total, fishing and natural mortality; and R_t is the biomass of new recruits (at age k) at the beginning of the year. The natural mortality rate M_t may vary over time. Instantaneous mortality rates in KLAMZ model calculations are biomass-weighted averages if von Bertalanffy growth is turned on in the model. However, biomass-weighted mortality estimates in KLAMZ are the same as rates for numerical estimates under the assumption of knife-edge selectivity because all individuals are fully recruited. The growth parameter $J_t = w_{t-1,k-1} / w_{t,k}$ is the ratio of mean weight one year before recruitment (age k-1 in year t-1) and mean weight at recruitment (age k in year t).

It is not necessary to specify body weights at and prior to recruitment in the KLAMZ model (parameters v_{t-1} and V_t in Schnute 1985) because the ratio J_t and recruitment biomass contain the same information. Schnute's (1985) original delay difference equation is:

$$B_{t+1} = (1+\rho)\,\tau_t\,B_t - \rho\,\tau_t\tau_{t-1}\,B_{t-1} + w_{t+1,k}N_{t+1} - \rho\tau_t w_{t-1,k-1}\,N_t$$

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[11] Otter Research Ltd., Box 2040, Sydney, BC, Canada V8L 3S3 (otter@otter-rsch.com).

To derive the equation used in KLAMZ, substitute recruitment biomass R_{t+1} for the product $w_{t+1,k} N_{t+1,k}$ and adjusted recruitment biomass $J_t R_t = (w_{t-1,k-1}/w_{t,k})\, w_{t,k}\, N_{t,k} = w_{t-1,k-1}\, N_t$ in the last term on the right hand side. The advantage in using the alternate parameterization for biomass dynamic calculations in KLAMZ is that recruitment is estimated directly in units of biomass and the number of growth parameters is reduced. The disadvantage is that numbers of recruits are not estimated directly by the model. When required, numerical recruitments must be calculated externally as the ratio of estimated recruitment biomass and the average body weight for new recruits.

Numerical population dynamics

Growth can be turned on off so that abundance, rather than biomass, is tracked in the KLAMZ model. Set J_t=1 and ρ=0 in the delay difference equation, and use N_t (for numbers) in place of B_t to get:

$$\mathrm{N}_{t+1} = \tau_t\, \mathrm{N}_t + \mathrm{R}_{t+1}$$

Mathematically, the assumption J_t=1 means that no growth occurs the assumption ρ=0 means that the von Bertalanffy K parameter is infinitely large (Schnute 1985). All tuning and population dynamics calculations in KLAMZ for biomass dynamics are also valid for numerical dynamics.

Growth

As described in Schnute (1985), biomass calculations in the KLAMZ model are based on Schnute and Fournier's (1980) re-parameterization of the von Bertalanffy growth model:

$$\mathrm{w}_a = \mathrm{w}_{k-1} + (\mathrm{w}_k - \mathrm{w}_{k-1})\,(1+\rho^{1+a-k})\,/\,(1-\rho)$$

where w_k=V and w_{k-1}=v. Schnute and Fournier's (1980) growth model is the same as the traditional von Bertalanffy growth model {$W_a = W_{max}\,[1 - \exp(-K(a-t_{zero})]$ where W_{max}, K and t_{zero} are parameters}. The two growth models are the same because $W_{max} = (w_k - \rho\, w_{k-1})/(1-\rho)$, $K = -\ln(\rho)$ and $t_{zero} = \ln[(w_k - w_{k-1})/(w_k - \rho\, w_{k-1})]\,/\,\ln(\rho)$.

In the KLAMZ model, the growth parameters J_t can vary with time but ρ is constant. Use of time-variable J_t values with ρ is constant is the same as assuming that the von Bertalanffy parameters W_{max} and t_{zero} change over time. Many growth patterns can be mimicked by changing W_{max} and t_{zero} (Overholtz et al., 2003). K is a parameter in the C++ version and, in principal, estimable. However, in most cases it is necessary to use external estimates of growth parameters as constants in KLAMZ.

Instantaneous growth rates

Instantaneous growth rate (IGR) calculations in the KLAMZ model are an extension to the original Deriso-Schnute delay difference model. IGRs are used extensively in KLAMZ for calculating catch biomass and projecting stock biomass forward to the time at which surveys occur. The IGR for new recruits depends only on growth parameters:

$$G_t^{New} = \ln\left(\frac{w_{k+1,t+1}}{w_{k,t}}\right) = \ln(1+\rho-\rho J_t)$$

IGR for old recruits is a biomass-weighted average that depends on the current age structure and growth parameters. It can be calculated easily by projecting biomass of old recruits $S_t=B_t-R_t$ (escapement) forward one year with no mortality:

$$S_t^* = (1+\rho)S_t - \rho\tau_{t-1}B_{t-1}$$

where the asterisk (*) means just prior to the start of the subsequent year t+1. By definition, the IGR for old recruits in year t is $G_t^{Old} = \ln(S_t^*/S_t)$. Dividing by S_t gives:

$$G_t^{Old} = \ln\left[(1+\rho) - \rho\tau_{t-1}\frac{B_{t-1}}{S_t}\right]$$

IGR for the entire stock is the biomass weighted average of the IGR values for new and old recruits:

$$G_t = \frac{R_t G_t^{New} + S_t G_t^{Old}}{B_t}$$

All IGR values are zero if growth is turned off.

Recruitment

In the Excel version of the KLAMZ model, annual recruitments are calculated $R_t = e^{\Omega_t}$ where Ω_t is a log transformed annual recruitment parameter, which is estimated in the model. In the C++ version, recruitments are calculated based on log geometric mean recruitment (μ) and a set of annual log scale deviation parameters (ω_t):

$$\Omega_t = \mu + \omega_t$$

The deviations ω_t are constrained to average zero.[12] With the constraint, estimation of μ and the set of ω_t values (1+ n years parameters) is equivalent to estimation of the smaller set (n years) of Ω_t values.

Natural mortality

Natural mortality rates (M_t) are assumed constant in the Excel version of the KLAMZ model. In the C++ version, natural mortality rates may be estimated as a constant value or as a set of values that vary with time. In the model:

$$M_t = me^{\varpi_t}$$

where $m=exp(\pi)$ is the geometric mean natural mortality rate, π is a model parameter that may be estimated (in principal but not in practical terms), and ϖ_t is the log scale year-specific deviation. Deviations may be zero (turned off) so that M_t is constant, may vary in a random fashion due to autocorrelated or independent process errors, or may be

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[12] The constraint is implemented by adding $L = \lambda\overline{\varpi}^2$ (where $\overline{\varpi}$ is the average deviation) to the objective function, generally with a high weighting factor (λ = 1000) so that the constraint is binding.

based on a covariate.[13] Model scenarios with zero recruitment may be initializing the parameter π to a small value (e.g. 10^{-16}) and not estimating it.

Random natural mortality process errors are effects due to predation, disease, parasitism, ocean conditions or other factors that may vary over time but are not included in the model. Calculations are basically the same as for survey process errors (see below).

Natural mortality rate covariate calculations are similar to survey covariate calculations (see below) except that the *user should standardized covariates to average zero over the time period included in the model*:

$$\kappa_t = K_t - \overline{K}$$

where κ_t is the standardized covariate, K_t is the original value, and $\overline{K}$ is the mean of the original covariate for the years in the model. *Standardization to mean zero is important because otherwise m is not the geometric mean natural mortality rate* (the convention is important in some calculations, see text).

Log scale deviations that represent variability around the geometric mean are calculated:

$$\varpi_t = \sum_{j=1}^{n} p_j \kappa_t$$

where n is the number of covariates and p_j is the parameter for covariate j. These conventions mean that the units for the covariate parameter p_j are 1/units of the original covariate, the parameter p_j measures the log scale effect of changing the covariate by one unit, and the parameter m is the log scale geometric mean.

Fishing mortality and catch

Fishing mortality rates (F_t) are calculated so that predicted and observed catch data (landings plus estimated discards in units of weight) "agree" to the extent specified by the user. It is not necessary, however, to assume that catches are measured accurately (see "Observed and predicted catch").

Fishing mortality rate calculations in Schnute (1985) are exact but relating fishing mortality to catch in weight is complicated by continuous somatic growth throughout the year as fishing occurs. The KLAMZ model uses a generalized catch equation that incorporates continuous growth through the fishing season. By the definition of instantaneous rates, the catch equation expresses catch as the product:

$$\hat{C}_t = F_t \overline{B}_t$$

where $\hat{C}_t$ is predicted catch weight (landings plus discard) and $\overline{B}_t$ is average biomass.

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[13] Another approach to using time dependent natural mortality rates is to treat estimates of predator consumption as discarded catch (see "Predator consumption as discard data"). In addition, estimates of predator abundance can be used in fishing effort calculations (see "Predator data as fishing effort").

Following Chapman (1971) and Zhang and Sullivan (1988), let $X_t=G_t-F_t-M_t$ be the net instantaneous rate of change for biomass.[14] If the rates for growth and mortality are equal, then $X_t=0$, $\overline{B}_t = B_t$ and $C_t = F_t B_t$. If the growth rate G_t exceeds the combined rates of natural and fishing mortality ($F_t + M_t$), then $X_t > 0$. If mortality exceeds growth, then $X_t < 0$. In either case, with $X_t \neq 0$, average biomass is computed:

$$\overline{B}_t \approx -\frac{\left(1-e^{X_t}\right)B_t}{X_t}$$

When $X_t \neq 0$, the expression for $\overline{B}_t$ is an approximation because G_t approximates the rate of change in mean body weight due to von Bertalanffy growth. However, the approximation is reasonably accurate and preferable to calculating catch biomass in the delay-difference model with the traditional catch equation that ignores growth during the fishing season.[15] Average biomass can be calculated for new recruits, old recruits or for the whole stock by using either G_t^{New}, G_t^{Old} or G_t.

In the KLAMZ model, the modified catch equation may be solved analytically for F_t given C_t, B_t, G_t and M_t (see the "Calculating F_t" section below). Alternatively, fishing mortality rates can be calculated using a log geometric mean parameter (Φ) and a set of annual log scale deviation parameters (ψ_t):

$$F_t = e^{\Phi+\psi_t}$$

where the deviations ψ_t are constrained to average zero. When the catch equation is solved analytically, catches must be assumed known without error but the analytical option is useful when catch is zero or very near zero, or the range of fishing mortality rates is so large (e.g. minimum F=0.000001 to maximum F=3) that numerical problems occur with the alternative approach. The analytical approach is also useful if the user wants to reduce the number of parameters estimated by nonlinear optimization. In any case, the two methods should give the same results for catches known without error.

Surplus production

Annual surplus production is calculated "exactly" by projecting biomass at the beginning of each year forward with no fishing mortality:

$$\mathrm{B}_t^* = (1+\rho)\, \mathrm{e}^{-\mathrm{M}}\, \mathrm{B}_t - \rho\, \mathrm{e}^{-\mathrm{M}}\, \mathrm{L}_{t-1}\, \mathrm{B}_{t-1} - \rho\, \mathrm{e}^{-\mathrm{M}}\, \mathrm{J}_t\, \mathrm{R}_t$$

By definition, surplus production $P_t=B^*_t-B_t$ (Jacobson et al. 2002).

Per recruit modeling

Per recruit model calculations in the Excel version of the KLAMZ simulate the life of a hypothetical cohort of arbitrary size (e.g. R=1000) starting at age k with constant

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[14] By convention, the instantaneous rates G_t, F_t and M_t are always expressed as numbers ≥ 0.

[15] The traditional catch equation $C_t = F_t(1-e^{-Z_t})B_t/Z_t$ where $Z_t=F_t+M_t$ underestimates catch biomass for a given level of fishing mortality F_t and overestimates F_t for a given level of catch biomass. The errors can be substantial for fast growing fish, particularly if recent recruitments were strong.

M_t, F (survival) and growth (ρ and J) in a population initially at zero biomass. In the first year:

$$B_1 = R$$

In the second year:

$$B_2 = (1+\rho)\, \tau\, B_1 - \rho\, \tau\, J\, R_1$$

In the third and subsequent years:

$$B_{t+1} = (1+\rho)\, \tau\, B_t - \rho\, \tau^2\, B_{t-1}$$

This iterative calculation is carried out until the sum of lifetime cohort biomass from one iteration to the next changes by less than a small amount (0.0001). Total lifetime biomass, spawning biomass and yield in weight are calculated by summing biomass, spawning biomass and yield over the lifetime of the cohort. Lifetime biomass, spawning biomass and yield per recruit are calculated by dividing totals by initial recruitment (R).

Status determination variables

The user may specify a range of years (e.g. the last three years) to use in calculating recent average fishing mortality $\overline{F}_{\mathrm{Re}cent}$ and biomass $\overline{B}_{\mathrm{Re}cent}$ levels. These status determination variables are used in calculation of status ratios such as $\overline{F}_{\mathrm{Re}cent} / F_{MSY}$ and $\overline{B}_{\mathrm{Re}cent}$/$B_{MSY}$.

Goodness of Fit and Parameter Estimation

Parameters estimated in the KLAMZ model are chosen to minimize an objective function based on a sum of weighted negative log likelihood (NLL) components:

$$\Xi = \sum_{v=1}^{N_\Xi} \lambda_v L_v$$

where N_Ξ is the number of NLL components (L_v) and the λ_v are emphasis factors used as weights. The objective function Ξ may be viewed as a NLL or a negative log posterior (NLP) distribution, depending on the nature of the individual L_v components and modeling approach. Except during sensitivity analyses, weighting factors for objective function components (λ_v) are usually set to one. An arbitrarily large weighting factor (e.g. λ_v =1000) is used for "hard" constraints that must be satisfied in the model. Arbitrarily small weighting factors (e.g. λ_v =0.0001) can be used for "soft" model-based constraints. For example, an internally estimated spawner-recruit curve or surplus production curve might be estimated with a small weighting factor to summarize stock-recruit or surplus production results with minimal influence on biomass, fishing mortality and other estimates from the model. Use of a small weighting factor for an internally estimated surplus production or stock-recruit curve is equivalent to fitting a curve to model estimates of biomass and recruitment or surplus production in the output file, after the model is fit (Jacobson et al. 2002).

Likelihood component weights vs. observation-specific weights

Likelihood component weights (λ_v) apply to entire NLL components. Entire components are often computed as the sum of a number of individual NLL terms. The NLL for an entire survey, for example, is composed of NLL terms for each of the annual survey observations. In KLAMZ, observation-specific (for data) or instance-specific (for constraints or prior information) weights (usually w_j for observation or instance j) can be specified as well. Observation-specific weights for a survey, for example, might be use to increase or decrease the importance of one or more observations in calculating goodness of fit.

NLL kernels

NLL components in KLAMZ are generally programmed as "concentrated likelihoods" to avoid calculation of values that do not affect derivatives of the objective function.[16] For x~N(μ,σ^2), the complete NLL for one observation is:

$$L = \ln(\sigma) + \ln\left(\sqrt{2\pi}\right) + 0.5\left(\frac{x-u}{\sigma}\right)^2$$

The constant $\ln\left(\sqrt{2\pi}\right)$ can always be omitted because it does not affect derivatives. If the standard deviation is known or assumed known, then ln(σ) can be omitted as well because it is a constant that does not affect derivatives. In such cases, the concentrated negative log likelihood is:

$$L = 0.5\left(\frac{x-\mu}{\sigma}\right)^2$$

If there are N observations with possible different variances (known or assumed known) and possibly different expected values:

$$L = 0.5\sum_{i=1}^{N}\left(\frac{x_i-\mu_i}{\sigma_i}\right)^2$$

If the standard deviation for a normally distributed quantity is not known and is (in effect) estimated by the model, then one of two equivalent calculations is used. Both approaches assume that all observations have the same variance and standard deviation. The first approach is used when all observations have the same weight in the likelihood:

$$L = 0.5N\ln\left[\sum_{i=1}^{N}(x_i-u)^2\right]$$

where N is the number of observations. The second approach is equivalent but used when the weights for each observation (w_i) may differ:

$$L = \sum_{i=1}^{N} w_i\left[\ln(\sigma) + 0.5\left(\frac{x_i-u}{\sigma}\right)^2\right]$$

In the latter case, the maximum likelihood estimator:

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[16] Unfortunately, concentrated likelihood calculations cannot be used with MCMC and other Bayesian approaches to characterizing posterior distributions. Therefore, in the near future, concentrated NLL calculations will be replaced by calculations for the entire NLL. At present, MCMC calculations in KLAMZ are not useful.

$$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \hat{x})^2}{N}}$$

(where $\hat{x}$ is the average or predicted value from the model) is used for σ. The maximum likelihood estimator is biased by $N/(N-d_f)$ where d_f is degrees of freedom for the model. The bias may be significant for small sample sizes but d_f is usually unknown.

Landings, discards, catch

Discards are from external estimates (d_t) supplied by the user. If $d_t \geq 0$, then the data are used as the ratio of discard to landed catch so that:

$$D_t = L_t \Delta_t$$

where $\Delta_t = D_t/L_t$ is the discard ratio. If $d_t < 0$ then the data are treated as discard in units of weight:

$$D_t = abs(d_t).$$

In either case, total catch is the sum of discards and landed catch ($C_t = L_t + D_t$). It is possible to use discards in weight $d_t < 0$ for some years and discard as proportions $d_t > 0$ for other years in the same model run. If catches are estimated (see below) so that the estimated catch $\hat{C}_t$ does not necessarily equal observed landings plus discard, then estimated landings are computed:

$$\hat{L}_t = \frac{\hat{C}_t}{1 + \Delta_t}$$

and estimated discards are:

$$\hat{D}_t = \Delta_t \hat{L}_t.$$

Calculating F_t

As described above, fishing mortality rates may be estimated based on the parameters Φ and ψ_t to satisfy a NLL for observed and predicted catches:

$$L = 0.5 \sum_{t=0}^{N} w_t \left(\frac{\hat{C}_t - C_t}{\kappa_t} \right)^2$$

where the standard error $\kappa_t = CV_{catch} \hat{C}_t$ with CV_{catch} and weights are w_t supplied by the user. The weights can be used, for example, if catch data in some years are less precise than in others. Using observation specific weights, any or every catch in the time series can potentially be estimated.

The other approach to calculating F_t values is by solving the generalized catch equation (see above) iteratively. Subtracting predicted catch from the generalized catch equation gives:

$$g(F_t) = C_t + \frac{F_t\left(1 - e^{X_t}\right)}{X_t} B_t = 0$$

where $X_t = G_t - M_t - F_t$. If $X_t = 0$, then $\overline{B}_t = B_t$ and $F_t = C_t/B_t$.

If $X_t \neq 0$, then the Newton-Raphson algorithm is used to solve for F_t (Kennedy and Gentle 1980). At each iteration of the algorithm, the current estimate F_t^i is updated using:

$$F_t^{i+1} = F_t^i - \frac{g\left(F_t^i\right)}{g'\left(F_t^i\right)}$$

where $g'\left(F_t^i\right)$ is the derivative F_t^i. Omitting subscripts, the derivative is:

$$g^{'}(F) = -\frac{Be^{-F}\left[\left(e^F - e^\gamma\right)\gamma + e^\gamma F\gamma - e^\gamma F^2\right]}{X^2}$$

where $\gamma = G - M_t$. Iterations continue until $g\left(F_t^i\right)$ and $abs\left[g\left(F_t^{i+1}\right) - g\left(F_t^{i+1}\right)\right]$ are both less than a small number (e.g. ≤ 0.00001).

Initial values are important in algorithms that solve the catch equation numerically (Sims 1982). If $M_t + F_t > G_t$ so that $X_t < 0$, then the initial value F_t^0 is calculated according to Sims (1982). If $M_t + F_t < G_t$ so that $X_t > 0$, then initial values are calculated based on a generalized version of Pope's cohort analysis (Zhang and Sullivan 1988):

$$F_t^0 = \gamma_t - \ln\left[\frac{\left(B_t e^{0.5\gamma_t} - C_t\right)e^{0.5\gamma_t}}{B_t}\right]$$

F for landings versus F for discards

The total fishing mortality rate for each year can be partitioned into a component due to landed catch ${}^L F_t = \frac{D_t}{C_t} F_t$, and a component due to discard ${}^D F_t = \frac{L_t}{C_t} F_t$.

