Northeast Fisheries Science Center Reference Document 04-06

Stock Assessment of the Gulf of Maine - Georges Bank Atlantic Herring Complex, 2003

by

W.J. Overholtz, L.D. Jacobson, G.D. Melvin,
M. Cieri, M. Power, D. Libby, and K. Clark

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Executive Summary

The Transboundary Resource Assessment Committee (TRAC) met during 10-14 February, 2003 in the Conference Center, Biological Station, St Andrews, NB, Canada, to a assess the Gulf of Maine-Georges Bank Atlantic herring complex. Some data were preliminary (i.e. 2002 landings) at the time of the meeting and all analyses were completed with these data. Two assessments were presented at the meeting, a forward projection analysis (Chapter 10) and an ADAPT assessment (Chapter 14). The review committee did not reject either assessment; therefore, the results of both approaches are contained in this document. However, much progress was made on many other facets of the status of the herring complex. For example, both counties agreed that an assessment of the overall complex was warranted, that historic tagging information was still relevant, that multiple research survey time-series should be used in the analysis, and that the new acoustics results should be used.

The assessment focused on the fishery during 1959-2002, but historically landings of herring in coastal Maine have occurred over several centuries. The fishery on Atlantic herring in the region shifted from fixed gear with landings dominated by juvenile herring in the 1950s and 1960s to an intense foreign trawl fishery that occurred offshore (Georges Bank) by ICNAF countries in the mid 1960s through the late 1970s. In recent years, the fishery captures adult herring and landings are dominated by mid-water trawlers. Landings during the last 15 years have averaged slightly over 100,000 mt, and almost 123,000 mt during 1998-2002.

The herring assessment utilized research survey data from a variety of sources. Indices are available from NMFS research bottom trawl surveys (winter (1992-2002), spring (1968-2002), autumn 1963-2002), Canadian research bottom trawl surveys (winter 1986-2002), US and Canadian larval herring surveys (US 1971-1994, Canada 1987-1995), US herring acoustic surveys on Georges Bank (1998-2002) and Maine DMR inshore herring acoustic surveys (1999-2002). Trends from US and Canadian bottom trawl surveys indicate a decline in herring during the late 1960s through the 1970s, a very low period of abundance during the late 1970s through the late 1980s, and recovery during the 1990s. Both larval herring surveys indicate an increasing trend during the late 1980s and early 1990s. The US herring acoustic survey on Georges Bank indicates that a major recovery of herring has occurred on Georges Bank and a large herring biomass is present, while the acoustic survey in Maine inshore waters indicates a relatively stable biomass for the inshore component.

The forward projection analysis suggests that a major recovery of the entire herring complex occurred during the 1990s. Fishing mortality increased steadily to about F=0.8 during the late 1960s and then increased further to above F=1.0 in the mid to late 1970s and early 1980s. Fishing mortality declined in the late 1980s and 1990s and has remained low during recent years (F2002=0.06). Total stock biomass declined from a high of 1.4 million mt in 1962 to a low of 87,000 mt in 1982. Stock biomass increased gradually thereafter to 1.0 million mt in 1994 and 1.8 million mt in 2000. Trends in spawning biomass are very similar to the pattern observed in total stock biomass, reaching about 1.6 million mt in 2001. Recruitment was very poor during the late 1970s and 1980s, but steadily improved in the 1990s with two very large year-classes, the 1994 and 1998 cohorts.

Results for the ADAPT assessment also suggest that Atlantic herring from the Gulf of Maine-Georges Bank complex have also recovered from low biomass in the 1980s. Fishing mortality increased steadlily from the late 1960s through the late 1970s, reaching F=1.1 in 1980. After 1980 fishing mortality declined and averaged about F=0.3 during 1983-1997. Recent F's have averaged about F=0.2 and F in 2002 was 0.18. Stock biomass declined from a high of about 1.2 million mt in 1967 to less than 100,000 mt in 1982. Total stock biomass recovered very slowly during 1983-1994 to about 220,000 mt and then more quickly to about 700,000 mt in 2002. Spawning biomass followed the same pattern, reaching about 600,000 mt in 2002. Recruitment was relatively low during 1972-1994 and two large year-classes occurred in 1994 and 1998.

Yield per recruit reference points were re-estimated and results were Fmax=0.40, F0.1=0.18, and F40%=0.15. Biomass dynamics based reference point estimates were obtained with a Fox (1975) model and results were Fmsy=0.25, MSY=222,000 mt, and Bmsy=896,000 mt. An Fmsy proxy (F95% Fmsy) was estimated in the ADAPT assessment from parametric and non-parametric stock-recruitment relationships and results were F95% MSY=0.20-0.22.

The prognosis from forward projection model results suggests that fishing the stock at an F of 0.1 would produce a catch of 170,000 mt in 2004 and a 2+ biomass of about 1.79 million mt in 2005. An F of 0.2 in 2004 would produce a catch of 323,000 mt in 2004 and a beginning year stock size of 1.64 million mt in 2005. Corresponding projections with the ADAPT results produce a 2004 catch of 60,000 mt (F=0.1) and a 3+ biomass of 550,000 mt. Fishing the stock at an F=0.2 would produce a 2004 catch of 100,000 mt and a 2005 biomass of 500,000 mt in 2005.

Assessment results from the two modeling approaches suggest a threefold difference in 2002 biomass (1.8 million mt vs. 600,000 mt and) and F (0.06 vs. 0.18). These results were not reconciled by the TRAC working group during the February 10-14, 2003 meeting, and future work was suggested.

1.0. Overview of Atlantic Herring in the Region

1.1. Introduction

Atlantic herring exhibit a high degree of "population richness" with a number of separate spawning areas and discrete egg and larval distributions throughout their range in the northwest Atlantic (Sinclair 1988, Sinclair and Iles 1988). The population structure of Atlantic herring has been described as a metapopulation (McQuinn 1997) and fitting the population complex models of Stephenson et al. (2001) and Smedbol and Stephenson (2001). In these models, it is recognized that herring form identifiable, relatively discrete and self-sustaining populations that persist both spatially and temporally.

In recent years there has been increasing emphasis on preserving all aspects of biodiversity, including within species diversity (Stephenson and Kenchington 2000). The biological rationale for preserving this diversity is that such variation allows adaptation to changing conditions (Smedbol and Stephenson 2001). The economic rationale is that the decrease or elimination of population richness may lead to the loss of fisheries, such as occurred during the mid 1970s when the Georges Bank herring stock collapsed.

Most fishery management units for herring are at the scale of the stock complex (Stephenson et al. 2001) rather than at the level of the individual spawning ground. The three recognized spawning groups within the Gulf of Maine-Georges Bank Atlantic herring stock complex present a unique challenge to management. Given the intermixing of these spawning groups, and the timing of the index surveys, it is currently not possible to assess each spawning group separately. At the same time, it is recognized that conspecific populations often differ in productivity and may not support equal levels of exploitation (Smedbol and Stephenson 2001).

Thus, appropriate fishing levels may not be the same for the different populations within the stock complex and individual spawning components must be monitored to ensure that they are not eroded by overfishing.

1.2. Herring stocks

Western Atlantic herring (*Clupea harengus*) range geographically from Labrador to Cape Hatteras, with major spawning areas restricted to the northern regions of this distribution (Scott and Scott 1983; Collette and Klein-MacPhee 2002). In the Gulf of Maine/Bay of Fundy region there are three separate stock components recognized; Southwest Nova Scotia-Bay of Fundy (4WX), coastal waters of the Gulf of Maine (5Y) and Georges Bank (5Z), the latter including Nantucket Shoals (Figure 1.1). However, our the perception of stock structure has varied over time and the delineation of stock boundaries has been challenging due to the degree of inter-seasonal mixing among the components. The movement and the seasonal distribution of fish has also had a significant impact on the assessment of stock status, on how fishing effort has been assigned, on the development of a catch-at-age matrix and on management.

A fishery for adult and juvenile herring in the coastal waters of the Gulf of Maine has been conducted for several centuries, but it wasn’t until the mid to late 1960s that the fisheries in the region markedly increased (Collette and Klein-MacPhee 2002). In 1961 an international fishery for herring developed in the offshore waters of Georges Bank and southern New England. The Georges Bank fishery peaked in 1968 with a catch of 373,000t, but the fishery collapsed in 1976 due to overfishing and poor recruitment. Only 2500t of herring were harvested from Georges Bank in 1977. An excellent summary of the Gulf of Maine fisheries is provided by Anthony and Waring (1980).

Assumptions regarding the seasonal movement, intermixing, and spawning of the individual components of the Gulf of Maine/Georges Bank herring stock have changed over the years. During the 1970s when herring in the Gulf of Maine region were assessed and managed by the International Commission for the Northwest Atlantic Fisheries (ICNAF), the three components (4WX, 5Y and 5Z) were assessed independently with the basic assumption of little intermixing among them (Figure 1.1). Stock boundaries were based on ICNAF (later NAFO) statistical reporting areas, and catches assigned accordingly. Today, we recognize that catches in

US waters may contain a mixture of herring, and that the distribution/mixing of fish varies from season to season. In this section of the report the information on the distribution, seasonal movement, and stock structure is summarized and reviewed.

1.3. Scientific and Management Units

Delineation of the Northwest Atlantic into statistical areas for reporting of fish landings began in US waters in the late 1800's, but it was not until 1932 that statistical areas were first agreed (Halliday and Pinhorn 1990). Over time, and several institutional changes, reporting boundaries and management units, were redefined and renamed. Presently, the statistical reporting areas developed by the International Commission for the Northwest Atlantic Fisheries (ICNAF) are used to define stock and management units.. ICNAF divisions were an attempt to define, based on the knowledge at the time, the entire stock unit while sub-divisions were used to define fisheries and fish densities (Halliday and Pinhorn 1990). Sub-areas and statistical areas within sub-divisions are used today to compile fishery data (Figure 1.1). Important modifications to the ICNAF statistical areas included the changing of the boundaries between Divisions 4X and 5Y to correspond with the US/Canada maritime boundary delineated in October 1984 and the recording and reporting of separate fisheries statistics for the Canadian and US portions of Georges Bank beginning in 1986.

1.4. Stock Structure

Perceptions of herring stock structure in the Gulf of Maine-Georges Bank region have changed over time. Mackenzie and Tibbo (1960) identified the main spawning groups in the Gulf of Maine based on distribution of <10mm larvae (Figure 1.2). Although they did not define stocks, their observations are generally consistent with later views of stock structure. In 1971 ICNAF defined the stock structure of herring in the region based on the available information (Figure 1.3). The stock structure, as revised in 1971, is today with few changes the foundation for the assessment and management of herring in the Gulf of Maine-Georges Banks region (Figure 1.4).

Herring in the Gulf of Maine and Georges Bank region are mixed during much of the year, except during spawning when they separate and return to their spawning grounds.

Documented spawning locations include:

- Inshore Coastal Areas of the Gulf of Maine: Scots Bay, Southwest shore of Grand Manan, off Eastern Maine, off Penobscot Bay, Western Gulf off Wood Island, Jeffreys Ledge, Stellwagen Bank (Figure 1.5) (Clark et al. 1999, Power et al. 2002, Reid et al. 1999, Tupper et al. 1998)
- Georges Bank (including Nantucket Shoals): Varied with time – contracted and protracted around Nantucket Shoals. Major grounds Northeast Peak (pre and post collapse), Cultivator Shoals and the Nantucket Shoals (Figure 1.5) (Melvin et al. 1996, Reid et al. 1999). Currently, spawning appears to be continuous from Massachusetts Bay into Great South Channel and along the northern fringe of Georges Bank to the Northeast Peak.

1.6. Larval Distribution

Larvae produced by the major spawning stocks in the Gulf of Maine/Georges Bank region remain discrete during the early part of the larval stage (Sinclair and Iles 1985; Tupper et al. 1998). Therefore, the distribution pattern of young larvae (<10mm) provides information on stock structure (Figure 1.6a to 1.6d).

Both Canada and the US have conducted larval surveys on Georges Bank and in the Gulf of Maine. In 1956 the Fisheries Research Board of Canada and the US Fish and Wildlife Service initiated a co-operative program to identify herring spawning grounds and nursery areas in the Gulf of Maine/Bay of Fundy region (Tibbo et al., 1958). A broad scale survey design was implemented to cover most of the offshore waters. Based on the distribution of 4-9mm larvae, the study concluded that the largest herring spawning area in the Gulf of Maine occurred on the northern edge of Georges Bank (Figure 1.7). Annual larval surveys were conducted throughout the 1960s in the Gulf of Maine (Boyar et al. 1973a, Boyar et al. 1973b; Tibbo and Legare, 1960). Again, the studies found that the largest herring spawning component occurred on the northeastern portion of Georges Bank. In 1971 ICNAF initiated an international larval survey that concentrated in NAFO sub-division 5Z (i.e., Massachusetts Bay, Nantucket Shoals, and northeastern portion of Georges Bank. In 1971 ICNAF initiated an international larval survey that concentrated in NAFO sub-division 5Z (i.e., Massachusetts Bay, Nantucket Shoals, and Georges Bank) and which formed the foundation for the future US larval programs summarized by Smith and Morse (1993).

1.6.1. US Larval Survey

The ICNAF larval herring survey in the Gulf of Maine ended in 1977, but was followed during 1977 to 1987 by a comprehensive US fisheries ecosystem study known as the Marine Resource Monitoring, Assessment, and Prediction program (MARMAP). Following the completion of the MARMAP program, larval surveys of the area were continued by the Northeast Fisheries Science Center (NEFSC) under a herring/sand lance interaction study. US larval surveys ceased in January 1995.

The information collected by the ICNAF and US larval programs provide an overview of herring abundance and distribution during the pre-collapse, the collapse, the post-collapse, and the recovery stages of the Georges Bank herring stock. Smith and Morse (1993) clearly illustrate the transition from pre-collapse to the recovery. Larval distribution figures from their study are reproduced here as Figures 1.6a to 1.6d. During the early to mid 1970's, recently hatched herring larvae (4-8mm) on Georges Bank were concentrated on the northeastern portion of the bank (consistent with previous studies) and in the Great South Channel, just south east of Cape Cod, but west of 69^{o} longitude. Only small concentrations were observed in the Massachusetts Bay region. Later stage larvae, 2 to 5 weeks of age, were dispersed from these epicenters of spawning and were distributed over most of the bank by the time they were 5 to 8 weeks of age (Figures 1.6a).

During 1976-1984, when the Georges Bank herring stock had collapsed, the distribution and abundance of larval herring contracted to the west with the only strong signs of newly hatched larvae occurring in the vicinity of Massachusetts Bay. The large and dense aggregations of young larvae on the eastern portion of the bank had all but disappeared. Older larvae were restricted to a much narrower geographical range in the western portion of the bank, with only small and sparse occurrences of 13+mm larvae on the eastern half of Georges Bank (Figure 1.6b).

During 1985-1987, herring on Georges Bank began to show signs of a recovery. While the newly hatched larvae were still restricted to the Massachusetts Bay/ Nantucket Shoals area, older larvae were found over more of the bank (Figure 1.6c). This time frame represents the transition period back to the pre-collapse distribution By 1988-1990, young herring larvae were still concentrated in the Massachusetts Bay/Nantucket Shoals area, but occurred across the bank to almost the Hague Line (Figure 1.6d). Large aggregations of newly hatched larvae first appeared on the Canadian portion of Georges Bank in 1992 (Figure 1.7). By the time the US larval surveys ended in 1994-1995, large aggregations of newly hatched larval herring were distributed throughout most of the Bank with dense aggregations characteristic of the pre-collapse era occurring on the northeastern portion. Dense concentrations of 4-7mm larvae were also found in the Nantucket Shoals area during this same time period (SARC, 1996).

1.6.2. Canadian Larval Survey

Canadian larval surveys on Georges Bank were initiated in 1987 to monitor the distribution and abundance of herring larvae during what appeared to be the early stages of recovery. Annual larval surveys were conducted from 1987 to 1995 with expansion of the survey area occurring in 1990 and 1992 to provide better coverage of potential spawning areas. Information pertaining to the timing of each survey and the number and size range of larvae caught is presented in Table 1.1. The spatial distribution of larvae <10 mm total length (size generally considered to reflect spawning area) sampled in 1988, 1990, 1992, and is presented in Figure 1.7. Detailed annual plots of sampling stations and total larval distribution are provided in Melvin et al. (1996).

During 1992-1995, the Canadian larval survey was conducted during late October to early November. During 1992-1995, the surveys were conducted 2-3 weeks later, from mid to late November. In these latter surveys, the number and size range of larvae caught markedly increased.

Canadian survey results clearly show herring spawning during 1986-1991 spawning, as reflected by aggregations of larvae <10mm in length, was concentrated west of the Hague line in the vicinity of Georges and Cultivator shoals. By 1992, however, the distribution of larvae <10 mm expanded well into Canadian waters. This pattern continued annually through the last survey in 1995. Interestingly, in October 2001 a plankton tow conducted just east of the Hague Line collected over 50,000 5-7mm larvae.

Annual distributions of herring larvae in the Canadian surveys were generally consistent with the those in US larval surveys through 1990, the last year for which detailed US data are available.

1.6.3 Summary of Information on Larval Distributions

Herring larvae produced on spawning grounds in eastern Maine and New Brunswick are transported in a westerly direction and recruit to the juvenile herring population along the Maine coast (Tupper et al 1998). Larvae from spawning grounds in the western Gulf of Maine recruit to the juvenile herring populations along the coast of central and western Maine and along the coast of New Hampshire and Massachusetts (Lazzari and Stevenson 1992, Tupper et al. 1998). Larvae produced in the Jeffreys Ledge area move inshore and disperse in all directions (Tupper et al 1998).

Georges Bank larvae may be retained in a clockwise current gyre for several months (Boyar et al. 1973a, Reid et al 1999). However, larvae from Georges Bank and Nantucket Shoals may also migrate inshore (herring younger than two years of age are not usually found on Georges Bank) (Anthony and Waring, 1980). This would most likely occur when the Georges Bank and Nantucket Shoals spawning populations are large (Tupper et al, 1998). Graham et al. (1972) report herring larvae entering the Sheepscot estuary of Western Maine in the early fall, soon after hatching. In the spring, additional larvae also entered the coastal area. The authors postulate that the spring larvae originated from Georges Bank because when the Georges Bank component declined so to did the abundance of spring larvae along the coast.

1.7. Distribution of Herring

The distribution of adult/juvenile herring on Georges Bank and in adjacent areas has changed dramatically since 1961. Figures 1.8a to 1.8d provide a chronological overview, in 5-year intervals, of the distribution of herring in the Gulf of Maine and on Georges Bank, as indicated in Canadian (1986-1995) and the US (1966-2002) fall research bottom trawl surveys. Annual plots of herring distribution (up to 1995) are presented in Melvin et al. (1996). During the early and peak years of the Georges Bank fishery, 1961-1970, adult and juvenile herring were sparsely scattered throughout the Gulf of Maine and Georges Bank, with concentrations in the vicinity of known spawning areas (i.e., northern reach of Georges Bank, Nantucket Shoals and in Massachusetts Bay) (Figure 1.8a to 1.8c). However, the survey abundance indices were relatively low during 1961-1970 compared to recent years.

Between 1971 and 1977 the abundance of herring declined sharply and the distribution of the resource contracted to a few areas on the northwestern flank of the Bank and around Nantucket Shoals (Figures 1.8c and 1.8d). By 1979 herring had all but disappeared from Georges Bank and Nantucket Shoals during the traditional spawning season (Oct/Nov) and only a single immature herring (total length 21cm) was taken in the USA 1979 autumn bottom trawl survey on Georges Bank and in the Gulf of Maine. This trend continued into 1980, when no herring were caught in 121 survey tows, and into 1981, when only two mature herring (26 and 33 cm) were collected at two stations just north of Cultivator Shoals on Georges Bank.

In 1982 adult herring began to appear again in limited numbers in the survey. The distribution of herring on Georges Bank was, however, restricted to survey sampling stations in the vicinity of Little Georges and Cultivator Shoals. Trawl stations near Nantucket Shoals and in Massachusetts Bay generally showed a wider distribution and greater number of herring during 1982-85. The first herring were collected on the Canadian portion of the Bank occurred in 1985, but it wasn't until 1986 that significant amounts of adult/juvenile herring were sampled east of the Hague line.

Between 1985 and 1989, trawl survey catches of herring increased substantially on Georges Bank and the surrounding area, especially in Massachusetts Bay. Survey catches from 1988 onward exceeded those taken in the 1960s when the stock was heavily exploited. The expanded spawning distributions and increases in abundance continued through the 1990s and into the new millennium (Figures 1.8b, 1.8c), however, it wasn’t until 1992 that spawning was detected on the Canadian portion of Georges Bank. In recent years spawning herring have been consistently taken in the autumn surveys in Massachusetts Bay, throughout Nantucket Shoals and along the northern flank of Georges Bank from the Great South Channel to the Northeast Peak in an almost continuous band.

Although survey coverage of the inshore waters of the Gulf of Maine is generally poor, increasing numbers of herring have been collected in the coastal areas of Maine since about 1990.

Herring from the Gulf of Maine and Georges Bank overwinter between Cape Cod and Cape Hatteras, with major aggregations occurring in coastal and shelf waters off Long Island. Distributions patterns of herring from the US spring bottom trawl survey series, which began in 1968, illustrate the winter distribution of Atlantic herring along the US coast and depict spatial changes over time. During the late 1960s and early 1970s, herring primarily occurred south of Cape Cod in both the inshore and offshore waters (Figure 1.9a). Limited numbers were also found east of Cape Cod and in the Gulf of Maine proper. Between 1976 and 1984 (Figure 1.9b), after the Georges Bank spawning component had collapsed, very few herring were found in the offshore waters of southern New England or the Mid-Atlantic. Herring aggregations occurred in Massachusetts Bay just north of Cape Cod, but elsewhere in the Gulf of Maine, herring were found only sporadically. This led some researchers to speculate that the herring from the inner Gulf of Maine overwinter in near-shore coastal areas, while those originating from Georges Bank overwinter offshore. During 1986 to 1990 (Figure 1.9c), the spring distribution of herring expanded; more fish occurred offshore and in Massachusetts Bay, and also became more common on Georges Bank, Nantucket Shoals, and along the coast of Maine. Since 1990, herring have continued to broaden their winter distribution and increase in abundance in both coastal and offshore waters from Cape Cod to Cape Hatteras (Figures 1.9c and 1.9d).

1.8. Seasonal migration

Tagging studies and fisheries data provide the background source of information on seasonal movements of adult and juvenile herring from each of the three spawning components (4WX, 5Y and 5Z). Conclusions based on this information may only apply in a general sense because herring from this region are extremely migratory, are known to inter-mix throughout most of the year, vary their migration patterns from year to year, and the majority of the tagging programs were undertaken more than 20 years ago. Furthermore, most of the tagging was conducted when the Georges Bank component had collapsed, and so little information is available on the seasonal movement or intermixing of this group.

1.9. Juveniles

Larval herring move into the inshore Gulf of Maine waters from southeast New Brunswick to southern Massachusetts during fall and winter and metamorphose into juvenile (brit) herring the following spring. During the early brit stage, herring are weak swimmers and probably do not travel long distances once they reach shore. During the first year of life there is probably little mixing between the different spawning groups along the New England and New Brunswick coasts (Tupper et al. 1998). In late summer and fall, first year brit move farther offshore and overwinter close to the bottom. They return inshore the following spring at age two when they are large enough to be recruited to the sardine fishery.

The movements of juvenile herring from the Georges Bank component are not well known. Significant numbers of age 1 and 2 fish were sampled in Canadian surveys during 1988 to 1995 (Melvin et al. 1996). Davis and Morris (1976) found brit distributed widely in the open waters of the Gulf of Maine and suggested that these might have originated from Georges Bank since there was no evidence of spawning in the offshore Gulf of Maine.

Tagging studies indicate that juvenile herring migrate little during the summer (Speirs 1977; Anthony and Waring 1980; Waring 1981; Stobo 1983a), but move into deep bays or offshore areas to overwinter (Reid et al. 1999).

Prior to the collapse of the Georges Bank stock, meristic evidence indicated that the coastal Maine and New Brunswick juvenile herring populations were augmented by juveniles from Georges Bank (Anthony and Waring 1980). However, since the coastal juvenile population did not seem to be seriously affected when the Georges Bank component collapsed, the juvenile contribution may have been small. Aggregations of juvenile herring along the coast of Maine and New Brunswick are therefore likely derived from a variety of spawning grounds.

Tagging studies conducted in the late 1970s and early 1980s by the Maine Department of Marine Resources found that juvenile herring migrate westward in the late autumn and overwinter as far south as Massachusetts Bay (Tupper et al. 1998). In spring, as the waters warm, they return back east. Juveniles tagged in the Passamaquoddy Bay area, however, seemed to remain in the Bay of Fundy throughout the year (Creaser et al. 1984). Tagging studies are currently underway in New Brunswick weirs that should provide further knowledge of juvenile and young adult movement and migration patterns.

After moving inshore from the deeper waters of the Gulf of Maine/Bay of Fundy in May, juvenile herring move very little during the summer feeding season. With the onset of fall, the young fish move offshore into deeper water where they remain until the next season. As the fish grow they tend to mix with adults and undergo more extensive migrations. Juvenile herring tagged along the Maine coast tended to move eastward as the feeding season progressed, while those tagged in the Passamaquoddy area overwinter in the Bay of Fundy. There is no indication from any of the tagging results that the juveniles observed along the coast of Maine make a significant contribution to other spawning stocks such as those in southwest Nova Scotia. However, Anthony and Waring (1980) found a relationship between age 3 herring recruiting to Georges Bank and catches of age 2 fish in Maine weirs.

1.10. Adults

Adult herring from all three spawning components (5Y, 5Z, and 4WX) undertake extensive summer feeding and overwintering migrations and intermix with stocks other than their own. At spawning, each stock seems to home to its individual spawning group. Unfortunately, neither the degree of seasonal intermixing nor the integrity (fidelity) of individual stocks to spawning grounds are known. However, there is strong evidence, both historical and recent, that the stocks fluctuate independently, demonstrate different size and age structures, and undertake distinct but overlapping migrations.

Three general migratory patterns have been recognized for herring in the Gulf of Maine (Figure 1.10):

1. Most herring that spend the summer and fall in southwest Nova Scotia overwinter primarily off Chedabucto Head and in Chedabucto Bay in eastern Nova Scotia.
2. Most herring in the western Gulf of Maine migrate southwest along the coast and overwinter in Massachusetts Bay and off southern New England (Tupper et al 1998).
3. Georges Bank herring overwinter along the Mid Atlantic coast and spend the summer and fall on Georges Bank. Some adults move into the Gulf of Maine in the summer and return to spawning grounds on the Bank and Nantucket Shoals in the fall (Tupper et al 1998).

1.11. Tagging

The annual life cycle of the herring can be divided into five seasonal phases: overwintering, spring migration, summer feeding, spawning and fall migration. Tagging of herring at each of these stages has previously been undertaken to characterize movements and identify stocks (Stobo 1983a,b, Tupper et al 1998). Gulf of Maine and Georges Bank herring components are mixed to various degrees during all phases of their annual life cycle, except during spawning.

A brief summary of information derived from various tagging studies is provided below.

1.11.1. Gulf of Maine

Herring tagged in the summer and fall along the Maine coast tend to move southwest and overwinter in Massachusetts Bay, although a few move south of Cape Cod and some move across the Bay of Fundy to Nova Scotia (Stobo 1983a; b; Tupper et al. 1998). Adult herring tagged off Cape Cod and the western Gulf of Maine move north and east from the central coast of Maine to southwest Nova Scotia during spring and summer (Grosslein 1986). Summer feeding adults and older juveniles (age 3) tagged in eastern Maine from 1976 to 1982 were recaptured on overwintering grounds in Massachusetts and Cape Cod Bays and in Southern New England (Creaser and Libby 1988).

1.11.2. Great South Channel and Jeffreys Ledge

Herring tagged in 1977 in the Great South Channel and on Jeffreys Ledge were recovered all along the northeast coast from Ipswich Bay, Massachusetts into the Bay of Fundy and along southwest Nova Scotia in the summer and autumn herring fisheries. Tagged fish were also returned during the winter fisheries in Chedabucto Bay, Cape Cod Bay and Block Island Sound (Almeida and Burns 1978, Anthony and Waring, 1980).

1.11.3. Canadian Tagging Studies

Herring tagged in the autumn in the Bay of Fundy and off Nova Scotia migrated north to Chedabucto Bay and south to Cape Cod Bay and Block Island Sound to overwinter (Stobo et al. 1975; Stobo 1976; 1982). During the feeding and pre-spawning period, the Bay of Fundy contained a large mixture of Gulf of Maine and Scotian Shelf stocks (Stobo 1982).

1.12. Other Stock Structure Studies

Studies of meristics, otolith characteristics, and genetics have also been used to investigate the distinctness of herring stocks in the Gulf of Maine. Pectoral fin ray counts were used in the past to distinguish between herring from the Maine coast, Georges Bank and Nova Scotia (Anthony and Waring 1980). However, the number of pectoral fin rays is related to water temperature and is determined at an early age. Adult herring from Georges to Cape Cod are expected to have fewer fin rays than adults from further north since they inhabit warmer waters (Reid et al. 1999). Pectoral fin ray counts from juvenile fish from the Maine coast were found to be similar to adults from Georges Bank to Cape Cod (Anthony and Waring 1980).

Libby (cited in Tupper et al.1998) examined a number of otolith size and shape characteristics from recently hatched larvae from southwest Nova Scotia, western Georges Bank and mid-coast Maine. Eighty-four percent of 38 otoliths were classified to the correct spawning area.

Genetics have provided little conclusive evidence of discrete stock structure (Tupper et al. 1998). Biochemical methods for distinguishing herring populations in the Northwest Atlantic have been conducted since the 1970s. The U.S. and USSR biochemical and serological studies of the 1970s were considered flawed and thus no conclusions could be reached based on their information (Anthony and Waring 1980). Kornfield and Bogdonowicz (1987) found no evidence of genetically distinct herring populations in the Gulf of Maine based on mtDNA RFLP analysis.

More recently, McPherson (2002) found evidence for four semi-isolated groupings of herring. These groupings were herring from the Bras d’Or Lakes, Eastern Passage, Southwestern Nova Scotia and the interior Bay of Fundy/Georges Bank.

1.13. Conclusions

The Gulf of Maine and Georges Bank contain three major (and perhaps additional smaller) distinct but seasonally intermixing components from Georges Bank, Nantucket Shoals (Great South Channel area) and the coast of Gulf of Maine. As a result of mixing outside of the spawning season, much of the fishery takes place on mixed aggregations.

Intermixing of components in the fishery and during resource surveys precludes separate assessment and management of the components. It is therefore necessary (as in recent years) to evaluate the entire complex, with subsequent consideration of the individual components.

Summary Statement

- Atlantic herring generally exhibits complex stock structure
- Gulf of Maine and Georges Bank support three major distinct but seasonally intermixing components
- Major components spawn on Georges Bank, Nantucket Shoals and the coastal Gulf of Maine
- Objectives related to preserving stock structure require consideration of individual components
- Intermixing of components in the fishery and in surveys preclude separate assessment and management
- The most robust strategy for evaluation and management of this resource is an assessment of the entire complex with subsequent consideration of individual components.

2.0. Management of the Stock Complex

2.1. Management

Atlantic herring stocks in the international waters off the US coast were first managed in 1972 by ICNAF, which set quotas and country allocations during 1972-1976. With the passing of the Magnuson Fishery Conservation and Management Act in 1976 and the extension of jurisdictional waters in 1977, the New England Fishery Management Council (NEFMC) developed a management plan for Atlantic herring that was approved in December1978. During 1977 and 1978 the Atlantic herring fishery (in US waters) was regulated by a NMFS prepared preliminary fishery management plan. The 1978 management plan had two main objectives (NEFMC 1999):

- "To manage the Gulf of Maine and Georges Bank adult herring stocks so as to achieve levels of spawning biomass providing continued and relatively stable recruitment," and
- "To manage the Gulf of Maine juvenile herring fishery resources to stabilize and rebuild the sardine industry."

Since most of the herring fishery took place in state waters, an Interstate Sea Herring Management Plan for Maine, New Hampshire, Massachusetts, and Rhode Island was developed in 1983 by the Atlantic States Marine Fisheries Commission (ASMFC). The ASMFC plan had a main objective and two sub-objectives as follows:

- "To acquire information that will allow development and facilitate implementation of management approaches designed to minimize prospects of a collapse of herring stocks on which New England fishermen depend,"
  - "To protect spawning herring,"
  - "To promote complementary management of all components of sea herring fisheries throughout the range of the stocks of interest to U.S. fishermen, including relevant Canadian waters."

During the early 1990s, the increase in the abundance of herring in the Gulf of Maine, Nantucket Shoals and Georges Bank created a situation in which the majority of catches shifted from state to federal waters. This, combined with other changes, promoted the adoption of another management plan in 1994, which defined Atlantic herring as an inter-jurisdictional resource. As the resource continued to expand, there was a need to address changing fishing patterns and the interests of new stakeholders. This eventually led to the development of the current Management Plan submitted jointly by the NEFMC and the ASMFC in 1999. The primary goals of the plan are:

- To achieve, on a continuing basis, optimum yield (OY) for the United States fishing industry and to prevent overfishing of the Atlantic sea herring resource
- To provide for the orderly development of the offshore and inshore fisheries, taking into account the variability of current participants in the fishery
- To provide controlled opportunities for fishermen and vessel in the other mid-Atlantic and New England fisheries

The FMP defined the management unit to include all the Atlantic herring within the US territorial sea and the Exclusive Economic Zone (EEZ). Three management areas were delineated to accommodate current knowledge of stock structure and existing fishing patterns (Figure 2.1), recognizing that changes might occur in the future due to new information. Area 1 includes the Gulf of Maine, Area 2 Nantucket Shoals and south, and area 3, Georges Bank east of the Great South Channel. Area 1 was further subdivided into Area 1a, the inshore waters and Area 1b, the offshore waters. In Canada, herring from the Gulf of Maine occur in two Canadian management areas: the Bay of Fundy Region of 4X, and the Canadian portion of Georges Bank (5Z).

The relative contribution of herring from each of the major spawning components (coastal Maine, Nantucket Shoals and Georges Bank) to the overall stock complex was evaluated using swept area estimates of minimum population size (both in number and weight) derived from NEFSC autumn bottom surveys within the three management areas. Based on these estimates during the ten-year period 1988 to 1997, the coastal Maine area accounted for 27% of the total herring biomass and 26% by number, Nantucket Shoals accounted for 63% of the total (in both biomass and number) and Georges Bank accounted for 10% of the herring biomass and 11% of the total abundance. Based on the five-year period, 1993-1997, the Coastal Maine and Nantucket Shoals areas accounted for slightly less of the total than during the ten-year period and Georges Bank accounted for slightly more (Table 2.1). In the 1999 FMP, the relative contributions (portion of biomass in each area during spawning season) of herring in the Gulf of Maine, Nantucket Shoals, and Georges Bank areas were assumed to be 25%, 55%, and 20% respectively.

Autumn survey data since 1997 show an increase in the relative contribution of herring in the Gulf of Maine (Figure 2.2). The most recent 5-year survey data (1997-2001) indicate that herring in the Gulf of Maine comprise 38% of the total biomass of the complex. Furthermore, the abundance of the Georges Bank/Nantucket Shoals population appears to be declining (Figure 2.3). Further investigation may reveal whether a different a survey strata set would better reflect changes in the relative abundance of herring among the three areas.

The seasonal distribution of herring in the Gulf of Maine, as reflected by patterns in the US spring and fall surveys, has also varied substantially over time. Table 2.2 summarizes the current view of how herring the herring components are seasonally distributed among the three management areas. These percentages are used to allocate the TAC for each of the sea herring management areas. An allocation of 20,000t is provided for Canadian weir landings, but herring catches on the Canadian portion of Georges Bank are not currently addressed in the US Atlantic herring fishery management plan.

3.0. A general overview of the fishery

3.1. Introduction

Atlantic herring which spawn in the Gulf of Maine (GOM) and on Georges Bank are harvested in five major fisheries: coastal Maine, New Hampshire, and Massachusetts (5Y); Nantucket Shoals/Georges Bank (5Z); Southern New England (5Zw); Mid Atlantic (SA 6); and along the New Brunswick coast (4X). An unknown portion of GOM herring are also caught in the Canadian Bay of Fundy/Southwest Nova Scotia (4WX) fishery, although the numbers are assumed to be small.

The coastal fisheries of 5Y and New Brunswick are amongst the oldest fisheries in the western Atlantic, dating back several centuries. Landings data for these fisheries are presented from 1938 to 2002 in Figure 3.1. During 1938-1954, a marked increase occurred in landings from the Gulf of Maine coastal area while landings in the NB weir fishery ranged between 30,000 and 45,000t annually. Landings in the GOM fishery peaked at 94,200t in 1950. Since then, annual landings have averaged 52,000t (1951-2002) with lows of 25,000t occurring in the mid-1960s, mid 1970s and mid-1980s. Landings since 1989 have been about equal to or have exceeded the long term average. Conversely, NB weir landings have shown a marked decline in recent years. Since 1994, the weir landings have been below the long-term average (1951-2002) of 26,000t. and were only 11,800t in 2002. A number of factors have contributed to the decline, including a reduction in the number of active weirs and changes in herring distribution.

In the early 1960s, total landings from the Gulf of Maine - Georges Bank region markedly increased with the development of a predominantly foreign fleet herring fishery in the international waters of Georges Bank and Southern New England (Figure 3.2). The Georges Bank fishery began in 1961 when the former USSR landed 68,000 mt of herring. Between 1961 and 1965 the fishery was dominated by the USSR, when annual catches ranged between 38,000 and 151,000 mt (Figure 3.2). The fishery expanded rapidly after 1966 when Poland and the German Democratic Republic entered the fishery. Over the next 9 years, vessels from 12 countries harvested herring from Georges Bank, including Canada and the US (Anthony and Waring, 1980). Annual catches during 1961-1977 are presented by country in Table 3.1. Fishing gear varied by country and year. Drift gillnets dominated during 1961-1963, followed by side and stern trawlers during 1963-1972, mid-water trawlers during 1971-1977 and purse seiners during 1969-1975. Fishing occurred throughout the year, but the majority of catches were taken between May and October, when large numbers of herring were on the Bank for summer feeding or spawning (September/October).

The Georges Bank fishery dominated landings from 1962 to 1976, peaking at 373,000t in 1968. This high level of exploitation could not be maintained and by 1976 the Georges Bank spawning component had collapsed due to over-fishing and a series of poor recruitment years. No directed fishery for herring occurred on the Bank between 1979 and 1995, and it wasn’t until 1996 that any substantial landings from the area occurred. Total herring landings from Georges Bank exceeded 39,000t in 1998 and 2001, but were less than 20,000t in 2002 (Table 3.2).

The Southern New England herring fishery has also increased substantially since 1995. Traditionally, annual landings from Southern New England have been a few thousand tonnes. However, during 1996-2000, the winter fishery just south of Cape Cod exceeded 20,000t annually (Figure 3.2). Landings of herring from the mid-Atlantic region have been minimal relative to the other herring fisheries. Typically, annual landings in the mid-Atlantic region have been a few hundred tonnes and have rarely exceeded 1,000t (Table 3.2).

3.2. Recent Landings

The Maine Department of Marine Resources (MDMR) is the primary state agency in the New England region involved in Atlantic herring research, resource monitoring, and management. The two primary types of information that are collected and processed at the Department's Fisheries Research Laboratory in Boothbay Harbor are: 1) catch and landings information from the commercial herring fishery; and 2) age, size, and other biological characteristics of the commercial catch throughout the range of the fishery. The Boothbay Harbor Laboratory has played an important role in monitoring the status of the Gulf of Maine herring resource and the US fishery for over 30 years.

Prior to 1994, US landings were collected by a combination of canning industry reports and reports by NMFS port agents. After 1994, harvesters using Vessel Trip Reports (VTR) directly reported US landings data. With implementation of the FMP in 1999, harvesters have been required to use both VTR and Interactive Voice Reports (IVR). Federally licensed dealers ware also required to submit monthly reports (NEFMC, 1999).

Harvesters report VTR data on a monthly basis. Because harvesters give location data (coordinates or Loran) on a per trip basis, this reporting system allows for summarizing catch information from specific areas. VTR data are useful for stock assessment and effort evaluation, but because they are reported on a monthly basis, the data are not useful for quota monitoring (NEFMC, 2001).

Using the IVR call-in system, harvesters report catches by management area on a weekly schedule. Although trip level information and location data are not reported, this system is useful for near real time quota monitoring. IVR data are not generally useful for stock assessments, or to address management questions that require information by area or gear.

Dealer reports include detailed information on amounts landed, price paid, and utilization of landings, usually on a per trip basis. The dealer reports do not contain information on area of catch..

Both IVR and VTR data include landings to foreign vessels by domestic harvesters. Dealer data only include landings made to domestic dealers. NMFS and state observers collect data on landings to foreign processing or fishing vessels. At the end of a fishing year, all reporting systems are analyzed to detect and reconcile discrepancies.

Total landings peaked in the 1970s (Figure 3.3), due to fishing by foreign fleets. Since 1990, total landings of herring from the stock complex have ranged between 77,000 and 150,000 mt (average; 107,000 mt).

Fixed gear was the predominate method of catching herring in the US until the early 1980s. After1981, the fishery was dominated first by purse seines, then by single mid-water trawls. Currently, most landings are taken by single and pair mid-water trawls (Figure 3.4).

Historically most of the herring landings from the coastal complex have been taken from Management Area 1A (Figure 3.5). In recent years, there has been an increase in harvests from Georges Bank and off Rhode Island. This is in part due to the change from purse seines to mid-water gear. Purse seines tend to be less effective in deeper water.

3.3. Samples

Samples of herring collected from the commercial catch are processed at the Maine Department of Marine Resources (DMR) laboratory in Boothbay Harbor. Historically samples were obtained from canning plants, some of which transported fish from other states, NMFS port agents, and fishery biologists in various states. The Canadian Department of Fisheries and Oceans would also provide samples to the State of Maine. Normally 4-8 samples are collected each month by statistical area harvested, with more extensive sampling occurring during foreign fishing or processing operations. The current sampling ratio is approximately one 50-fish sample per 500 mt.

Usually, between 150 and 200 length samples (7,500- 10,000 fish) are processed each year (Figure 3.6). Samples of 50 fish are processed for length (mm total length), weight (grams), sex, and, where applicable, sexual maturity and gonad stage, using standard procedures and criteria. From each sample, the sagittal otoliths are removed from two fish per centimeter group and embedded in plastic trays for ageing. Periodic calibration of ageing procedure is done with NMFS scientists.

A large reduction in weight at age (for age groups 3 and older) has occurred, since the early 1980s (Table 3.2 & Figure 3.7). A similar reduction in total length is also evident (Figure 3.8)

3.4. BIOSTAT and Catch at Age

Biostat is a software program which uses catch and sample files to produce catch at age data in both numbers of fish at age and total weight of fish at age by Unit. A Unit is defined as a month, geographical area (composed of one or more statistical areas) and gear type (fixed or mobile). Currently geographical areas are defined for the purpose of catch-at-age analysis as Eastern Gulf of Maine, Western Gulf of Maine, Southern New England/ Mid-Atlantic, and Georges Bank. Gear type is defined as fixed (stop seine and weir) or mobile (purse seine, pair mid-water trawl, single mid-water trawl and bottom trawl). The sample parameters for a given Unit are weighted by the total catch from that Unit. In the event that sample data is unavailable for a particular Unit, sample data are borrowed from the next adjacent Unit, with preference given to borrowing between months as opposed to geographically. The catch-at-age matrix for each Unit are summed across all Units for total catch at age for the year for all US landings from the complex.

BIOSTAT first sums the catch (in metric tons) by a Unit. A length frequency grouped by centimeters is then developed from the sample data in that Unit. An age-length key is then developed from the frequency of age by centimeter length group (mm as total length) from all samples in that Unit. The age frequencies are proportioned across ages for each length group. Mean weights (grams) at age are calculated from all individual weights within an age class from all samples in a particular Unit. The mean weights at age are then multiplied by the sum of numbers at age, which gives an expanded weight at age in that Unit. Catches in weight (mt) at age are derived from total weight of the catch multiplied by the weight at age proportion. Catch in numbers at age is calculated from catch in weight at age divided by the mean weight at age times 1,000,000 (convert grams to metric tons) for each Unit.

Strong 1994, 1996, and 1998 year classes are evident in the catch-at-age matrix (Table 3.3). Since the early 1990s, greater numbers of older fish (7+) have occurred in the stock. This is probably due to the demise of the inshore fixed gear fishery (which tended to catch smaller fish) and an overall reduction in fishing mortality on the stock complex during the last decade.

4.0. Research Surveys

Over the years both Canada and the United States have surveyed the distribution and abundance of herring in the Gulf of Maine (Table 4.1). While both bottom trawl and larval surveys have been explored as indices of abundance for herring, only the former provide a continuous time series, and both countries abandoned larval surveys in the mid 1990s. Recently, the US and Canada have each moved toward acoustic surveys to estimate herring biomass. The US now conducts annual acoustic surveys to assess the abundance and distribution of herring in the Gulf of Maine and on Georges Bank. Canada and the US also use industry based acoustic surveys to provide supplemental estimates of spawning stock biomass on specific inshore spawning grounds.

4.1. Indices of abundance

Indices of abundance, which are considered to reflect changes in the population, are critical in the evaluation of stock status Both Canada and the US have conducted fall larval surveys on Georges Bank and in the Gulf of Maine. The US larval survey, which extends from 1971-1994, was used in past Gulf of Maine/Georges Banks assessments (1991, 1993, 1996) as a tuning index along with indices from bottom trawl surveys. The US index of the number of 4-7mm larvae per 10 m^2 (#/larvae/10m^2) was developed as a composite of four individual annual surveys conducted under various programs (Smith and Morse, 1993). Canada conducted fall larval surveys from 1987-1995 and used the # larvae (<10mm)/m^2 as an abundance index on Georges Bank (Melvin et al.. 1996).

Both surveys showed that rebuilding began in the mid to late 1980s and continued during the early 1990s (Figure 4.1).

4.2. Research Vessel Bottom Trawl Surveys

Several research vessel bottom trawl survey series have been conducted within the geographical range of the Gulf of Maine-Georges Bank herring complex. These surveys vary in temporal and spatial coverage from almost the entire range to selected portions on Georges Bank and southern New England. Trends in survey abundance indices are shown in Figure (4.2).

The Canadian spring bottom trawl survey (conducted primarily to assess the abundance of ground fish, on Georges Bank and west as far as Nantucket Shoal (in some years)), covers the northern extent of the winter/spring distribution of herring in the GOM and on Georges Bank (Table 4.2).

The US autumn bottom survey covers the entire distribution of herring off the northeast coast. The survey, which began in 1963, occurs when the majority of adult herring are aggregated to spawn (Table 4.4). During the early years of the survey, catches of herring were relatively low (Figure 4.2). Catches of herring increased during the mid 1980s until 1992, declined slightly in 1993-94, and then sharply increased in 1995. The 1995 increase is the result of large catches of age 1 herring which nearly doubled the index. Catches thereafter declined through 1998, but increased afterwards and reached a record high in 2002. Autumn survey indices for ages 2 to 8 are presented in Figure 4.4.

The US winter bottom trawl survey was initiated in 1992 and covers a large portion of the spatial distribution of over-wintering herring. The annual survey, which begins in early February (Table 4.3), extends from Cape Hattaras to Cape Cod and along the southern flank of Georges Bank. The survey indices were variable during the early 1990s, peaked in 1996, and then declined in 1997. Since 1998, the index has steadily increased (Figure 4.5). Catch-at-age indices for age groups 2 to 8 during 1992-2002 are presented in Figure 4.6.

The US spring bottom trawl survey covers the entire US range of herring during the late winter and early spring. This survey series , which began in 1968 (Table 4.5), has used the same sampling gear except for a net change to the Yankee 41 trawl during 1973-1981 and for a door change in 1985. The survey vessel has variously been the R/V Albatross IV and the R/V Delaware II with appropriate fishing power corrections incorporated into the index (Figure 4.7).

The spring survey herring abundance index was relatively flat during 1975-1983 when herring were scarce, then gradually increased during the early 1990s; the index markedly increased and peaked at a record high in 1999. The index has since declined to about the long-term (1983-2002) mean in 2000 (Figure 4.7; 4.8).

5.0. Growth

Annual growth, as represented by the mean length-at-age of herring collected during the fall spawning season on Georges Bank, has undergone some marked changes ($P<0.01$) since the early 1980s. Herring from the 1983-1985 year-classes grew more rapidly than those spawned during 1987-1991 (Figure 5.1). At age 2, the year-class mean lengths are distributed over a 2cm interval; however, by age 4 there is almost a continuous decrease in the mean length from 1983-1991. By the time the fish reach age 5 and 6, a difference in mean length of 2 cm or more can be observed. The 1986 year-class seems to represent a transition between the two trajectories. Assuming a constant weight-length relationship, a 6 year old from the early period would weight 245g compared to196g for the same size fish collected in the late stages of the recovery, a 20% difference in biomass

6.0. Canada/US Age comparisons

Consistent and comparable aging is critical when data are being combined from two independent sources. To investigate potential difference or biases in aging, 213 otoliths from the Gulf of Maine were selected for aging by readers from both countries. Three independent agers, one from the NMFS Northeast Fisheries Science Center (US-1), one from the Maine Department of Marine Resources (US-2), and one from the DFO St. Andrews Biological Station (Can-1), read each otolith.

Age determinations between the two US readers were very consistent; percent agreement between the two agers was 85% with a slight bias toward under-aging (10%) vs over-aging (5%) by US-1 relative to US-2 (Table 6.1). However, significant differences ($P<0.01$) were detected between the age determinations of the Canadian reader and both US readers (Tables 6.2 and 6.3). Percent agreement was 76% with US-1 and 78% with US-2. In both cases, there was a tendency for the Canadian reader to under-age (16% and 18%) rather than over-age (8% and 4%) relative to US age readers. Beyond age 6, the disagreements exceeded 50%.

Differences between the Canadian and US age reading are of concern and will require some time and effort to resolve. An aging workshop amongst the readers from both countries will be convened during 2003 to address this issue. In the interim age-length keys will be applied according to the data origin. That is, data collected by the US will use US ages and Canadian data Canadian ages. While this may affect the catch-at-age matrix and age-disaggregated indices of abundance, mixing of the data sources would further complicate the issue.

7.0 Acoustic Surveys and Results

This section describes various acoustics surveys, their design, and results.

7.1. Survey design and Cruise Tracks

7.1.1. 1998 Surveys

Acoustic survey objectives during September-October 1998 were focused on locating spawning and pre-spawning concentrations of Atlantic herring in the Gulf of Maine and on Georges Bank. A series of fine scale and broad scale systematic parallel transect surveys were completed during the 1998 Atlantic Herring Hydroacoustic Survey in the Gulf of Maine. Fine-scale systematic grids of transects spaced 2 nmi were surveyed to cover important historic spawning areas and sites of recent commercial activity (Figure 7.1). The broader scale survey (with 20 nmi spacing) was designed to encounter herring over the entirety of the Gulf of Maine region (Figure 7.2).

On Georges Bank, two surveys were conducted to sample herring in the large historic spawning site that runs from Nantucket Shoals to eastern Georges Bank. A systematic zigzag survey design was employed (Figure 7.3). Time constraints allowed for only a small portion of the Georges Bank site to be covered.

7.1.2. 1999 Surveys

In September-October 1999, important herring spawning areas in the Gulf of Maine and on Georges Bank were surveyed to acquire information on spatial and temporal distribution patterns and abundance. As in 1998, sites were covered with systematic parallel designs in 1999 in the Gulf of Maine (Figure 7.4). The extent of spatial coverage was broadened and two zigzag surveys with 10 nmi spacing at the nodes were completed. In addition, a systematic parallel survey was conducted over the entire Georges Bank region (Figure 7.5). During this survey, no herring were found on the southern side of Bank.

7.1.3. 2000 Surveys

During September-October 2000 survey sites in the Gulf of Maine received the same level of coverage as in the previous two years (Figure 7.6). On Georges Bank, a more extensive coverage of the historic spawning sites was completed. Three survey designs (parallel, zigzag, and stratified random) were employed to sample herring distribution and abundance (Figures 7.6-7.8). These surveys were designed to cover the entire extent of the spawning aggregations and to provide valuable additional spatial, temporal, and quantitative information for conducting future surveys. The zigzag and parallel surveys used 10 nmi spacing between transects.

Three survey strata were chosen for the stratified random survey, corresponding to western (Strata 1), central (Strata 2), and eastern (Strata 3) strata areas (Figure 7.9). The strata were chosen on the basis of bathymetry, geographic features (*i.e.*, the Great South Channel, Cultivator Shoals, and the Northern Edge of Georges Bank), and previous knowledge of the spatial distribution of herring in these areas. Transects were allocated to strata based on the total length of transects and the strata area. There were 13 transects available in stratum 1 and 2 and 12 in strata 3. The set of potential transects for the stratified random survey were spaced at 5 nmi intervals. Five randomly selected transects were surveyed in strata 1 and 2 and four in stratum 3 (Figure 7.9).

7.1.4. 2001 Surveys

In September-October 2001, specific sites in the Gulf of Maine again received the same level of coverage as in the previous years (Figure 7.10). Coverage of the Georges Bank region was similar to the 2000 Atlantic Herring Hydroacoustic Survey, but some transects were extended to provide more complete coverage of the spawning concentrations (Figure 7.11-7.13).

Several additional transects were added to the stratified random survey in 2001 to increase the sample size in each strata. The spacing of the possible transects for the stratified random survey were changed from 5 nmi to 3 nmi and the number of possible transects in both stratum 1 and 2 were changed to 21, and to 19 in stratum 3 (Figure 7.14). Of these, seven transects were sampled in strata 1 and 2, and six in stratum 3.

7.1.5. 2002 Surveys

In 2002, the first leg of surveying operations was devoted to a systematic parallel design that covered the Jeffreys Ledge area much more extensively than in previous years. This survey extended over depths up to 200 m and covered the Jeffreys Basin area to the west of Jeffreys Ledge and areas to the east (Figure 7.15).

An enhanced version of the systematic parallel survey designs used in the 2000 and 2001 surveys on Georges Bank was deployed during 2002. More transects were added and additional mid-water trawl stations were completed (Figure 7.16). The area of coverage was somewhat larger than in the two previous years and the transect spacing was decreased to 8 nmi.

7.2. Atlantic Herring Acoustic Survey Results

All of the Gulf of Maine acoustic surveys used a downward looking EK500 SIMRAD echosounder operating at 12, 38, and 120 kHz. In this report, analyses are presented using only the 38 kHz data from Georges Bank.

7.2.1. 1998

The 1998 survey operations only covered a portion of the herring spawning grounds on Georges Bank and transects were not sufficiently long to fully sample the extent of the distribution in the north-south direction (Figure 7.17). Herring backscatter (Sa) was confined to a narrow band along the 100 m contour (Figure 7.17). Herring appeared to be present at the northern end of most transects and in shallower depths along the 100 m contour (Figure 7.17). Transects that extended further on the Bank (< 50 m depth) contained few if any herring.

7.2.2. 1999

In 1999, a much larger area was surveyed on Georges Bank. Herring were present along the 100 m contour and further to the north in deeper water (>200 m) (Figures 7.18, 7.19). Herring were again present at the northern end of the survey transects, indicating that some fish were being missed by the survey beyond the northern limit of the transects. Portions of transects that extended into shallow water (< 50 m depth) contained few herring (Figures 7.18, 7.19).

On the parallel survey in 1999, herring were found only along the Great South Channel, West of Cultivator Shoals, and on the Northern Edge. Herring were present along the 100 m contour and further to the north in deeper water (>200 m) (Figure 7.20). Herring were again present at the northern limit of some of the survey transects. Portions of transects that extended into shallow water (< 50 m depth) on Georges Bank contained few herring (Figures 7.20).

7.2.3. 2000

In 2000, three different survey designs were used to sample herring on Georges Bank. In the systematic zigzag survey, herring were distributed in a broad band from west to east over the whole survey area (Figure 7.21). Fish were abundant between the 100 and 200 m contours, with fish particularly abundant in the middle section of the survey area, adjacent to the Cultivator Shoals region. Fewer herring occurred at the western and eastern most locations in the survey, and most transects began and ended little or no herring.

In the systematic parallel survey, herring occurred from Nantucket Shoals to the northern edge of Georges Bank (Figure 7.22). Herring were abundant between the 100 and 200 m isobaths and broadly distributed in the western and central parts of the survey area. Herring were most abundant in the central part of the area, with few fish found at the western and eastern extremes of the area. Most transects began and ended in areas with little or no herring.

The stratified random survey confirmed the broad east-west distribution of herring. Herring were very abundant between the 100 and 200+ contours and were widely distributed in the western and central areas (Figure 7.23). Abundance was greatest in the central area with few herring observed at western and eastern transects.

7.2.4. 2001

In 2001, herring were very abundant between 50 and 200 meters and were concentrated in the central and western areas adjacent to Georges Bank in the parallel survey (Figure 7.24). Most of the transects began and ended with few or no herring.

Herring were very abundant along the 50-100+ m contours from the Great South Channel to the Northern Edge of Georges Bank in both the zigzag and stratified random surveys. The highest Sa values were obtained in the central region of the distribution, in deeper water to the west, and along the 100 m contour to the east. (Figure 7.25).

7.2.5. 2002

In the 2002 survey, herring were abundant along the 100 m contour and in deeper water as in previous years, and the highest backscatter values were observed in the central and eastern parts of the pre-spawning aggregation (Figure 7.27).

7.3. Length-Weight and Total Length Relationships

Mid-water trawl hauls were conducted during all surveys to confirm the species composition of the acoustic backscatter. Mid-water trawl samples were separated by species, weighed (g), measured (FL, cm), and all information recorded on trawl logs or in the FSCS electronic database management system.

Length-weight equations for Atlantic herring were estimated from herring sampled during autumn bottom trawl surveys. Length-weight results from the autumn bottom trawl surveys were used because fish collected during the acoustic surveys were experiencing rapid changes in weight due to spawning, and were not be useful for estimating a general equation. Non-linear regression was used to estimate the parameters of the length weight equation as

$$W_t = aL^b$$

where W_t is the weight in kg, L is fork length in cm and a and b are parameters. Parameters for 1999-2002 are shown in Table 7.1.

Data collected in 1999, were used in developing a fork length-total length conversion equation. Fork length measurements were converted to total length using:

$$L_{TL} = 0.01 + 1.102972 L_{FL}$$

Length compositions from each survey during 1999-2002 were converted to total length and then used in the target strength analyses.

7.4. Herring Backscatter (Sa)

Species compositions from mid-water trawling operations were used to partition the total backscatter into components. Atlantic herring Sa values for all surveys were plotted in ArcView and polygons drawn to encompass the herring distribution. Areas of each survey region were estimated using the polygon area feature in ArcView. Data from 1999-2002 were then analyzed with the geostatistical methods package available in SPLUS. Herring Sa data were converted from longitude and latitude (in decimal degrees) to a grid of observations in nautical mile format. After correction for geometric anisotrophy in most cases, and setting the maximum distance at 50 n.mi., robust variograms were fit for all the surveys. Parameters from variogram fits were roughly similar among the designs and years, and spherical variograms were used to describe the spatial structure in the herring Sa (Figure 7.28).

A consistent spatial autocorrelation pattern existed in the data used to model herring abundance. Kriging was used to estimate the mean and standard deviation of the herring backscatter from surveys conducted during 1999-2002. These analyses produced mean herring backscatter values that ranged between 1036-3385 during 1999, 1065-1824 in 2000, 1256-1823 in 2002, and 567 in 2002 (Table 7.2). The standard deviation of the herring backscatter is also listed in Table 7.2. The CV of these estimates was much smaller using the model based approach than with the design approach with ranges between 9.8% and 20.9% in 1999, 10%-16.9% in 2000 and 9.9%-15.3% in 2001, and 13.6% in 2002 (Table 7.2).

7.5. Herring Acoustic Target Strength

As no local target strength (TS) equation is currently available for converting echo intensity to herring biomass, the intercepts from eleven target strength equations for other herring stocks in the North Atlantic were used (ICES 2001) (Table 7.3).

These studies were all conducted at similar frequencies (~38kh). The intercepts were used in the standard TS equation (Foote 1991) as:

$$TS = 20\log_{10} TL - I$$

where TS is the target strength, TL is the average total length of the entire length composition surveyed, and I is the intercept. The TS equation with each intercept was used to calculate an acoustic back scattering cross sectional area as:

$$\sigma = 4\pi 10^{TS/10}$$

where σ is the acoustic backscattering cross sectional area. For each intercept, TS was calculated for each length in the survey length composition and then weighted by the numbers at length. A weighted mean σ was produced for each intercept and used to calculate total abundance as:

$$N = {SA}/{\sigma} * A$$

where N is the total number of herring in the survey, SA is the mean backscatter for the survey, and A is the total surveyed area(in square nautical miles) of the survey area. Biomass for each intercept was calculated as:

$$B = N * wt$$

where B is the total biomass and wt is the mean weight, weighted by the length composition. This process was repeated for all eleven TS intercepts and an average biomass for the each survey was then calculated (Table 7.4).

During 1999-2001, three surveys were completed in each year on Georges Bank. Biomass estimates from these surveys were weighted by the inverse of the geostatistical CV for each survey, and a weighted mean biomass calculated for each survey year (Table 7.4).

7.6. Bootstrap Analysis

A bootstrap analysis was used to evaluate the precision of the survey biomass estimates. The mean areal herring backscatter for each systematic parallel or zigzag survey was calculated using the methods described by Jolly and Hampton (1990).

$$\overline{SA} = \frac{1}{n}\sum_{i=1}^{n} W_i Sa_i$$

where $\overline{SA}$ is the mean herring backscatter, W_i is the weighting coefficient for transect length, Sa_i is the mean herring backscatter for each transect, and n is the number of transects, with

$$W_i = \frac{L_i}{\overline{L}},\ \overline{Sa}_i = \frac{\sum Sa_k}{n(esdu)_k}$$

where L_i is the individual transect length, the mean $\overline{L}$ is the mean transect length, $\overline{Sa}_i$ is the mean herring backscatter for each transect, Sa_k is the herring backscatter for each elementary sampling distance unit (ESDU = 0.5 nmi) and $n(esdu)_k$ is the number of segments in each transect, with

$$\overline{L}_i = \frac{1}{n}\sum L_i$$

The mean herring backscatter for a stratified random survey was calculated as:

$$\overline{Sa}_i = \frac{1}{n}\sum_{j=1}^{n_i} W_{ij}\overline{Sa}_{ij}$$

where mean $\overline{Sa}_i$ is the mean herring backscatter for the i^{th} stratum, W_{ij} and $\overline{Sa}_{ij}$ are the weighting coefficients and mean herring backscatter for the i^{th} stratum and j^{th} transect. The stratified mean herring backscatter was also weighted by the area of each stratum as:

$$\overline{SA} = \frac{\sum A_i \overline{Sa}_i}{\sum A_i}$$

where mean $\overline{SA}$ is the stratified mean herring backscatter and A_i are the area for each stratum. Point estimates from the surveys are given in Table 7.5.

Some of the survey data were produced from systematic designs, which according to classical statistical approaches cannot be used to produce an estimate of variance. Therefore, bootstrap results from all the surveys were scaled by the geostatistical variance as;

$$\bar{S}a = u_{boot} - (u_{geo} - u_{boot}) * sqrt\left({\sigma^{2}}_{geo} \middle/ {\sigma^{2}}_{boot} \right)$$

This approach is outlined in Simmonds (2002). The transect mean Sa's from each survey were bootstrapped 2500 times and scaled with the geostatistical variance using the above equation.

The median biomass from bootstrap replicates ranged from 1.14-1.40 million mt during 1999, 1.26-1.76 million mt in 2000, 1.47-2.34 million mt in 2001, and was 0.838 million mt in 2002 (Figures 7.29-7.32).

VPA Calibration and Diagnostics

8.0. Previous Assessments

Assessments of Atlantic herring have always been complicated due to the migratory behavior and the intermixing of stocks. Over the years, a variety of assumptions have been made about stock structure and seasonal composition.

During the 1970s, independent assessments of the Gulf of Maine and the Georges Bank herring stocks were undertaken by ICNAF (Anthony and Waring, 1980, Stevenson et. al., 1997). Estimates of population size were based on un-tuned VPAs or cohort analyses, had no fishery independent information to estimate F, and relied on juvenile catch information to estimate recruitment. These models estimate population biomass to be approximately 1.3 m mt in 1967-1968, and 204,000t (4+) in 1976. In 1976, the population size of the western GOM was estimated to have been 159,000t, less than 100,000t in the early 1970s and only 65,000t in 1976 (ICNAF Redbook, 1976).

One approach to avoiding the problem of stock intermixing is to perform a "pooled assessment." Anthony (1977) combined herring catches from south of Cape Cod, Georges Bank, the Gulf of Maine, and the Bay of Fundy and as far north as Chedabucto Bay. Sissenwine and Waring (1979) did the same thing when they pooled catch-at-age data for all herring fisheries between Southwest Nova Scotia and Cape Hattaras in their analysis of herring fisheries of the Northwest Atlantic.

After the decline in fishing effort by foreign fleets and the collapse of Georges Bank herring stock around 1976, assessments undertaken during the 1980s concentrated on the GOM stock. Three assessments of the GOM stock were conducted during this period using the spring bottom trawl survey indices (number/tow) to tune a VPA developed using pooled catch-at-age data. These assessment were considered flawed in that the tuning indices did not solely represent the GOM stock, but, also included fish from GB and Nantucket Shoals . Spawning stock biomass estimates for the GOM stock were relatively low in the late 1970s, 30,000t in 1982, then increased rapidly throughout late 1980s to exceed 150,000t.

Confusion over the definition of Georges Bank versus Gulf of Maine fish continued in the 1980s. Anthony et al. (1981) attempted to exclude Georges Bank fish in their assessment of herring stocks of the Gulf of Maine, but they included herring from the southern New England winter fishery in their analysis. At the 1989 SAW Fogarty et al. (1989) stated that "Atlantic herring throughout the Gulf of Maine, Southern New England and mid-Atlantic regions are considered to be part of a single stock. Accordingly, we developed a single abundance index for this region." Until 1989, it was assumed that the US fall survey might provide an index of abundance for the individual stocks. However, the fall survey data were determined to be too variable, to be a reliable indicator of abundance for either the individual stocks or the stock complex.

Uncertainties in distribution, stock inter-mixing, and assignment of catches continued to plague the assessment in 1990. At the Eleventh SAW (NEFC, 1990, p. 58) the Gulf of Maine herring stock was defined as:

> "The Gulf of Maine stock was considered to include all fish found in NAFO areas 5Y and 5Zw (i.e., excluding fish from area 6, which were assumed to belong to either Georges Bank or Nantucket Shoals stocks; and excluding fish from Sub-area 4, which were assumed to belong to Atlantic Canadian stocks). However, an unknown amount of mixing occurs during winter/spring between Gulf of Maine, Georges Bank and Nantucket Shoals stocks in the Mid Atlantic and Southern New England Areas."

Prior to 1991, the Georges Bank/Nantucket Shoals and the coastal Gulf of Maine stocks were therefore assessed separately (Anthony and Waring, 1980, Fogarty and Clark, 1983 and Fogarty et al., 1989).

In 1991, two major changes were made in the assessment of GOM/GB herring. The first was the introduction of a correction factor (approximately 50% reduction in catch rates) to account for differences in fishing power of the R/V Delaware II vs. R/V Albatross IV. Secondly, a change was made from assessing the stocks separately to treating them all as a single stock complex. Examination of the NEFSC spring survey data series revealed that no geographical grouping of strata could be used to represent either the Georges Bank or Gulf of Maine stock unit. Consequently, for the purposes of assessing abundance, herring from the coastal Gulf of Maine, Nantucket Shoals and Georges Bank were treated as a single highly migratory coastal herring population that had distinct spawning areas.

> "...the SARC consensus was that both the catch at age matrix and the spring survey indices of abundance reflect not only the "coastal" stock but also intermixing of fish from New Brunswick weir catches and Georges Bank stocks. The SARC, therefore, decided that the assessment should be based on an aggregate stock complex including coastal, Georges Bank and New Brunswick weir caught fish" (NEFSC, 1992, p. 62).

Since 1991, Georges Bank/Nantucket Shoals and the coastal Gulf of Maine stocks have been considered part of a migratory coastal herring complex possessing distinct spawning components. Other important changes to the assessment have included; the inclusion of New Brunswick fixed gear (weir/shutoff) catches in the catch-at-age in the 1993 assessment; the use of a larval abundance estimate as an index of SSB in the 1991,1993 and 1996 assessments; and the introduction of the NEFSC winter survey index which in the 1998 assessment. The fall bottom survey was also reexamined in 1998, but was not used as a tuning index.

The last assessment was conducted on the coastal stock complex in 1998 and estimated SSB through 1997. The VPA was tuned using the US spring bottom trawl index from 1968-1997 (ages 2-8), and the winter survey index during 1992-1997 (ages 2-8). The spring indices were based on herring catches in survey strata 1-30, 36-40, and 61-76, while the winter survey indices were based on herring catches in survey strata 1-3, 5-7, 9-11, 13-14, 16, 61-63, 65-67, 69-71, and 73-75.

9.0 VPA

Input data (catch-at-age, winter and spring survey indices, mean weights, etc.) for the VPA were updated through 2001 and a new calibration was completed using the same formulation as in the previous (1998) assessment. The VPA results indicate that spawning biomass increased greatly in the 1990s and fishing mortality was very low in 1999-2001 (Figures 9.1 and 9.2). Recruitment improved dramatically in the 1990s with several large year classes (1994, 1998) and moderate year classes (1993, 1995, 1996) being produced (Figure 9.3).

Retrospective Analysis of VPA

A retrospective analysis of the VPA for the herring complex was completed using the FACT 1.05 software for the years 1995-2001. The formulation was the same as used in the 1998 assessment except that catch-at-age and research survey indices for winter and spring were added for 1998-2001. Results were similar to those obtained in the last assessment, in that severe retrospective patterns were apparent in spawning stock biomass, fishing mortality, and recruitment. Both spawning stock biomass and recruitment were overestimated in successive years during 1995-2001 (Figure 9.1 and 9.3), while fishing mortality was underestimated (Figure 9.2). Recent landings of herring from the complex are low relative to stock size; resulting in fishing mortality (F) being very low relative to natural mortality (M). A succession of moderate to large year classes in the 1990s has apparently made it difficult to estimate recruitment accurately. In addition, the increase in biomass apparent from survey indices in the 1990s is not estimated very well. Examination of trends in SSB from the 1997 and 2001 VPAs, revealed that increases in biomass are very abrupt with SSB reaching high values in only the last year of each run (Figure 9.4). Because of the retrospective pattern and the inability to precisely estimate biomass in the 1990s, a forward projection modeling was used to assess stock status.

10.0. Forward Projection Approach-Application and Description

An initial base case forward projection model was developed and refined. Surveys, stock-recruitment, and hydroacoustic information were all given equal weighting (1) in the final model.

10.1. Growth

Growth was modeled using a time-series of mean weight at age data from the commercial landings during 1967-2000. These were used to estimate von Bertalanffy parameters (Schnute form for KLAMZ (FPA) model, see appendix 1) for the 1968-2000 year classes, beginning at age 1 (which is one year before recruitment at age 2 in the model). A von Bertalanffy curve was fit to the data for each cohort assuming a common value of K for all cohorts and cohort specific W-infinity and t-zero values. Problems were encountered with negative predicted weights at age 1 for some cohorts so the series average was substituted for the predicted values at age one in all years (e.g. 0.015 g was used as the predicted value for weight at age one for all cohorts). Values of j were calculated as:

$$j = {}^{wt(1)}\!\big/_{wt(2)}$$

The j values were then calculated and used with von-Bertalanffy parameters in the model to estimate annual growth changes (see appendix 1 for details).

10.2. Maturity

Maturity was assumed to be 0.0 at age 2 and 1.0 at age 3 and older (see below).

10.3. Maturity Data From Acoustics Studies

Herring maturity stages were recorded during biological sampling of herring during the 1999-2002 hydroacoustics cruises. Age 2 herring were all immature and age 3 + fish were mature. The overall maturity status of herring was different in each of the survey years. In all years, most of the fish observed were in a developing stage, but the relative proportions were different in each year (Figure 10.1). In 1999 about 20% of the mature fish were ripe, with smaller proportions in subsequent surveys (Figure 10.1).

In 1999, about 20% of the fish were ripe in the first Georges Bank survey and about 30% in the last survey (Figure 10.2). No spent or resting herring were observed in 1999. In 2000, a few ripe fish were sampled during the first survey and about 7-8% were spent thereafter (Figure 10.3). In 2001, 2-3% of the herring were spent or resting during the first survey, and between 14-22% were spent and 4-5% were resting on the subsequent surveys (Figure 10.4). In 2002, only one survey was completed, 14% of the herring were spent and 16% were resting (Figure 10.5).

The large proportion of spent and resting fish encountered during 2002 suggests that a large proportion of the spawning fish were not encountered by the survey. This is the likely reason why the survey biomass estimate in 2002 is so low compared to previous surveys. Biomass in 2002 was expected to increase due to growth of several large year classes (1994, 1998) in the spawning stock.

10.4. Natural Mortality

Natural mortality (M) was assumed equal to 0.2 as in previous assessments (NEFSC 1998). The forward projection analysis allows for the estimation of annual changes in M by modeling deviations from a mean value (see Appendix 1), but this feature was not used in the current assessment.

10.5. Recruitment

Recruitment was modeled with a Beverton-Holt stock-recruitment relationship with alpha and beta parameters estimated internally by the model (see Appendix 1 for details). A Ricker modeling formulation was tried, but was less satisfactory than the Beverton-Holt model.

10.6. Variability in recruitment

Annual variability in recruitment for herring in the model was measured by log scale recruitment residuals:

$$r_t = \ln\left[Exp\left(R_t\right)\right] - \ln\left(R_t\right)$$

where $Exp(R_t)$ is the expected value of recruitment based on a recruitment model (see Recruitment Models in Appendix 1). The variance of log scale recruitment residuals $\left(\sigma_r^2\right)$ is important because it is used to compute the log likelihood of recruitment estimates and to estimate model parameters (Appendix 1). This variance was estimated, rather than specifying it as a fixed and predetermined quantity as in NEFSC (2001).

Estimation of σ_r^2 in the model used prior information about ten North Atlantic herring stocks from the Stock Recruitment Database.[1] All North Atlantic herring stocks with at least 15 spawner-recruit observations were used (Table 10.1). The Gulf of Maine and Georges Bank herring stocks were not used as prior information although variances were calculated for comparison.

To estimate variances, nonparametric stock-recruit models (which were smooth loess regression lines) were fit to spawning biomass and log transformed recruitment data for each stock. Most data sets showed evidence of a spawner-recruit relationship but the shape of the relationship varied from stock to stock (Figure 10.6) as:

$$\sigma_r^2 = \sum_{j=1}^{N} r_j^2 \Big/ \left(N - d_f\right)$$

for each stock. The distribution of residual variances for the 10 herring stocks was skewed to the right but log transformed variances were approximately normal (Figure 10.7) with

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[1] Stock-recruitment database maintained by R. Myers at Dalhousie University; see www.mscs.dal.ca/~myers/welcome.html.

mean= -0.707, median= -0.818 and variance= 1.02. The median was used as the measure of central tendency instead of the mean because the median of ten observations is more robust. Thus, the log likelihood of the prior estimates (or log prior probability) given the model's estimate of σ_r^2 was computed:

$$L = 0.5\frac{\left[\ln\left(\sigma_r^2\right) - (-0.818)\right]^2}{1.02}$$

10.7. Surplus Production

Surplus production for the herring complex was estimated using a Fox (1975) stock production model. Parameters were estimated internally and λ was set at 0.0001. A Schaefer (1954) model was also estimated by fitting a quadratic equation to the calculated surplus production after the model converged as:

$$Y = \alpha B - \beta B^2$$

where Y is the yield and B is the biomass.

10.8. Landings

A time-series of total landings for the Gulf of Maine-Georges Bank region during 1959-2002 were used in the model (Table 10.2). These data were obtained from NMFS, Maine DMR, DFO Canada, and ICNAF and NAFO sources. The total was composed of landings from the US fishery in the Gulf of Maine and on Georges Bank, Canadian landings on Georges Bank and in the New Brunswick weir fishery, and reported landings from foreign nations during 1961-1978.

10.9. Research Surveys

A total of eleven research survey time-series were used to tune the model. Atlantic herring catch/tow indices (age 2 and age 3+) from MNFS winter (1992-2002), spring (1968-2002) and autumn (1963-2002) groundfish surveys were used (Table 10.3). Survey number per tow indices were converted to weight per tow indices by applying US fishery weight at age data

Atlantic herring catch per tow indices from Canadian groundfish surveys during 1986-2002 were also used for tuning. The same procedure applied to the US surveys was used for converting number/tow indices to weight/tow indices (Table 10.3).

Larval herring survey indices from both USA and Canada were used as tuning indices of spawning biomass. The US survey series covered 1971-1994 and the Canadian survey 1987-1995 (Table 10.4).

Biomass estimates from US hydroacoustic surveys during 1999-2002 were also used to model trend. These data represent the overall biomass encountered in each acoustic survey of herring (Table 10.4). The estimates for 1999-2001 represent a weighted average of the three acoustic surveys conducted in each of those years. In 2002, only one herring acoustic survey was conducted.

10.10. Survey Covariates

The NMFS autumn time-series, 1963-2002 has been an erratic measure of herring abundance and biomass since its start in 1963. Few herring were captured during the early part of the series 1963-1974, in spite of herring being abundant during much of this time period. Herring catches during the middle part of the series were low, but so was abundance. Herring were seemingly much more available during the mid 1980s and 1990s, and autumn survey catches were relatively high. Because of the inconsistencies in this survey, several hypotheses were examined that might explain the apparent changes in catchability in the autumn time-series. Impacts of temperature on the catchability of herring were hypothesized, so temperature data were obtained for the Gulf of Maine and Georges Bank during both the spring and autumn. These data consisted of average surface and bottom temperatures and temperature anomalies for both seasons. The GOM series was analyzed since all the spawning components utilize this area: both the surface and bottom temperatures were used with one number expressing both values. By differencing the autumn surface and bottom series from the GOM, an increasing trend was detected (Figure 10.8). However, if this trend were real it should have also been present in the temperature anomalies for the region, but this was not the case (Figure 10.9).

It was noted that the timing of the autumn survey might have changed during 1963-2002. The mean and median Julian date for the autumn survey in each year were obtained and plotted

(Figure 10.10). A distinct declining trend in survey timing is evident since the early 1960s (Figure 10.10). The fall survey residuals were also negatively correlated to fall survey timing (Figure 10.11).

A temperature effect was selected to represent any of several processes that might influence the aerial and depth distribution of herring, ultimately affecting catchability. As such an effect could profoundly influence survey catches of herring, a variable was added to the total likelihood representing this effect on q via:

$$I = qB \text{ and } I = q'B$$

where

$$q = q' e^{\alpha T}$$

where T is the standardized temperature anomaly ((surface-bottom)-mean of the surface-bottom)) and α is the estimated parameter for the autumn survey during 1963-2002. The spring surface-bottom gradient was also calculated and unlike the autumn, exhibited no trend (Figure 10.12). As the spring survey showed no trend in timing (Figure 10.13), and spring survey residuals were not related to spring timing, no attempt was made to correct for timing changes of the spring.

It was hypothesized that the use of polyvalent doors beginning in 1985 may have affected the catch of herring in the NMFS spring and autumn surveys. Although the coefficient for weight per tow for herring was not significant at the p=.203 level from the door conversion experiments that were conducted, these experiments were not designed to estimate the effects of the door change on herring. So, an indicator variable approach for introducing the door change effect variable to the likelihood function as:

$$q' = qe^{\delta D}$$

where δ is the estimated parameter and D is 1 during 1985-2002 and 0 for all other years in the spring and autumn surveys. If both survey covariates are used in the model they would be estimated as:

$$q = qe^{\alpha T + \delta D}$$

In initial model fits, adding a covariate for doors improved the fit of the spring surveys for both age 2 (Figure 10.14b vs. Figure 10.14c) and age 3+. For age 2 the addition of a dummy covariate for doors was significant in a simple t-test (t=7.17), but the covariate for spring age 3+ was not significant.

Adding a door covariate also improved the residual pattern for the autumn survey age 2 and 3+ indices in the NMFS aautumn survey (Figure 10.15).

Adding a temperature covariate for survey timing also produced better fits and lower residuals for both autumn age 2 and age 3 indices (Figure 10.15E).

The combination of door and temperature covariates greatly improved the residual patterns for the autumn survey (Figure 10.15F). Simple t-tests for age 2 were significant for doors (t=9.43) and age 3+ for doors and temperature(t=2.70, 3.62).

10.11. Acoustic Results Used to Scale Biomass

Biomass estimates from 1999-2002 acoustic surveys were available for scaling the forward projection modeling results. To develop an appropriate ratio for the proportion of Georges Bank fish to the overall complex total, information from the US acoustic surveys, previous assessments, and acoustic surveys conducted by ME DMR-GOM Aquarium was used.

1. Georges Bank biomass estimate from acoustic surveys 2001 1.82 million mt
   Gulf of Maine biomass estimate NEFSC (1998) 0.40 million mt
   1.82/2.22=0.82
2. Georges Bank biomass estimate from acoustic surveys 2001 1.82 million mt
   Gulf of Maine biomass estimate from acoustic surveys 2001 0.32 million mt
   1.82/2.14=0.85
3. Gulf of Maine acoustic surveys from commercial vessels revealed an order of magnitude difference in average biomass between the Gulf of Maine and Georges Bank during 1999 and 2000 (Figure 10.16)
   1999 30/300 = 10%
   2000 30/330 = 9% ~ 90% Georges Bank

Based on these resultsa Q ratio of 0.85 was selected as the proportion of Georges Bank fish (age 2+) represented in the US acoustic surveys. A prior distribution with mean τ and CV=φ (see Appendix 1 for details) was used as:

$$NLL = [{}^{\ln(Q)-\tau}\!/_{\varphi}]^2$$

where tau was determined to be ln(0.85) and phi is the log scale sd=0.597 (CV=0.429). Q represents the proportion of the Georges Bank component in the coastal herring complex, determined from several independent sources.

10.12. Survey Diagnostics and Residuals

Plots of survey residuals for the eleven time-series used to tune the model were used as diagnostic measures of goodness of fit (Figures 10.16-10.19). The US spring age 2 and age 3+ seem to fit well with few residual patterns or clumping (Figure 10.17). The US winter survey age 2 does not fit particularly well, and the age 3+-winter survey residual fit is only somewhat better; however, both series are relatively short (Figure 10.17). The US fall age 2 survey residuals fit fairly well as do the US fall age 3+ residuals (Figure 10.17). The hydroacoustic survey series is very short (1999-2002) and the diagnostic plots show a large contrast between the 2001 and 2002 data (Figure 10.18). The US larval survey performs fairly well, but has a string of positive residuals at the end of the series (Figure 10.18). The Canadian larval survey also performs well, but has a large residual in 1991 (Figure 10.18). The Canadian age 2 spring survey does not fit well, exhibiting several large residuals and some clumping of residuals (Figure 10.19). The Canadian age 3+ residuals fits well, showing an even distribution and only a small amount of clumping (Figure 10.19).

10.13. Sensitivity Analyses

Likelihood Profiles

A likelihood profile analysis was completed for Q values ranging between 0.1-1.7. The best fit occurred when Q=1.3 for non-surveys and Q=0.5 for the survey components of the likelihood (Table 10.5). The lowest likelihood component values for the surveys occur at both ends of the spectrum. The low component likelihood value for the spring age 3+ and the Canadian larval survey occur at Q values of 1.1 or greater (Table 10.5). The lowest values for the rest of the surveys occur at Q values of 0.5 or less (Table 10.5).

11.0. Forward Projection Analysis Results

A full table of output and results is provided in Appendix II.

11.1. Estimates of Fishing Mortality

Fishing mortality was below 0.2 during the early 1960s followed by a large increase in F to about 0.8 during the late 1960s (Figure 11.1). This coincides with a major increase in fishing effort during this period. F increased again in the mid and late 1970s to above 1.0 but declined sharply in 1984 to F=0.2 (Figure 11.1). F remained steady at about this rate during 1985-1989 and then fell further after 1990. The fishing mortality in 2002 on the coastal complex was about 0.06 (Figure 11.1).

11.2. Estimates of Biomass

Total stock biomass in the Gulf of Maine - Georges Bank herring complex was about 1.4 millionmt in 1962, and steadily declined to a low of 87,000 mt in 1982 (Figure 11.2). Stock biomass increased gradually after 1983, reaching 1.0 million mt in 1994 and 1.8 million mt in 2000 (Figure 11.2).

Spawning stock biomass followed a trend nearly identical to total biomass, declining from 1.2 million mt in 1962 to a low of 42,000 mt in 1982 (Figure 11.3). SSB increased steadily afterward this to 1.0 million mt in 1996 and 1.7 million mt in 2001.

11.3. Recruitment

Recruitment during the 1960's was generally moderate with large 1968 and 1970 year-classes (Figure 11.4). All subsequent year-classes through 1986 were below average or poor (Figure 11.4). Recruitment markedly improved during the 1990s with the very large 1994 and 1998 year-classes.

11.4. Stock-Recruitment

A Beverton-Holt stock-recruitment relationship was estimated within the forward projection model. This relationship added some stability to the model and provided a reasonable fit to the available time-series of data (Figure 11.5). Most years fit the model well with the exception of large residuals (implied) for the 1994 and 1998 year-classes (Figure 11.5).

11.5. Precision of FPA Estimates

The precision of terminal 2002 year estimates of spawning biomass and fishing mortality were estimated using bootstrap procedures. Estimates of spawning stock biomass in 2002 ranged from 0.8-2.7 million mt with a median of 1.5 million mt and 80% CI of 1.2-1.8 million mt (Figure 11.6). Estimates of F in 2002 ranged from 0.02-0.12 with a median value of F=0.066 and 80% CI of 0.054-0.084 (Figure 11.7).

11.6. Retrospective Analysis of FPA

A retrospective analysis was performed using the FPA model including terminal catch years 1996-2002. No discernable patterning was evident in the estimates of fishing mortality in the retrospective runs. Estimates of fishing rates were relatively close in successive terminal years (1996-2002) (Figure 11.8).

Similarly, no retrospective patterns were detected in spawning stock biomass estimates (Figure 11.9). There is a break between 1998 and 1999 associated with the time when estimates of biomass from hydroacoustic surveys first become available (Figure 11.9). This discontinuity continues back until 1992 where it disappears.

Estimates of recruitment exhibit little retrospective patterning over the 1996-2002 period (Figure 11.10). There are some differences in the estimation of the size of the 1994 and 1998 year-classes in 1996 and 2000 respectively, but these do not occur in a sequential pattern.

11.7. Losses to Natural Mortality

Landings greatly exceeded losses to natural mortality during the late 1960s through the mid 1970s (Figure 11.11). Since 1970, landings have been less than losses to M (Figure 11.11).

12.0. Biological Reference Points

12.1. YPR and SSB/R

Yield per recruit and SSB per recruit reference points for the Gulf of Maine - Georges Bank herring complex were last estimated in the assessment conducted in 1996 (NEFSC 1996). Reference points from that analysis were $F_{0.1}$=0.20, $F_{20\%}$=0.34, and F_{max}=0.40. Yield per recruit and SSB per recruit reference points were re-estimated with more recent data (last 5 years) using the Thompson and Bell (1934) model (Table 12.1). Herring were assumed to be fully recruited at age 2 and fully mature at age 3. Estimated reference points were $F_{0.1}$=0.18, $F_{40\%}$=0.15 and F_{max}=0.40 (Table 12.2: Figure 12.1).

12.2. Surplus Production

Estimates of surplus production parameters from the 1998 assessment (NEFSC 1998) were derived using an ASPIC model that was conditioned with the B1 ratio fixed at 1.0 to produce stable estimates of parameters. This was the model accepted by the Overfishing Definition Review Panel (ODRP) in 1998 (NEFMC 1998). Estimates of biological reference points from 1998 surplus production analysis were MSY=317,000 mt, Bmsy=1.066 million mt and Fmsy=0.30.

Surplus production parameters were re-estimated using a Fox (1975) model and also a Schaefer (1954) model. The Fox model is asymmetric and was considered a better match with the Beverton-Holt stock-recruitment model. Biological reference points from the Fox model were MSY=222,000 mt, B_{msy}=896,000 mt and F_{msy}=0.25 (Figure 12.2). Reference points from the Schaefer model were MSY= 243,000 mt, B_{msy}=1.03 million mt, and F_{msy}=0.24.

During the early 1960s through the late 1970s, landings and surplus production were about equal (Figure 12.3). Starting in 1982, landings declined leading to a gradual and then large increase in the stock during the 1990s. Surplus production in the 1990s exhibited several large peaks representing the recruitment of the very large 1994 and 1998 year-classes (Figure 12.3)

13.0. Projections

Given that total stock biomass of the Gulf of Maine-Georges Bank herring complex has been above Bmsy since the mid 1990s, projections were conducted to estimate 2+ stock size in 2004 and 2005 under several assumptions of fishing mortality. The landings in 2003 were assumed to be 100,000 mt, approximately equal to that in 2002. Natural mortality was assumed to be 0.2 and two levels of F were used in the projections; F=0.2, a fishing rate approximately equal to the Fmsy reference point for the complex and F=0.1. A delay-difference projection model was constructed to simulate the dynamics of the herring complex. Bootstrap estimates of stock biomass for 2001 and 2002 were input to the model. Recruitment was modeled using the Beverton-Holt stock-recruitment relationship, parameters from the FPA final model, and a lognormal error structure. Results were summarized for the 750 bootstrap runs and median (50%) 2+ stock size and F values were produced.

An F=0.2 in 2004 would produce a catch of 323,000 mt and a reduction in stock size from 1.80 million mt in 2004 to about 1.64 million mt in 2005. An F of 0.1 in 2004 would produce a catch of 170,000m t but no change in biomass (1.79 million mt in 2005).

14.0. Gulf of Maine Herring Complex Adapt (VPA) analysis

14.1. Introduction

This section of the report deals with the ADAPT formulation used to assess the status of the Gulf of Maine/Georges Bank herring stock complex. Specific input parameters such as age composition, mean weight at age, percent maturity and details on tuning indices are only discussed in general as they are discussed in depth in other sections of this report.

14.2. Analytical Approach

The assessment process was initiated with the reproduction of the 1998 assessment formulation using data through 1997. Some difficulty was initially encountered in exactly matching the F's on the older ages and the use of the age 11 as a plus group. However, when age 11 was considered as a non-plus group the results were almost identical to the 1998 VPA results. The ratio of population numbers in the preliminary VPA was compared with population numbers from the 1998 assessment (Table 14.1). Most ratio values are close to 1 indicating little or no difference. Blank cells in the table are due to zero values in the 1998 assessment while large values (>1) are assumed to be due to precision errors from using population numbers rounded to millions.

As an initial run, the data series were updated for 1998-2002 and the VPA re-run using the 1998 assessment formulation. Indices of abundance included the NMFS spring bottom trawl survey stratified mean number per tow for strata 1-30, 36-40, and 61-76 from 1968 to 2002 and the winter NMFS bottom trawl index for strata (1-3, 5-7, 9-11, 13-14, 16, 61, 63, 65-67, 69-71, 73-75 for 1992-2002.

The results were examined in relation to how the age 11 in the catch at age was used and what effect various assumptions had on the results. Treatment of age 11 as a plus group appeared to be inconsistent with the observations from research surveys and the fishery. Specifically:

- Older ages formed a very small portion of the catch at age (less than 0.5% for ages 9 and 10 since 1973 (Table14. 2).
- There was no accumulation effect in the plus group.
- A high and variable mortality after age 7, especially in most recent years, was seen in the VPA results and PR patterns.
- Very few fish older than age 8 were observed in the any of the survey series.

Several modified versions of the initial formulations were investigated. Estimates of SSB from the various treatments of age 11 are shown in Figure 14.1. All runs used the same formulations.

Treatments included:

- age 11 as a plus group using FIRST method with F11=F10, F10 = weighted avg. 5-9. This method closely matches the 1998 assessment formulation.

- age 1-11 no plus group, oldest age using F11=F10
- age 1-10 no plus group, age 11 removed, oldest age using F10 = weighted average ages 5-9.

However, since 11+ fish do not occur in either the fishery or in the population (from trawl surveys) the treatment of these older fish should not be a significant source of error for short-term projections. The issue remaining is, will there be accumulation in the population at older ages if F is maintained at moderate levels and the implications for stock biomass, stock recruitment and reference points.

14.3. Summary of the 1998 Extended VPA

Input parameters and results for the initial VPA matching the 1998 assessment formulation and extending time series are summarized as follows.

1998 extended analysis (Appendix III):

- catch at age for 1967 to 2001 for ages 1-10 only (note that the 2002 catch at age was not available when this analysis was first done)
- no plus group assumed for reasons explained
- tune using winter survey 1992-2002 for ages 2-8 and spring survey 1968-2002 for ages 2-8; no special weighting with each value getting equal weight
- m=0.2; F on oldest age 10 calculated based on F on age 9
- Year 2002: estimate ages 5,6,7 and assign ages 1-2
- Year 2001: remaining ages 2,3,7,8,9 calculated as a weighted F of ages 4,5,6 in 2001

Details of the 1998 extended ADAPT run are presented in Appendix III. Using the above assumptions, total stock (age 1+) biomass in 2003 was calculated to be 1,580 kt; 3+ biomass, 1,400 kt; and SSB, 1,350kt (Figure 14.11). The mean squared residuals (MSR) by age were high for both surveys with many values >1.0 (Table 14.2, Figure 14.3) and the residual plots by year and age showed patterns that were either all positive or all negative by year and are large (Fig. 14.2, 14.3, 14.4). Age by age plots of observed vs predicted abundance show a relatively poor fit for the winter survey, but a much better pattern for the spring (Figs 14.5, 14.6) Diagnostic plots of survey q's by age also showed time trends and were not consistent over the series (Fig. 14.7, 14.9). Overall survey q's by age were dome shaped (Fig. 14.8, 14.10) indicating lower catchability for younger and older ages included in the formulation. There was an indication of several strong recruiting year-classes in recent years, a pattern of reduced fishing mortality since 1982, and a trend of increasing biomass since about 1997 (Figure 14.11). A severe retrospective pattern was detected beginning in 1999 but it was not as pronounced in 2000 and 2001 (Fig 14.12).

14.4. Final VPA

Several factors affecting the input parameters and the diagnostics were examined before adopting the final formulation. These included the analysis of a truncated time series and the use of the mean square residual as a selection criteria for the tuning indices.

14.5. Analysis using split survey series

In reviewing the survey abundance indices, several of the indices exhibited inconsistencies between the pre and post collapse period. A breakpoint was identified around 1984 which corresponded with a door change in the NMFS spring survey. Catch rates after 1984 were consistently higher than the previous period. Although several VPA scenarios were explored, including a truncated time series (1983-present), the final VPA run utilized all of the survey data; the spring and fall bottom trawl indices were split into two series (1968-1984; 1985-2002).

14.6. Selection of inputs based on Mean Square Residual (MSR)

An important diagnostic output of the ADAPT formulation is the Mean Square Residual (MSR) of the overall formulation as well as for each survey index by age and year. Given that tuning of the VPA uses $\log_e$ (ln) transformed data, the square root of the MSR is considered approximately equal to the CV (CV=sd/mean) on the linear scale. Consequently, a MSR of 2.0 implies that the standard deviation of the survey is about 1.4 times the size of the mean. MSR values can thus be used as a selection criteria for the inclusion or exclusion of indices and age groups within a survey series. Weighting based on the MSR could also achieve the same end but exclusion was initially considered simpler given the divergence in the MSR between survey series and ages.

The observed overall MSR for various ADAPT formulations on the Gulf of Maine herring complex was quite large (typically > 1.0) indicating poor resolution of the data. An MSR of < 3.0 was therefore used for selection of ages and survey series to calibrate the VPA. This corresponds to CV’s that are up to 1.7 on a linear scale.

ADAPT has an intrinsic weighting option that uses the inverse of the mean square residual to weight the indices. This provides a mechanism to incorporate all indices of abundance with an objective weighting function. The final VPA run, reported in the SSR and as follows, utilized this approach to weight the individual indices.

14.7. Summary of final ADAPT formulation ‘Final Run’

The final ADAPT formulation had the following features:

- catch at age for ages 1-10 without a plus group for 1967 to 2002
- m=0.2; F on oldest age 10 calculated based on weighted F on ages 7,8,9
- Year 2003: estimate ages 3,4,5,6,7 and assign age 1 at 2000 in year 2002 and 2003
- Year 2002: remaining ages 7,8,9 calculated as a weighted F of ages 4,5,6 in 2002
- all available survey abundance indices were used with the ADAPT intrinsic weighting option
    1. fall 1967-1984 ages 2-8; with split in series for gear change
    2. fall 1985-2002 ages 2-8; with split in series for gear change
    3. spring 1968-1984 ages 2-8; with split in series for gear change
    4. spring 1985-2002 ages 2-8; with split in series for gear change
    5. winter 1992-2002 ages 2-8
    6. US larval 1971-1988 weighted mean compared to 3+ midyear biomass; with split due to data calculation issues
    7. US larval 1989-1994 weighted mean compared to 3+ midyear biomass; with split due to data calculation issues
    8. Canadian larval 1987-1995 mean compared to 3+ midyear biomass
    9. US 1999-2002 acoustics survey abundance compared to 3+ midyear biomass

10. Canadian spring bottom trawl 1986-2002 ages 2-8 (with 1993 and 1994 surveys excluded due to lack of complete survey coverage)

Details of the ‘Complex Final Fit’ ADAPT formulation and input parameters are presented in Appendix III. Based on the above specifications and inputs, the total stock (age1+) biomass in 2003 was estimated to be 692 kt; 3+ biomass, 629 kt; and SSB 599 kt (Figure 14.31).

The MSR for the overall formulation was 1.106, while the average for each of the indices was 1.023, substantially better than the initial formulation. However, residual plots by year and age still exhibit patterns that were either all positive or all negative by year (Fig. 14.13-14.15). Age by age plots by survey of observed and predicted values show poor correspondence for most surveys and ages (Fig. 14.16-14.21). Diagnostic plots of the aggregated survey indices of observed and predicted also show poor fits (Fig. 14.22). Diagnostic plots of the survey q’s by age show time trends and are not consistent over the series (Fig. 14.23, 14.25, 14.27, 14.29).Overall survey q’s by age were variable; dome shaped for the US fall and US spring showing lower catchability for younger and older ages and increasing over the ages for the US winter and Canadian spring surveys (Fig 14.24, 14.26, 14.28, 14.30).

The ‘final run’ formulation still has severe retrospective patterns starting in 1999 but slightly improved in 2001 and 2002 (Figure 14.32). The reasons for these patterns may be due to a change in the survey q’s since 1996. When annual PR patterns in the fishery were investigated a prominent dip (or saddle-back) was detected with age 2 fully recruited, ages 3-5 fully recruited and then full recruitment from age 6 onwards (Fig. 14.33, 14.34). The trends were found to be consistent over the time series (1967-present) but there was increased variability in most recent years, especially in the older age groups.

14.8. Complex Final Fit Adapt formulation projections

Deterministic projections were conducted using the bias adjusted VPA results. Two F scenarios were considered, F = 0.2, (approximating the F estimated by the VPA in recent years and corresponding roughly to an F_{MSY} proxy), and F = 0.1.

Landings in 2003 were assumed to be 100,000t, approximately equal to those in 2002. The fishery partial recruitment was assumed to be 0.01 for age 1 and 1.0 (full recruitment) for ages 2 and older. Fishery and stock weights at age were set as the average from 1992 to 2002. Natural mortality was assumed to be 0.2.

A catch of about 100,000t in 2004 corresponds to an F = 0.2 and would generate a decrease in 3+ biomass from about 550,000t in 2004 to about 500,000t in 2005 (Table 14.4B). With an F = 0.1 in 2002, the resulting catch is about 60,000t and the 3+ biomass stays constant at about 550,000t (Table 14.4A).

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Table 1.1. Canadian larval survey timing, number of larvae caught and size range.

Year			CATCH				LENGTH			
	Start Date	End Date	Number of Sets	Number Caught	Mean # per tow	Mean # SE	Mean (mm)	Standard Deviation	Min	Max
87	23-Oct	10-Nov	40	4,898	22.0	1.2	9.4	1.9	5	19
88	28-Oct	7-Nov	76	4,075	6.5	0.4	13.1	3.1	6	21
89	25-Oct	5-Nov	90	4,386	7.4	0.5	12.4	1.8	7	21
90	31-Oct	10-Nov	79	5,903	10.2	0.5	11.6	1.9	7	19
91	4-Nov	12-Nov	76	1,508	3.3	0.3	13.4	3.7	5	20
92	24-Nov	30-Nov	86	7,743	12.6	0.4	14.6	4.4	5	29
93	12-Nov	26-Nov	71	15,715	30.8	0.7	12.8	2.2	5	26
94	16-Nov	29-Nov	81	43,106	52.9	1.0	11.3	1.6	5	28
95	16-Nov	30-Nov	85	41,286	47.3	1.0	14.1	3.8	4	27

Table 2.1

Table 1 . Contribution to Complex Biomass. Based on Swept-area estimates of minimum population size for select strata from the fall survey representing Coastal Maine, Nantucket Shoals and Georges Bank

Component	1988 -	1997	1993 -	1997
	Number	Weight	Number	Weight
Coastal Maine	26%	27%	24-26%	24-26%
Nantucket Shoals	63%	63%	57%	57%
Georges Bank	10%	11%	17-18%	17-18%

Table 2.2. Distribution of Spawning Components by season. Used for TAC

Time of Year	Component	Percent of	Component in	Management Area
		1	2	3
Dec - Mar	GOM	100	20	0
	GB/NS	0	80	0
Apr - Jul	GOM	50	0	0
	GB/NS	50	100	100
Aug - Nov	GOM	100	0	0
	GB/NS	0	100	100

Table 3. 1. Summary of reported Georges Bank herring catches by country for 1961-1977. Note "Others" includes Cuba, Iceland, Norway and others. (Reproduced from Anthony and Waring 1980).

Year	USA	Canada	FRG	GDR	USSR	Poland	Japan	Bulgaria	France	Romania	Others	Total
1961	105				67,550							67,655
1962	101				151,864	277						152,242
1963	322				97,646							97,968
1964	489				130,914	35						131,438
1965	1,191				38,262	1,447				1,982		42,882
1966	4,308			1,133	120,113	14,473				2,677		142,704
1967	1,211	1,306	28,171	22,159	126,759	36,677	40			1,420		217,743
1968	758	13,674	71,086	67,719	143,097	75,080	171			1,656	357	373,598
1969	3,678	945	61,990	44,624	138,673	45,021	583	812		337	14,095	310,758
1970	2,011	7	82,498	28,063	61,579	70,691	1,412	348		685		247,294
1971	3,822	12,863	54,744	18,447	81,258	88,325	2,466	4,551		898		267,374
1972	2,782	53	27,703	40,016	48,072	49,392	1,161	2,355	500	2,156		174,190
	(4,000)	(5,800)	(31,600)		(48,200)	(49,400)	(200)			(600)	(8,200)	(150,000)
1973	4,627	5,083	31,501	53,326	52,340	49,275	1,722	1,380	2,784	297		202,335
	(5,250)	(5,050)	(31,600)		(48,200)	(49,400)	(1,200)			(1,300)	(8,000)	(150,000)
1974	3,370	217	23,690	31,530	41,541	39,312	4,242	1,773	3,617	2,018		151,310
	(6,955)	(2,980)	(23,900)	(31,440)	(41,725)	(39,000)					(4,000)	(150,000)
1975	4,582	0	22,957	30,901	40,945	38,392	1,878	421	3,304	1,544	1,172	146,096
	(8,400)	(3,000)	(23,750)	(31,150)	(41,100)	(38,400)					(4,200)	(150,000)
1976	744		8,806	7,891	12,996	10,517	868	105	1,166	115	299	43,507
	(12,400)	(1,000)	(9,200)	(9,300)	(12,190)	(11,000)	(1,100)	(900)	(1,100)	(800)	(1,010)	(60,000)
1977	361	2			1,492	119		1			152	2,127
	(12,000)	(1,000)	(4,725)	(4,825)	(3,400)	(5,100)		(100)	(1,000)	(100)	(750)	(33,000)

National allocation in parentheses.

Table 3.2. GEORGES BANK (GB), GULF OF MAINE (GOM), SOUTHERN NEW ENGLAND (SNE), MIDDLE ATLANTIC (MAT) AND NEW BRUNSWICK, CANADA (NB) HERRING CATCH, 1960-2002. (INCLUDES FOREIGN FISHING, INTERNAL WATERS PROCESSING OPERATIONS AND AT-SEA TRANSFERS TO CANADIAN CARRIERS IN THE GOM).

YEAR	FOR GB[1]	U.S. GB[2]	CAN GB	FOR GOM	US GOM[3]	SNE[4]	MAT[5]	TOT US	NB[6]	TOTAL FOR	TOTAL
1960					60,237	261	152	60,650	34,304	34,304	94,954
1961	67,550	105			25,548	197	101	25,951	8,054	75,604	101,555
1962	152,141	101			69,980	131	98	70,310	20,698	172,839	243,149
1963	97,646	322			67,736	195	78	68,331	29,366	127,012	195,343
1964	130,949	489			27,226	200	148	28,063	29,432	160,381	188,444
1965	41,691	1,191			34,104	303	208	35,806	33,460	75,151	110,957
1966	138,396	4,308			29,167	3,185	176	36,836	35,805	174,201	211,037
1967	217,532	1,211		5,226	30,191	247	524	32,173	30,032	252,790	284,963
1968	372,840	758		21,497	40,928	245	122	42,053	33,145	427,482	469,535
1969	307,080	3,678		25,084	28,336	2,104	193	34,311	26,539	358,703	393,014
1970	245,283	2,011		13,716	28,070	1,037	189	31,307	15,840	274,839	306,146
1971	263,525	3,822		19,498	32,631	1,318	1,151	38,922	12,660	295,683	334,605
1972	171,408	2,782		24,220	37,444	2,310	409	42,945	32,699	228,327	271,272
1973	197,708	4,627		10,725	21,767	4,249	233	30,876	19,935	228,368	259,244
1974	146,155	3,370		7,865	29,491	2,918	200	35,979	20,602	174,622	210,601
1975	141,513	4,583		5,249	31,938	4,119	117	40,757	30,819	177,581	218,338
1976	42,758	744		921	49,887	191	57	50,879	29,206	72,885	123,764
1977	1,776	381		382	50,348	301	33	51,063	23,487	25,645	76,708
1978		2,059			48,734	1,730	46	52,569	38,842	38,842	91,411
1979		1,270			63,492	1,341	31	66,134	37,828	37,828	103,962
1980		1,700			82,244	1,200	21	85,165	13,525	13,525	98,690
1981		672			64,324	749	16	65,761	19,080	19,080	84,841
1982		1,378			32,157	1,394	20	34,949	25,963	25,963	60,912
1983		58			24,824	72	21	24,975	11,383	11,383	36,358
1984		53			33,958	79	10	34,100	8,698	8,698	42,798
1985		316			27,157	196	13	27,682	27,863	27,863	55,545
1986		586			27,942	632	20	29,180	27,883	27,883	57,063
1987		11			39,970	376	87	40,444	27,320	27,320	67,764
1988					39,568	1,307	365	41,240	33,421	33,421	74,661
1989					52,774	269	39	53,082	44,112	44,112	97,194
1990			91		54,192	761	48	55,001	38,778	38,869	93,870
1991			64		50,984	3,947	402	55,333	24,576	24,640	79,973
1992					55,948	716	4,564	61,228	31,968	31,968	93,196
1993					53,929	1,829	1,347	57,105	31,572	31,572	88,677
1994		474	266		51,413	1,935	502	54,324	22,241	22,507	76,831
1995		64			69,989	14,630	856	85,539	18,248	18,248	103,787
1996		1,758	2,491		78,885	26,876	1,079	108,598	15,913	18,404	127,002
1997		6,262	79		71,395	20,914	527	99,098	20,552	20,631	119,729
1998		31,067			52,683	20,084	1,903	105,737	20,092	20,092	125,829
1999		6,243			76,861	21,528	1,028	105,659	18,592	18,592	124,251
2000		16,171	275		64,839	27,275	568	108,853	16,830	17,105	125,958
2001	1,241	34,510	3,317		55,815	17,691	420	108,436	20,210	24,768	133,204
2002*		15,217	1,605		68,543	7,486	29	91,275	11,800	13,405	104,680

[1] 1961-1987: foreign catch from areas 5Z and 6, including some U.S. landings (<5,000 mt/yr)

[2] 1994-2002: catch from NMFS statistical areas 521, 522, 525, 526, 561 and 562

[3] ME, MA & NH landings; [4] RI, CT, NY landings; [5] NJ, DE, MD, VA landings; [6] fixed gear catch only. *Note 2002 landings are preliminary

Table 3.3. Mean weight at age (kg), U.S. Atlantic herring stock complex, 1967-2002.

Year	AGE 1	AGE 2	AGE 3	AGE 4	AGE 5	AGE 6	AGE 7	AGE 8	AGE 9	AGE 10	AGE 11+
1967	0.005	0.029	0.078	0.118	0.162	0.257	0.275	0.342	0.288	0.292	0.313
1968	0.007	0.025	0.059	0.142	0.194	0.215	0.245	0.260	0.273	0.292	0.313
1969	0.010	0.039	0.079	0.051	0.252	0.270	0.320	0.296	0.273	0.292	0.313
1970	0.021	0.063	0.106	0.167	0.210	0.240	0.304	0.309	0.311	0.292	0.313
1971	0.019	0.049	0.115	0.180	0.234	0.327	0.294	0.291	0.329	0.331	0.313
1972	0.035	0.051	0.120	0.187	0.234	0.273	0.314	0.357	0.273	0.292	0.313
1973	0.016	0.054	0.108	0.170	0.233	0.257	0.293	0.325	0.338	0.263	0.324
1974	0.017	0.053	0.108	0.169	0.204	0.232	0.247	0.272	0.286	0.293	0.305
1975	0.023	0.051	0.096	0.169	0.192	0.230	0.274	0.274	0.302	0.293	0.314
1976	0.018	0.042	0.114	0.179	0.206	0.211	0.260	0.282	0.319	0.334	0.399
1977	0.016	0.042	0.103	0.161	0.189	0.219	0.228	0.260	0.304	0.294	0.281
1978	0.013	0.040	0.120	0.186	0.226	0.256	0.273	0.285	0.317	0.349	0.345
1979	0.008	0.032	0.089	0.198	0.255	0.281	0.182	0.325	0.332	0.313	0.313
1980	0.015	0.041	0.103	0.169	0.268	0.319	0.344	0.241	0.306	0.391	0.372
1981	0.012	0.045	0.114	0.190	0.232	0.293	0.316	0.342	0.470	0.304	0.373
1982	0.020	0.049	0.130	0.194	0.250	0.267	0.300	0.322	0.342	0.423	0.313
1983	0.022	0.055	0.138	0.216	0.223	0.310	0.348	0.368	0.390	0.397	0.313
1984	0.019	0.051	0.133	0.182	0.227	0.260	0.305	0.343	0.314	0.402	0.528
1985	0.013	0.049	0.139	0.181	0.203	0.229	0.281	0.273	0.289	0.292	0.313
1986	0.021	0.053	0.116	0.166	0.215	0.230	0.251	0.260	0.299	0.292	0.313
1987	0.018	0.044	0.093	0.141	0.178	0.218	0.233	0.227	0.251	0.265	0.320
1988	0.009	0.034	0.090	0.129	0.164	0.187	0.228	0.238	0.254	0.292	0.247
1989	0.005	0.046	0.101	0.136	0.168	0.196	0.235	0.248	0.244	0.313	0.300
1990	0.005	0.044	0.099	0.148	0.183	0.194	0.207	0.229	0.240	0.258	0.300
1991	0.005	0.053	0.087	0.133	0.166	0.193	0.214	0.225	0.229	0.243	0.300
1992	0.005	0.046	0.090	0.128	0.153	0.175	0.201	0.219	0.229	0.256	0.300
1993	0.005	0.044	0.096	0.132	0.158	0.182	0.211	0.238	0.258	0.282	0.300
1994	0.005	0.049	0.086	0.119	0.139	0.159	0.184	0.214	0.243	0.261	0.300
1995	0.026	0.056	0.097	0.123	0.140	0.155	0.170	0.192	0.224	0.256	0.272
1996	0.025	0.054	0.091	0.125	0.152	0.171	0.191	0.206	0.235	0.249	0.332
1997	0.016	0.057	0.090	0.122	0.145	0.170	0.187	0.216	0.264	0.332	0.345
1998	0.000	0.050	0.082	0.119	0.144	0.165	0.184	0.198	0.213	0.247	0.267
1999	0.030	0.058	0.088	0.116	0.139	0.158	0.178	0.196	0.201	0.290	0.000
2000	0.000	0.071	0.107	0.128	0.154	0.173	0.198	0.212	0.229	0.243	0.267
2001	0.039	0.057	0.100	0.132	0.153	0.171	0.189	0.213	0.218	0.282	0.262
2002	0.025	0.059	0.094	0.125	0.147	0.165	0.181	0.198	0.217	0.208	0.208

Table 3.4. Catch at age (millions) for coastal US Atlantic herring fishery. Note 2002 data are preliminary.

Year	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11+
1967	6.83	261.94	166.40	42.60	10.64	15.53	9.05	0.67	0.45	0.39	0.17
1968	13.29	695.48	177.37	24.09	32.00	29.87	28.93	19.01	3.24	2.49	0.65
1969	10.02	231.06	229.66	18.80	14.41	24.28	22.29	22.85	20.03	5.73	1.03
1970	2.02	168.93	55.35	30.74	20.29	25.96	33.00	26.75	21.09	14.70	2.88
1971	73.72	55.51	44.23	45.07	44.84	44.01	29.17	17.86	12.18	8.55	3.53
1972	0.68	357.84	23.73	45.07	43.79	49.60	25.20	9.49	2.89	2.68	1.65
1973	11.36	143.56	96.75	7.64	11.85	13.75	13.09	7.47	1.80	0.55	0.34
1974	31.36	181.33	63.52	110.36	8.82	5.46	2.96	2.05	0.94	0.44	0.35
1975	28.26	181.47	49.20	25.75	90.98	9.54	3.81	2.27	1.09	0.45	0.27
1976	23.59	331.48	137.18	20.55	15.88	57.96	3.70	0.68	0.89	0.18	0.09
1977	82.21	454.92	72.68	42.87	12.48	10.79	42.90	2.30	0.56	0.39	0.32
1978	56.02	328.01	80.67	20.10	37.80	4.62	7.68	30.85	1.10	0.65	0.22
1979	4.16	750.35	170.08	43.40	14.86	15.84	5.67	3.42	6.90	0.34	0.00
1980	67.15	224.72	301.08	163.46	20.85	6.03	8.09	0.78	0.62	4.43	0.12
1981	8.37	874.47	15.58	57.90	41.52	4.55	1.31	1.17	0.04	0.14	0.81
1982	22.49	274.05	36.94	3.52	28.47	17.70	1.98	0.38	0.75	0.12	0.15
1983	30.28	132.19	37.42	21.37	0.81	6.22	7.17	0.33	0.19	0.13	0.00
1984	4.53	98.45	113.11	32.12	22.00	1.00	3.13	1.35	0.37	0.04	0.00
1985	9.90	177.30	36.89	31.60	17.81	8.92	0.25	1.51	0.49	0.00	0.00
1986	37.47	111.15	103.49	24.21	27.30	11.52	5.38	0.00	0.34	0.00	0.33
1987	15.28	92.12	85.28	124.43	20.67	11.00	3.12	1.71	0.02	0.21	0.01
1988	3.23	153.08	64.73	38.69	85.45	18.80	6.58	1.53	0.69	0.00	0.03
1989	0.21	129.19	84.62	86.70	58.62	87.67	17.74	5.29	1.39	0.03	0.00
1990	0.01	116.25	151.56	58.67	31.64	35.94	67.45	25.11	12.19	3.64	1.09
1991	0.01	123.52	135.99	78.08	55.77	30.12	20.67	18.01	8.29	3.08	1.20
1992	0.00	171.06	121.89	57.78	77.73	52.05	25.13	15.28	13.25	3.54	0.00
1993	0.00	139.82	137.40	64.29	65.33	38.47	29.75	16.34	4.48	1.62	0.33
1994	0.00	131.53	112.22	62.74	69.02	62.08	33.44	17.84	5.12	1.39	0.05
1995	1.38	205.59	93.44	38.53	36.12	82.00	89.96	56.16	17.32	3.39	0.88
1996	0.44	344.50	135.92	60.78	73.16	166.97	96.98	27.66	6.25	2.20	0.15
1997	1.91	75.70	422.38	69.52	49.80	76.80	82.09	18.44	2.76	0.04	0.10
1998	0.00	236.62	80.71	210.01	45.23	22.83	26.06	14.92	5.47	1.49	0.28
1999	0.67	103.61	277.84	77.51	196.55	71.26	32.12	17.89	4.49	0.36	0.00
2000	0.00	190.11	37.28	95.16	134.31	147.58	35.15	12.83	2.43	1.02	0.31
2001	0.12	72.93	245.86	36.63	67.99	96.37	108.74	22.38	4.89	0.48	0.09
2002	9.48	78.82	96.37	198.71	66.52	58.96	60.60	26.68	3.12	0.35	0.05

Table 3.5. Catch at age (millions) for Georges Bank Atlantic herring fishery. Note 2002 data are preliminary

Year	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11+
1967	0.00	1.80	6.90	60.60	108.00	250.70	379.20	49.40	11.10	10.00	0.00
1968	0.00	2.50	52.10	133.30	336.00	233.40	432.90	336.40	21.80	6.60	0.00
1969	0.00	0.00	73.40	210.80	277.10	278.10	188.50	190.50	109.70	23.60	0.00
1970	0.00	12.60	125.40	450.50	270.30	122.30	92.90	51.60	29.60	17.70	0.00
1971	0.00	12.90	332.50	275.50	284.60	175.80	103.90	50.40	13.90	21.80	0.00
1972	0.00	28.00	35.00	110.00	214.00	158.00	100.00	45.00	29.00	21.00	0.00
1973	0.00	10.00	1026.00	266.00	64.00	33.00	23.00	12.00	3.00	5.00	0.00
1974	0.00	1.90	39.90	608.90	68.60	12.90	6.10	3.50	2.10	0.00	0.00
1975	0.00	1.40	11.30	76.80	503.00	34.60	12.50	6.20	4.20	0.10	0.00
1976	0.00	0.50	7.50	6.80	18.60	140.80	5.10	2.30	1.20	0.30	0.00
1977	0.00	0.10	0.30	6.70	1.20	0.20	1.90	0.10	0.10	0.00	0.00
1978	0.00	0.10	5.60	2.30	4.30	0.50	0.30	1.20	0.00	0.00	0.00
1979	0.00	0.10	5.10	2.10	0.40	0.40	0.00	0.10	0.00	0.00	0.00
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	5.79	2.29	1.02	1.23	2.81	1.63	0.46	0.10	0.04	0.00
1997	0.00	2.00	49.00	5.29	1.18	1.50	1.16	0.51	0.09	0.00	0.00
1998	0.00	3.99	29.13	111.66	10.84	6.44	5.58	1.14	0.30	0.13	0.00
1999	0.00	0.00	7.48	5.45	20.03	8.29	3.04	1.67	0.03	0.00	0.00
2000	0.00	4.99	4.61	25.95	21.03	28.25	8.93	2.56	0.41	0.02	0.01
2001	0.00	1.83	134.00	14.66	30.07	31.10	27.11	4.39	0.26	0.00	0.00
2002	0.00	0.00	2.53	49.34	16.21	10.52	10.89	7.02	0.29	0.00	0.00

Table 4.1. Summary of the US and Canadian fishery independent surveys that have been used to evaluate the distribution and abundance of Atlantic herring

Country	Season	Start Year	End Year	Gear	Status	Index Type
US	*Spring*	1967	2002	*BT*	*Continuing*	*Age*
US	Fall	1963	2002	BT	Continuing	Age
US	Winter	1992	2002	BT	Continuing	Age
Can	Spring	1987	2002	BT	Continuing	Age
Can	Fall	1986	1995	Bongo	Terminated	Biomass
US	Fall/Winter	1971	1994	Bongo	Terminated	Biomass
US	Fall	1999	2002	Acoustic	Continuing	Biomass

Table 4.2. Summary of Canadian spring bottom trawl surveys from 1986-2002.

Year	**vessel /cruise**	**start date**	**end date**	**mid date**	**sets**	**Number Fish**	**Weight (kg)**
1986	NED / 059	4-Mar	13-Mar	8-Mar	86	965	63
1987	NED / 077	10-Mar	18-Mar	14-Mar	74	73	5
1988	NED / 097	1-Mar	15-Mar	8-Mar	142	408	66
1989	NED / 116	23-Feb	6-Mar	28-Feb	122	6537	225
1990	NED / 133	21-Feb	6-Mar	27-Feb	131	3035	87
1991	NED / 148	13-Feb	27-Feb	20-Feb	142	15096	1304
1992	NED / 165	26-Feb	11-Mar	4-Mar	93	1802	195
1993	TEM / 134	9-Mar	18-Mar	13-Mar	66	5129	832
1994	NED / 200	16-Feb	24-Feb	20-Feb	46	429	50
1995	NED / 216	14-Feb	23-Feb	18-Feb	89	3209	212
1996	NED / 237	20-Feb	28-Feb	24-Feb	93	3966	254
1997	NED / 254	25-Feb	5-Mar	1-Mar	96	19444	1612
1998	NED / 773	17-Feb	26-Feb	21-Feb	100	1610	208
1999	NED / 871	16-Feb	24-Feb	20-Feb	87	14496	2074
2000	NED / 965	16-Feb	24-Feb	20-Feb	103	24803	1145
2001	NED / 003	14-Feb	23-Feb	18-Feb	80	30945	3309
2002	NED / 002	19-Feb	28-Feb	23-Feb	93	5999	168

Table 4.3. Summary of the US Winter bottom trawl survey from 1992 to 2002.

Year	Cruise Number	Vessel	Gear Type	Start Date	End Date	Mid-Date	Number Sets	Number Herring	Weight Herring
1992	199201	AL		12-Feb-92	4-Mar-92	21-Feb-92	129	4846	458.4
1993	199301	AL		3-Feb-93	26-Feb-93	15-Feb-93	122	4877	644.2
1994	199401	AL		1-Feb-94	20-Feb-94	9-Feb-94	92	562	70.9
1995	199502	AL		7-Feb-95	28-Feb-95	17-Feb-95	144	1923	285.7
1996	199601	AL		6-Feb-96	28-Feb-96	15-Feb-96	129	11835	759.3
1997	199701	AL		4-Feb-97	26-Feb-97	14-Feb-97	112	6154	959.6
1998	199801	AL		8-Feb-98	26-Feb-98	16-Feb-98	124	5724	610.2
1999	199901	AL		2-Feb-99	23-Feb-99	10-Feb-99	123	5976	720.8
2000	200001	AL		10-Feb-00	29-Feb-00	19-Feb-00	118	4333	273.8
2001	200101	AL		30-Jan-01	22-Feb-01	9-Feb-01	148	10376	1037.4
2002	200201	AL		6-Feb-02	2-Mar-02	18-Feb-02	153	8801	1120.5

Table 4.4. Summary of the US fall bottom trawl surveys from 1963 to 2001. Note the total number of set refers to the number of valid sets in the entire Gulf of Maine and South of Cape Cod.

Year	Cruise Number	Vessel	Gear Type	Start Date	End Date	Mid-date	Number Sets	Number Sets GB	Number sets GB+NS	Number Sets GB+NS+ GOM
1963	196307	AL	11	317	343	330.0	113	43	73	113
1964	196413	AL	11	303	339	317.3	115	50	78	115
1965	196514	AL	11	279	307	292.7	118	53	82	118
1966	196614	AL	11	285	314	298.1	120	57	83	120
1967	196721	AL	11	312	343	328.7	119	56	84	119
1968	196817	AL	11	294	330	312.6	124	60	88	124
1969	196911	AL	11	301	327	311.6	132	65	95	132
1970	197006	AL	11	296	324	307.8	132	65	90	132
1971	197106	AL	11	288	323	301.8	131	61	91	131
1972	197208	AL	11	292	324	304.3	134	62	94	134
1973	197308	AL	11	282	323	301.5	133	59	90	133
1974	197411	AL	11	283	314	292.9	137	62	91	137
1975	197512	DE	11	281	322	293.2	147	61	94	147
1976	197609	AL	11	297	327	309.3	123	57	83	123
1977	197712	DE	11	292	349	314.4	176	73	123	176
1978	197806	DE	11	273	324	297.1	279	114	180	279
1979	197910	AL	11	305	313	309.3	74	108	188	286
	197910	DE	11	286	322	304.3	212			
1980	198007	DE	11	286	319	301.3	160	85	117	160
1981	198106	AL	11	307	311	309.0	34	66	95	148
	198106	DE	11	286	311	297.0	104			
1982	198206	AL	11	285	315	301.9	165	56	88	134
1983	198306	AL	11	281	313	296.5	193	54	85	133
1984	198405	AL	11	255	311	284.7	225	61	91	137
1985	198508	AL	11	295	319	307.1	97	62	92	146
	198508	DE	11	290	298	294.9	59			
1986	198606	AL	11	290	309	298.6	107	59	85	135
	198606	DE	11	280	296	284.7	31			
1987	198705	AL	11	275	309	287.7	144	60	86	133
1988	198803	AL	11	273	301	289.7	131	59	84	135
	198803	DE	11	286	287	286.6	11			
1989	198904	DE	11	279	306	291.1	137	56	84	129
	198904	DE	94	281	282	281.7	13			
1990	199004	DE	11	270	297	284.6	150	65	97	142
1991	199105	DE	11	273	297	284.8	155	53	88	135
1992	199206	AL	11	280	301	289.4	153	57	87	133
1993	199306	DE	11	270	298	282.4	146	52	85	135
1994	199406	AL	11	277	300	287.1	148	60	92	142
1995	199507	AL	11	268	299	284.0	171	56	88	141
1996	199604	AL	11	272	305	288.4	176	53	87	138
1997	199706	AL	11	278	303	290.1	180	53	90	138
1998	199804	AL	11	283	313	298.7	187	49	82	146
1999	199908	AL	11	284	314	299.7	155	57	90	152
2000	200005	AL	11	268	294	280.8	142	56	86	138
2001	200109	AL	11	268	295	281.6	146	57	88	132

Table 4.5. Summary of the US spring bottom trawl surveys from 1968 to 2002. Note that the total number of sets refers to the number of sets in the Gulf of Maine and on Georges Bank (5Y, 5Z and a few sets in 4X).

Year	Cruise Number	Vessel	Gear Type	Start Date	End Date	Mid-date	Number Sets	Number Sets GB	Number Sets GB+NS	Number Sets GB+NS+GOM	Number Herring	Weight Herring (kg)
1968	196803	AL	11	6-Mar	13-May	22-Mar	119	54	85	119	4045	506
1969	196902	AL	11	5-Mar	10-Apr	23-Mar	130	63	96	130	1942	353
1970	197003	AL	11	12-Mar	29-Apr	7-Apr	127	58	85	127	1777	142
1971	197101	AL	11	8-Mar	24-Apr	4-Apr	170	87	127	170	614	72
1972	197202	AL	11	8-Mar	24-Apr	4-Apr	186	72	100	142	865	52
1973	197303	AT	11	16-Mar	4-Jun	5-May	122	61	87	122	3794	482
	197303	AL	11	16-Mar	4-Jun	5-May						
	197303	DE	11	16-Mar	4-Jun	5-May						
1974	197404	AL	11	13-Mar	4-May	19-Apr	120	57	81	120	1479	204
	197404	DE	11	13-Mar	4-May	19-Apr						
	197404	AT	11	13-Mar	4-May	19-Apr						
1975	197503	AL	11	4-Mar	11-May	18-Apr	159	55	84	125	412	72
	197503	AT	11	4-Mar	11-May	18-Apr						
1976	197602	AL	11	4-Mar	7-May	30-Mar	139	55	88	139	1463	214
	197602	DE	11	4-Mar	7-May	30-Mar						
1977	197702	AL	11	19-Mar	19-May	17-Apr	143	61	89	143	632	116
	197702	DE	11	19-Mar	19-May	17-Apr						
1978	197804	AL	11	21-Mar	24-May	19-Apr	147	63	96	147	2041	329
1979	197904	AL	11	22-Mar	25-Jun	14-Apr	217	98	151	217	8261	726
	197904	DE	11	22-Mar	25-Jun	14-Apr						
1980	198002	AL	11	18-Mar	7-May	8-Apr	145	68	101	145	8858	1051
	198002	DE	11	18-Mar	7-May	8-Apr						
1981	198102	DE	11	19-Mar	24-May	12-Apr	138	59	88	138	8659	1567
1982	198202	DE	11	11-Mar	8-May	3-Apr	150	66	95	145	713	122
1983	198303	AL	11	9-Mar	30-Apr	31-Mar	153	59	90	144	1084	247
1984	198402	AL	11	2-Mar	24-Apr	22-Mar	144	56	88	137	1879	190
1985	198502	AL	11	26-Feb	12-Apr	19-Mar	139	56	82	129	4590	618
1986	198603	AL	11	4-Mar	27-Apr	31-Mar	137	55	87	135	8163	884
1987	198702	AL	11	24-Mar	28-Apr	12-Apr	144	63	95	134	3243	443
	198702	DE	11	24-Mar	28-Apr	12-Apr						
1988	198801	AL	11	5-Mar	20-Apr	24-Mar	134	52	82	132	7088	866
1989	198901	DE	11	28-Feb	13-Apr	15-Mar	126	55	80	121	7031	942
1990	199002	DE	11	6-Mar	17-Apr	21-Mar	141	55	86	130	6083	568
1991	199102	DE	11	6-Mar	16-Apr	26-Mar	137	56	84	131	11755	1270
1992	199202	AL	11	3-Mar	15-Apr	23-Mar	143	54	77	127	9769	906
1993	199302	AL	11	9-Mar	29-Apr	31-Mar	135	52	81	131	20699	2320
1994	199402	DE	11	1-Mar	26-Apr	17-Mar	152	59	91	139	14020	1690
1995	199503	AL	11	7-Mar	27-Apr	6-Apr	143	52	85	134	9399	938
1996	199602	AL	11	6-Mar	29-Apr	4-Apr	135	54	78	127	15518	870
1997	199702	AL	11	4-Mar	22-Apr	22-Mar	148	54	87	135	25922	1520
1998	199802	AL	11	3-Mar	20-Apr	23-Mar	167	50	88	159	14073	1176
1999	199902	AL	11	2-Mar	22-Apr	27-Mar	141	54	85	136	20666	2278
2000	200002	AL	11	16-Mar	3-May	4-Apr	137	53	83	133	8386	720
2001	200102	AL	11	28-Feb	30-Apr	31-Mar	145	57	91	138	10107	953
2002	200202	AL	11	6-Mar	24-Apr	28-Mar	149	48	86	141	14485	1040

Table 6.1. Comparison of otolith ages from the US National Marine Fisheries Service (US-1) and the Maine Department of Marine Resources (US-2).

Ager	US-2								
US-1	2	3	4	5	6	7	8	9	Total
2	30								30
3		76	5						81
4		5	12	1					18
5			1	22	3	1			27
6				1	9	4	1		15
7					2	23	4		29
8						1	9	3	13
9									
Total	30	81	18	24	14	29	14	3	213

Table 6.2. Comparison of otolith ages from Canadian Department of Fisheries & Oceans (Can-1) and the US National Marine Fisheries Service (US-1).

Ager	US-1								
Can-1	2	3	4	5	6	7	8	9	Total
2	30								30
3		78	8						81
4		3	8	6					18
5			2	18	8	2			27
6				2	7	20	1		15
7				1		6	9		29
8						1	3	3	13
9									
Total	30	82	18	27	15	29	13	3	213

Table 6.3. Comparison of otolith ages from Canadian Department of Fisheries & Oceans (Can-1) and the US National Marine Fisheries Service (US-1).

Ager	US-2								
Can-1	2	3	4	5	6	7	8	9	Total
2	30								30
3		77	9						86
4		4	8	5					17
5			1	17	7	5			30
6				1	7	19	3		30
7				1		5	8	2	16
8							3	1	4
Total	30	81	18	24	14	29	14	3	213

Table 7.1. Parameters for length weight equations for Atlantic herring from NMFS autumn research vessel bottom trawl surveys in the Gulf of Maine-Georges Bank Region.

Year	a	b
1999	0.0000115	2.924232
2000	0.0000459	2.502584
2002	0.0000160	2.810323
2002	0.0000160	2.810323

Table 7.2. Mean herring backscatter (Sa) and SD of backscatter from acoustic surveys on Georges Bank during 1999-2002.

Survey	Mean Sa	SD	Survey Area nmi^2
1999			
Zigzag 1	3385.122	634.372	2322.13
Zigzag 2	2731.073	569.702	2116.66
Parallel	1036.231	101.447	6108.88
2000			
Zigzag	1064.997	106.499	6297.86
Parallel	1824.410	209.625	4376.42
Stratified random	1191.143	201.184	7085.98
2001			
Zigzag	1453.494	156.977	6539.68
Parallel	1822.759	180.271	6405.58
Stratified random	1256.025	192.172	7284.11
2002			
Parallel	566.997	76.885	7658.70

Table 7.3. Intercepts from target strength equations from studies on herring stocks in the North Atlantic.

	Study	Intercept
1	Hagstrom&Rottigen 1982	-73.5
2	Halldorsson & Reynesson 1983	-69.4
3	Degnbol et al 1985	-72.6
4	Lasson and Staehr 1985	-70.8
5	Foote et al. 1986	-72.1
6	Foote et al. 1987	-71.9
7	Rudstam et al. 1988	-69.9
8	Bailey and Simmonds 1990	-71.2
9	Reynisson 1993	-67.1
10	Misund and Beltstad 1995	-69.8
11	Vabo et al. 1999	-67.6

Table 7.4. Geostatistical estimates of biomass, CV, CV inverse, weighted biomass (W) and weighted CV (W) for Acoustic surveys on Georges Bank during 1999-2002.

	Biomass	CV	1/CV	W Biomass	W CV
1999					
Zigzag1	1.4173	18.74	0.0534		
Zigzag2	1.0409	20.86	0.0479	1.19276E6	10.712
Parallel	1.1467	9.79	0.1021		
2000					
Parallel	1.5025	11.49	0.0870		
Zigzag	1.2680	10.00	0.1000	1.426880E6	7.222
S random	1.5838	16.89	0.0592		
2001					
Parallel	2.1484	9.89	0.1011		
Zigzag	1.6172	10.80	0.0926	1.819177E6	6.604
S random	1.5960	15.30	0.0654		
2002					
Parallel	0.7628	13.56		0.762759E6	13.560

Table 7.5. Point estimates of mean Sa and biomass (million mt) from standard statistical analysis for surveys on Georges Bank during 1999-2002.

Year	Survey	Mean Sa	Biomass (million mt)
1999	Zigzag 1	3444.588	1.4422
	Zigzag 2	3059.560	1.1661
	Parallel	1164.686	1.2889
2000	Zigzag	1053.267	1.2540
	Parallel	2132.484	1.7562
	Stratified Random	1291.377	1.7171
2001	Zigzag	1447.870	1.6109
	Parallel	1997.915	2.3549
	Stratified Random	1168.296	1.4845
2002	Parallel	627.614	0.8443

Table 10.1. Variance, number of observations, and degrees of freedom from spawner recruit models for various North Atlantic stocks of herring.

Stock	**Variance** (σ_r^2)	**N**	**Residual Degrees of Freedom (*d*$_f$)**
Used in analysis			
Downs Stock	0.57	65	62.0
Gulf of Finland	0.45	18	14.6
ICES VIa(north)	0.32	18	14.0
ICES Via(south) and VIIb,c	0.27	19	15.1
Iceland (spring spawners)	1.77	23	20.0
Iceland (summer spawners)	0.40	49	45.0
NAFO 4-5$_1$	0.43	22	18.3
North Sea	0.47	41	37.5
Northern Irish Sea	0.08	18	14.4
Norway (spring spawners)	3.36	44	40.4
Not used in analysis:			
Georges Bank	2.35	30	26.8
Gulf of Maine	0.62	46	43.1
summary_recr_var_1.xls			

1 Includes Gulf of Maine and Georges Bank components.

Table 10.2. Landings (2+, 000s mt) of Atlantic herring from the Gulf of Maine-Georges Bank complex during 1959-2002.

1959	94.001
1960	93.955
1961	100.556
1962	242.150
1963	194.344
1964	187.445
1965	109.844
1966	210.038
1967	285.245
1968	469.978
1969	392.655
1970	307.131
1971	330.520
1972	271.744
1973	258.551
1974	209.886
1975	216.957
1976	121.925
1977	67.080
1978	88.165
1979	104.178
1980	93.234
1981	84.097
1982	59.852
1983	35.627
1984	42.442
1985	55.155
1986	56.202
1987	66.846
1988	73.950
1989	97.059
1990	93.805
1991	79.943
1992	93.191
1993	88.667
1994	76.821
1995	102.253
1996	126.852
1997	119.553
1998	125.829
1999	124.101
2000	125.818
2001	133.165
2002	104.430

Table 10.3 Research survey catch per tow (kg) for age 2 and age 3+ for US winter, spring, and fall and Canadian spring during 1963-2002.

Year	US Win 2	US Win 3+	US Sp 2	US Sp 3+	US Fall 2	US Fall 3+	Can 2	Can 3+
1963					0.0007	0.6396		
1964					0.0006	0.0865		
1965					0.0000	0.3492		
1966					0.0002	1.0030		
1967					0.0017	0.3234		
1968			0.0385	4.0238	0.0006	0.1304		
1969			0.0046	2.8576	0.0009	0.0648		
1970			0.2425	0.7814	0.0019	0.0583		
1971			0.0098	0.3326	0.0007	0.3329		
1972			0.0240	0.4417	0.0065	0.0734		
1973			0.0036	1.4868	0.0000	0.0071		
1974			0.0014	0.9982	0.0000	0.0179		
1975			0.0019	0.2122	0.0004	0.0621		
1976			0.0018	0.1968	0.0000	0.0229		
1977			0.0025	0.1729	0.0003	0.0046		
1978			0.0049	0.4572	0.0004	0.0940		
1979			0.1450	0.6270	0.0004	0.0023		
1980			0.0046	1.0499	0.0000	0.0006		
1981			0.0009	0.5044	0.0000	0.0011		
1982			0.0198	0.0425	0.0002	0.0198		
1983			0.0084	0.0686	0.0020	0.0230		
1984			0.0985	0.1550	0.0005	0.2244		
1985			0.0957	0.3465	0.0017	0.3821		
1986			0.8970	4.2002	0.0012	0.1428	0.0963	1.2768
1987			0.0572	0.8099	0.0890	0.9074	0.0355	0.0136
1988			0.1098	1.4101	0.0345	1.2456	0.0137	0.5563
1989			0.0763	1.1943	0.0643	1.8146	3.1252	0.4792
1990			0.1307	0.8733	0.1144	1.2696	1.5893	0.2202
1991			0.2428	2.2723	0.1432	1.9079	2.0854	8.1996
1992	0.3544	3.2568	0.5060	2.7256	0.1032	6.3418	0.4042	4.9939
1993	0.0140	6.5446	0.3186	7.6045	0.0156	2.3624	0.0193	30.0806
1994	0.0040	0.5886	0.2131	3.8900	0.0311	1.7832	0.0179	0.2981
1995	0.0041	2.6609	0.3396	2.9269	0.0327	9.7751	0.0975	4.8333
1996	4.0268	5.8776	2.2093	3.2156	0.5835	3.7706	1.7286	2.4164
1997	0.0810	8.6201	0.9788	4.7696	0.0839	4.3264	0.9881	31.0152
1998	0.0689	6.6631	0.1918	5.5111	0.0654	2.5404	0.0601	3.1638
1999	0.0130	7.6771	0.1271	10.7960	0.0120	1.6884	0.0322	41.2759
2000	2.9168	9.1597	0.9217	2.6557	0.0672	3.1045	28.4954	7.0423
2001	0.3642	8.7139	0.3058	3.7324	0.0184	3.7760	0.1243	47.8367
2002	0.4000	9.3000	0.0200	2.5000	0.1500	10.8981	0.0500	15.0000

Table 10.4. Time series of survey catch for the US acoustic survey (000's t), the US larval survey (# larvae/10 m^2), and the Canadian larval survey (# larva/ m^2) during 1971-1995

Year	US Acoustic	US Larval	Canadian Larval
1971		89.7	
1972		81.4	
1973		355.2	
1974		304.5	
1975		55.9	
1976		2.2	
1977		19.2	
1978		2.4	
1979		6.0	
1980		1.9	
1981		29.7	
1982		18.2	
1983		3.7	
1984		2.3	
1985		95.4	
1986		60.4	
1987		31.4	12.59
1988		184.9	6.05
1989		454.3	7.37
1990		394.1	10.21
1991		354.2	3.29
1992		577.1	12.17
1993		397.6	30.35
1994		610.0	52.26
1995			41.29
1996			
1997			
1998			
1999	1193.0		
2000	1427.0		
2001	1819.0		
2002	763.0		

Table 10.5. Likelihood profile analysis for base case forward projection model. Profile runs were carried out by fixing the scaling parameter (*Q*) for the herring hydroacoustic survey to values between 0.5 and 1.7. The basecase run had *Q*=0.91. In rows with negative log likelihood values, the lowest value (indicating best fit) is shaded and in a bold-italic font.

Profile results:	**Profile run with Q=0.5**	**Profile run with Q=0.6**	**Profile run with Q=0.7**	**Profile run with Q=0.8**	**Basecase Q=0.91**	**Profile run with Q=1.1**	**Profile run with Q=1.3**	**Profile run with Q=1.5**	**Profile run with Q=1.7**
Weighted likelihoods used by model									
Non Survey	7.80	-12.73	-13.71	-14.24	***-14.47***	-14.32	-13.74	-12.95	-12.05
Surveys	***399.49***	413.20	413.26	413.35	413.44	413.62	413.80	413.98	414.15
Total	407.29	400.47	399.56	399.11	***398.97***	399.30	400.05	401.03	402.10
Unweighted likelihoods for profile analysis									
Non Survey	17.12	-42.00	-48.05	-52.61	-56.47	-61.51	***-63.06***	-61.64	-59.00
Surveys	***399.49***	413.20	413.26	413.35	413.44	413.62	413.80	413.98	414.15
Total	416.61	371.20	365.21	360.74	356.97	352.11	***350.74***	352.33	355.16
Unweighted non survey likelihood components									
PriorQ_Hydroacoustic_3+	0.59	0.21	0.04	***0.00***	0.06	0.35	0.77	1.26	1.79
Recruitment Model	7.60	-15.39	-16.76	-17.65	-18.18	***-18.44***	-18.16	-17.61	-16.97
Constrain_first_few_recruitments	-0.60	-1.75	-1.82	-1.86	-1.88	***-1.89***	-1.88	-1.85	-1.82
Fox_surplus_production	9.48	-25.49	-30.01	-33.65	-37.05	-42.11	***-44.37***	-43.99	-42.52
Prior_Log_Rec_Residual_Var	***0.02***	0.42	0.48	0.52	0.55	0.56	0.55	0.52	0.49
Constrain_inital_IGR	0.03	***0.01***	***0.01***	0.02	0.02	0.02	0.02	0.03	0.03
Unweighted survey trend likelihood components									
Trend_Spring_Age_2	***57.75***	63.29	63.70	64.01	64.28	64.66	64.94	65.16	65.33
Trend_Spring_Age_3+	51.87	51.18	50.65	50.18	49.71	48.92	48.20	47.58	***47.06***
Trend_Winter_Age_2	***19.50***	20.62	20.71	20.77	20.83	20.91	20.97	21.01	21.05
Trend_Winter_Age_3+	***8.06***	8.19	8.28	8.36	8.43	8.55	8.65	8.74	8.82
Trend_Fall_Age_2	***71.72***	76.26	76.34	76.37	76.38	76.37	76.37	76.37	76.40
Trend_Fall_Age_3+	***74.08***	74.61	74.41	74.37	74.42	74.70	75.11	75.55	75.99
Trend_Hydroacoustic_3+	***15.28***	16.04	16.02	15.98	15.94	15.83	15.70	15.54	15.36
Trend_Larval_Herring_Index	***41.45***	42.11	42.10	42.10	42.12	42.18	42.24	42.29	42.34
Trend_Canadian_Larval_Survey	6.05	6.08	6.08	6.07	6.06	6.04	6.02	6.00	***5.98***
Trend_Canadian_Age_2	***26.53***	28.05	28.12	28.18	28.23	28.30	28.36	28.40	28.43
Trend_Canadian_Age_3+	27.20	***26.75***	26.87	26.96	27.05	27.16	27.26	27.33	27.39
Recent average F (2000-2002)	0.04	0.05	0.05	0.06	0.07	0.08	0.10	0.11	0.13
Recent average B (2000-2002)	3,258	2,743	2,362	2,076	1,844	1,532	1,309	1,145	1,020
Log(recruitment variance)	0.53	0.17	0.16	0.16	0.15	0.15	0.15	0.16	0.16
Fox Production modeling (biomass * 0.001)									
K_(carrying_capacity)=	3.10	4.27	3.46	2.87	2.43	1.99	1.78	1.69	1.64
Bmsy=	1.14	1.57	1.28	1.06	0.90	0.73	0.66	0.62	0.60
MSY=	0.24	0.27	0.24	0.23	0.22	0.22	0.21	0.21	0.20
Fmsy=	0.21	0.17	0.19	0.22	0.25	0.30	0.33	0.34	0.34
Recent_F/Fmsy=	0.18	0.27	0.28	0.28	0.28	0.28	0.30	0.33	0.37
Recent_B/Bmsy=	2.86	1.75	1.85	1.97	2.06	2.09	1.99	1.84	1.69

Table 12.1. Input data for yield per recruit model run for the GOM-GB Atlantic herring complex.

```
   The NEFC Yield and Stock Size per Recruit Program - PDBYPRC
    PC Ver.2.0 [Method of Thompson and Bell (1934)] 9-Aug-2001
             ----------------------------------------
             Run Date: 10- 2-2003;  Time: 18:45:35.45
 GOM-GB Herring
 ____________________________________________________________________
 Proportion of F before spawning:  .7500
 Proportion of M before spawning:  .7500
 Natural Mortality is Constant at:  .200
 Initial age is:  1; Last age is: 11
 Last age is a PLUS group;
 Original age-specific PRs, Mats, and Mean Wts from file:
 ==> herrnew.dat
------------------------------------------------------------
 Age-specific Input data for Yield per Recruit Analysis
------------------------------------------------------------
  Age | Fish Mort  Nat Mort | Proportion | Average Weights
      |  Pattern    Pattern |   Mature   |  Catch   Stock
------------------------------------------------------------
   1  |   .0000     1.0000  |    .0000   |   .015    .003
   2  |  1.0000     1.0000  |    .0000   |   .051    .028
   3  |  1.0000     1.0000  |   1.0000   |   .092    .070
   4  |  1.0000     1.0000  |   1.0000   |   .128    .109
   5  |  1.0000     1.0000  |   1.0000   |   .153    .139
   6  |  1.0000     1.0000  |   1.0000   |   .172    .169
   7  |  1.0000     1.0000  |   1.0000   |   .192    .189
   8  |  1.0000     1.0000  |   1.0000   |   .213    .191
   9  |  1.0000     1.0000  |   1.0000   |   .233    .214
  10  |  1.0000     1.0000  |   1.0000   |   .265    .236
  11+ |  1.0000     1.0000  |   1.0000   |   .303    .243

------------------------------------------------------------
 Summary of Yield per Recruit Analysis for:
 GOM-GB Herring
 ____________________________________________________________________
  Slope of the Yield/Recruit Curve at F=0.00: -->      .6644
    F level at slope=1/10 of the above slope (F0.1): ----->    .184
      Yield/Recruit corresponding to F0.1: ----->      .0458
    F level to produce Maximum Yield/Recruit (Fmax): ----->    .400
      Yield/Recruit corresponding to Fmax: ----->      .0505
    F level at 40 % of Max Spawning Potential (F40): ----->    .145
      SSB/Recruit corresponding to F40: -------->      .2062
 ____________________________________________________________________
1
```

Table 12.2. Listing of Yield per Recruit Results for:
GOM-GB Herring

	FMORT	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% MSP
	.000	.00000	.00000	5.5167	.6251	3.1828	.5157	100.00
	.050	.16375	.02387	4.7013	.4601	2.3898	.3599	69.79
	.100	.27291	.03626	4.1589	.3563	1.8687	.2638	51.16
F40%	.145	.34342	.04244	3.8094	.2930	1.5374	.2062	39.99
	.150	.35088	.04300	3.7724	.2864	1.5026	.2004	38.85
F0.1	.184	.39255	.04579	3.5664	.2508	1.3102	.1686	32.70
	.200	.40937	.04675	3.4834	.2369	1.2332	.1563	30.30
	.250	.45485	.04881	3.2594	.2004	1.0280	.1245	24.14
	.300	.49124	.04989	3.0808	.1726	.8674	.1008	19.55
	.350	.52101	.05037	2.9353	.1510	.7392	.0828	16.06
	.400	.54582	.05049	2.8146	.1338	.6350	.0688	13.34
Fmax	.400	.54595	.05049	2.8140	.1338	.6345	.0687	13.33
	.450	.56681	.05038	2.7130	.1199	.5492	.0577	11.20
	.500	.58481	.05012	2.6264	.1085	.4778	.0489	9.48
	.550	.60040	.04978	2.5517	.0990	.4176	.0417	8.08
	.600	.61405	.04939	2.4868	.0910	.3666	.0357	6.93
	.650	.62609	.04896	2.4299	.0842	.3231	.0308	5.98
	.700	.63679	.04853	2.3797	.0784	.2856	.0267	5.18
	.750	.64637	.04809	2.3350	.0734	.2532	.0233	4.51
	.800	.65498	.04766	2.2952	.0690	.2251	.0203	3.94
	.850	.66278	.04724	2.2595	.0651	.2005	.0178	3.46
	.900	.66987	.04684	2.2272	.0618	.1790	.0157	3.05
	.950	.67634	.04645	2.1981	.0588	.1601	.0139	2.69
	1.000	.68228	.04607	2.1716	.0561	.1435	.0123	2.38

Table14. 1. Ratio of population numbers in preliminary VPA compared with population numbers from the 1998 herring assessment. Blank cells due to zero values in the 1998 assessment and large values (>1) are assumed due to precision errors caused by rounding to millions of fish

ratio to G11	1	2	3	4	5	6	7	8	9	10	11
1967	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.7	0.6	0.2	0.2
1968	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.7	0.5	0.4
1969	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.7	0.5	0.6
1970	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.7	0.4	0.4
1971	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.6	0.6
1972	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.8	0.9
1973	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	0.5
1974	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.3
1975	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3	0.8
1976	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	1.6	
1977	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.0	0.8	0.7
1978	1.0	1.0	1.0	1.1	1.0	1.1	1.1	1.2	1.1	1.0	
1979	1.1	1.0	1.0	1.0	1.1	1.0	1.2	1.4	1.6	0.9	
1980	1.0	1.1	1.0	1.0	1.1	1.4	1.0	2.4	2.7	2.3	
1981	0.9	1.0	1.3	1.1	1.0	1.4	1.9	1.2			4.6
1982	0.9	0.9	1.0	2.0	1.2	1.0	1.8	3.3	1.9		
1983	0.9	0.9	0.9	1.1	2.5	1.5	1.0	3.9	2.3		
1984	1.0	0.9	0.9	0.8	1.1	2.9	1.8	1.1	2.9		
1985	0.9	1.0	0.9	0.8	0.8	1.2	4.1	2.3	1.2		
1986	0.8	0.9	1.0	0.9	0.8	0.7	1.3	9.1	3.1		1.5
1987	0.9	0.8	0.9	1.0	0.9	0.7	0.6	1.6	7.1	3.6	
1988	1.0	0.9	0.7	0.9	0.9	0.9	0.7	0.5	2.3	5.6	5.6
1989	1.0	1.0	0.9	0.7	0.9	0.9	0.8	0.6	0.5		4.5
1990	1.0	1.0	1.0	0.9	0.6	0.8	0.9	0.7	0.5	0.4	0.4
1991	0.9	1.0	1.0	1.0	0.8	0.5	0.7	0.8	0.6	0.2	0.2
1992	1.0	0.9	1.0	1.0	1.0	0.8	0.4	0.6	0.6	0.3	
1993	1.0	1.0	0.9	1.0	1.0	1.0	0.7	0.3	0.4	0.3	0.2
1994	1.0	1.0	1.0	0.9	1.0	1.0	1.0	0.7	0.2	0.2	0.2
1995	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.0	0.6	0.1	0.1
1996	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.4	0.4	0.5
1997	1.0	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	3.7	4.6
1998		1.0	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.0

Table 14.2. US catch-at-age for coastal stock complex as percent by age (numbers) by year

USA CAA	1	2	3	4	5	6	7	8	9	10	11+	Total
1967	7%	23%	12%	11%	7%	15%	21%	3%	1%	1%	0%	100%
1968	0%	41%	8%	5%	12%	8%	14%	11%	1%	0%	0%	100%
1969	3%	23%	16%	9%	12%	12%	9%	9%	5%	1%	0%	100%
1970	0%	26%	10%	26%	15%	8%	7%	4%	3%	2%	0%	100%
1971	8%	12%	21%	17%	17%	11%	7%	4%	1%	2%	0%	100%
1972	0%	51%	3%	8%	13%	11%	6%	3%	2%	1%	0%	100%
1973	2%	16%	60%	14%	4%	2%	2%	1%	0%	0%	0%	100%
1974	2%	29%	10%	51%	5%	1%	1%	0%	0%	0%	0%	100%
1975	3%	40%	7%	7%	38%	3%	1%	1%	0%	0%	0%	100%
1976	6%	45%	21%	4%	4%	18%	1%	0%	0%	0%	0%	100%
1977	42%	41%	6%	5%	1%	1%	3%	0%	0%	0%	0%	100%
1978	15%	70%	8%	1%	2%	0%	0%	2%	0%	0%	0%	100%
1979	0%	69%	25%	3%	1%	1%	0%	0%	0%	0%	0%	100%
1980	29%	20%	31%	16%	2%	1%	1%	0%	0%	0%	0%	100%
1981	4%	84%	2%	5%	3%	0%	0%	0%	0%	0%	0%	100%
1982	6%	75%	12%	1%	3%	2%	0%	0%	0%	0%	0%	100%
1983	8%	66%	15%	7%	0%	2%	2%	0%	0%	0%	0%	100%
1984	5%	45%	32%	10%	7%	1%	1%	0%	0%	0%	0%	100%
1985	4%	73%	11%	7%	4%	2%	0%	0%	0%	0%	0%	100%
1986	7%	40%	36%	8%	6%	3%	1%	0%	0%	0%	0%	100%
1987	8%	34%	20%	27%	7%	3%	1%	0%	0%	0%	0%	100%
1988	9%	54%	12%	7%	14%	4%	1%	0%	0%	0%	0%	100%
1989	3%	43%	16%	10%	8%	17%	3%	1%	0%	0%	0%	100%
1990	1%	52%	20%	8%	3%	4%	7%	3%	1%	0%	0%	100%
1991	1%	51%	20%	11%	7%	4%	3%	2%	1%	0%	0%	100%
1992	0%	51%	21%	9%	8%	5%	3%	2%	1%	0%	0%	100%
1993	0%	41%	26%	11%	10%	5%	4%	2%	1%	0%	0%	100%
1994	0%	47%	20%	8%	10%	8%	4%	2%	1%	0%	0%	100%
1995	6%	46%	13%	5%	4%	8%	9%	6%	2%	0%	0%	100%
1996	0%	50%	13%	6%	6%	14%	8%	2%	1%	0%	0%	100%
1997	1%	25%	51%	7%	4%	5%	6%	1%	0%	0%	0%	100%
1998	0%	50%	12%	26%	5%	2%	3%	1%	0%	0%	0%	100%
1999	0%	16%	37%	12%	21%	8%	3%	2%	0%	0%	0%	100%
2000	0%	43%	5%	12%	16%	17%	4%	1%	0%	0%	0%	100%
2001	0%	17%	43%	5%	9%	11%	12%	2%	0%	0%	0%	100%

Table 14.3. Average squared residuals by age for VPA Version 1.

Age	Winter Avg. squared Residual	Spring Avg. squared Residual
2	3.46	2.97
3	0.87	1.88
4	0.70	1.47
5	0.40	1.25
6	1.24	0.89
7	1.89	2.58
8	2.84	3.75

Table 14.4A Option 1 scenario with F = 0.1.

It was assumed that the catch in 2003 would be 100,000t, approximately equal to that in 2002. The fishery partial recruitment was assumed to be fully recruited for ages 2 and older and 0.01 at age 1. The fishery and population weights at age were taken as the average from 1992 to 2002. Natural mortality was assumed to be 0.2 as in the assessment.

```
Projection results using analytical bias adjusted point estimates

Projected Population Numbers
                1        2        3        4        5        6        7        8        9       10
 2003.00     2000     1598      856      364     1946      195      229      402      189       19
 2004.00     2000     1636     1105      592      252     1346      135      159      278      131
 2005.00     2000     1636     1212      819      438      187      997      100      118      206

Fishing Mortality
                1        2        3        4        5        6        7        8        9       10
 2003.00    0.001    0.169    0.169    0.169    0.169    0.169    0.169    0.169    0.169    0.169
 2004.00    0.001    0.100    0.100    0.100    0.100    0.100    0.100    0.100    0.100    0.100


M
                1        2        3        4        5        6        7        8        9       10
 2003.00     0.20     0.20     0.20     0.20     0.20     0.20     0.20     0.20     0.20     0.20
 2004.00     0.20     0.20     0.20     0.20     0.20     0.20     0.20     0.20     0.20     0.20


PR
                1        2        3        4        5        6        7        8        9       10
 2003.00     0.01     1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00
 2004.00     0.01     1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00     1.00


Pop weights
                1        2        3        4        5        6        7        8        9       10
 2003.00     0.01     0.03     0.07     0.11     0.14     0.16     0.18     0.20     0.23     0.26
 2004.00     0.01     0.03     0.07     0.11     0.14     0.16     0.18     0.20     0.23     0.26
 2005.00     0.01     0.03     0.07     0.11     0.14     0.16     0.18     0.20     0.23     0.26


Projected Population Biomass
           1        2        3        4        5        6        7        8        9       10       1+       2+       3+       4+
 2003.00    17       40       58       39      265       31       41       80       44        5      621      603      563      505
 2004.00    17       41       75       63       34      213       24       32       64       34      598      581      540      465
 2005.00    17       41       82       87       60       30      179       20       27       54      597      579      538      456


Projected Catch Numbers
                1        2        3        4        5        6        7        8        9       10
 2003.00        2      226      121       51      275       28       32       57       27        3
 2004.00        1      141       95       51       22      116       12       14       24       11
 2005.00


Fishery weights
                1        2        3        4        5        6        7        8        9       10
 2003.00     0.01     0.05     0.09     0.13     0.15     0.17     0.19     0.21     0.25     0.28
 2004.00     0.01     0.05     0.09     0.13     0.15     0.17     0.19     0.21     0.25     0.28


Projected Catch Biomass
           1        2        3        4        5        6        7        8        9       10       1+       2+       3+       4+
 2003.00     0       11       11        6       41        5        6       12        7        1      100      100       88       77
 2004.00     0        7        9        6        3       20        2        3        6        3       59       59       52       43
 2005.00
```

Table 14.4B Option 2 scenario with F = 0.2, approximating the F estimated by the VPA in recent years and corresponding roughly to an F_{MSY} proxy..