Predator consumption as discard data

In modeling population dynamics of prey species, estimates of predator consumption can be treated like discard in the KLAMZ model as a means for introducing time dependent natural mortality. Consider a hypothetical example with consumption data (mt y^{-1}) for three important predators. If the aggregate consumption data are included in the model as "discards", then the fishing mortality rate for discards ${}^d F_t$ (see above) would be an estimate of the component of natural mortality due to the three predators. In using this approach, the average level of natural mortality m would normally be reduced (e.g. so that $m_{new} + {}^d\overline{F} = m_{old}$) or estimated to account for the portion of natural mortality attributed to bycatch.

Surplus production calculations are harder to interpret if predator consumption is treated as discard data because surplus production calculations assume that $F_t = 0$ (see above) and because surplus production is defined as the change in biomass from one year to the next in the absence of fishing (i.e. no landings or bycatch). However, it may be useful to compare surplus production at a given level of biomass from runs with and without consumption data as a means of estimating maximum changes in potential fishery yield if the selected predators were eliminated (assuming no change in disease, growth rates, predation by other predators, etc.).

Effort calculations

Fishing mortality rates can be tuned to fishing effort data for the “landed” catch (i.e. excluding discards). Years with non-zero fishing effort used in the model must also have landings greater than zero. Assuming that effort data are lognormally distributed, the NLL for fishing effort is:

$$NLL = 0.5\sum_{y=1}^{n_{eff}} w_y \left[\frac{\ln\left(E_y / \hat{E}_y\right)}{\sigma} \right]^2$$

where w_y is an observation-specific weight, n_{eff} is the number of active effort observations (i.e. with $w_y > 0$), E_y and $\overline{E}_y$ are observed and predicted fishing effort data, and the log scale variance σ is a constant calculated from a user-specified CV.

Predicted fishing effort data are calculated:

$$\hat{E}_y = \zeta F_y^{\vartheta}$$

where $\zeta = e^u$, $\vartheta = e^b$, and u and b are parameters estimated by the model. If the parameter b is not estimated, then $\vartheta=1$ so that the relationship between fishing effort and fishing mortality is linear. If the parameter b is estimated, then $\vartheta \neq 1$ and the relationship is a power function.

Predator data as fishing effort

As described under “Predator consumption as discard data”, predator consumption data can be treated as discard. If predator abundance data are available as well, and assuming that mortality due predators is a linear function of the predator-prey ratio, then both types of data may be used together to estimate natural mortality. The trick is to: 1) enter the predator abundance data as fishing effort; 2) enter the actual fishery landings as “discard”; 3) enter predator consumption estimates of the prey species as “landings” so that the fishing effort data in the refer to the predator consumption data; 4) use an option in the model to calculate the predator-prey ratio for use in place of the original predator abundance “fishing effort” data; and 5) tune fishing mortality rates for landings (a.k.a. predator consumption) to fishing effort (a.k.a. predator-prey ratio).

Given the predator abundance data κ_y, the model calculates the predator-prey ratio used in place of fishing effort data (E_y) as:

$$E_y = \frac{\kappa_y}{B_y}$$

where B_y is the model’s current estimate of total (a.k.a “prey”) biomass. Subsequent calculations with E_y and the model’s estimates of “fishing mortality” (F_y, really a measure of natural mortality) are exactly as described above for effort data. In using this approach, it is probably advisable to reduce *m* (the estimate of average mortality in the model) to account for the proportion of natural mortality due to predators included in the calculation. Based on experience to date, natural mortality due to consumption by the suite of predators can be estimated but only if *m* is assumed known.

Initial population age structure

In the KLAMZ model, old and new recruit biomass during the first year (R_1 and $S_1 = B_1 - R_1$) and biomass prior to the first year (B_0) are estimated as log scale parameters. Survival in the year prior to the first year ("year 0") is $\tau_0 = e^{-F_0 - M_1}$ with F_0 chosen to obtain catch C_0 (specified as data) from the estimated biomass B_0. IGRs during year 0 and year 1 are assumed equal ($G_0 = G_1$) in catch calculations.

Biomass in the second year of as series of delay-difference calculations depends on biomass (B_0) and survival (τ_0) in year 0:

$$\mathrm{B}_2 = (1+\rho)\,\tau_1\,\mathrm{B}_1 - \rho\,\tau_1\,\tau_0\,\mathrm{B}_0 + \mathrm{R}_2 - \rho\,\tau_1\,\mathrm{J}_1\,\mathrm{R}_1$$

There is, however, there is no direct linkage between B_0 and escapement biomass ($S_1 = B_1 - R_1$) at the beginning of the first year.

The missing link between B_0, S_1 and B_1 means that the parameter for B_0 tends to be relatively free and unconstrained by the underlying population dynamics model. In some cases, B_0 can be estimated to give good fit to survey and other data, while implying unreasonable initial age composition and surplus production levels. In other cases, B_0 estimates can be unrealistically high or low implying, for example, unreasonably high or low recruitment in the first year of the model (R_1). Problems arise because many different combinations of values for R_1, S_1 and B_0 give similar results in terms of goodness of fit. This issue is common in stock assessment models that use forward simulation calculations because initial age composition is difficult to estimate. It may be exacerbated in delay-difference models because age composition data are not used.

The KLAMZ model uses two constraints to help estimate initial population biomass and initial age structure.[17] The first constraint links IGRs for escapement (G^{Old}) in the first years to a subsequent value. The purpose of the constraint is to ensure consistency in average growth rates (and implicit age structure) during the first few years. For example, if IGRs for the first n_G years are constrained[18], then the NLL for the penalty is:

$$L_G = 0.5 \sum_{t=1}^{n_G} \left[\frac{\ln\left(G_t^{Old} \middle/ G_{n_G+1}^{Old}\right)}{\sigma_G} \right]^2$$

where the standard deviation σ_G is supplied by the user. It is usually possible to use the standard deviation of Q_t^{Old} for later years from a preliminary run to estimate σ_G for the first few years. The constraint on initial IGRs should probably be "soft" and non-binding ($\lambda \approx 1$) because there is substantial natural variation in somatic growth rates due to variation in age composition.

The second constraint links B_0 to S_1 and ensures conservation of mass in population dynamics between years 0 and 1. In other words, the parameter for escapement biomass in year 1 is constrained to match an approximate projection of the biomass in year 0, accounting for growth, and natural and fishing mortality. The constraint is intended to be binding and satisfied exactly (e.g. $\lambda = 1000$) because incompatible values of S_1 and B_0 are biologically impossible. In calculations:

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[17] Quinn and Deriso (1999) describe another approach attributed to a manuscript by C. Walters.

[18] Normally, $n_G \le 2$.

$$S_1^p = B_0 e^{G_1 - F_0 - M_1}$$

where S_1^p is the projected escapement in year 1 and B_0 is the model's estimate of total biomass in year 0. The instantaneous rates for growth and natural mortality from year 1 (G_1 and M_1) are used in place of G_0 and M_0 because the latter are unavailable. The NLL for the constraint:

$$L = \left[\ln\left(\frac{S_1^p}{S_1} \right)^2 \right]^2 + \left(S_1^p - S_1 \right)^2$$

uses a log scale sum of squares and an arithmetic sum of squares. The former is effective when S_1 is small while the latter is effective when S_1 is large. Constants and details in calculation of NLL for the constraint are not important because the constraint is binding (e.g. λ=1000).

Equilibrium pristine biomass

It may be useful to constrain the biomass estimate for the first year in a model run towards an estimate of equilibrium pristine biomass if, for example, stock dynamics tend to be stable and catch data are available for the first years of the fishery, or as an alternative to the approach described above for initializing the age structure of the simulated population in the model. Equilibrium pristine biomass $\widetilde{B}_0$ is calculated based on the model's estimate of average recruitment and with no fishing mortality (calculations are similar to those described under "Per-recruit modeling" except that average recruitment is assumed in each year).[19] The NLL term for the constraint is:

$$L = \ln\left(\frac{\widetilde{B}_0}{B_0} \right)^2$$

Pristine equilibrium biomass is used as a hard constraint with a high emphasis factor (λ) so that the variance and constants normally used in NLL calculations are not important.

Estimating natural mortality

As described above, natural mortality calculations involve a parameter for the geometric mean value (m) and time dependent deviations (ϖ_t, which may or may not be turned on). Constraints on natural mortality process errors and natural mortality covariates can be used to help estimate the time dependent deviations and overall trend. The geometric mean natural mortality rate is usually difficult to estimate and best treated as a known constant. However, in the C++ version of the KLAMZ model, $m=e^{\pi}$ (where π is an estimable parameter in the model) and estimates of m can be conditioned on the constraint:

$$L = 0.5 \left[\frac{\ln\left(w / w_{Target} \right)}{\sigma_{\varpi}} \right]^2$$

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[19] Future versions of the KLAMZ model will allow equilibrium initial biomass to be calculated based on other recruitment values and for a user-specified level of F (Butler et al. 2003).

where w_{Target} is a user supplied mean or target value and σ_{ϖ} is a log scale standard deviation. The standard deviation is calculated from an arithmetic scale CV supplied by the user. Upper and lower bounds for m may be specified as well.

Goodness of fit for trend data

Assuming lognormal errors[20], the NLL used to measure goodness-of-fit to "survey" data that measure trends in abundance or biomass (or survival, see below) is:

$$L = 0.5 \sum_{j=1}^{N_v} \left[\frac{\ln\left(I_{v,j} \Big/ \hat{I}_{v,j} \right)}{\sigma_{v,j}} \right]^2$$

where $I_{v,t}$ is an index datum from survey v, hats "^" denote model estimates, $\sigma_{v,j}$ is a log scale standard error (see below), and N_v is the number of observations. There are two approaches to calculating standard errors for log normal abundance index data in KLAMZ and it is possible to use different approaches for different types of abundance index data in the same model (see below).

Standard errors for goodness of fit

In the first approach, all observations for one type of abundance index share the same standard error, which is calculated based on overall goodness of fit. This approach implicitly estimates the standard error based on goodness of fit, along with the rest of the parameters in the model (see "NLL kernels" above).

In the second approach, each observation has a potentially unique standard error that is calculated based on its CV. The second approach calculates log scale standard errors from arithmetic CVs supplied as data by the user (Jacobson et al. 1994):

$$\sigma_{v,t} = \sqrt{\ln\left(1 + CV_{v,t}^2\right)}$$

Arithmetic CV's are usually available for abundance data. It may be convenient to use $CV_{v,t}$=1.31 to get $\sigma_{v,t}$=1.

There are advantages and disadvantages to both approaches. CV's carry information about the relative precision of abundance index observations. However, CV's usually overstate the precision of data as a measure of fish abundance[21] and may be misleading in comparing the precision of one sort of data to another as a measure of trends in abundance (e.g. in contrasting standardized LPUE that measure fishing success, but not abundance, precisely with survey data that measure trends in fish abundance

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[20] Abundance indices with statistical distributions other than log normal may be used as well, but are not currently programmed in the KLAMZ model. For example, Butler et al. (2003) used abundance indices with binomial distributions in a delay-difference model for cowcod rockfish. The next version of KLAMZ will accommodate presence-absence data with binomial distributions.

[21] The relationship between data and fish populations is affected by factors (process errors) that are not accounted for in CV calculations.

directly, but not precisely). Standard errors estimated implicitly are often larger and more realistic, but assume that all observations in the same survey are equally reliable.

Predicted values for abundance indices

Predicted values for abundance indices are calculated:

$$\hat{I}_{v,t} = Q_v A_{v,t}$$

where Q_v is a survey scaling parameter (constant here but see below) that converts units of biomass to units of the abundance index. $A_{v,t}$ is available biomass at the time of the survey.

In the simplest case, available biomass is:

$$A_{v,t} = s_{v,New} R_t e^{-X_t^{New} \Delta_{v,t}} + s_{v,Old} S_t e^{-X_t^{Old} \Delta_{v,t}}$$

where $s_{v,New}$ and $s_{v,Old}$ are survey selectivity parameters for new recruits (R_t) and old recruits (S_t); $X_t^{New} = G_t^{New} - F_t - M_t$ and $X_t^{Old} = G_t^{Old} - F_t - M_t$; $j_{v,t}$ is the Julian date at the time of the survey, and $\Delta_{v,t}=j_{v,t}/365$ is the fraction of the year elapsed at the time of the survey.

Survey selectivity parameter values ($s_{v,New}$ and $s_{v,Old}$) are specified by the user and must be set between zero and one. For example, a survey for new recruits would have $s_{v,New}=1$ and $s_{v,Old}=0$. A survey that measured abundance of the entire stock would have $s_{v,New}=1$ and $s_{v,Old}=1$.

Terms involving $\Delta_{v,t}$ are used to project beginning of year biomass forward to the time of the survey, making adjustments for mortality and somatic growth.[22] As described below, available biomass $A_{v,t}$ is adjusted further for nonlinear surveys, surveys with covariates and surveys with time variable $Q_{v,t}$.

Scaling parameters (Q) for log normal abundance data

Scaling parameters for surveys with lognormal statistical errors were computed using the maximum likelihood estimator:

$$Q_v = e^{\frac{\sum_{i=1}^{N_v} \left[\ln\left(\frac{I_{v,i}}{A_{v,i}} \right) \Big/ \sigma_{v,j}^2 \right]}{\sum_{j=1}^{N_j} \left(1 \big/ \sigma_{v,j}^2 \right)}}$$

where N_v is the number of observations with individual weights greater than zero. The closed form maximum likelihood estimator gives the same answer as if scaling parameters are estimated as free parameters in the assessment model assuming lognormal survey measurement errors.

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[22] It may be important to project biomass forward if an absolute estimate of biomass is available (e.g. from a hydroacoustic or daily egg production survey), if fishing mortality rates or high or if the timing of the survey varies considerably from year to year.

Survey covariates

Survey scaling parameters may vary over time based on covariates in the KLAMZ model. The survey scaling parameter that measures the relationship between available biomass and survey data becomes time dependent:

$$\hat{I}_{v,t} = Q_{v,t} A_{v,t}$$

and

$$Q_{v,t} = Q_v e^{\sum_{r=1}^{n_v} d_{r,t} \theta_r}$$

with n_v covariates for the survey and parameters θ_r estimated in the model. Covariate effects and available biomass are multiplied to compute an adjusted available biomass:

$$A'_{v,t} = A_{v,t} e^{\sum_{r=1}^{n_v} d_{r,t} \theta_r}$$

The adjusted available biomass $A'_{v,t}$ is used instead of the original value $A_{v,t}$ in the closed form maximum likelihood estimator described above.

Covariates might include, for example, a dummy variable that represents changes in survey bottom trawl doors or a continuous variable like average temperature data if environmental factors affect distribution and catchability of fish schools. Dummy variables are usually either 0 or 1, depending on whether the effect is present in a particular year. With dummy variables, Q_v is the value of the survey scaling parameter with no intervention ($d_{r,t}$=0).

For ease in interpretation of parameter estimates for continuous covariates (e.g. temperature data), it is useful to center covariate data around the mean:

$$d_{r,t} = d'_{r,t} - \overline{d'_r}$$

where $d'_{r,t}$ is the original covariate. When covariates are continuous and mean-centered, Q_v is the value of the survey scaling parameter under average conditions ($d_{r,t}$=0) and units for the covariate parameter are easy to interpret (for example, units for the parameter are 1/°C if the covariate is mean centered temperature in °C).

It is possible to use a survey covariate to adjust for differences in relative stock size from year to year due to changes in the timing of a survey. However, this adjustment may be made more precisely by letting the model calculate $\Delta_{v,t}$ as described above, based on the actual timing data for the survey during each year.

Nonlinear abundance indices

With nonlinear abundance indices, and following Methot (1990), the survey scaling parameter is a function of available biomass:

$$Q_{v,t} = Q_v A_{v,t}^{\Gamma}$$

so that:

$$\hat{I}_{v,t} = \left(Q_v A_{v,t}^{\Gamma}\right) A_{v,t}$$

Substituting $e^{\gamma}=\Gamma+1$ gives the equivalent expression:

$$\hat{I}_{v,t}=Q_v A_{v,t}^{e^{\gamma}}$$

where γ is a parameter estimated by the model and the survey scaling parameter is no longer time dependent. In calculations with nonlinear abundance indices, the adjusted available biomass:

$$A'_{v,t}=A_{v,t}^{e^{\gamma}}$$

is computed first and used in the closed form maximum likelihood estimator described above to calculate the survey scaling parameter. In cases where survey covariates are also applied to a nonlinear index, the adjustment for nonlinearity is carried out first.

Survey Q process errors

The C++ version of the KLAMZ model can be used to allow survey scaling parameters to change in a controlled fashion from year to year (NEFSC 2002):

$$Q_{v,t}=Q_v e^{\varepsilon_{v,t}}$$

where the deviations $\varepsilon_{v,t}$ are constrained to average zero. Variation in survey Q values is controlled by the NLL penalty:

$$L=0.5\sum_{j=1}^{N_v}\left[\frac{\varepsilon_{v,j}}{\sigma_v}\right]^2$$

where the log scale standard deviation σ_v based on an arithmetic CV supplied by the user (e.g. see NEFSC 2002). In practice, the user increases or decreases the amount of variability in Q by decreasing or increasing the assumed CV.

<u>Survival ratios as surveys</u>

In the C++ version of KLAMZ, it is possible to use time series of survival data as "surveys". For example, an index of survival might be calculated using survey data and the Heinke method (Ricker 1975) as:

$$A_t=\frac{I_{k+1,t+1}}{I_{k,t}}$$

so that the time series of A_t estimates are data that may potentially contain information about scale or trends in survival. Predicted values for a survival index are calculated:

$$\hat{A}_t=e^{-Z_t}$$

After predicted values are calculated, survival ratio data are treated in the same way as abundance data (in particular, measurement errors are assumed to be lognormal). Selectivity parameters are ignored for survival data but all other features (e.g. covariates, nonlinear scaling relationships and constraints on Q) are available.

Recruitment models

Recruitment parameters in KLAMZ may be freely estimated or estimated around an internal recruitment model, possibly involving spawning biomass. An internally estimated recruitment model can be used to reduce variability in recruitment estimates (often necessary if data are limited), to summarize stock-recruit relationships, or to make use of information about recruitment in similar stocks. There are four types of internally estimated recruitment models in KLAMZ: 1) random variation around a constant mean; 2) random walk around a constant mean (autocorrelated variation); 3) random variation around a Beverton-Holt recruitment model; and 4) random variation around a Ricker recruitment model. The user must specify a type of recruitment model but the model is not active unless the likelihood component for the recruitment model is turned on ($\lambda > 0$).

The first step in recruit modeling is to calculate the expected log recruitment level *E[ln(R$_t$)]* given the recruitment model. For random variation around a constant mean, the expected log recruitment level is the log geometric mean recruitment:

$$E[\ln(R_t)] = \sum_{j=1}^{N} \ln(R_j) \Big/ N$$

For a random walk around a constant mean recruitment, the expected log recruitment level is the logarithm of recruitment during the previous year:

$$E[\ln(R_t)] = \ln(R_{t-1})$$

with no constraint on recruitment during the first year R_1.

For the Beverton-Holt recruitment model, the expected log recruitment level is:

$$E[\ln(R_t)] = \ln\left[e^a T_{t-\ell} / \left(e^b + T_{t-\ell}\right)\right]$$

where $a=e^{\alpha}$ and $b=e^{\beta}$, the parameters α and β are estimated in the model, T_t is spawning biomass, and ℓ is the lag between spawning and recruitment. Spawner-recruit parameters are estimated as log transformed values (e^{α} and e^{β}) to enhance model stability and ensure the correct sign of values used in calculations. Spawning biomass is:

$$T_t = m_{new} R_t + m_{old} S_t$$

where m_{new} and m_{old} are maturity parameters for new and old recruits specified by the user. For the Ricker recruitment model, the expected log recruitment level is:

$$E[\ln(R_t)] = \ln\left(S_{t-\ell} e^{a-bS_{t-\ell}}\right)$$

where $a=e^{\alpha}$ and $b=e^{\beta}$, and the parameters α and β are estimated in the model.

Given the expected log recruitment level, log scale residuals for the recruitment model are calculated:

$$r_t = \ln(R_t) - E[\ln(R_t)]$$

Assuming that residuals are log normal, the NLL for recruitment residuals is:

$$L = \sum_{t=t_{first}}^{N} w_t \left[\ln(\sigma_r) + 0.5\left({r_t}/{\sigma_r} \right)^2 \right]$$

where λ_t is an instance-specific weight usually set equal one. The additional term in the NLL [$ln(\sigma_r)$] is necessary because the variance σ_r^2 is estimated internally, rather than specified by the user.