It was assumed that the catch in 2003 would be 100,000t, approximately equal to that in 2002. The fishery partial recruitment was assumed to be fully recruited for ages 2 and older and 0.01 at age 1. The fishery and population weights at age were taken as the average from 1992 to 2002. Natural mortality was assumed to be 0.2 as in the assessment.

```
Projection results using analytical bias adjusted point estimates

Projected Population Numbers
              1       2       3       4       5       6       7       8       9      10
 2003.00   2000    1598     856     364    1946     195     229     402     189      19
 2004.00   2000    1636    1105     592     252    1346     135     159     278     131
 2005.00   2000    1635    1096     741     397     169     902      90     106     186

Fishing Mortality
              1       2       3       4       5       6       7       8       9      10
 2003.00  0.001   0.169   0.169   0.169   0.169   0.169   0.169   0.169   0.169   0.169
 2004.00  0.001   0.200   0.200   0.200   0.200   0.200   0.200   0.200   0.200   0.200

M
              1       2       3       4       5       6       7       8       9      10
 2003.00   0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20
 2004.00   0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20


PR
              1       2       3       4       5       6       7       8       9      10
 2003.00   0.01    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00
 2004.00   0.01    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00


Pop weights
              1       2       3       4       5       6       7       8       9      10
 2003.00   0.01    0.03    0.07    0.11    0.14    0.16    0.18    0.20    0.23    0.26
 2004.00   0.01    0.03    0.07    0.11    0.14    0.16    0.18    0.20    0.23    0.26
 2005.00   0.01    0.03    0.07    0.11    0.14    0.16    0.18    0.20    0.23    0.26


Projected Population Biomass
             1       2       3       4       5       6       7       8       9      10      1+      2+      3+      4+
 2003.00    17      40      58      39     265      31      41      80      44       5     621     603     563     505
 2004.00    17      41      75      63      34     213      24      32      64      34     598     581     540     465
 2005.00    17      41      75      79      54      27     162      18      24      49     545     528     487     412


Projected Catch Numbers
              1       2       3       4       5       6       7       8       9      10
 2003.00      2     226     121      51     275      28      32      57      27       3
 2004.00      3     270     182      98      42     222      22      26      46      22
 2005.00


Fishery weights
              1       2       3       4       5       6       7       8       9      10
 2003.00   0.01    0.05    0.09    0.13    0.15    0.17    0.19    0.21    0.25    0.28
 2004.00   0.01    0.05    0.09    0.13    0.15    0.17    0.19    0.21    0.25    0.28

Projected Catch Biomass
          1       2       3       4     5       6       7     8       9      10    1+      2+      3+      4+
 2003.00  0      11      11       6    41       5       6    12       7       1   100     100      88      77
 2004.00  0      14      17      12     6      37       4     5      12       6   113     113     100      83
 2005.00
```

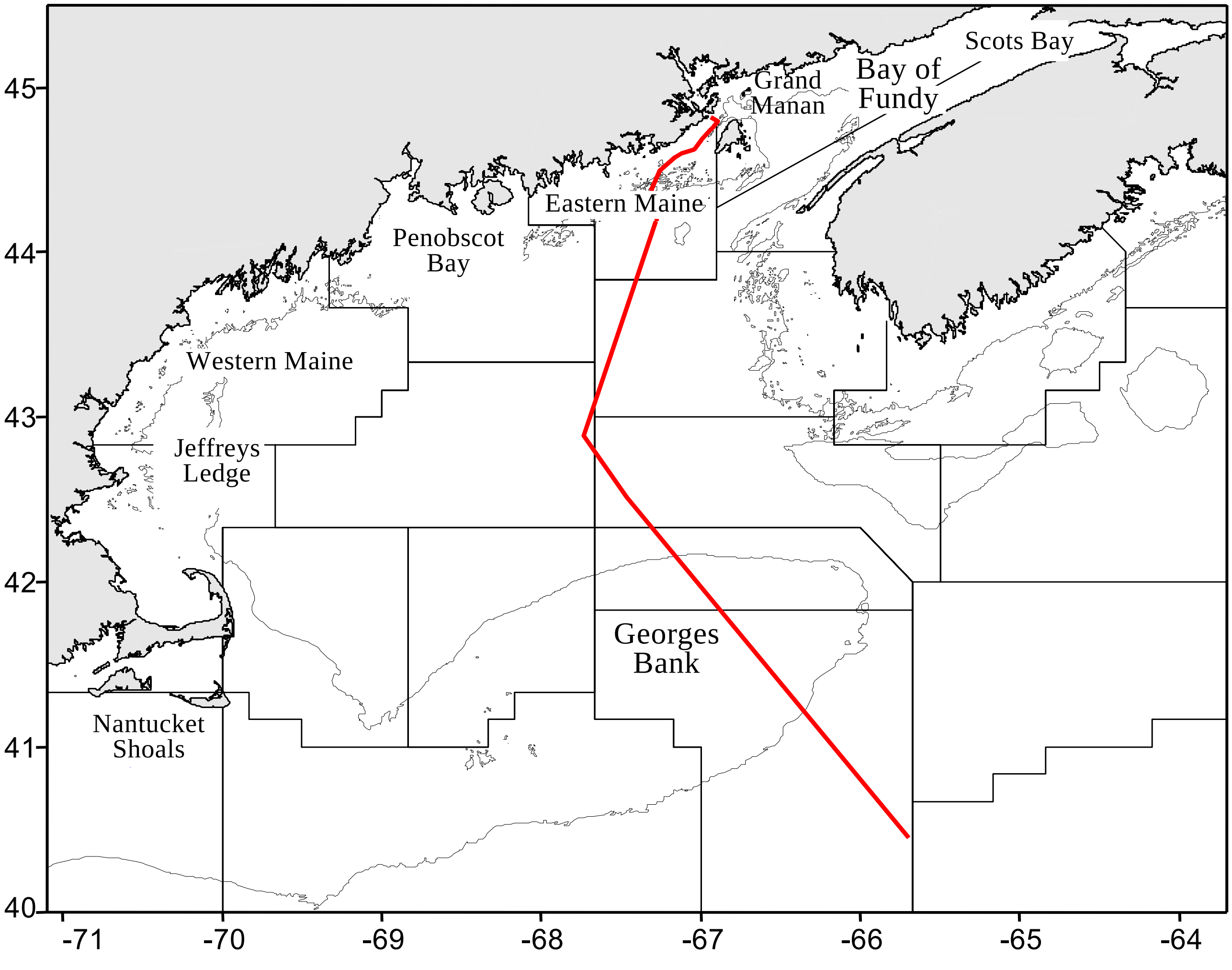


Figure 1.1. Map of the Gulf of Maine, Georges Bank, and the Bay of Fundy illustrating NAFO area boundaries and the location of areas discussed in the document.

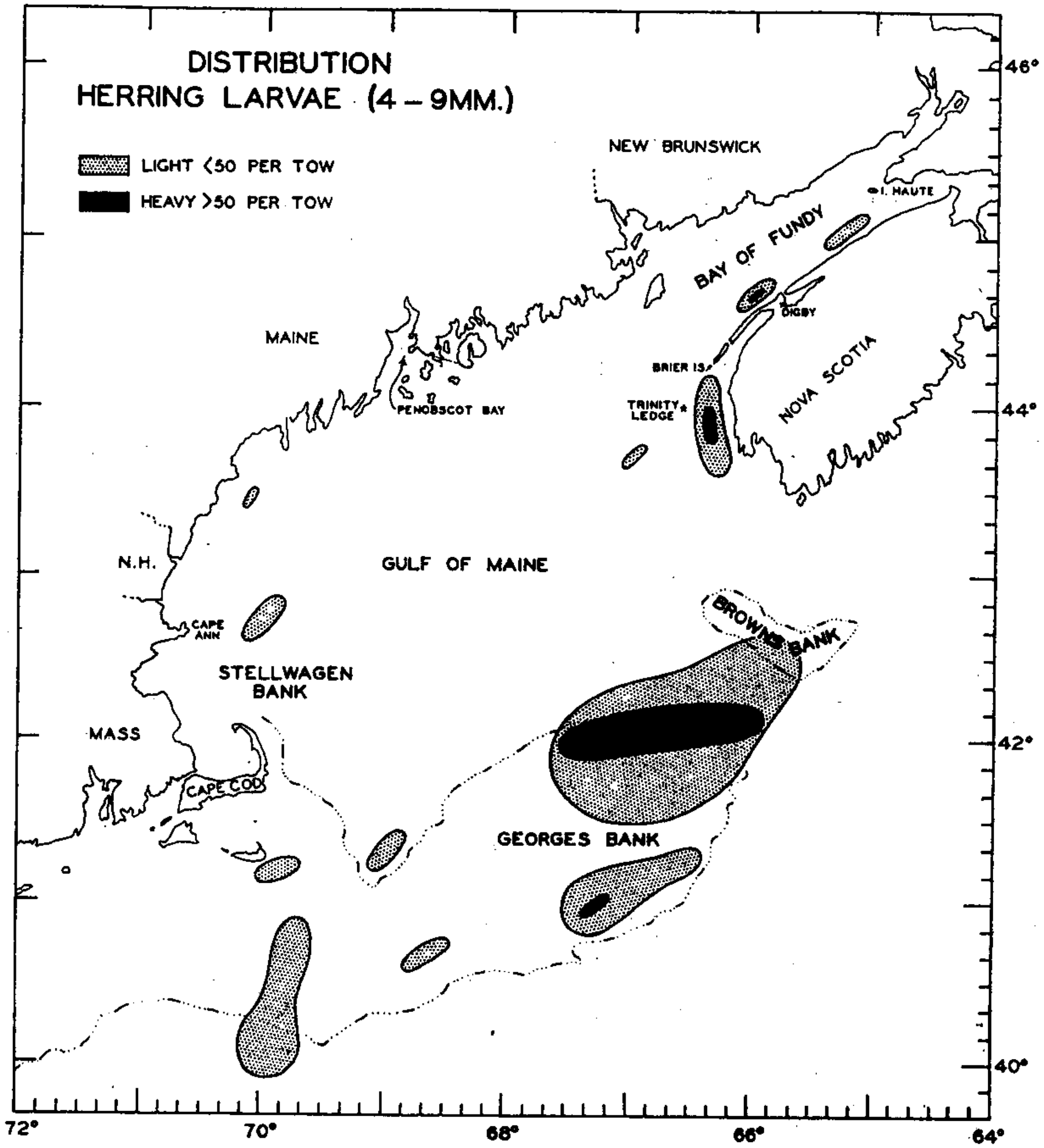


Figure 1.2. Herring spawning areas in the Bay of Fundy and the Gulf of Maine estimated from the distribution of newly hatched (4-9mm) larvae.

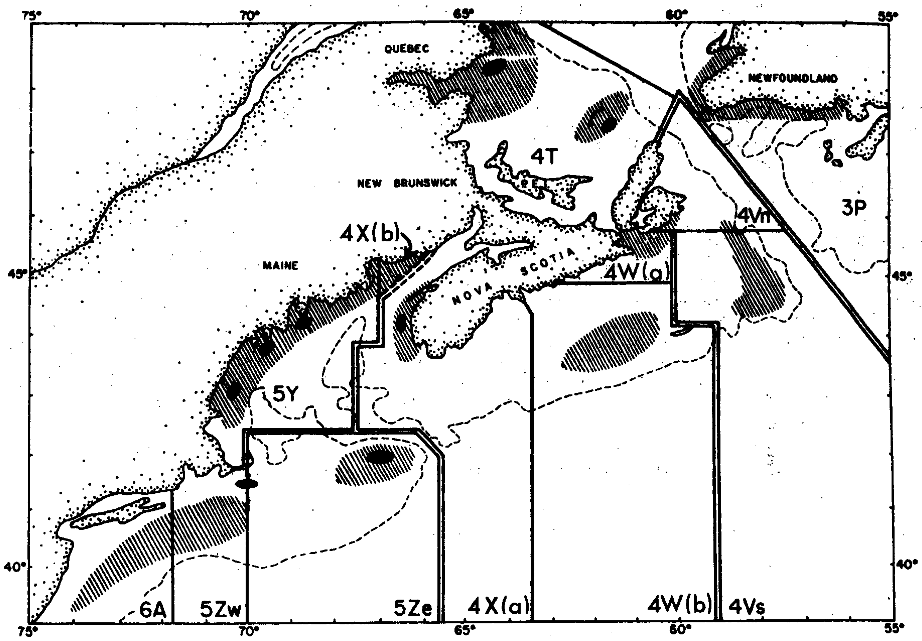


Fig. 1. Herring stock structure in Subareas 4 and 5 and Statistical Area 6. (Double lines indicate stock management areas; solid black areas indicate the general spawning grounds.)

Figure 1.3. The 1971 ICNAF view of herring stock structure in the Gulf of Maine and Georges Bank.

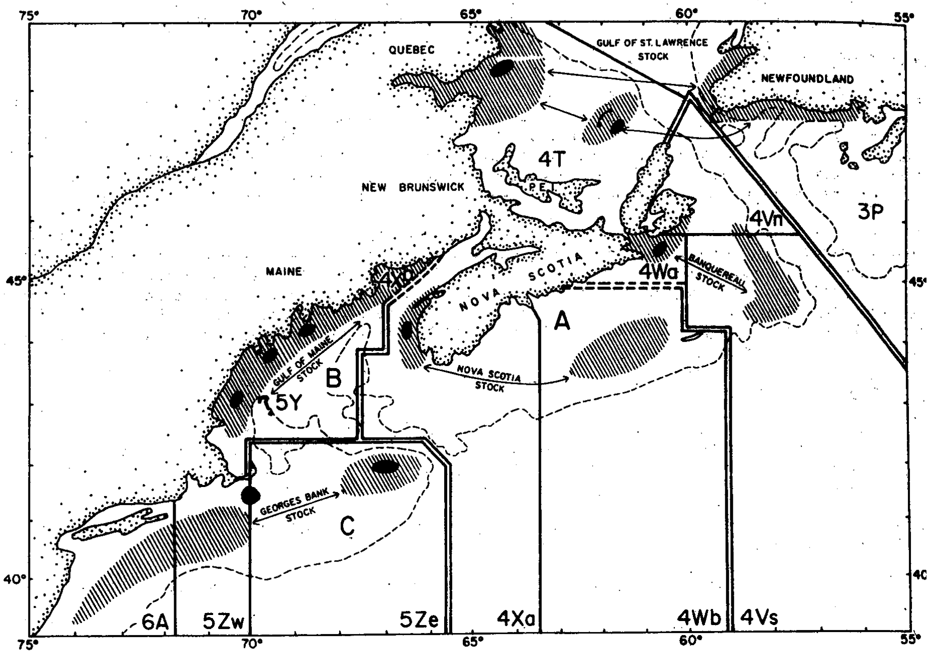


Fig. 1. Herring stock structure in the ICNAF Area (double lines indicate stock boundaries and the solid black areas indicate the general spawning grounds).

Figure 1.4. The 1976 ICNAF view of herring stock structure in the Gulf of Maine and Georges Bank.

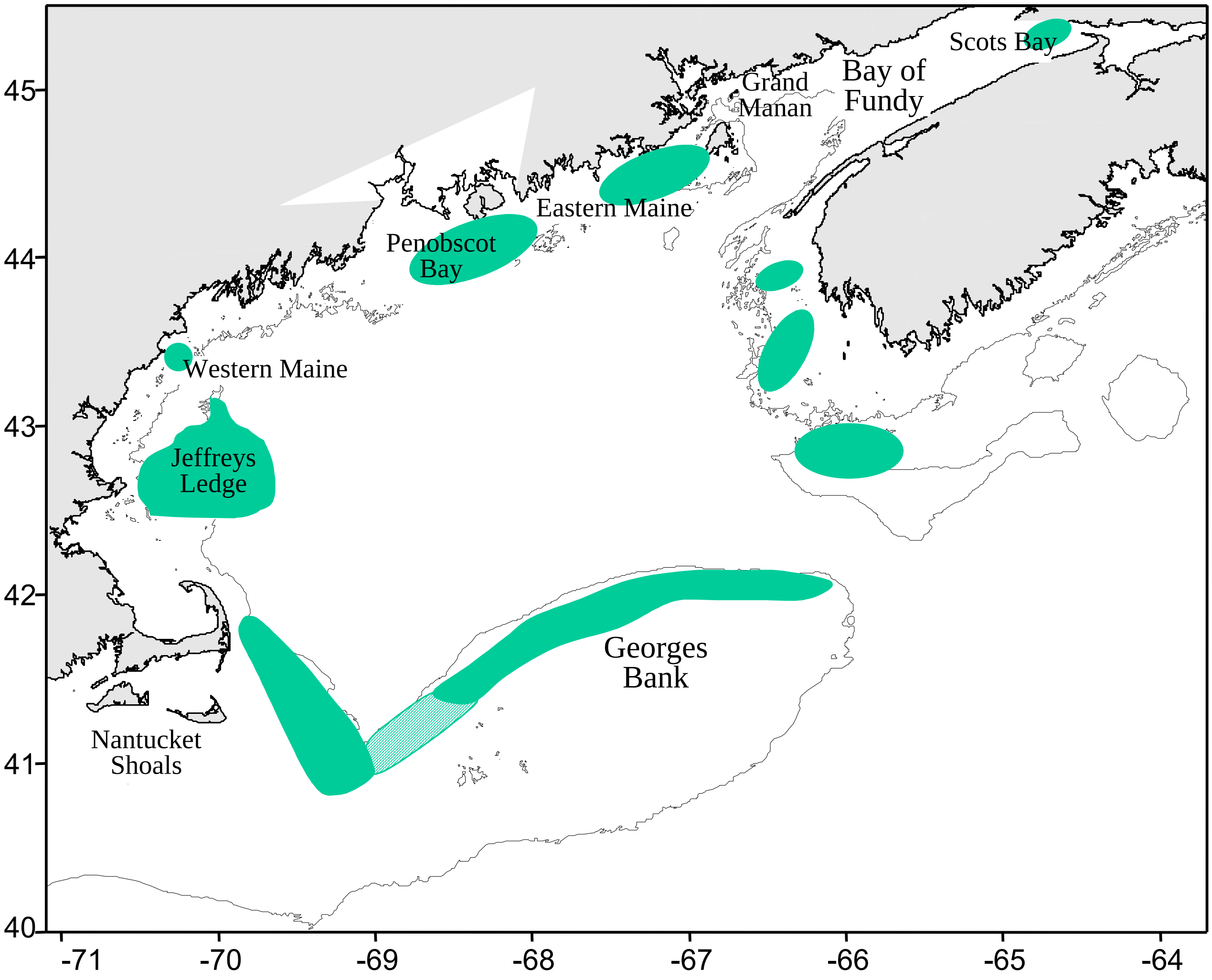
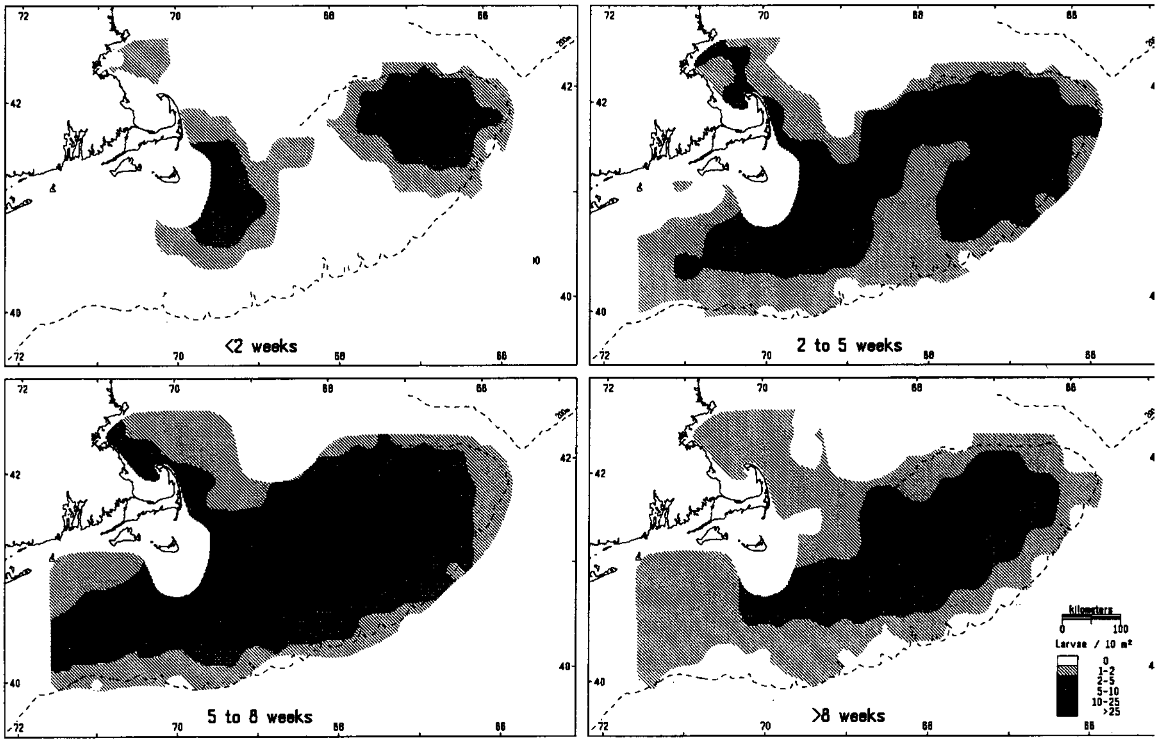
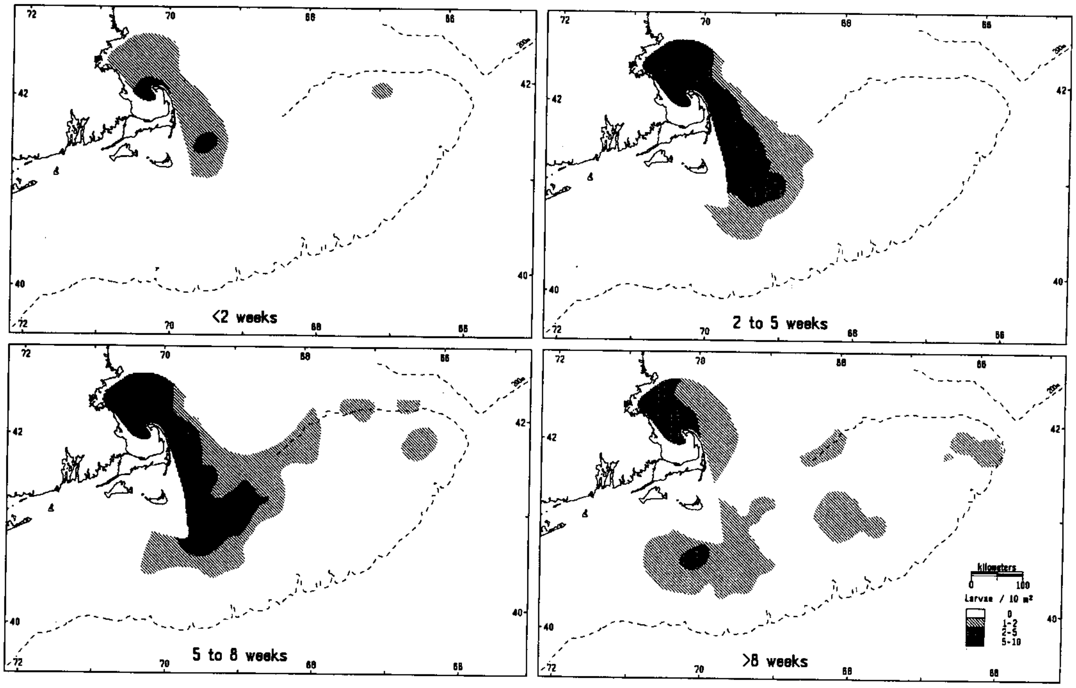


Figure 1.5. Generalized view of the current major herring spawning areas in the Gulf of Maine and on George Bank.



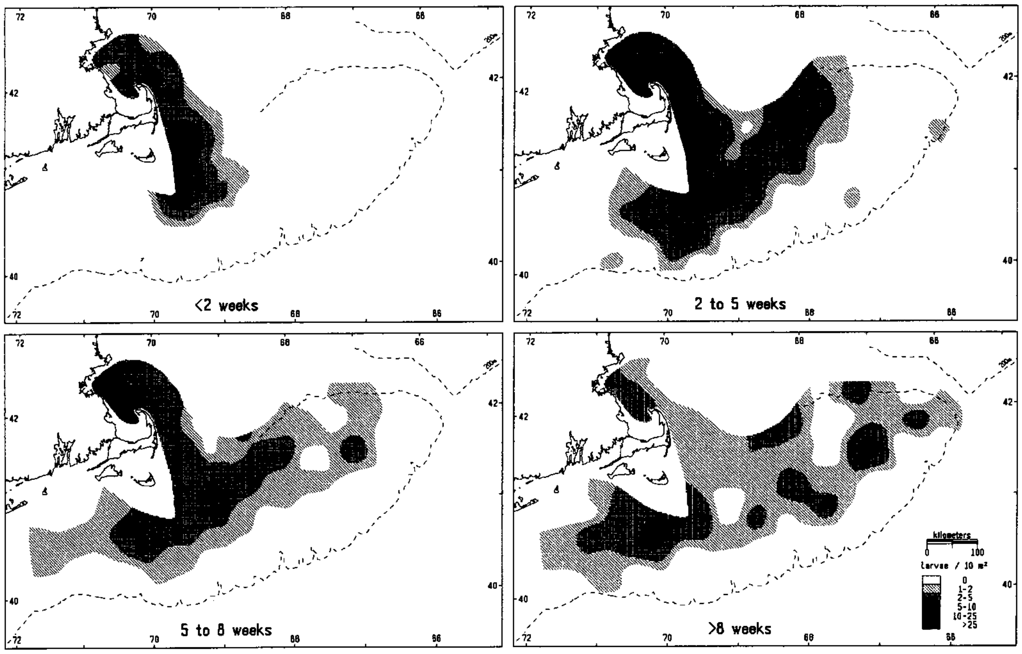
Composite representation of the distribution of Atlantic herring *Clupea harengus* larvae by age in the Georges Bank area, 1971–75.

Figure 1.6a.



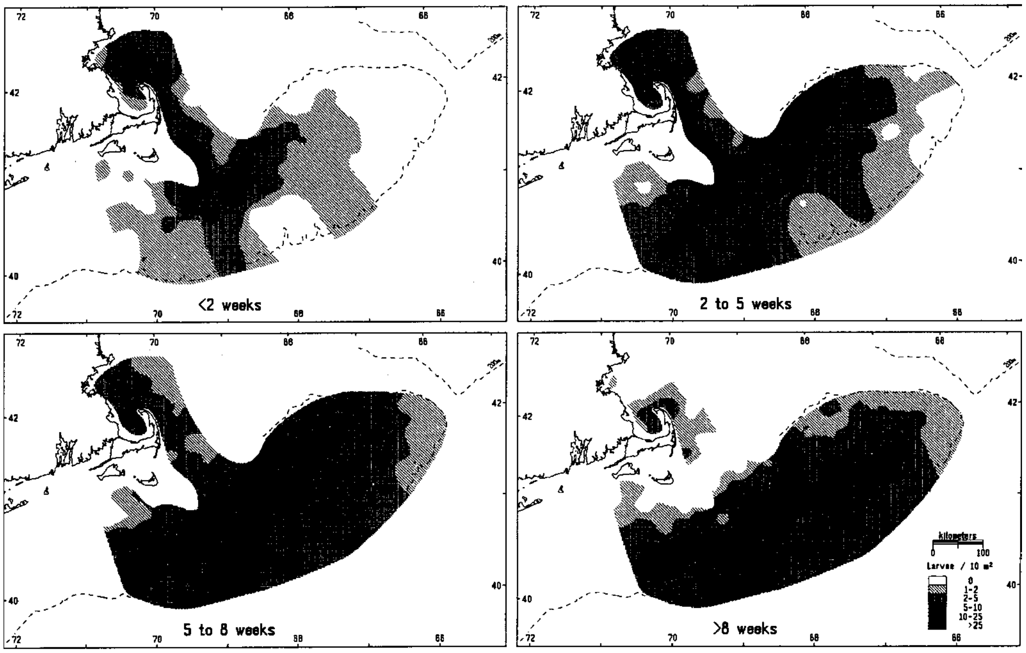
Composite representation of the distribution of Atlantic herring *Clupea harengus* larvae by age in the Georges Bank area, 1976–84.

Figure 1.6b.



Composite representation of the distribution of Atlantic herring *Clupea harengus* larvae by age in the Georges Bank area, 1985–87.

Figure 1.6c.



Composite representation of the distribution of Atlantic herring *Clupea harengus* larvae by age in the Georges Bank area, 1988–90.

Figure 1.6d.

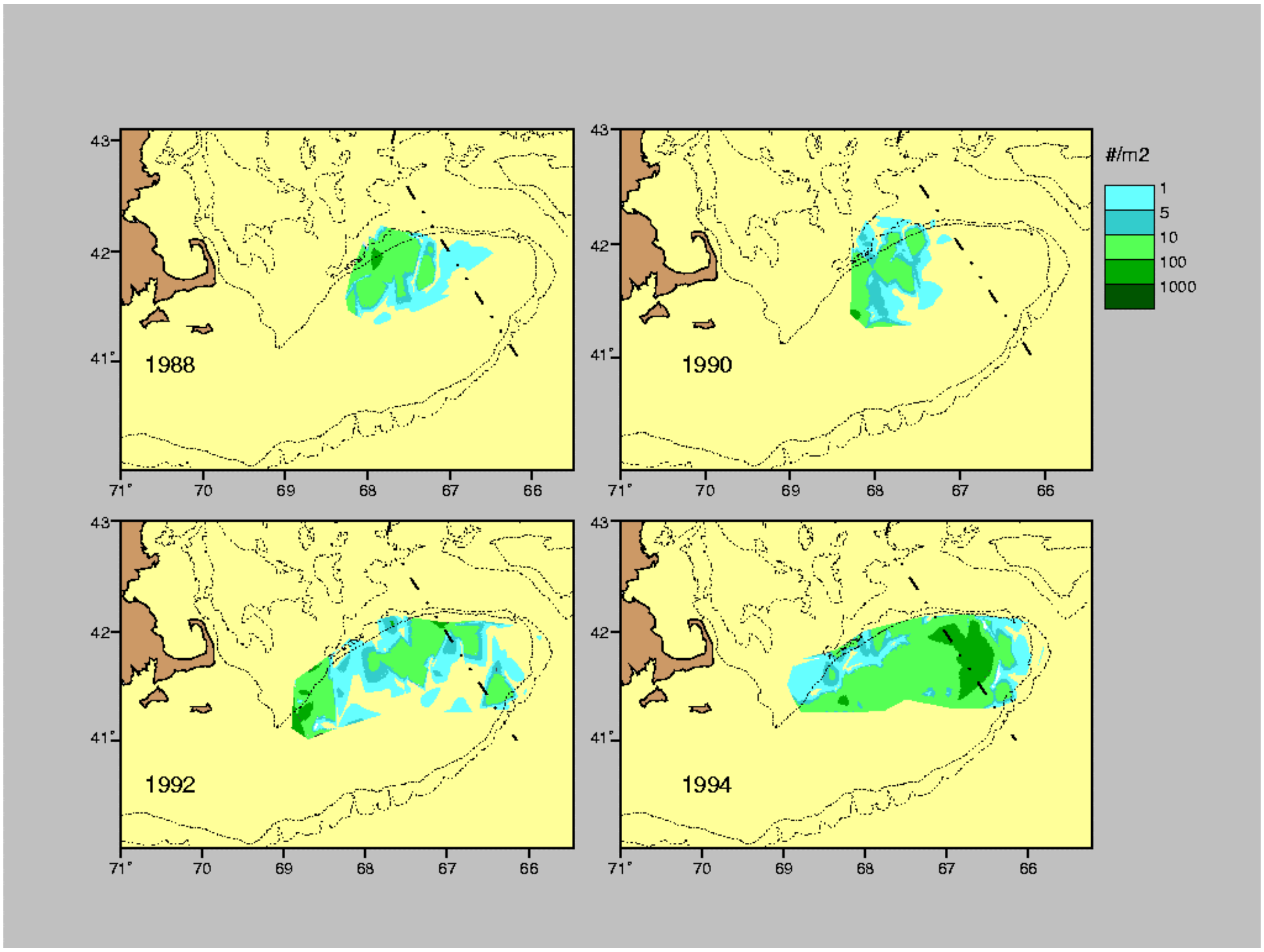


Figure 1.7. Distribution of <10mm larval herring for selected years from the Canadian Georges Bank larval survey.

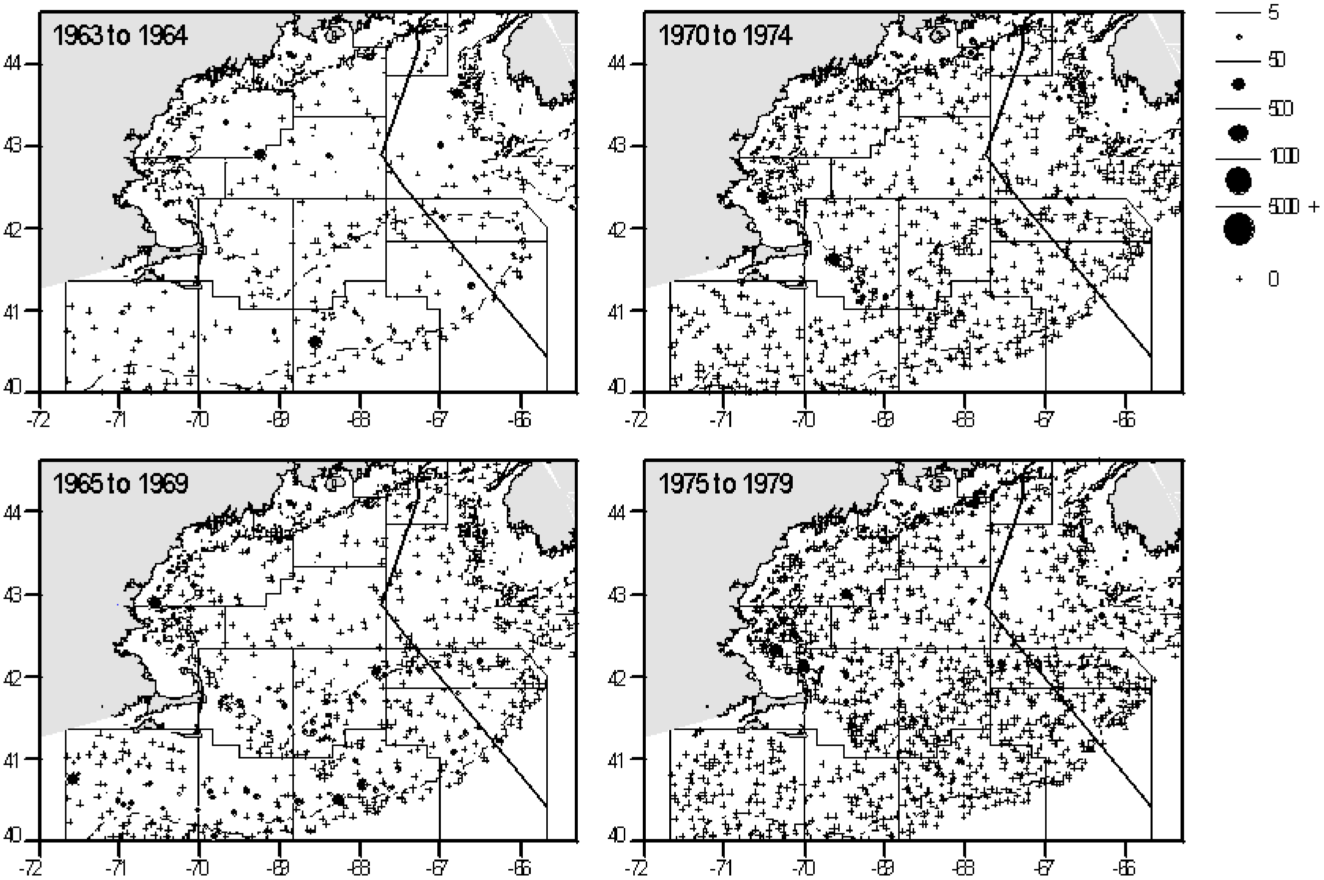


Figure 1.8a. Distribution and abundance of Atlantic herring observed in the U.S. fall bottom trawl survey from 1963 to 1979.

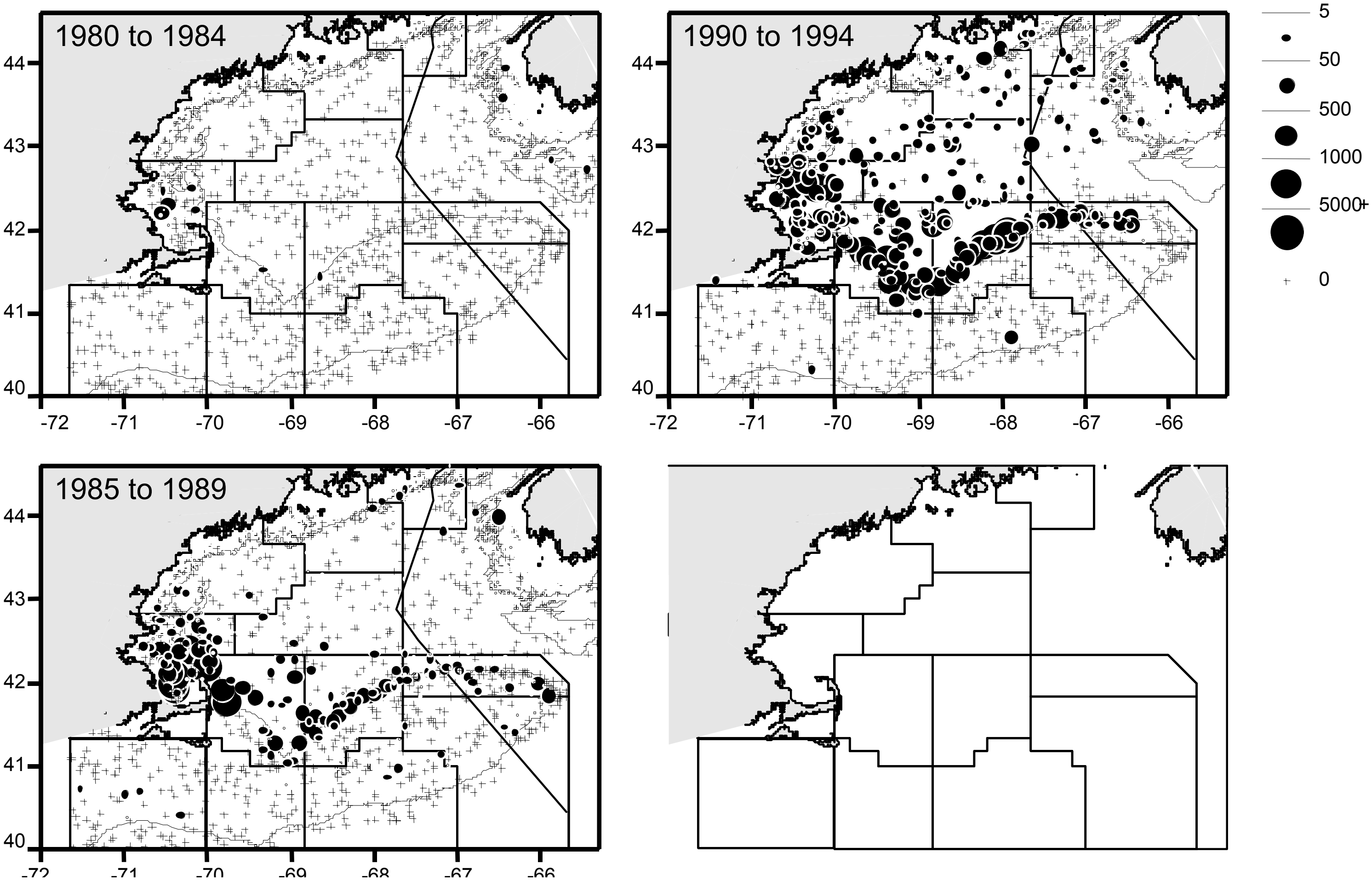


Figure 1.8b. Distribution and abundance of Atlantic herring observed in fall bottom trawl surveys from 1980 to 1999 (1995-1999 not currently available). Includes all US fall survey data and data from the Canadian fall surveys from 1986 to 1995 and 1999.

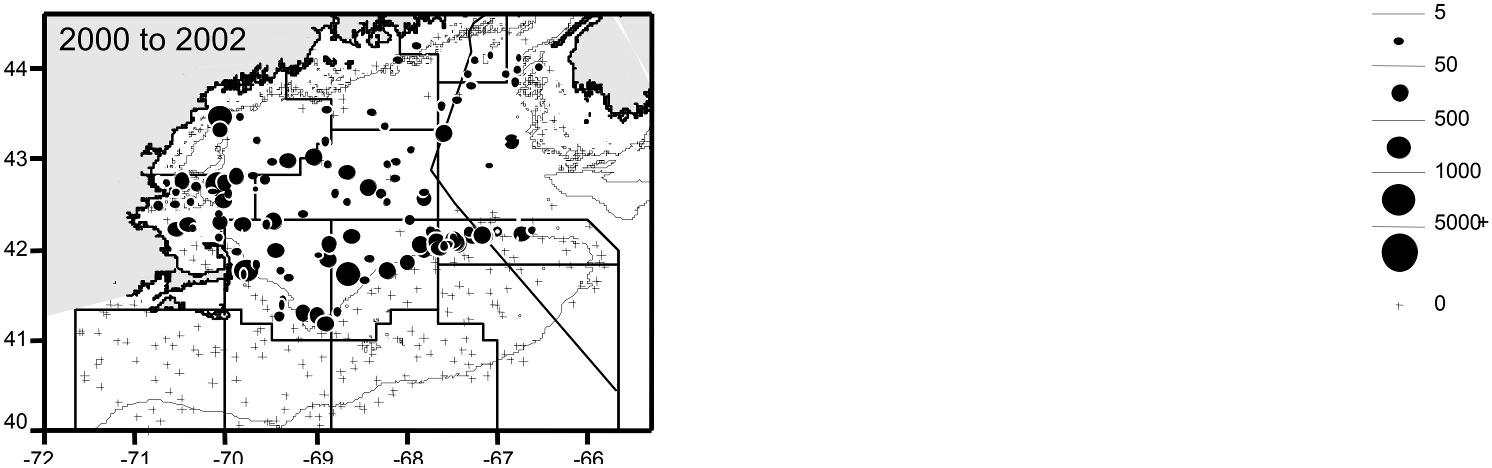
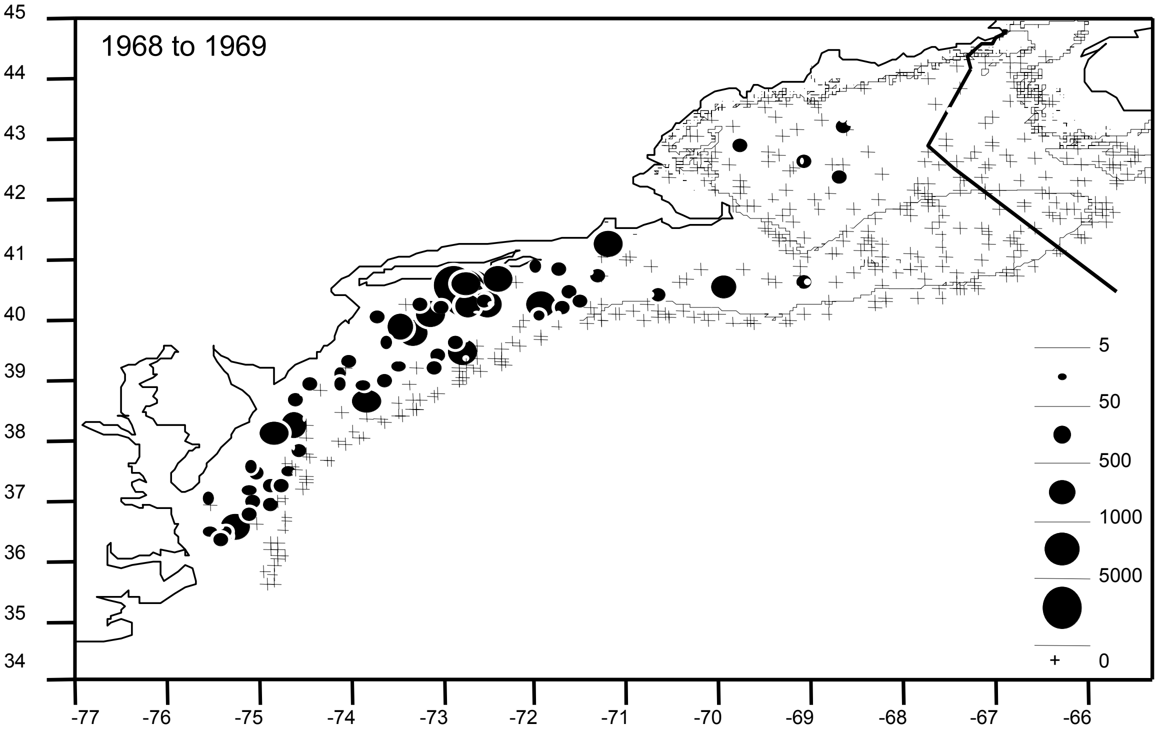


Figure 1.8c. Distribution and abundance of Atlantic herring observed in the U.S. fall bottom trawl survey from 2000 to 2002.



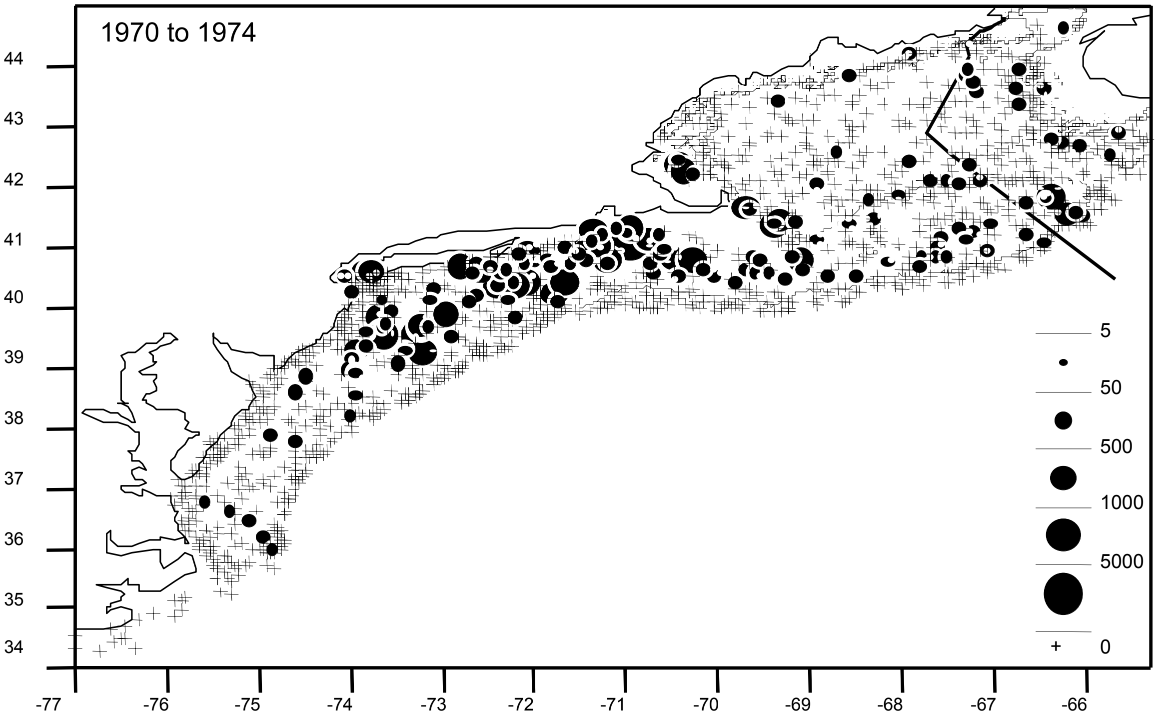


Figure 1.9a. Distribution of herring catches in the 1968-1969 and the 1970-1974 spring bottom trawl survey.

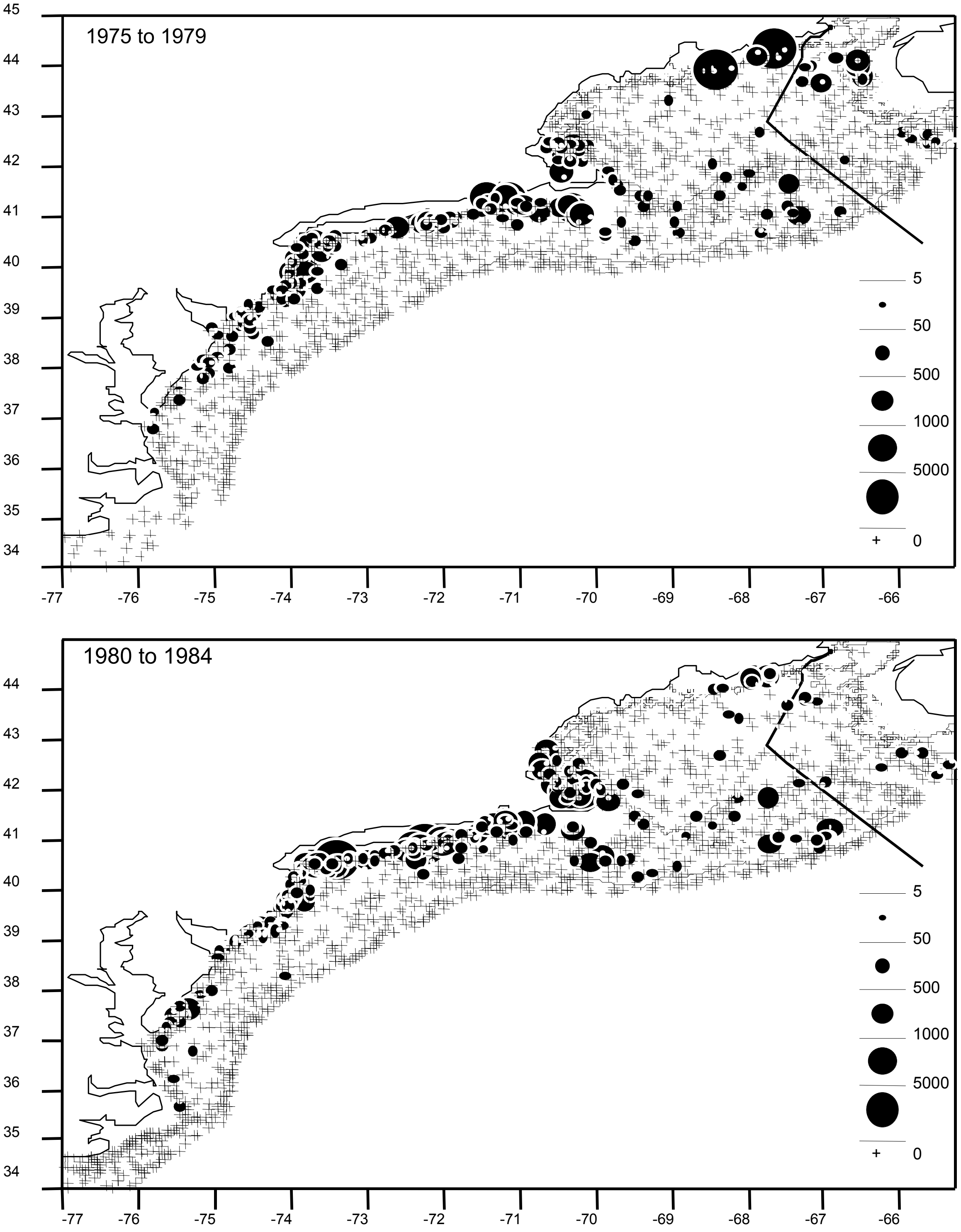


Figure 1.9b. Distribution of herring catches in the 1975-1979 and the 1980-1984 spring bottom trawl survey

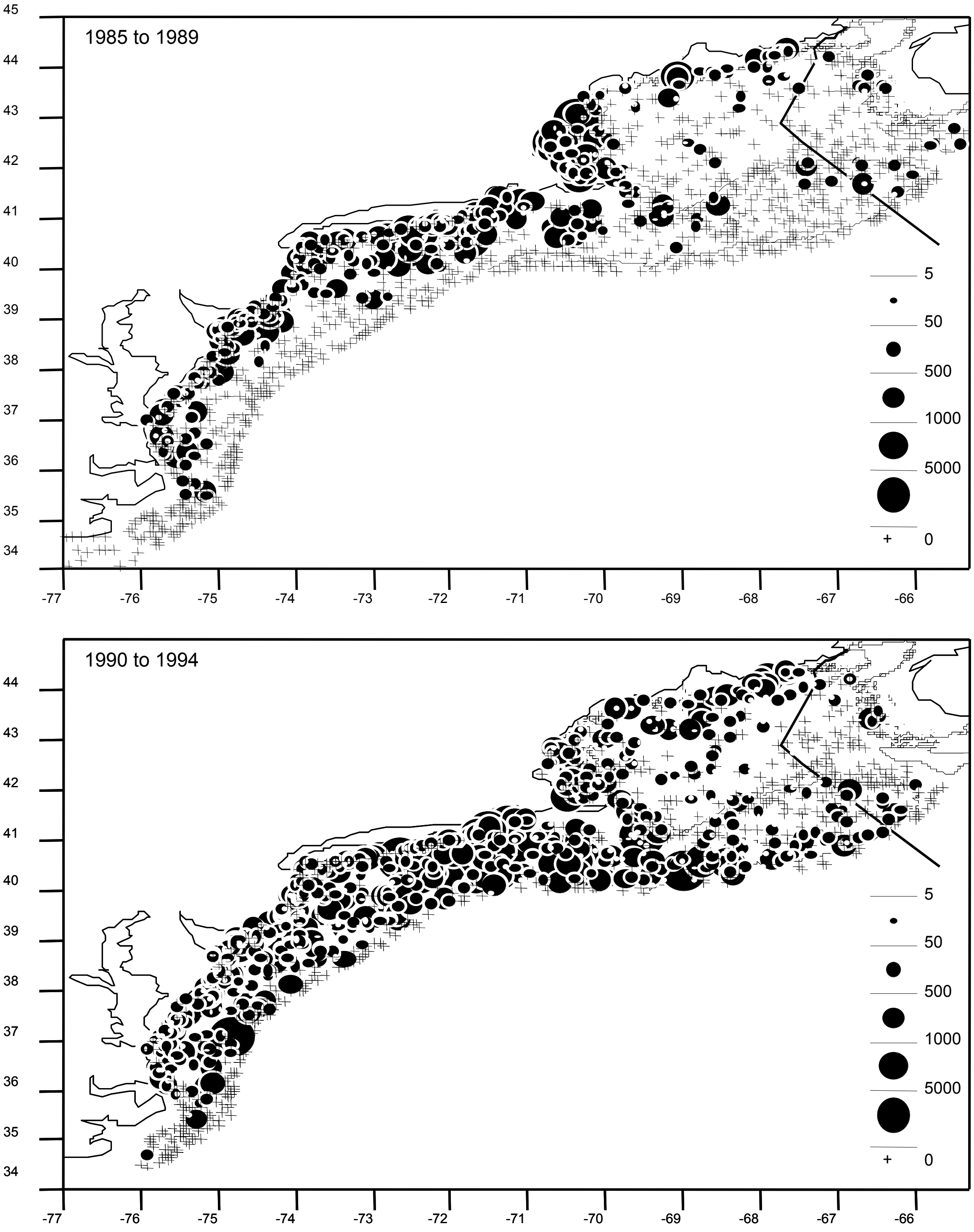


Figure 1.9c. Distribution of herring catches in the 1985-1989 and the 1990-1994 spring bottom trawl survey

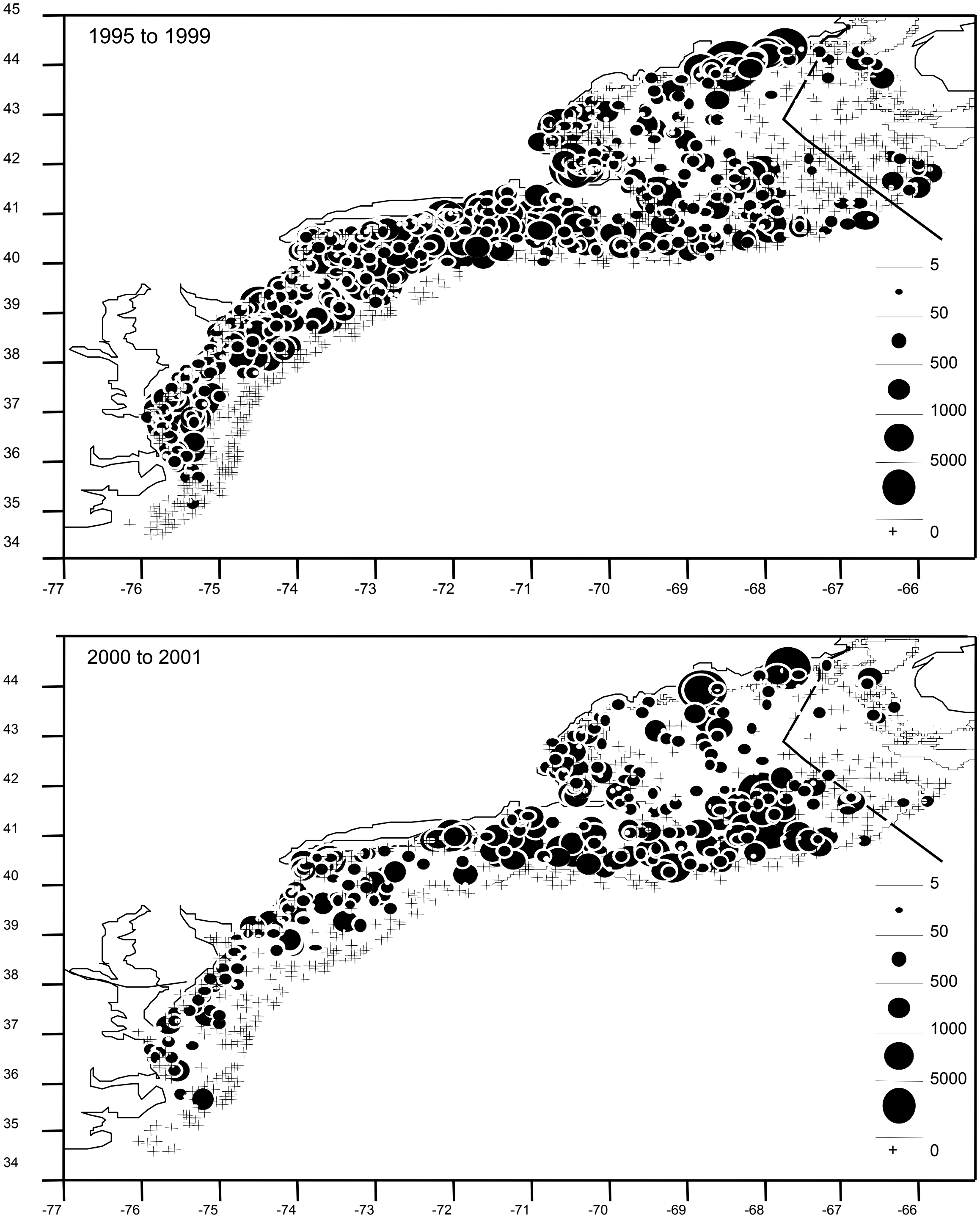


Figure 1.9d. Distribution of herring catches in the 1985-1989 and the 1990-1994 spring bottom trawl survey

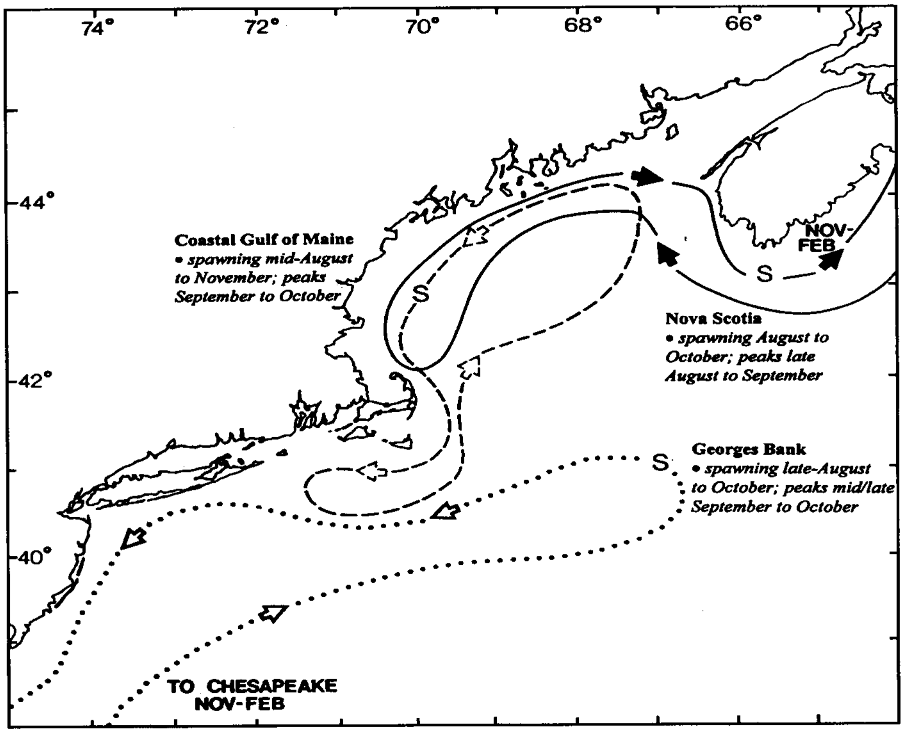


Figure 5. Hypothesized seasonal movements of three Atlantic herring spawning stocks inhabiting U.S. waters (modified from Sindermann 1979).

Figure 1.10. Source (Reid et. al, 1999)

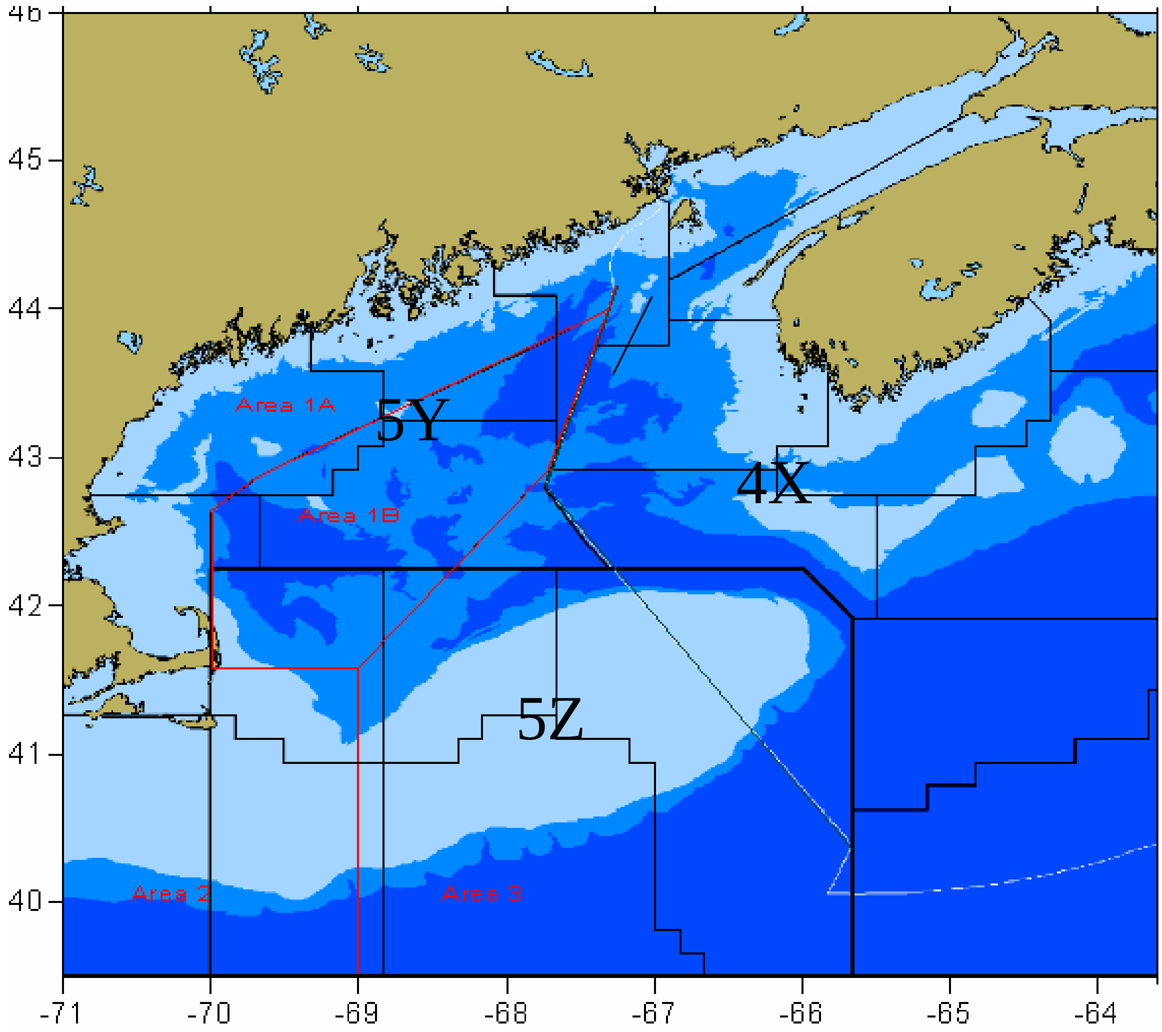


Figure 2.1. Map illustrating the stock and sea herring management boundaries in the Gulf of Maine and on Georges Bank.

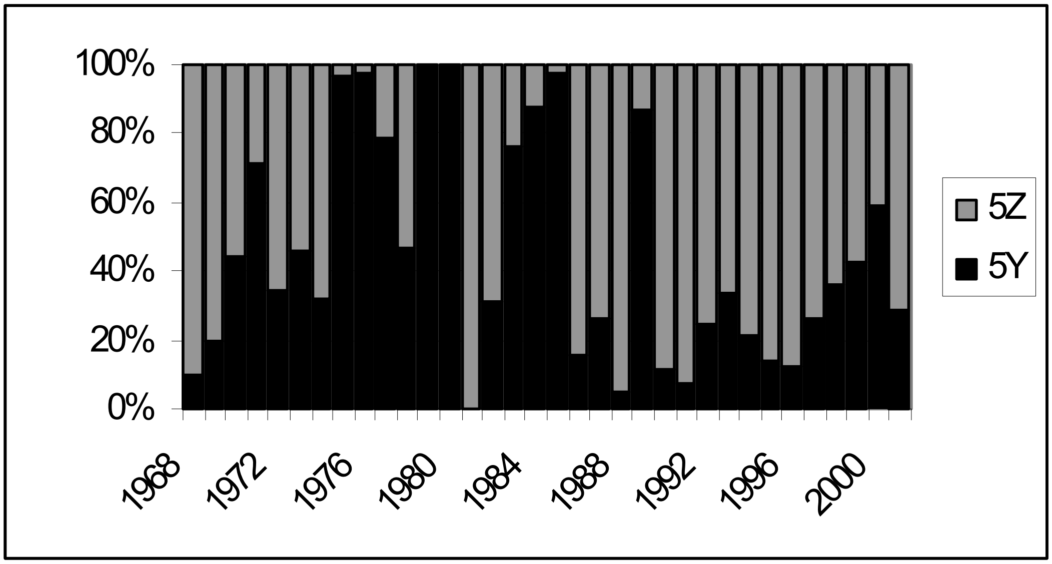


Figure 2.2. Relative contribution of 5Y and 5Z herring by number to the fall survey estimate of minimum population size for 1968-2001.

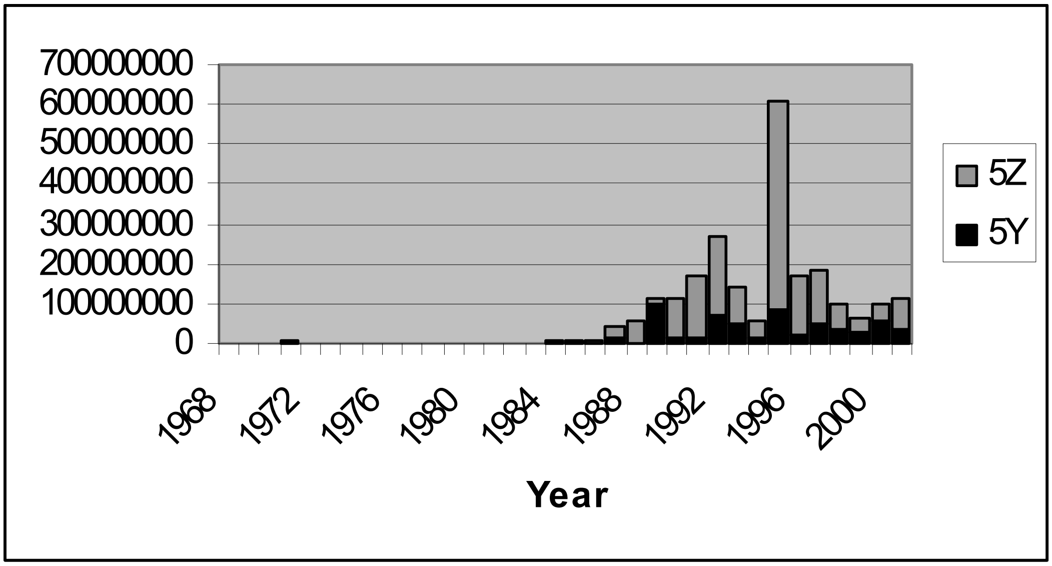


Figure 2.3. Estimated minimum population size for the 5Y and 5Z (includes Nantucket Shoals) in numbers of fish from the fall bottom survey.

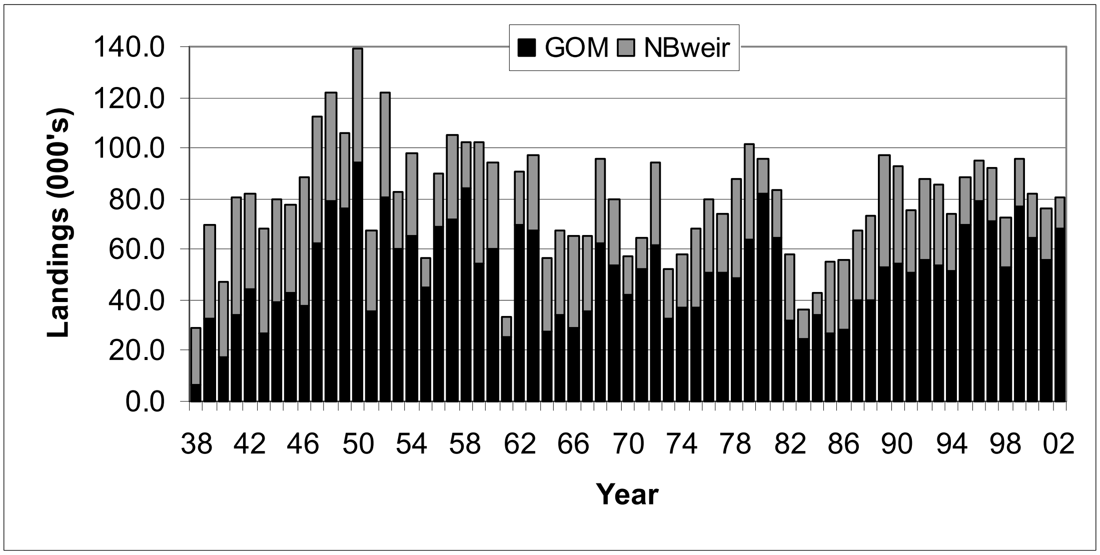


Figure 3.1. Gulf of Maine (5Y) and New Brunswick weir fishery reported herring landings from 1938-2002. (Sources: Anthony and Waring 1980, McKenzie and Tibbo 1960.

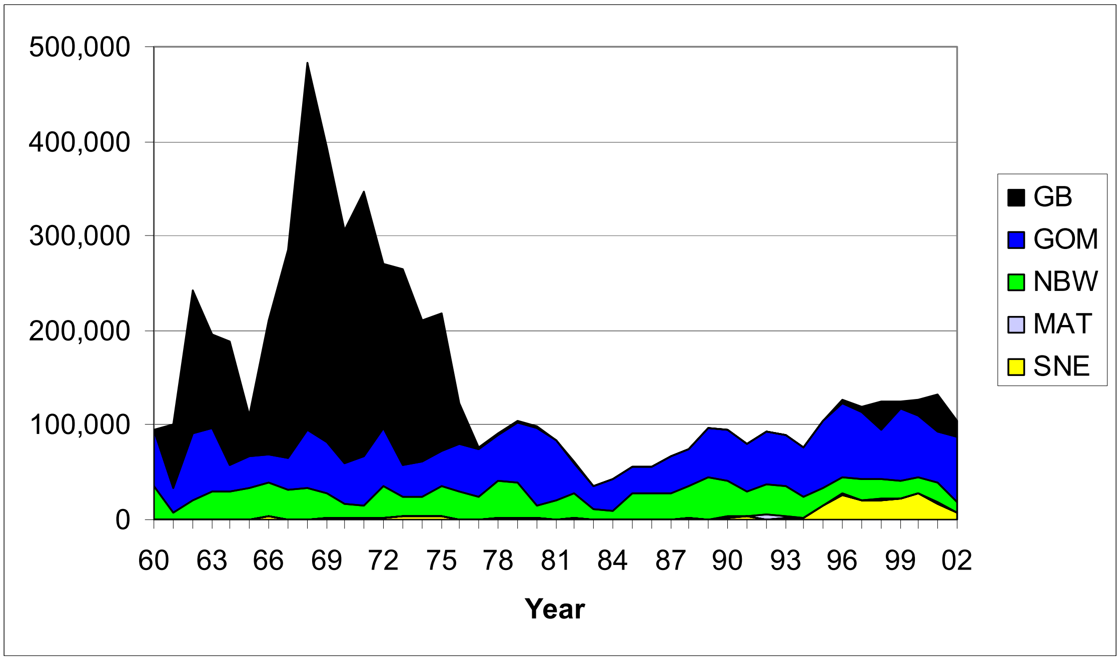


Figure 3.2. Herring landing for Georges Bank (GB), Gulf of Maine (GOM), New Brunswick weirs (NBW), Southern New England (SNE) and the mid-Atlantic states (MAT) from 1960-2002.

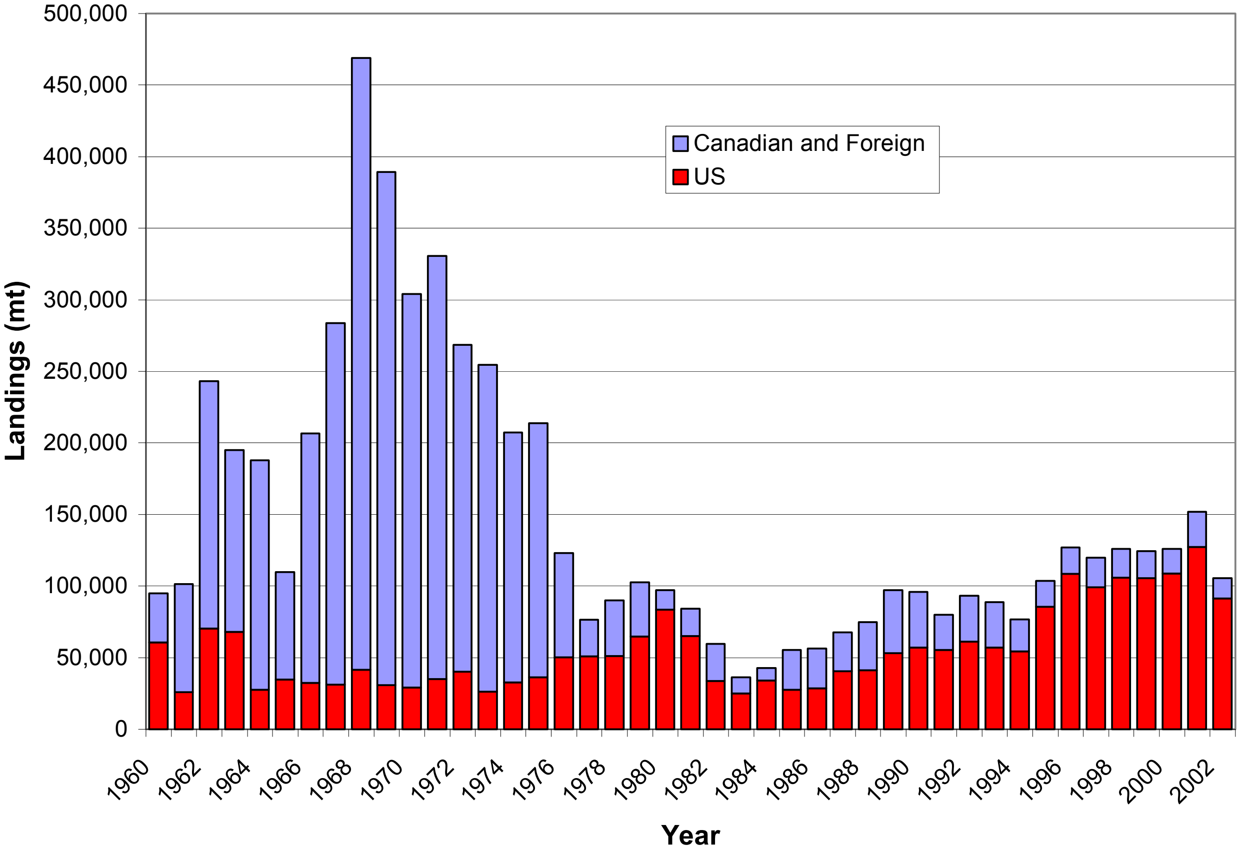


Figure 3.3 Landings from the Atlantic Herring Complex. Note 2002 data are preliminary

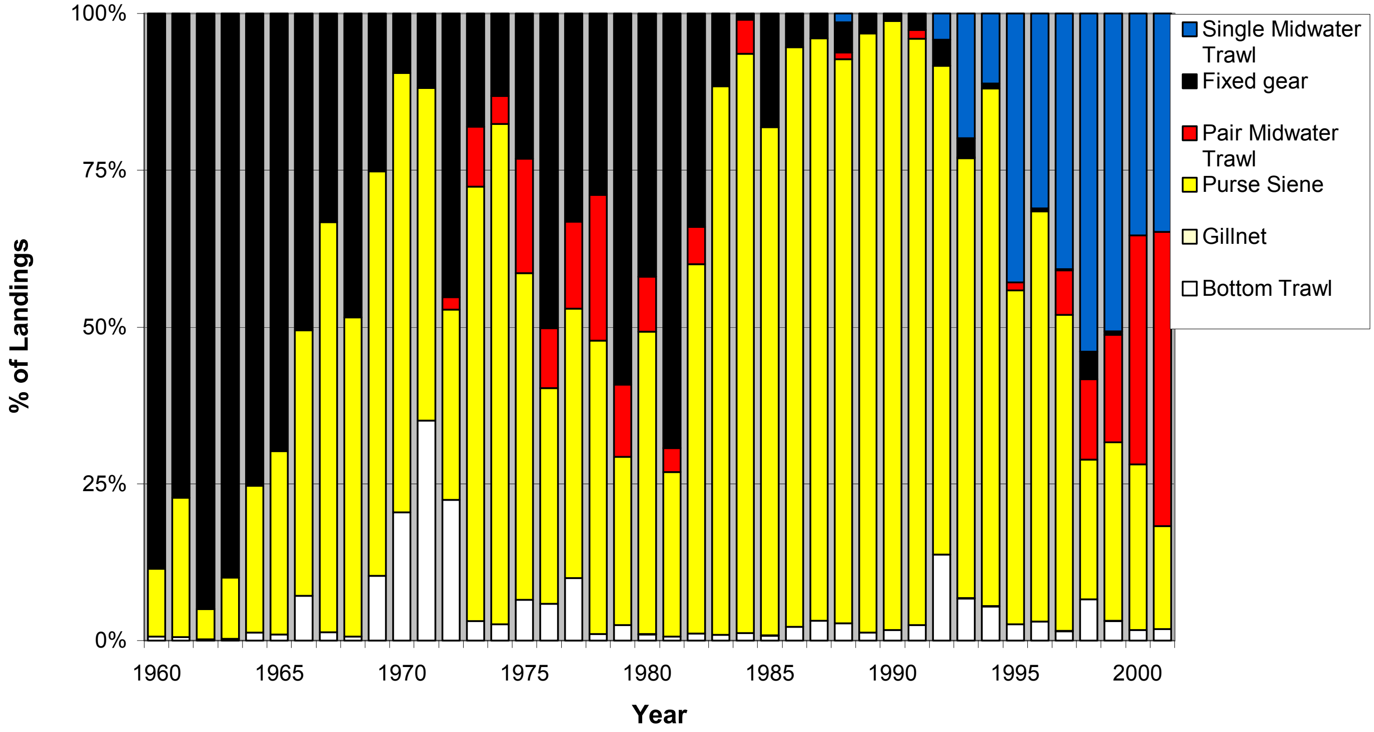


Figure 3.4. Percentage of landings by gear type for the US Atlantic Herring fishery

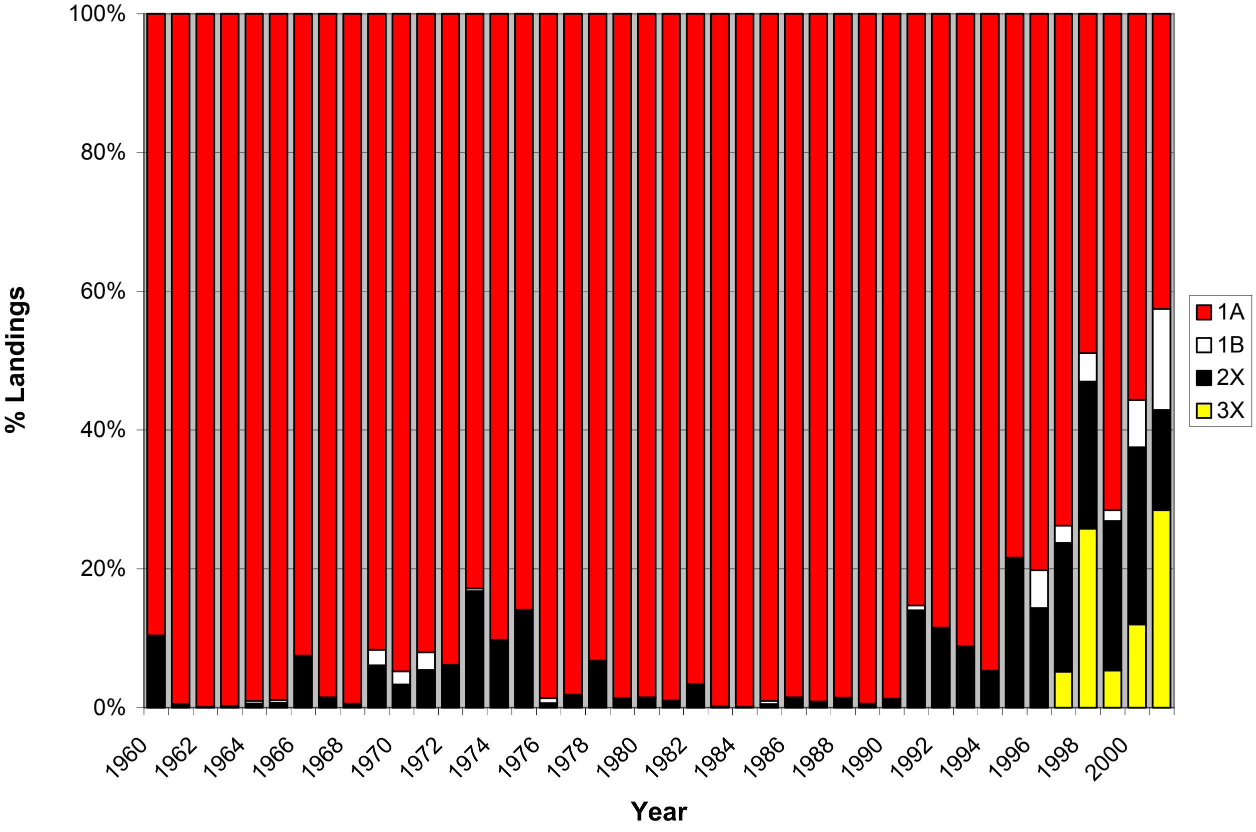


Figure 3.5. Percentage of landings by management area for the US Atlantic Herring fishery

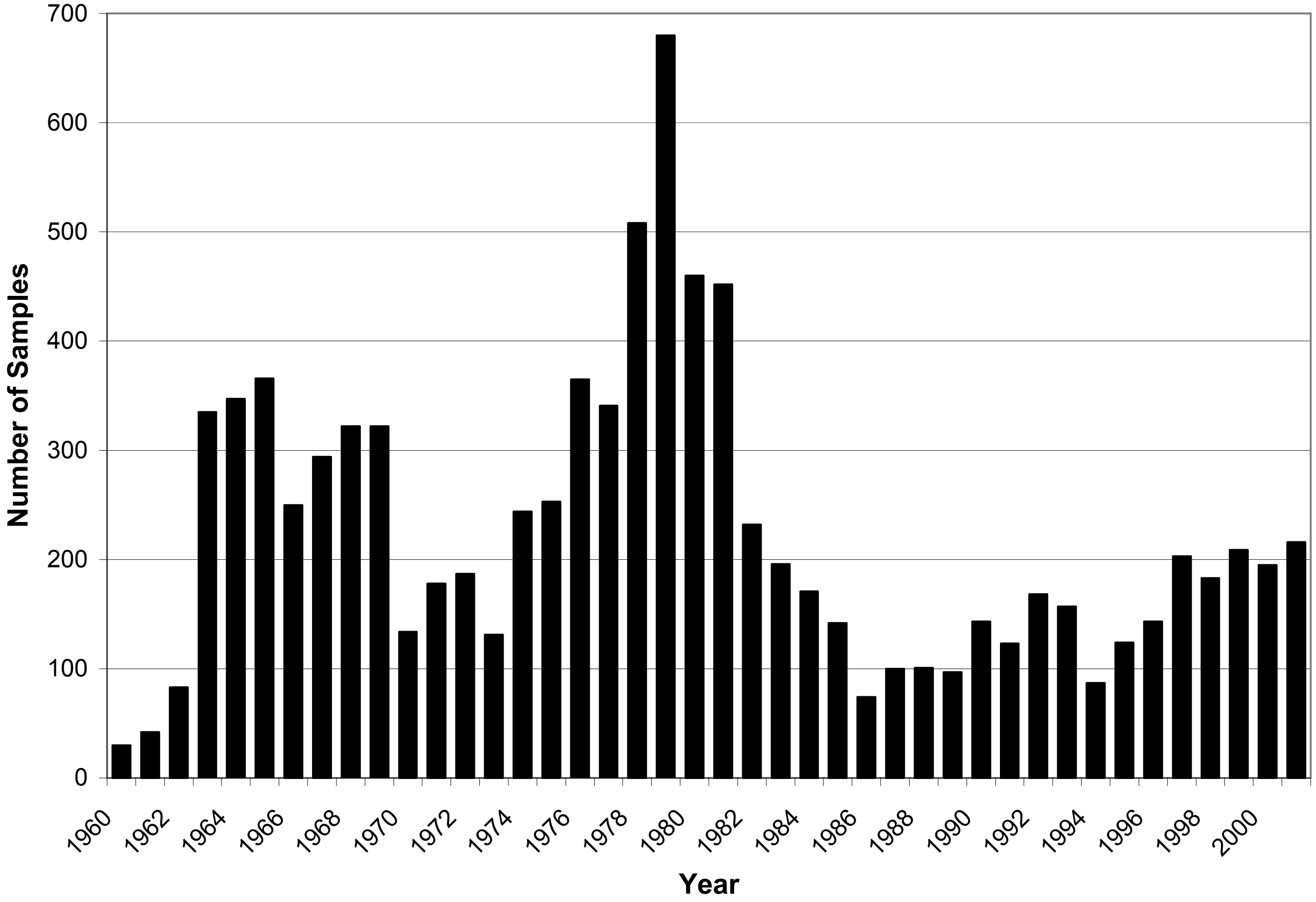


Figure 3.6. Number of samples processed for the US Atlantic herring Fishery

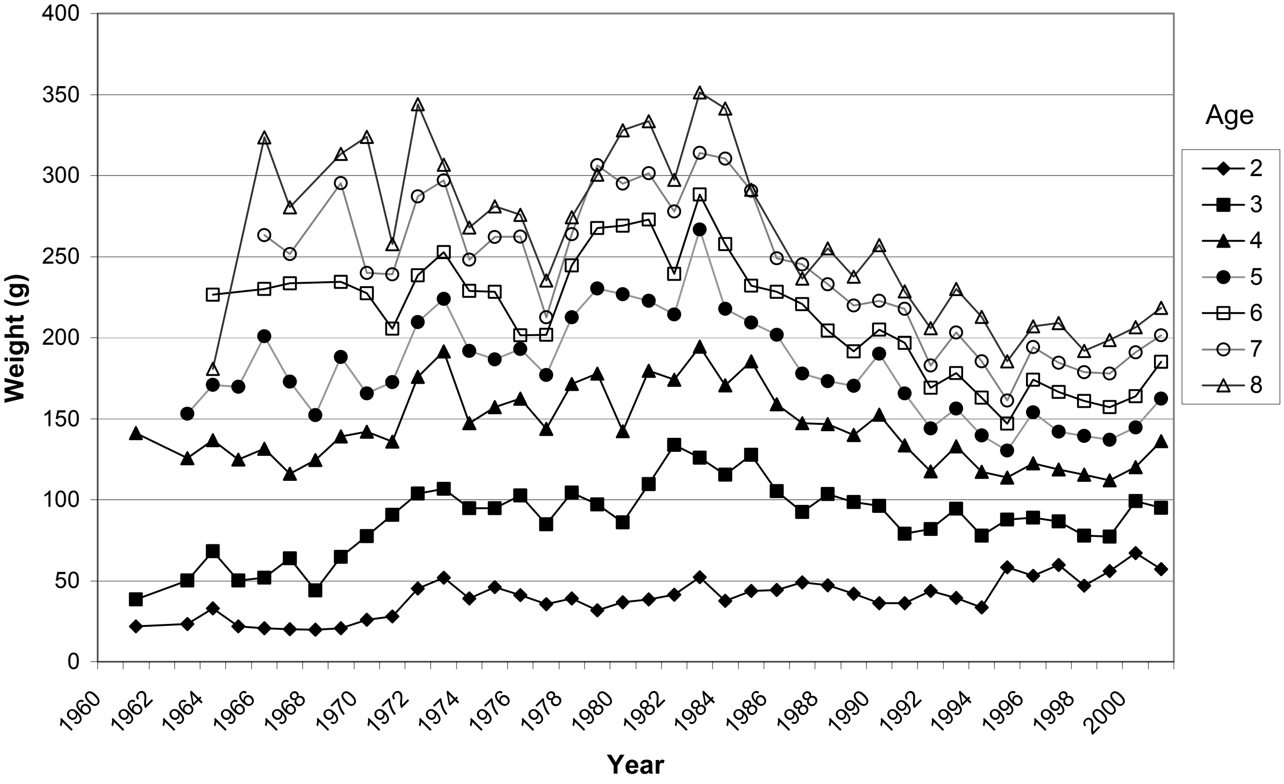


Figure 3.7. Weight at age for individual fish sampled from the US Atlantic Herring Fishery

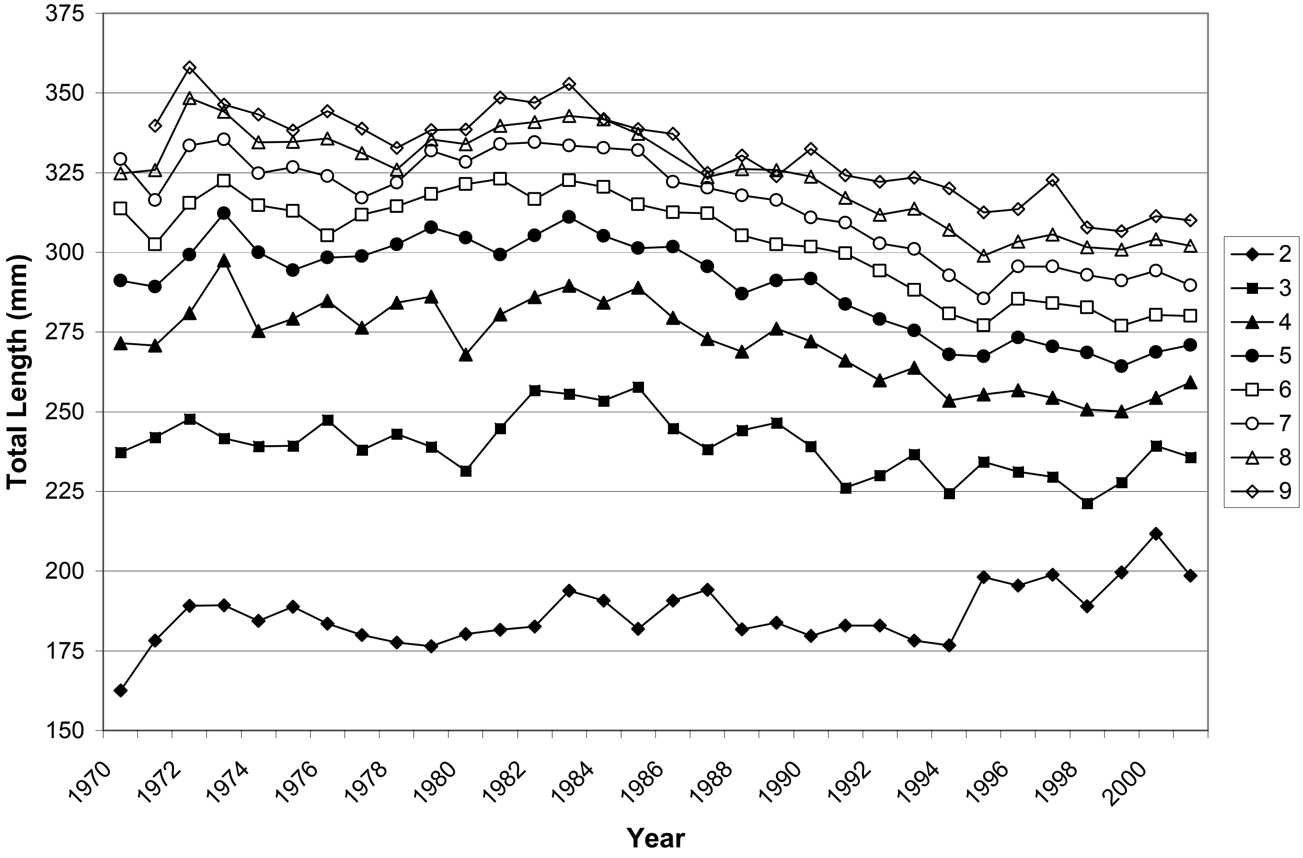


Figure 3.8. Total Length at age for individual fish sampled from the US Atlantic Herring Fishery

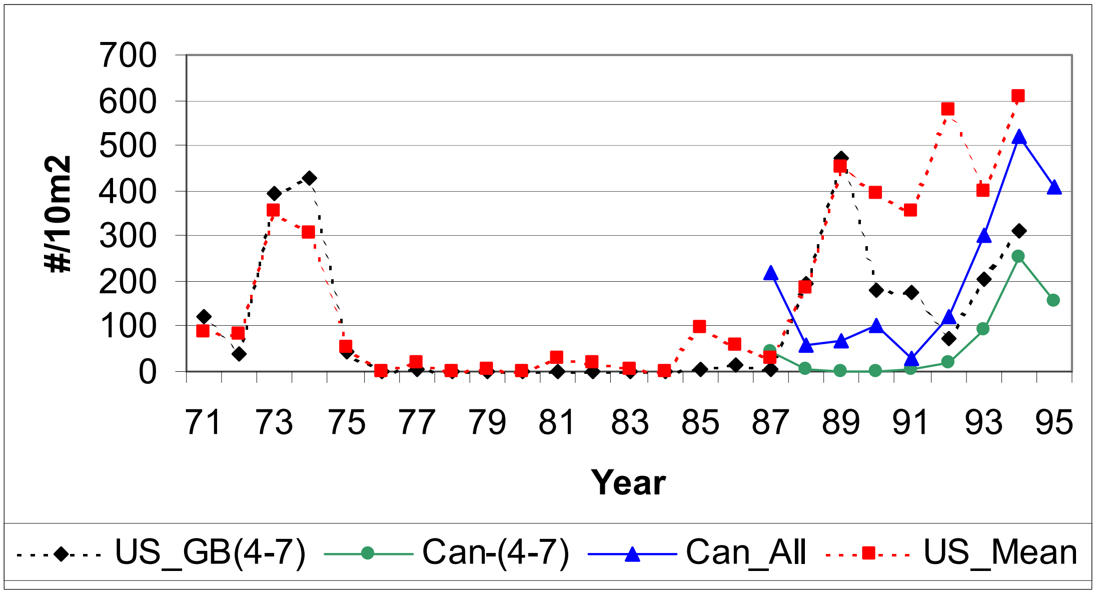


Figure 4.1. Canadian and US larval abundance indices in number/10m^2 for the US Georges Bank (US_GB), Canadian Georges Bank 4-7mm larvae (Can(4-7), Canadian all sizes (Can_All), and US the weighted mean from Georges Bank, Mass Bay, and Nantucket Shoals.

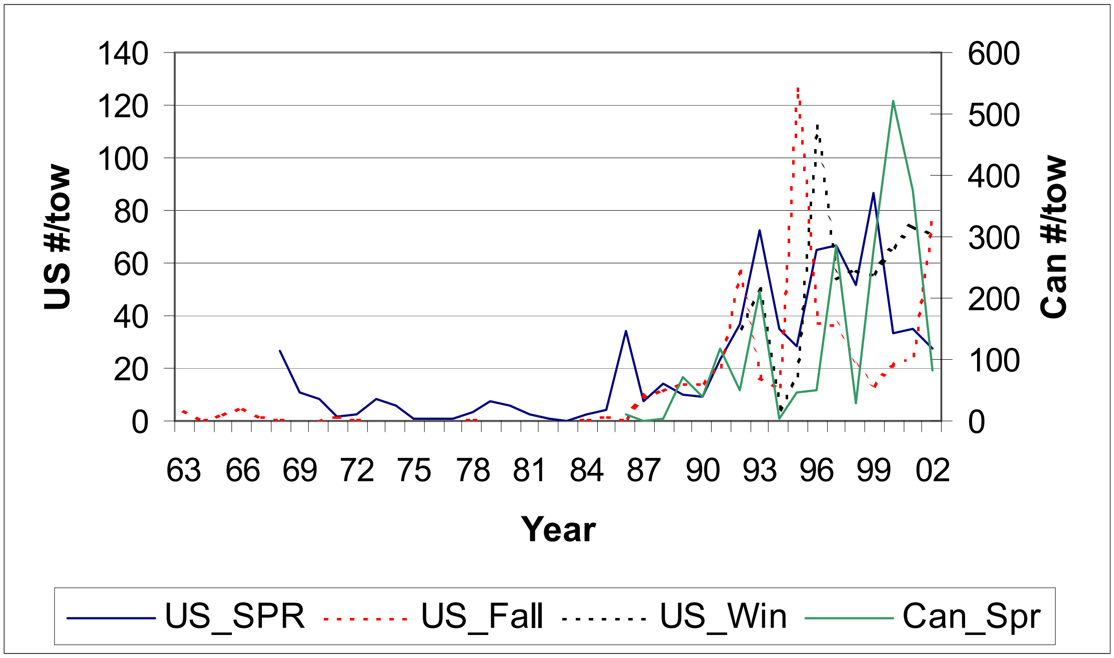


Figure 4.2. Summary of the US fall bottom trawl survey (US-Fall), the US spring bottom trawl survey (US_Spr), the US winter bottom trawl survey (US_Win), and the Canadian Spring bottom trawl survey (Can_Spr).

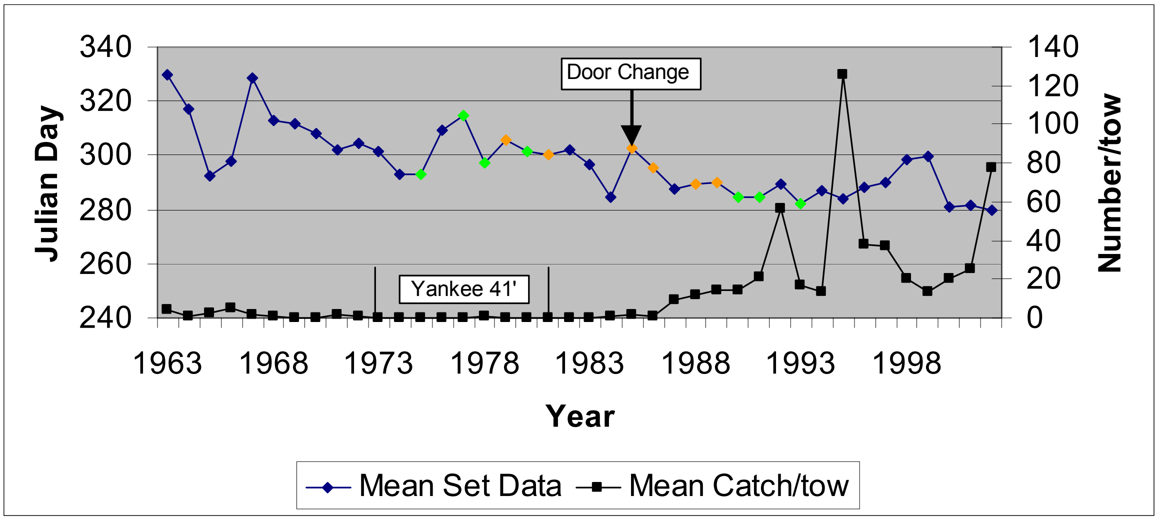


Figure 4.3. Comparison of the mean set Julian day and the stratified mean number per tow from the US fall bottom trawl survey for ages 1 to 11+.

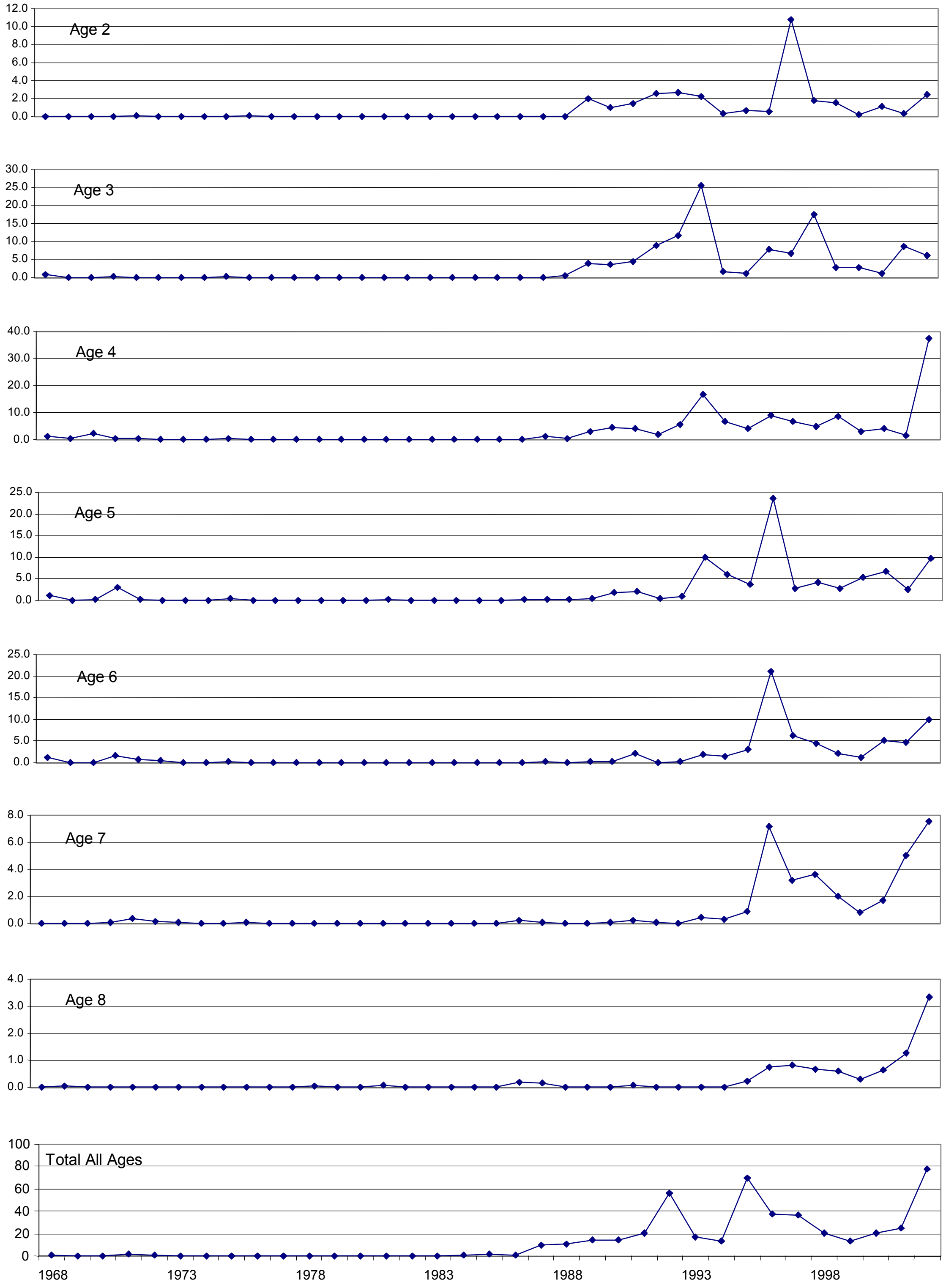


Figure 4.4. US Fall bottom trawl survey index of abundance for ages 2-8 from 1963 to 2002. The overall index for all ages is displayed in the lower right panel.

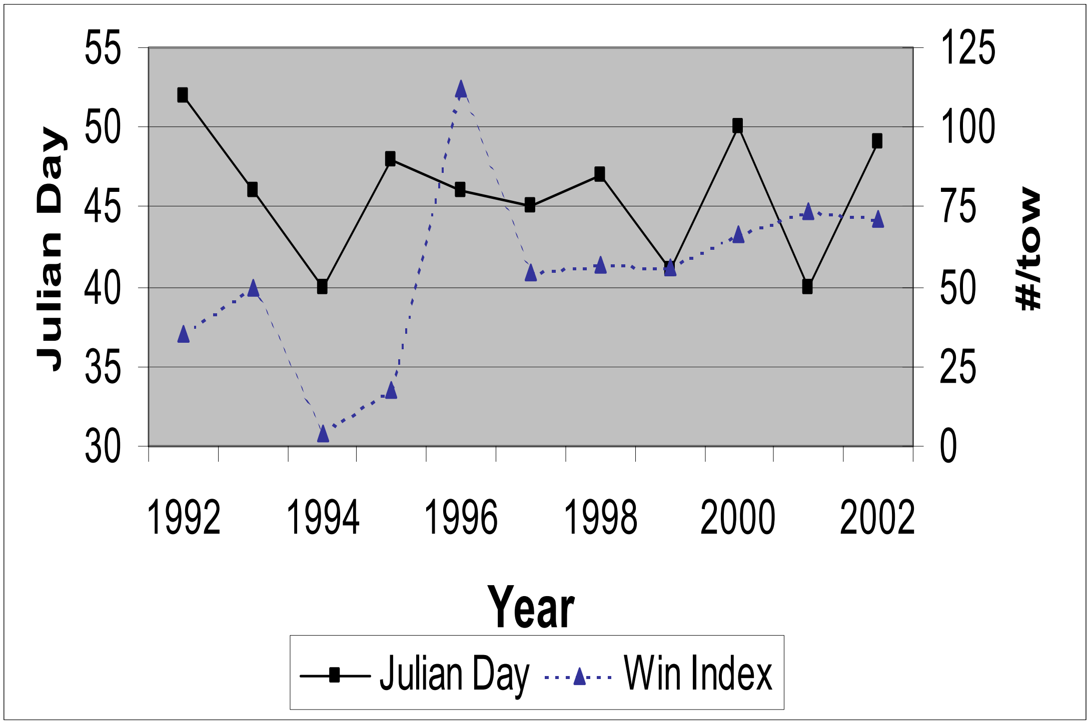


Figure 4.5. Comparsion of the mean set Julian Day and the stratified mean number per tow from the US Winter bottom trawl survey for 1992 to 2002.

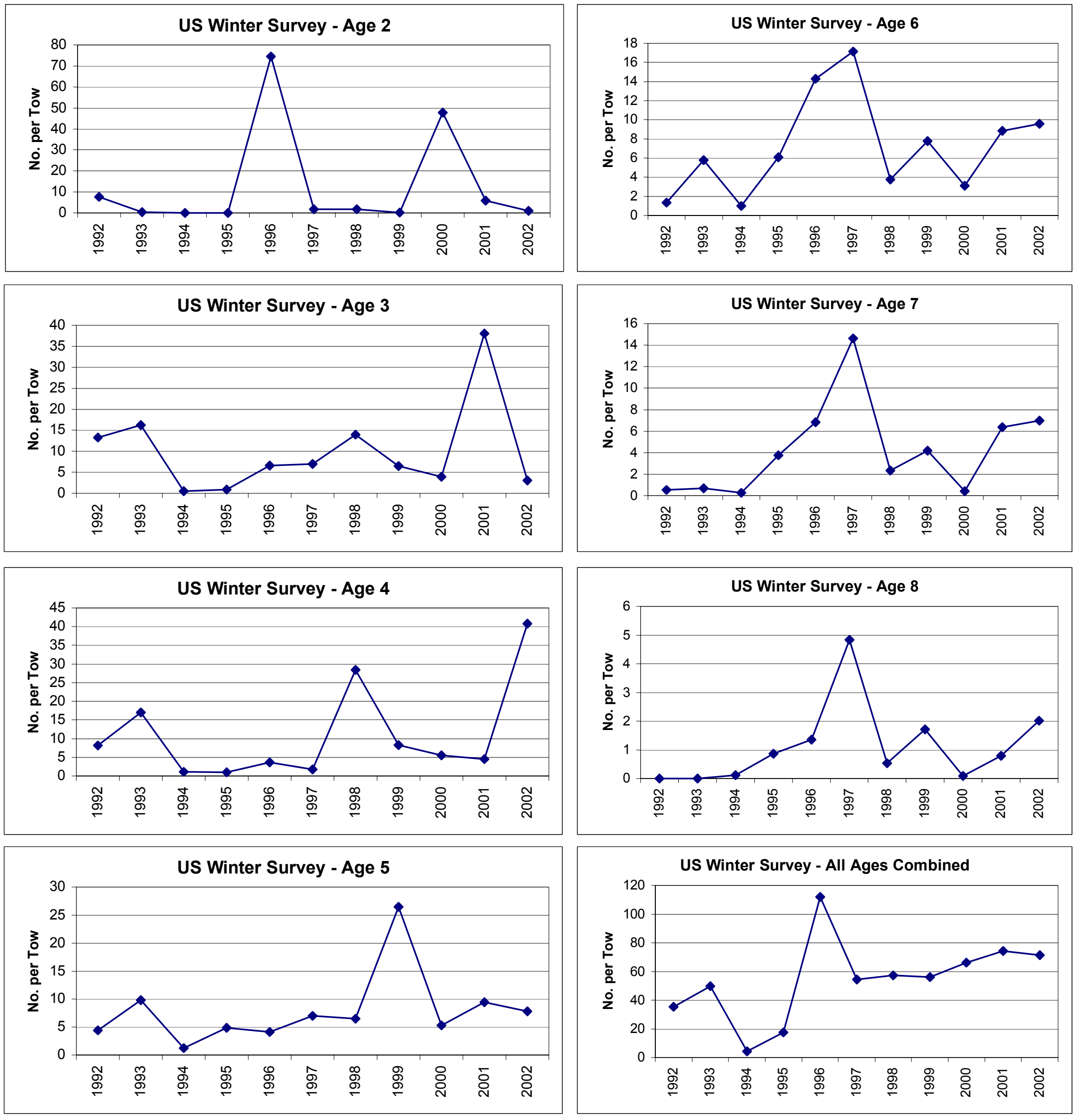


Figure 4.6. Winter bottom trawl survey index of abundance for ages 2-8 from 1992 to 2002. The overall index for all ages is displayed in the lower right panel.

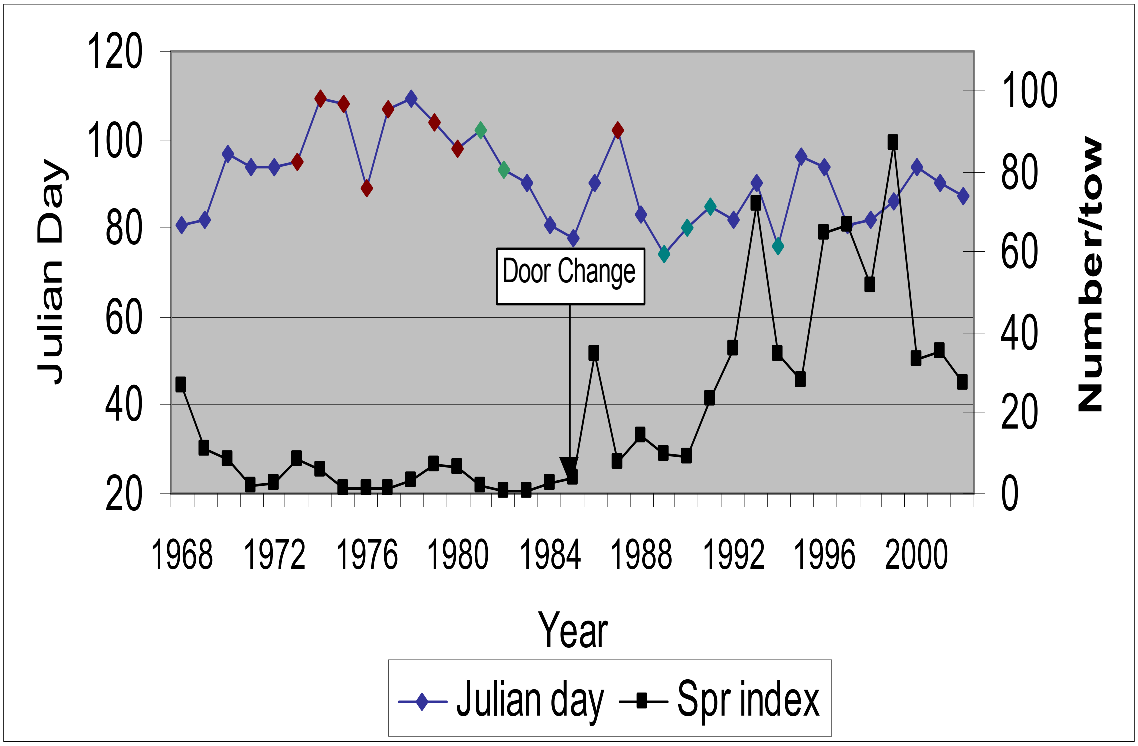


Figure 4.7. Comparison of the mean set Julian day and the stratified mean number per tow from the US Spring bottom trawl survey for those strata used to tune the vpa.

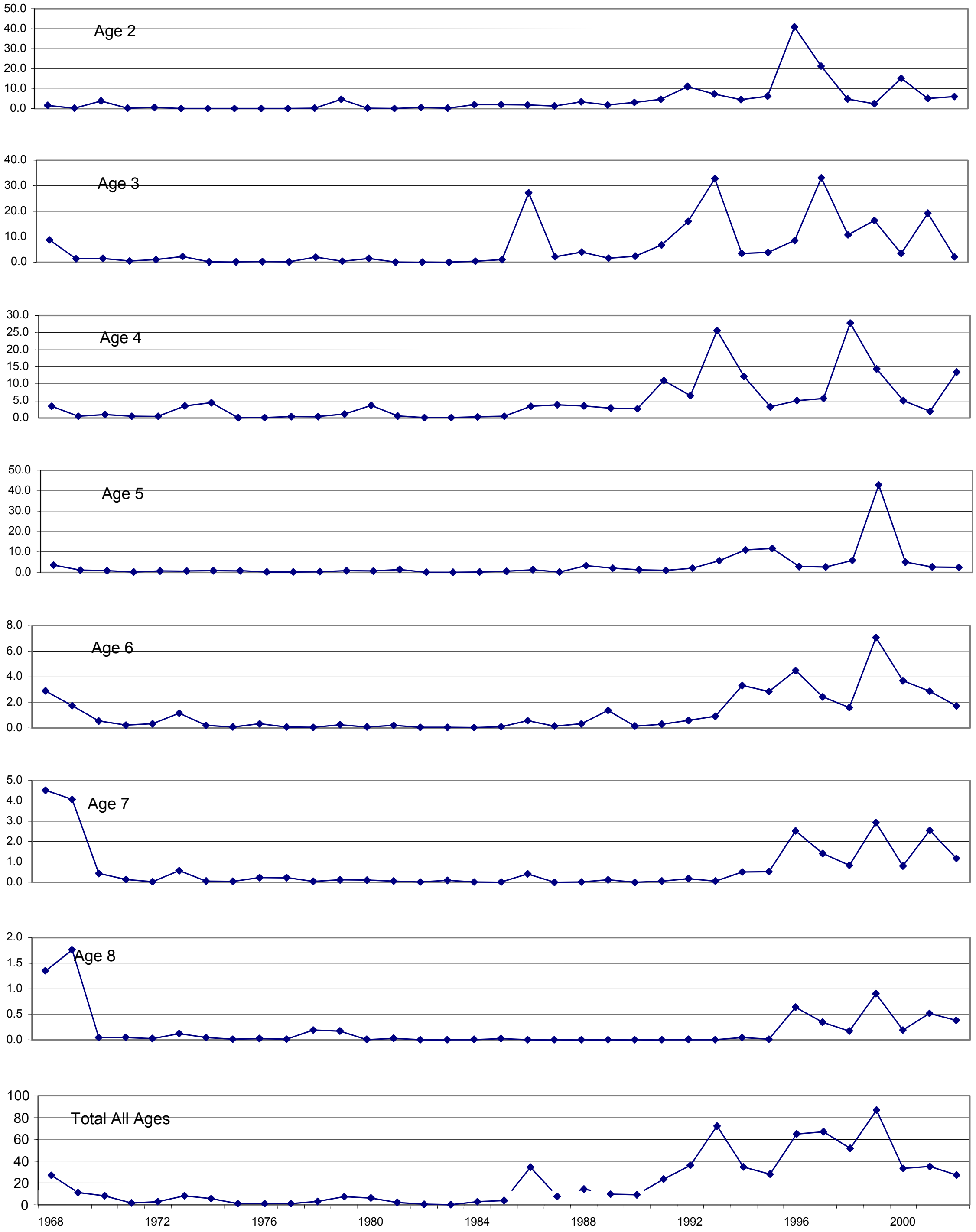


Figure 4.8. US spring bottom trawl survey index of abundance for ages 2-8 from 1968 to 2002. The index for all ages is displayed in the lower panel.

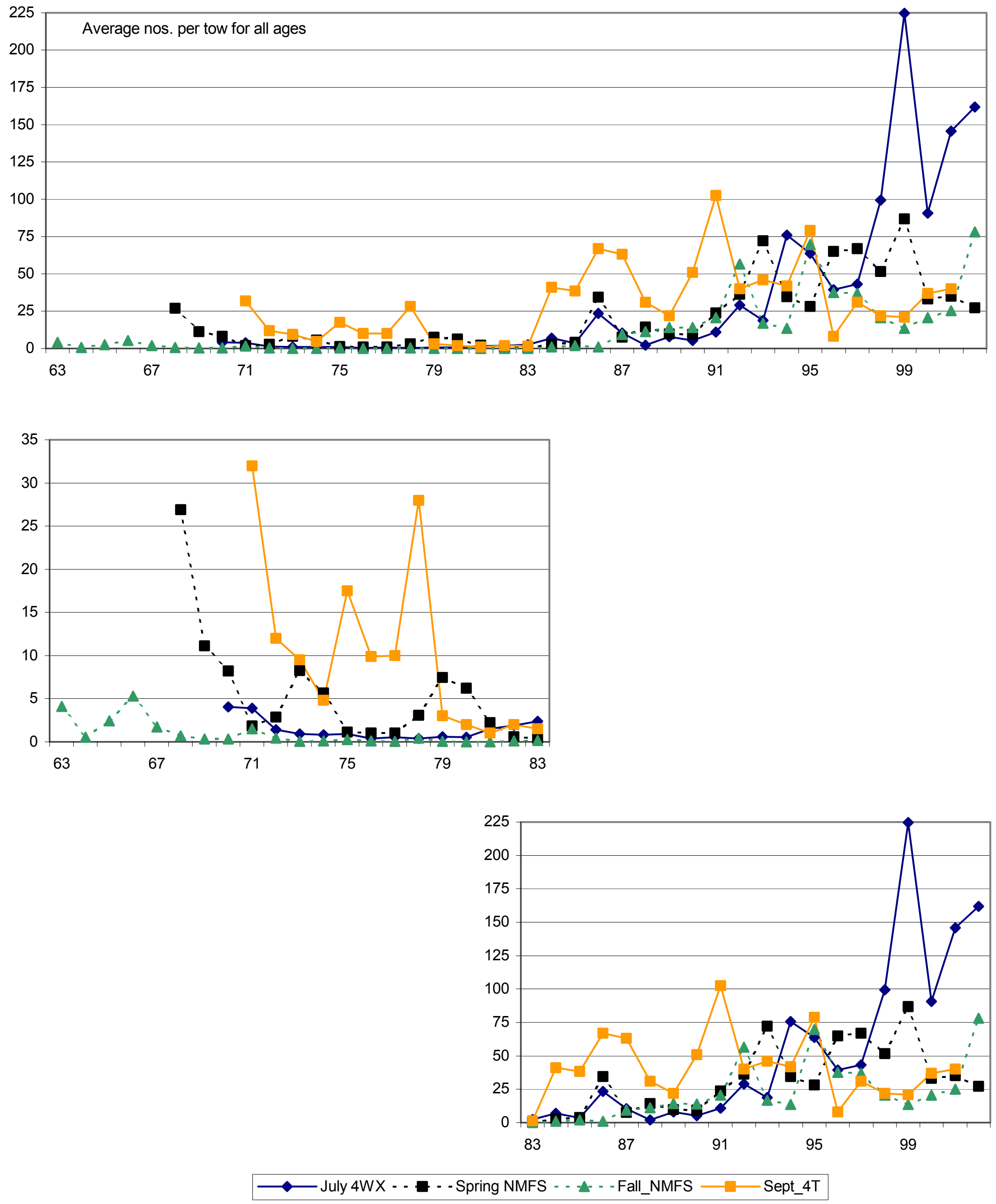


Figure 4.9. Summary of number per tow for the US spring and fall and the Canadian 4WX and 4T bottomtrawl surveys from 1963 to 2002. The middle graph represents a blow-up of the 1963-1983 and the lower graph 1983

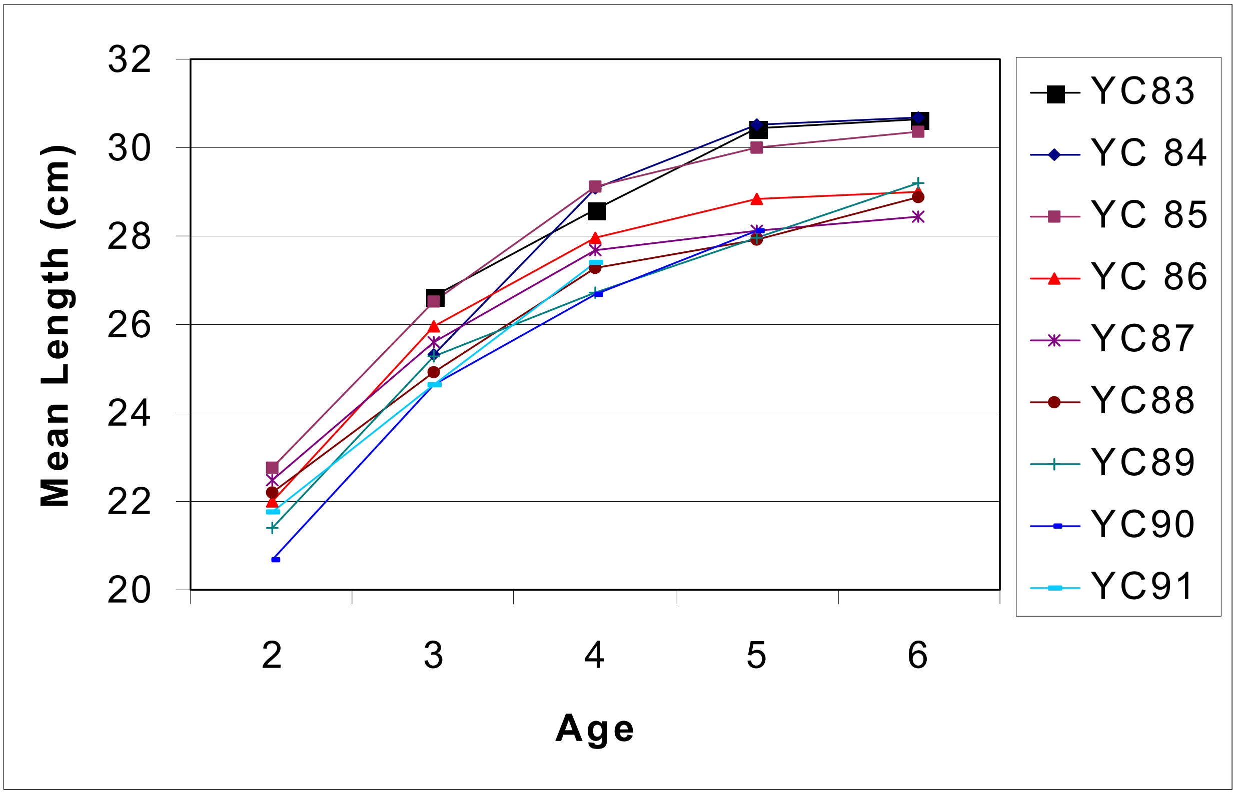


Figure 5.1. Summary of mean length-at-age for the 1983 to 1991 years-classes from Georges Bank.

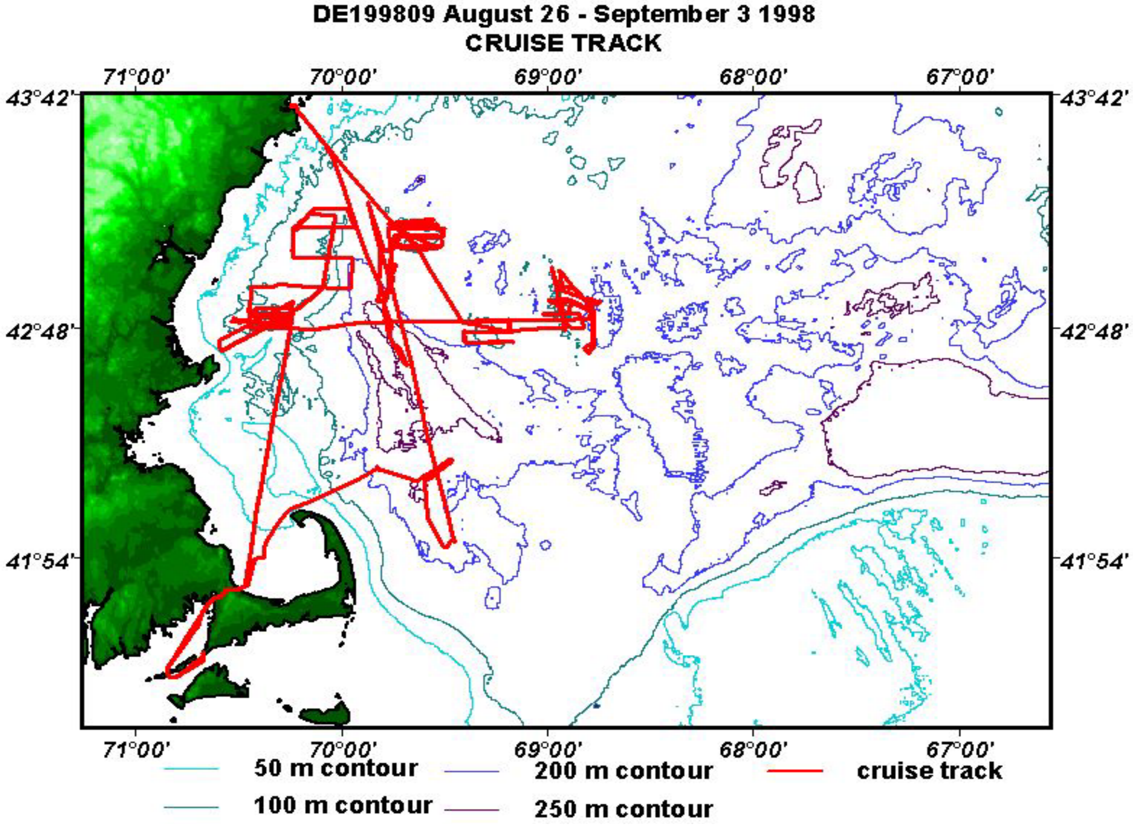


Figure 7.1. Cruise tracks for surveys on Jeffreys Ledge, Platts Bank, Cashes Ledge and Fippennies Ledge during the 1998 Atlantic Herring Hydroacoustic Survey.

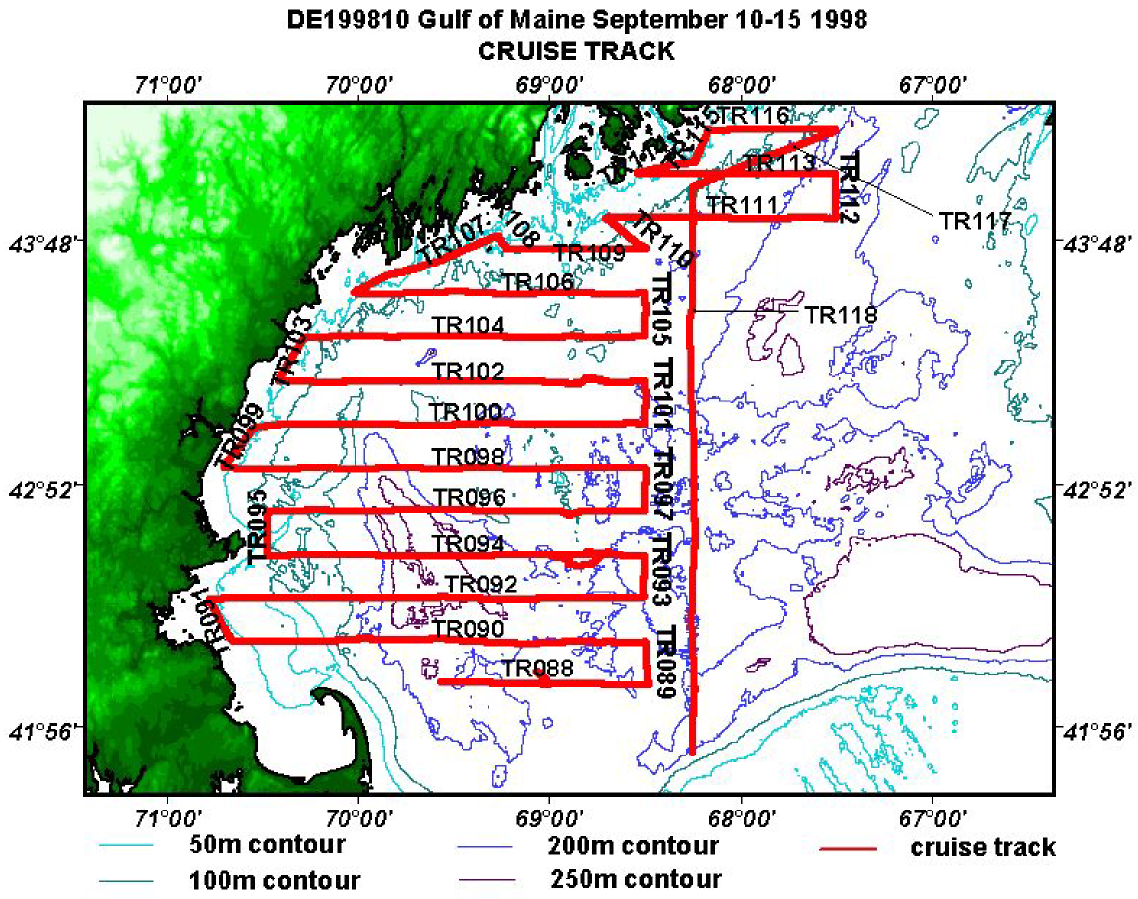


Figure 7.2. Cruise track for the systematic parallel survey (20 nautical miles spacing between transects) in the Gulf of Maine during the 1998 Atlantic Herring Hydroacoustic Survey

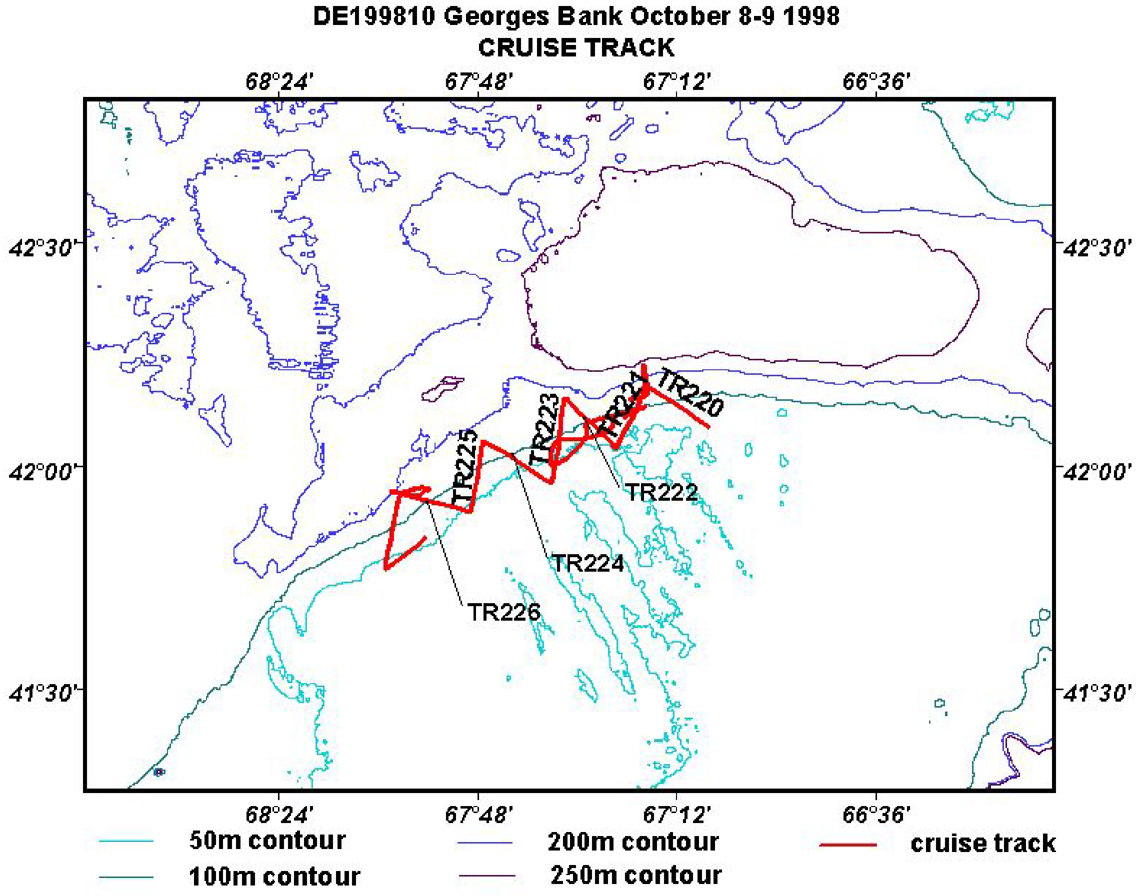


Figure 7.3. Cruise track for one zigzag survey on the northern edge of Georges Bank during the 1998 Atlantic Herring Hydroacoustic Survey.

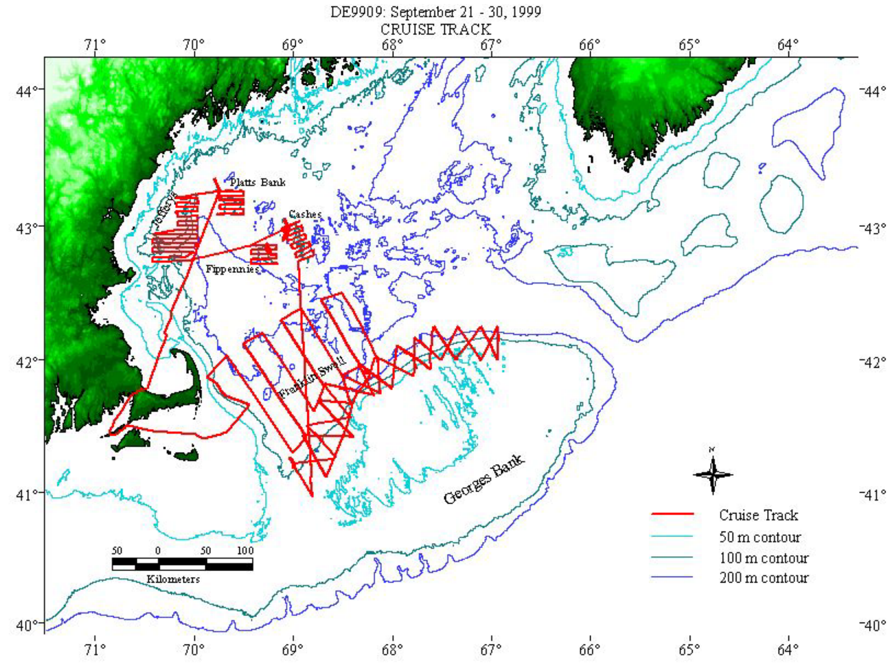


Figure 7.4. Cruise track for surveys on Jeffreys Ledge, Platts Bank, Fippennies Ledge, Cashes Ledge, Franklin Swell, and Georges Bank during the 1999 Atlantic Herring Hydroacoustic Survey. Two systematic zigzag survey designs were conducted on Georges Bank, while systematic parallel surveys were conducted in the Gulf of Maine survey areas.

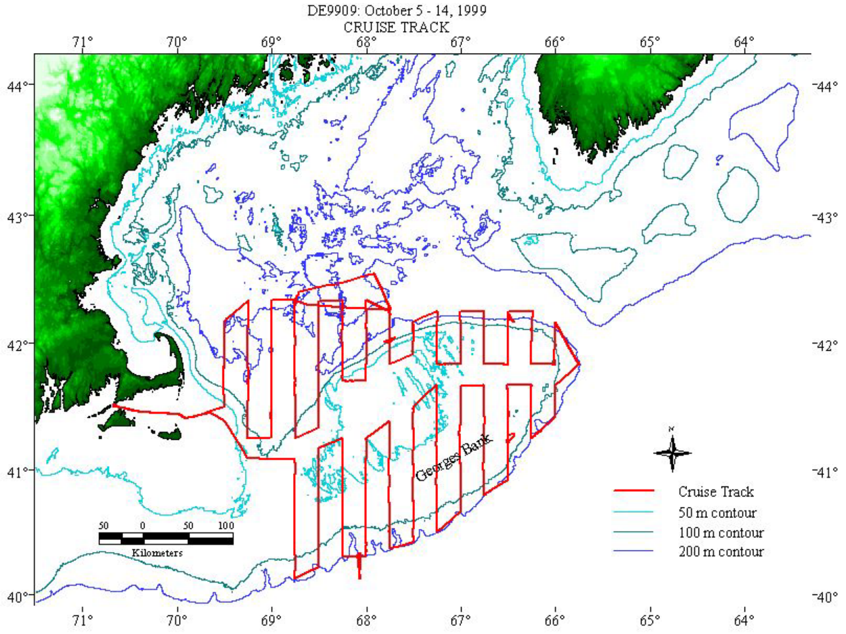


Figure 7.5. Cruise track for the systematic parallel survey circumscribing Georges Bank during the 1999 Atlantic Herring Hydroacoustic Survey

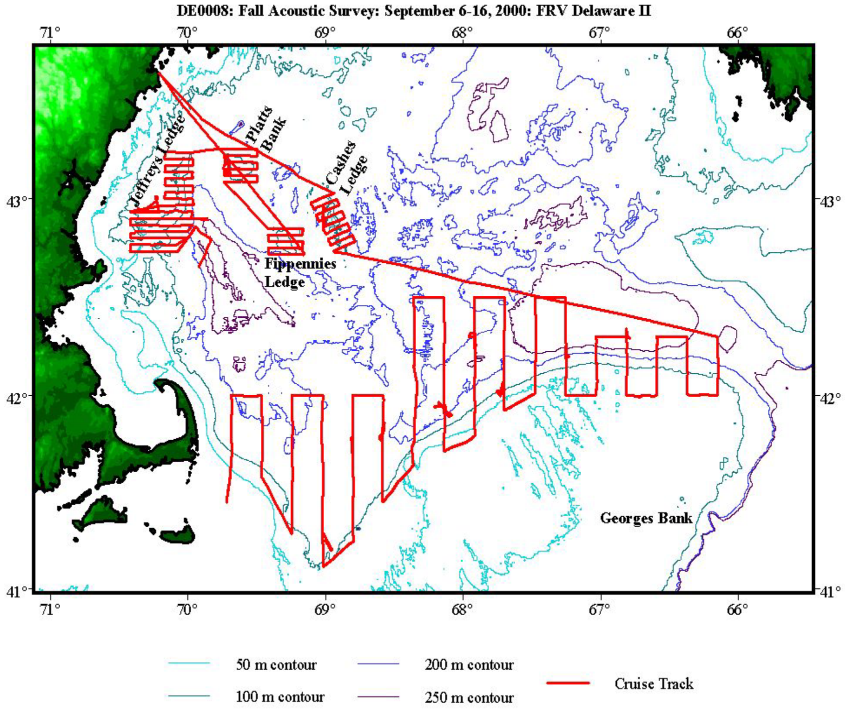


Figure 7.6. Cruise track for systematic parallel surveys conducted on Jeffreys Ledge, Platts Bank, Fippennies Ledge, Cashes Ledge, and Georges Bank during the 2000 Atlantic Herring Hydroacoustic Surveys

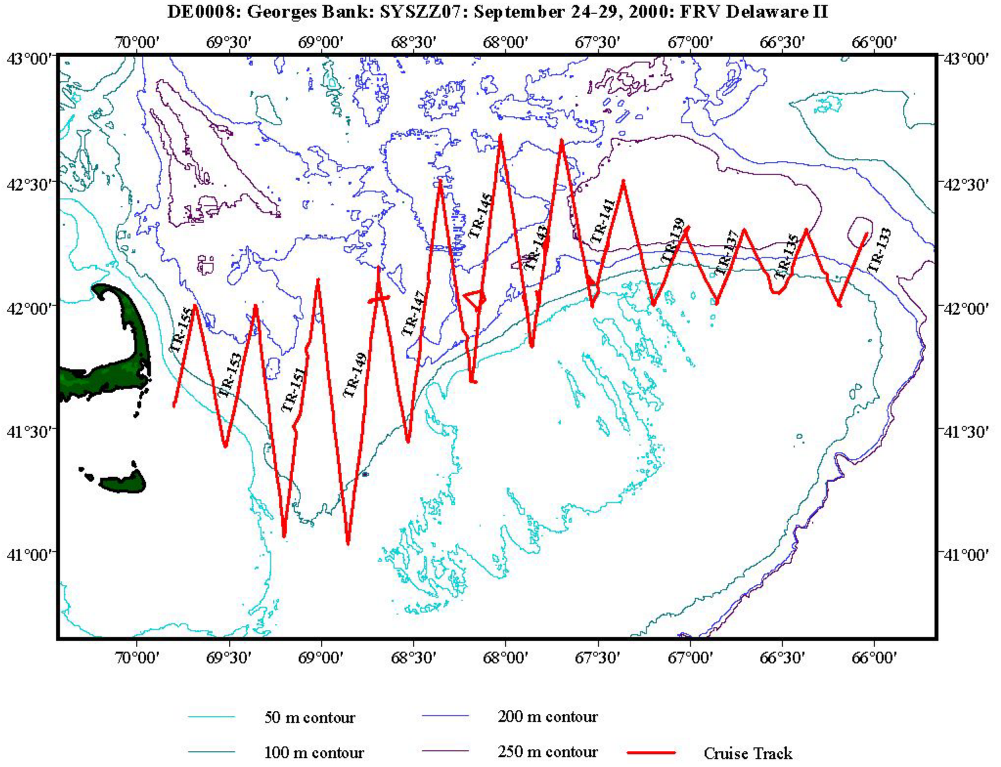


Figure 7.7. Cruise track for the systematic zigzag survey on Georges Bank during 2000.

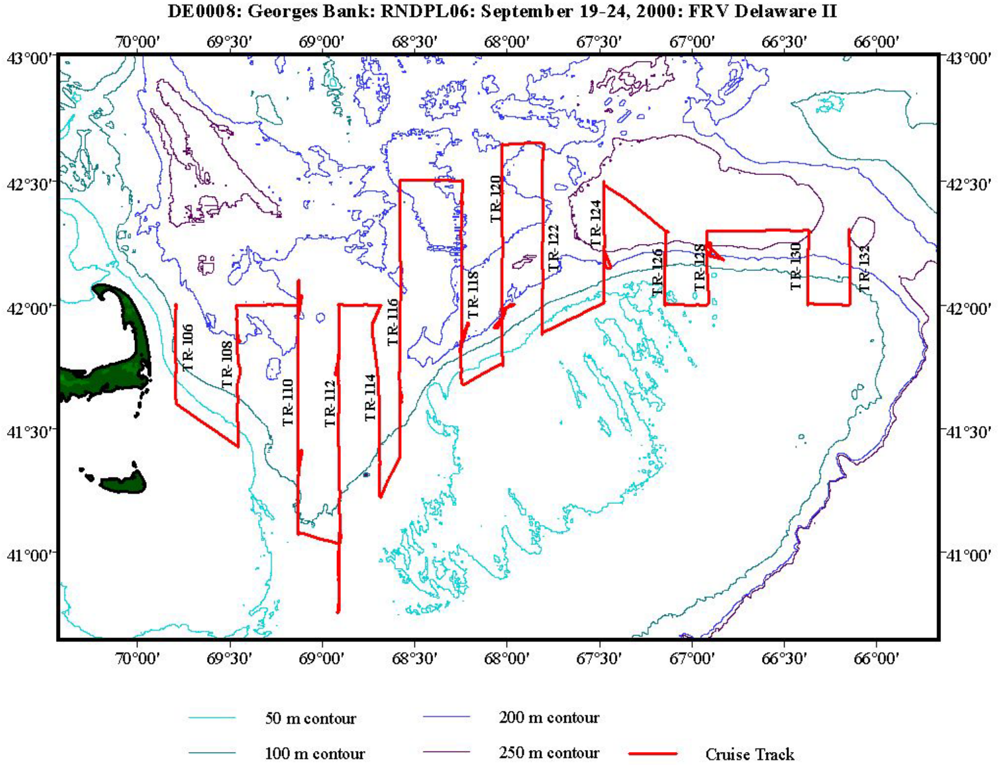


Figure 7.8. Cruise track for the stratified random survey design on Georges Bank during 2000.

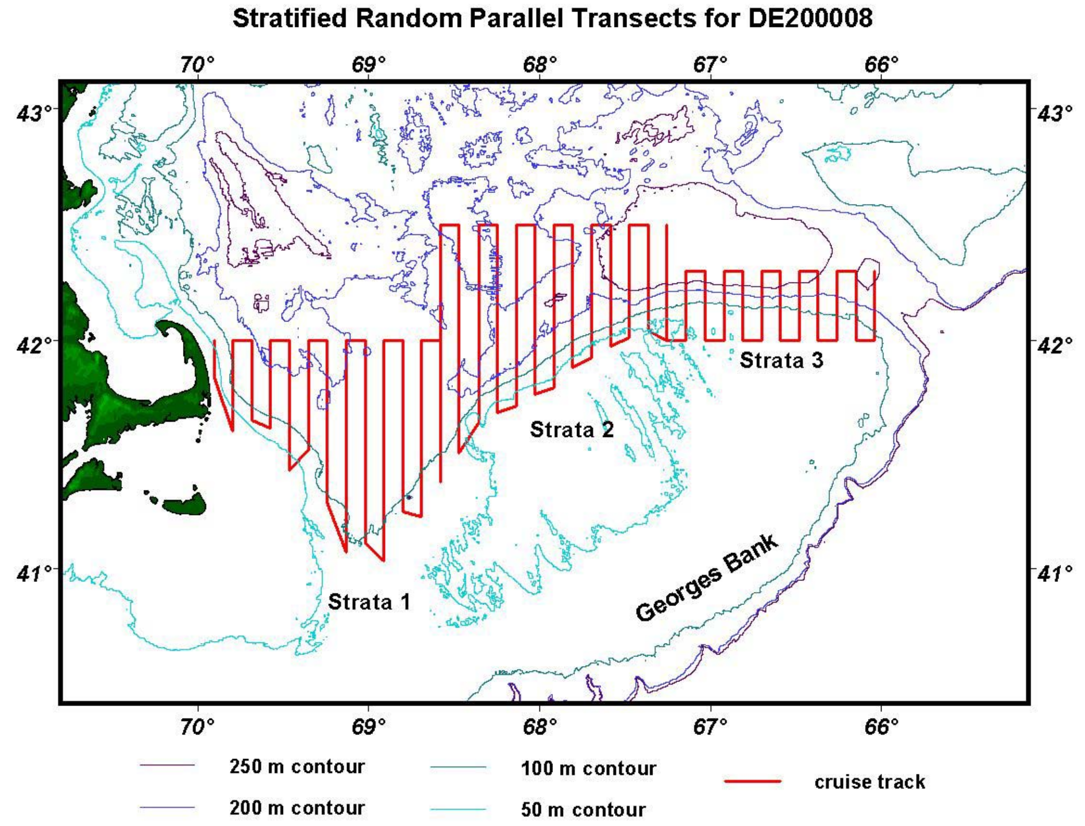


Figure 7.9. Complete set of potential stratified random parallel transects for surveyin Atlantic herring on Georges Bank during the 2000 Atlantic Herring Hydroacoustic Survey.

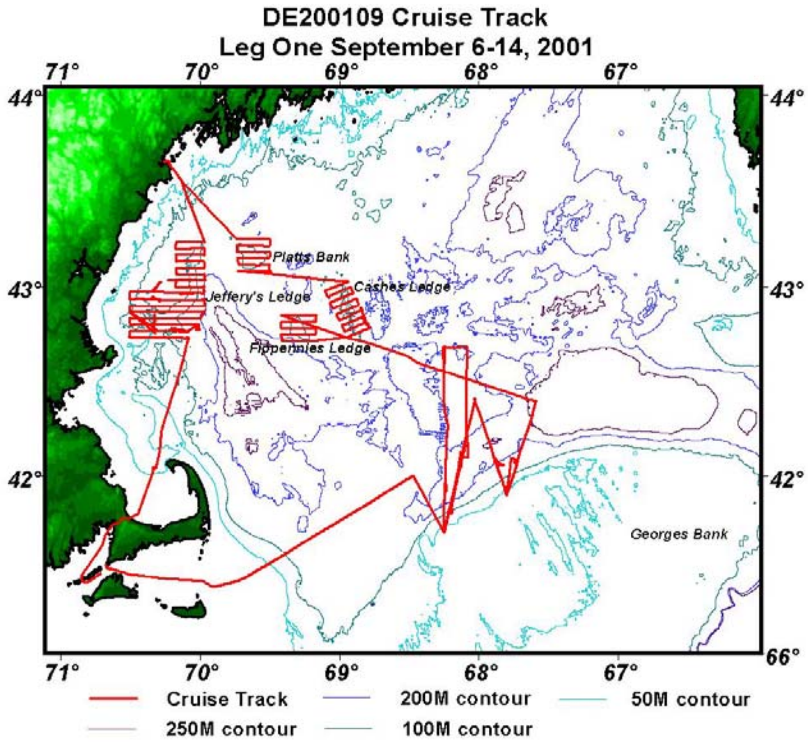


Figure 7.10. Cruise tracks for systematic parallel surveys on Jeffreys Ledge, Platts Bank, Fippennies Ledge, and Cashes Ledge during 2001. The cruise tracks on Georges Bank represent experimental work with broadband and low-frequency acoustics.

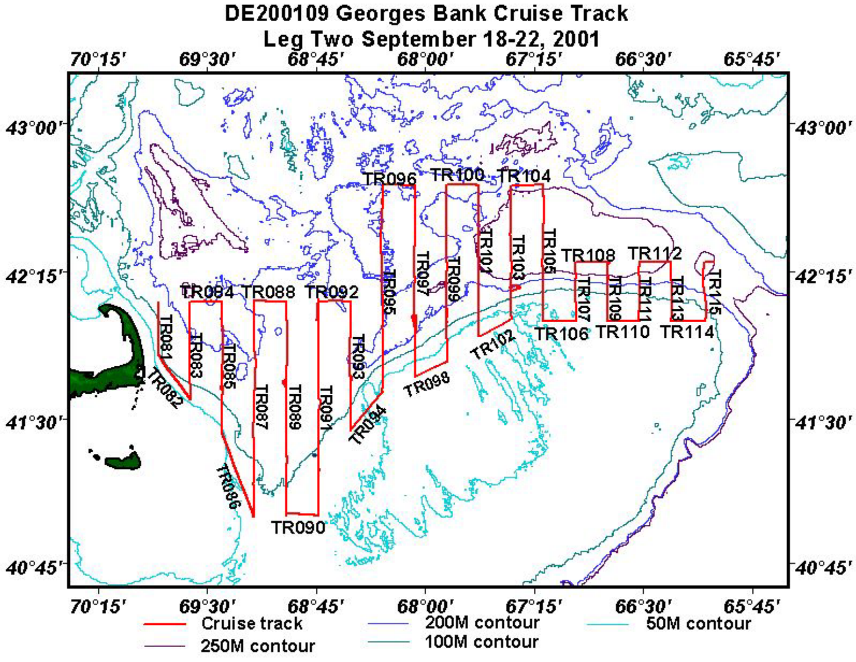


Figure 7.11. Cruise track for the systematic parallel survey on Georges Bank during the 2000 Atlantic Herring Hydroacoustic Survey.

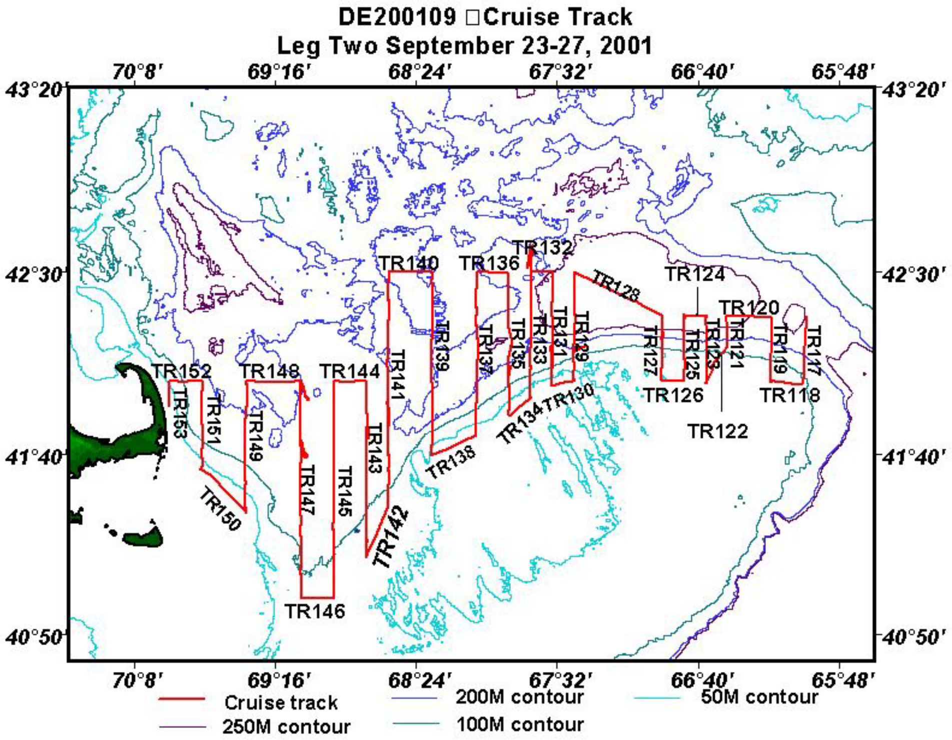


Figure 7.12. Cruise track for the random parallel survey on Georges Bank during the 2001 Atlantic Herring Hydroacoustic Survey.

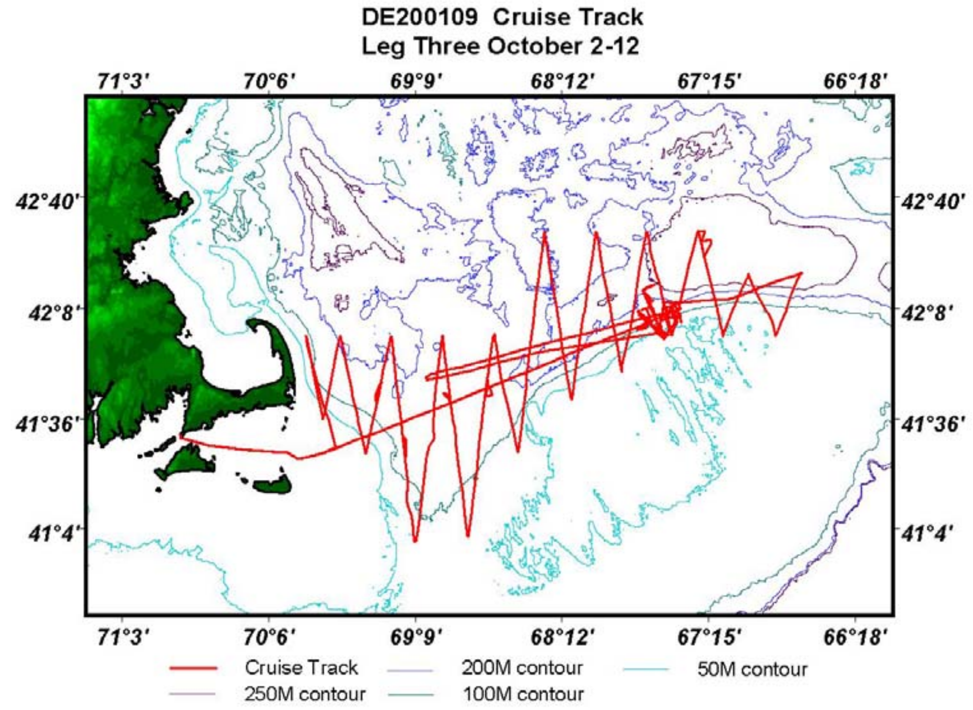


Figure 7.13. Cruise track for systematic zigzag survey and experimental work on Georges Bank during the 2001 Atlantic Herring Hydroacoustic Survey.