The log scale variance for residuals is calculated using the maximum likelihood estimator:

$$\sigma_r^2 = \frac{\sum_{j=t_{first}}^{N} r_j}{N}$$

where N is the number of residuals. For the recruitment model with constant variation around a mean value, t_{first}=1. For the random walk recruitment model, t_{first}=2. For the Beverton-Holt and Ricker models, $t_{first}=\ell+1$ and the recruit model imposes no constraint on variability of recruitment during years 1 to ℓ (see below). The biased maximum likelihood estimate for σ^2 (with N in the divisor instead of the degrees of freedom) is used because actual degrees of freedom are unknown. The variance term σ^2 is calculated explicitly and stored because it is used below.

Constraining the first few recruitments

It may be useful to constrain the first { years of recruitments when using either the Beverton-Holt or Ricker models if the unconstrained estimates for early years are erratic. In the KLAMZ model, this constraint is calculated:

$$NLL = \sum_{t=1}^{t_{first}-1} w_t \left\{ \ln(\sigma_r + 0.5\left[\frac{\ln\left(R_t / E\left(R_{t_{first}}\right)\right)}{\sigma_r} \right]^2 \right\}$$

where t_{first} is the first year for which expected recruitment $E(R_l)$ can be calculated with the spawner-recruit model. In effect, recruitments that not included in spawner-recruit calculations are constrained towards the first spawner-recruit prediction. The standard deviation is the same as used in calculating the NLL for the recruitment model.

Prior information about abundance index scaling parameters (Q)

A constraint on one or more scaling parameters (Q_v) for abundance or survival indices may be useful if prior information is available (e.g. NEFSC 2000; NEFSC 2001; NEFSC 2002). In the Excel version, it is easy to program these (and other) constraints in an *ad-hoc* fashion as they are needed. In the AD Model Builder version, log normal and beta distributions are preprogrammed for use in specifying prior information about Q_v for any abundance or survival index.

The user must specify which surveys have prior distributions, minimum and maximum legal bounds (q_{min} and q_{max}), the arithmetic mean $(\overline{q})$ and the arithmetic CV for the prior the distribution. Goodness of fit for Q_v values outside the bounds (q_{min}, q_{max}) are calculated:

$$L = \begin{vmatrix} 10000\,(Q_v - q_{\max})^2 \; if \; Q_v \geq q_{\max} \\ 10000\,(q_{\min} - Q_v)^2 \; if \; Q_v \leq q_{\min} \end{vmatrix}$$

Goodness of fit for Q_v values inside the legal bounds depend on whether the distribution of potential values is log normal or follows a beta distribution.

Lognormal case

Goodness of fit for lognormal Q_v values within legal bounds is:

$$L = 0.5\left[\frac{\ln(Q_v) - \tau}{\varphi}\right]^2$$

where the log scale standard deviation $\varphi = \sqrt{\ln(1 + CV)}$ and $\tau = \ln(\bar{q}) - \frac{\varphi^2}{2}$ is the mean of the corresponding log normal distribution.

Beta distribution case

The first step in calculation goodness of fit for Q_v values with beta distributions is to calculate the mean and variance of the corresponding "standardized" beta distribution:

$$\bar{q}' = \frac{\bar{q} - q_{\min}}{D}$$

and

$$Var(q') = \left(\frac{\bar{q}\;CV}{D}\right)^2$$

where the range of the standardized beta distribution is $D{=}q_{max}{-}q_{min}$. Equating the mean and variance to the estimators for the mean and variance for the standardized beta distribution (the "method of moments") gives the simultaneous equations:

$$\bar{q}' = \frac{a}{a + b}$$

and

$$Var(q') = \frac{ab}{(a + b)^2(a + b + 1)}$$

where a and b are parameters of the standardized beta distribution.[23] Solving the simultaneous equations gives:

$$b = \frac{(\bar{q}' - 1)[Var(q') + (\bar{q}' - 1)\bar{q}']}{Var(q')}$$

and:

$$a = \frac{b\bar{q}'}{1 - \bar{q}'}$$

Goodness of fit for beta Q_v values within legal bounds is calculated with the NLL:

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[23] If x has a standardized beta distribution with parameters a and b, then the probability of x is

$$P(x) = \frac{x^{a-1}(1 - x)^{b-1}}{\Gamma(a,b)}.$$

$$L = (a-1)\ln(Q'_v) + (b-1)\ln(1-Q'_v)$$

where $Q'_v = Q_v / (Q_v - q_{\min})$ is the standardized value of the survey scaling parameter Q_v.

Surplus production modeling

Surplus production models can be fit internally to biomass and surplus production estimates in the model (Jacobson et al. 2002). Models fit internally can be used to constrain estimates of biomass and recruitment, to summarize results in terms of surplus production, or as a source of information in tuning the model. The NLL for goodness of fit assumes normally distributed process errors in the surplus production process:

$$L = 0.5 \sum_{j=1}^{N_P} \left(\frac{\tilde{P}_j - P_j}{\sigma} \right)^2$$

where N_p is the number of surplus production estimates (number of years less one), $\tilde{P}_t$ is a predicted value from the surplus production curve, P_t is the assessment model estimate, and the standard deviation σ is supplied by the user based, for example, on preliminary variances for surplus production estimates.[24] Either the symmetrical Schaefer (1957) or asymmetric Fox (1970) surplus production curve may be used to calculate $\tilde{P}_t$ (Quinn and Deriso 1999).

It may be important to use a surplus production curve that is compatible with recruitment patterns or assumptions about the underlying spawner-recruit relationship. More research is required, but the asymmetric shape of the Fox surplus production curve appears reasonably compatible with the assumption that recruitment follows a Beverton-Holt spawner-recruit curve (Mohn and Black 1998). In contrast, the symmetric Schaefer surplus production model appears reasonably compatible with the assumption that recruitment follows a Ricker spawner-recruit curve.

The Schaefer model has two log transformed parameters that are estimated in KLAMZ:

$$\tilde{P}_t = e^{\alpha} B_t - e^{\beta} B_t^2$$

The Fox model also has two log transformed parameters:

$$\tilde{P}_t = -e\left(e^{e^{\alpha}}\right) \frac{B_t}{e^{\beta}} \log\left(\frac{B_t}{e^{\beta}} \right)$$

See Quinn and Deriso (1999) for formulas used to calculate reference points (F_{MSY}, B_{MSY}, MSY, and K) for both surplus production models.

Catch/biomass

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[24] Variances in NLL for surplus production-biomass models are a subject of ongoing research. The advantage in assuming normal errors is that negative production values (which occur in many stocks, e.g. Jacobson et al. 2001) are accommodated. In addition, production models can be fit easily by linear regression of P_t on B_t and B_t^2 with no intercept term. However, variance of production estimate residuals increases with predicted surplus production. Therefore, the current approach to fitting production curves in KLAMZ is not completely satisfactory.

Forward simulation models like KLAMZ may tend to estimate absurdly high fishing mortality rates, particularly if data are limited. The likelihood constraint used to prevent this potential problem is:

$$L = 0.5\sum_{t=0}^{N}\left(d_t^2 + q^2\right)$$

where:

$$d_t = \left| \begin{array}{l} Ft - \Phi \; if \; Ft > \Phi \\ 0 \; otherwise \end{array} \right.$$

and

with the threshold value κ normally set by the user to about 0.95. Values for κ can be linked to maximum F values using the modified catch equation described above. For example, to use a maximum fishing mortality rate of about $F\approx4$ with M=0.2 and G=0.1 (maximum X=4+0.2-0.1=4.1), set $\kappa \approx F/X(1-e^{-X})$=4 / 4.1 (1-$e^{-4}$)=0.96.

Uncertainty

The AD Model Builder version of the KLAMZ model automatically calculates variances for parameters and quantities of interest (e.g. R_t, F_t, B_t, F_{MSY}, B_{MSY}, $\overline{F}_{\mathrm{Re}cent}$, $\overline{B}_{\mathrm{Re}cent}$, $\overline{F}_{\mathrm{Re}cent}/F_{MSY}$, $\overline{B}_{\mathrm{Re}cent}/B_{MSY}$, etc.) by the delta method using exact derivatives. If the objective function is the log of a proper posterior distribution, then Markov Chain Monte Carlo (MCMC) techniques implemented in AD Model Builder libraries can be used estimate posterior distributions representing uncertainty in the same parameters and quantities.[25]

Bootstrapping

A FORTRAN program called BootADM can be used to bootstrap survey and survival index data in the KLAMZ model. Based on output files from a "basecase" model run, BootADM extracts standardized residuals:

$$r_{v,j} = \frac{\ln\left(I_{v,j} \Big/ \hat{I}_{v,j}\right)}{\sigma_{v,j}}$$

along with log scale standard deviations ($\sigma_{v,j}$, originally from survey CV's or estimated from goodness of fit), and predicted values $\left(\hat{I}_{v,j}\right)$ for all active abundance and survival observations. The original standardized residuals are pooled and then resampled (with replacement) to form new sets of bootstrapped survey "data":

$${}^{x}I_{v,j} = \hat{I}_{v,j}e^{r\sigma_{v,j}}$$

where r is a resampled residual. Residuals for abundance and survival data are combined in bootstrap calculations. BootADM builds new KLAMZ data files and runs the KLAMZ model repetitively, collecting the bootstrapped parameter and other estimates at each iteration and writing them to a comma separated text file that can be processed in

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[25] MCMC calculations are not available in the current version because objective function calculations use concentrated likelihood formulas. However, the C++ version of KLAMZ is programmed in other respects to accommodate Bayesian estimation.

Excel to calculate bootstrap variances, confidence intervals, bias estimates, etc. for all parameters and quantities of interest (Efron 1982).

Projections

Stochastic projections can be carried out using another FORTRAN program called SPROJDDF based on bootstrap output from BootADM. Basically, bootstrap estimates of biomass, recruitment, spawning biomass, natural and fishing mortality during the terminal years are used with recruit model parameters from each bootstrap run to start and carryout projections.[26] Given a user-specified level of catch or fishing mortality, the delay-difference equation is used to project stock status for a user-specified number of years. Recruitment during each projected year is based on simulated spawning biomass, log normal random numbers, and spawner-recruit parameters (including the residual variance) estimated in the bootstrap run. This approach is similar to carrying out projections based on parameters and state variables sampled from a posterior distribution for the basecase model fit. It differs from most current approaches because the spawner-recruit parameters vary from projection to projection.

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[26] At present, only Beverton-Holt recruitment calculations are available in SPROJDDF.

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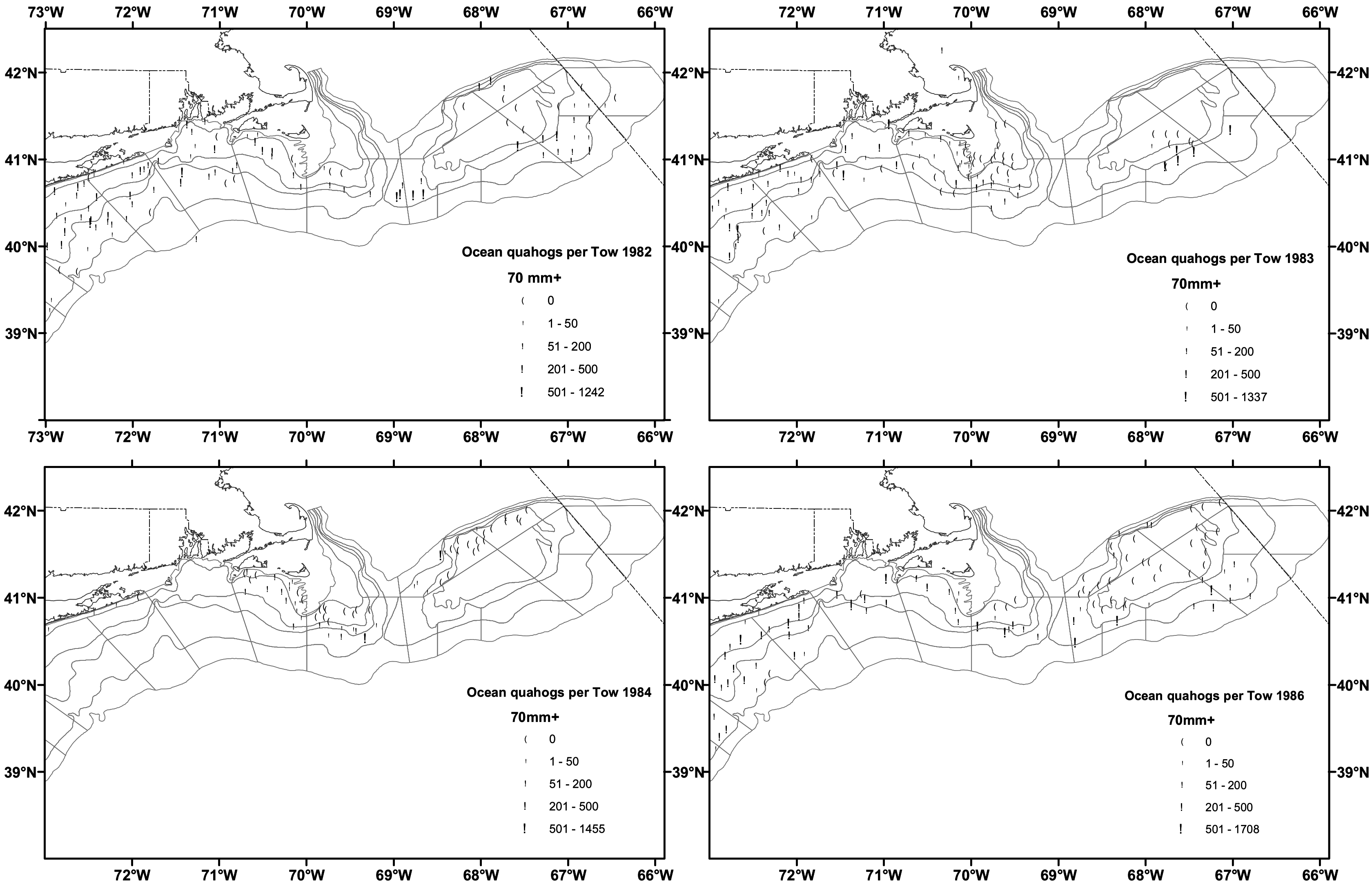
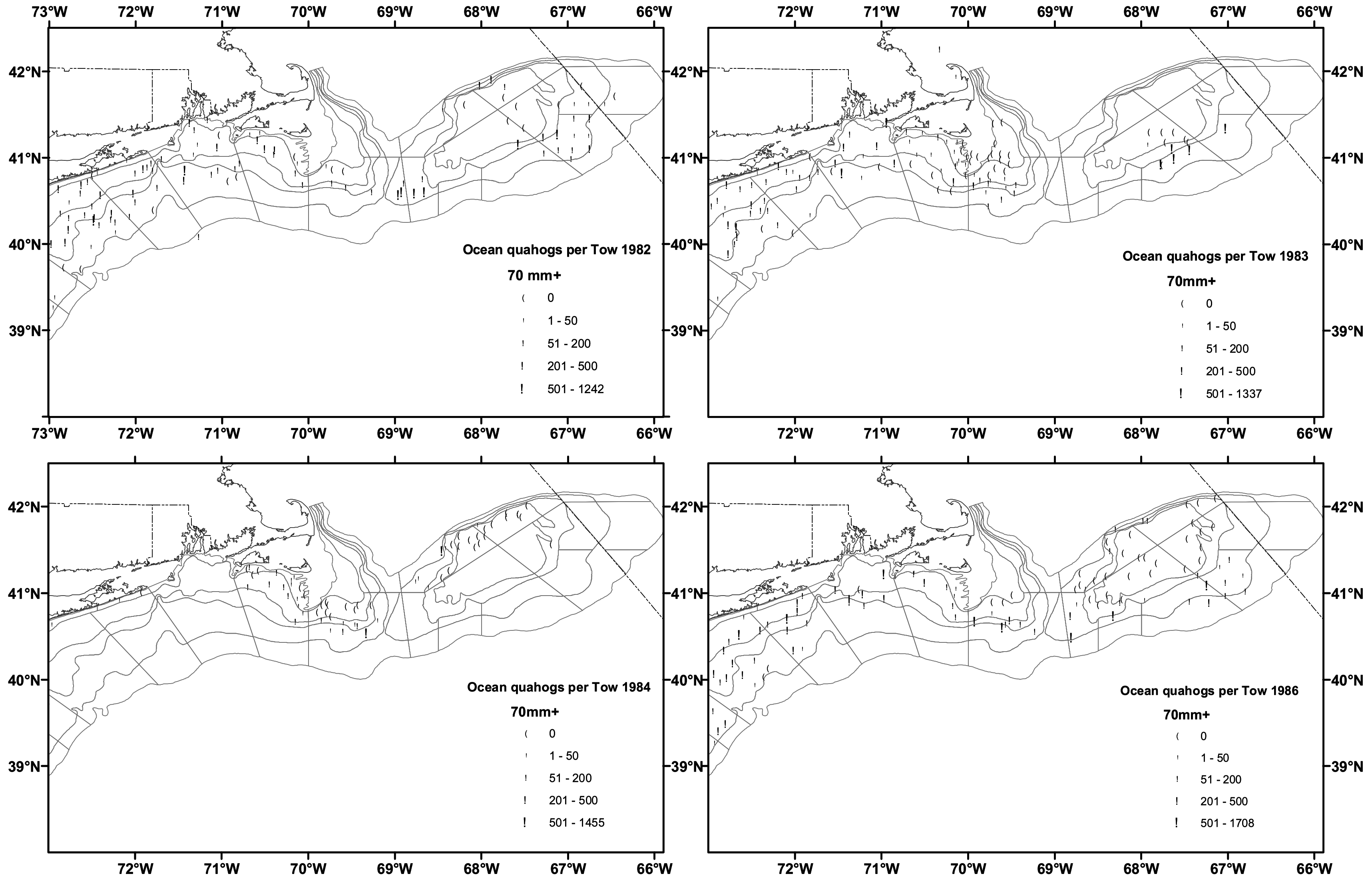
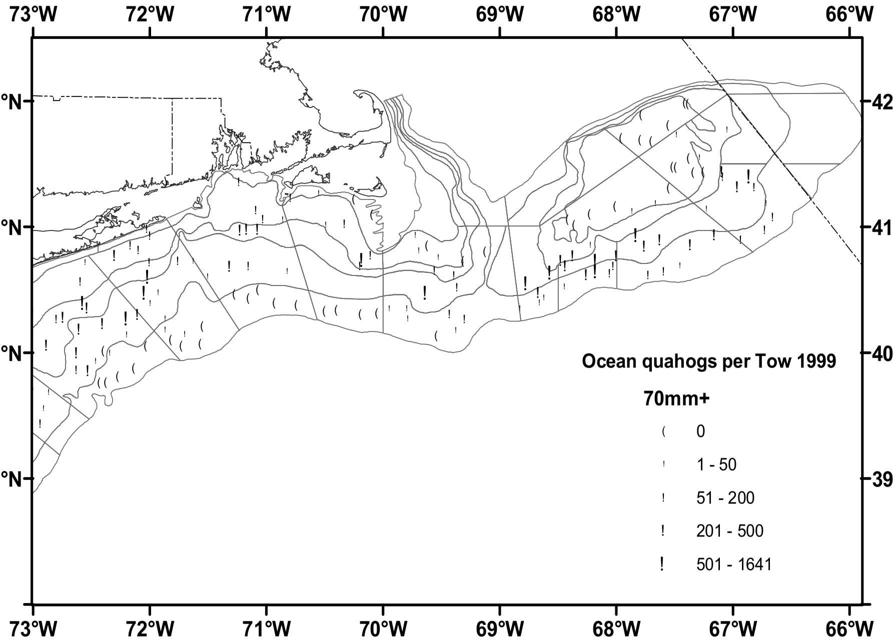
APPENDIX A6. Location and size of northern ocean quahog (70+ mm SL) survey catches between Georges Bank and Long Island, 1982-2005.