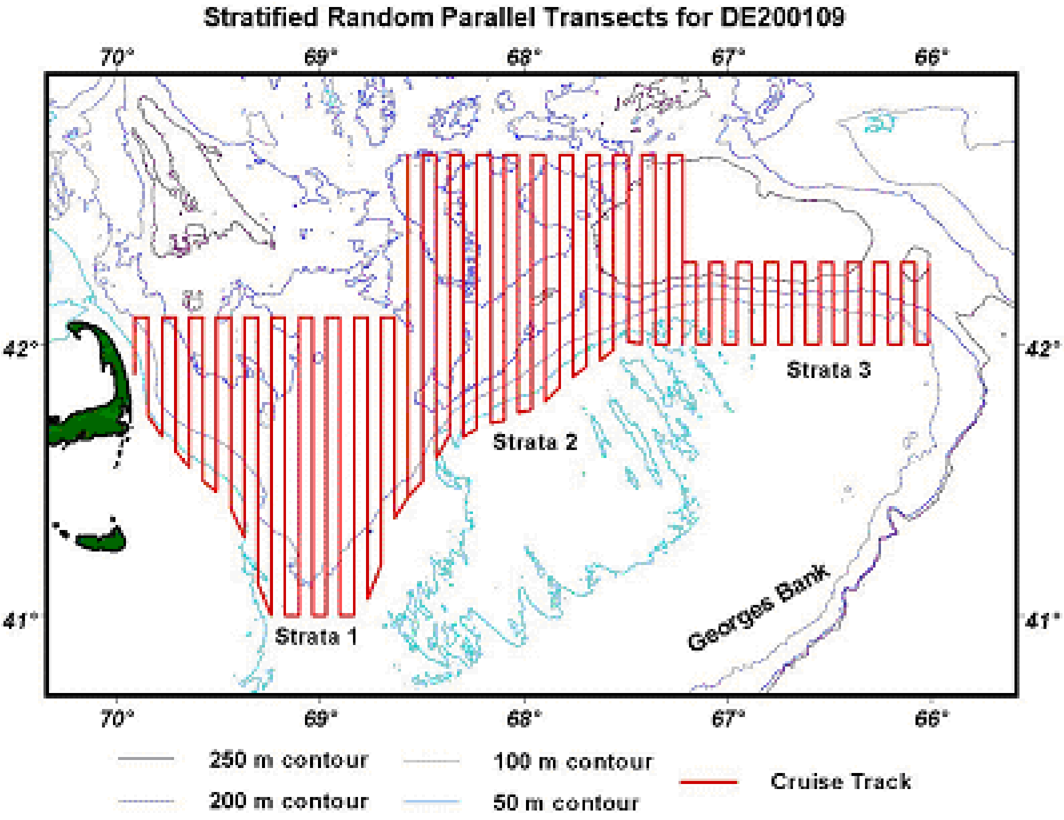


Figure 7.14. Stratified random parallel transect design for surveying Atlantic herring on Georges Bank during 2001

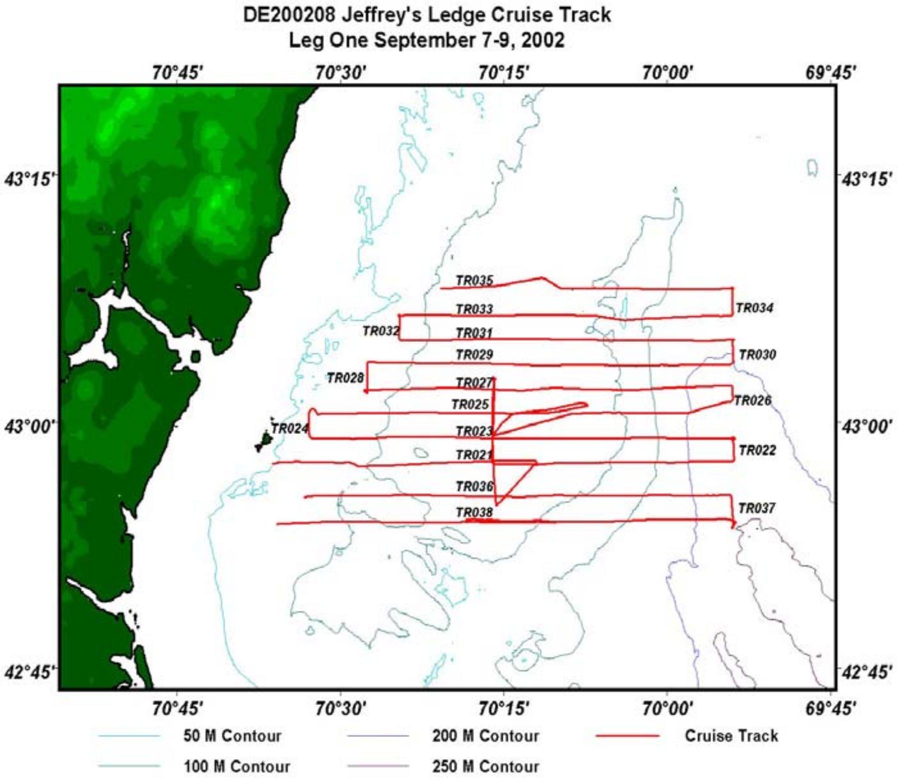


Figure 7.15. Parallel design for surveying Atlantic herring on Jefferys Ledge during 2002

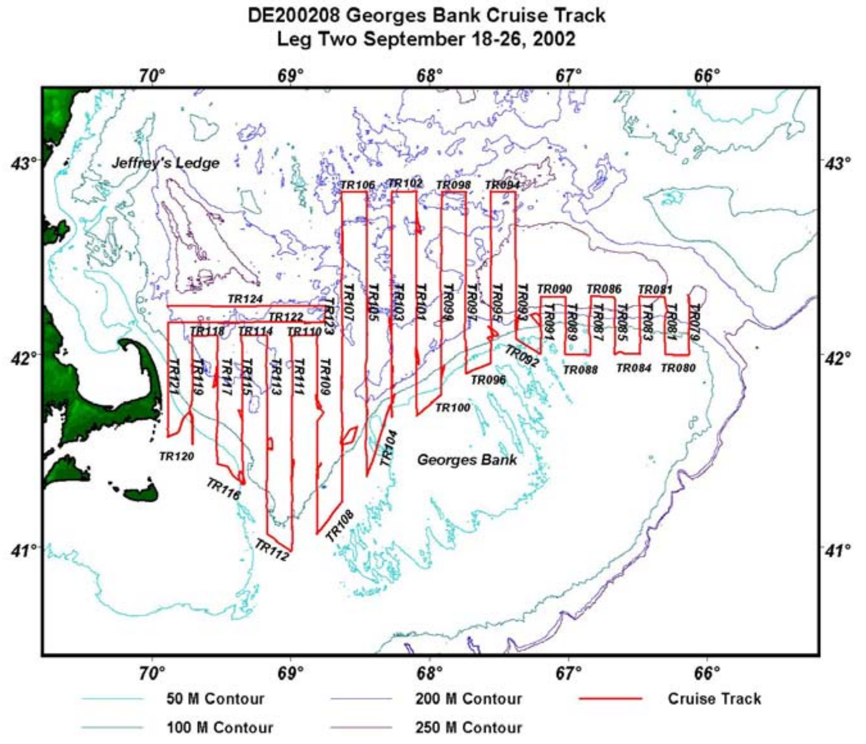


Figure 7.16. Parallel design for surveying Atlantic herring on Georges Bank during 2002.

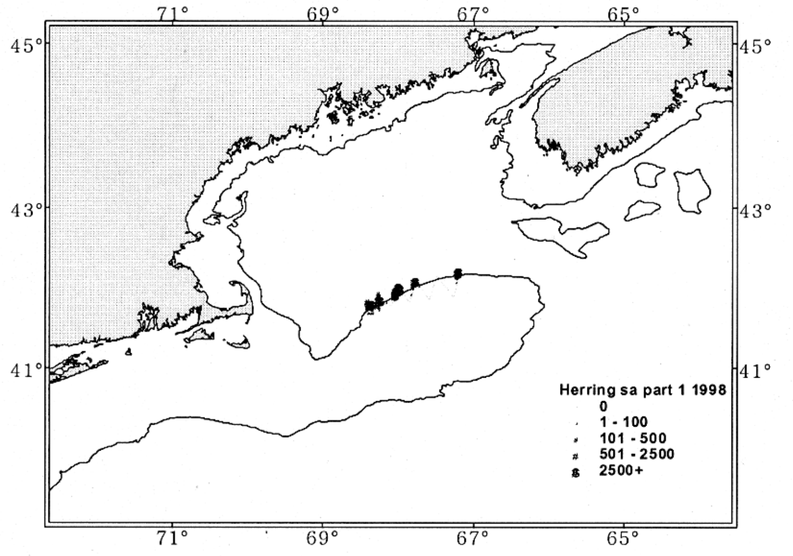


Figure 7.17. Herring backscatter (Sa) on transects from a zigzag survey design on Georges Bank during 1998.

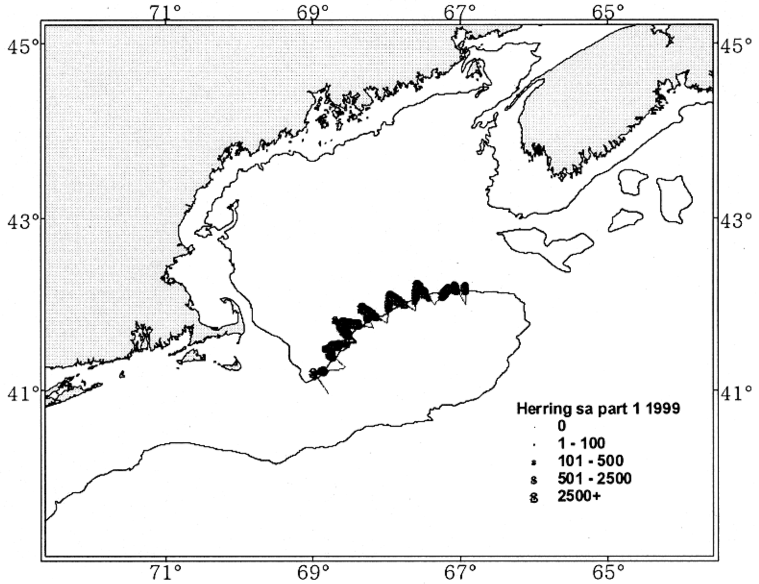


Figure 7.18. Herring backscatter on transects from a zigzag survey (part 1) design on Georges Bank during 1999.

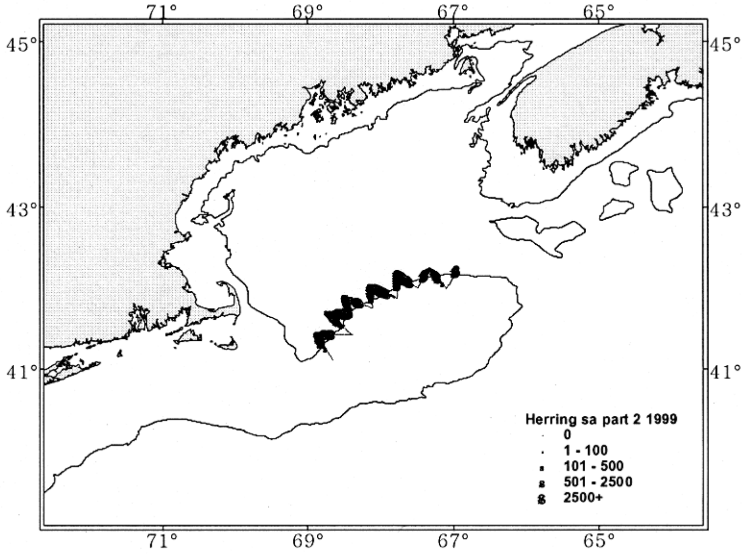


Figure 7.19. Herring backscatter on transects from a zigzag survey (Part 2) on Georges Bank during 1999.

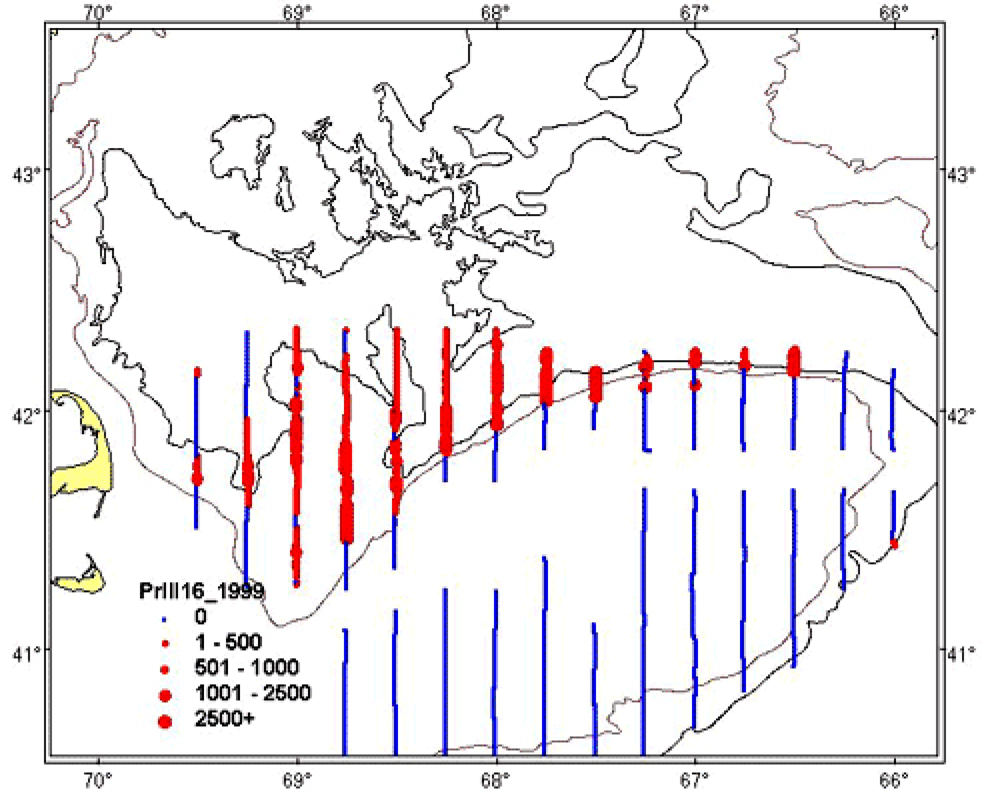


Figure 7.20. Herring backscatter (Sa) on transects from a parallel design on Georges Bank during 1999.

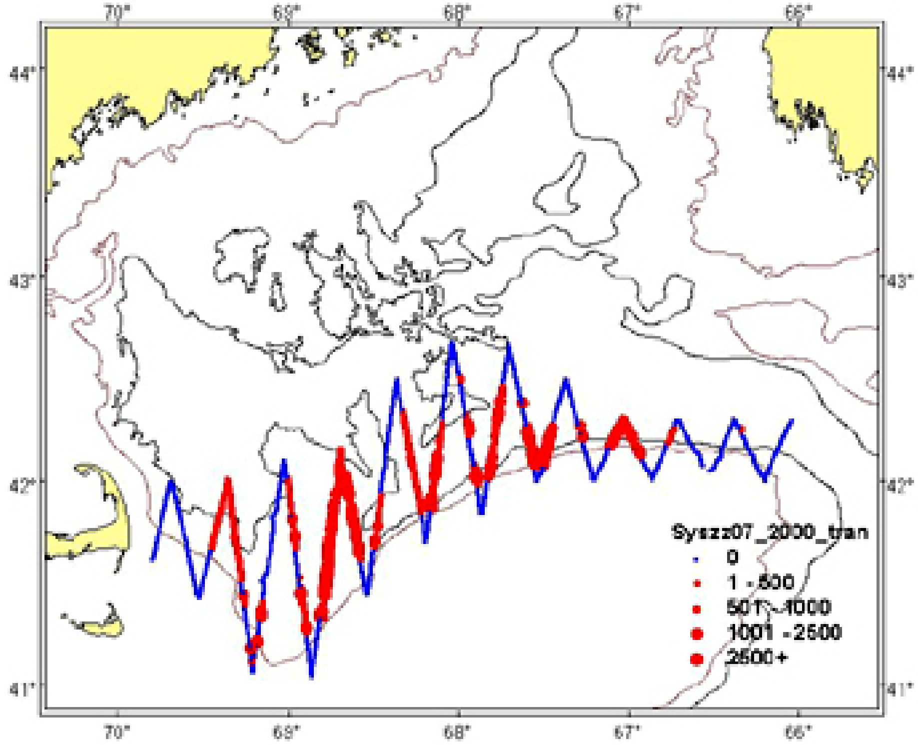


Figure 7.21. Herring backscatter (Sa) on transects from a zigzag survey design on Georges Bank during 2000.

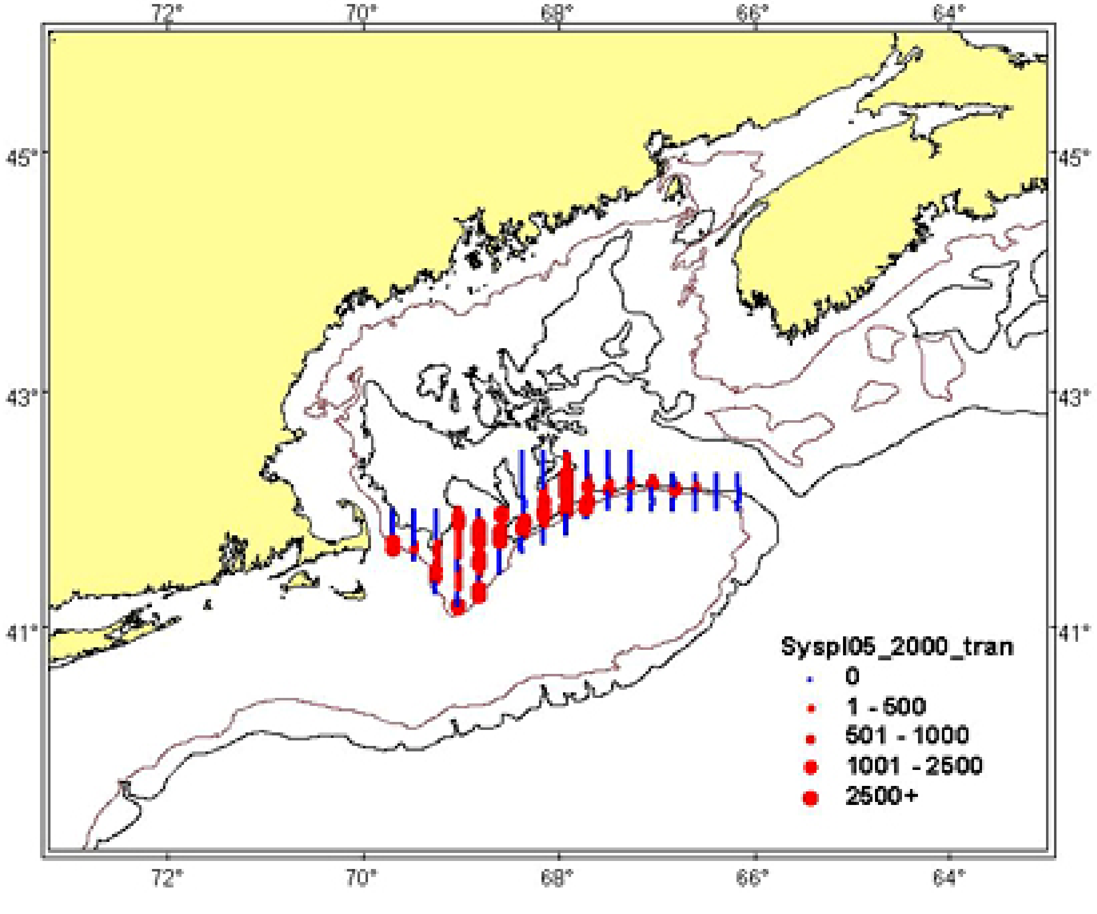


Figure 7.22. Herring backscatter (Sa) on transects from a Parallel survey design on Georges Bank during 2000

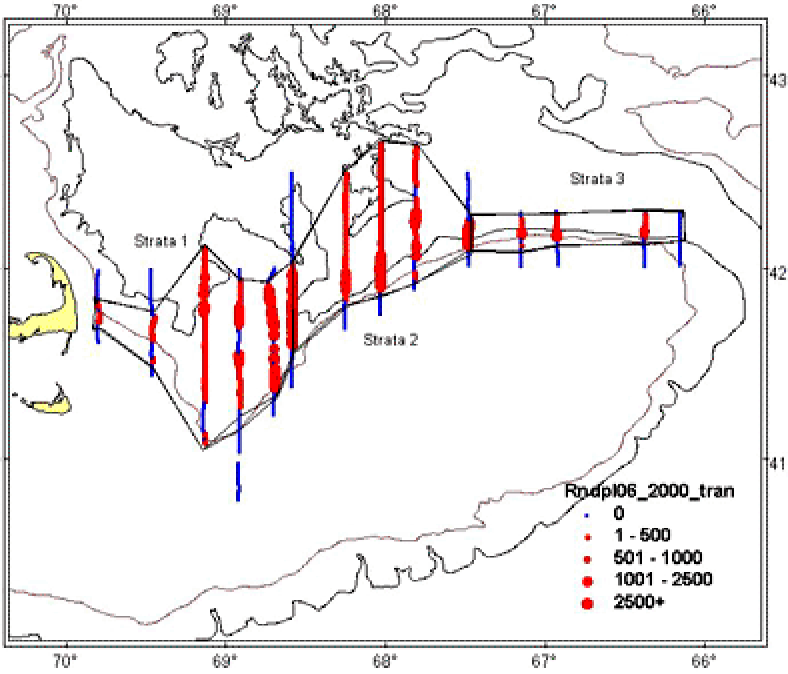


Figure 7.23. Herring backscatter (Sa) on transects from a stratified random survey on Georges Bank during 2000.

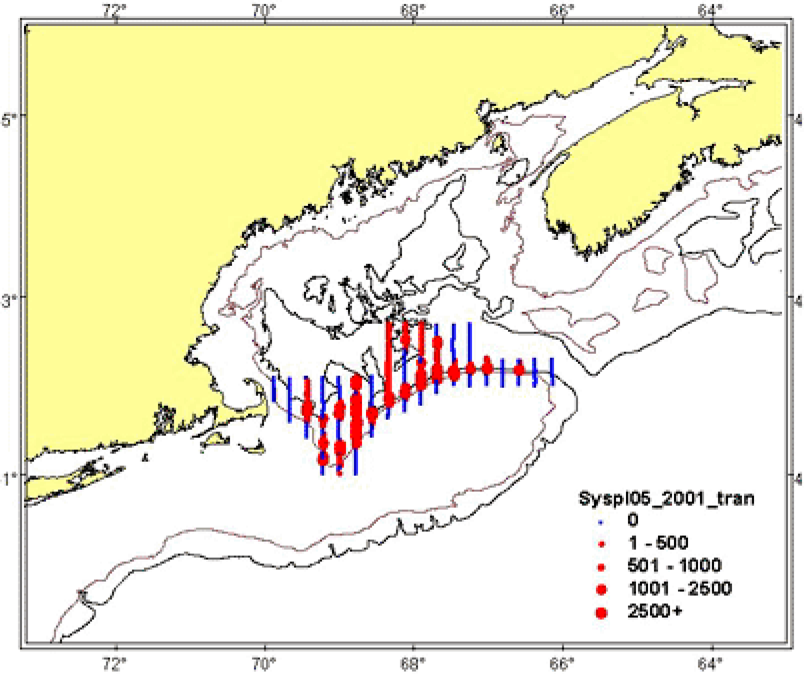


Figure 7.24. Atlantic herring backscatter (Sa) on transects from a parallel survey design on Georges Bank during 2001.

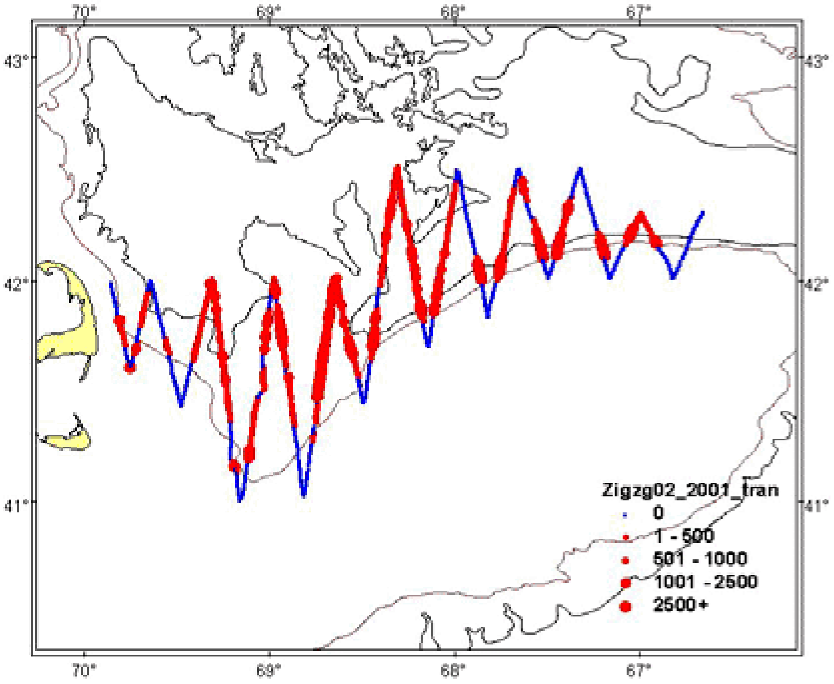


Figure 7.25. Atlantic herring backscatter (Sa) on transects from a zigzag survey design on Georges Bank during 2001.

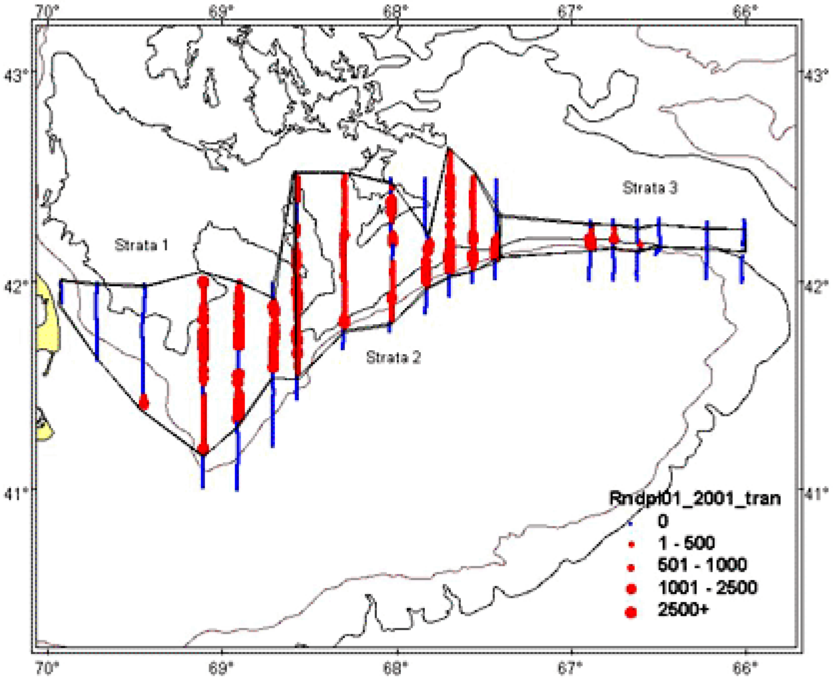


Figure 7.26. Atlantic herring backscatter (Sa) on transects from a stratified random design on Georges Bank during 2001

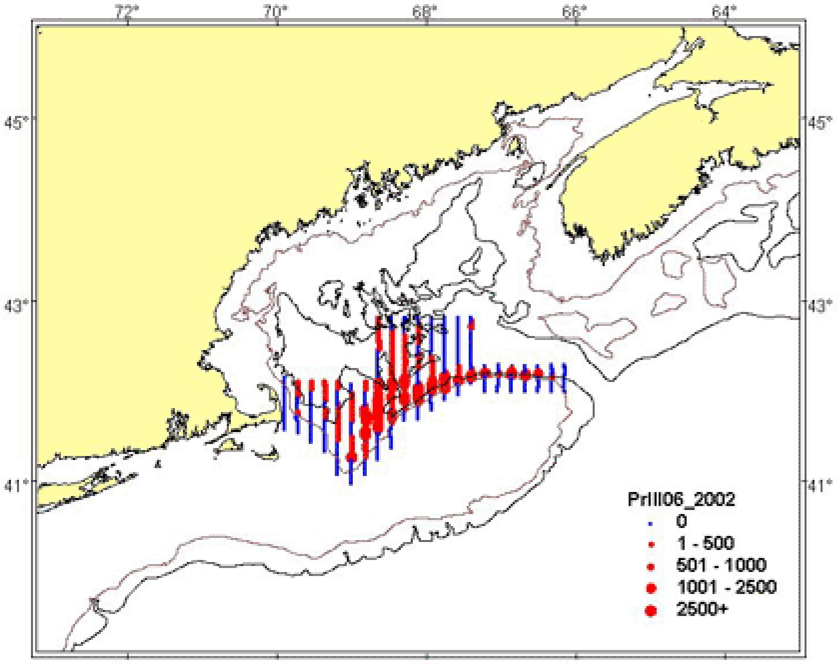


Figure 7.27. Atlantic herring backscatter (Sa) on transects from a parallel survey design on Georges Bank during 2002.

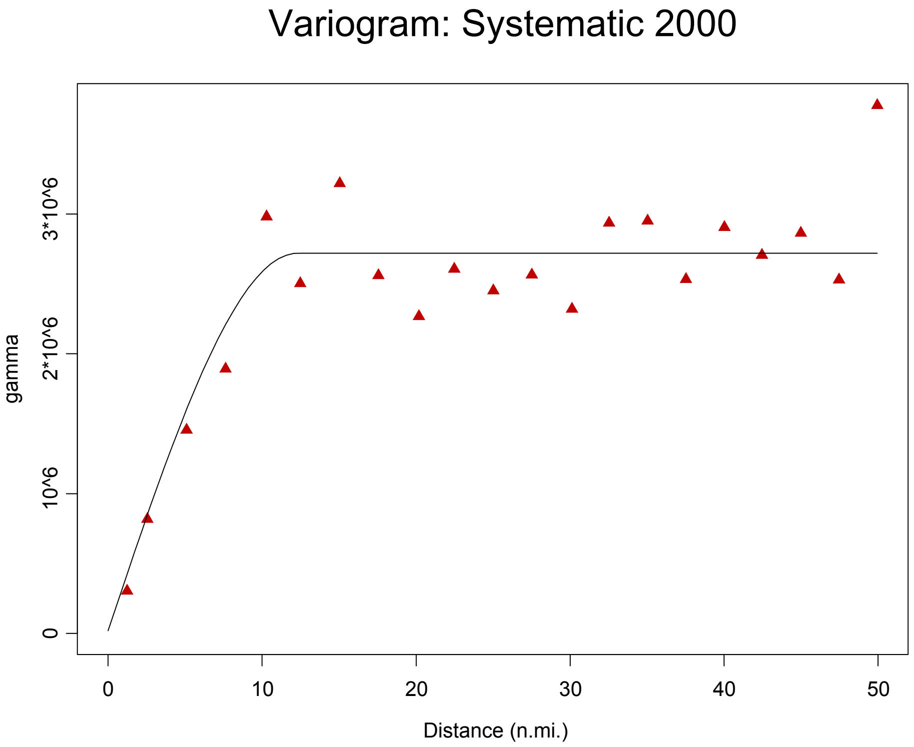


Figure 7.28. Variogram from the parallel survey design on Georges Bank during 2000.

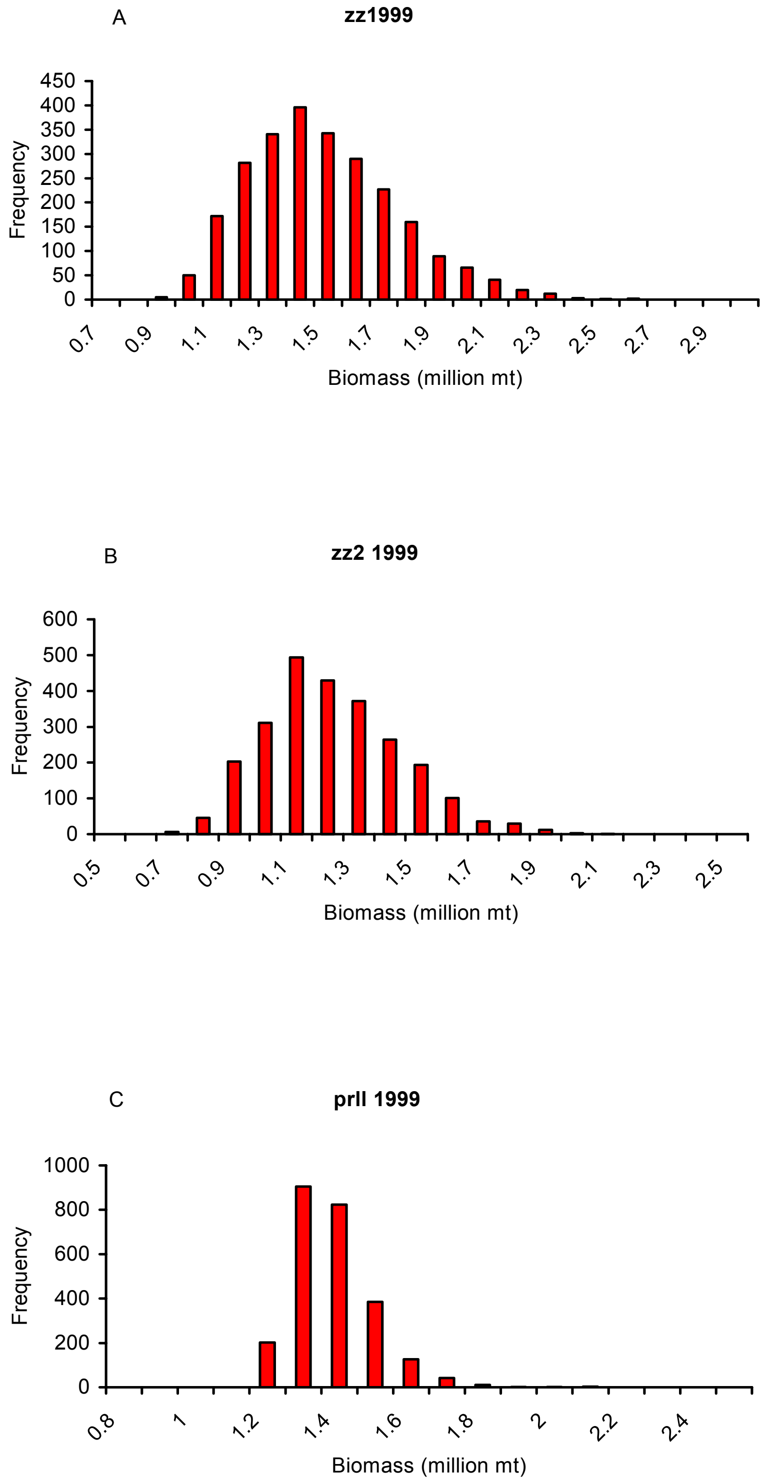


Figure 7.29. Biomass from bootstrap analysis for zigzag part 1 (A), zigzag part 2 (B), and parallel survey (C)designs on Georges Bank during 1999

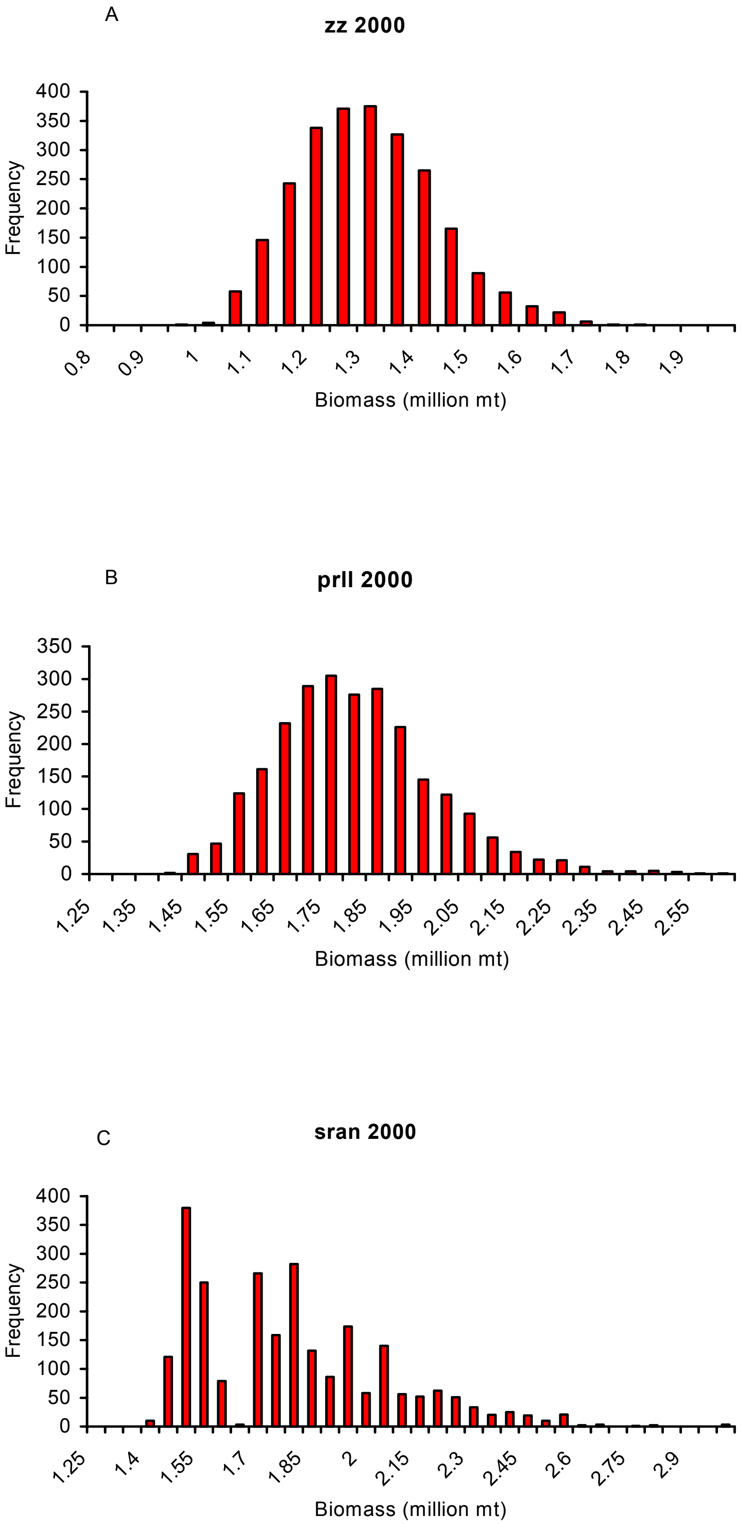


Figure 7.30. Biomass from bootstrap analysis for zigzag (A), parallel (B), and stratified random (C) survey designs on Georges Bank during 2000.

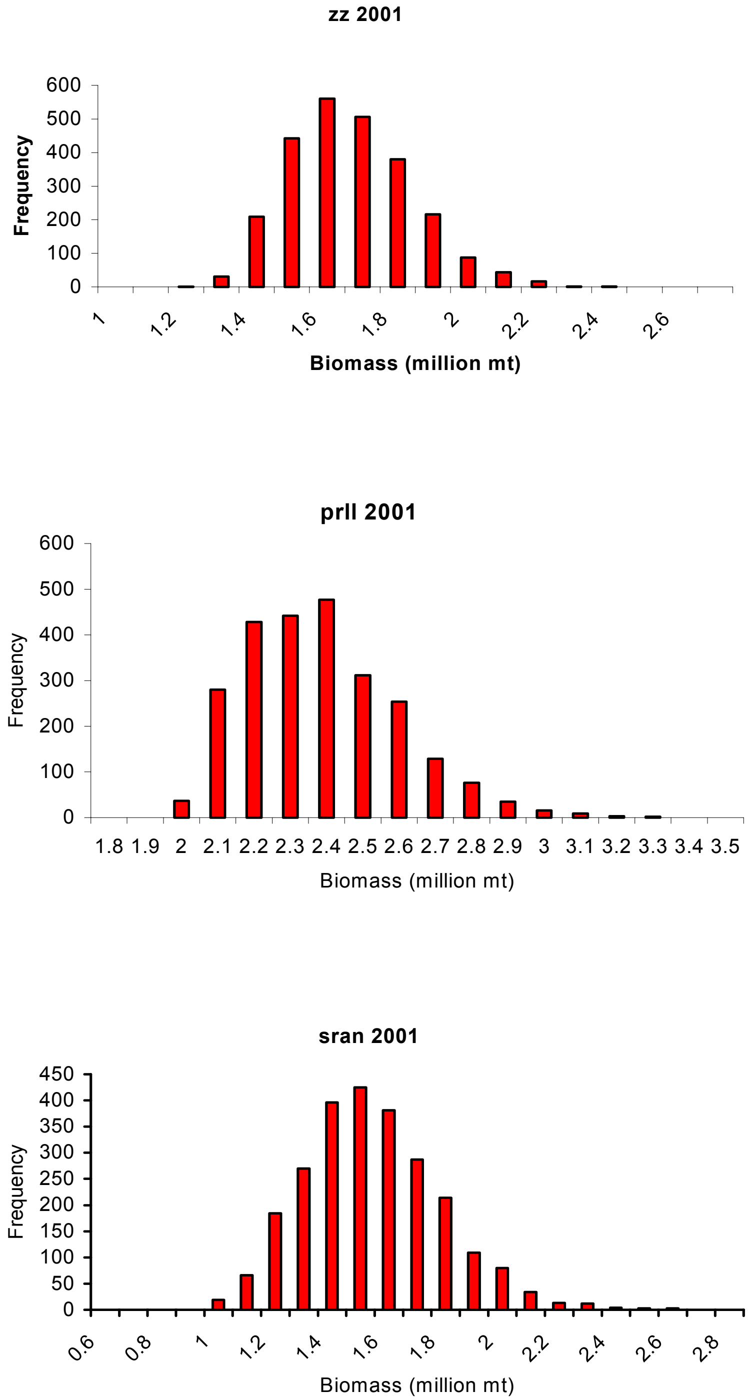


Figure 7.31. Biomass from bootstrap analysis for zigzag (A), parallel (B), and stratified random (C) survey designs on Georges Bank during 2001

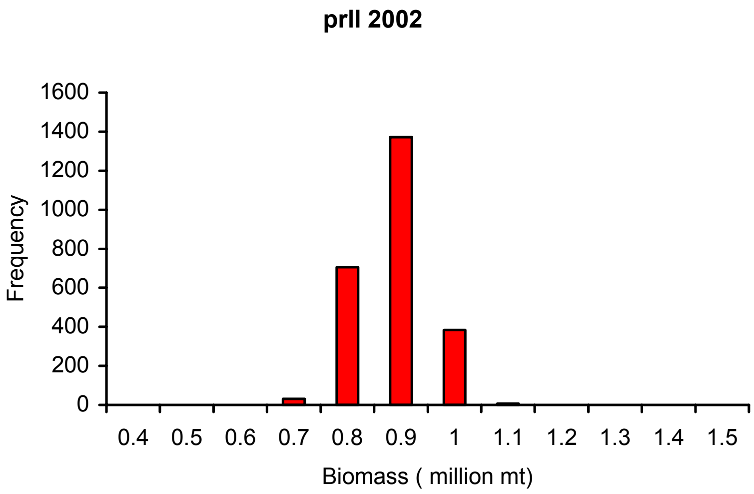


Figure 7.32. Biomass from bootstrap analysis for a parallel survey design on Georges Bank during 2002.

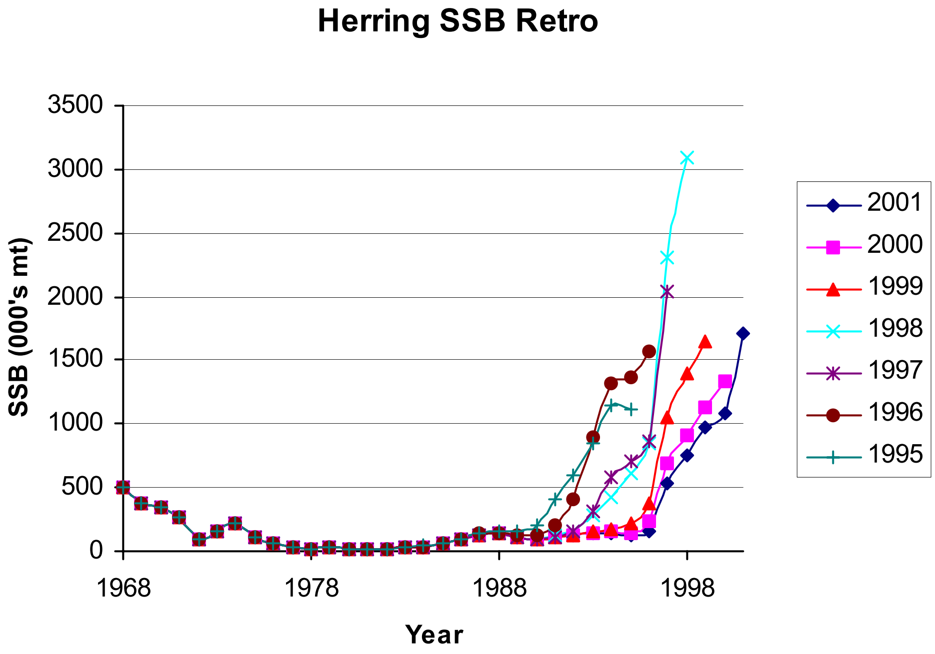


Figure 9.1. Retrospective pattern in spawning stock biomass during 1995-2001 in VPA.

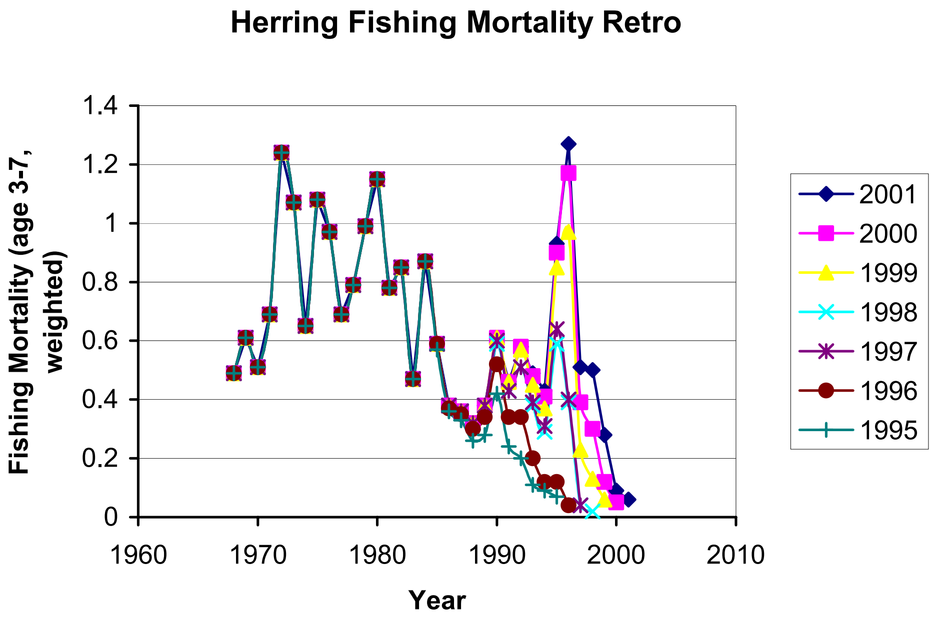


Figure 9.2. Retrospective pattern in fishing mortality during 1995-2001 from VPA.

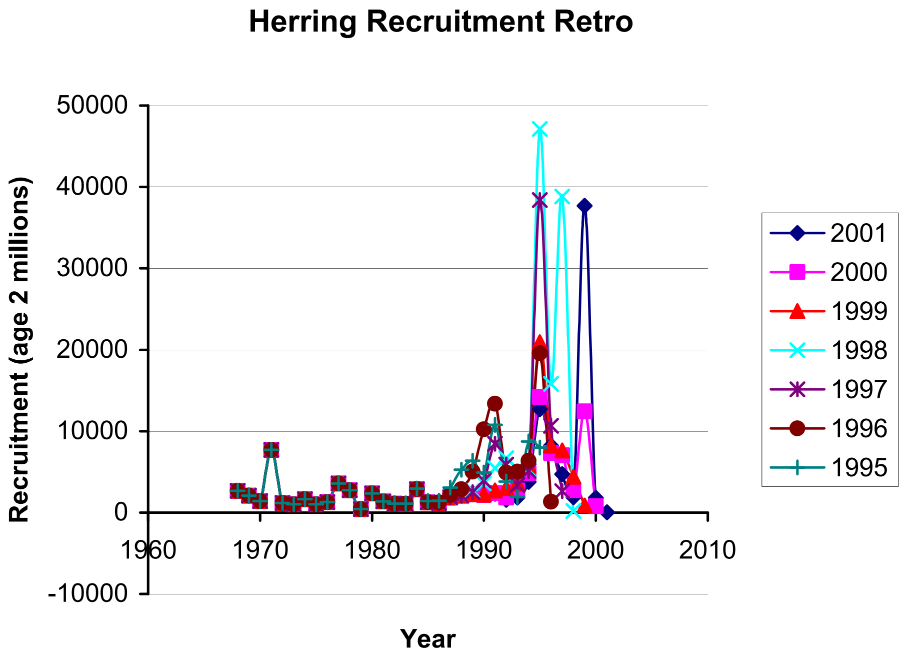


Figure 9.3. Retrospective pattern in recruitment (age 2 millions) during 1995-2001 from VPA.

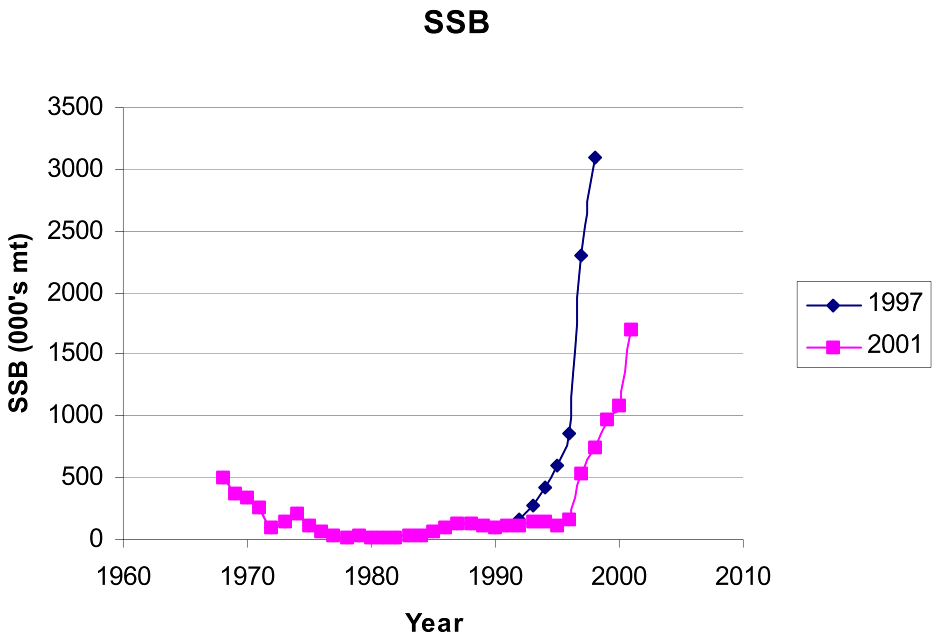


Figure 9.4. Spawning stock biomass from VPA runs starting in 1997 and 2001

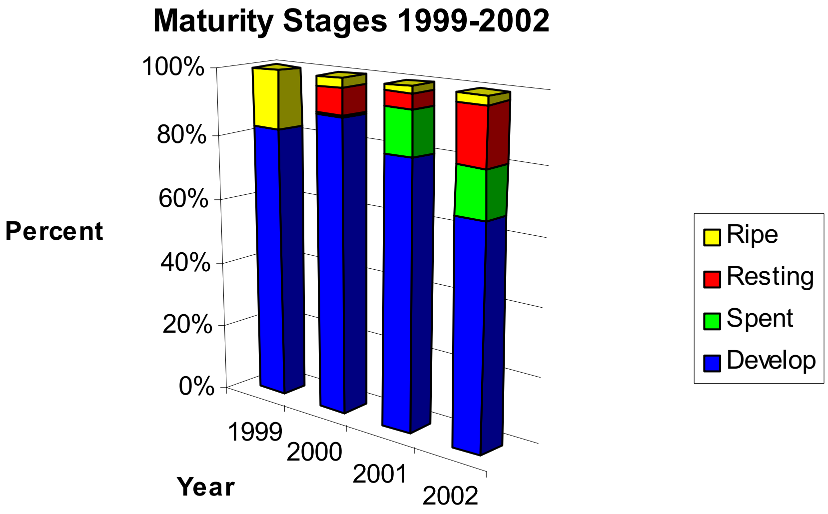


Figure 10.1. Overall proportion of mature herring at different maturity stages during acoustic survey cruises during 1999-2002

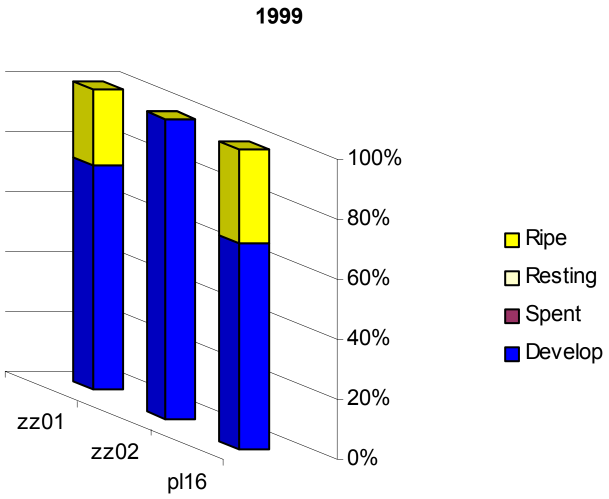


Figure 10.2. Maturity stages observed during consecutive herring acoustic surveys (starting with zz01) on Georges Bank during 1999.

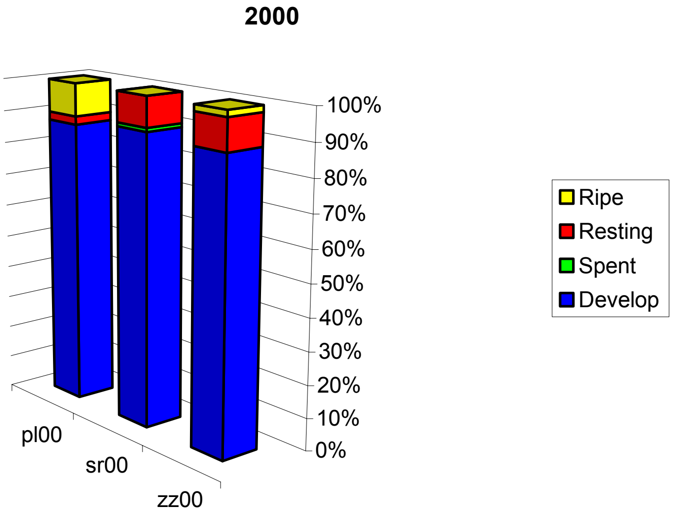


Figure 10.3. Maturity stages observed during consecutive herring acoustic surveys (starting with pl00) on Georges Bank during 2000

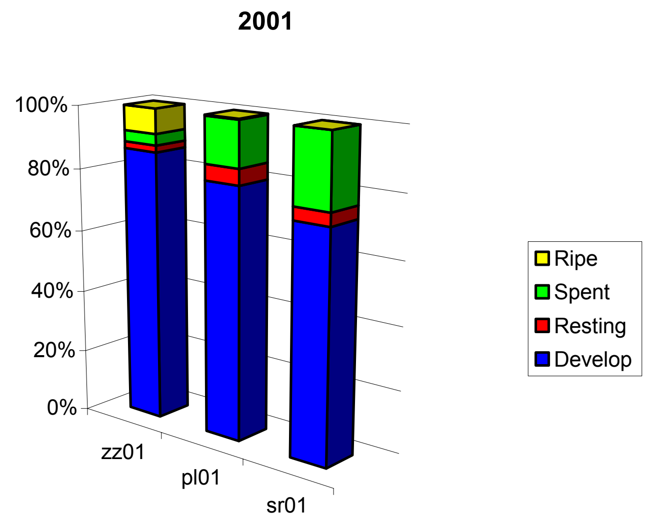


Figure 10.4. Maturity stages observed during consecutive herring acoustic surveys (starting with zz01) on Georges Bank during 2001

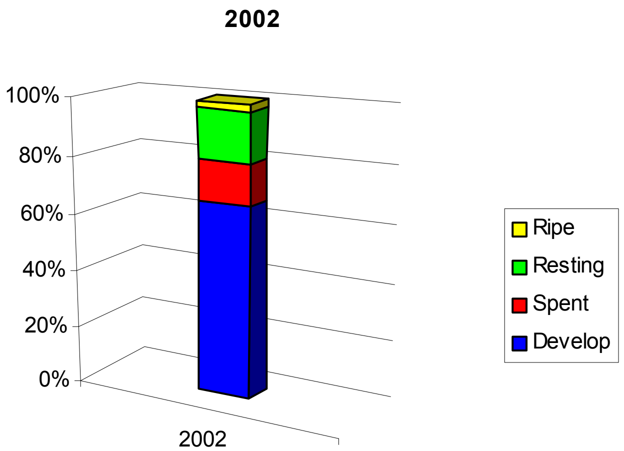


Figure 10.5. Maturity stages observed on a herring acoustic survey on Georges Bank during 2002.

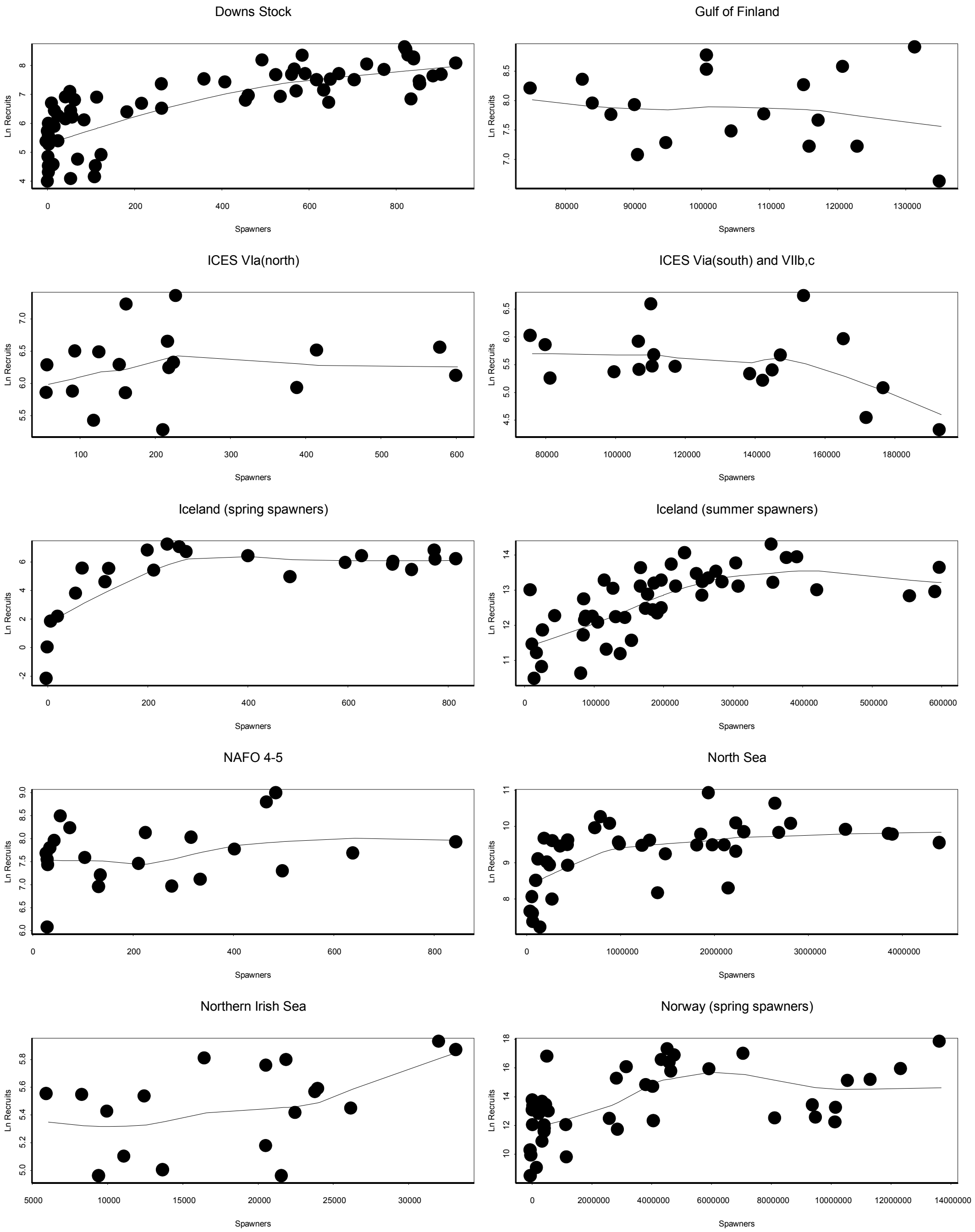


Figure 10.6. Log recruit numbers plotted against spawning biomass for ten North Atlantic Herring Stocks. Smooth lines are nonparametric stock-recruit models fit by loess regression.

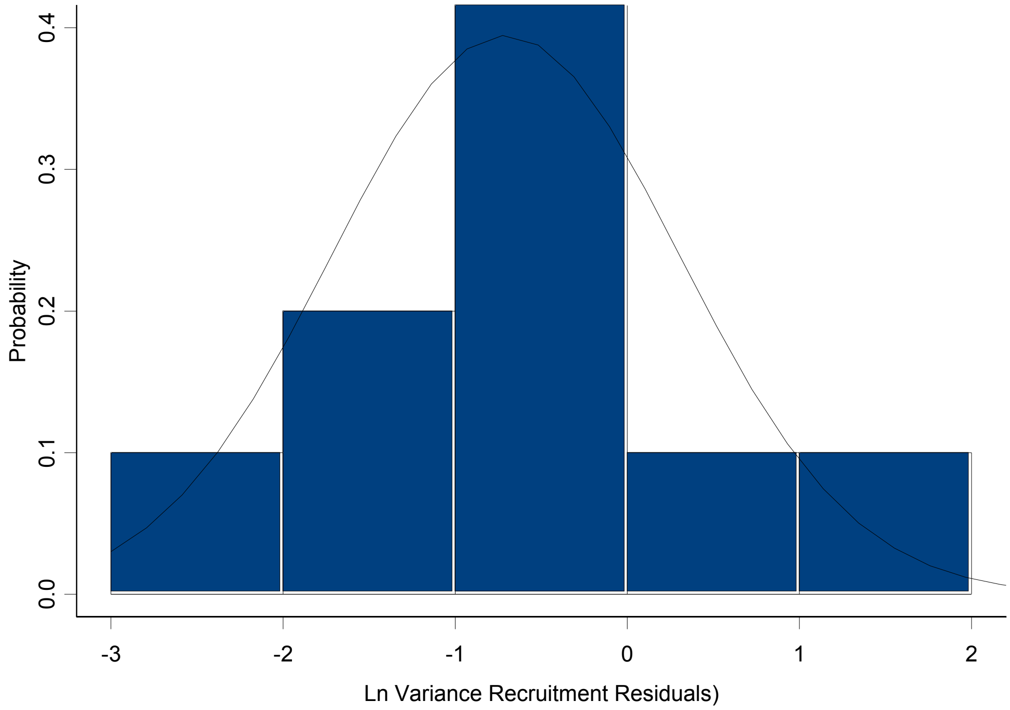


Figure 10.7. Distribution of variance estimates for log recruitment residuals from nonparametric stock recruit models for ten North Atlantic herring stocks.

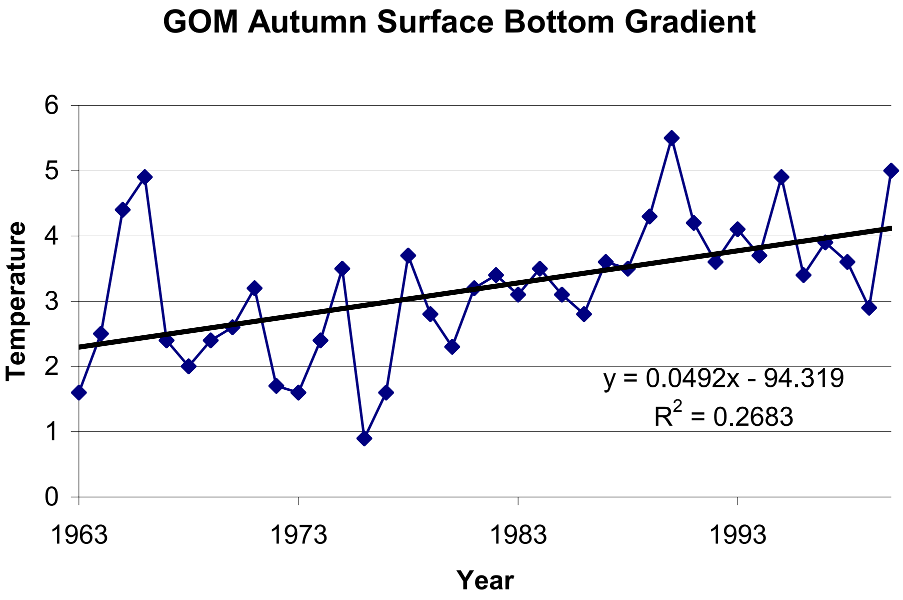


Figure 10.8 Surface-Bottom gradient from differencing the surface and bottom temperatures from the Gulf of Maine during 1963-2000

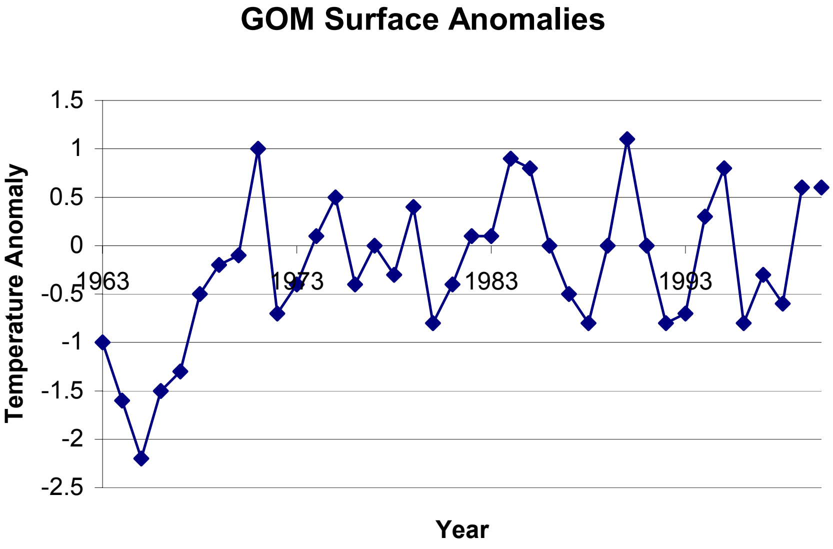


Figure 10.9. Sea surface temperature anomalies for the Gulf of Maine during 1963-2000.

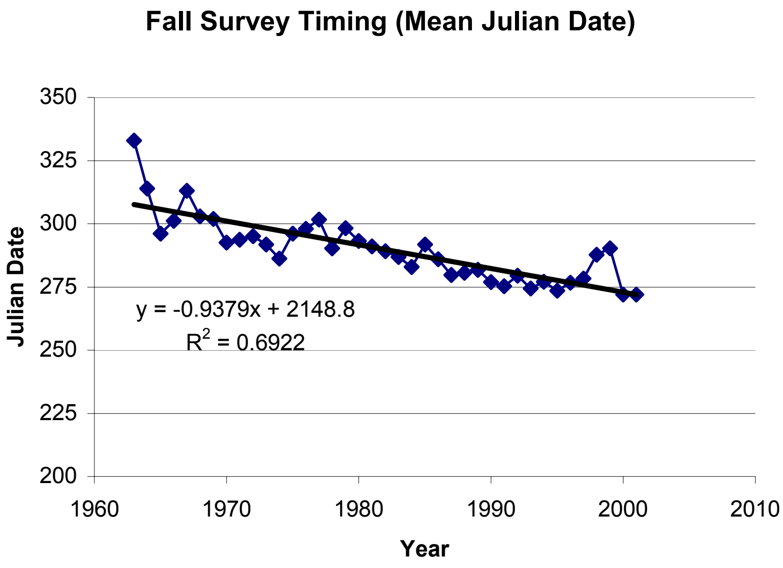


Figure 10.10. Autumn survey timing (mean Julian date) during 1963-2001.

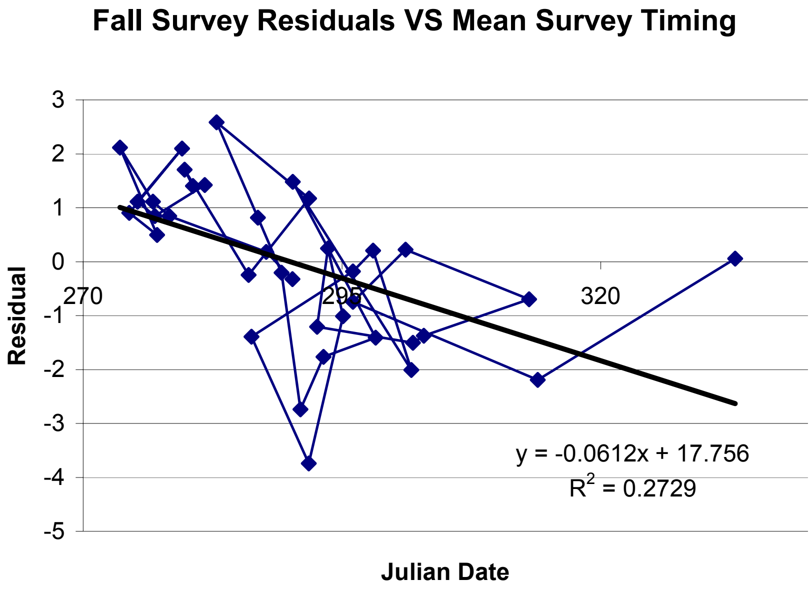


Figure 10.11. Autumn survey residuals and mean survey timing (Julian date) for 1963-2000.

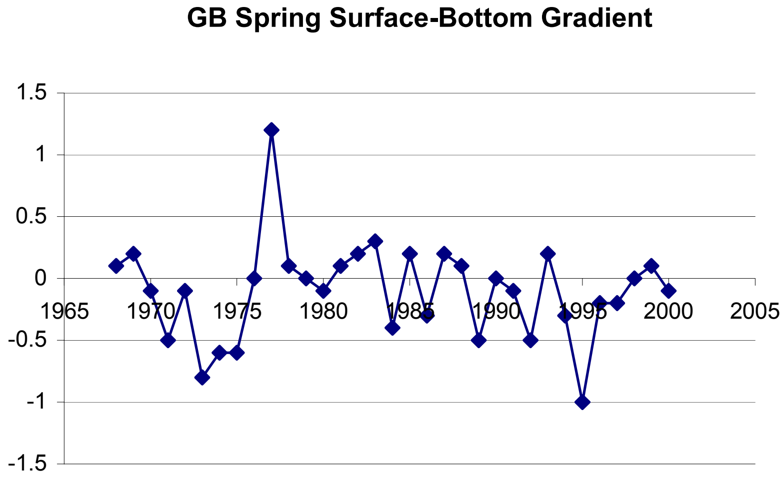


Figure 10.12. Spring surface-bottom gradient from differencing the surface and bottom temperatures from the Gulf of Maine during 1968

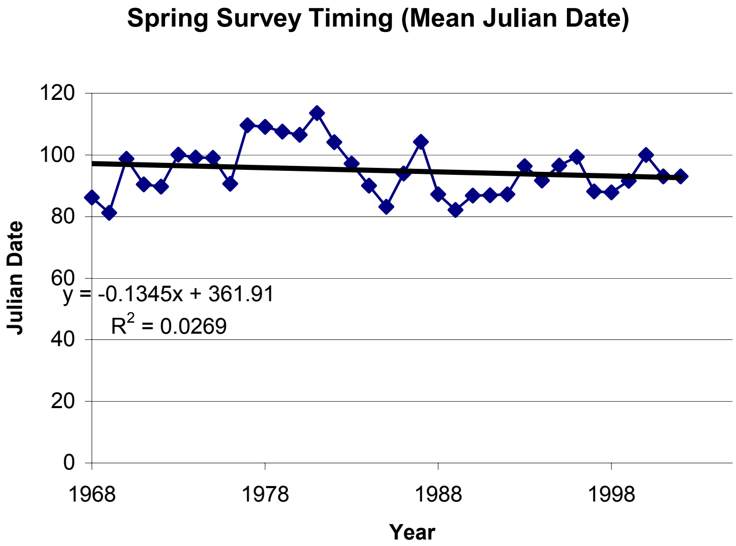


Figure 10.13. Spring survey timing (mean Julian date) during 1968-2002.

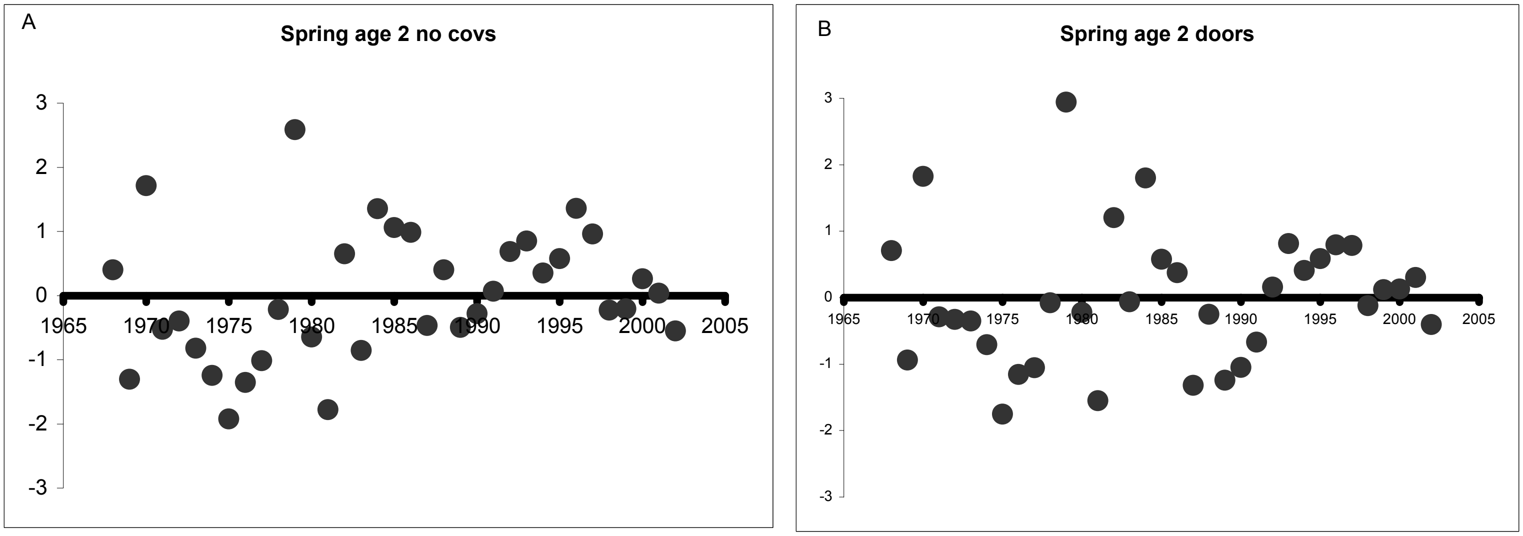


Figure 10.14. Spring surveys age 2 weight/tow showing differences in residual patterns for age 2 without and with a door covariate (panels A and B) for 1968-2002

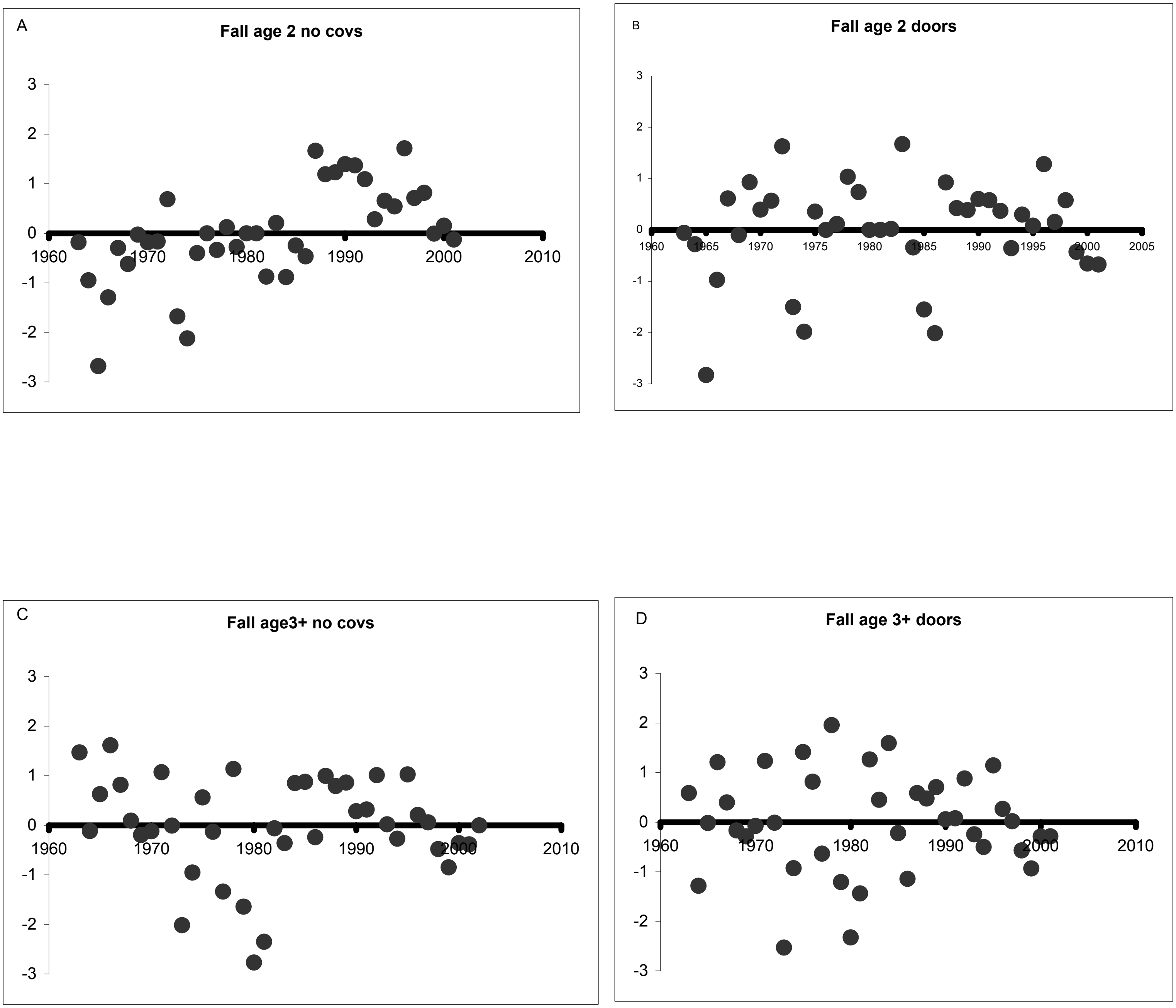


Figure 10.15. Autumn surveys age 2 and age 3+ weight/tow showing differences in residual patterns for age 2 without and with a door covariate (panels A and B) and age 3+ (panel C and D) for 1963-2002

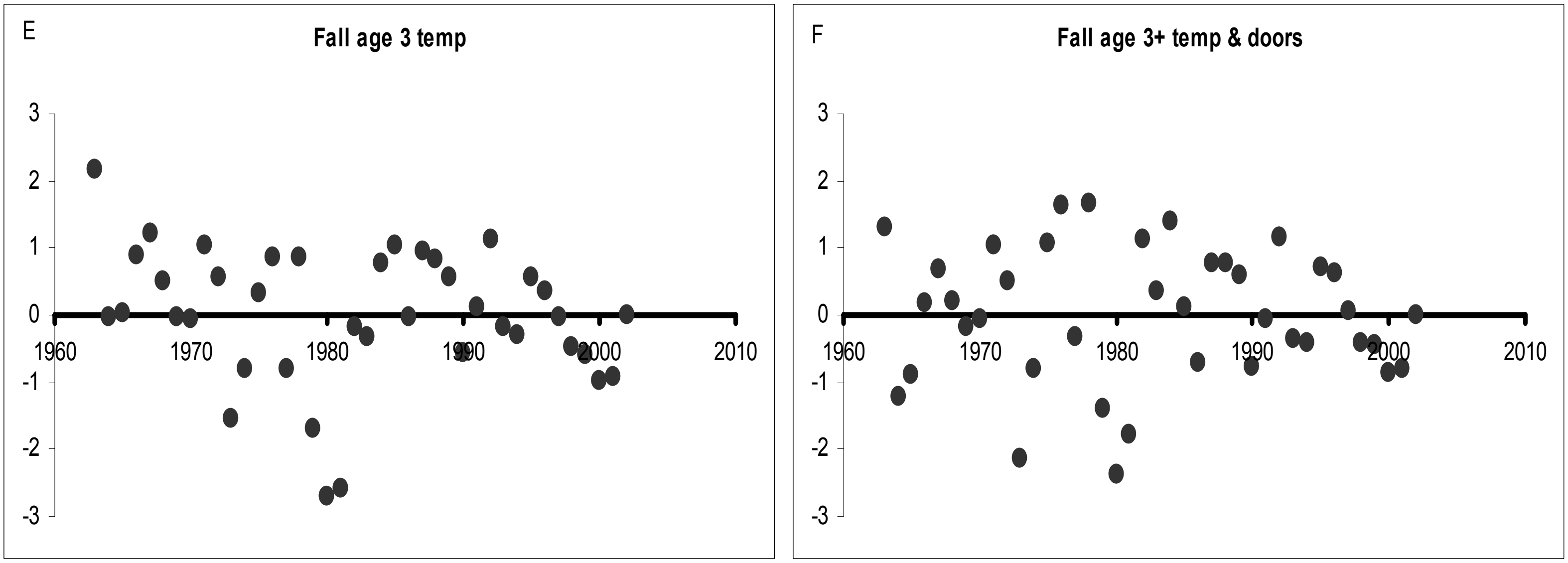
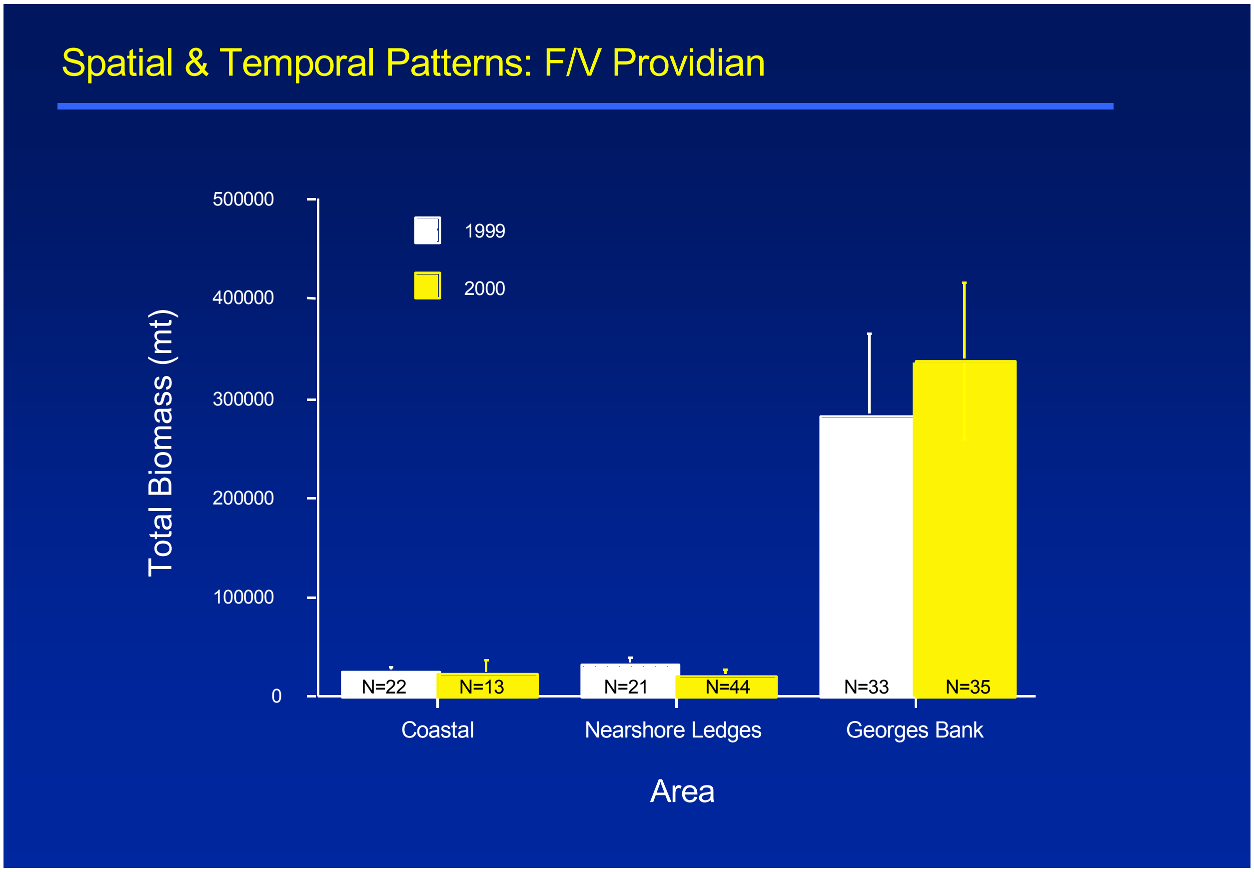


Figure 10.15 cont'd. Autumn surveys age 3+ weight/tow showing differences in residual patterns for age 3+ with a temperature and with a temperature and door covariate (panel E and F) for 1963-2002



Spatial & Temporal Patterns: F/V Providian

Figure 10.16. Average biomass estimates from F/V Providian for inshore and nearshore Gulf of Maine and Georges Bank during 1999 and 2000.