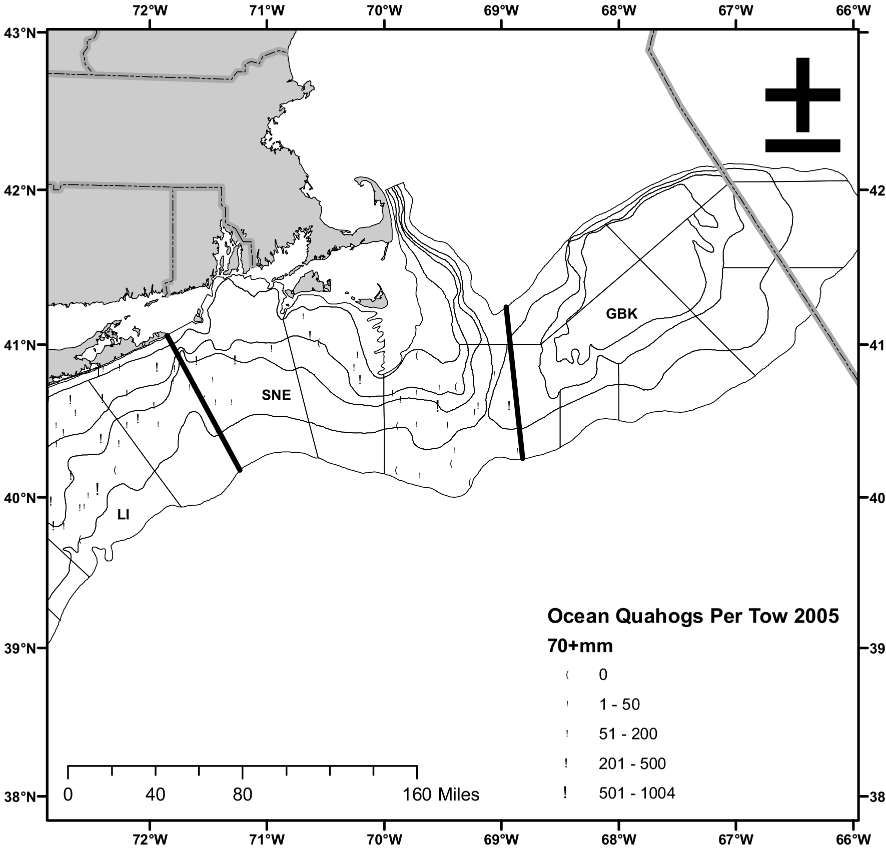


Appendix A6. (cont.)



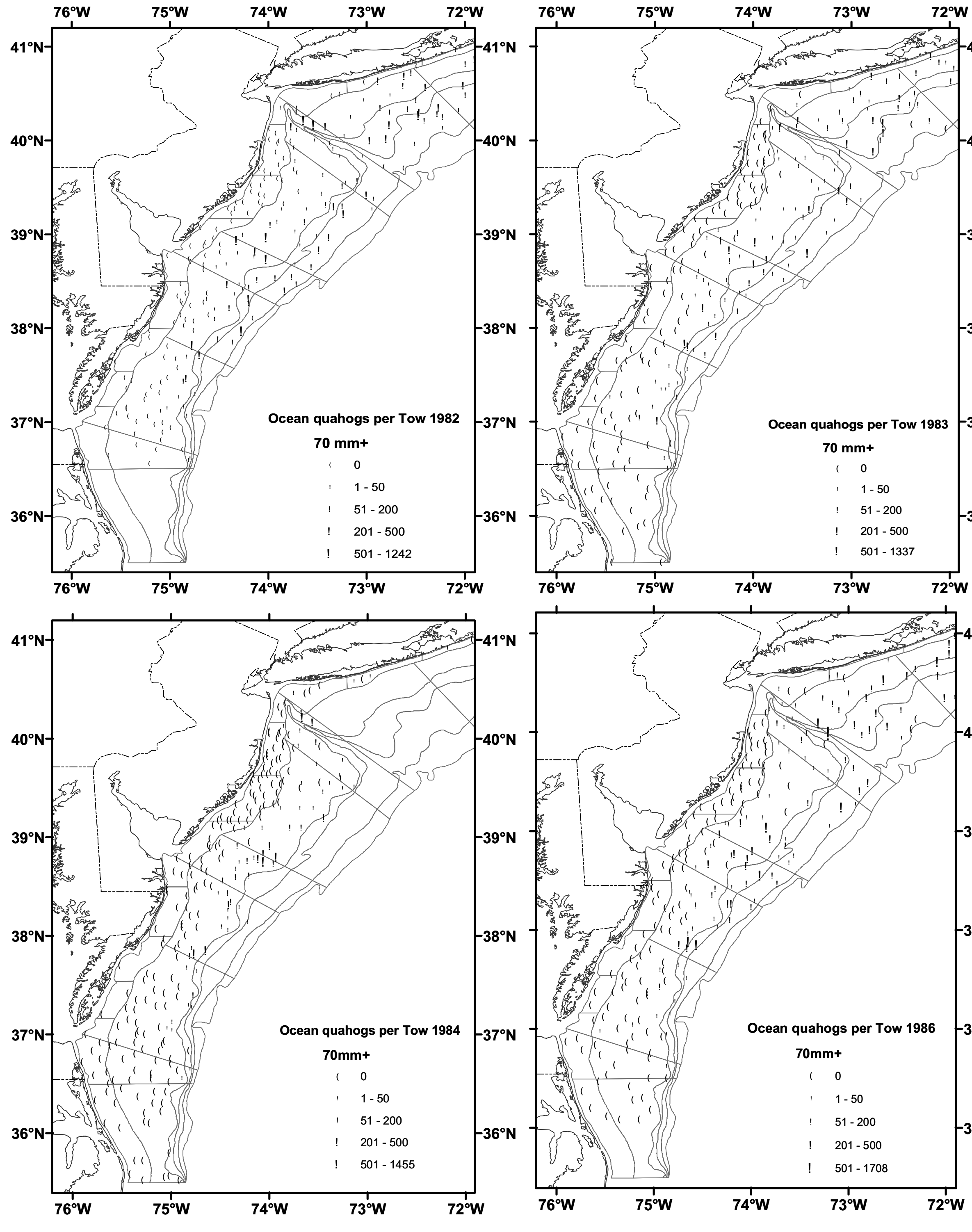
Appendix A6. (cont.)



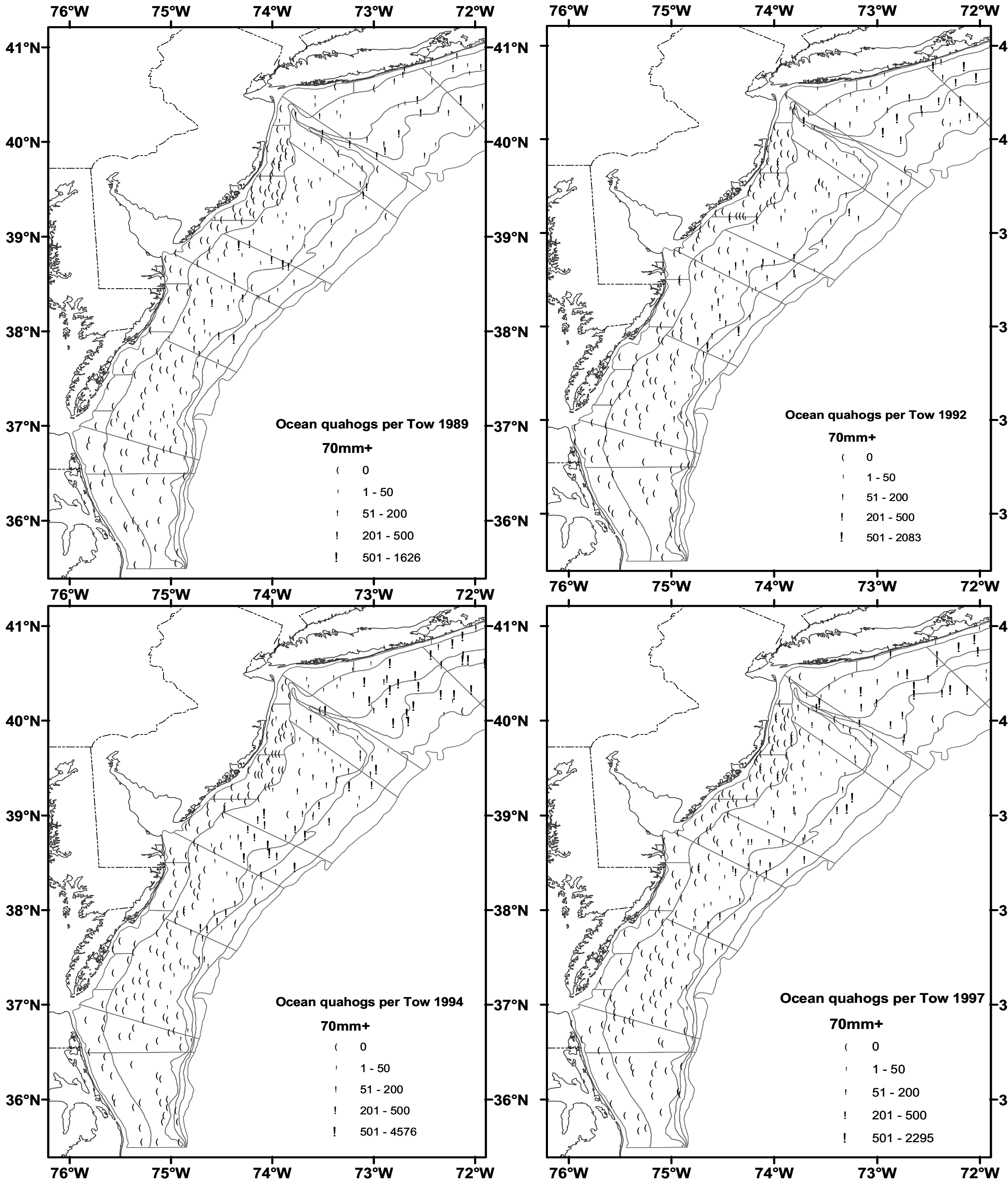


Appendix A6. (cont.)

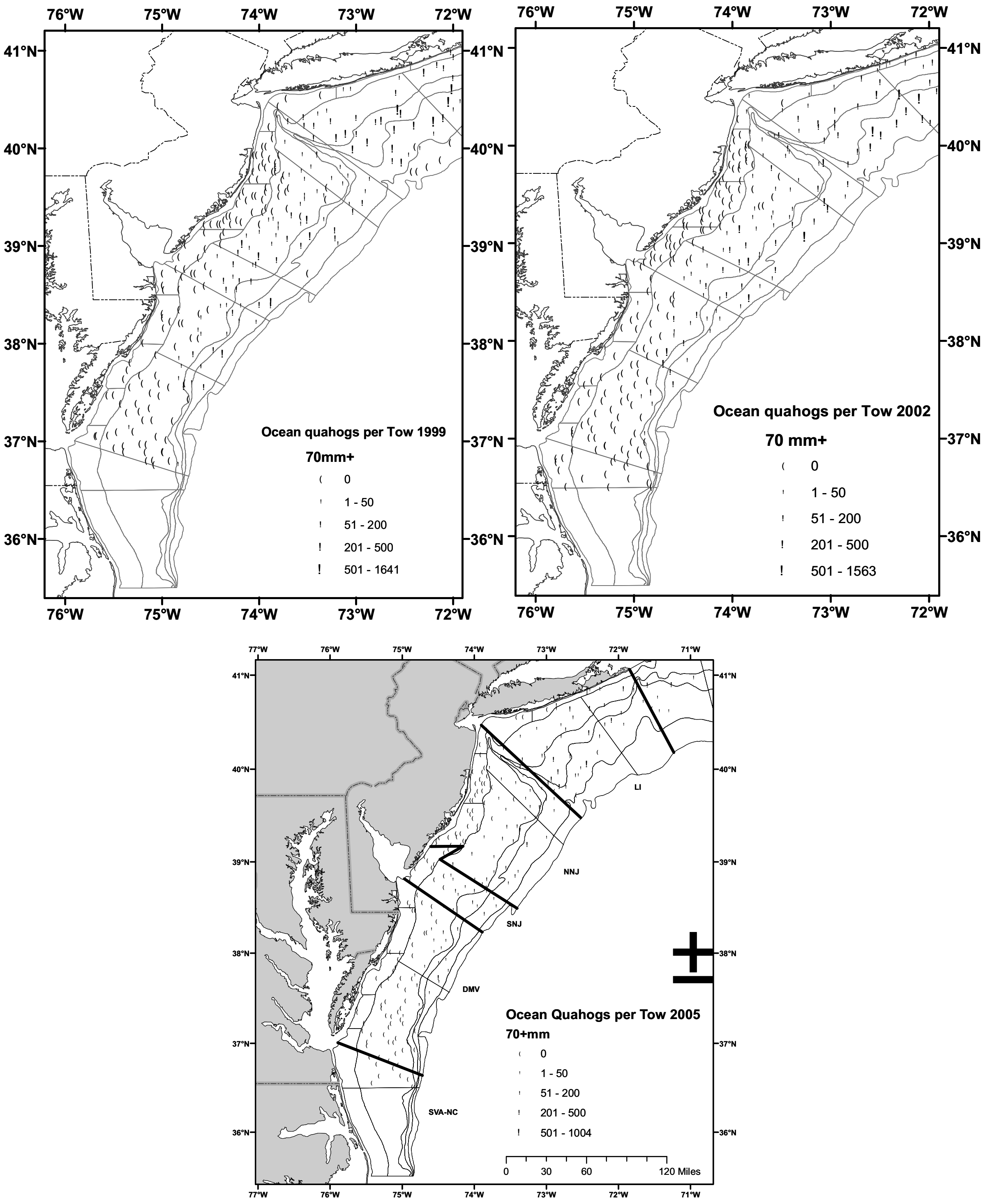
APPENDIX A7. Location and size of Mid-Atlantic ocean quahog (70+ mm SL) catches. Mid-Atlantic Bight, 1982-2005.



Appendix A7. (cont.)



Appendix A7. (cont.)



Appendix A7. (cont.)

APPENDIX A8. Stock Assessment for Ocean Quahog in Maine Waters

Prepared by Robert Russell (assessment lead, Maine Department of Marine Resources, BoothBay Harbor, ME) and the Invertebrate Subcommittee

Executive Summary

The Maine ocean quahog resource is a unique segment of the quahog stock in Federal waters. As of 1999 under Amendment 10 to the Fishery Management Plan (FMP) for Atlantic Surfclam and Ocean Quahog, Maine was given a separate annual quota of 100,000 “Maine” bushels (bushels used to record landings in Maine are 66% as large as bushels used to report landings in the rest of the EEZ). Fishing is carried out using a “dry” dredge (with no water jets to loosen sediments).

Maine quahogs, often referred to as “mahogany” clams are a substitute for *Mercinaria mercinaria* in the half shell market. Maine quahogs are harvested at a much smaller size (38-64 mm shell length) than MidAtlantic quahogs (89-140 mm shell length).

Landings peaked in Maine in 2002 at 147,191 bushels and have fallen since to a level of 98,153 bushels in 2005. During this time period paralytic shellfish poisoning (PSP) kept many productive beds closed.

The State of Maine conducted a pilot survey for ocean quahogs in 2002 which provided useful information on abundance and distribution along with estimates of key biological parameters. Results from the pilot study were used to plan and narrow the focus of the 2005 survey.

Lacking from the pilot study was an estimate of dredge efficiency which is required to estimate biomass and mortality rates from landings and survey data. Based on data from boxcore samples and “follow on” survey tows during 2005-2006, the efficiency of the commercial dredge used during the 2005 survey was 16.1%. In other words, 16.1% of relatively large (fully recruited) ocean quahogs in the path of the dredge are captured in each pass.

Based on survey density data and estimated dredge efficiency, the biomass of harvestable ocean quahogs during 2005 in the commercial fishing grounds (54 nm^2) surveyed off Maine is 22,493 mt meat weight. Based on the ratio of landings and biomass, the fishing mortality rate in the commercial fishing grounds surveyed off Maine is F=0.022 y^{-1}.

Biological reference points have not been established for the Maine segment of the ocean quahog stock. However, a per recruit model analysis with parameters for the Maine segment of the stock was used to estimate reference points that are often used in fishery management. Based on per recruit modeling, F_{max}=0.0561, $F_{0.1}$=0.0247 and $F_{50\%}$=0.013 y^{-1}.

$F_{0.1}$=0.0247 y^{-1} (corresponding to a harvest rate of 2.5% per year) might be a reasonable reference point for managers if the goal is to maximize yield per recruit while preserving some spawning stock. Simulation analysis (Clark 2002) indicates that $F_{50\%}$=0.013 (1.3% per year) might be a reasonable reference point for managers if the goal was to preserve enough spawning potential to maintain the resource in the long term. The estimated fishing mortality rate during 2005 F=0.022 y^{-1} is nearly equal to $F_{0.1}$=0.0247 y^{-1} and the assumed natural mortality rate M=0.02 y^{-1} but higher than $F_{50\%}$=0.013.

Survey size frequency distributions indicate differences in the size of quahogs between the “western” and “eastern” beds inside the commercial fishing grounds. Larger quahogs were found in eastern beds that had been closed to fishing for three year due to PSP.

Size frequency distributions from boxcores showed signs of recent settlement in the eastern bed (quahogs less than 5 mm SL). However size classes between 5 and 35 mm SL were entirely missing throughout the survey indicating that recruitment is sporadic. Although growth is relatively rapid in Maine waters, it may be 3 decades or longer before these recruits become large enough to enter the fishery.

Stock assessment advice concerning ocean quahog in Maine waters would be easier to provide if management goals were formulated and if biological reference points for biomass and fishing mortality were defined.

Introduction

The Maine fishery for Ocean quahogs, although harvesting the same species (*Artica islandica*), is persecuted in a different way and fills a different sector of the shellfish market than the rest of the EEZ fishery. The Maine "mahogany" quahog is harvested at a smaller size (38-64 mm or 1.5-2.5 in shell length, SL) than elsewhere in the EEZ fishery where ocean quahogs are harvested at 89-140 mm (3.5-5.5 in) SL.

Ocean quahog from Maine waters are marketed as a less expensive alternative for *Mercenaria mercinaria* (Maine DMR 2003). Harvesting takes place year round with the highest market demand during the summer holidays (Memorial Day through Labor Day). During this peak harvest period 30-40 out of a total of 57 license holders may land some volume of product.

The majority of the vessels in the Maine fleet are between 10.7-13.7 m (35-45 ft) and classified as "undertonnage" or "small" in issuing permits. All of the vessels use a "dry" dredge (with no hydraulic jets to loosen the sediments) with a cutter bar set by regulation at no more than 0.91 m (36 in). There are no restrictions on any other dimension of the dredge.

Quahog Fishing in Maine takes place in relatively few locations along the coast north of 43 degree 50 minute latitude (Figure 1). Historically the bulk of fishing activity has taken place between Mt. Desert Rock and Cross Island with two significant quahog beds south of Addison and Great Wass Island covering an area of approximately 60 square nautical miles.

The Maine fishery began to expand into Federal waters in the 1980's due in part to PSP closures within state waters. In 1990 it was determined that this fishing activity conflicted with the Magnuson-Stevens Fishery Management Conservation Act which calls for a stock to be managed as a unit throughout its range. The Maine fishery was granted "experimental" status from 1990-1997. In 1998, the Maine fishery was fully incorporated under Amendment 10 of the FMP and given an initial annual quota of 100,000 bushels based on historical landings data. There was no independent assessment of the resource available at that time. The State of Maine is responsible under Amendent 10 to certify harvest areas free of PSP and to conduct stock assessments.

In 2002 the State of Maine conducted a pilot survey to assess the distribution and abundance of quahogs along the Maine coast (MEDMR 2003[27]). This survey was a critical first step in establishing distribution, size composition and relative abundance information for the Maine fishery and for directing the design of the current survey work. While this initial survey provided valuable

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[27] Available with assessment for reviewer's convenience.

information it did not have the resources to estimate dredge efficiency and therefore was not able to estimate total biomass or biological reference points. The survey during 2005 focused effort on two issues: determining dredge efficiency, and mapping quahog densities in the region of highest commercial activity.

Estimates of biomass and mortality presented in this report are only for the commercial beds south of Addison and Jonesport/GreatWass Maine. This approach was chosen due to available resources and because it was conservative. Other quahog beds are known to exist along many parts of the Maine coast. If mortality targets could be met using the estimates from the primary fishing grounds then biomass outside the survey area can act as a *defacto* preserve.

Fishery Data

Data throughout this report is presented in metric units. In some cases there are specialized terms and conversion factors which are listed below.

"MidAtlantic" bushels of Ocean Quahogs x 10 = lbs meat.
"MidAtlantic" bushels of ocean quahogs x 4.5359 = kg meat
1 "MidAtlantic" (= "industry") bushel = 1.88cubic feet
1 "Maine" (= "US Standard") bushel = 1.2448 cubic feet
"Undertonnage" vessel = 1-4.9 GRT
"Small" vessel = 5-49.9 GRT
1 "Maine" bushel = 0.0049 mt meat weight

In 2005 there were 57 ocean quahog licenses in the State of Maine. Of these 57 licenses 30 reported landings. The number of active licenses has decreased each year since 2002 when 38 licenses had reported fishing activity.

Landings have also decreased steadily since 2002 when they were at a recorded high of 147,191 Maine bushels (TableZ 1). Landings for 2005 were 98,153 Maine bushels. LPUE in recent years tracked downward with landings until the 2005 season when it showed a slight increase from 5.37 to 5.85 Maine bushels per hour towing (Figure 2). This increase may be an artifact of the open and closed status of parts of the main commercial beds due to PSP because the most productive quahog bed was reopened at the end of 2005 after a 3 year closure.

Incidental mortality in ocean quahog off Maine is an important topic for future research. Maine has a very high level of fishing activity relative to the size of the fleet. Approximately 16,766 hours of fishing took place during 2005 representing over 67,000 tows at 8 min per tow. Using standard industry dredge dimensions and tow speeds this level of fishing activity represents 28.68 nautical miles^2 of bottom swept by commercial dredges.

All catches are tagged and vessel logbooks are submitted to track quota status. Marine Patrol has not had enough resources to check the validity of logbook entry or to confirm the vessels on purchased quota are reporting accurately.

Research Surveys

With the limited funds dedicated for survey work on quahogs, it was decided to focus all of the 2005 survey effort on the primary commercial fishing grounds south of Addison and Great Wass. This decision is important in the interpretation of all following data as results because estimates pertain only to these two beds and not to the coast of Maine as a whole. Vessel logbooks and the 2002 independent survey abundance indices show that the majority of fishing activity and a sizable portion of the resource was in this region (Figure 3).

The first step in designing the survey was to establish a 1 km^2 grid overlay using Arcveiw 3.2 over the known commercial beds. Based on number of days at sea, 260 sites (tows) could be completed. The centers of the 260 1 km^2 grids covering the commercial beds were selected as start points for survey tows (Figure 4). These points were transferred to The Cap'n Voyager Software for use on board the survey vessel.

The Quahog bed south of Addison, (referred to as “western”) had been the only open fishing grounds for 3 years due to PSP issues in other beds. The quahog bed south of Great Wass Island, (referred to as “eastern”) had been unfished for 3 years but had previously been one of the most productive fishing grounds.

Survey gear and procedures

The commercial vessel F/V Promise Land is a 12.8 m (42 ft) Novi Style dragger piloted by Capt. Michael Danforth that was contracted to perform all the survey drag operations. All survey tows were conducted using the same dredge with dimensions: cutter bar 0.91 m (36 in), 2.44 m (8 ft) long x 1.83 m (6 ft) wide x 1.22 m (4 ft) high, overall weight 1,361 kg (3,000 lbs), bar spacing all grills 19.05 mm (¾ in) (Figure 5). The survey dredge was the same dredge used by the F/V Promise Land during normal fishing activity.

As the vessel approached the start of a tow, bottom type and the feasibility of conducting a tow were assessed. If suitable bottom was not immediately present at the predetermined start point, the vessel would start crossing runs within the grid. If after 5 to 6 crosses no towable bottom or a tow path free of fixed lobster gear could not be found, then the grid location was deemed untowable, a note was made, and the captain continued on to the next site. When a suitable tow path was found within a grid the dredge was lowered to the bottom by free-spooling until the ratio of cable length to depth was 3:1. Once the desired cable length was reached the drum was locked, a two minute timer was started and a GPS point was taken.

Tows were made into the current at approximately 6.48 km/hr (3.5 knots) speed over ground (average tow 214 m). After two minutes elapsed, a second GPS point was taken and the dredge was brought to the surface.

Tow distances calculated using the start and stop GPS points are good estimates of the distance actually traveled by the dredge. The manner in which the dredge is set and retrieved does not create a situation in which the dredge continues to fish as it is retrieved or before the drum is locked. In particular, the weight of the dredge keeps it in place on the bottom when the drum is unlocked at the end of the tow. In addition, the practice of backing the vessel toward the stopping point at the end of each tow means that the dredge was unlikely to travel very far at the end of the tow as it is lifted into the water column.

After the dredge was retrieved and before it was brought on board the vessel, excess mud was cleaned from the dredge by steaming in tight circles with the dredge in the vessel's prop wash (Figure 6). Once on board, the dredge was emptied and photographed with a digital camera (Figure 7). The contents were placed on a shaker table (Figure 8), bycatch was noted and then all live quahogs were sorted out from the catch. From each tow a 5 L subsample of quahogs was taken at random (the entire catch was taken if catch was less than 5 L). The subsample was used to estimate tow counts, volume, and size frequency of the catch. The remainder of the catch was placed in calibrated buckets to determine total catch volume.

All data collected on board during operations were entered into a Juniper Systems handheld Allegro field computer running Data Plus Professional Software. All GPS data were collected using a pair of Garmin Etrex handheld units and transmitted in real time to the Allegro and a laptop running Cap'n Voyager Software. Data entry screens on the Allegro for the abundance survey consisted of: 1) trip information (date, time out, weather, sea state, time in, and comments); 2) site information (depth, bottom type, start tow GPS position, speed, end tow GPS position, and comments); 3) catch information (sample portion 5 L or all, volume, weight, count, photo id, size frequency 5 L or all, and comments); and 4) bycatch information (species, abundance).

The lengths (longest dimension) of all subsampled quahogs were measured to the nearest 0.01 mm and entered into the Allegro handheld using a Fowler Ultra-Cal IV digital caliper with an RS232 port. Estimated counts of quahogs were made by counting the number of clams in the 5 L sample and then expanding that value using the total volume of the catch. All data were analyzed using Excel with variances calculated using a bootstrap program (10,000 iterations) written by Dr. Yong Chen at the University of Maine, Orono.

Tow distances were determined by The Cap'n Software and were checked using ESRI ArcInfo software. All data from the tows were standardized to a 200 m tow prior to further analysis.

Dredge efficiency

The Maine dry dredge is much less efficient (2-17%, ME DMR 2003) than hydraulic dredges used in the rest of the EEZ which can be up to 95% efficient (Medcolf and Caddy, 1971). A reliable estimate of dredge efficiency is needed to convert survey densities to a biomass estimate (NEFSC 2004).

One method of estimating dredge efficiency is through depletion experiments which are used to measure survey dredge efficiency for NEFSC clam surveys in Federal waters. Depletion studies for ocean quahog involve sensor and data processing equipment that were not readily available. The dry dredge used in the Maine survey is relatively small compared to the depth of fishing. We hypothesized that it would be difficult to control the dredge precisely given the depth, size of dredge and strong currents in the region off Maine.

For the conditions off Maine is was determined that the best approach to estimating dredge efficiency would be through the use of a boxcore samples (to directly estimate quahog density) followed by survey tows in the same area. Considering only ocean quahog available to the fishery, the ratio of density measured by "follow on" dredge tows divided by boxcore density is an estimate of survey dredge efficiency (Thorarinsdottir and Jacobson 2005).

The *F/V Promise Land* with its large A frame and winches was able to deploy the 544 kg (1,200 lb) Ocean Instruments 610 boxcore with a core capacity of 0.062 m^2 and maximum penetration up to 60 cm (Figure 9). Follow on tows were conducted using the same gear used during all previous portions of the survey.

Boxcore work was conducted at three locations during three separate trips, one in August of 2005, one in January of 2006 and the last in April 2006. In all three experiments, follow on survey tows were made the day after the cores had been taken. The locations sampled were in the eastern quahog bed in an area of relatively high abundance (Figure 10). This area was also selected because it was a closed fishing ground during the August 2005 trip which would eliminate the possibility of the boxcore sites being commercially towed before follow on tows could be made. In January and April 2006 the region had been reopened to commercial fishing. However, VHF radio announcements describing the type of work underway were broadcast to local fisherman who were very cooperative and stayed well away from the experimental areas until all follow on tows could be completed the next day. Data entered into the Juniper Systems Allegro field computer included information about: 1) the trip (date, start tow, end tow), core (core #, core length, count, volume, weight, count of newly settled).

Each experiment began by establishing a single long towpath. To do this, the vessel was slowed to the standard tow speed of 3.5 kts and a GPS point was taken and plotted. After 2 min steaming along a fixed heading, a second GPS point was taken and plotted. These waypoints determined the endpoints for the follow on commercial tows and the path for boxcore sampling. Cores were then taken haphazardly along the tow path (60 for the August 2005 trip, 34 on the January 2006 trip and 30 on the April 2006 trip).

Once a core was brought on board it was measured for overall length and sieved through a large screen (1cm^2 mesh size). All quahogs were counted and their total volume and weight were measured.

During coring operations, it was noted that the upper 1-2 cm of very soft sediment contained recently settled quahogs (< 5mm length). The number of quahogs in this size range were recorded separately for all further cores and newly settled quahogs were retained to be preserved. During the January and April 2006 trips the top 5 cm of each core was removed and washed separately through a 300 μ sieve and all quahogs <5mm SL were preserved.

It was noted during boxcore sampling during the August 2005 boxcore trip that there was a change in sediment type beginning around 12-15 cm from the surface of each core. At this transition the sediment turned to a matrix of solid clay and old quahog shell. None of the live quahogs found in the cores in 2005 were below this transition. To assess this, the maximum depth within the core of live quahogs was measured during the 2006 trips.

After the maximum number of cores had been completed for a given trip the commercial dredge was deployed at one of the endpoints of the established tow path. Standard commercial towing was conducted for 2 min along the same path as the cores had been taken allowing the dredge to tow from one endpoint to the next. After each round of coring, 6 tows were made along the same path, three in one direction and 3 opposing to help mitigate any effect from tide.

Dredge survey results

A total of 259 1km 2 survey grids were selected for sampling (TableZ2). Out of the 259 there were 183 (121 in the western bed and 62 in the eastern bed) or 70.7% that were towable. Only two stations were untowable due to fixed lobster gear or other known obstructions. The remainder of the untowable sites were due to inappropriate substrate.

Calculations of fishable area were reduced by the area of the sites that were untowable. Total biomass calculations are based only on the towable area (183 km^2). The site that had a known obstruction was not included as it is not fished by area harvesters because of the risk to their gear and the site with lobster gear was not included based on personal comments from Capt. Mike Danforth that it was an area of hard untowable substrate. Tow distance, catch volume and counts were all standardized to a 200m tow. Actual tow distances averaged 214 m.

The density plot for the survey (Figure 11) shows the highest concentration of biomass in the eastern bed. The eastern section had been closed to quahog fishing for almost three years. Substrate data (Figure 12) from Kelly et al. (1998) show the complexity of the substrate in the eastern section with highest quahog densities found near the boundary of hard rocky substrate with gravels, sands or mud. Substrate data collected independently using sidescan imaging showed that Kelly et al.'s (1998) substrate information was relatively accurate. However, in some cases substrate labeled as “sand” or “gravel-sand mix” near our most productive tows may have been shell hash from old quahog beds that was seen in boxcores from the same area.

Size frequencies for all subsampled quahogs (n=20,737) taken during the survey are shown in Figure 13. Size frequencies were also plotted separately for quahogs sampled from the western and eastern beds (Figure 14). The western bed had a mean SL of 47.6 mm ± 4.6 mm and the eastern bed had a mean SL of 52.4 mm ± 5.1 mm. Cumulative size frequency distributions and a Kolmogorov-Smirnov test were used to test the null hypothesis that the size frequency distributions in the eastern and western areas were the same (Zar 1999). The null hypothesis was rejected (p=0.001)

Because the two beds have differing size compositions and abundance levels, it was decided to calculate abundance for the two beds separately before estimating combined abundance for the entire survey area. Abundance estimates (see below) assume a dredge efficiency of 0.161 (Table Z3 shows effects of different dredge efficiencies on abundance and bushel estimates).

To estimate the total biomass for the commercial fishing grounds the size frequency distributions were converted to proportion of the population in each 1 mm size bin. Shell length (L) was converted to meat wet weight (W) using $W=4.97x10-6 \times L^{3.5696}$ (Maine DMR 2003). Meat weights were converted to total biomass (meats and shells) by applying the average meat yield from the pilot survey of 17.5% and combining the values for the separate beds.

Variable	**Bed**	**Estimate**	**CV**
Abundance	Western	1.7108×10^9	8%
	Eastern	2.4058×10^9	11%
	Total	4.1163×10^9	8%
Bushels	Western	1.715×10^6	9%
	Eastern	2.787×10^6	11%
	Total	4.502×10^6	9%
Total Biomass (mt)	Western	47,704	8%
	Eastern	94,977	13%
	Total	128,529	7%
Meat Weight (mt)	Western	8,348	8%
	Eastern	16,621	11%
	Total	22,493	8%

Box core results

Efficiency estimates from box core experiments are presented based on sizes taken in the commercial fishery (35mm SL and greater). The estimated dredge efficiency was 16.1% with a 95% bootstrap confidence interval of 11.4%-21.6%.

Another important result from the boxcore work was that the average depth of live quahogs in the region sampled was no deeper than 9.55 cm (CV 20%)._The standard commercial dry dredge has cutting teeth that are set to a depth of 7.62cm. We did not see evidence of anaerobic quahogs located deep in the sediments as has been reported elsewhere (Chenowith and Dennison,1993; Taylor 1976). Based on these results, it would seem that the majority of quahogs in this region would be impacted after one pass of a dredge.

Per recruit modeling

Biological and fishery parameters from a variety of sources were used to carry out a per recruit analysis for ocean quahog in Maine waters. Age at length and growth information was taken from Kraus et al. (1992). Von Bertalanffy growth parameters estimated from a sample of 663 quahogs from Machias Bay were: $L_{inf} = 59.470 \pm 2.089$, $K = 0.055 \pm 0.006$, and $t_o = -0.235 \pm 0.483$. The growth curves from Maine indicate relatively fast growth the first few years of life in comparison to curves for other areas (Figure 19). Length-weight parameters were from the 2002 Maine Quahog survey: $W = 4.97 \times 10^{-6} * L^{3.5696}$. Length-weight curves for the Maine ocean quahogs and the rest of the EEZ stock were similar (Figure 20). Size at maturity data estimates were based on Rowell et al. (1990) who found that females became fully mature at an average size of 49.2mm for a quahog stock in Nova Scotia, Canada.

Fishery selectivity was modeled as a linear ramp function that was zero at 37 mm SL and one at 47mm. Following surveys, quahog of various sizes were pushed through the grates on the commercial dredge (19.05 mm, 3/4 in. bar spacing) to see what sizes might be retained. Clams from 34mm to 38mm generally passed through the grate with some getting caught. After 41mm almost all clams were thick enough to be retained. The regression model for shell depth and shell length in Feindel (2003) shows that a 19.05 mm (¾ in) bar spacing is the thickness of an ocean quahog with 38.7 mm SL.

The per recruit model used in this analysis was a length based approach which can be downloaded from the Northeast Fisheries Science Center as part of the NMFS Stock Assessment Toolbox.[28] The length based per recruit model was also used by Thorarinsdottir and Jacobson (2005). The biological reference points estimated in per recruit modeling for ocean quahog were F_{max} =0.0561, $F_{0.1}$=0.0247 and $F_{50\%}$ =0.013 y^{-1} (Figure 18).

Sensitivity analysis (Figure 21) shows biological reference points from the per recruit model for ocean quahog are most sensitive to fishery selectivity parameters and, in particular, the length at which ocean quahogs in Maine waters become fully recruited to the fishery.

Fishing mortality rate

For this report fishing mortality is estimated as the catch in biomass/average biomass^{-1}. The survey during 2005 took place over a period of two months and mortality rates are relatively low so that survey biomass is a good proxy for average biomass. Following NEFSC (2004), the catch for 2005 used in fishing mortality estimation was landings plus a 5% allowance for incidental mortality to account for clams that are killed during fishing activity but not harvested. Catch including the 5% incidental mortality allowance for 2005 was 505 mt and the biomass estimate was 22,493 mt giving F=505÷22,493 = 0.022 y^{-1}. Thus, the estimated fishing mortality rate is roughly equal to $F_{0.1}$ but higher than $F_{50\%}$.

Stock Status

Ocean quahog biomass in Maine waters was 22,493 mt meat weight and 2.7 million mt meat weight for the EEZ stock as a whole during 2005. It is not necessary to evaluate stock status of ocean quahog in Maine waters relative overfishing definitions because the stock component off Maine is a relatively small part of the EEZ stock as a whole. Overfishing definitions apply to the EEZ stock as a whole.

It was not possible to evaluate current biomass levels relative to a biological reference points associated with maximum productivity, depleted stock or historical levels because no appropriate biological reference points or historical biomass estimates are available.

The fishing mortality rate during 2005 F=0.022 $y^{-1}$was almost equal to $F_{0.1}$=0.0247 and the assumed natural mortality rate M=0.02 y^{-1} but almost double $F_{50\%}$ =0.013 y^{-1}. $F_{0.1}$ might be a

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[28] Contact Alan.Seaver@noaa.gov for information about the NMFS Stock Assessment Toolbox.

reasonable reference point for managers if the goal is to maximize yield per recruit while preserving some spawning stock. Simulation analysis (Clark 2002) indicates that $F_{50\%}$ (1.3% per year) might be a reasonable reference point for managers if the goal was to preserve enough spawning potential to maintain the resource in the long term. However, preservation of spawning potential may not be necessary if recruitment originates mostly outside of Maine waters.

There is evidence of recent recruitment (newly settled ocean quahog < 5 mm SL) in one of the beds that were surveyed. However, although growth is relatively rapid in Maine waters, it may be 3 decades or longer before these recruits become large enough to enter the fishery.

Stock assessment advice concerning ocean quahog in Maine waters would be easier to provide if management goals were formulated and if biological reference points for biomass and fishing mortality were defined.

Research Recommendations

1. Impact on habitat and substrate should be investigated for the Maine Dredge along with good estimates of area swept by fishing activity,
2. More work needs to be done to determine age, growth rates and size/age at maturity for Maine ocean quahogs. New digitized methods may help in this process.
3. Need better estimates of gear selectivity.

Acknowledgements

This report was completed with extensive help from the Captains and crews of the F/V Promise Land and F/V Whitney and Ashley. Additional assistance was provided by Scott Feindel, Larry Jacobson and the NEFSC Invertebrate (Clam) working group.

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**Maine Ocean Quahog Report -- Appendix - **Paired Tows Experiment

Survey design

The current (2005) survey for ocean quahogs was conducted using a substantially larger vessel (F/V Promise Land 12.8m) and drag than the 2002 survey vessel the F/V Whitney and Ashley (11m). In order to link the data from the 2002 pilot survey with the 2005 survey we needed a correction factor between the two vessels and drags. One concern with the pilot survey from industry members had been that the drag on the Ashley and Whitney was to light to get a good sample of the quahogs on bottom and would tend to underestimate abundance. The State of Maine contracted the original vessel, captain and drag to conduct side by side tows with the current survey vessel on April 16, 2005. It was determined that the two vessels would steam to an area in the closed fishing grounds that had a relatively high abundance of quahogs and conduct 8 coordinated close side by side tows in three replicate areas, 24 tows in all.

Survey gear

Each vessel was equipped with the same survey gear as had been used during their respective trips. Once a suitable tow path had been established both vessels in unison deployed there dredges and let out equal lengths of cable (Figure 22). The captain of the F/V Promise Land was responsible for setting the pace and path of towing and for radioing the precise start and stop times for a tow. Tow positions were recorded onboard the F/V Promise Land. Once both dredges had been recovered and washed in the vessel wake all live quahogs were removed and placed in graduated containers to determine total volume. Either a 5L subsample or the entire catch, which ever was greater, was taken for count estimates and size frequency measurements.

Data collection

Both vessels were equipped with a Allegro handheld field computer and data was entered under the categories: trip information (date, vessel, weather, sea state), tow information (tow number, depth, bottom type, start tow gps, speed, end tow gps, weight 5L, count 5L, estimated total count), size information (length). All tow locations were also entered into the Cap'n Voyager software. All data was analyzed in Excel and bootstrapped using Dr. Chen's program.