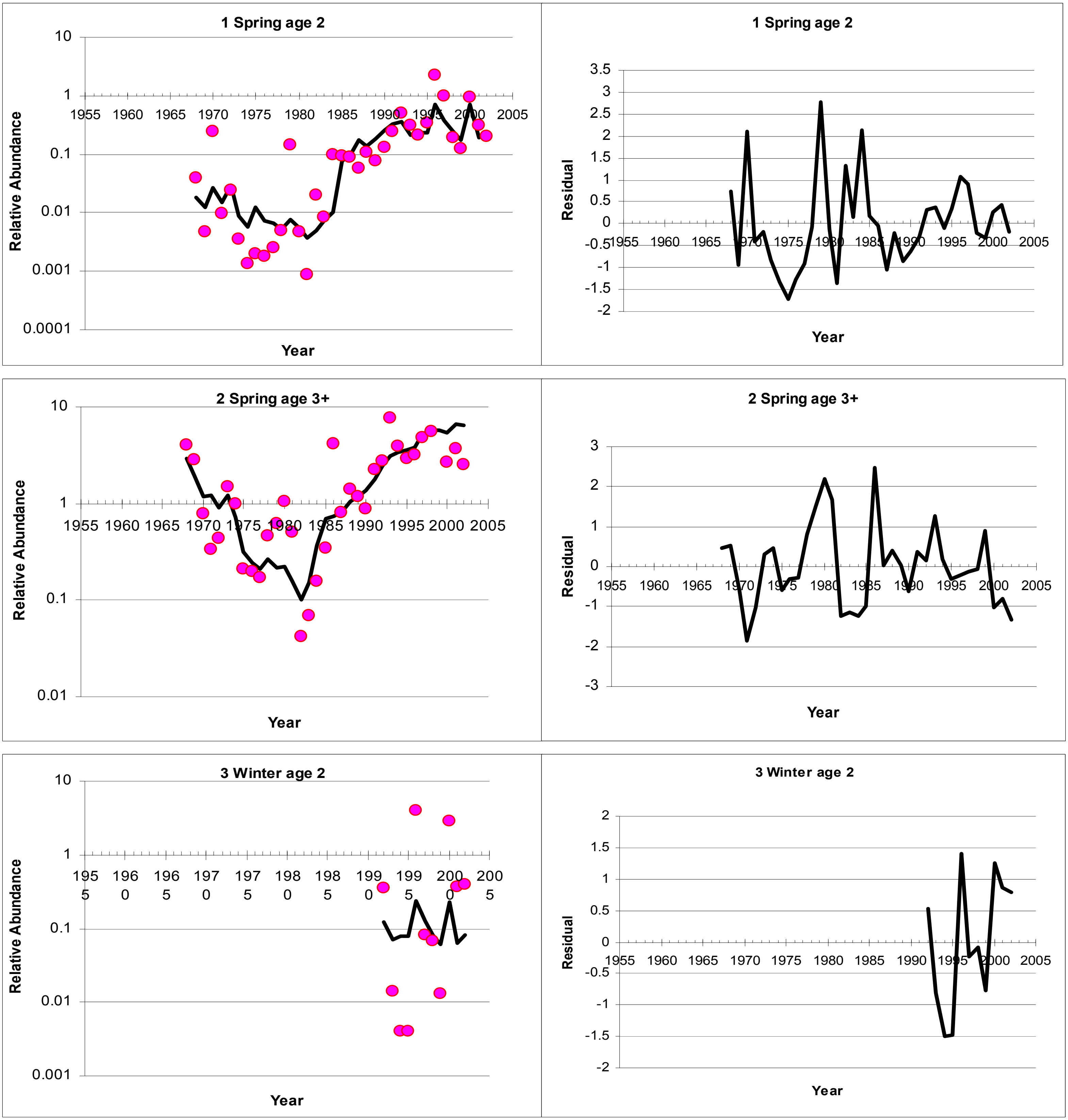


Figure 10.17. Observed vs predicted (log scale) and residuals vs time for the spring age 2, spring age 3+, and winter age 2 US surveys.

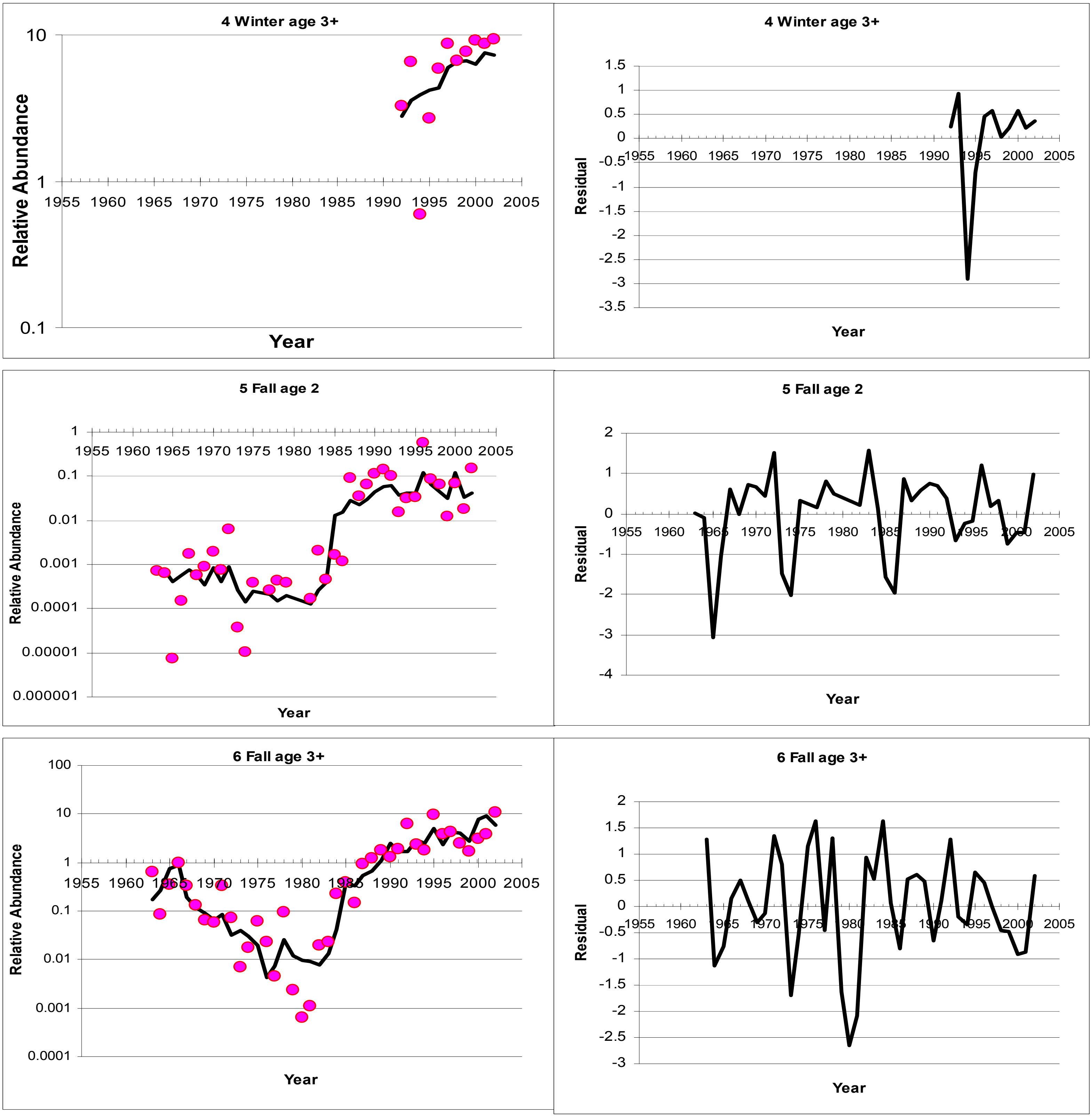


Figure 10.17 cont'd. Observed vs predicted (log scale) and residuals vs time for the winter age 3+, fall age 2, and fall age 3+ US surveys.

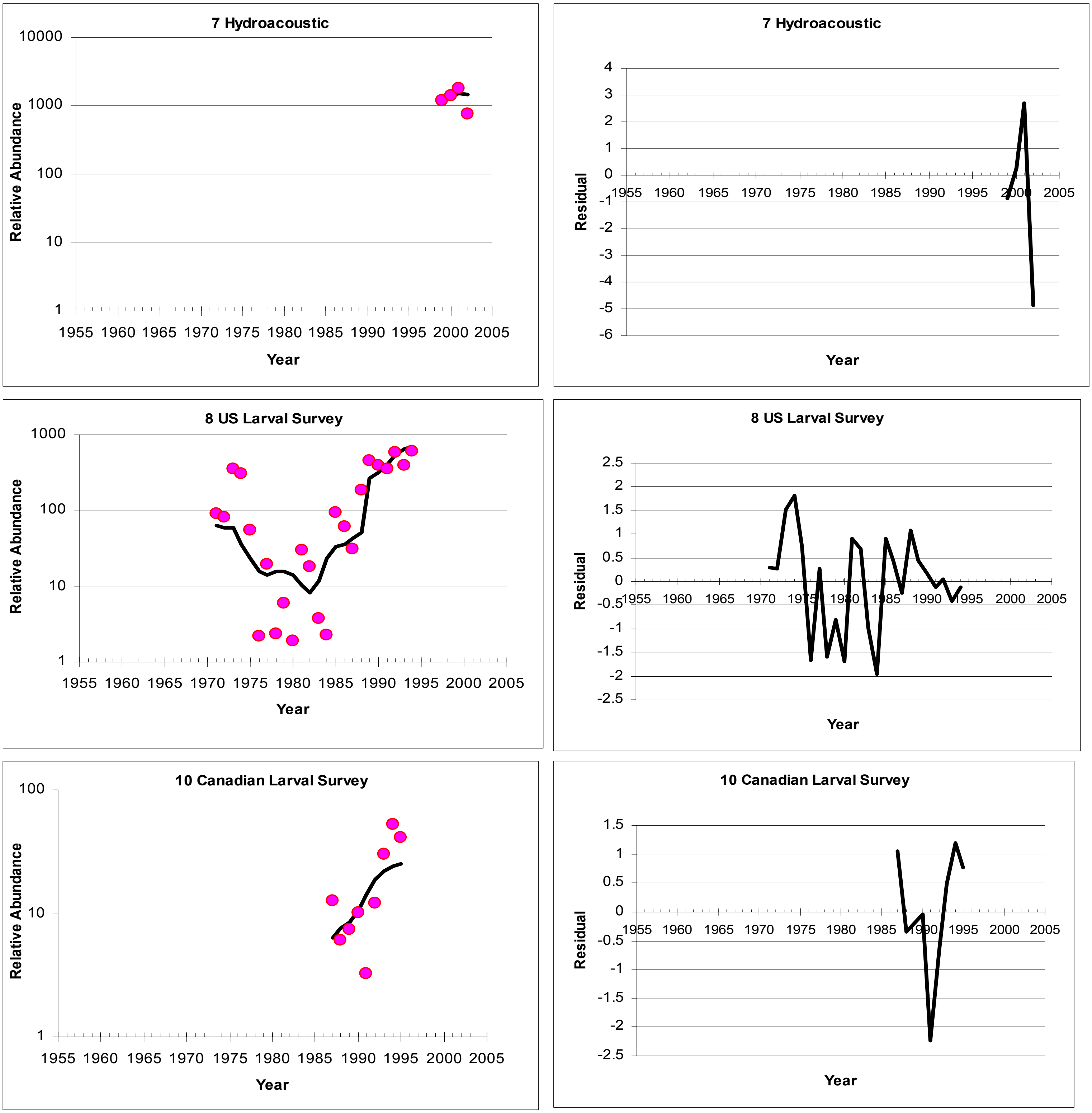


Figure 10.18. Observed vs predicted, and residuals vs time for the hydroacoustic, US Larval survey, and the Canadian Larval survey.

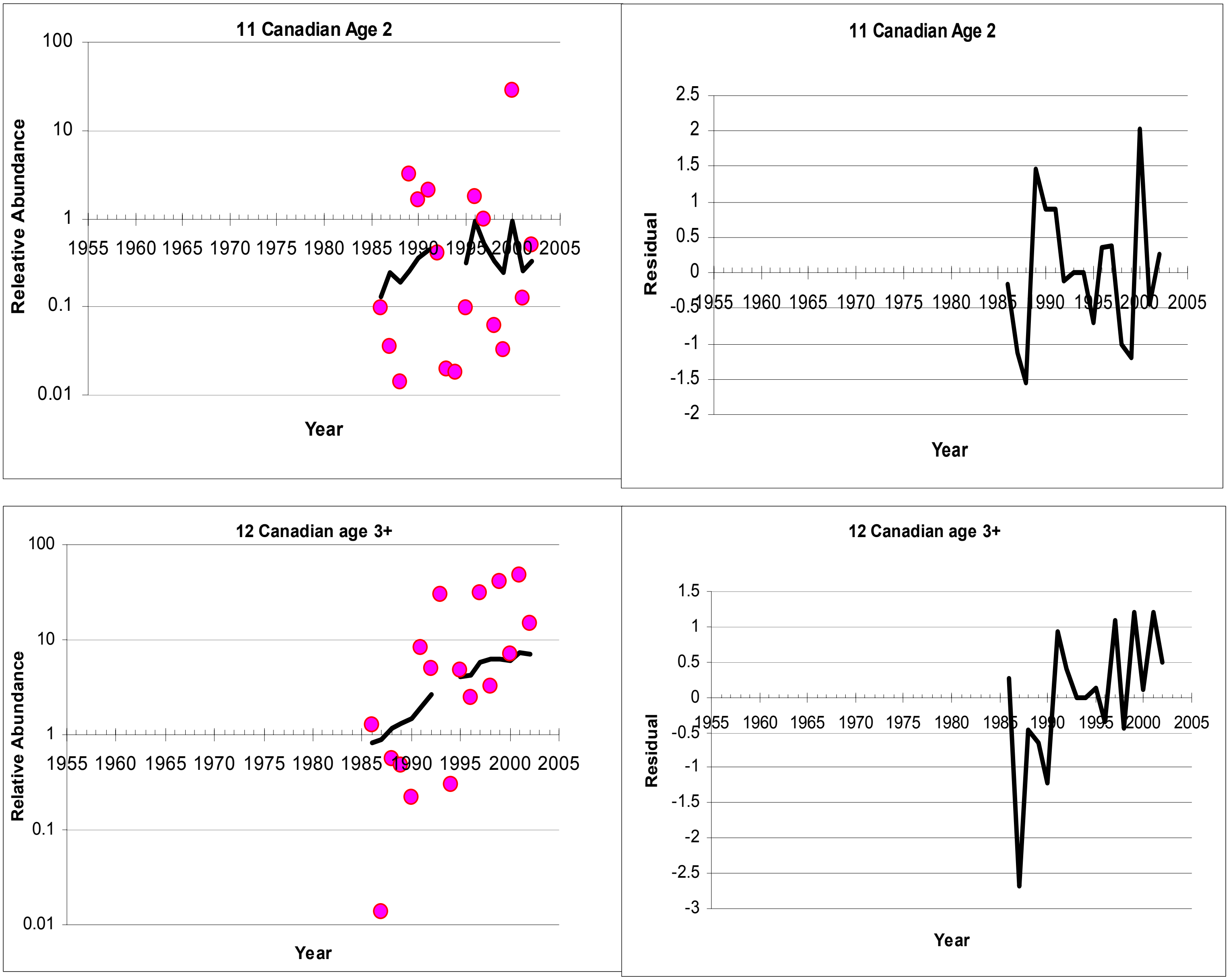


Figure 10.19. Observed and predicted relative abundance and residuals vs time.for the Canadian age 2 survey, and Canadian age 3+ survey

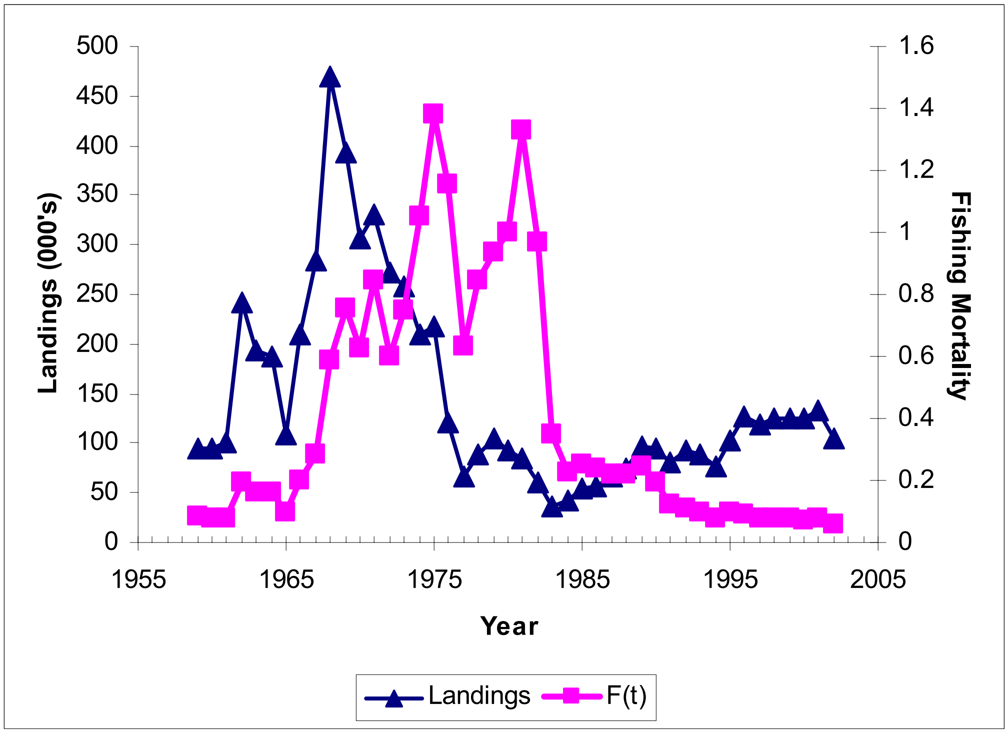


Figure 11.1 Estimated fishing mortality (F(t)) and landings from the Gulf of Maine-Georges Bank Atlantic herring complex during 1959-2002

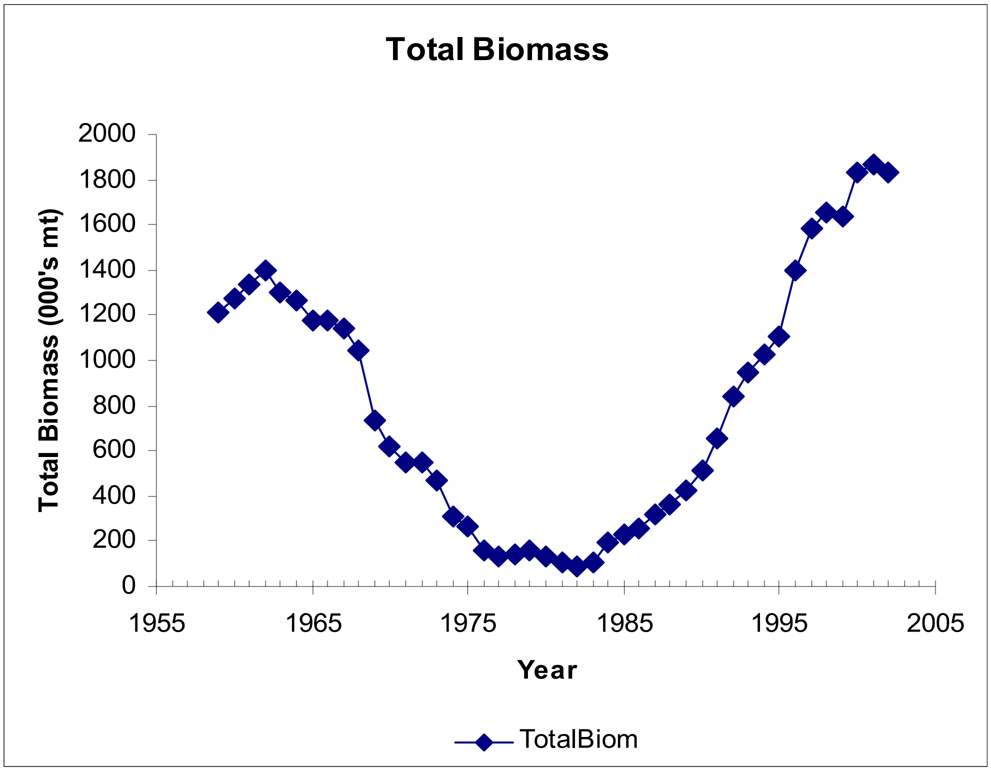


Figure 11.2 Total stock biomass from the Gulf of Maine-Georges Bank Atlantic herring complex during 1959-2002.

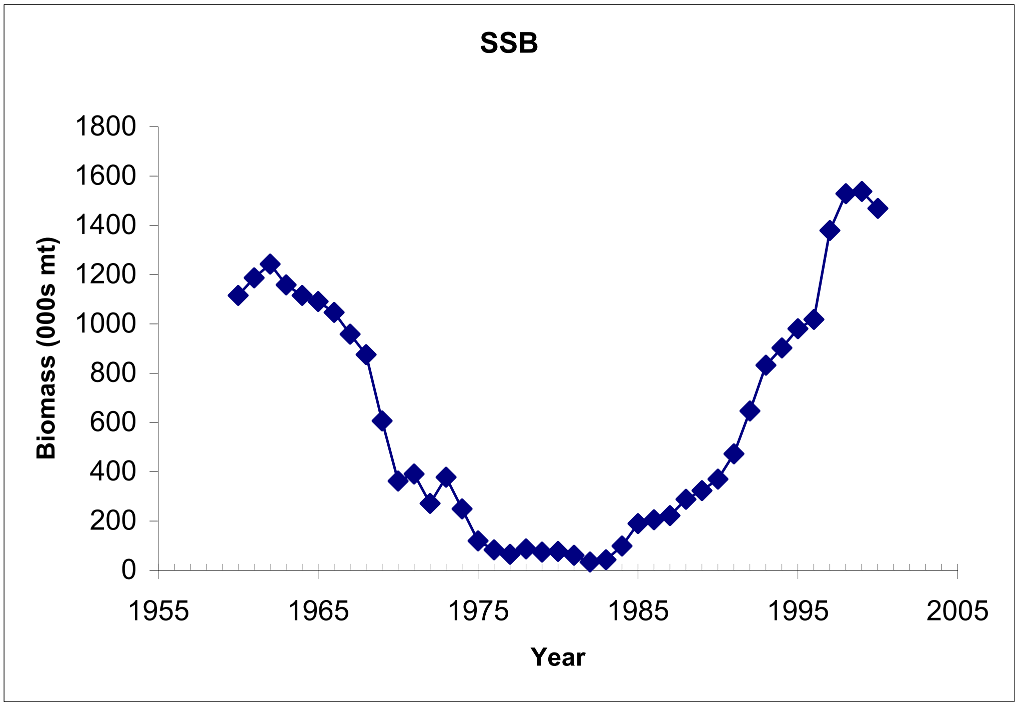


Figure 11.3. Spawning stock biomass (SSB) from the Gulf of Maine-Georges Bank Atlantic herring complex during 1960-2002.

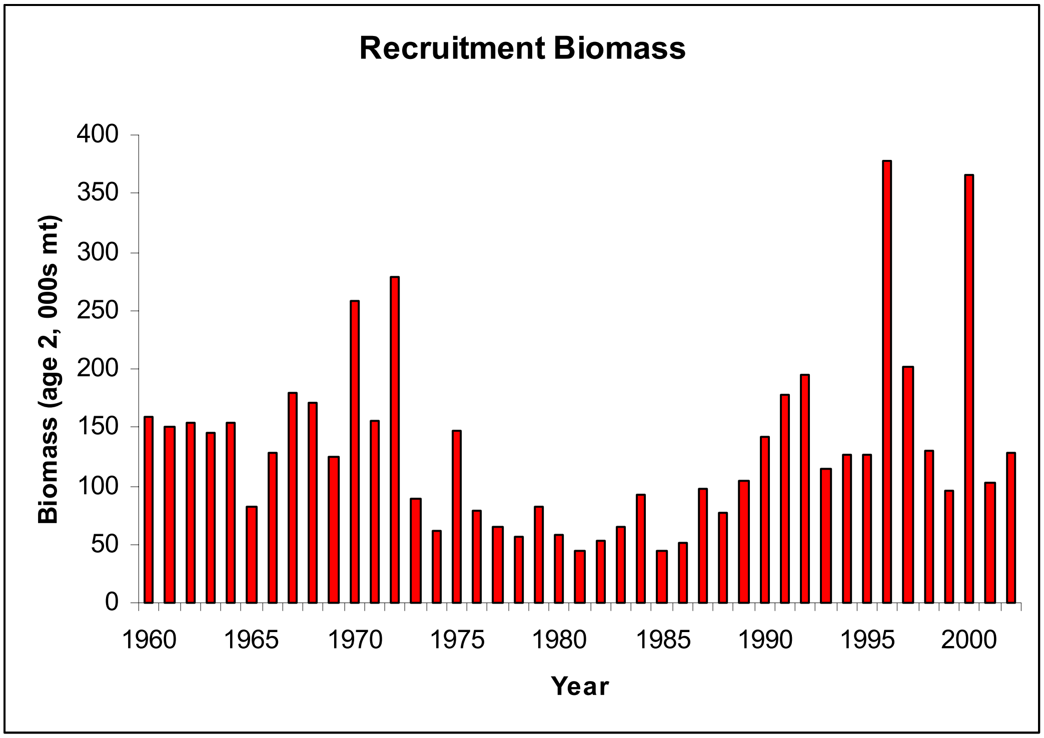


Figure 11.4. Recruitment biomass (age 2, 000s mt) from the Gulf of Maine-Georges Bank Atlantic herring complex during 1960-2002.

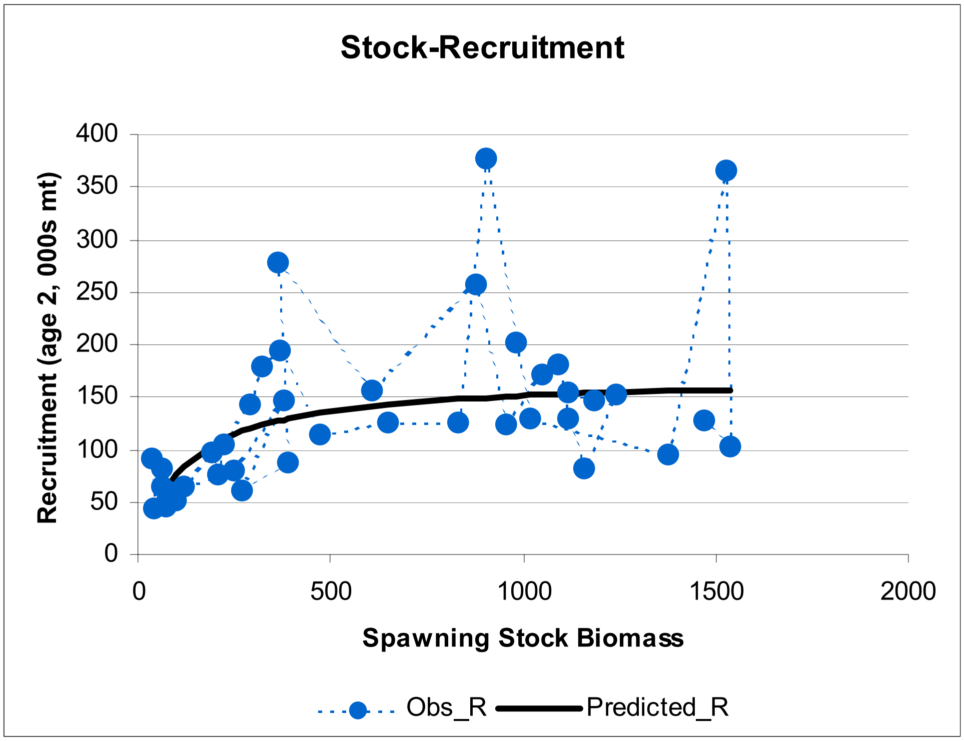


Figure 11.5. Stock-recruitment plot for the Gulf of Maine-Georges Bank herring complex during 1960-2000.

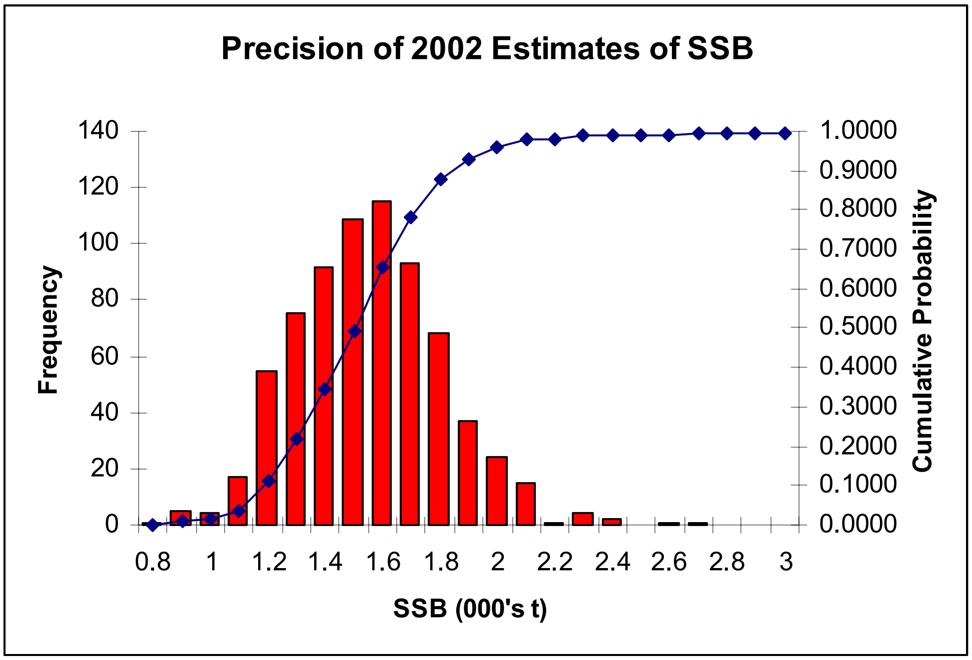


Figure 11.6. Frequency histogram of bootstrap values of terminal year (2002) spawning stock biomass from 750 replicates of the forward projection analysis

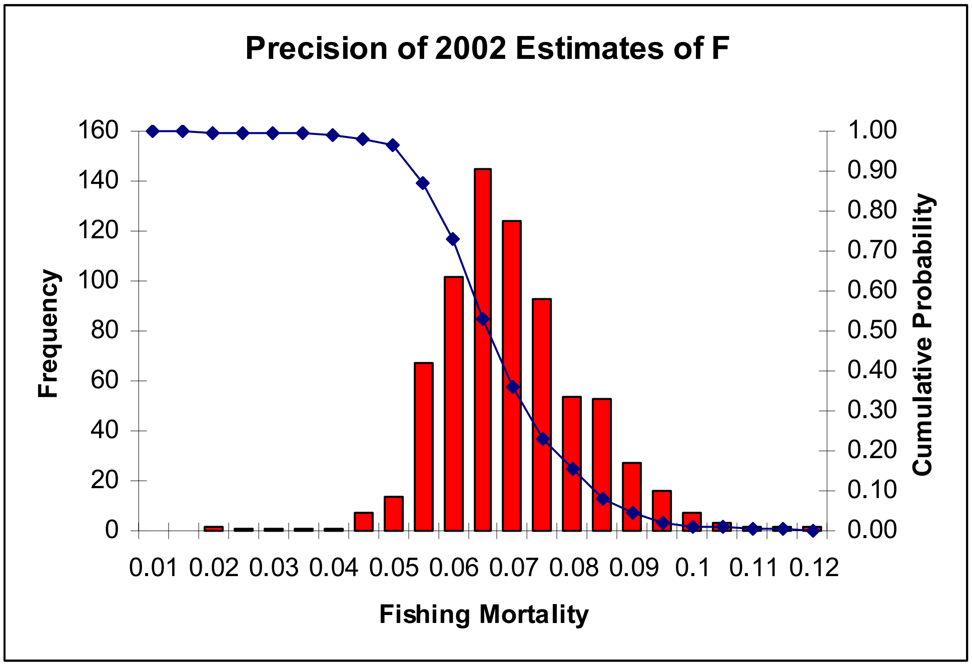


Figure 11.7. Frequency histogram of bootstrap values of terminal year (2002) fishing mortality from 750 replicates of the forward projection analysis

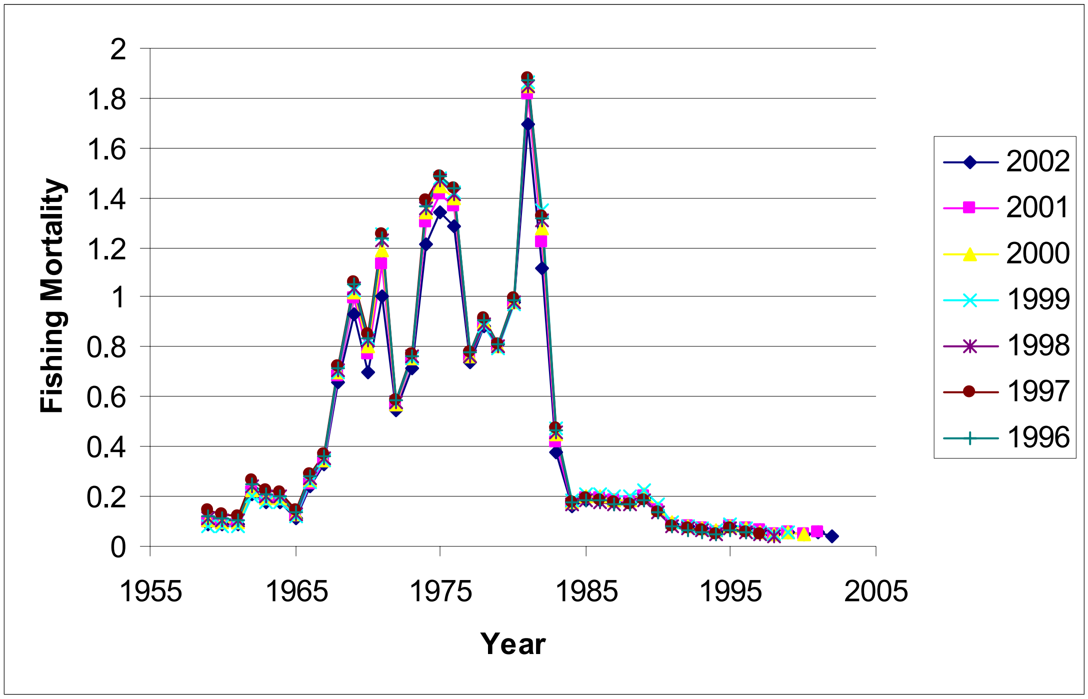


Figure 11.8. Trends in fishing mortality from retrospective analysis for 1996-2002.

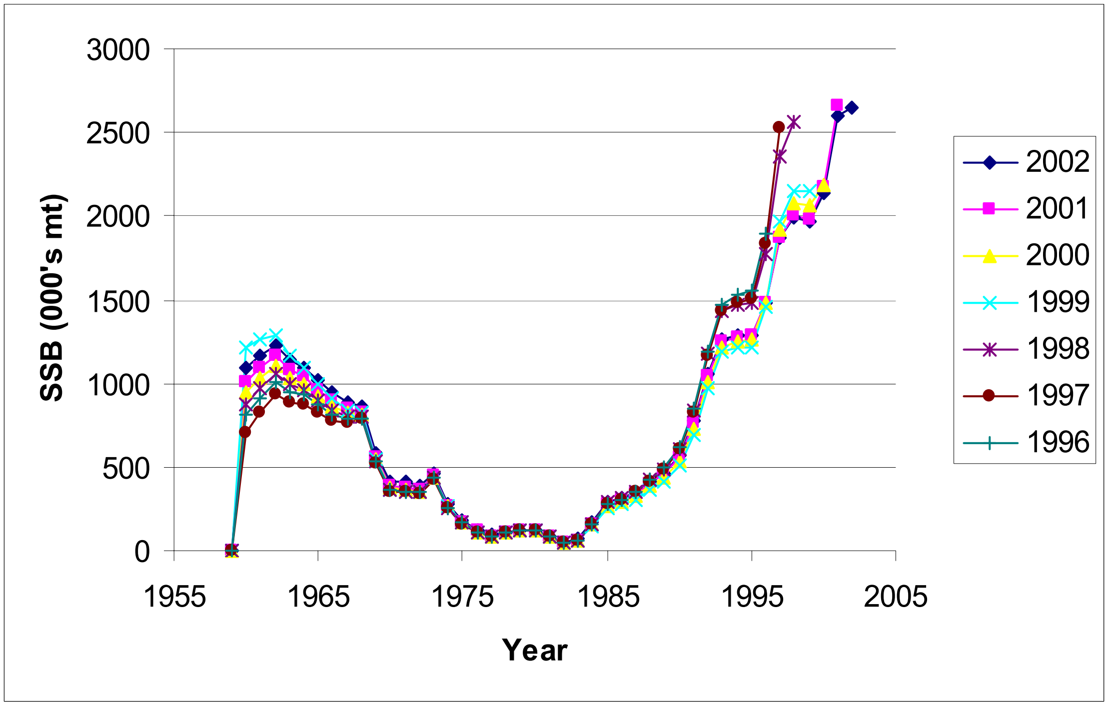


Figure 11.9. Trends in spawning stock biomass from retrospective analysis for 1996-2002.

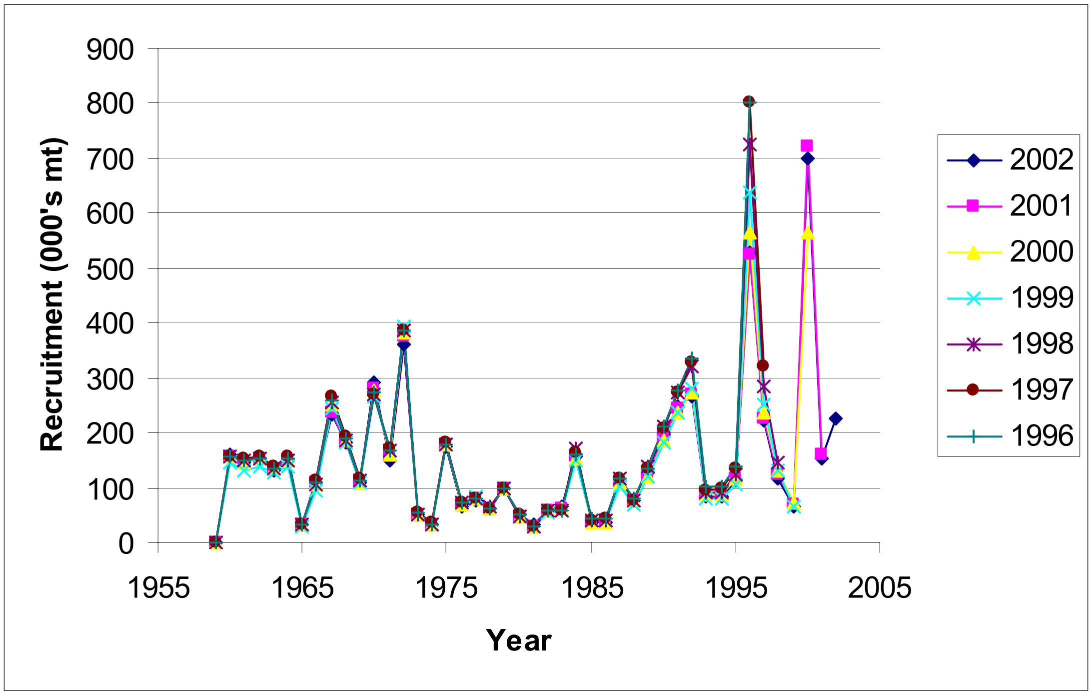


Figure 11.10. Trends in recruitment from retrospective analysis for 1996-2002.

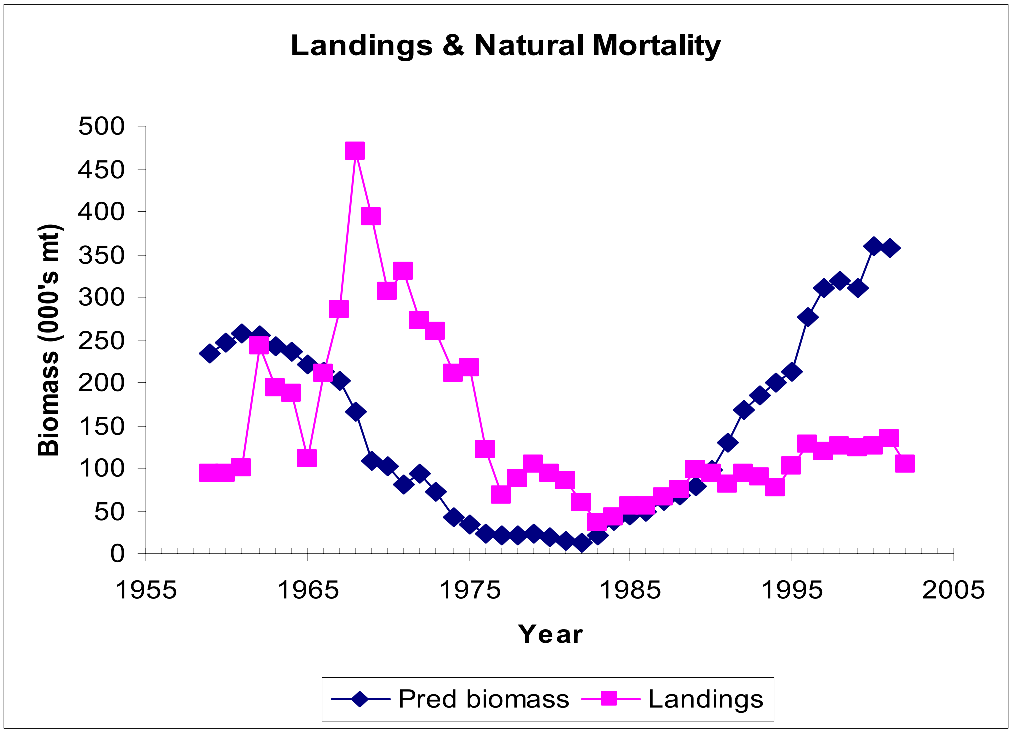


Figure 11.11. Losses to natural mortality (000’s t) and landings during 1959-2002

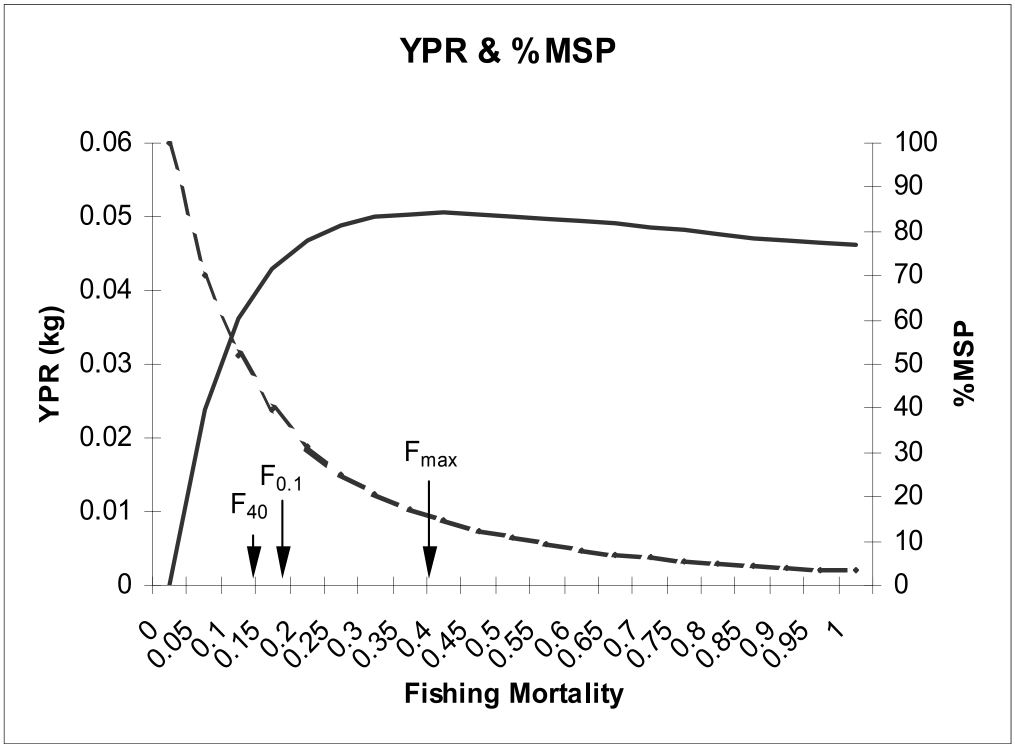


Figure 12.1. Yield per recruit and % maximum spawning potential for Atlantic herring from the Gulf of Maine-Georges Bank complex

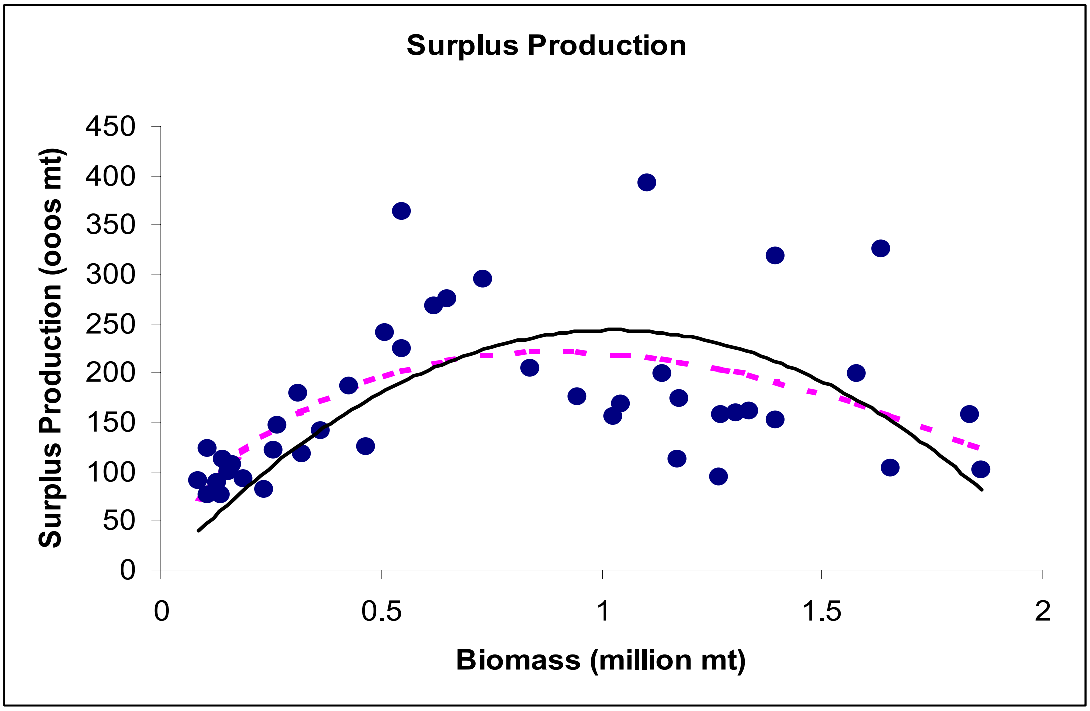


Figure 12.2. Surplus production for the Gulf of Maine-Georges Bank Atlantic herring complex, showing observed data (dots), the curve from the Fox model fit (dashed line), and Schaefer fit (solid line).

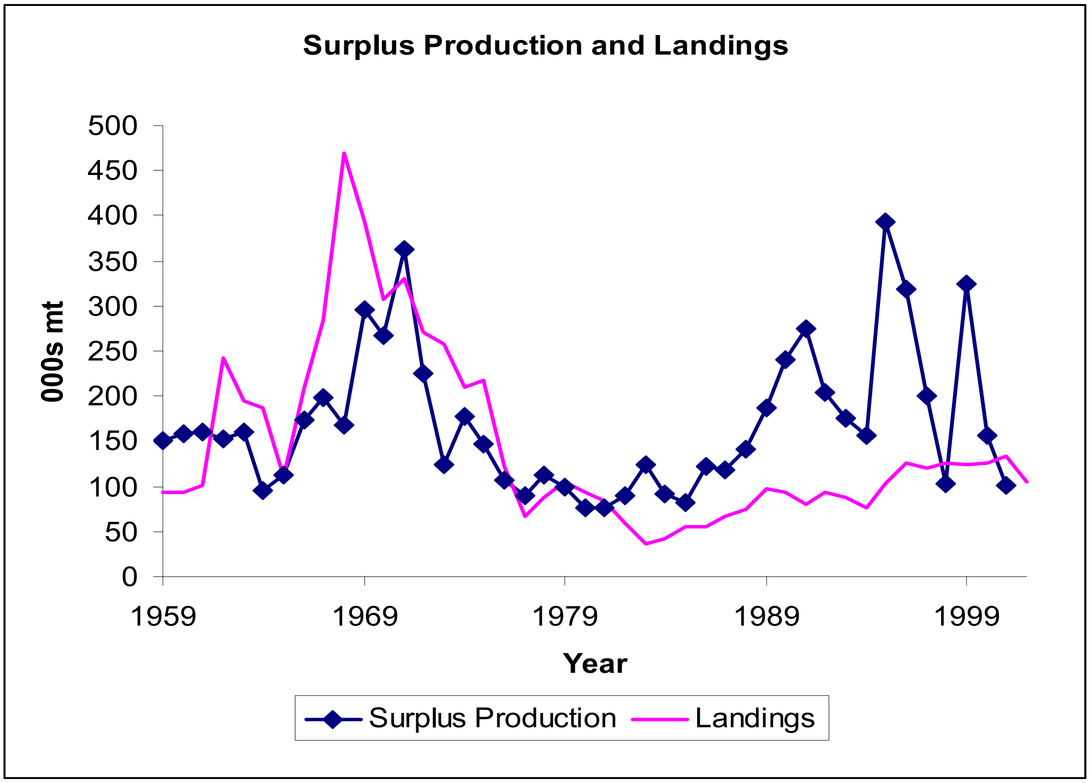


Figure 12.3 Surplus Production and Landings for the Gulf of Maine-Georges Bank Atlantic herring complex during 1959-2002

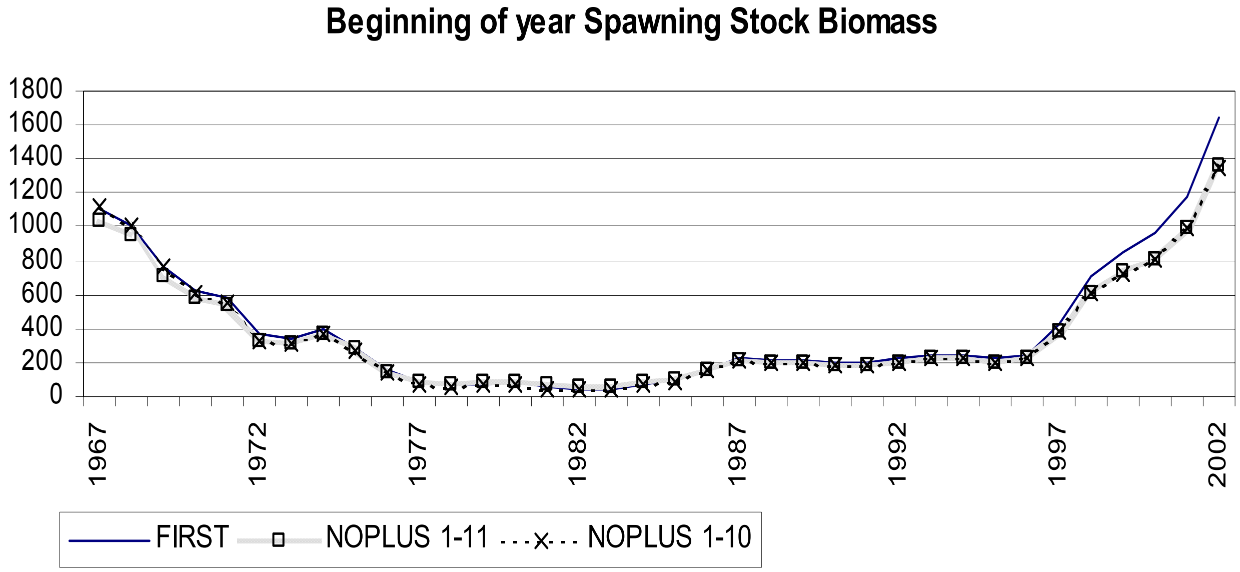


Figure 14.1. Trends in SSB with various assumptions on the plus group using the same ADAPT formulation as in SAW27

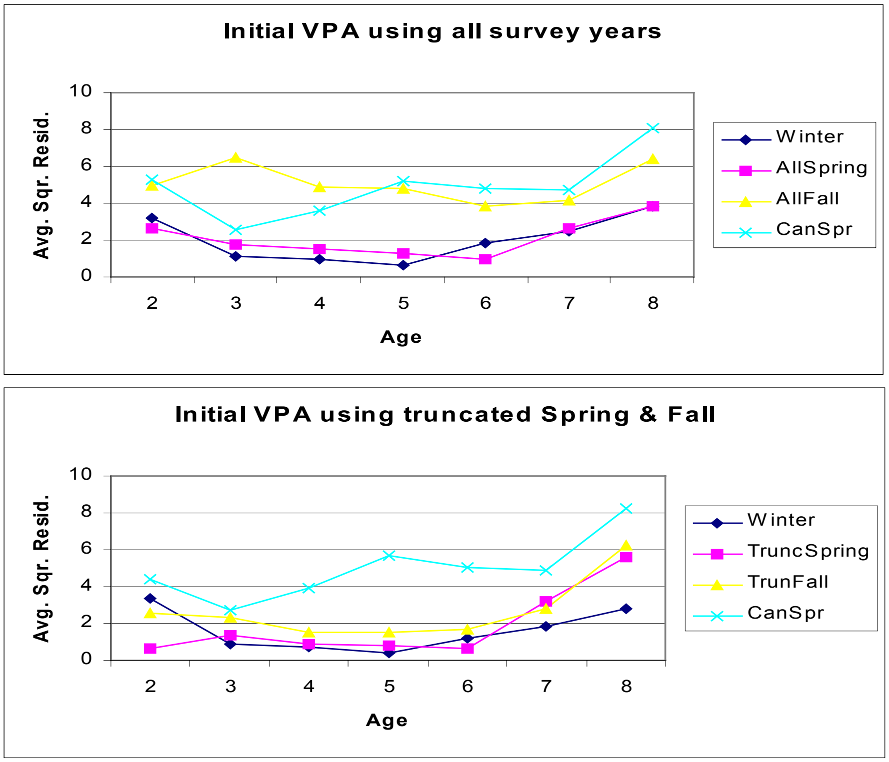


Figure 14.2. Mean square residuals by age for ADAPT formulations using the 4 trawl survey series; top panel with NMFS spring and fall for all years; bottom panel for NMFS spring and fall truncated to 1983 to 2002

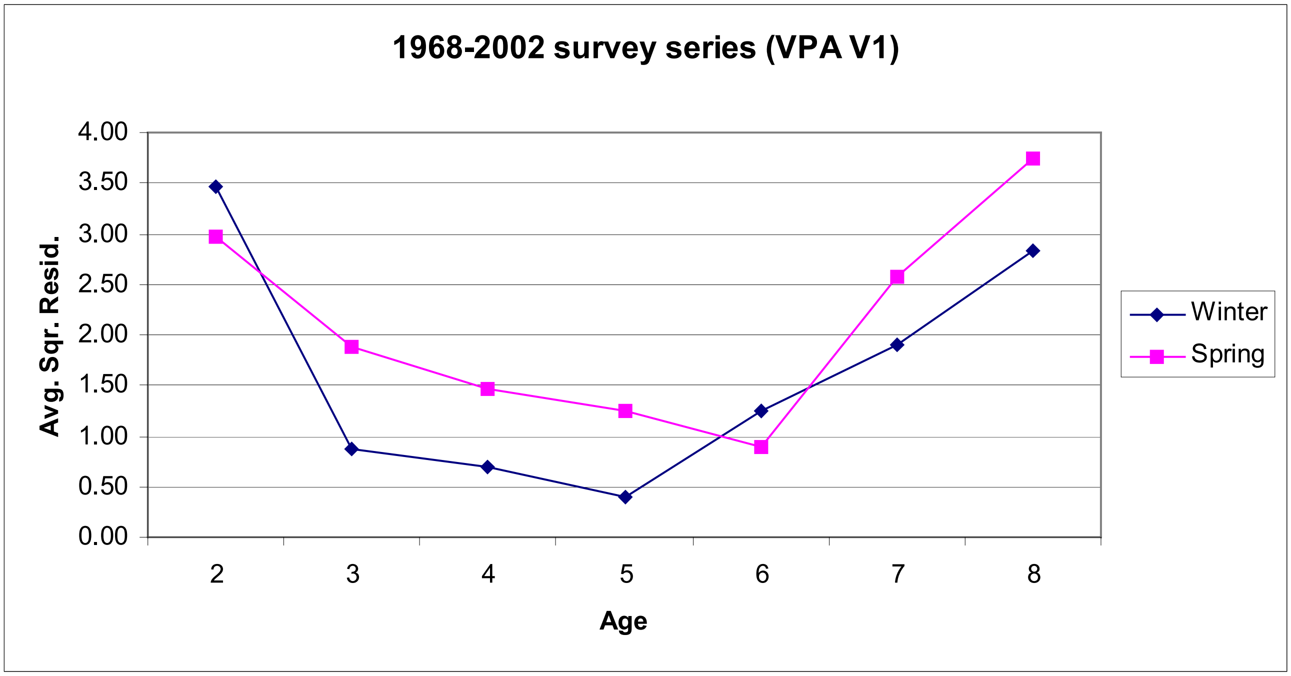
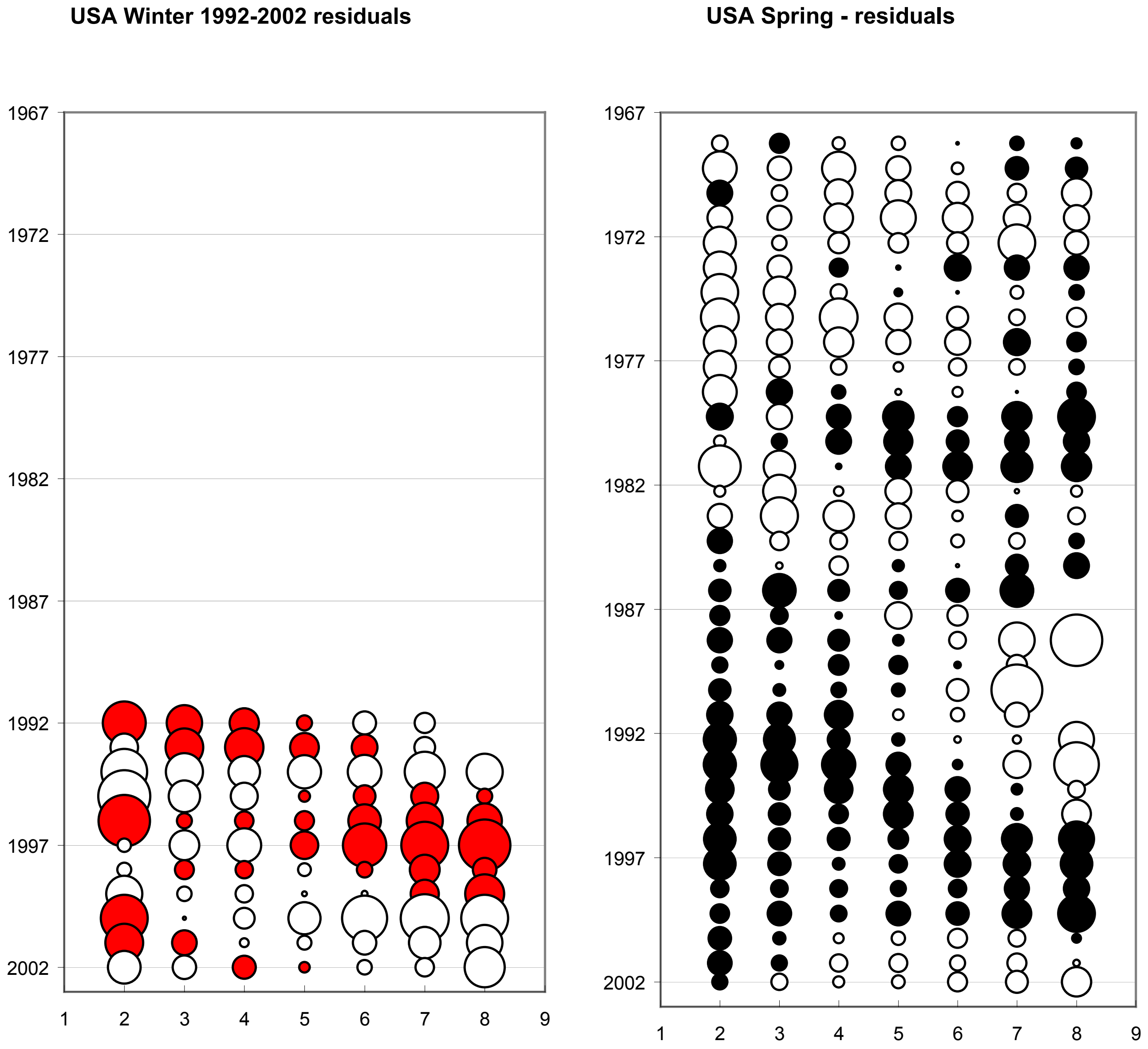


Figure 14.3. Average squared residuals by age from initial VPA (SAW27 extended) for the NMFS winter (1992-2002) and spring survey series (1968 to 2002).


USA Winter 1992-2002 residuals

USA Spring - residuals

Figure 14.4. Residuals by year and age group for each survey index. Solid symbols represent positive residual values, open symbols represent negative values, bubble area is proportional to magnitude.

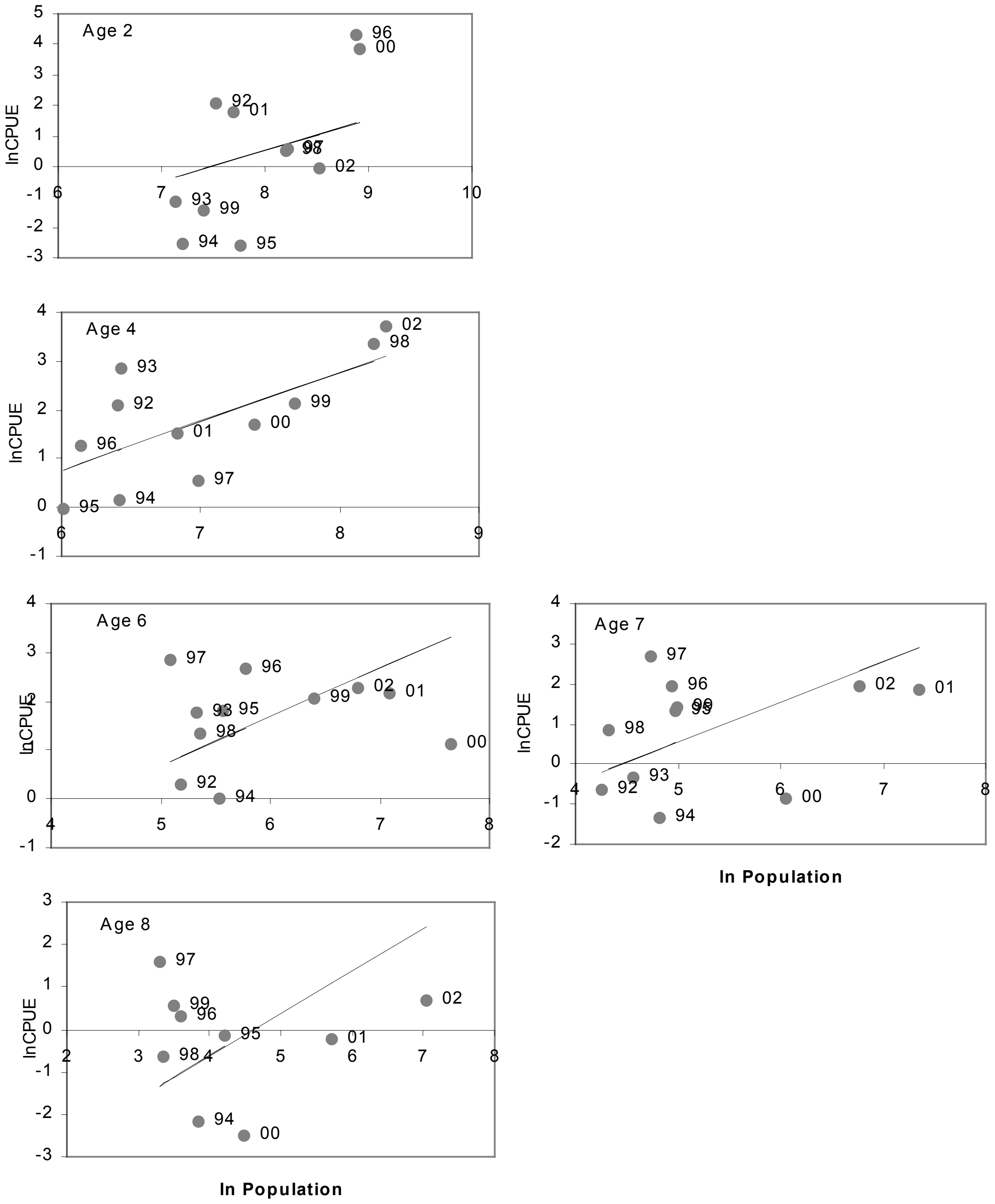


Figure 14.5. Age by age plots of the observed and predicted (ln) abundance index versus (ln) population numbers for herring in the USA winter trawl survey.

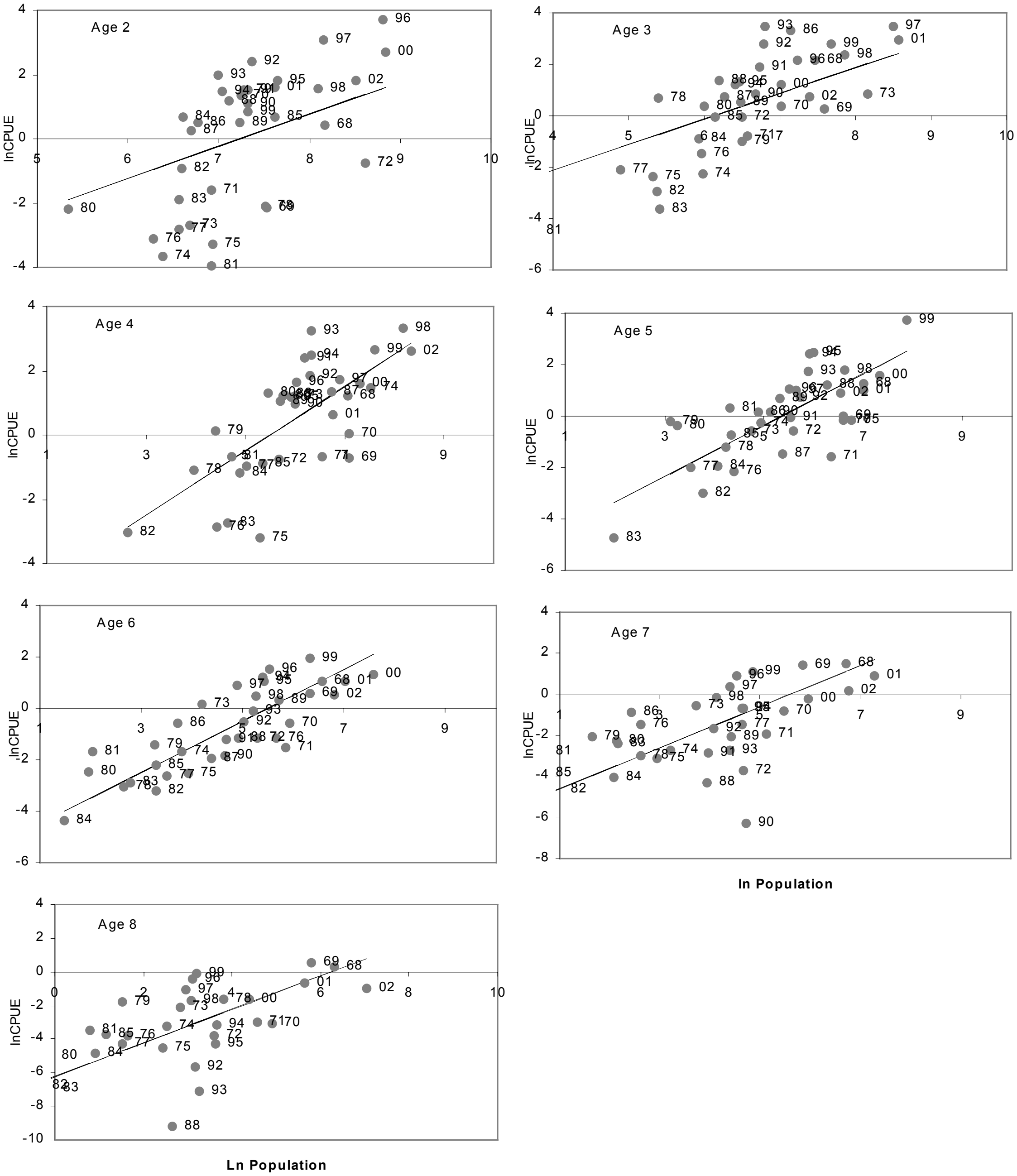


Figure 14.6. Age by age plots of the observed and predicted (ln) abundance index versus (ln) population numbers for herring in the USA spring trawl survey.

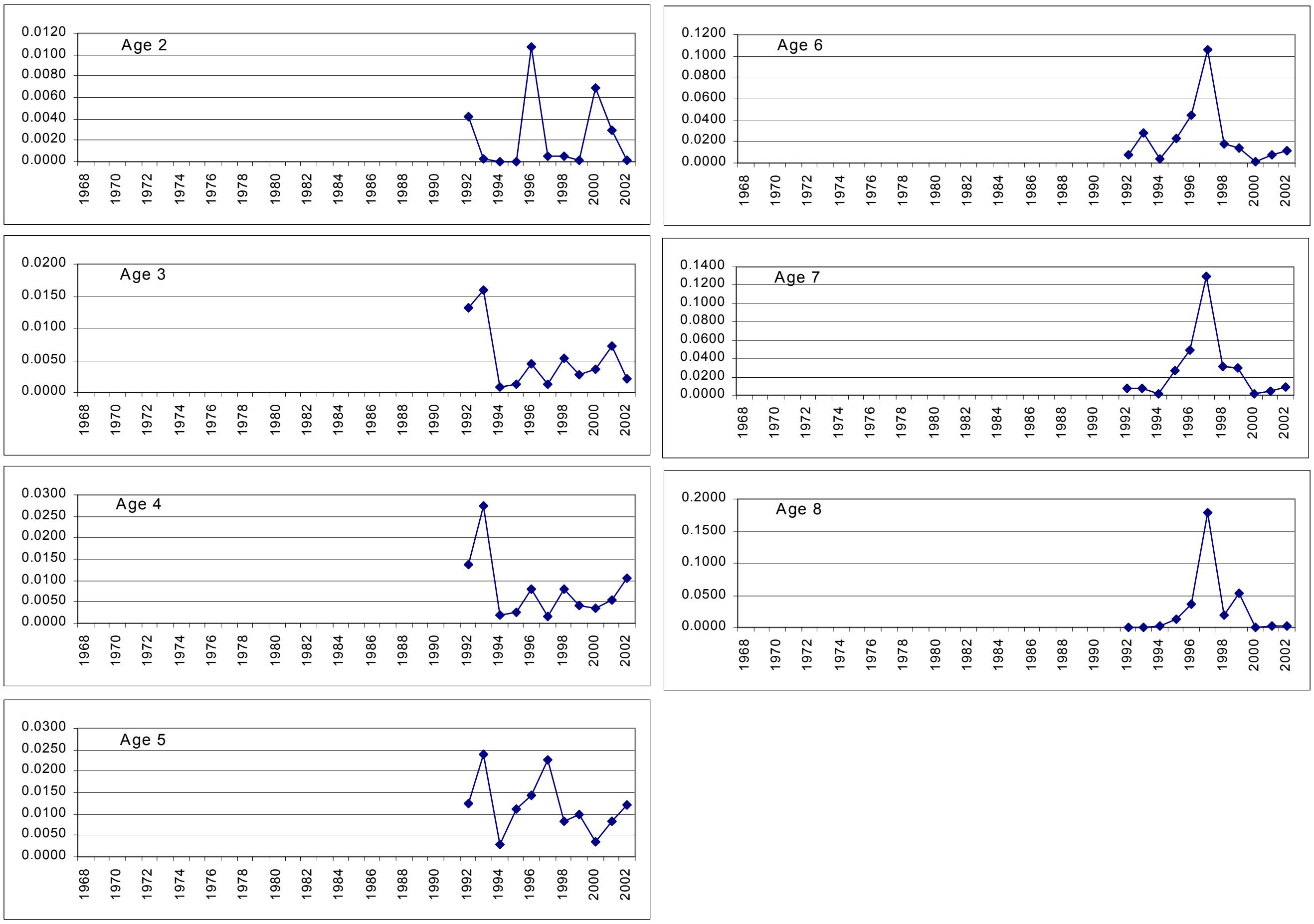


Figure 14.7. US Winter survey Q's by year (survey / popn nos) by age.

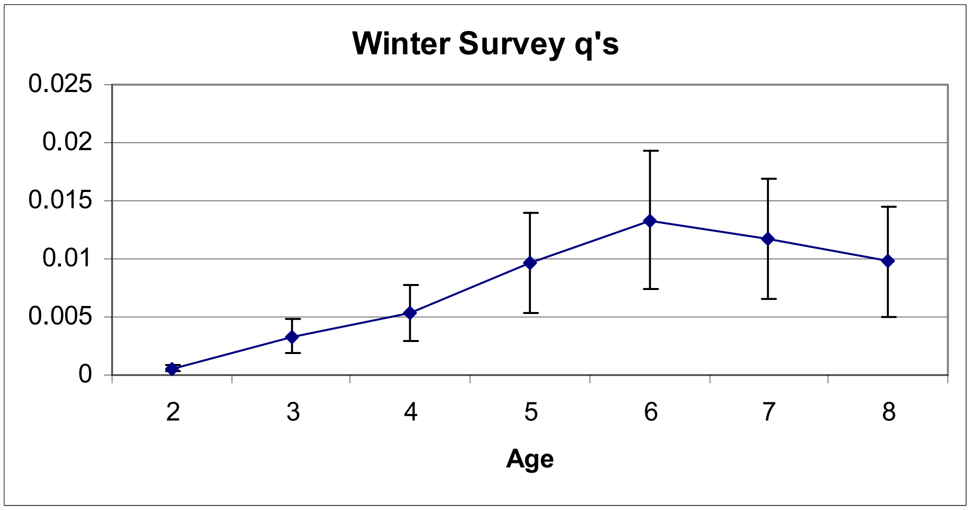


Figure 14.8. US Winter survey Q's by age for overall series 1992 to 2002

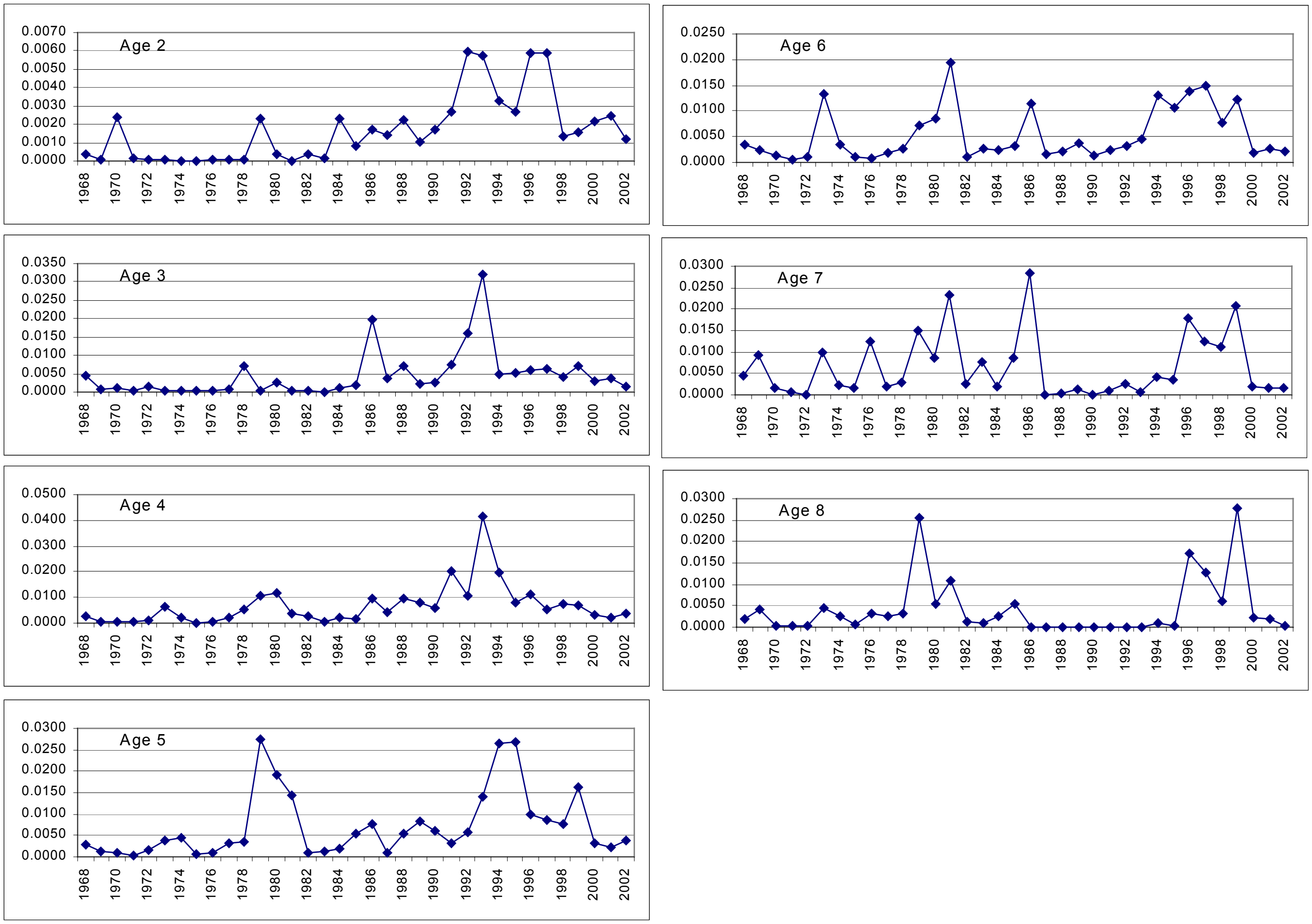


Figure 14.9. US Spring survey Q's by year (survey / popn nos) by age.