Paired tows results

Results from the side by side tows indicate a 2.5:1 ratio between the F/V Promise Land and the F/V Whitney and Ashley. The data collected from the tows was bootstrapped 10,000 times to estimate the standard error and 95% CI (Figure 23) Mean number per tow from the F/V Promise land was 1452 (CV 14%). Mean number per tow from F/V Whitney and Ashley was 583 (CV 13%).

The size frequency distribution from quahogs collected from subsamples during the tows (Figure 24) indicates a difference in selectivity between the two drags. A K/S test run on cumulative fractions shows a difference in the two distributions at the 0.02 level (Figure 25). The square mesh liner in the dredge on the F/V Whitney and Ashley was 19.05mm on a side while the bar spacing on the F/V Promise Land is 19.05mm. The smallest quahog present in both dredges subsamples is only 1 mm different at 35mm and 36mm SL respectively. Bar spacing may play a role in the selectivity difference since a square grid would have many more intersections to trap smaller animals or increase the likelihood of clogging the dredge with mud.

The size frequencies not only show that the lighter drag on the F/V Whitney and Ashley retained smaller quahogs it did not sample larger quahogs present in the area. This effect would not be caused by smaller openings but is an indication that the dredge may under sample larger quahogs. If smaller quahogs need to be closer to the surface because of siphon length or substrate availability than the lighter drag on the F/V Whitney and Ashley would have a bias to select a smaller quahog than a heavier dredge that can cut deeper into the substrate. Also the tow speeds set by the F/V Promise Land were faster than those regularly used by the F/V Whitney and Ashley. The lighter drag may not have been as effective at the slightly higher speeds used in the paired towing. The 2002 survey had two types of tows. Those conducted randomly through out the State and those done systematically based on distance from reported commercial catches. The systematic survey may be biased towards heavy catch areas so only the random sites that overlap the 2005 survey area were used for this rough comparison. Area biomass estimates from the 2002 pilot study are based on 25 completed tows.

The current estimate for the region which overlaps many of the same stations is based on 183 completed tows at a much finer scale. This may partly explain the differences between the two estimates. Also three years of fishing has taken place since the initial survey in which nearly 467,000 Maine bushels have been landed from the same region.

The updated 2002 estimate for the current survey area is 5.99 x 10^6 bushels with a 95%CI within 47% of the mean. The estimate from the 2005 survey is 4.502 x 10^6 bushels with a 95%CI within 25.4% of the mean.

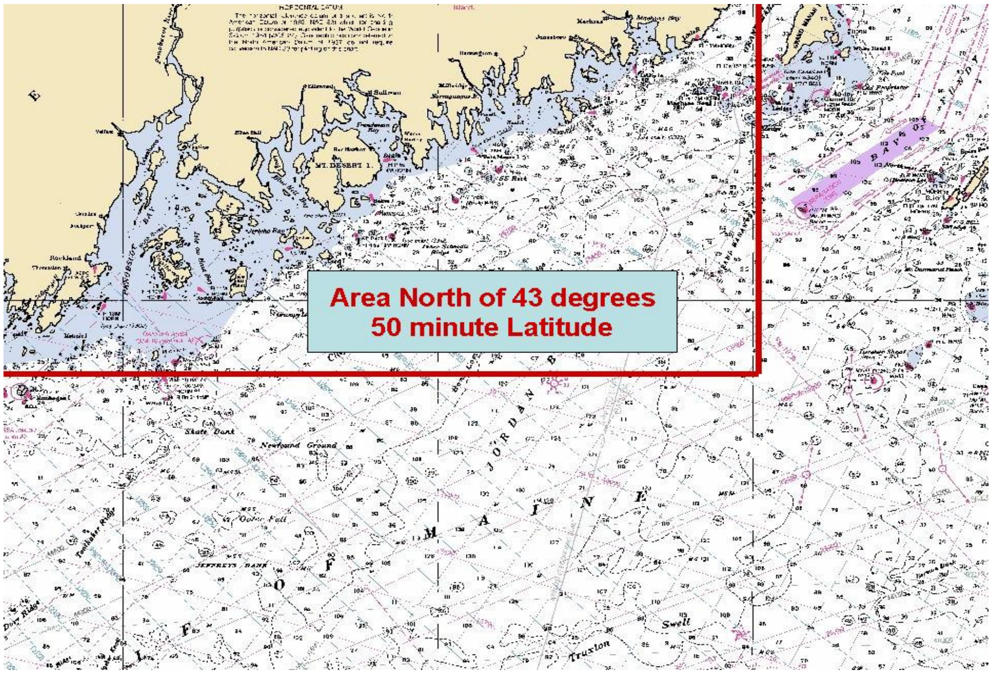
Year	Landings(Maine bushels) all vessel classes combined	Landings (only records with both effort and catch>0)	Effort (hrs fished)	Nominal LPUE (ME bushel/hr)
1990	1018	1018	286	3.56
1991	36679	34360	17163	2.00
1992	24839	24519	13469	1.82
1993	17144	17144	5748	2.98
1994	21672	21672	5106	4.24
1995	37912	37912	5747	6.60
1996	47025	47025	8483	5.54
1997	72706	72706	11829	6.15
1998	72466	72152	11745	6.14
1999	93015	92285	11151	8.28
2000	121274	119103	12739	9.35
2001	110272	110272	13511	8.16
2002	147191	147191	19681	7.48
2003	119675	119675	17853	6.70
2004	102187	102187	19022	5.37
2005	98153	98153	16766	5.85

Appendix A8. Table 1. Landings data for 1990-2005 from vessel logbooks. LPUE is reported for those records with both catch and effort data.

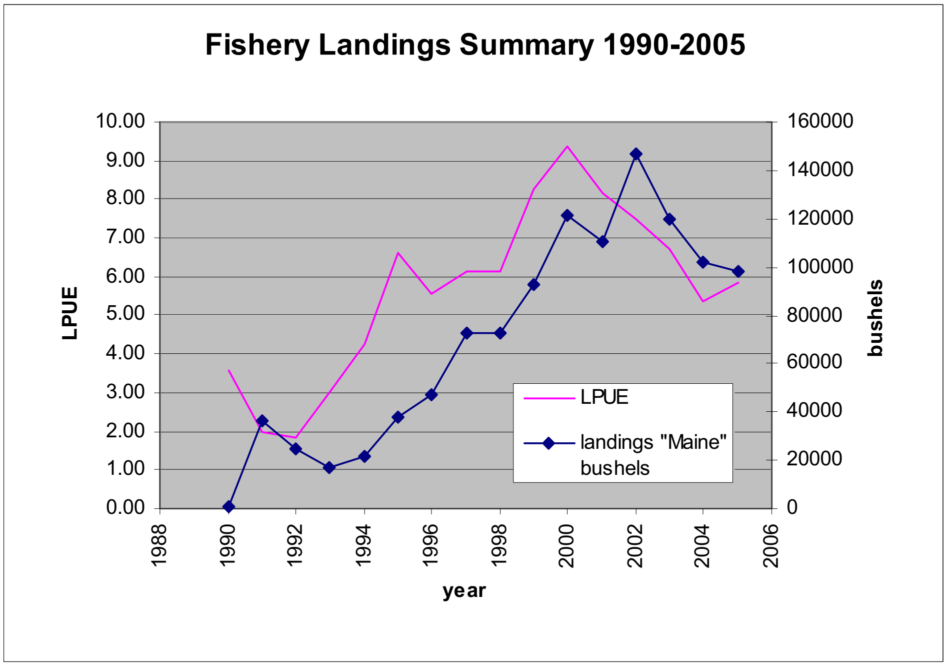
		sizes selected by dredge(>34mm SL)				all sizes		
		lower 95%	**average**	upper 95%		lower95%	**average**	upper 95%
Efficiency %		11.4	16.1	21.6		3.9	5.4	7.1
east	mean	3.3977E+09	2.4058E+09	1.7932E+09		9.9317E+09	7.1729E+09	5.4554E+09
	se	3.6358E+08	2.5744E+08	1.9189E+08		1.0628E+09	7.6757E+08	5.8378E+08
west	mean	2.4161E+09	1.7108E+09	1.2752E+09		7.0625E+09	5.1007E+09	3.8794E+09
	se	1.9464E+08	1.3782E+08	1.0272E+08		5.6894E+08	4.1090E+08	3.1251E+08
all	mean	5.8134E+09	4.1163E+09	3.0682E+09		1.6993E+10	1.2273E+10	9.3341E+09
	se	4.6013E+08	3.2580E+08	2.4284E+08		1.3450E+09	9.7138E+08	7.3880E+08

Bushel Estimates based on 10,000 bootstrap runs				
Efficiency (%)		11.4	16.1	21.6
east	mean	3.936E+06	2.787E+06	2.078E+06
	se	4.156E+05	2.943E+05	2.193E+05
west	mean	2.422E+06	1.715E+06	1.278E+06
	se	2.209E+05	1.564E+05	1.166E+05
all	mean	2.160E+01	4.502E+06	3.356E+06
	se	1.793E+09	3.872E+05	2.886E+05

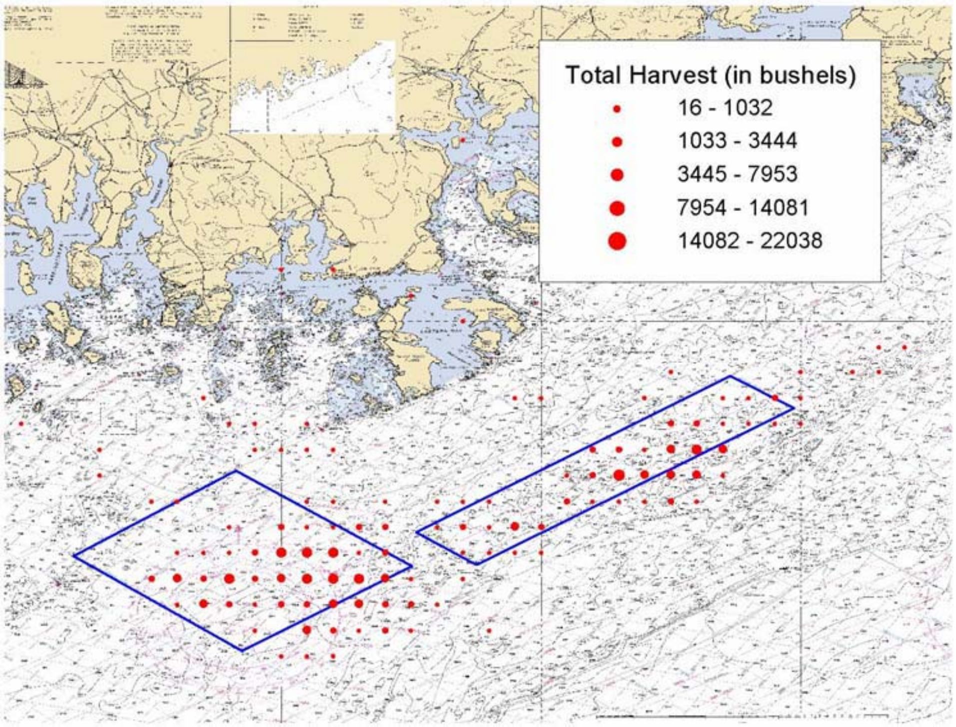
Appendix A8. Table 2. Effects of efficiency estimates on count and bushel estimates.



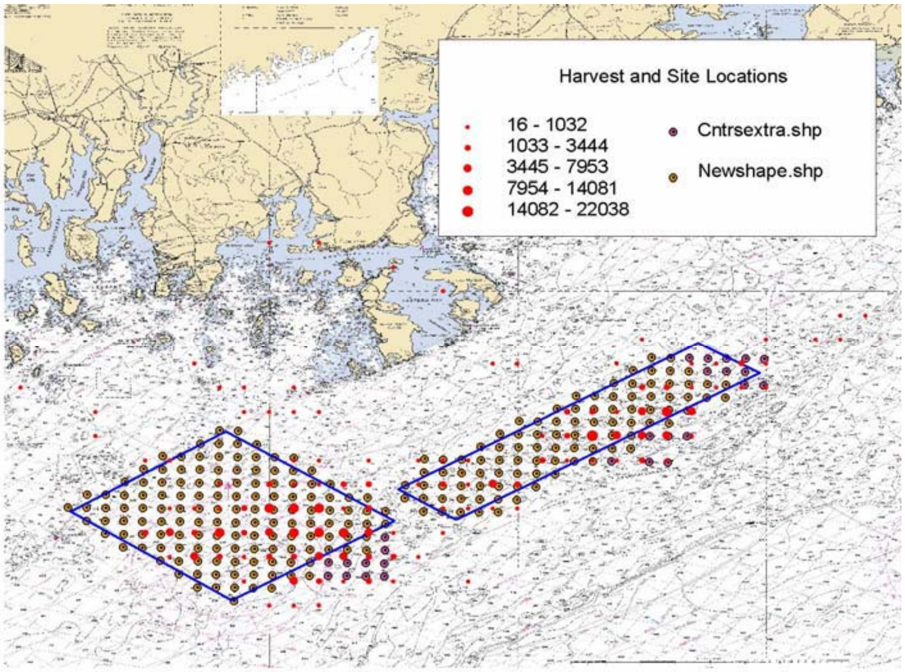
Appendix A8. Figure 1. Under the current Surfclam/Ocean Quahog FMP, the Maine fishing area is defined as north of the 43° 50’ N. This line roughly splits the Maine coast in two.



Appendix A8. Figure 2. Catch and effort trends in the Maine quahog fishery. In 2002 one of the primary quahog beds was closed due to PSP. It was reopened in the last quarter of 2005.



Appendix A8. Figure 3. Commercial harvest locations during 2003-2005. Point size represents total bushels reported to that location by all vessels.



Appendix A8. Figure 4. Spatial grids for abundance survey in relation to commercial activity.

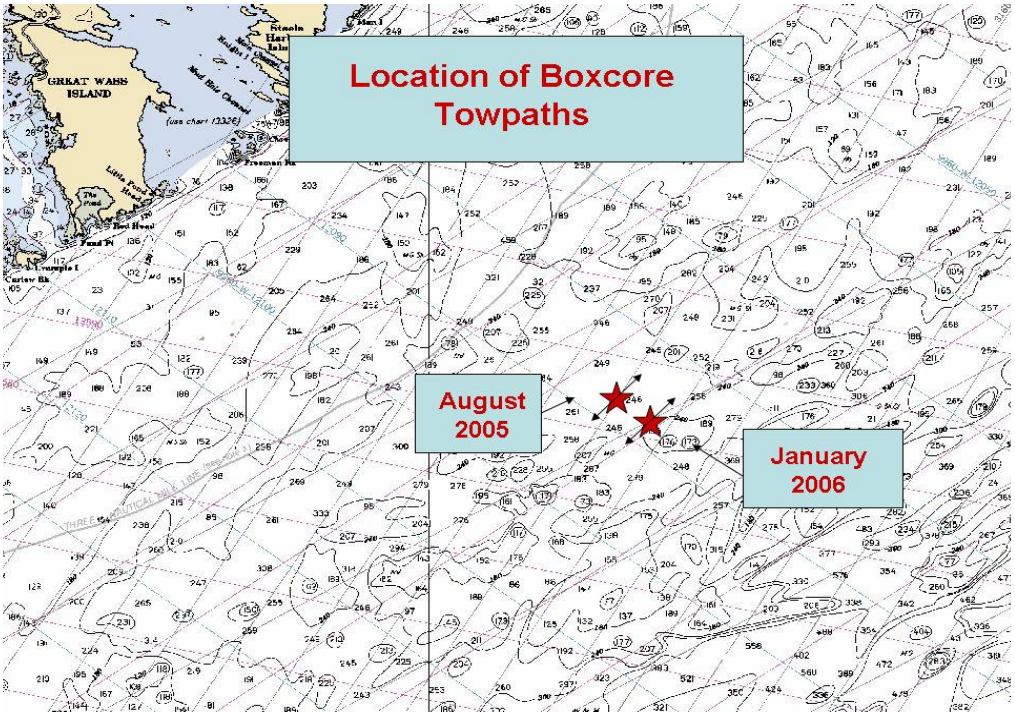
Appendix A8. Figure 5. Commercial drag used in all surveys in 2005.

Appendix A8. Figure 6. Cleaning the catch before it is brought on board. This practice is used in commercial operations as well.

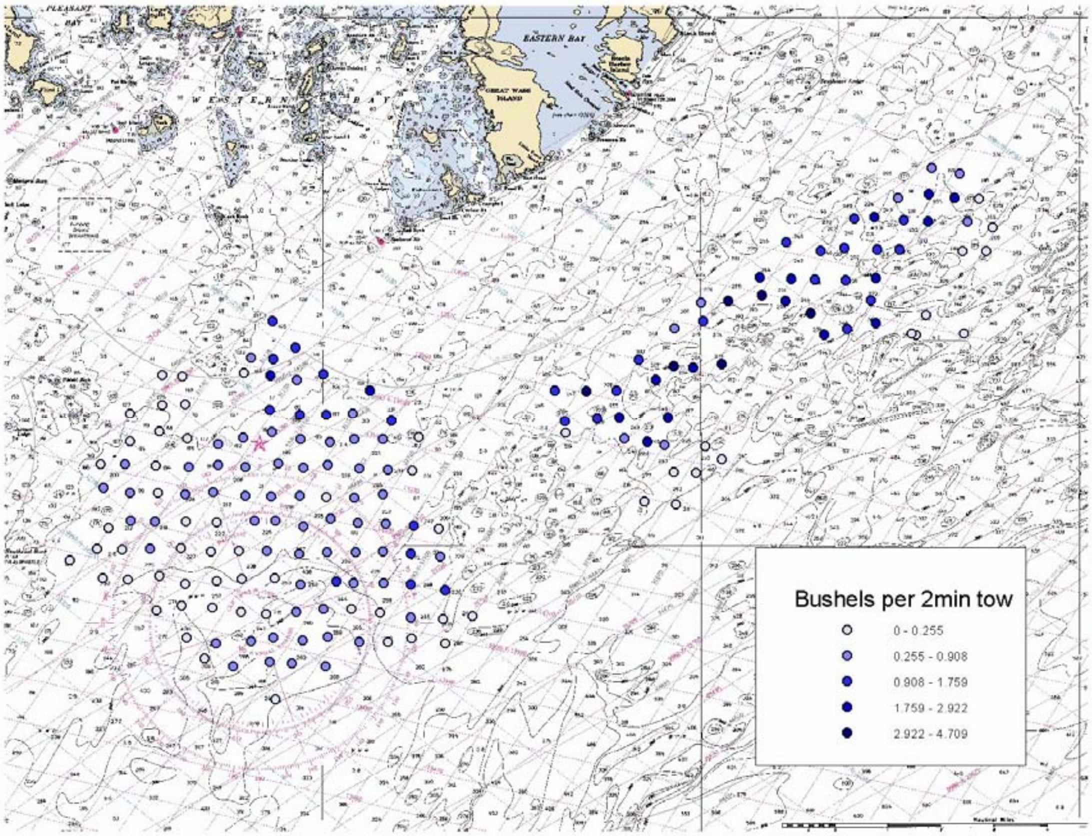
Appendix A8. Figure 7. Typical catch as it comes on board. Tow duration 2 minutes.

Appendix A8. Figure 8. The catch being processed on a standard shaker table.

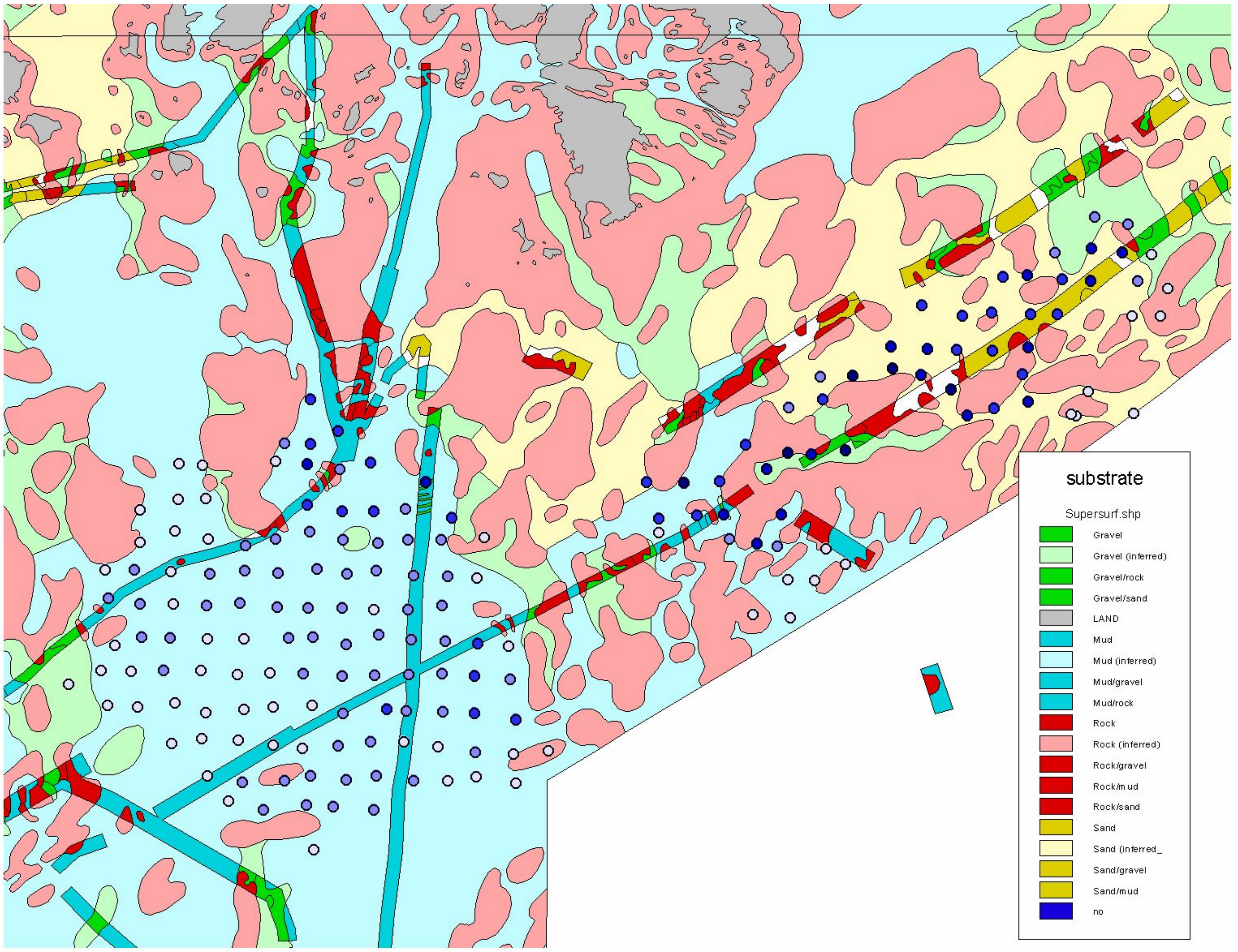
Appendix A8. Figure 9. Ocean Instruments 610 Boxcore along with a typical core sampled.



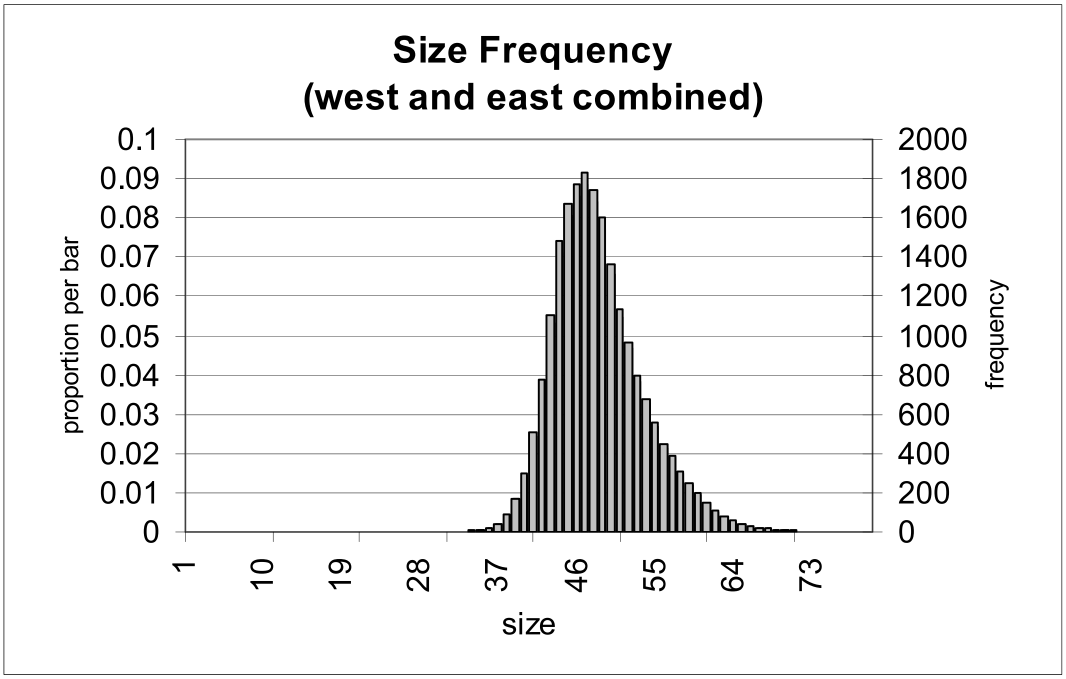
Appendix A8. Figure 10. Locations of Boxcore samples.
Areas with high quahog density were chosen from the abundance survey results.



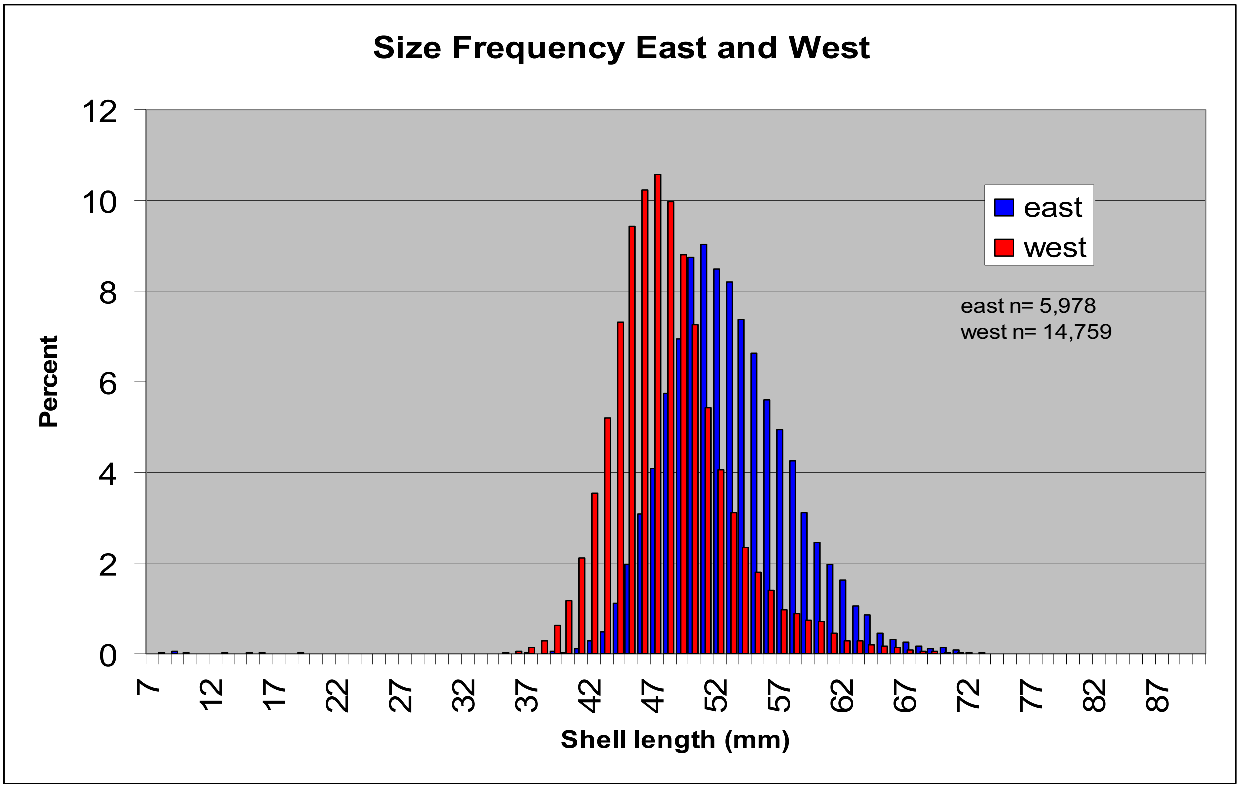
Appendix A8. Figure 11. Density Plot from towable 2005 survey locations.



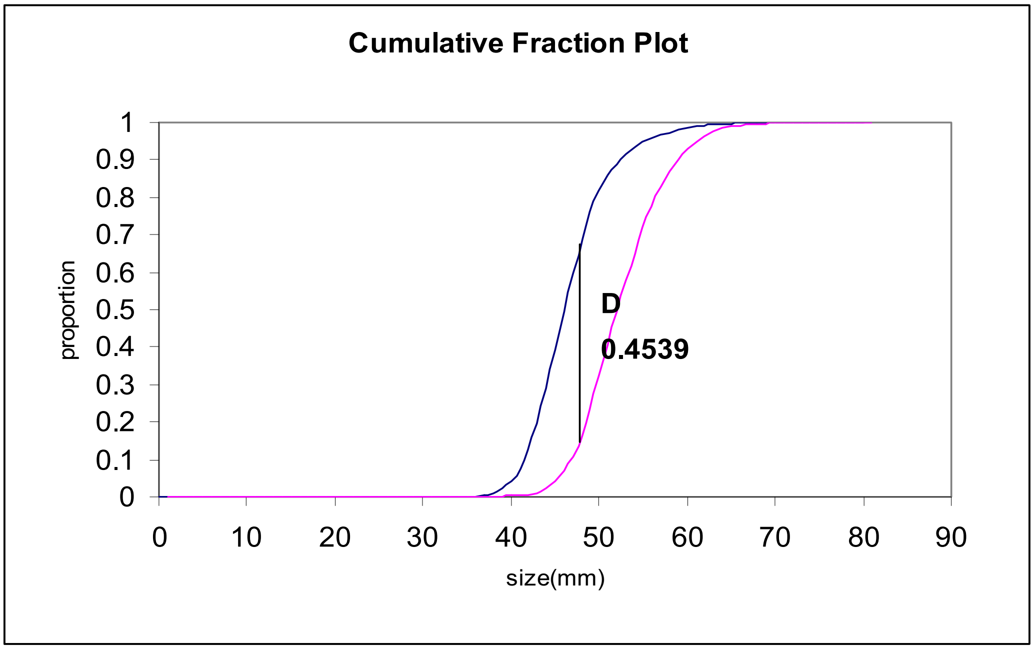
Appendix A8. Figure 12. Survey tows overlay on substrate data from Joe Kelly.



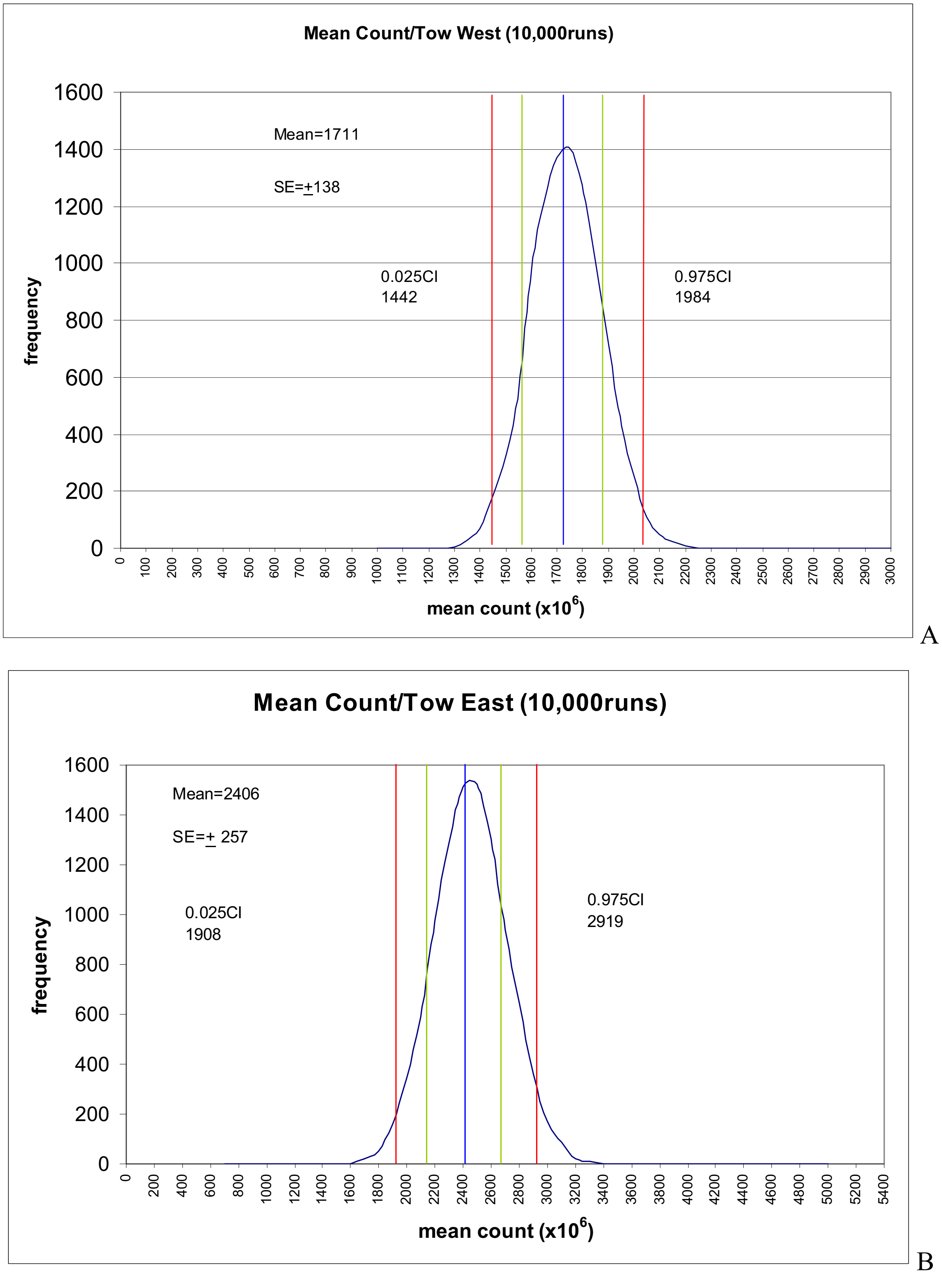
Appendix A8. Figure 13. Size frequencies for all tows in the western and eastern beds.



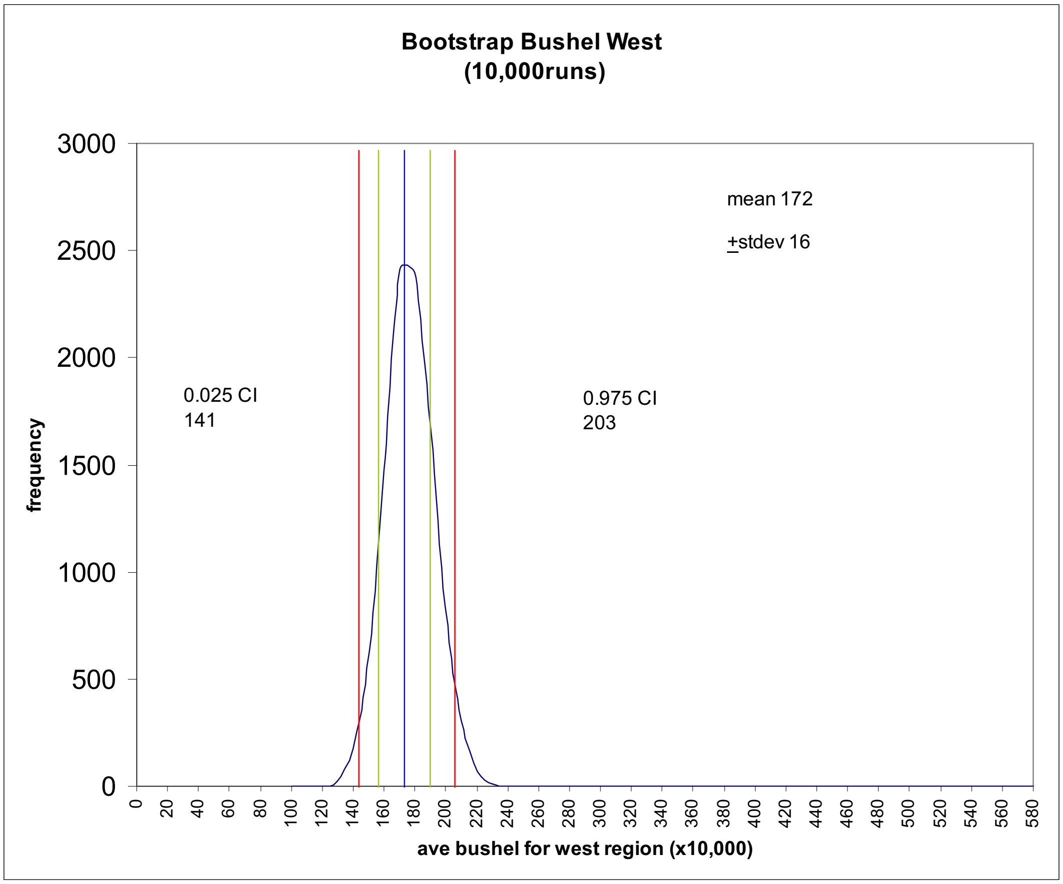
Appendix A8. Figure 14. Size frequencies for western and eastern bed. Used as basis for K/S test



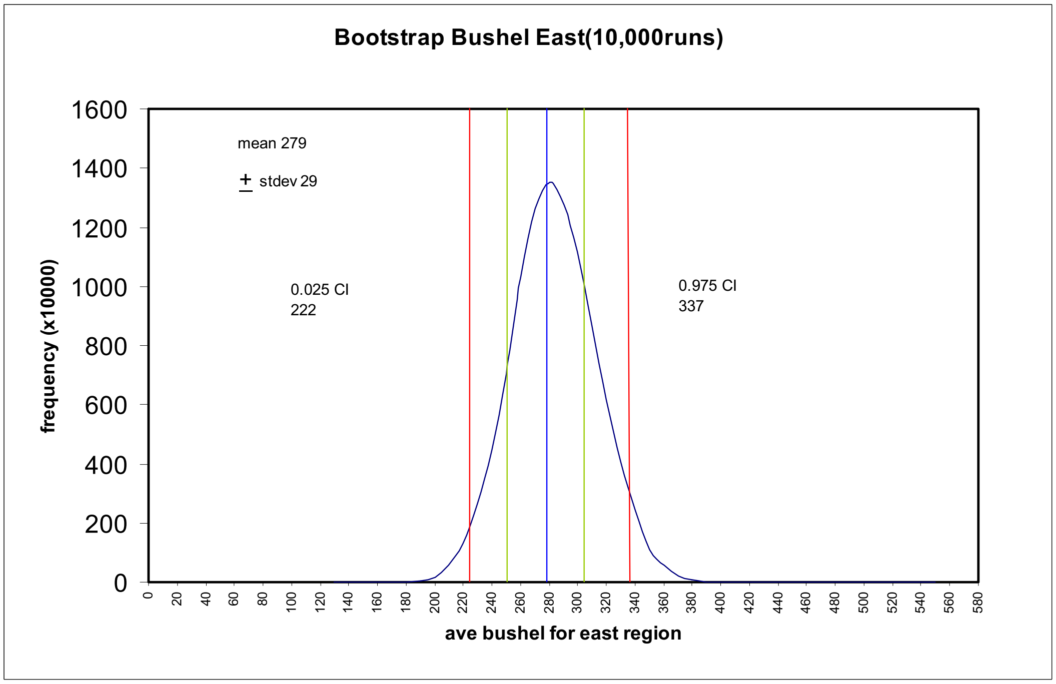
Appendix A8. Figure 15. Cumulative distributions for length composition in the western and eastern beds. The curves are significantly different at the *p*=0.001 level.