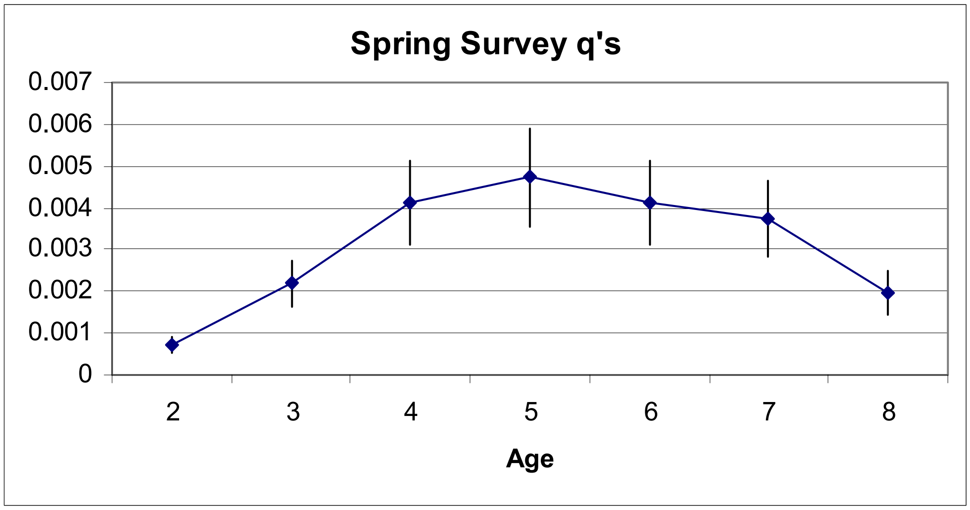


Figure 14.10. US Spring survey Q's by age for overall series 1968 to 2002.

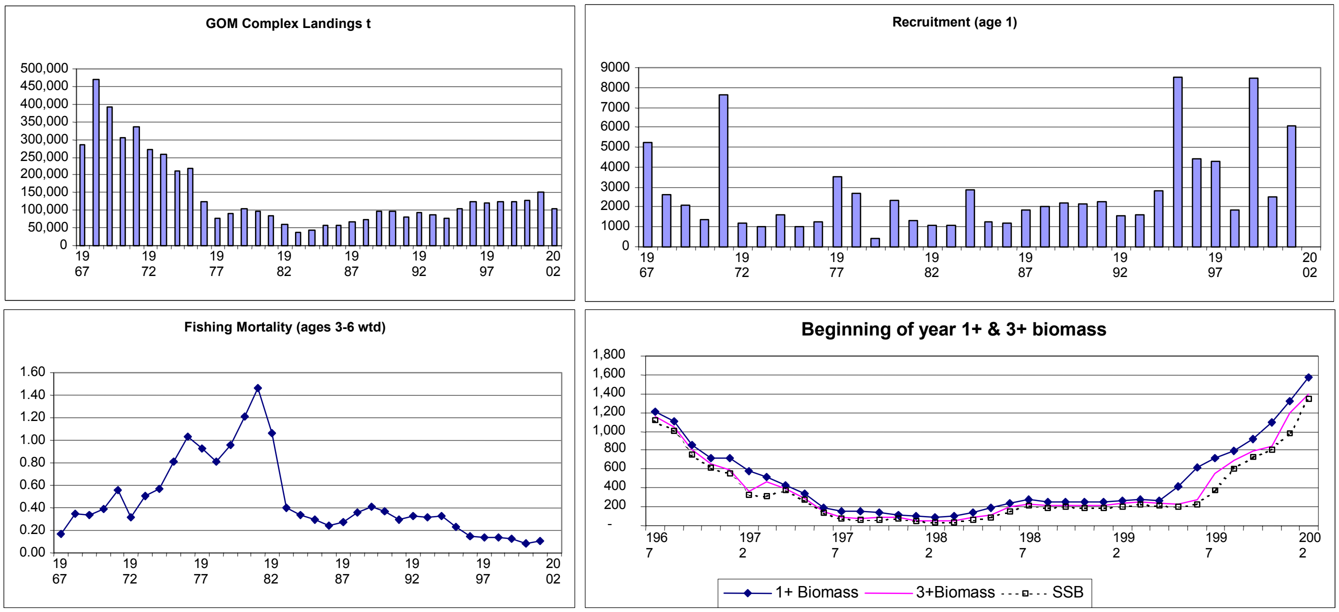


Figure 14.11. GOM complex landings, recruitment, fishing mortality and beginning of year biomass estimates from VPA version 1 (SAW27 extended) formulation.

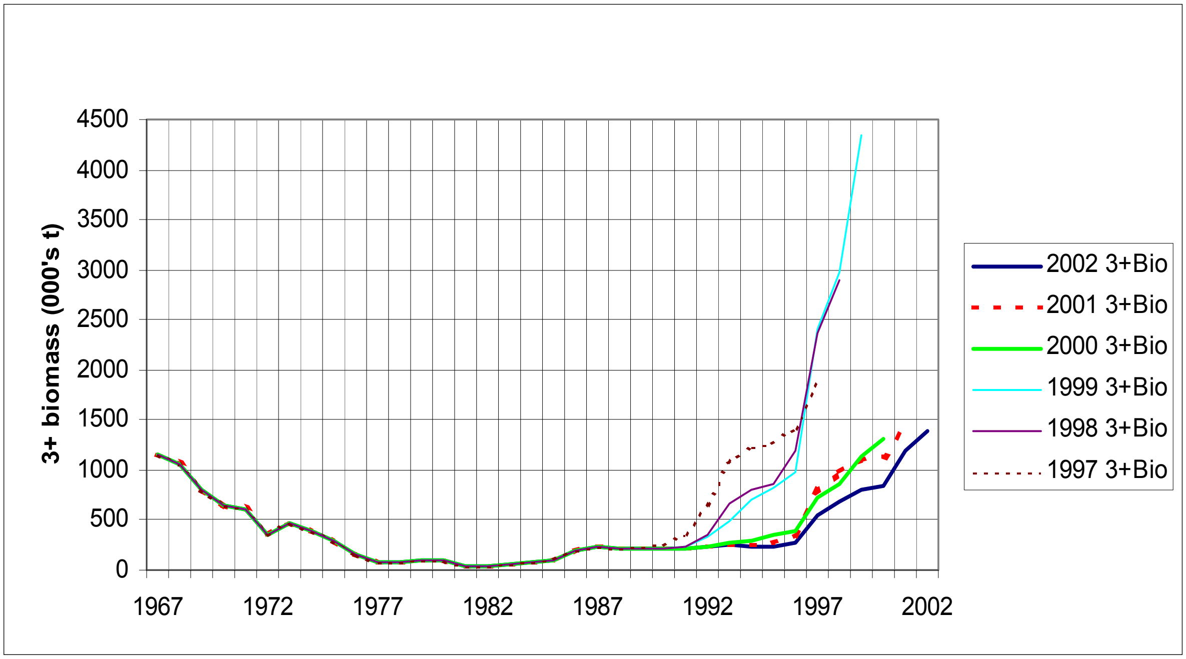


Figure 14.12. GOM complex herring retrospective analysis for 3+ biomass from the VPA version 1 (SAW27 extended) formulation

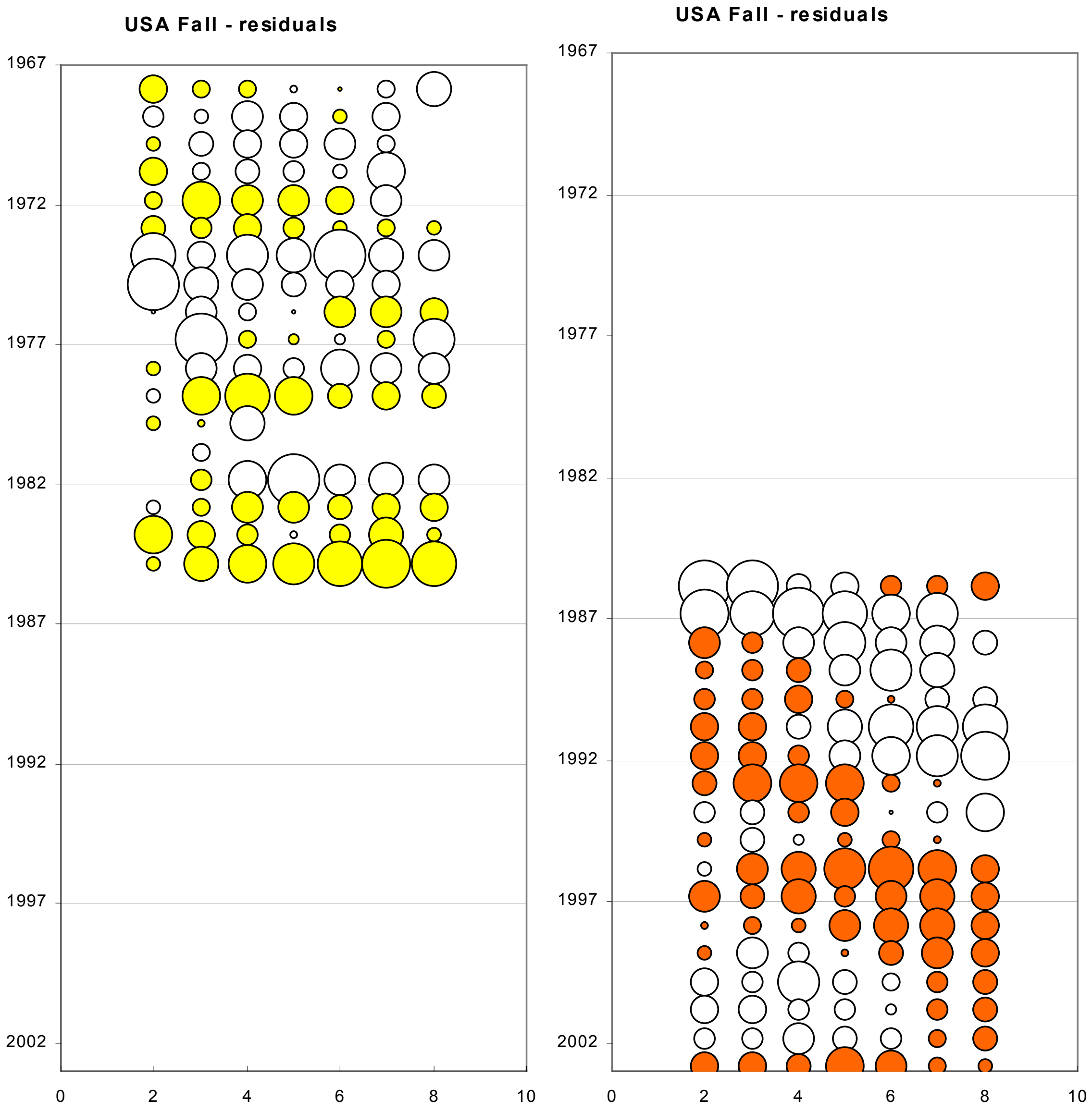


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Figure 14.13. Residuals by year and age group for the NMFS fall bottom trawl survey herring index (left panel 1968 to 1984; right panel 1985 to 2002). Solid symbols represent positive residual values, open symbols represent negative values, bubble area is proportional to magnitude.

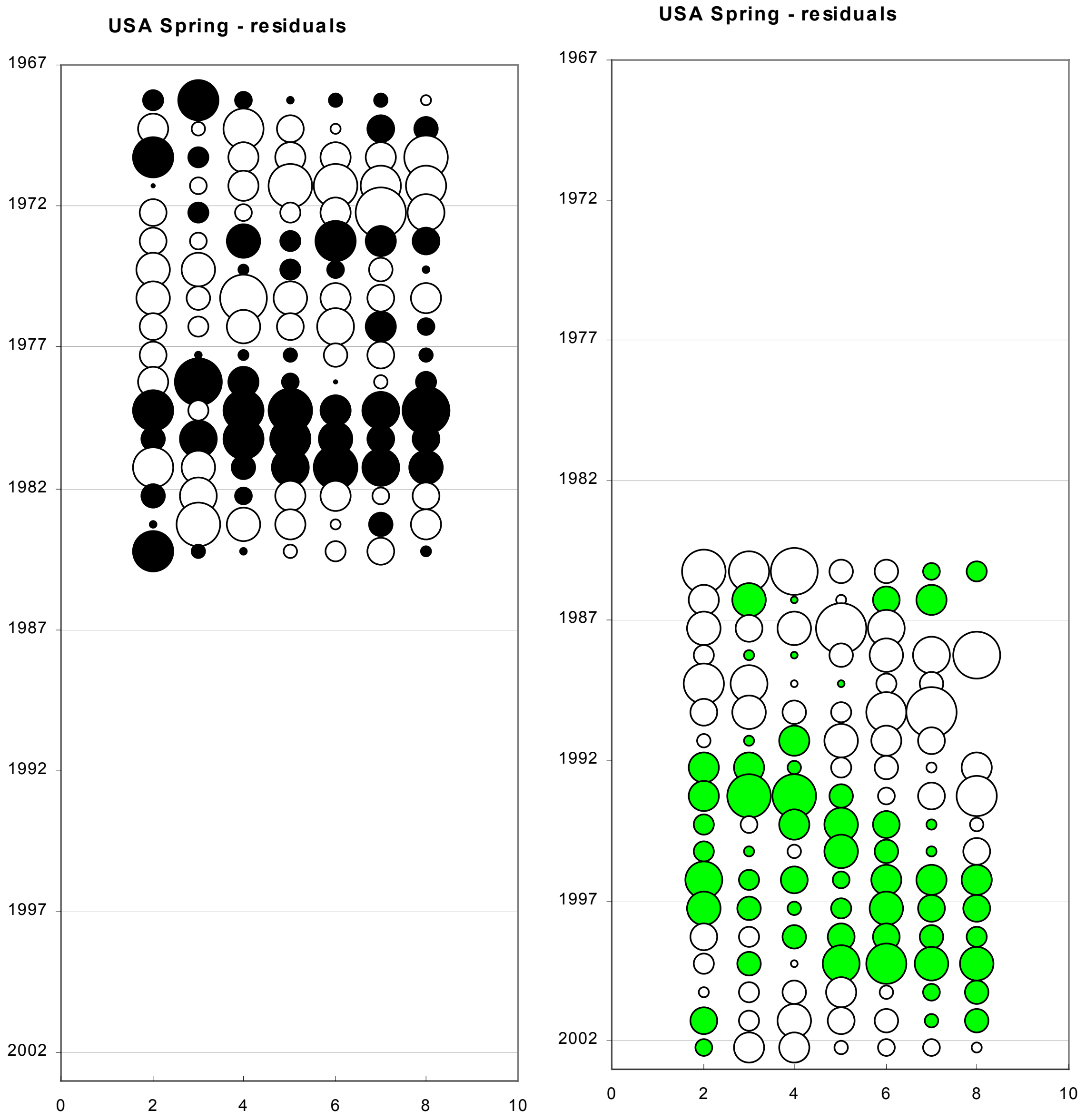

Figure 14.14. Residuals by year and age group for the NMFS spring bottom trawl survey herring index (left panel 1968 to 1984; right panel 1985 to 2002). Solid symbols represent positive residual values, open symbols represent negative values, bubble area is proportional to magnitude.

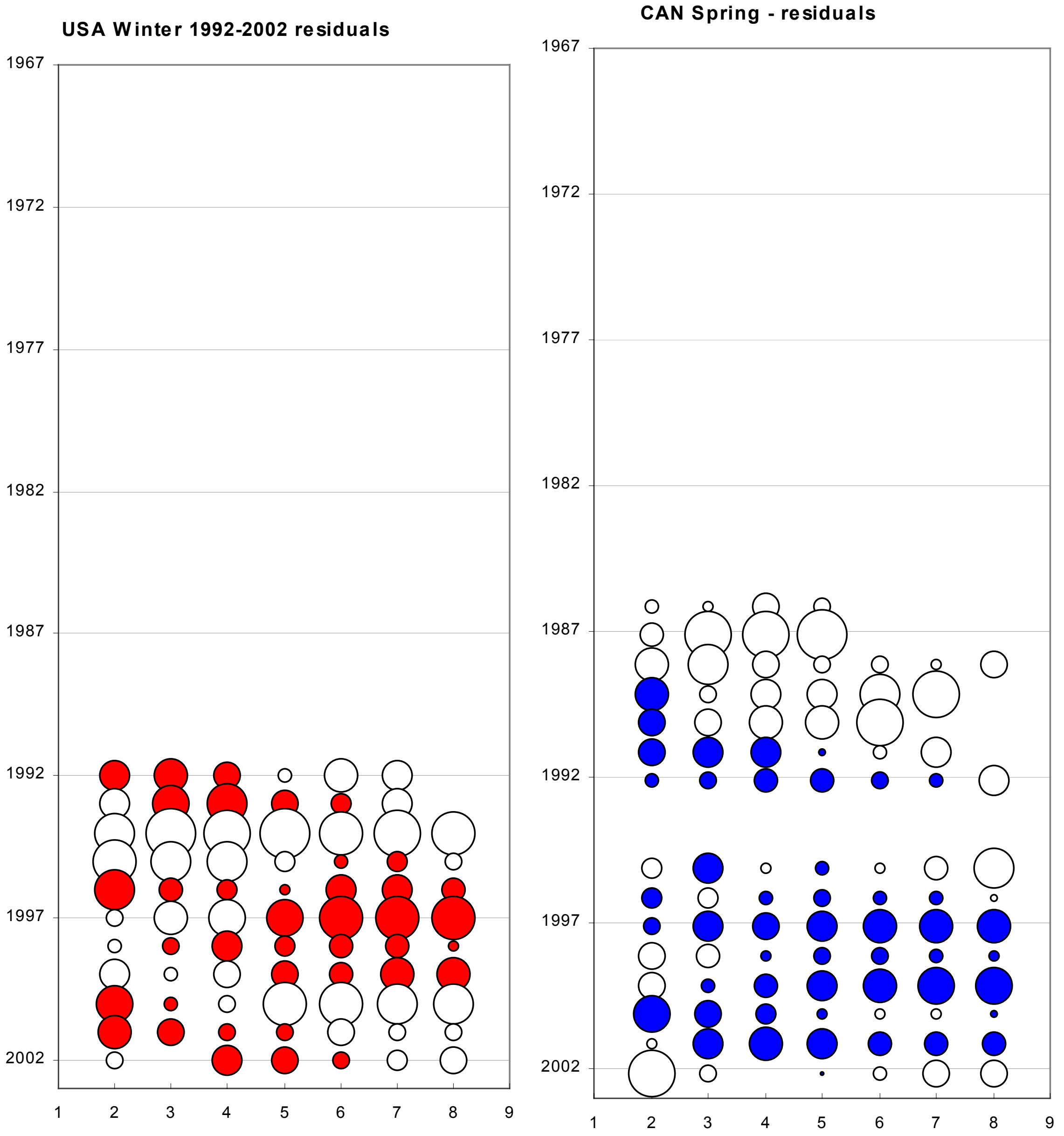

Figure 14.15. Residuals by year and age group for the NMFS winter bottom trawl survey herring index (left panel; 1992 to 2002) and Canadian spring bottom trawl survey herring index (right panel; 1986 to 2002 with 1993-1994 surveys excluded). Solid symbols represent positive residual values, open symbols represent negative values, bubble area is proportional to magnitude.

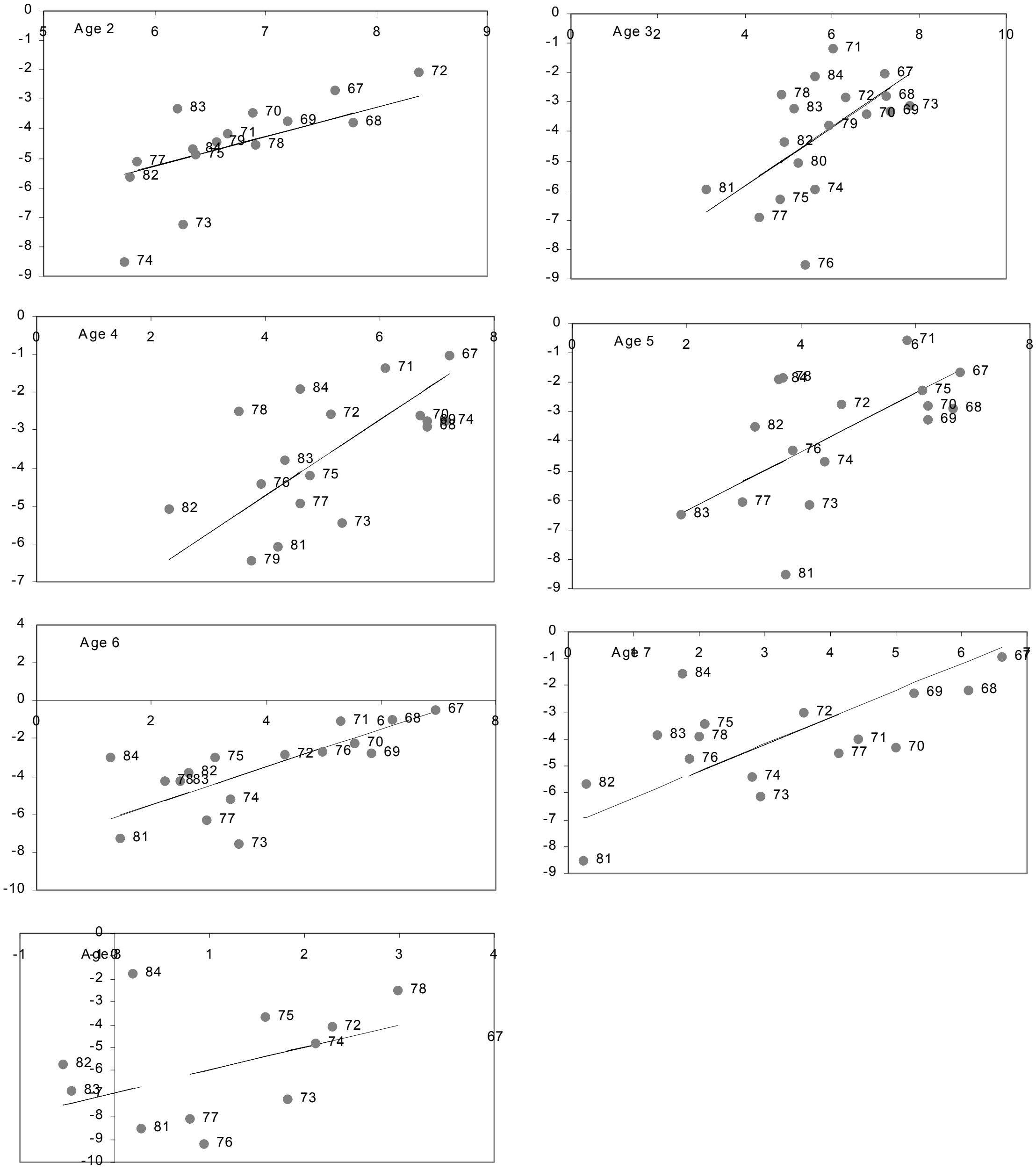

Figure 14.16. Age by age plots of the observed and predicted ln abundance index versus ln population numbers for herring in the USA fall trawl survey for 1967-1984.

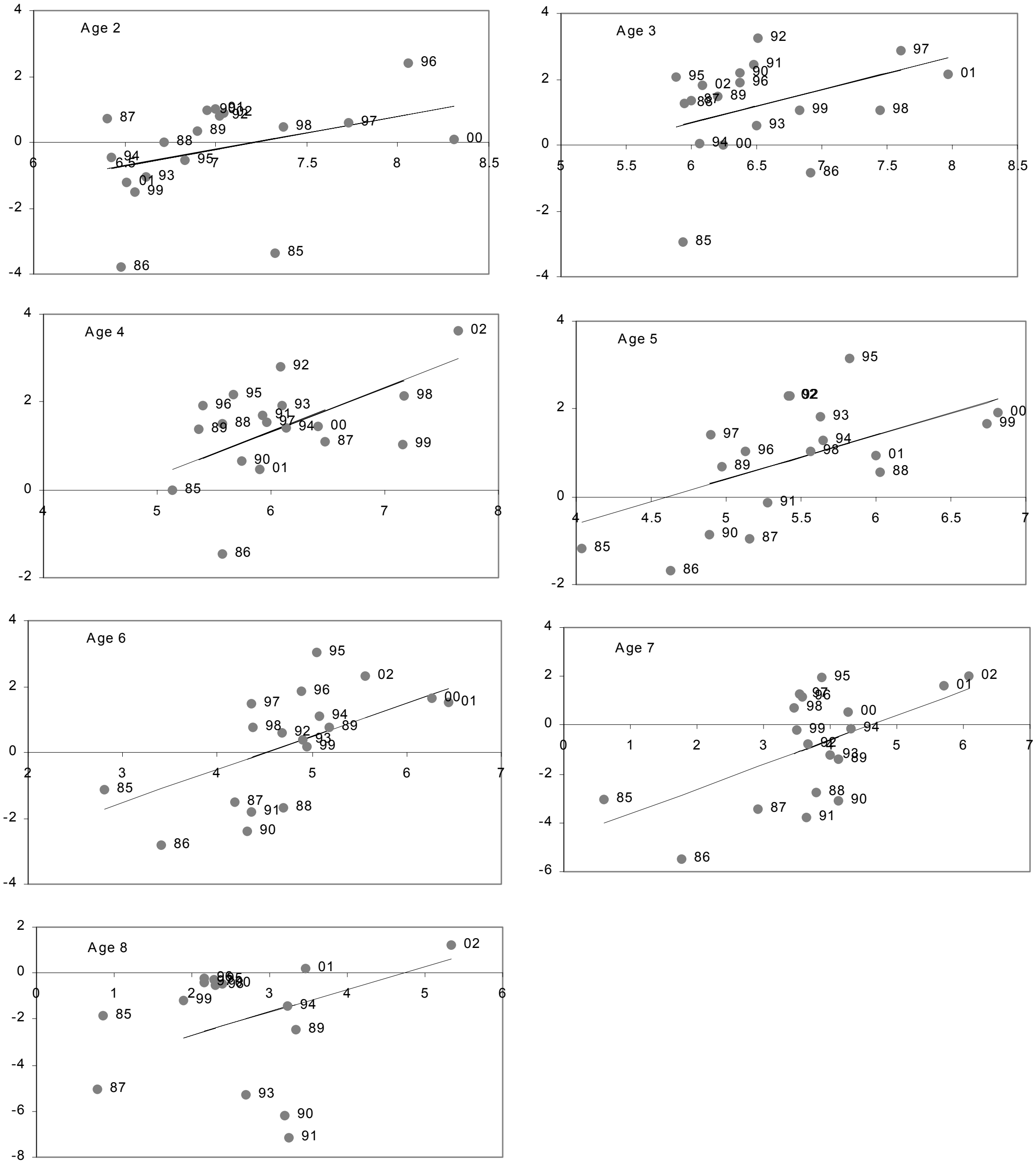

Figure 14.17. Age by age plots of the observed and predicted ln abundance index versus ln population numbers for herring in the USA fall trawl survey for 1985-2002.

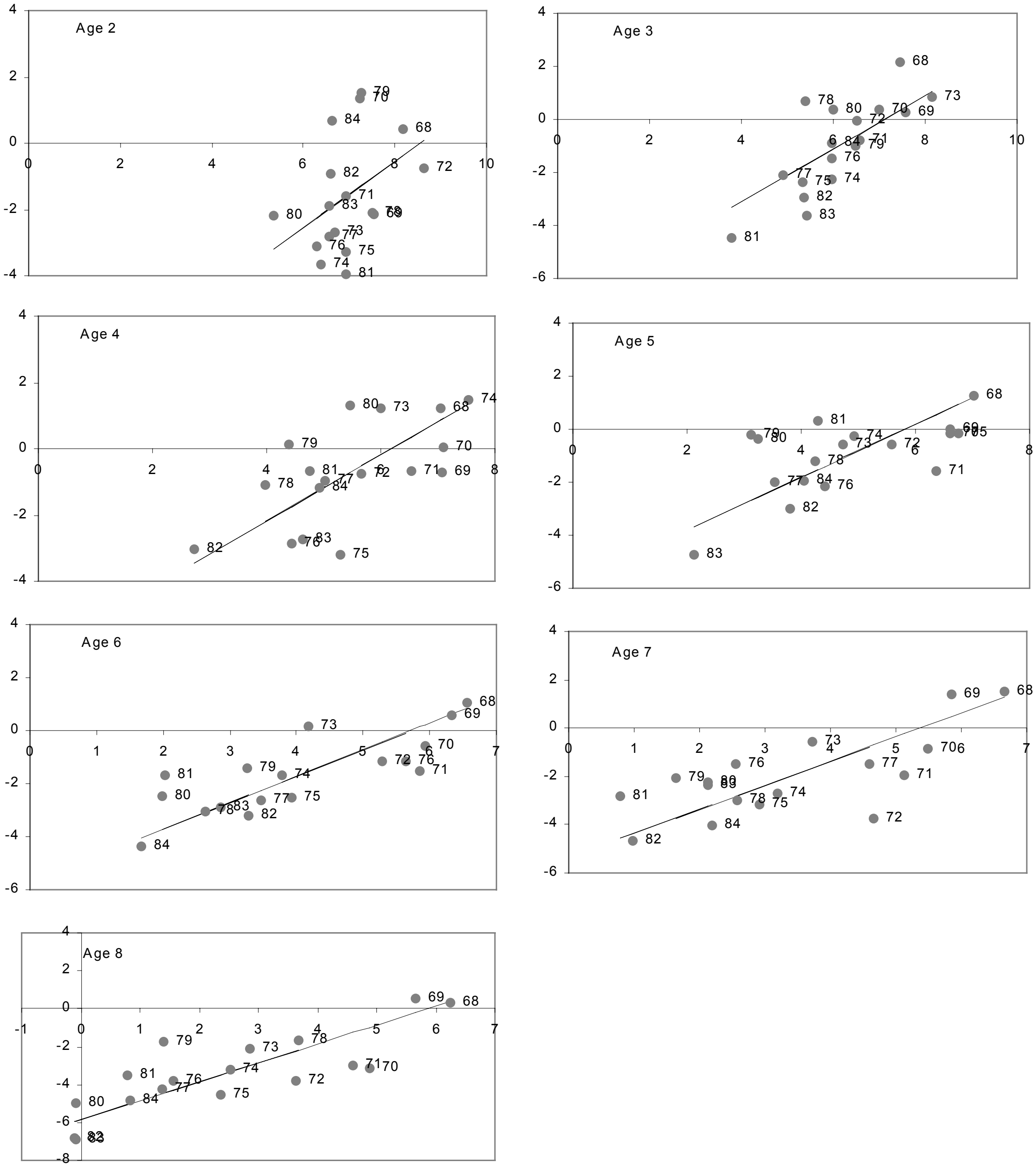

Figure 14.18. Age by age plots of the observed and predicted ln abundance index versus ln population numbers for herring in the USA spring trawl survey for 1968-1984.

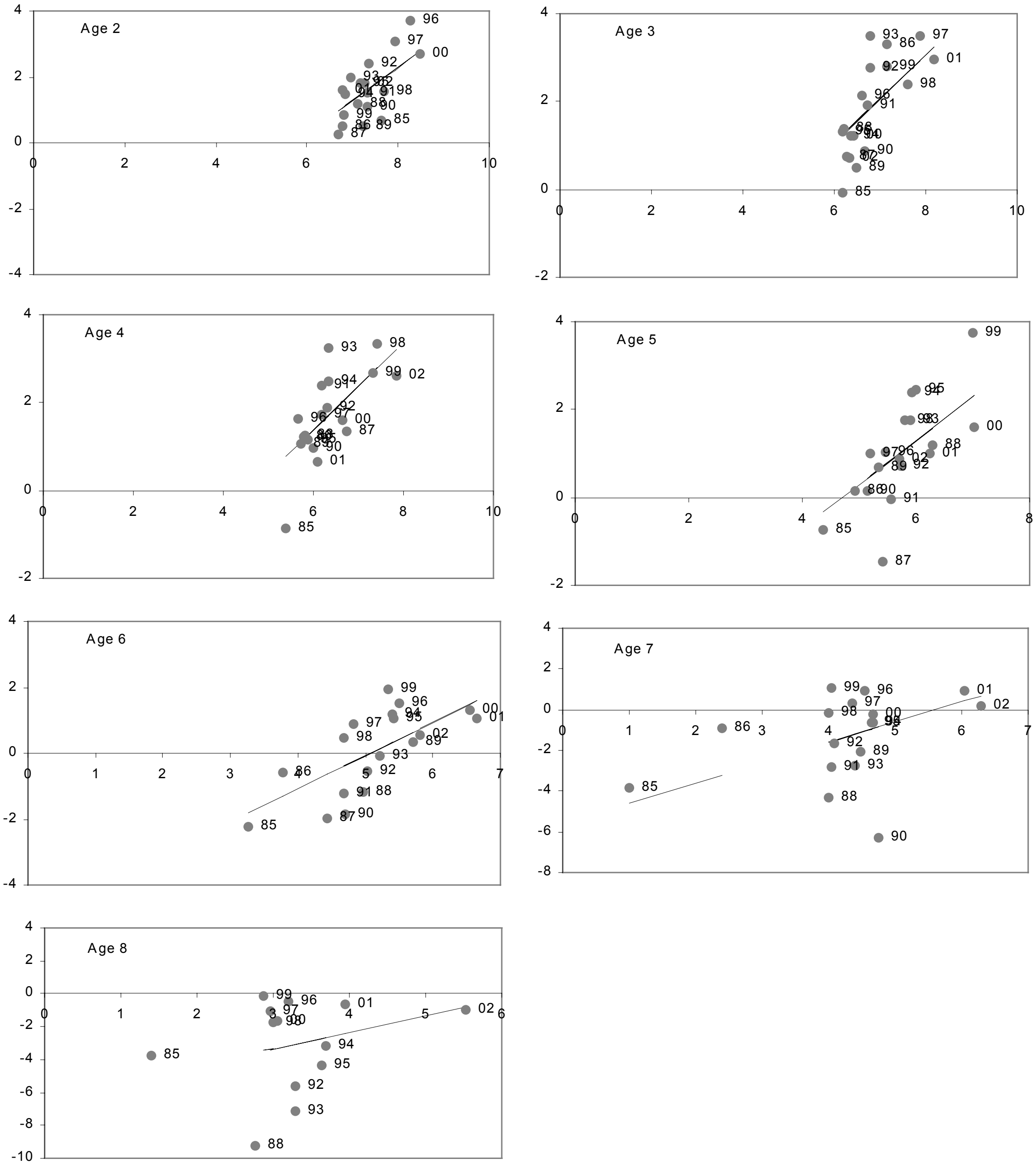

Figure 14.19. Age by age plots of the observed and predicted ln abundance index versus ln population numbers for herring in the USA spring trawl survey for 1985-2002.

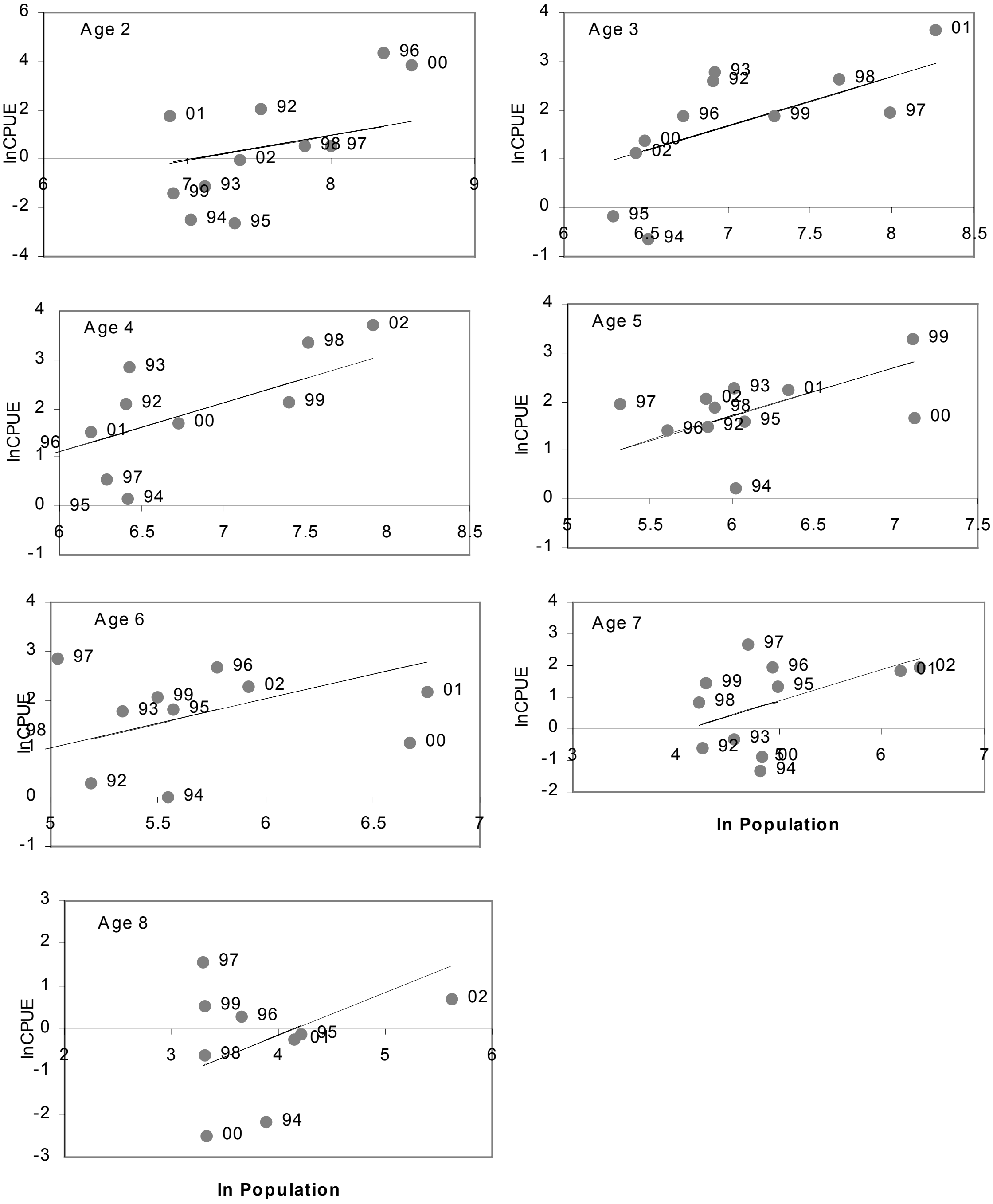

Figure 14.20. Age by age plots of the observed and predicted ln abundance index versus ln population numbers for herring in the USA winter trawl survey for 1992-2002.

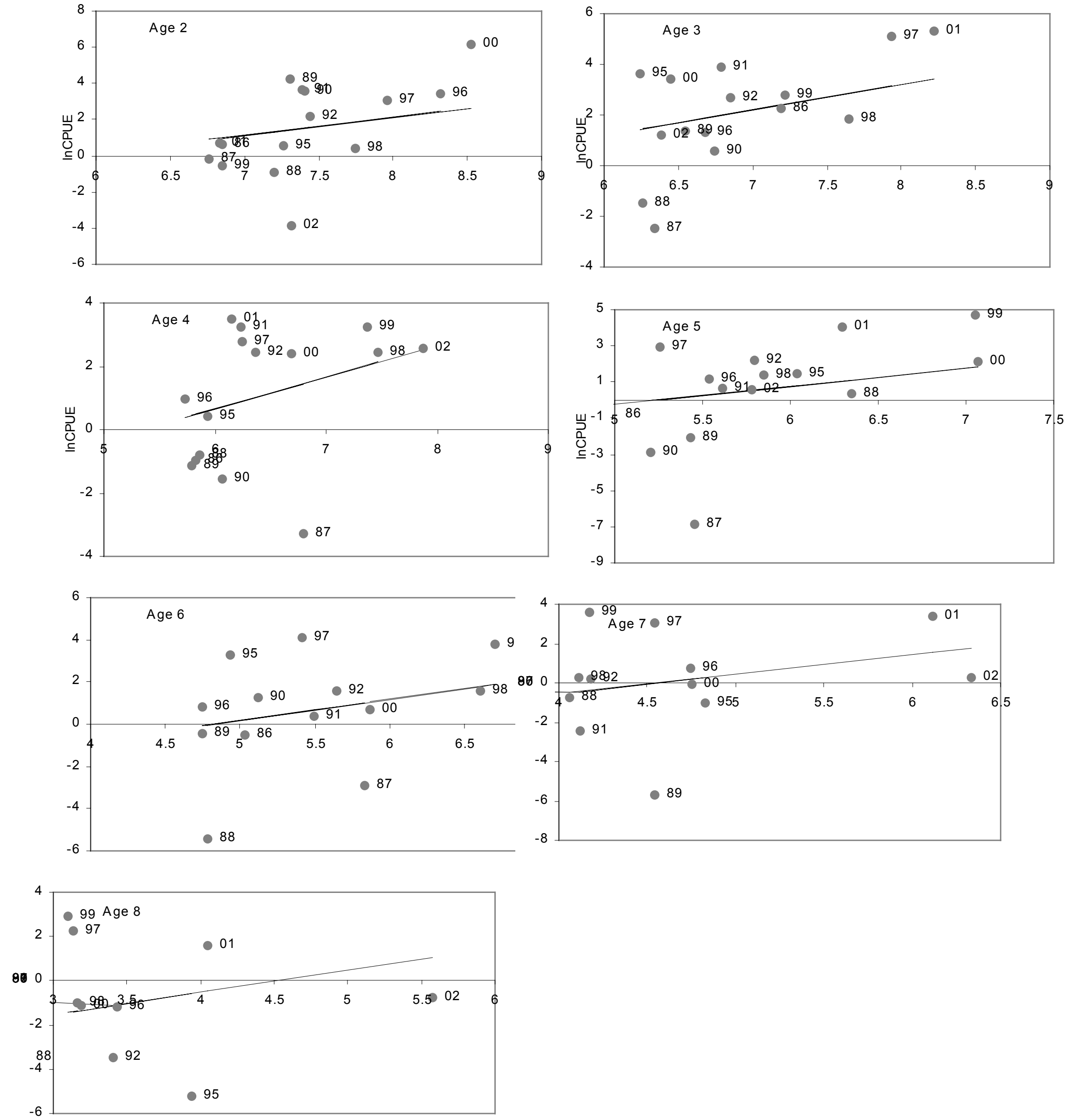

Figure 14.21. Age by age plots of the observed and predicted ln abundance index versus ln population numbers for herring in the Canadian spring trawl survey for 1986 to 2002 (with 1993-94 removed).

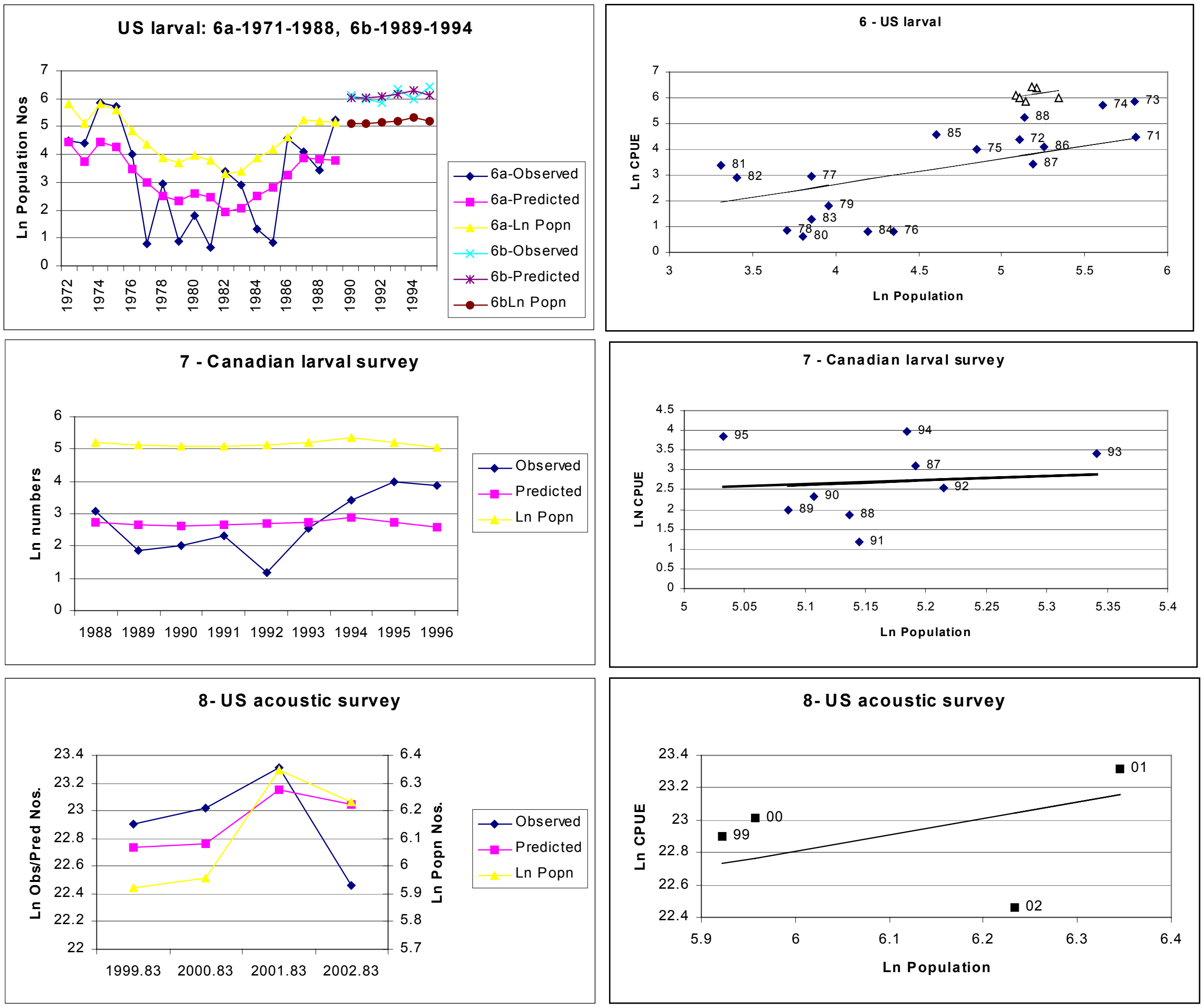

Figure 14.22. Observed and predicted plots for age aggregated indices; left panels are the observed, predicted population numbers by year; right panels are the observed versus predicted with the year labels for each observation.

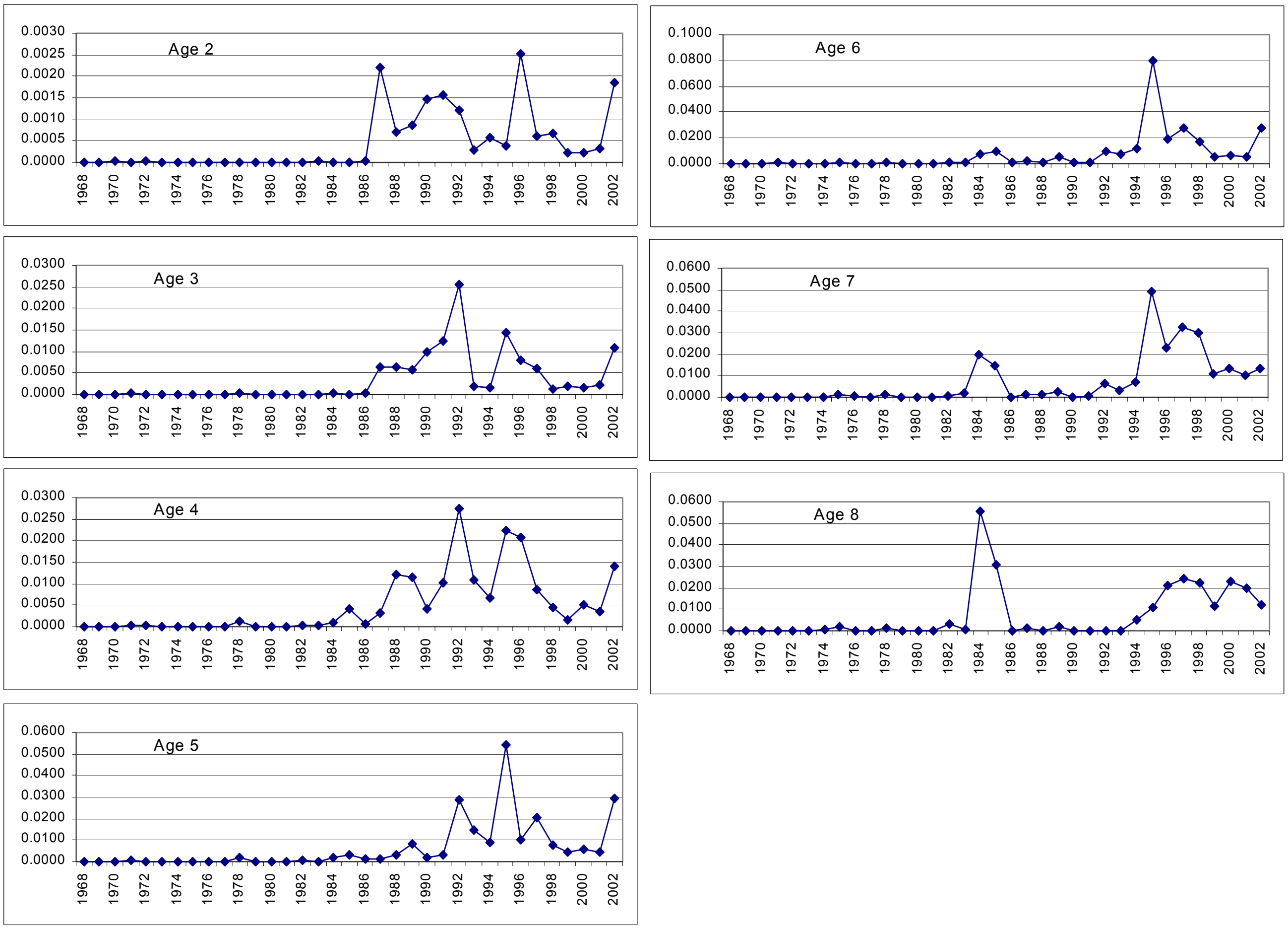

Figure 14.23. NMFS fall survey Q's (survey / popn. nos.) by year and age for the complex final fit formulation .

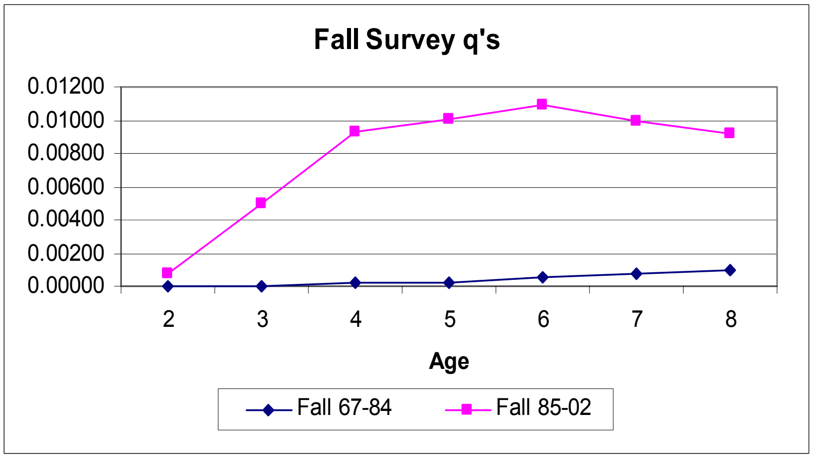

Figure 14.24. NMFS fall survey Q's by age for the complex final fit formulation

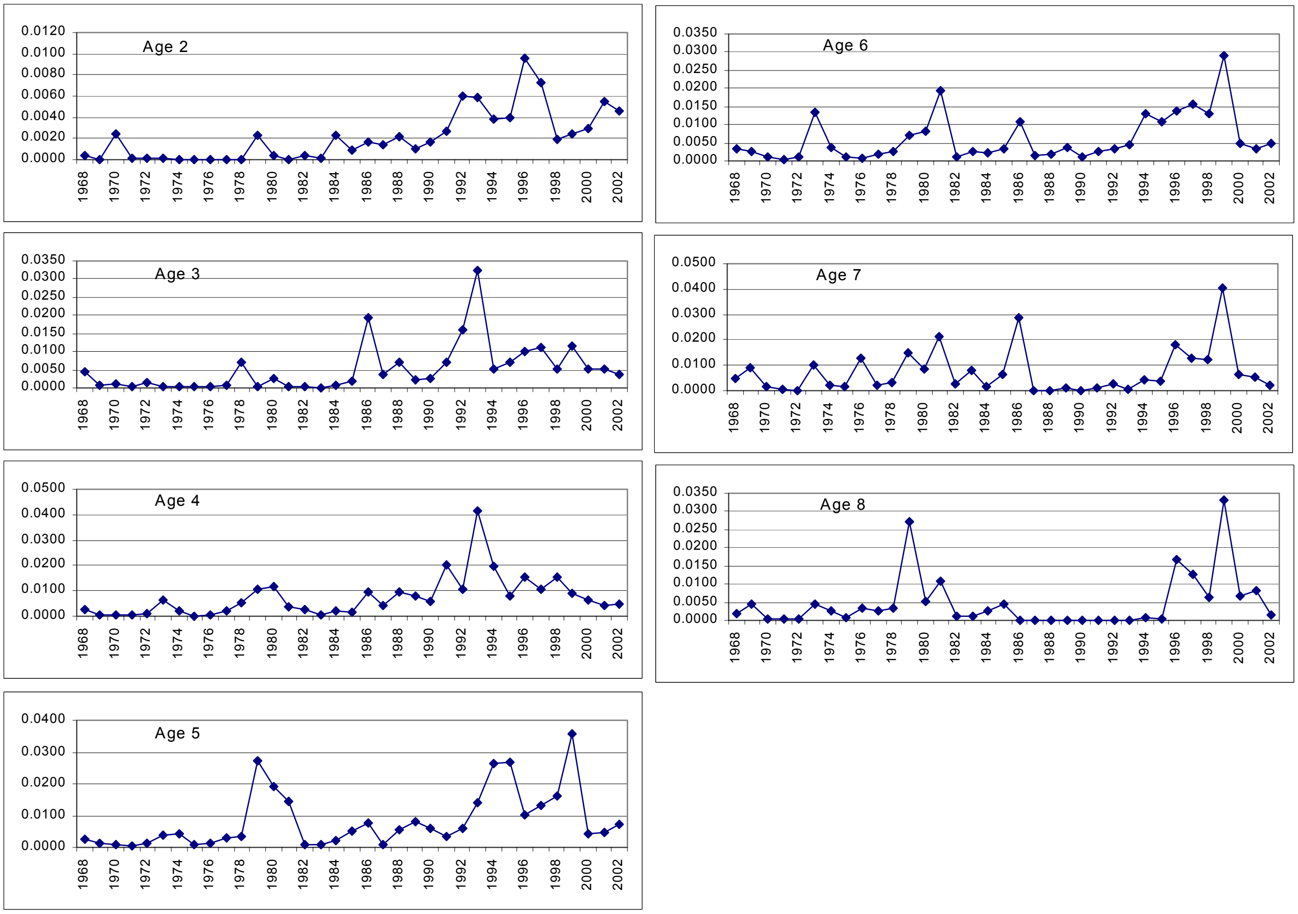

Figure 14.25. NMFS spring survey Q's (survey / popn. nos.) by year and age for the complex final fit formulation

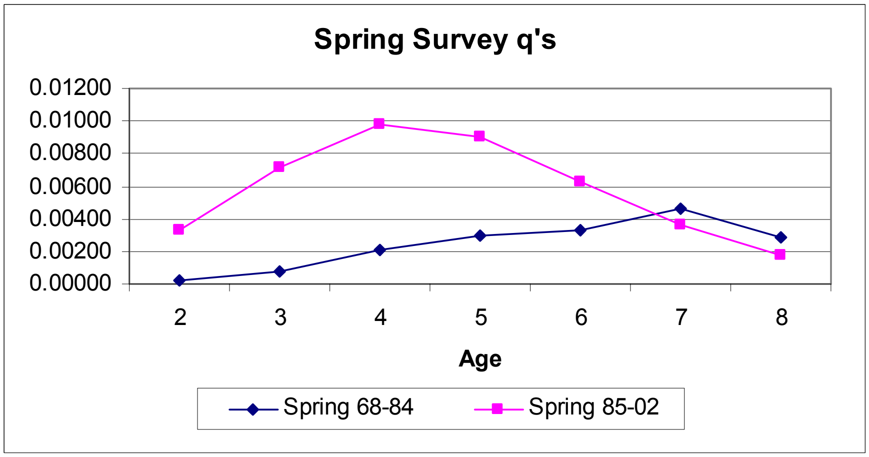

Figure 14.26 NMFS spring survey Q's by age for the complex final fit formulation

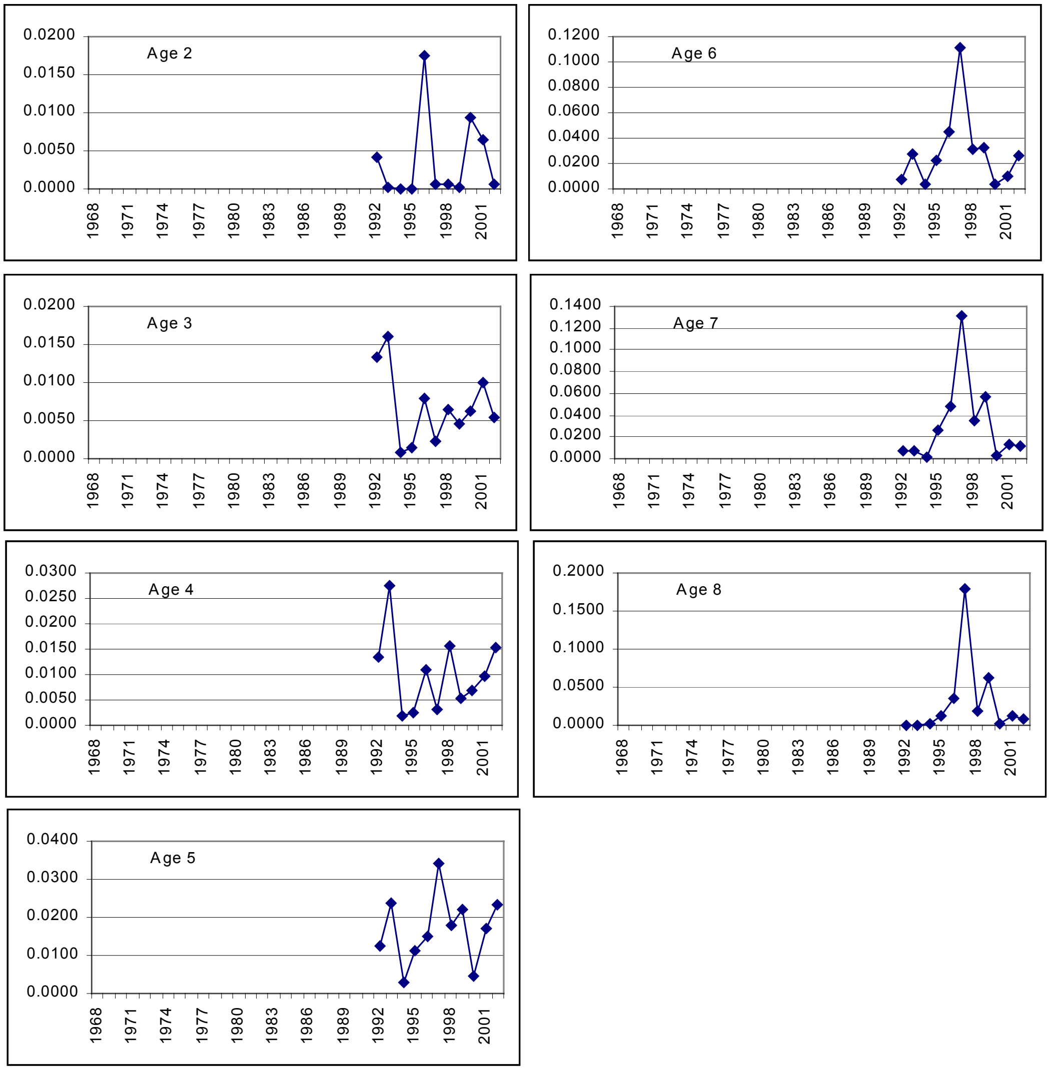

Figure 14.27 NMFS winter survey Q's (survey / popn. nos.) by year and age for the complex final fit

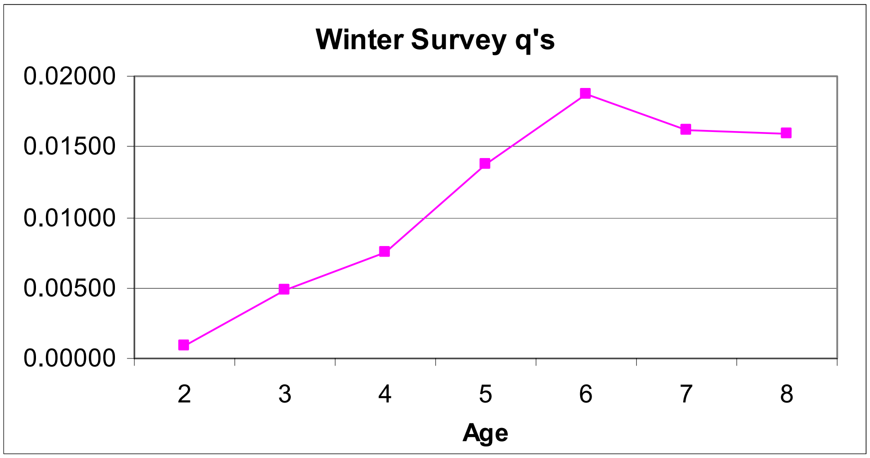

Figure 14.28.NMFS winter survey Q's by age for the complex final fit formulation

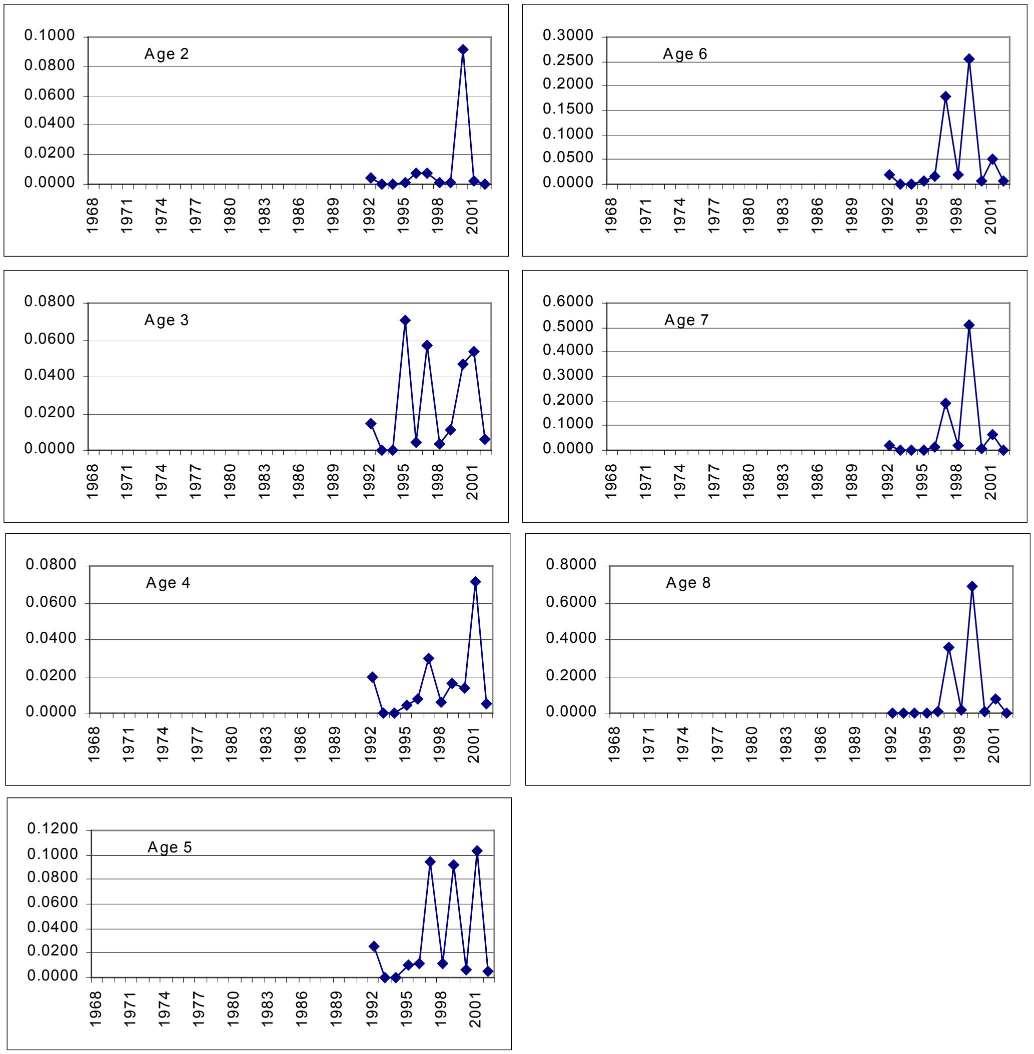

Figure 14.29. Canadian spring survey Q's (survey / popn. nos.) by year and age for the complex final fit formulation

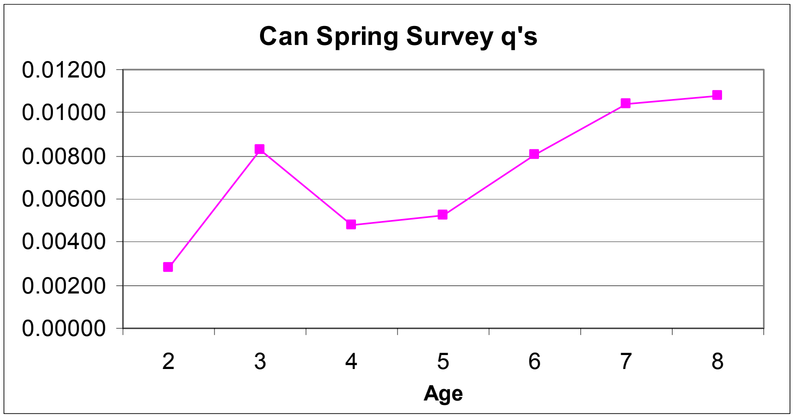

Figure 14.30. Canadian spring survey Q's by age for the complex final fit formulation

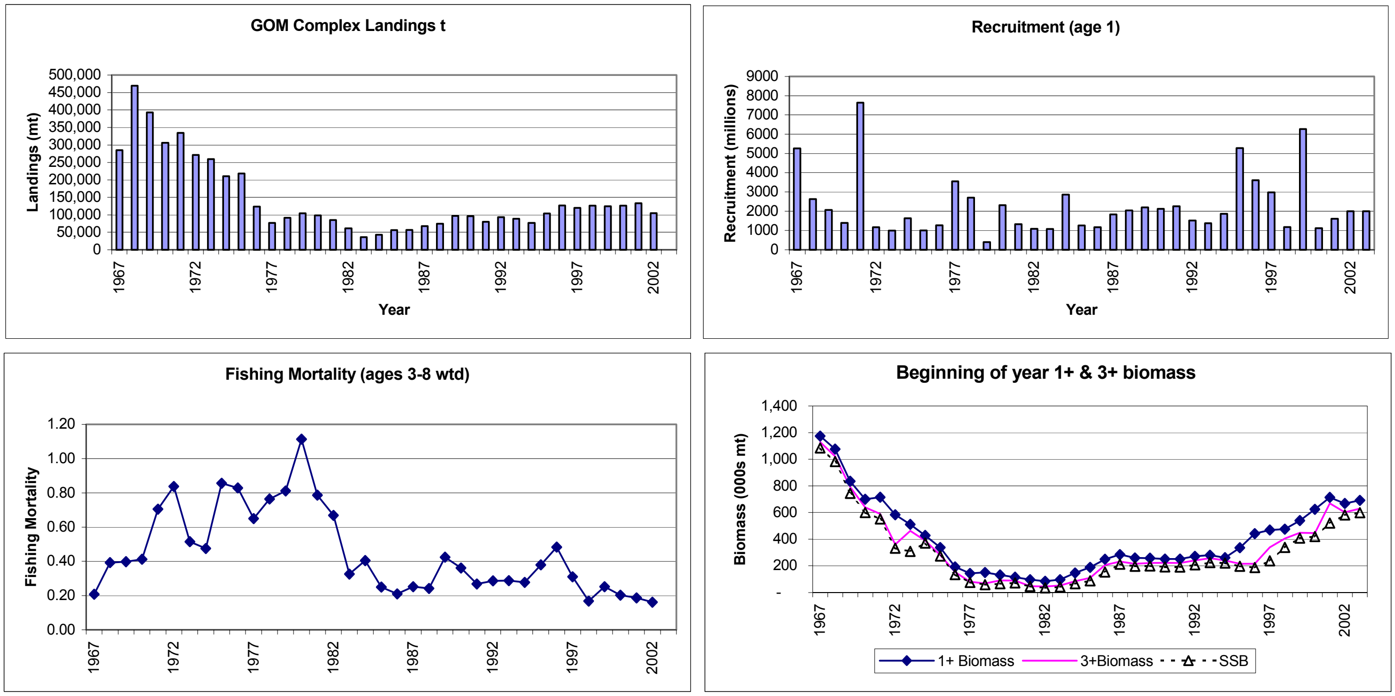

Figure 14.31. Landings, recruitment, fishing mortality and beginning of year biomass estimates from ‘Final Complex Fit’ VPA formulation.

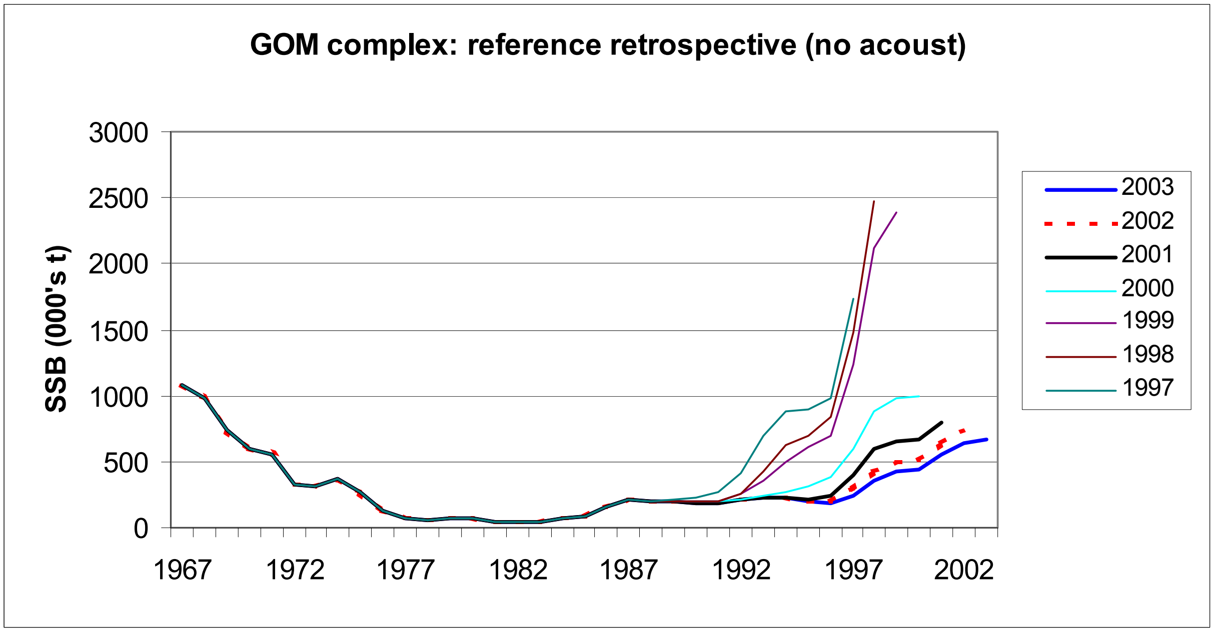

Figure 14.32 Retrospective plot of SSB for ‘Final Complex Fit’ VPA formulation (note that the acoustic survey is not included in retrospective analysis).

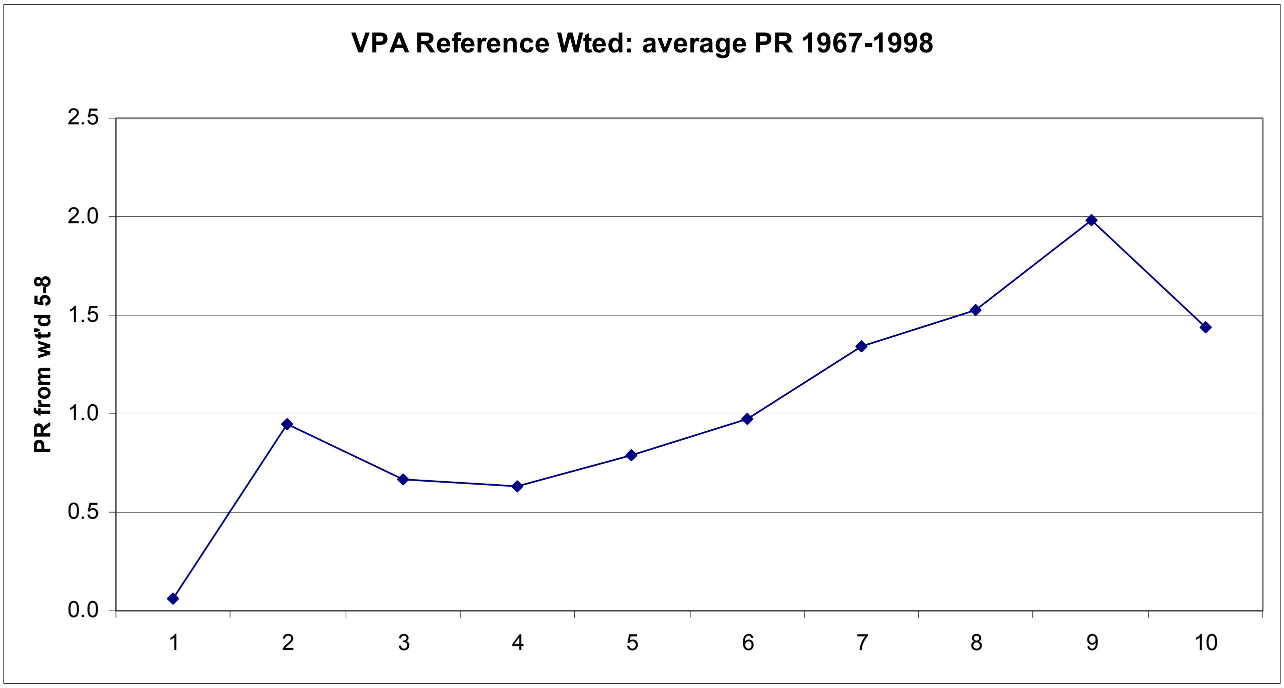

Figure 14.33. Partial recruitment pattern for the period 1967 to 1999 for the VPA Final Complex Fit (using population weighted age 5-8 F as the reference value).

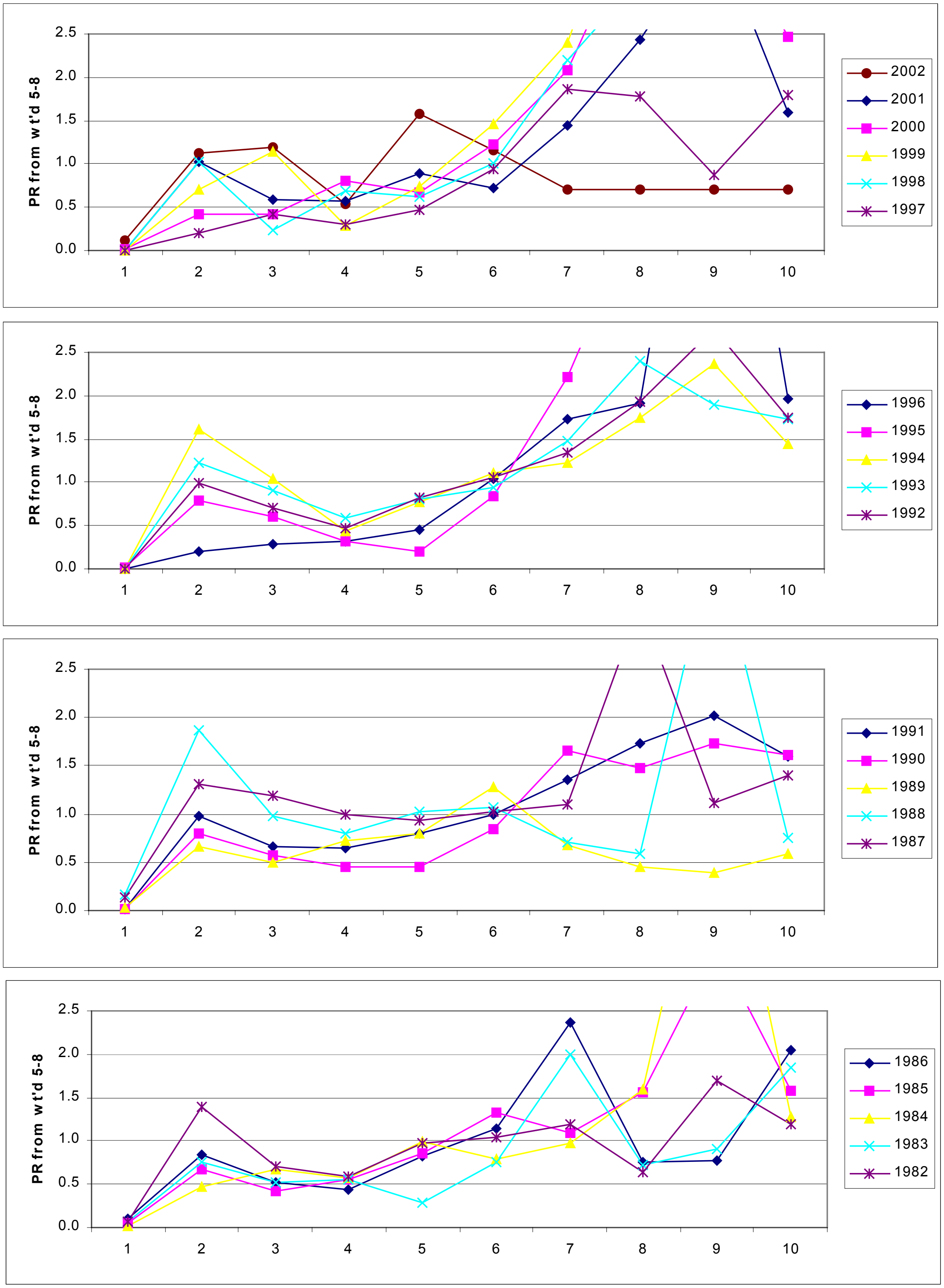

Figure 14.34. Annual partial recruitment pattern for 1982 to 2002 for the VPA Final Complex Fit (using population weighted age 5-8 F as the reference value).

Appendix 1: The KLAMZ (FPA) Assessment Model

Introduction

The KLAMZ assessment model (NEFSC 2000; 2001) 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 model that counts 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”, 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.[2] 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.

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 and “old” recruits. New recruits are individuals that recruited at the beginning or during the current year. Old recruits are all older individuals in the model. 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 (Deriso 1978; 1980). As described above, delay-difference calculations can be carried out in units of biomass or numerical abundance.

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[2] 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 cohorts due to spawning in 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*).

The KLAMZ model includes simple numerical models as special cases (e.g. Conser 1995) because growth can be turned off so that all calculations are in numerical units (see below).

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), internal calculation of surplus production or are used to stabilize biomass estimates for the first few years in the model.