Appendix A8. Figure 16. Results from bootstrap runs on mean count per tow split by west (A) east (B) and on bushels per tow split west (C, next page) east (D, next page).

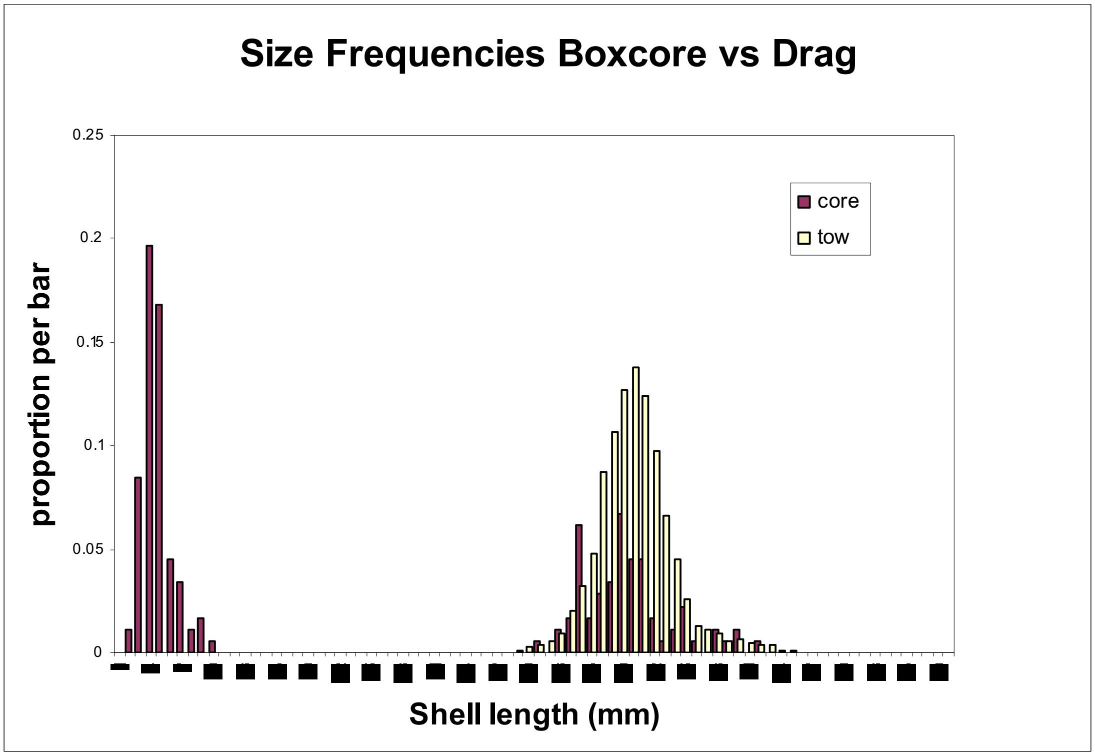


C

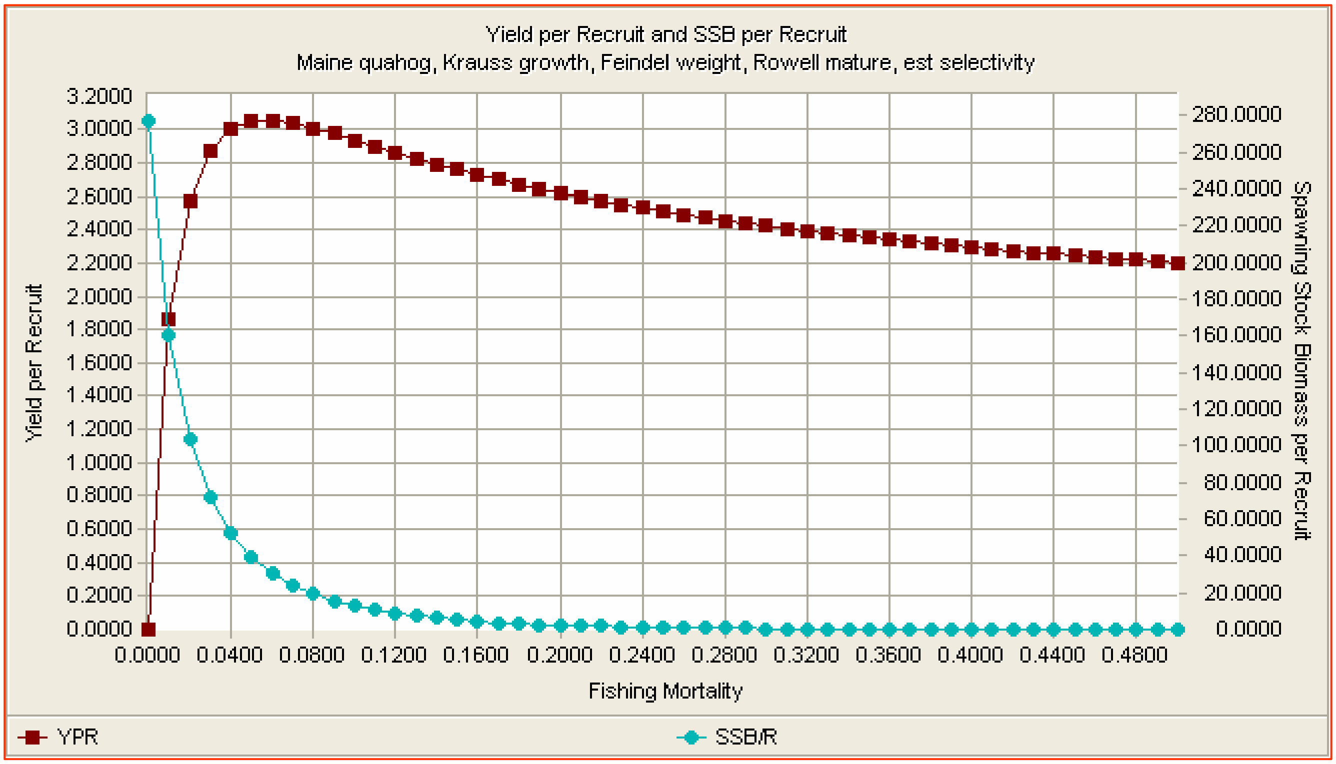


D

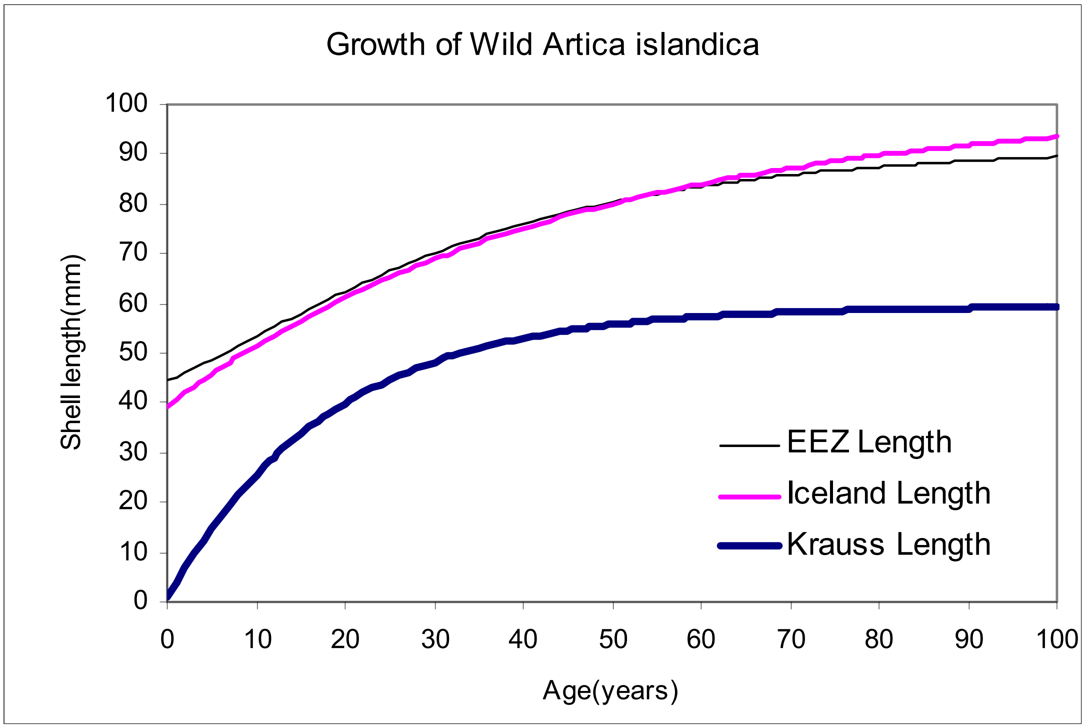
Figure 16. (cont.)



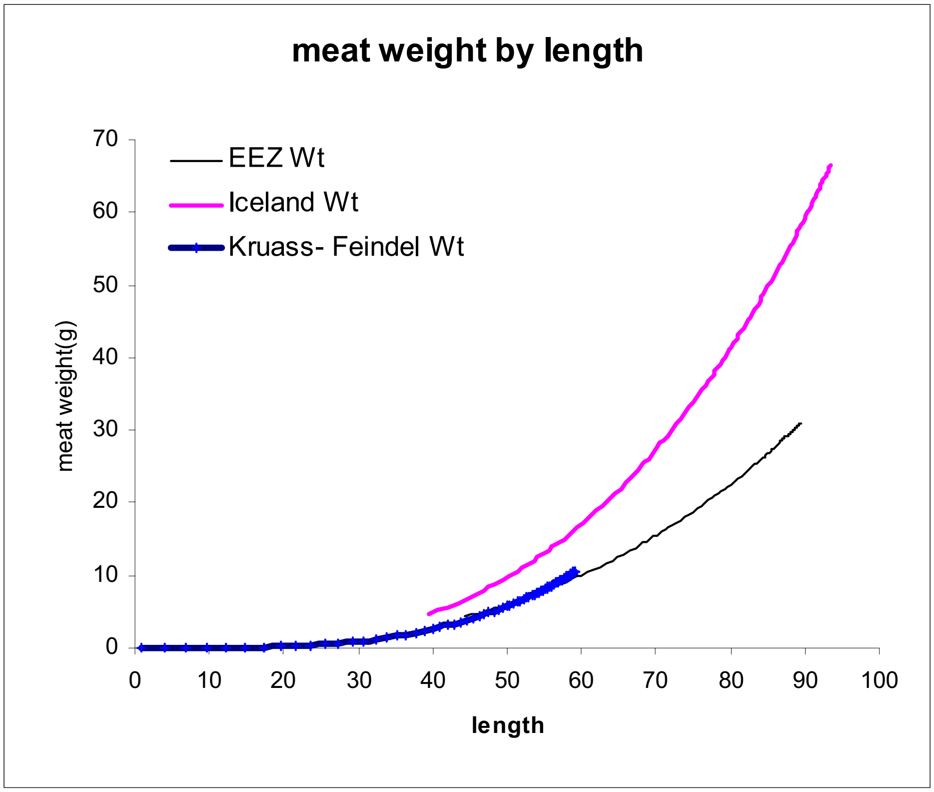
Appendix A8. Figure 17. Size frequencies from boxcore and follow on tows.



Appendix A8. Figure 18. Per recruit model results for Maine ocean quahogs.



Appendix A8. Figure 19. Three growth curves for quahog. Data for the Krauss curve was from Maine.



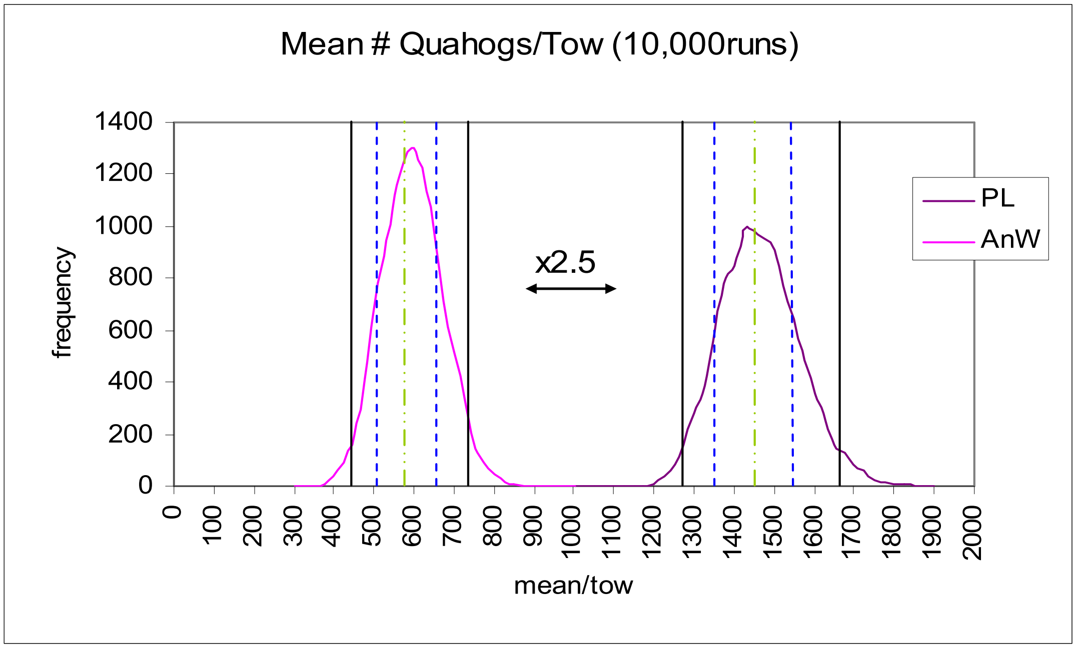
Appendix A8. Figure 20. Meat weight shell length relationships for three quahog stocks. Data for the Kruass-Feindel curve was from Maine.

Fully recruited length			
length	F-01	Fmax	F50%MSP
30	0.0196	0.0348	0.0109
35	0.0215	0.0419	0.0116
40	0.0242	0.0543	0.0126
45	0.0275	0.0801	0.0143
50	0.0319	0.168	0.018
55	0.0376	-1	0.0309

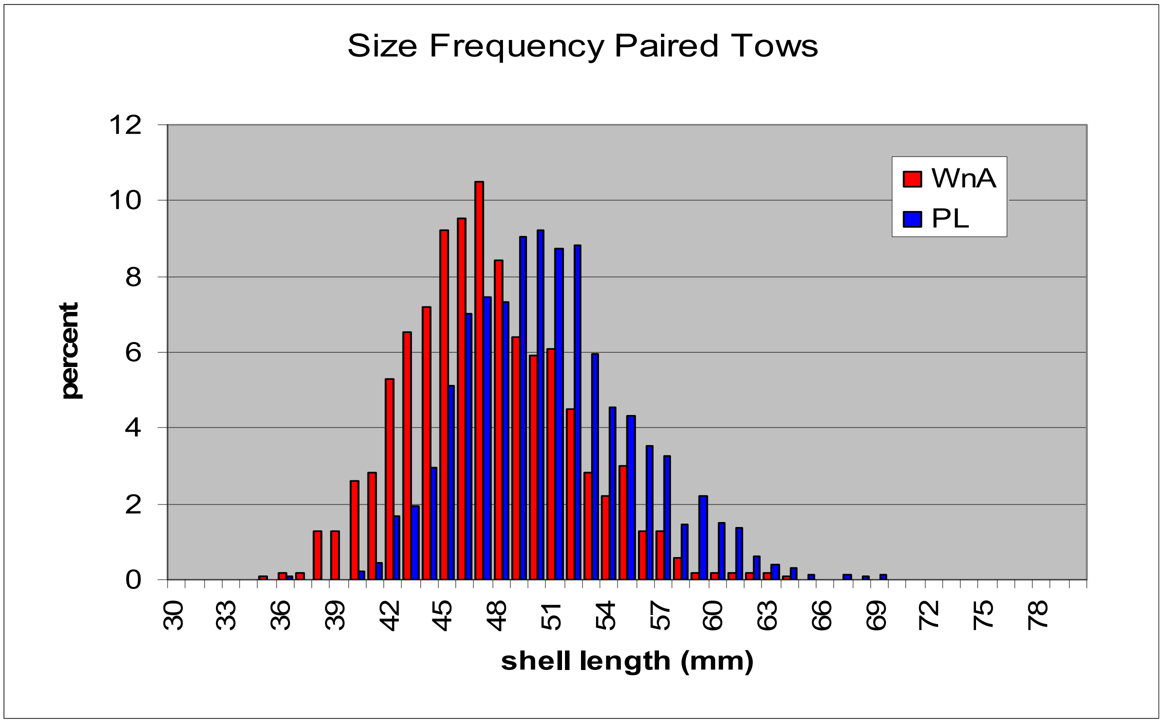
Fully Mature			
length	F-01	Fmax	F50%MSP
30	0.0253	0.0604	0.0168
35	0.0253	0.0604	0.0164
40	0.0253	0.0604	0.0157
45	0.0253	0.0604	0.0146
50	0.0253	0.0604	0.013
55	0.0253	0.0604	0.0105
60	0.0253	0.0604	-1
65	0.0253	0.0604	-1

Appendix A8. Figure 21. Sensitivity of YPR to size at recruitment and maturity.

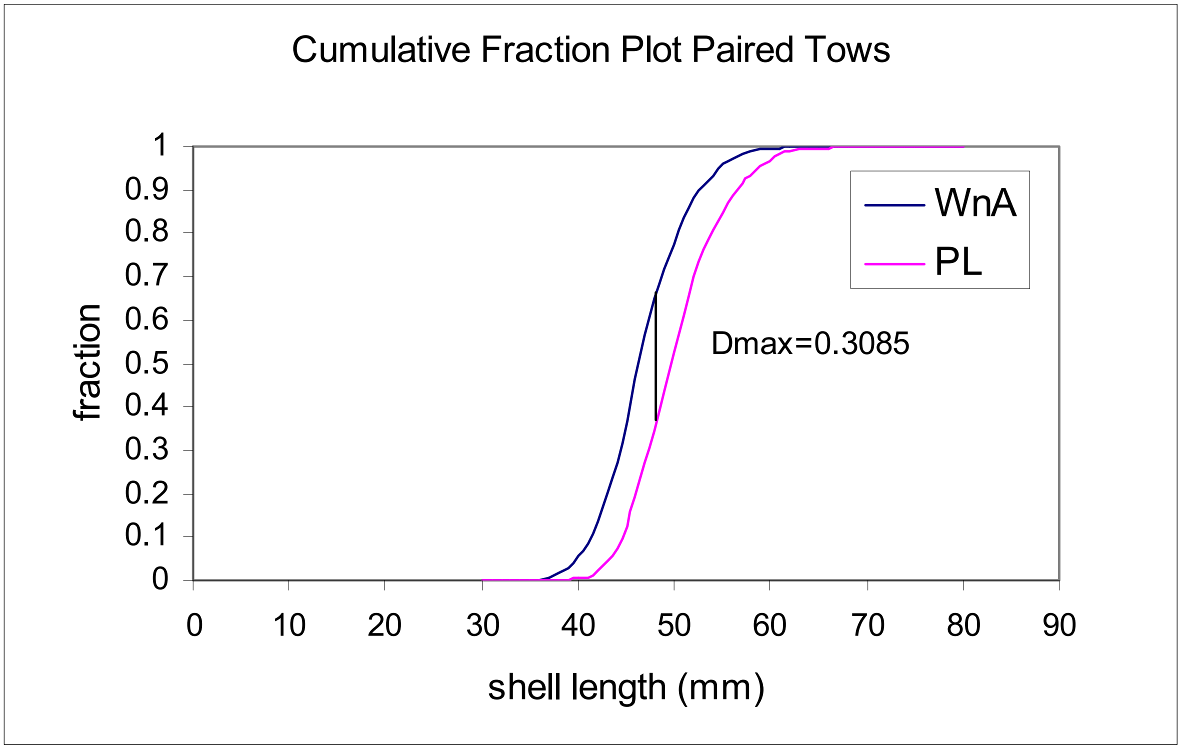
Appendix A8. Figure 22. Side by side towing operations underway.



Appendix A8. Figure 23. Results from both bootstrap runs for the paired tows between the F/V Promise Land and the F/V Whitney and Ashley. The F/V Promise Land has a catch ratio to the F/V Whitney and Ashley of 2.5:1



Appendix A8. Figure 24. Size frequencies for the two vessels in the paired tow experiments.



Appendix A8. Figure 25. Cumulative distribution plots for length data in paired tows.