The KLAMZ model is programmed in both Excel and in C++ using AD Model Builder libraries[3]. The AD Model Builder version is faster, more reliable, includes a wider variety of tools for characterizing uncertainty, and I probably better for producing "official" stock assessment results. The Excel version is slower but useful in developing prototype assessment models, teaching and checking calculations.

Population dynamics

The birth date for fish in the model and first day of the accounting year for catch data are assumed to be the 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.

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

$$\mathrm{B}_{\mathrm{t+1}} = (1+\rho)\,\tau_{\mathrm{t}}\,\mathrm{B}_{\mathrm{t}} - \rho\,\tau_{\mathrm{t}}\,\tau_{\mathrm{t-1}}\,\mathrm{B}_{\mathrm{t-1}} + \mathrm{R}_{\mathrm{t+1}} - \rho\,\tau_{\mathrm{t}}\,\mathrm{J}_{\mathrm{t}}\,\mathrm{R}_{\mathrm{t}}$$

where B_t is total biomass of individuals at the beginning of year t; ρ is Ford's growth coefficient (see below); $\tau_t = e^{-Z_t} = e^{-F_t - M_t}$ is the fraction of the stock that survived in year t, Z_t, F_t, and M_t are year-specific 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 or be constant 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 calculations 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

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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 recruitment age k and at age k-1 in the KLAMZ model (parameters V_t and v_{t-1} in Schnute 1985) because the ratio J_t and recruitment biomass R_t contain the same information.

Schnute's (1985) original delay difference equation is:

$$\mathrm{B}_{t+1} = (1+\rho)\,\tau_t\,\mathrm{B}_t - \rho\,\tau_t\tau_{t-1}\,\mathrm{B}_{t-1} + w_{t+1,k}\mathrm{N}_{t+1} - \rho\tau_t w_{t-1,k-1}\,\mathrm{N}_t$$

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 $J_t R_t = (w_{t-1,k-1}/w_{t,k})\, w_{t,k}\, N_{t,k} = w_{t-1,k-1}\, N_t$ for 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.

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 and w_{k-1}. Schnute and Fournier's (1980) growth model is the same as the traditional von Bertalanffy growth model $w_a = W_\infty\left[1-e^{-K(a-t_0)}\right]$ where W_∞, K and t_0 are parameters. The two growth models are the same because $W_\infty = (w_k - \rho w_{k-1})/(1-\rho)$, $K = -ln(\rho)$ and $t_0 = \ln[(w_k - w_{k-1})/(w_k - \rho w_{k-1})]/\ln(\rho)$.

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. It is possible to accommodate a wide range growth patterns by changing only W_{max} and t_{zero}. Growth parameters are usually estimated externally, rather than directly in the KLAMZ model. The KLAMZ model uses catch-at-age information indirectly, if catch-at-age is used to estimate growth parameters.

Numerical population dynamics (growth turned off)

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:

$$\mathrm{N}_{\mathrm{t+1}} = \tau_{\mathrm{t}}\ \mathrm{N}_{\mathrm{t}} + \mathrm{R}_{\mathrm{t+1}}$$

All of the calculations in KLAMZ for biomass dynamics are also valid for numerical dynamics.

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 an approximation used extensively in KLAMZ for calculating catch biomass and projecting stock biomass forward to the time at which surveys occur. IGR calculations are approximate because the instantaneous growth rate model approximates seasonal von Bertalanffy growth. However, the approximation is reasonably accurate and preferable to ignoring seasonal growth during the fishing season (see “Solving the generalized catch equation” and “Predicted values for abundance indices” below).

IGR for new recruits depends only on growth parameters:

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

New recruit IGR is constant if the growth parameter J_t is constant.

IGR for old recruits is a biomass-weighted average that depends on the current age structure and growth parameters. Old recruit IGR naturally changes from year to year, even if growth parameters are constant, due to changes in the stocks age structure. IGR for old recruits 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 $G_t^{Old} = \ln\left(S_t^*/S_t\right)$. Therefore, divide the expression for S_t^* by S_t and take logs to get:

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

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

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

Whole stock IGR varies over time, even if growth parameters are constant, due to changes in age structure. 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 an annual log recruitment parameter usually 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.[4] 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) are assumed constant in the Excel version of the KLAMZ model but can change from year to year in the AD Model Builder version based on covariates (e.g. predator density) or natural mortality rate process errors. Natural mortality rate process errors are variation in predation, disease, parasitism and other biological factors that affect natural mortality in fish populations. Calculations are basically the same as for survey covariates and survey process errors described below.

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[4] The constraint is implemented by adding $L = \lambda\overline{\varpi}^2$ to the objective function, generally with $\lambda = 1000$.

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”. 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 applicable when catches are in units of numbers but catch data are usually in units of weight. Calculation of predicted catches in units of weight is more complicated because somatic growth occurs 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 $\hat{C}_t$ was predicted catch weight (landings plus discard) and $\overline{B}_t$ is average biomass.

Following Ricker (1970) and Zhang and Sullivan (1988), let $X_t=G_t-F_t-M_t$ be the net instantaneous rate of change for biomass.[5] 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 $X_t \neq 0$, the formula for average biomass in year y is derived by integrating $B_t = B_0 e^{tX_y}$ over t from zero to one:

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

When $X_t \neq 0$, the expression for $\overline{B}_t$ is an approximation to the actual average biomass because G_t approximates the rate of change in mean body weight for von Bertalanffy growth.[6] 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 Excel version of KLAMZ, the modified catch equation is solved analytically for F_t given C_t, B_t, G_t and M (see “Solving the generalized catch equation” below). In the AD Model Builder

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

[6] 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.

version, fishing mortality rates are 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.

Solving the generalized catch equation

Subtracting predicted catch from the generalized catch equation (see above) from the observed catch data gives:

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

where $X_t = G_t - M_t - F_t$. In the simplest case $X_t = 0$, $\overline{B}_t = B_t$ and $F_t = C_t / B_t$.

If $X_t \neq 0$, then the Newton-Raphson algorithm (Kennedy and Gentle 1980) is used to solve for F_t. 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 with respect to 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 $\gamma = G - M$. 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 ≤ 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):

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

Surplus production

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

$$B_t^* = (1+\rho)\, e^{-M}\, B_t - \rho\, e^{-M}\, L_{t-1}\, B_{t-1} - \rho\, e^{-M}\, J_t\, R_t$$

By definition, surplus production $P_t=B^*_t-B_t$. This exact formula is preferable to Jacobson et al.'s (2002) approximation $P_t = B_{t+1} - B_t + \delta C_t$ because the correction factor δ is not required.

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) with constant M, 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 (in each iteration). 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. $\overline{F}_{\mathrm{Re}cent}$ and $\overline{B}_{\mathrm{Re}cent}$ are often useful in calculation of ratios involving management targets (e.g. $\overline{F}_{\mathrm{Re}cent} / F_{MSY}$ 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 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. $\lambda_v = 1000$) is used for "hard" constraints that must be satisfied in the model. Arbitrarily small weighting factors (e.g. $\lambda_v = 0.0001$) can be used for "soft" 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).

In practice, it is often convenient to use a different emphasis factor ($\lambda_{v,i}$) for each observation so that the importance of a few specific observations or instances of a constraint can be increased or decreased. KLAMZ allows the user to specify observation- an instance-specific weights for most types of data and constraints.

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. For $x \sim N(\mu, \sigma^2)$, 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 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 different variances (known or assumed known) or different expected values, then:

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

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:

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

The second approach is equivalent but used when the weights for each observation (λ_i) may differ:

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

In the latter case, the maximum likelihood estimator:

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

(where $\hat{x}$ is the average or predicted value from the model) is used explicitly 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.

Observed and predicted catch

In the AD Model Builder version, fishing mortality rates (based on the parameters Φ and ψ_t) are estimated to satisfy a NLL for observed and predicted catches:

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

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. The AD Model Builder version of KLAMZ can potentially estimate any or every catch in the time series. A few years of catches can be estimated in the Excel version of KLAMZ (see below) but catches are generally assumed measured without error.

Initial population age structure

In the KLAMZ model, old and new recruit biomass during the first year (R_1 and S_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 produce 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 to estimate intitial conditions.

The KLAMZ model uses two constraints to help estimate initial population biomass and initial age structure.[7] The first constraint links IGRs for escapement (G^{Old}) in the first years to an adjacent 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[8], 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 be 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. λ=1000) because incompatible values of S_1 and B_0 are biologically impossible. In calculations:

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

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.

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

[8] Normally, $n_G \leq 2$.

Goodness of fit for survey trends

The NLL used to measure goodness-of-fit for abundance index data with lognormal errors 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 abundance index datum from survey v, hats "^" denote model estimates, $\sigma_{v,j}$ was a log scale standard error (see below), and N_v was the number of observations. There are two approaches to calculating standard errors for log normal abundance index data in KLAMZ. The first is based on goodness of fit and the second is based on user specified CV's (see below). It is possible to use different approaches for different types of abundance index data in the same model.

Abundance indices with statistical distributions other than log normal may be useful, but are not currently programmed in the KLAMZ model. For example, Butler et al. (in press) used abundance indices with binomial distributions in a delay-difference model for cowcod rockfish.

Standard errors for goodness of fit

The first approach to calculating standard errors for survey data is based on goodness of fit. The first approach assumes that all observations for one type of abundance index share the same standard error and estimates the standard error along with the rest of the parameters in the model (see "NLL kernels" above).

In the second approach, each observation has a potentially different 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 is sometimes 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.[9] Implicitly estimated standard errors are often larger and more realistic, but imply 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 $X_t^{Old} = G_t^{Old} - F_t - M_t$; $j_{v,t}$ was the Julian date at the time of the survey, and $\Delta_{v,t}=j_{v,t}/365$ was 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 should 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.[10] 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:

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

[10] 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.

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

where N_v was 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.

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.

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 either 0 or 1, depending on whether the effect was 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 modeling, it is useful to center continuous covariates around their mean:

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

where $d'_{r,t}$ is the original covariate. With covariates that 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).

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 for Q_v described above.

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. In portraying results, it is often useful to calculate the scaling parameter for each survey observation, including effects of nonlinearity and covariates:

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

where the denominator is the raw (unadjusted) available biomass.

Survey Q process errors

The AD Model Builder version of the KLAMZ model incorporates a very useful ability to let survey scaling parameters change in a tightly controlled fashion from year to year (NEFSC 2002):

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

where the deviations $\varepsilon_{v,t}$ are survey Q process errors constrained to average zero. Variation in survey Q process errors 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 is supplied by the user (e.g. see NEFSC 2002).

Recruitment models

Recruitment parameters in KLAMZ may be freely estimated or estimated around an internal recruitment model, possibly based on spawning biomass. An internally estimated recruitment model may 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 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 $b=e^{\beta}$, α and β are parameters 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 α and β are parameters 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:

$$L = \sum_{t=t_{first}}^{N} \lambda_t \left[\ln(\sigma_r) + 0.5 \left({r_t}/{\sigma_r} \right)^2 \right]$$

where λ_t is an instance-specific weight usually set equal one. The additional term $ln(\sigma_r)$ in the NLL 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 is calculated explicitly because it is used in other calculations.

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:

$$NLL = \sum_{t=1}^{t_{first}-1} \lambda_t \left\{ \ln(\sigma_r + 0.5 \left[\frac{\ln\left(R_t / E\left(R_{t_{first}}\right)\right)}{\sigma_r} \right]^2 \right\}$$

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 and weights used are 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 survey scaling parameters (Q_v) may be useful if prior information about potential values 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, lognormal and beta distributions may be used as prior information in estimating Q_v for any abundance 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:

$$L = \left| \begin{array}{l} 10000\,(Q_v - q_{\max})^2 \;\; if \;\; Q_v \geq q_{\max} \\ 10000\,(q_{\min} - Q_v)^2 \;\; if \;\; Q_v \leq q_{\min} \end{array} \right.$$

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:

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

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.[11] Solving the simultaneous equations gives:

$$b = \frac{(\bar{q}' - 1)[Var(q') + (\bar{q}' - 1)\bar{q}']}{Var(q')}$$

and:

$$a = \frac{b\bar{q}'}{1 - \bar{q}'}$$

---

[11] If x has a standardized beta distribution with parameters a and b, then the probability of x is $P(x) = \frac{x^{a-1}(1 - x)^{b-1}}{\Gamma(a,b)}$.

Goodness of fit for beta Q_v values within legal bounds was calculated with the NLL:

$$L = (a-1)\ln(Q'_v) + (b-1)\ln(1-Q'_v)$$

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 model estimates in terms of surplus production parameters, 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 was 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.[12] 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 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 a Ricker spawner-recruit curve.

The Schaefer model has two log transformed parameters that are estimated in KLAMZ:

$$\tilde{P}_t = e^{\alpha} B_t - e^{\beta} B_t^2$$

---

[12] 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, while simple and useful, is not completely satisfactory.

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

Forward simulation models like KLAMZ may estimate absurdly high fishing mortality rates. The likelihood constrain used to prevent this potential problem was calculated:

$$L = 0.5\sum_{t=0}^{N} d_t^2$$

where:

$$d_t = \left| \begin{array}{c} \left(C_t/B - \kappa\right) if \;\; C_t/B > \kappa \\ 0 \; otherwise \end{array} \right.$$

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 $F \approx 4$ with M=0.2 and G=0.1 (maximum X = 0.1 - 4.0 - 0.2 = -4.1), set $\kappa \approx -F/X(1-e^{X})$ = 4 / 4.1 (1-$e^{-4.1}$)=0.96.

Uncertainty

The AD Model Builder version of the KLAMZ model automatically calculates variances for parameters and many quantities of interest by the delta method using AD Model Builder libraries with 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.

Bootstrapping

A FORTRAN program called BootADM can be used to bootstrap survey data in the KLAMZ model. BootADM extracts the standardized residuals:

$$r_{v,j} = \frac{\ln\left(I_{v,j} \Big/ \hat{I}_{v,j} \right)}{\sigma_{v,j}}$$

using log scale standard deviations $(\sigma_{v,j})$, and predicted values $\left(\hat{I}_{v,j}\right)$ for all active survey observations in a "base case" KLAMZ model run. The standardized residuals are resampled from a single pool 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 for the x^{th} bootstrap iteration.

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 Excel to calculate variances, confidence intervals, bias estimates, etc. (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.[13] 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

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[13] At present, only Beverton-Holt recruitment calculations are available in SPROJDDF.

basecase model fit. It differs from most current approaches because the spawner-recruit parameters vary from projection to projection.

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Appendix 2. Output from final FPA model Run.

```
#lobound_vonbert_k
0.0001
#hibound_vonbert_k
1
#--
#fyear_jratios
1960
#lyear_jratios
2002
#jratios
 1960 0.0499206
 1961 0.0499206
 1962 0.0499206
 1963 0.0499206
 1964 0.0499206
 1965 0.0499206
 1966 0.0499206
 1967 0.0499206
 1968 0.0483747
 1969 0.0492063
 1970 0.0502046
 1971 0.0504322
 1972 0.0513853
 1973 0.0536338
 1974 0.0572812
 1975 0.0631707
 1976 0.0688843
 1977 0.0742901
 1978 0.0788632
 1979 0.0835613
 1980 0.0875766
 1981 0.0909363
 1982 0.0930431
 1983 0.0943188
 1984 0.0943851
 1985 0.0938452
 1986 0.0933588
 1987 0.093164
 1988 0.0930146
 1989 0.0931039
 1990 0.0933475
 1991 0.0941285
 1992 0.0951191
 1993 0.096404
 1994 0.0978588
 1995 0.099283
 1996 0.100514
 1997 0.101728
 1998 0.103042
 1999 0.104303
 2000 0.105067
 2001 0.105382
 2002 0.105382
#check_after_growth_pars
12345
#--
#emphasis_fpart_igr
1
#cv_igr
0.264
#igr_years_to_constrain
2
#--
#year_lag_recruits
2
#maturity
 0 1
#--
#phase_log_mean_recruit_par
1
#phase_recruit_dev_pars
1
#--
#type_recruit_model
3
#phase_spawner_recruit
1
#emphasis_recruit_model
1
```

```
#fyear_recruit_model_weights
1959
#lyear_recruit_model_weights
2002
#recruit_dev_weights
 1959 1
 1960 1
 1961 1
 1962 1
 1963 1
 1964 1
 1965 1
 1966 1
 1967 1
 1968 1
 1969 1
 1970 1
 1971 1
 1972 1
 1973 1
 1974 1
 1975 1
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 1989 1
 1990 1
 1991 1
 1992 1
 1993 1
 1994 1
 1995 1
 1996 1
 1997 1
 1998 1
 1999 1
 2000 1
 2001 1
 2002 1
#--
#emphasis_fpart_firstfew_recr
1
#--
#emphasis_fpart_log_rvar
10
#target_log_rvar
-0.82124
#std_log_rvar
1.01475
#check_after_recruit_stuff
12345
#--
#phase_surplus_production
1
#use_fox
1
#emphasis_fpart_surplus_production
0.0001
#--
#phase_m
-1
#lobound_m
0.0001
#hibound_m
1
#--
#n_natmat_covariates
1
#natmat_covariate_names
Timmy_Turtle
#phase_natmat_covariates
```

```
 -2
#fyear_natmat_covariates
1960
#lyear_natmat_covariates
2002
#natmat_covariates
 1960 -0.85375
 1961 -1.94446
 1962 -1.07196
 1963 -0.442837
 1964 -1.364
 1965 0.0423344
 1966 -0.426332
 1967 1.23901
 1968 -1.94446
 1969 -1.07196
 1970 -0.442837
 1971 -1.364
 1972 0.0423344
 1973 -0.426332
 1974 1.23901
 1975 -0.845328
 1976 0.364838
 1977 1.63832
 1978 -0.85375
 1979 -0.310524
 1980 1.25189
 1981 0.0719867
 1982 -1.08938
 1983 0.536718
 1984 0.0600732
 1985 0.733052
 1986 1.40342
 1987 -0.057267
 1988 -1.52887
 1989 0.628372
 1990 0.516373
 1991 1.85809
 1992 -0.628517
 1993 -1.1758
 1994 -0.230763
 1995 1.23099
 1996 -0.0266012
 1997 -0.306805
 1998 -1.00959
 1999 0.566808
 2000 1.46092
 2001 -0.290394
 2002 -0.40651
#check_after_natmat_covariates
12345
#--
#type_natmat_devs
1
#phase_natmat_devs
-1
#emphasis_fpart_natmat_devs
-1
#cv_natmat_devs
-0.1
#fyear_natmat_dev_weights
1959
#lyear_natmat_dev_weights
2002
#natmat_dev_weights
 1959 1
 1960 1
 1961 1
 1962 1
 1963 1
 1964 1
 1965 1
 1966 1
 1967 1
 1968 1
 1969 1
 1970 1
 1971 1
 1972 1
 1973 1
 1974 1
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 1975 1
 1976 1
 1977 1
 1978 1
 1979 1
 1980 1
 1981 1
 1982 1
 1983 1
 1984 1
 1985 1
 1986 1
 1987 1
 1988 1
 1989 1
 1990 1
 1991 1
 1992 1
 1993 1
 1994 1
 1995 1
 1996 1
 1997 1
 1998 1
 1999 1
 2000 1
 2001 1
 2002 1
#check_after_natmat_dev_stuff
12345
#--
#phase_fdevs
1
#emphasis_fpart_catch
1e+06
#cv_catch
0.2
#--
#fyear_katch
1959
#lyear_katch
2002
# katch year sex area catch discard
 1959 0 0 94.001 0 1
 1960 0 0 93.955 0 1
 1961 0 0 100.556 0 1
 1962 0 0 242.15 0 1
 1963 0 0 194.344 0 1
 1964 0 0 187.445 0 1
 1965 0 0 109.844 0 1
 1966 0 0 210.038 0 1
 1967 0 0 285.245 0 1
 1968 0 0 469.978 0 1
 1969 0 0 392.655 0 1
 1970 0 0 307.131 0 1
 1971 0 0 330.52 0 1
 1972 0 0 271.744 0 1
 1973 0 0 258.551 0 1
 1974 0 0 209.886 0 1
 1975 0 0 216.957 0 1
 1976 0 0 121.925 0 1
 1977 0 0 67.08 0 1
 1978 0 0 88.165 0 1
 1979 0 0 104.178 0 1
 1980 0 0 93.234 0 1
 1981 0 0 84.097 0 1
 1982 0 0 59.852 0 1
 1983 0 0 35.627 0 1
 1984 0 0 42.442 0 1
 1985 0 0 55.155 0 1
 1986 0 0 56.202 0 1
 1987 0 0 66.846 0 1
 1988 0 0 73.95 0 1
 1989 0 0 97.059 0 1
 1990 0 0 93.805 0 1
 1991 0 0 79.943 0 1
 1992 0 0 93.191 0 1
 1993 0 0 88.667 0 1
 1994 0 0 76.821 0 1
 1995 0 0 102.253 0 1
 1996 0 0 126.852 0 1
```

```
 1997 0 0 119.553 0 1
 1998 0 0 125.829 0 1
 1999 0 0 124.101 0 1
 2000 0 0 125.818 0 1
 2001 0 0 133.165 0 1
 2002 0 0 104.43 0 1
#check_after_katch
12345
#--
#c_over_b_threshold
0.95
#emphasis_fpart_c_over_b
10000
#--
#check_after_catch_stuff
12345
#--
#nsurveys
12
#survey_names
Spring_Age_2
Spring_Age_3+
Winter_Age_2
Winter_Age_3+
Fall_Age_2
Fall_Age_3+
Hydroacoustic_3+
Larval_Herring_Index
ICNAF_and_USA_CPUE
Canadian_Larval_Survey
Canadian_Age_2
Canadian_Age_3+
#----done_with_survey_names
#survey selex
 1 0
 0 1
 1 0
 0 1
 1 0
 0 1
 0.5 1
 0.5 1
 1 1
 0.5 1
 1 0
 0 1
#scale_biomass
 0.001 0.001 0.001 0.001 0.001 0.001 1 0.001 0.001 0.001 0.001 0.001
#emphasis_fpart_surveys
 1 1 1 1 1 1 1 1 0 1 1 1
#use_survey_cvs
 -99 -99 -99 -99 -99 -99 1 -99 -99 -99 -99 -99
#phase_nonlinear_indices
 0 0 0 0 0 0 0 0 -1 0 0 0
#n_survey_covariates
 2 2 0 0 3 3 1 1 0 0 0 0
#nobs_surveys
 35 35 11 11 37 40 4 24 26 9 17 17
#--
#survey_data survey_id year sex area julian_date datum cv covariates
 1 1968 0 0 86.14 0.0385175 0.385 1 0
 1 1969 0 0 81.19 0.004641 0.683 1 0
 1 1970 0 0 98.72 0.242537 0.282 1 0
 1 1971 0 0 90.47 0.0098343 0.296 1 0
 1 1972 0 0 89.67 0.024021 0.361 1 0
 1 1973 0 0 100.04 0.0036018 0.456 1 0
 1 1974 0 0 99.14 0.0013674 0.295 1 0
 1 1975 0 0 99.02 0.0019482 0.433 1 0
 1 1976 0 0 90.67 0.0018354 0.208 1 0
 1 1977 0 0 109.63 0.0024738 0.659 1 0
 1 1978 0 0 109.12 0.004888 0.526 0 0
 1 1979 0 0 107.6 0.145027 0.406 0 0
 1 1980 0 0 106.5 0.0046453 0.295 0 0
 1 1981 0 0 113.61 0.000864 0.377 0 0
 1 1982 0 0 104.17 0.0198009 0.309 0 0
 1 1983 0 0 97.23 0.0084095 0.416 0 0
 1 1984 0 0 90.05 0.098532 0.319 0 0
 1 1985 0 0 83.2 0.0956823 0.411 0 1
 1 1986 0 0 93.97 0.0896972 0.457 0 1
 1 1987 0 0 104.26 0.0571987 0.246 0 1
 1 1988 0 0 87.21 0.109776 0.335 0 1
```

```
1 1989 0 0 82.1 0.0762634 0.471 0 1
1 1990 0 0 86.76 0.130737 0.292 0 1
1 1991 0 0 86.9 0.242798 0.233 0 1
1 1992 0 0 87.18 0.506074 0.283 0 1
1 1993 0 0 96.39 0.318608 0.295 0 1
1 1994 0 0 91.66 0.213091 0.267 0 1
1 1995 0 0 96.56 0.339567 0.25 0 1
1 1996 0 0 99.38 2.20928 0.27 0 1
1 1997 0 0 88.2 0.978834 0.261 0 1
1 1998 0 0 87.81 0.191786 0.278 0 1
1 1999 0 0 91.59 0.127084 0.206 0 1
1 2000 0 0 100 0.921753 0.272 0 1
1 2001 0 0 93 0.305769 0.185 0 1
1 2002 0 0 93 0.2 0.185 0 1
2 1968 0 0 86.14 4.02381 0.385 1 0
2 1969 0 0 81.19 2.85755 0.683 1 0
2 1970 0 0 98.72 0.781455 0.282 1 0
2 1971 0 0 90.47 0.332553 0.296 1 0
2 1972 0 0 89.67 0.441679 0.361 1 0
2 1973 0 0 100.04 1.48675 0.456 1 0
2 1974 0 0 99.14 0.998222 0.295 1 0
2 1975 0 0 99.02 0.212204 0.433 1 0
2 1976 0 0 90.67 0.196818 0.208 1 0
2 1977 0 0 109.63 0.172891 0.659 1 0
2 1978 0 0 109.12 0.457187 0.526 0 0
2 1979 0 0 107.6 0.626994 0.406 0 0
2 1980 0 0 106.5 1.04988 0.295 0 0
2 1981 0 0 113.61 0.504389 0.377 0 0
2 1982 0 0 104.17 0.042464 0.309 0 0
2 1983 0 0 97.23 0.0685557 0.416 0 0
2 1984 0 0 90.05 0.154971 0.319 0 0
2 1985 0 0 83.2 0.346548 0.411 0 1
2 1986 0 0 93.97 4.2002 0.457 0 1
2 1987 0 0 104.26 0.809923 0.246 0 1
2 1988 0 0 87.21 1.41009 0.335 0 1
2 1989 0 0 82.1 1.19425 0.471 0 1
2 1990 0 0 86.76 0.873336 0.292 0 1
2 1991 0 0 86.9 2.27234 0.233 0 1
2 1992 0 0 87.18 2.72562 0.283 0 1
2 1993 0 0 96.39 7.60452 0.295 0 1
2 1994 0 0 91.66 3.89002 0.267 0 1
2 1995 0 0 96.56 2.9269 0.25 0 1
2 1996 0 0 99.38 3.21558 0.27 0 1
2 1997 0 0 88.2 4.76961 0.261 0 1
2 1998 0 0 87.81 5.51109 0.278 0 1
2 1999 0 0 91.59 10.796 0.206 0 1
2 2000 0 0 100 2.65571 0.272 0 1
2 2001 0 0 93 3.73244 0.185 0 1
2 2002 0 0 93 2.5 0.215 0 1
3 1992 0 0 53.59 0.354412 0.26
3 1993 0 0 45.92 0.014014 0.255
3 1994 0 0 41.28 0.003969 0.31
3 1995 0 0 49.8 0.0040992 0.286
3 1996 0 0 46.45 4.02681 0.368
3 1997 0 0 45.23 0.0810106 0.619
3 1998 0 0 47.75 0.0689128 0.261
3 1999 0 0 42.04 0.0129708 0.192
3 2000 0 0 50 2.91682 0.323
3 2001 0 0 41 0.364207 0.471
3 2002 0 0 50 0.4 0.541
4 1992 0 0 53.59 3.25676 0.26
4 1993 0 0 45.92 6.54461 0.255
4 1994 0 0 41.28 0.588561 0.31
4 1995 0 0 49.8 2.66092 0.286
4 1996 0 0 46.45 5.87763 0.368
4 1997 0 0 45.23 8.62009 0.619
4 1998 0 0 47.75 6.66305 0.261
4 1999 0 0 42.04 7.67709 0.192
4 2000 0 0 50 9.15969 0.323
4 2001 0 0 41 8.71385 0.471
4 2002 0 0 50 9.3 0.541
5 1963 0 0 332.97 0.0007125 0.259 -1.672 1 0
5 1964 0 0 313.89 0.0006375 0.308 -0.772 1 0
5 1965 0 0 296.06 7.5e-06 0.29 1.128 1 0
5 1966 0 0 301.15 0.00015 0.192 1.628 1 0
5 1967 0 0 313.08 0.0017125 0.256 -0.872 1 0
5 1968 0 0 302.9 0.0005575 0.222 -1.272 1 0
5 1969 0 0 301.85 0.0009048 0.383 -0.872 1 0
5 1970 0 0 292.59 0.0019404 0.444 -0.672 1 0
5 1971 0 0 293.66 0.0007448 0.72 -0.072 1 0
5 1972 0 0 295.12 0.0064617 0.375 -1.572 1 0
```

```
5 1973 0 0 291.8 3.78e-05 0.578 -1.672 1 0
5 1974 0 0 286.26 1.06e-05 0.581 -0.872 1 0
5 1975 0 0 296.06 0.0003825 0.468 0.228 1 0
5 1977 0 0 301.68 0.0002562 0.316 -1.672 1 0
5 1978 0 0 290.26 0.000428 0.274 0.428 0 0
5 1979 0 0 298.25 0.0003808 0.446 -0.472 0 0
5 1982 0 0 289.17 0.0001715 0.321 0.128 0 0
5 1983 0 0 286.88 0.0020075 0.272 -0.172 0 0
5 1984 0 0 282.9 0.0004692 0.485 0.228 0 0
5 1985 0 0 291.82 0.0016758 0.913 -0.172 0 1
5 1986 0 0 286 0.0011978 0.361 -0.472 0 1
5 1987 0 0 279.81 0.0889812 0.354 0.328 0 1
5 1988 0 0 280.6 0.0345474 0.521 0.228 0 1
5 1989 0 0 281.75 0.0643126 0.406 1.028 0 1
5 1990 0 0 276.94 0.114365 0.583 2.228 0 1
5 1991 0 0 275.26 0.143248 0.635 0.928 0 1
5 1992 0 0 279.54 0.103242 0.301 0.328 0 1
5 1993 0 0 274.45 0.0155892 0.417 0.828 0 1
5 1994 0 0 277.14 0.0311003 0.218 0.428 0 1
5 1995 0 0 273.55 0.0327376 0.368 1.628 0 1
5 1996 0 0 276.73 0.58347 0.313 0.128 0 1
5 1997 0 0 278.32 0.083904 0.316 0.628 0 1
5 1998 0 0 287.7 0.0654524 0.096 0.328 0 1
5 1999 0 0 290.23 0.0120366 0.177 -0.372 0 1
5 2000 0 0 272 0.0671549 0.258 1.728 0 1
5 2001 0 0 272 0.0183549 0.25 1.628 0 1
5 2002 0 0 278 0.149969 0.433 0.908 0 1
6 1963 0 0 332.97 0.639601 0.259 -1.672 1 0
6 1964 0 0 313.89 0.0864806 0.308 -0.772 1 0
6 1965 0 0 296.06 0.349221 0.29 1.128 1 0
6 1966 0 0 301.15 1.00297 0.192 1.628 1 0
6 1967 0 0 313.08 0.323385 0.256 -0.872 1 0
6 1968 0 0 302.9 0.130374 0.222 -1.272 1 0
6 1969 0 0 301.85 0.0647873 0.383 -0.872 1 0
6 1970 0 0 292.59 0.0583215 0.444 -0.672 1 0
6 1971 0 0 293.66 0.332917 0.72 -0.072 1 0
6 1972 0 0 295.12 0.0733762 0.375 -1.572 1 0
6 1973 0 0 291.8 0.0071231 0.578 -1.672 1 0
6 1974 0 0 286.26 0.0179494 0.581 -0.872 1 0
6 1975 0 0 296.06 0.062106 0.468 0.228 1 0
6 1976 0 0 298.01 0.0228836 0.606 -2.372 1 0
6 1977 0 0 301.68 0.0045698 0.316 -1.672 1 0
6 1978 0 0 290.26 0.0940207 0.274 0.428 0 0
6 1979 0 0 298.25 0.0023015 0.446 -0.472 0 0
6 1980 0 0 293.22 0.0006386 0.527 -0.972 0 0
6 1981 0 0 290.98 0.0011165 0.385 -0.072 0 0
6 1982 0 0 289.17 0.0198178 0.321 0.128 0 0
6 1983 0 0 286.88 0.0230087 0.272 -0.172 0 0
6 1984 0 0 282.9 0.224414 0.485 0.228 0 0
6 1985 0 0 291.82 0.382118 0.913 -0.172 0 1
6 1986 0 0 286 0.14279 0.361 -0.472 0 1
6 1987 0 0 279.81 0.907407 0.354 0.328 0 1
6 1988 0 0 280.6 1.24556 0.521 0.228 0 1
6 1989 0 0 281.75 1.81458 0.406 1.028 0 1
6 1990 0 0 276.94 1.26961 0.583 2.228 0 1
6 1991 0 0 275.26 1.90785 0.635 0.928 0 1
6 1992 0 0 279.54 6.34181 0.301 0.328 0 1
6 1993 0 0 274.45 2.36244 0.417 0.828 0 1
6 1994 0 0 277.14 1.78319 0.218 0.428 0 1
6 1995 0 0 273.55 9.7751 0.368 1.628 0 1
6 1996 0 0 276.73 3.77061 0.313 0.128 0 1
6 1997 0 0 278.32 4.32641 0.316 0.628 0 1
6 1998 0 0 287.7 2.54039 0.096 0.328 0 1
6 1999 0 0 290.23 1.68844 0.177 -0.372 0 1
6 2000 0 0 272 3.1045 0.258 1.728 0 1
6 2001 0 0 272 3.77602 0.25 1.628 0 1
6 2002 0 0 278 10.8981 0.433 0.908 0 1
7 1999 0 0 273 1193 0.1071 -0.1353
7 2000 0 0 265 1427 0.0722 -0.0734
7 2001 0 0 265 1819 0.066 0.0332
7 2002 0 0 265 763 0.1365 0.1755
8 1971 0 0 90 89.7 0.2 0
8 1972 0 0 90 81.4 0.2 0
8 1973 0 0 90 355.2 0.2 0
8 1974 0 0 90 304.5 0.2 0
8 1975 0 0 90 55.9 0.2 0
8 1976 0 0 90 2.2 0.2 0
8 1977 0 0 90 19.2 0.2 0
8 1978 0 0 90 2.4 0.2 0
8 1979 0 0 90 6 0.2 0
8 1980 0 0 90 1.9 0.2 0
```

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8 1981 0 0 90 29.7 0.2 0
8 1982 0 0 90 18.2 0.2 0
8 1983 0 0 90 3.7 0.2 0
8 1984 0 0 90 2.3 0.2 0
8 1985 0 0 90 95.4 0.2 0
8 1986 0 0 90 60.4 0.2 0
8 1987 0 0 90 31.4 0.2 0
8 1988 0 0 90 184.9 0.2 0
8 1989 0 0 90 454.3 0.2 1
8 1990 0 0 90 394.1 0.2 1
8 1991 0 0 90 354.2 0.2 1
8 1992 0 0 90 577.1 0.2 1
8 1993 0 0 90 397.6 0.2 1
8 1994 0 0 90 610 0.2 1
9 1960 0 0 180 0.154094 1
9 1961 0 0 180 0.145542 1
9 1963 0 0 180 0.16747 1
9 1964 0 0 180 0.119432 1
9 1965 0 0 180 0.0503471 1
9 1966 0 0 180 0.0936122 1
9 1967 0 0 180 0.165301 1
9 1968 0 0 180 0.225098 1
9 1969 0 0 180 0.164017 1
9 1970 0 0 180 0.193137 1
9 1971 0 0 180 0.150286 1
9 1972 0 0 180 0.0931927 1
9 1973 0 0 180 0.103168 1
9 1974 0 0 180 0.0981641 1
9 1975 0 0 180 0.071347 1
9 1976 0 0 180 0.0731125 1
9 1977 0 0 180 0.103725 1
9 1978 0 0 180 0.12956 1
9 1979 0 0 180 0.177007 1
9 1980 0 0 180 0.128225 1
9 1982 0 0 180 0.0710141 1
9 1983 0 0 180 0.0437593 1
9 1984 0 0 180 0.0492521 1
9 1985 0 0 180 0.058507 1
9 1986 0 0 180 0.0724594 1
9 1987 0 0 180 0.0764225 1
10 1987 0 0 311 12.5893 0.428706
10 1988 0 0 309 6.05366 0.192931
10 1989 0 0 304 7.3743 0.356369
10 1990 0 0 308 10.214 0.186788
10 1991 0 0 311 3.28665 0.258948
10 1992 0 0 333 12.172 0.148202
10 1993 0 0 324 30.3514 0.134717
10 1994 0 0 326 52.2595 0.165629
10 1995 0 0 325 41.294 0.202032
11 1986 0 0 60 0.0962586 0.53915
11 1987 0 0 60 0.0354864 0.625298
11 1988 0 0 60 0.0137315 0.286945
11 1989 0 0 60 3.12522 0.50749
11 1990 0 0 60 1.58928 0.42794
11 1991 0 0 60 2.08539 0.568197
11 1992 0 0 60 0.404232 0.548984
11 1993 0 0 60 0.0192857 -0.69347
11 1994 0 0 60 0.0178963 -0.617265
11 1995 0 0 60 0.0975029 0.695333
11 1996 0 0 60 1.72861 0.458356
11 1997 0 0 60 0.988147 0.704324
11 1998 0 0 60 0.0601231 0.754251
11 1999 0 0 60 0.0322447 0.418691
11 2000 0 0 60 28.4954 0.391581
11 2001 0 0 60 0.124303 0.380895
11 2002 0 0 60 0.5 0.685102
12 1986 0 0 60 1.27675 0.536046
12 1987 0 0 60 0.0135768 0.326106
12 1988 0 0 60 0.556319 0.321023
12 1989 0 0 60 0.479208 0.486534
12 1990 0 0 60 0.220152 0.418123
12 1991 0 0 60 8.19958 0.492509
12 1992 0 0 60 4.99388 0.309343
12 1993 0 0 60 30.0806 -0.430868
12 1994 0 0 60 0.298118 -0.344542
12 1995 0 0 60 4.83328 0.442822
12 1996 0 0 60 2.41639 0.249246
12 1997 0 0 60 31.0152 0.396522
12 1998 0 0 60 3.16382 0.284036
12 1999 0 0 60 41.2759 0.259872
12 2000 0 0 60 7.04226 0.312992
```

```
 12 2001 0 0 60 47.8367 0.229625
 12 2002 0 0 60 15 0.324383
#check_after_survey_data
12345
#--
#phase_survey_covariate_pars
 -9 1 -9 -1 -1 -9 1 1 -9 1 -9 1
#survey_covariate_names
Spring_Age2_Effort_Dummy
Spring_Age2_Door_Dummy
Spring_Age3_Effort_Dummy
Spring_Age3_Door_Dummy
Fall_Age2_Temp_Anomaly
Fall_Age2_Effort_Anomaly
Fall_Age2_Door_Dummy
Fall_Age3_Temp_Anomaly
Fall_Age3_Effort_Anomaly
Fall_Age3_Door_Dummy
Percent_spent_and_resting
Break_US_Larval_1988_89
#----done_with_survey_covariate_names
#phase_survey_q_devs
-1
#emphasis_survey_q_devs
 0 0 0 0 0 0 0 0 0 0 0 0
#cv_survey_q_devs
 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
#--
#emphasis_fpart_bayes_q
 0 0 0 0 0 0 1 0 0 0 0 0
#distn_prior_q_(1=log_normal;2=beta;other=NONE)
  0 0 0 0 0 0 1 0 0 0 0 0
#min_prior_q
 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06
#max_prior_q
 99 99 99 99 99 99 99 99 99 99 99 99
#mean_qprior
 9 9 9 9 9 9 0.85 9 9 9 9 9
#cv_qprior
 9 9 9 9 9 9 0.429 9 9 9 9 9
#--
#emphasis_fpart_profile_q
0
#profile_q
-99
#profile_q_target
-99
#--
#fyear_fstatus
2000
#lyear_fstatus
2002
#--
#fyear_bstatus
2000
#lyear_bstatus
2002
#check_eof
12345
#--------------------------------------
#OUTPUT_CALCULATIONS:
#--------------------------------------
total_number_of_objective_function_calls 250
objective_function_calls_last_phase 249
final_obj_func 398.974
#--------------------------------------
Miscellaneous_Biology:
VonBert_K 0.173515
#--------------------------------------
#--------------------------------------
Goodness_of_fit_summary:
#--------------------------------------
Objective_function_components:
ComponentName Component_Value Emphasis Product
Survey_trends  see_below see_below 413.441
Prior_survey_Q  see_below see_below 0.0642656
survey_q_devs_(survey_Q_process_errors)  see_below  see_below 0 (not_used)
BEVERTON-HOLT_MODEL -18.1769 1 -18.1769
Constrain_first_few_recruitments -1.88142 1 -1.88142 (see_below)
Fox_surplus_production -37.0455 0.0001 -0.00370455
Natural_mortality_process_errors 0 0 0 (not_used)
```

```
Profile_Survey_Q 0 0 0 (not_used)
Prior_Log_Rec_Residual_Var 0.551205 10 5.51205 (see_below)
Catch 5.17475e-13 1e+06 5.17475e-07
C/B_constraint 0 10000 0
B_too_small 0 1000 0
B_too_big 0 1000 0
Constrain_Bzero 6.18217e-12 1000 6.18217e-09
Constrain_inital_IGR 0.0186878 1 0.0186878
Center_fdevs 1.79123e-18 1000 1.79123e-15
Center_recruit_devs 9.35824e-20 1000 9.35824e-17
Center_survey_q_devs 0 0 0 (not_used)
Center_natmat_devs 0 0 0 (not_used)
Total_LogLikelihood NA NA 398.974
#-------------------------------------
Constrain_first_few_recruitments
#-------------------------------------
Constrain_first_few_recruitments
Years_constrained 2
sd_recruit_devs 0.389325
Predicted_recruitment_(year_1962) 152.869
Year  1960 1961
Recruit_dev_weights  1 1
Recruits  158.148 149.687
#-------------------------------------
Goodness_of_fit_survey_trends
#-------------------------------------
SurveyNo ComponentName  Component_Value  Emphasis  Product
1 Trend_Spring_Age_2 64.2804 1 64.2804
2 Trend_Spring_Age_3+ 49.7078 1 49.7078
3 Trend_Winter_Age_2 20.8307 1 20.8307
4 Trend_Winter_Age_3+ 8.43102 1 8.43102
5 Trend_Fall_Age_2 76.3778 1 76.3778
6 Trend_Fall_Age_3+ 74.4223 1 74.4223
7 Trend_Hydroacoustic_3+ 15.9366 1 15.9366
8 Trend_Larval_Herring_Index 42.1214 1 42.1214
9 Trend_ICNAF_and_USA_CPUE 0 0 0
10 Trend_Canadian_Larval_Survey 6.06144 1 6.06144
11 Trend_Canadian_Age_2 28.226 1 28.226
12 Trend_Canadian_Age_3+ 27.046 1 27.046
Subotal All NA NA 413.441
#-------------------------------------
Goodness_of_fit_prior_survey_Q:
#-------------------------------------
SurveyNo Survey_Name NegLogLike Emphasis Product
1 PriorQ_Spring_Age_2 0 0 0 (not_used)
2 PriorQ_Spring_Age_3+ 0 0 0 (not_used)
3 PriorQ_Winter_Age_2 0 0 0 (not_used)
4 PriorQ_Winter_Age_3+ 0 0 0 (not_used)
5 PriorQ_Fall_Age_2 0 0 0 (not_used)
6 PriorQ_Fall_Age_3+ 0 0 0 (not_used)
7 PriorQ_Hydroacoustic_3+ 0.0642656 1 0.0642656
8 PriorQ_Larval_Herring_Index 0 0 0 (not_used)
9 PriorQ_ICNAF_and_USA_CPUE 0 0 0 (not_used)
10 PriorQ_Canadian_Larval_Survey 0 0 0 (not_used)
11 PriorQ_Canadian_Age_2 0 0 0 (not_used)
12 PriorQ_Canadian_Age_3+ 0 0 0 (not_used)
Subtotal All NA NA 0.0642656
#-------------------------------------
Goodness_of_fit_survey_Q_process_errors:
#-------------------------------------
SurveyNo. Survey_Name NegLogLike Emphasis Product
1 survey_q_devs_Spring_Age_2 0 0 0 (not_used)
2 survey_q_devs_Spring_Age_3+ 0 0 0 (not_used)
3 survey_q_devs_Winter_Age_2 0 0 0 (not_used)
4 survey_q_devs_Winter_Age_3+ 0 0 0 (not_used)
5 survey_q_devs_Fall_Age_2 0 0 0 (not_used)
6 survey_q_devs_Fall_Age_3+ 0 0 0 (not_used)
7 survey_q_devs_Hydroacoustic_3+ 0 0 0 (not_used)
8 survey_q_devs_Larval_Herring_Index 0 0 0 (not_used)
9 survey_q_devs_ICNAF_and_USA_CPUE 0 0 0 (not_used)
10 survey_q_devs_Canadian_Larval_Survey 0 0 0 (not_used)
11 survey_q_devs_Canadian_Age_2 0 0 0 (not_used)
12 survey_q_devs_Canadian_Age_3+ 0 0 0 (not_used)
Subtotal All NA NA 0 (not_used)
#-------------------------------------
Goodness_of_fit_survey_Q_profile_details
#-------------------------------------
For_survey_no NOT_USED named NOT_USED
Q Q_Scaled_For_Calcs Target  Residual  GOF  Weight  Product
Total NA NA NA NA NA 0 NA NA NA
#-------------------------------------
```

```
Goodness_of_fit_prior_on_log_variance_recruit_model_residuals:
#-------------------------------------
Constraint_on_log(Variance)_log_recruit_model_residuals_turned_ON
Variance_recruit_model_residuals 0.151574
Log_variance -1.88668
target_log_rvar -0.82124
std_log_rvar 1.01475
Scaled_residual -1.04996
#-------------------------------------
Goodness_of_fit_to_center_survey_survey_q_devs
#-------------------------------------
#n_surveys_with_survey_q_devs= 0
SurveyNo SurveyName Ndevs Component_Value  Emphasis  Product MeanDev Target Residual
1 CENTER_Spring_Age_2 0 0 0 0 0 0 0 (not_used)
2 CENTER_Spring_Age_3+ 0 0 0 0 0 0 0 (not_used)
3 CENTER_Winter_Age_2 0 0 0 0 0 0 0 (not_used)
4 CENTER_Winter_Age_3+ 0 0 0 0 0 0 0 (not_used)
5 CENTER_Fall_Age_2 0 0 0 0 0 0 0 (not_used)
6 CENTER_Fall_Age_3+ 0 0 0 0 0 0 0 (not_used)
7 CENTER_Hydroacoustic_3+ 0 0 0 0 0 0 0 (not_used)
8 CENTER_Larval_Herring_Index 0 0 0 0 0 0 0 (not_used)
9 CENTER_ICNAF_and_USA_CPUE 0 0 0 0 0 0 0 (not_used)
10 CENTER_Canadian_Larval_Survey 0 0 0 0 0 0 0 (not_used)
11 CENTER_Canadian_Age_2 0 0 0 0 0 0 0 (not_used)
12 CENTER_Canadian_Age_3+ 0 0 0 0 0 0 0 (not_used)
Subtotal All NA NA NA 0
#-------------------------------------
Goodness_of_fit_constrain_Bzero_details
#-------------------------------------
Model_biomass_1959= 1216.61
Model_escapment_1960= 1115.55
Z=M+F-G_in_1959= 0.0867248
Escapement_by_projecting_b-zero= 1115.55
Difference= -2.4864e-06
#-------------------------------------
#Survey_stuff
#-------------------------------------
Survey_name Spring_Age_2
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 35
Nobs_used_for_tuning= 35
Root_mean_square_residual= 1.06068
#---
Survey_CVs NOT_USED
Min_survey_CV= 0.185
Max_survey_CV= 0.683
Mean_survey_CV=  0.340086
CV_implied_by_goodness_of_fit= 1.44234
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 0.109291
#---
N_covariates_for_survey_Q 2
survey_covariate_names: Spring_Age2_Effort_Dummy Spring_Age2_Door_Dummy
Covariate_pars: not_used 2.76925
Phase_survey_covariate_pars  -9 1
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
```

```
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB  Covariate_Spring_Age2_Door_Dummy
1 1968 0 0 1968.24 0.0385175 0.385  1 1 0.163362 0.163362 0.017854 0.768887 0.724902 0.109291 0
1 1969 0 0 1969.22 0.004641 0.683  1 1 0.114362 0.114362 0.0124987 -0.990693 -0.934019 0.109291 0
1 1970 0 0 1970.27 0.242537 0.282  1 1 0.241313 0.241313 0.0263733 2.2188 2.09187 0.109291 0
1 1971 0 0 1971.25 0.0098343 0.296  1 1 0.138847 0.138847 0.0151747 -0.433756 -0.408942 0.109291 0
1 1972 0 0 1972.25 0.024021 0.361  1 1 0.264499 0.264499 0.0289072 -0.185164 -0.174571 0.109291 0
1 1973 0 0 1973.27 0.0036018 0.456  1 1 0.0799019 0.0799019 0.00873253 -0.885621 -0.834958 0.109291 0
1 1974 0 0 1974.27 0.0013674 0.295  1 1 0.0515949 0.0515949 0.00563884 -1.41677 -1.33572 0.109291 0
1 1975 0 0 1975.27 0.0019482 0.433  1 1 0.1117 0.1117 0.0122078 -1.83517 -1.73019 0.109291 0
1 1976 0 0 1976.25 0.0018354 0.208  1 1 0.0654665 0.0654665 0.00715488 -1.36053 -1.2827 0.109291 0
1 1977 0 0 1977.3 0.0024738 0.659  1 1 0.0602433 0.0602433 0.00658403 -0.978892 -0.922893 0.109291 0
1 1978 0 0 1978.3 0.004888 0.526  1 1 0.0485109 0.0485109 0.00530179 -0.0812621 -0.0766134 0.109291 0
1 1979 0 0 1979.29 0.145027 0.406  1 1 0.0696591 0.0696591 0.0076131 2.94705 2.77846 0.109291 0
1 1980 0 0 1980.29 0.0046453 0.295  1 1 0.0488929 0.0488929 0.00534354 -0.140033 -0.132022 0.109291 0
1 1981 0 0 1981.31 0.000864 0.377  1 1 0.0333999 0.0333999 0.0036503 -1.44099 -1.35856 0.109291 0
1 1982 0 0 1982.29 0.0198009 0.309  1 1 0.0445741 0.0445741 0.00487153 1.40232 1.3221 0.109291 0
1 1983 0 0 1983.27 0.0084095 0.416  1 1 0.0656051 0.0656051 0.00717003 0.159453 0.150331 0.109291 0
1 1984 0 0 1984.25 0.098532 0.319  1 1 0.0947988 0.0947988 0.0103606 2.25237 2.12352 0.109291 0
1 1985 0 0 1985.23 0.0956823 0.411  1 1 0.0452013 0.720808 0.0787776 0.194404 0.183283 1.74282 1
1 1986 0 0 1986.26 0.0896972 0.457  1 1 0.0535027 0.853187 0.0932454 -0.0387948 -0.0365754 1.74282 1
1 1987 0 0 1987.29 0.0571987 0.246  1 1 0.100841 1.60808 0.175748 -1.12252 -1.0583 1.74282 1
1 1988 0 0 1988.24 0.109776 0.335  1 1 0.0794978 1.26772 0.13855 -0.232791 -0.219473 1.74282 1
1 1989 0 0 1989.22 0.0762634 0.471  1 1 0.107352 1.71191 0.187095 -0.897425 -0.846086 1.74282 1
1 1990 0 0 1990.24 0.130737 0.292  1 1 0.14812 2.36202 0.258146 -0.680339 -0.641419 1.74282 1
1 1991 0 0 1991.24 0.242798 0.233  1 1 0.18914 3.01614 0.329636 -0.30576 -0.288269 1.74282 1
1 1992 0 0 1992.24 0.506074 0.283  1 1 0.206174 3.28778 0.359324 0.342458 0.322867 1.74282 1
1 1993 0 0 1993.26 0.318608 0.295  1 1 0.122416 1.95213 0.213349 0.401032 0.37809 1.74282 1
1 1994 0 0 1994.25 0.213091 0.267  1 1 0.135895 2.16706 0.23684 -0.105664 -0.0996191 1.74282 1
1 1995 0 0 1995.26 0.339567 0.25  1 1 0.135637 2.16296 0.236391 0.362184 0.341465 1.74282 1
1 1996 0 0 1996.27 2.20928 0.27  1 1 0.406622 6.48424 0.708667 1.13704 1.07199 1.74282 1
1 1997 0 0 1997.24 0.978834 0.261  1 1 0.21686 3.45818 0.377947 0.951608 0.89717 1.74282 1
1 1998 0 0 1998.24 0.191786 0.278  1 1 0.138668 2.21128 0.241673 -0.231204 -0.217977 1.74282 1
1 1999 0 0 1999.25 0.127084 0.206  1 1 0.102729 1.63819 0.179038 -0.342752 -0.323145 1.74282 1
1 2000 0 0 2000.27 0.921753 0.272  1 1 0.396903 6.32927 0.69173 0.287081 0.270658 1.74282 1
1 2001 0 0 2001.25 0.305769 0.185  1 1 0.110272 1.75846 0.192184 0.464379 0.437813 1.74282 1
1 2002 0 0 2002.25 0.2 0.185  1 1 0.137792 2.19732 0.240147 -0.182934 -0.172469 1.74282 1
#------------
Survey_name Spring_Age_3+
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 35
Nobs_used_for_tuning= 35
Root_mean_square_residual= 0.699456
#---
Survey_CVs NOT_USED
Min_survey_CV= 0.185
Max_survey_CV= 0.683
Mean_survey_CV=  0.340943
CV_implied_by_goodness_of_fit= 0.794402
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 3.84788
#---
N_covariates_for_survey_Q 2
survey_covariate_names: Spring_Age3_Effort_Dummy Spring_Age3_Door_Dummy
Covariate_pars: not_used not_used
Phase_survey_covariate_pars  -9 -1
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB
2 1968 0 0 1968.24 4.02381 0.385  1 1 0.754476 0.754476 2.90313 0.32644 0.466706 3.84788
2 1969 0 0 1969.22 2.85755 0.683  1 1 0.509091 0.509091 1.95892 0.377572 0.539809 3.84788
2 1970 0 0 1970.27 0.781455 0.282  1 1 0.303478 0.303478 1.16775 -0.401673 -0.574264 3.84788
2 1971 0 0 1971.25 0.332553 0.296  1 1 0.319569 0.319569 1.22966 -1.3077 -1.86959 3.84788
2 1972 0 0 1972.25 0.441679 0.361  1 1 0.235205 0.235205 0.905038 -0.717394 -1.02564 3.84788
2 1973 0 0 1973.27 1.48675 0.456  1 1 0.312113 0.312113 1.20097 0.21346 0.30518 3.84788
2 1974 0 0 1974.27 0.998222 0.295  1 1 0.18841 0.18841 0.724977 0.319836 0.457264 3.84788
2 1975 0 0 1975.27 0.212204 0.433  1 1 0.0824059 0.0824059 0.317088 -0.401631 -0.574204 3.84788
```

```
2 1976 0 0 1976.25 0.196818 0.208  1 1 0.0637615 0.0637615 0.245346 -0.220391 -0.315089 3.84788
2 1977 0 0 1977.3 0.172891 0.659  1 1 0.05423 0.05423 0.20867 -0.188094 -0.268914 3.84788
2 1978 0 0 1978.3 0.457187 0.526  1 1 0.0683088 0.0683088 0.262844 0.553532 0.791375 3.84788
2 1979 0 0 1979.29 0.626994 0.406  1 1 0.0568788 0.0568788 0.218862 1.05249 1.50473 3.84788
2 1980 0 0 1980.29 1.04988 0.295  1 1 0.0585413 0.0585413 0.22526 1.53918 2.20053 3.84788
2 1981 0 0 1981.31 0.504389 0.377  1 1 0.0411085 0.0411085 0.15818 1.15961 1.65788 3.84788
2 1982 0 0 1982.29 0.042464 0.309  1 1 0.026285 0.026285 0.101141 -0.867862 -1.24077 3.84788
2 1983 0 0 1983.27 0.0685557 0.416  1 1 0.0395403 0.0395403 0.152146 -0.797196 -1.13974 3.84788
2 1984 0 0 1984.25 0.154971 0.319  1 1 0.095021 0.095021 0.365629 -0.858381 -1.22721 3.84788
2 1985 0 0 1985.23 0.346548 0.411  1 1 0.18164 0.18164 0.698926 -0.701524 -1.00296 3.84788
2 1986 0 0 1986.26 4.2002 0.457  1 1 0.193556 0.193556 0.744778 1.7298 2.47307 3.84788
2 1987 0 0 1987.29 0.809923 0.246  1 1 0.208208 0.208208 0.80116 0.0108788 0.0155532 3.84788
2 1988 0 0 1988.24 1.41009 0.335  1 1 0.274565 0.274565 1.05649 0.2887 0.412749 3.84788
2 1989 0 0 1989.22 1.19425 0.471  1 1 0.305701 0.305701 1.1763 0.0151464 0.0216546 3.84788
2 1990 0 0 1990.24 0.873336 0.292  1 1 0.352796 0.352796 1.35751 -0.44109 -0.630619 3.84788
2 1991 0 0 1991.24 2.27234 0.233  1 1 0.459866 0.459866 1.76951 0.250109 0.357576 3.84788
2 1992 0 0 1992.24 2.72562 0.283  1 1 0.630981 0.630981 2.42794 0.115654 0.165348 3.84788
2 1993 0 0 1993.26 7.60452 0.295  1 1 0.810598 0.810598 3.11908 0.891205 1.27414 3.84788
2 1994 0 0 1994.25 3.89002 0.267  1 1 0.879217 0.879217 3.38312 0.139617 0.199608 3.84788
2 1995 0 0 1995.26 2.9269 0.25  1 1 0.945179 0.945179 3.63693 -0.217197 -0.310522 3.84788
2 1996 0 0 1996.27 3.21558 0.27  1 1 0.98002 0.98002 3.771 -0.159331 -0.227793 3.84788
2 1997 0 0 1997.24 4.76961 0.261  1 1 1.34898 1.34898 5.1907 -0.0846044 -0.120957 3.84788
2 1998 0 0 1998.24 5.51109 0.278  1 1 1.48786 1.48786 5.72509 -0.0380961 -0.0544653 3.84788
2 1999 0 0 1999.25 10.796 0.206  1 1 1.48664 1.48664 5.72041 0.635135 0.908041 3.84788
2 2000 0 0 2000.27 2.65571 0.272  1 1 1.41238 1.41238 5.43467 -0.716087 -1.02378 3.84788
2 2001 0 0 2001.25 3.73244 0.185  1 1 1.71055 1.71055 6.58199 -0.567275 -0.811022 3.84788
2 2002 0 0 2002.25 2.5 0.215  1 1 1.65139 1.65139 6.35435 -0.932848 -1.33368 3.84788
#------------
Survey_name Winter_Age_2
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 11
Nobs_used_for_tuning= 11
Root_mean_square_residual= 2.00321
#---
Survey_CVs NOT_USED
Min_survey_CV= 0.192
Max_survey_CV= 0.619
Mean_survey_CV=  0.353273
CV_implied_by_goodness_of_fit= 7.36908
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 0.608126
#---
N_covariates_for_survey_Q 0
survey_covariate_names: NONE
Covariate_pars NONE
phase_estimation NA
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB
3 1992 0 0 1992.15 0.354412 0.26  1 1 0.201417 0.201417 0.122487 1.06245 0.530377 0.608126
3 1993 0 0 1993.13 0.014014 0.255  1 1 0.117949 0.117949 0.0717282 -1.63283 -0.815107 0.608126
3 1994 0 0 1994.11 0.003969 0.31  1 1 0.130606 0.130606 0.0794247 -2.99629 -1.49575 0.608126
3 1995 0 0 1995.14 0.0040992 0.286  1 1 0.131076 0.131076 0.0797105 -2.96761 -1.48143 0.608126
3 1996 0 0 1996.13 4.02681 0.368  1 1 0.390957 0.390957 0.237751 2.82951 1.41249 0.608126
3 1997 0 0 1997.12 0.0810106 0.619  1 1 0.209696 0.209696 0.127522 -0.453706 -0.22649 0.608126
3 1998 0 0 1998.13 0.0689128 0.261  1 1 0.134428 0.134428 0.0817492 -0.170814 -0.0852705 0.608126
3 1999 0 0 1999.12 0.0129708 0.192  1 1 0.0988834 0.0988834 0.0601336 -1.53387 -0.765707 0.608126
3 2000 0 0 2000.14 2.91682 0.323  1 1 0.381422 0.381422 0.231953 2.53172 1.26383 0.608126
3 2001 0 0 2001.11 0.364207 0.471  1 1 0.105869 0.105869 0.0643819 1.73289 0.865058 0.608126
3 2002 0 0 2002.14 0.4 0.541  1 1 0.132991 0.132991 0.0808754 1.59855 0.797998 0.608126
#------------
Survey_name Winter_Age_3+
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 11
Nobs_used_for_tuning= 11
Root_mean_square_residual= 0.64889
```

```
#---
Survey_CVs NOT_USED
Min_survey_CV= 0.192
Max_survey_CV= 0.619
Mean_survey_CV=  0.353273
CV_implied_by_goodness_of_fit= 0.723584
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 4.36407
#---
N_covariates_for_survey_Q 0
survey_covariate_names: NONE
Covariate_pars NONE
phase_estimation NA
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB
4 1992 0 0 1992.15 3.25676 0.26  1 1 0.637187 0.637187 2.78073 0.158018 0.243521 4.36407
4 1993 0 0 1993.13 6.54461 0.255  1 1 0.821733 0.821733 3.5861 0.601576 0.927084 4.36407
4 1994 0 0 1994.11 0.588561 0.31  1 1 0.892221 0.892221 3.89372 -1.88944 -2.9118 4.36407
4 1995 0 0 1995.14 2.66092 0.286  1 1 0.962097 0.962097 4.19866 -0.456094 -0.702883 4.36407
4 1996 0 0 1996.13 5.87763 0.368  1 1 1.00045 1.00045 4.36603 0.2973 0.458166 4.36407
4 1997 0 0 1997.12 8.62009 0.619  1 1 1.36346 1.36346 5.95024 0.370663 0.571227 4.36407
4 1998 0 0 1998.13 6.66305 0.261  1 1 1.50629 1.50629 6.57355 0.0135233 0.0208407 4.36407
4 1999 0 0 1999.12 7.67709 0.192  1 1 1.51435 1.51435 6.60874 0.149847 0.230928 4.36407
4 2000 0 0 2000.14 9.15969 0.323  1 1 1.44061 1.44061 6.28695 0.376337 0.57997 4.36407
4 2001 0 0 2001.11 8.71385 0.471  1 1 1.73903 1.73903 7.58924 0.138183 0.212952 4.36407
4 2002 0 0 2002.14 9.3 0.541  1 1 1.67619 1.67619 7.31501 0.240086 0.369995 4.36407
#------------
Survey_name Fall_Age_2
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 37
Nobs_used_for_tuning= 37
Root_mean_square_residual= 1.29538
#---
Survey_CVs NOT_USED
Min_survey_CV= 0.096
Max_survey_CV= 0.913
Mean_survey_CV=  0.381351
CV_implied_by_goodness_of_fit= 2.08684
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 0.00388664
#---
N_covariates_for_survey_Q 3
survey_covariate_names: Fall_Age2_Temp_Anomaly Fall_Age2_Effort_Anomaly Fall_Age2_Door_Dummy
Covariate_pars: not_used not_used 4.22564
Phase_survey_covariate_pars  -1 -9 1
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB  Covariate_Fall_Age2_Door_Dummy
5 1963 0 0 1963.91 0.0007125 0.259  1 1 0.179024 0.179024 0.000695804 0.0237126 0.0183055 0.00388664 0
5 1964 0 0 1964.86 0.0006375 0.308  1 1 0.185988 0.185988 0.000722867 -0.125672 -0.0970151 0.00388664 0
5 1965 0 0 1965.81 7.5e-06 0.29  1 1 0.103745 0.103745 0.00040322 -3.98458 -3.07599 0.00388664 0
5 1966 0 0 1966.83 0.00015 0.192  1 1 0.150449 0.150449 0.000584743 -1.36054 -1.0503 0.00388664 0
5 1967 0 0 1967.86 0.0017125 0.256  1 1 0.196463 0.196463 0.000763583 0.807687 0.623513 0.00388664 0
```

```
5 1968 0 0 1968.83 0.0005575 0.222  1 1 0.145194 0.145194 0.000564319 -0.0121574 -0.00938521 0.00388664 0
5 1969 0 0 1969.83 0.0009048 0.383  1 1 0.0917125 0.0917125 0.000356454 0.931509 0.7191 0.00388664 0
5 1970 0 0 1970.8 0.0019404 0.444  1 1 0.212712 0.212712 0.000826735 0.853165 0.65862 0.00388664 0
5 1971 0 0 1971.8 0.0007448 0.72  1 1 0.107527 0.107527 0.000417917 0.577832 0.446071 0.00388664 0
5 1972 0 0 1972.81 0.0064617 0.375  1 1 0.234845 0.234845 0.000912759 1.95718 1.51089 0.00388664 0
5 1973 0 0 1973.8 3.78e-05 0.578  1 1 0.0660164 0.0660164 0.000256582 -1.91514 -1.47844 0.00388664 0
5 1974 0 0 1974.78 1.06e-05 0.581  1 1 0.0366655 0.0366655 0.000142506 -2.59853 -2.00599 0.00388664 0
5 1975 0 0 1975.81 0.0003825 0.468  1 1 0.0650081 0.0650081 0.000252663 0.41467 0.320114 0.00388664 0
5 1977 0 0 1977.83 0.0002562 0.316  1 1 0.0526148 0.0526148 0.000204495 0.225416 0.174015 0.00388664 0
5 1978 0 0 1978.8 0.000428 0.274  1 1 0.0383304 0.0383304 0.000148977 1.05533 0.81469 0.00388664 0
5 1979 0 0 1979.82 0.0003808 0.446  1 1 0.0518864 0.0518864 0.000201664 0.635672 0.490721 0.00388664 0
5 1982 0 0 1982.79 0.0001715 0.321  1 1 0.0328825 0.0328825 0.000127803 0.294097 0.227035 0.00388664 0
5 1983 0 0 1983.79 0.0020075 0.272  1 1 0.0662637 0.0662637 0.000257544 2.05346 1.58521 0.00388664 0
5 1984 0 0 1984.78 0.0004692 0.485  1 1 0.102166 0.102166 0.000397081 0.166888 0.128833 0.00388664 0
5 1985 0 0 1985.8 0.0016758 0.913  1 1 0.0482425 3.30065 0.0128285 -2.03538 -1.57126 0.265916 1
5 1986 0 0 1986.78 0.0011978 0.361  1 1 0.0573015 3.92045 0.0152374 -2.54327 -1.96333 0.265916 1
5 1987 0 0 1987.77 0.0889812 0.354  1 1 0.108114 7.39691 0.0287492 1.12982 0.872188 0.265916 1
5 1988 0 0 1988.77 0.0345474 0.521  1 1 0.0860977 5.89063 0.0228948 0.411423 0.317608 0.265916 1
5 1989 0 0 1989.77 0.0643126 0.406  1 1 0.114712 7.84838 0.0305039 0.745902 0.575817 0.265916 1
5 1990 0 0 1990.76 0.114365 0.583  1 1 0.162229 11.0994 0.0431393 0.97496 0.752643 0.265916 1
5 1991 0 0 1991.75 0.143248 0.635  1 1 0.214329 14.6639 0.0569935 0.92164 0.711481 0.265916 1
5 1992 0 0 1992.77 0.103242 0.301  1 1 0.235664 16.1236 0.0626668 0.499244 0.385403 0.265916 1
5 1993 0 0 1993.75 0.0155892 0.417  1 1 0.13957 9.54911 0.037114 -0.867416 -0.669622 0.265916 1
5 1994 0 0 1994.76 0.0311003 0.218  1 1 0.157281 10.7609 0.0418237 -0.296245 -0.228693 0.265916 1
5 1995 0 0 1995.75 0.0327376 0.368  1 1 0.154388 10.5629 0.0410544 -0.226373 -0.174754 0.265916 1
5 1996 0 0 1996.76 0.58347 0.313  1 1 0.463832 31.7344 0.12334 1.55405 1.19968 0.265916 1
5 1997 0 0 1997.76 0.083904 0.316  1 1 0.25161 17.2147 0.0669073 0.226365 0.174748 0.265916 1
5 1998 0 0 1998.79 0.0654524 0.096  1 1 0.161907 11.0774 0.0430538 0.418872 0.323358 0.265916 1
5 1999 0 0 1999.8 0.0120366 0.177  1 1 0.119709 8.19024 0.0318325 -0.972537 -0.750773 0.265916 1
5 2000 0 0 2000.75 0.0671549 0.258  1 1 0.45512 31.1384 0.121024 -0.588986 -0.454682 0.265916 1
5 2001 0 0 2001.75 0.0183549 0.25  1 1 0.126875 8.68052 0.0337381 -0.608732 -0.469924 0.265916 1
5 2002 0 0 2002.76 0.149969 0.433  1 1 0.160507 10.9816 0.0426814 1.25667 0.970112 0.265916 1
#------------
Survey_name Fall_Age_3+
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 40
Nobs_used_for_tuning= 40
Root_mean_square_residual= 1.01625
#---
Survey_CVs NOT_USED
Min_survey_CV= 0.096
Max_survey_CV= 0.913
Mean_survey_CV=  0.3907
CV_implied_by_goodness_of_fit= 1.34492
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 0.43631
#---
N_covariates_for_survey_Q 3
survey_covariate_names: Fall_Age3_Temp_Anomaly Fall_Age3_Effort_Anomaly Fall_Age3_Door_Dummy
Covariate_pars: 0.522073 not_used 1.71708
Phase_survey_covariate_pars  1 -9 1
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB  Covariate_Fall_Age3_Temp_Anomaly Covariate_Fall_Age3_Door_Dummy
6 1963 0 0 1963.91 0.639601 0.259  1 1 0.950375 0.397006 0.173218 1.3063 1.28541 0.182262 -1.672 0
6 1964 0 0 1964.86 0.0864806 0.308  1 1 0.92651 0.619172 0.270151 -1.13906 -1.12085 0.291579 -0.772 0
6 1965 0 0 1965.81 0.349221 0.29  1 1 0.964585 1.73818 0.758388 -0.77549 -0.76309 0.786232 1.128 0
6 1966 0 0 1966.83 1.00297 0.192  1 1 0.840896 1.96727 0.858341 0.15572 0.15323 1.02075 1.628 0
6 1967 0 0 1967.86 0.323385 0.256  1 1 0.710574 0.45071 0.19665 0.49742 0.489467 0.276747 -0.872 0
6 1968 0 0 1968.83 0.130374 0.222  1 1 0.518899 0.267103 0.11654 0.112176 0.110383 0.22459 -1.272 0
6 1969 0 0 1969.83 0.0647873 0.383  1 1 0.316324 0.200641 0.0875419 -0.301008 -0.296195 0.276747 -0.872 0
6 1970 0 0 1970.8 0.0583215 0.444  1 1 0.214478 0.151014 0.065889 -0.122001 -0.12005 0.307206 -0.672 0
6 1971 0 0 1971.8 0.332917 0.72  1 1 0.202766 0.195285 0.0852049 1.36283 1.34104 0.420214 -0.072 0
6 1972 0 0 1972.81 0.0733762 0.375  1 1 0.169828 0.0747455 0.0326122 0.810912 0.797946 0.19203 -1.572 0
6 1973 0 0 1973.8 0.0071231 0.578  1 1 0.216694 0.0905209 0.0394952 -1.71284 -1.68545 0.182262 -1.672 0
6 1974 0 0 1974.78 0.0179494 0.581  1 1 0.110559 0.0701267 0.030597 -0.533345 -0.524817 0.276747 -0.872 0
6 1975 0 0 1975.81 0.062106 0.468  1 1 0.0389438 0.0438666 0.0191394 1.17709 1.15827 0.491463 0.228 0
```

```
6 1976 0 0 1976.82 0.0228836 0.606  1 1 0.034176 0.00990625 0.0043222 1.66666 1.64001 0.126469 -2.372 0
6 1977 0 0 1977.83 0.0045698 0.316  1 1 0.040025 0.0167199 0.00729505 -0.467727 -0.460248 0.182262 -1.672 0
6 1978 0 0 1978.8 0.0940207 0.274  1 1 0.0461341 0.0576851 0.0251686 1.31792 1.29684 0.545553 0.428 0
6 1979 0 0 1979.82 0.0023015 0.446  1 1 0.0356686 0.0278784 0.0121636 -1.66489 -1.63827 0.341018 -0.472 0
6 1980 0 0 1980.8 0.0006386 0.527  1 1 0.0361282 0.0217501 0.0094898 -2.69869 -2.65554 0.26267 -0.972 0
6 1981 0 0 1981.8 0.0011165 0.385  1 1 0.0220418 0.0212287 0.00926229 -2.11575 -2.08192 0.420214 -0.072 0
6 1982 0 0 1982.79 0.0198178 0.321  1 1 0.0164528 0.0175898 0.00767461 0.948663 0.933494 0.466463 0.128 0
6 1983 0 0 1983.79 0.0230087 0.272  1 1 0.0341814 0.0312458 0.0136328 0.52339 0.515022 0.398839 -0.172 0
6 1984 0 0 1984.78 0.224414 0.485  1 1 0.0875436 0.0986097 0.0430244 1.65173 1.62531 0.491463 0.228 0
6 1985 0 0 1985.8 0.382118 0.913  1 1 0.162227 0.82574 0.360279 0.0588514 0.0579104 2.22083 -0.172 1
6 1986 0 0 1986.78 0.14279 0.361  1 1 0.171641 0.747003 0.325925 -0.825292 -0.812096 1.89887 -0.472 1
6 1987 0 0 1987.77 0.907407 0.354  1 1 0.186464 1.2322 0.537623 0.523434 0.515065 2.88325 0.328 1
6 1988 0 0 1988.77 1.24556 0.521  1 1 0.245876 1.54216 0.672862 0.615801 0.605955 2.73659 0.228 1
6 1989 0 0 1989.77 1.81458 0.406  1 1 0.266473 2.53778 1.10726 0.493968 0.486069 4.15524 1.028 1
6 1990 0 0 1990.76 1.26961 0.583  1 1 0.318642 5.67785 2.47731 -0.668462 -0.657773 7.77457 2.228 1
6 1991 0 0 1991.75 1.90785 0.635  1 1 0.432285 3.90749 1.70488 0.112484 0.110685 3.94387 0.928 1
6 1992 0 0 1992.77 6.34181 0.301  1 1 0.596586 3.9424 1.72011 1.30478 1.28391 2.88325 0.328 1
6 1993 0 0 1993.75 2.36244 0.417  1 1 0.772505 6.62758 2.89168 -0.202143 -0.198911 3.74326 0.828 1
6 1994 0 0 1994.76 1.78319 0.218  1 1 0.83295 5.79936 2.53032 -0.349941 -0.344346 3.03778 0.428 1
6 1995 0 0 1995.75 9.7751 0.368  1 1 0.883794 11.5131 5.02328 0.665755 0.65511 5.68377 1.628 1
6 1996 0 0 1996.76 3.77061 0.313  1 1 0.914565 5.44446 2.37547 0.462039 0.454652 2.59738 0.128 1
6 1997 0 0 1997.76 4.32641 0.316  1 1 1.28672 9.94473 4.33899 -0.00290299 -0.00285657 3.37212 0.628 1
6 1998 0 0 1998.79 2.54039 0.096  1 1 1.39921 9.24635 4.03428 -0.462509 -0.455114 2.88325 0.328 1
6 1999 0 0 1999.8 1.68844 0.177  1 1 1.38055 6.33033 2.76199 -0.492145 -0.484276 2.00064 -0.372 1
6 2000 0 0 2000.75 3.1045 0.258  1 1 1.31942 18.1092 7.90121 -0.934163 -0.919226 5.98839 1.728 1
6 2001 0 0 2001.75 3.77602 0.25  1 1 1.61605 21.0521 9.18524 -0.888927 -0.874714 5.68377 1.628 1
6 2002 0 0 2002.76 10.8981 0.433  1 1 1.54882 13.8546 6.04489 0.589375 0.579951 3.90291 0.908 1
#------------
Survey_name Hydroacoustic_3+
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 1
N_all_observations 4
Nobs_used_for_tuning= 4
Root_mean_square_residual= 0.346342
#---
Survey_CVs USED
Min_survey_CV= 0.066
Max_survey_CV= 0.1365
Mean_survey_CV=  0.09545
CV_implied_by_goodness_of_fit= 0.356993
#---
Prior_Q_ON_(assumed_distribution_is_LOG_NORMAL)
Emphasis 1
#---
Q_for_adj_biomass 0.905171
#---
N_covariates_for_survey_Q 1
survey_covariate_names: Percent_spent_and_resting
Covariate_pars: not_used
Phase_survey_covariate_pars  -9
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB
7 1999 0 0 1999.75 1193 0.1071  0.106795 87.6799 1448.51 1448.51 1311.15 -0.0944327 -0.884245 0.905171
7 2000 0 0 2000.73 1427 0.0722  0.0721062 192.334 1549.38 1549.38 1402.45 0.0173516 0.24064 0.905171
7 2001 0 0 2001.73 1819 0.066  0.0659283 230.068 1682.73 1682.73 1523.16 0.177499 2.6923 0.905171
7 2002 0 0 2002.73 763 0.1365  0.135871 54.1688 1635.21 1635.21 1480.14 -0.662637 -4.87697 0.905171
#------------
Survey_name Larval_Herring_Index
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 24
Nobs_used_for_tuning= 24
Root_mean_square_residual= 1.18061
#---
Survey_CVs NOT_USED
Min_survey_CV= 0.2
Max_survey_CV= 0.2
Mean_survey_CV=  0.2
CV_implied_by_goodness_of_fit= 1.74078
#---
```

```
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 162.523
#---
N_covariates_for_survey_Q 1
survey_covariate_names: Break_US_Larval_1988_89
Covariate_pars: 1.5245
Phase_survey_covariate_pars  1
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB  Covariate_Break_US_Larval_1988_89
8 1971 0 0 1971.25 89.7 0.2  1 1 0.389371 0.389371 63.2817 0.348874 0.295503 162.523 0
8 1972 0 0 1972.25 81.4 0.2  1 1 0.367306 0.367306 59.6957 0.310116 0.262674 162.523 0
8 1973 0 0 1973.25 355.2 0.2  1 1 0.358486 0.358486 58.2622 1.80773 1.53118 162.523 0
8 1974 0 0 1974.25 304.5 0.2  1 1 0.219611 0.219611 35.6919 2.14375 1.8158 162.523 0
8 1975 0 0 1975.25 55.9 0.2  1 1 0.142534 0.142534 23.1651 0.880919 0.746156 162.523 0
8 1976 0 0 1976.25 2.2 0.2  1 1 0.0966699 0.0966699 15.7111 -1.96591 -1.66516 162.523 0
8 1977 0 0 1977.25 19.2 0.2  1 1 0.0864814 0.0864814 14.0552 0.311917 0.2642 162.523 0
8 1978 0 0 1978.25 2.4 0.2  1 1 0.0960643 0.0960643 15.6127 -1.87261 -1.58614 162.523 0
8 1979 0 0 1979.25 6 0.2  1 1 0.0951723 0.0951723 15.4677 -0.946994 -0.802122 162.523 0
8 1980 0 0 1980.25 1.9 0.2  1 1 0.0862462 0.0862462 14.017 -1.99842 -1.6927 162.523 0
8 1981 0 0 1981.25 29.7 0.2  1 1 0.0624359 0.0624359 10.1473 1.07394 0.90965 162.523 0
8 1982 0 0 1982.25 18.2 0.2  1 1 0.0500578 0.0500578 8.13554 0.805179 0.682003 162.523 0
8 1983 0 0 1983.25 3.7 0.2  1 1 0.0725505 0.0725505 11.7911 -1.15902 -0.981708 162.523 0
8 1984 0 0 1984.25 2.3 0.2  1 1 0.142422 0.142422 23.1468 -2.30895 -1.95572 162.523 0
8 1985 0 0 1985.25 95.4 0.2  1 1 0.20362 0.20362 33.093 1.05876 0.896788 162.523 0
8 1986 0 0 1986.25 60.4 0.2  1 1 0.22075 0.22075 35.877 0.520892 0.441206 162.523 0
8 1987 0 0 1987.25 31.4 0.2  1 1 0.260218 0.260218 42.2915 -0.297778 -0.252224 162.523 0
8 1988 0 0 1988.25 184.9 0.2  1 1 0.313923 0.313923 51.0197 1.2876 1.09063 162.523 0
8 1989 0 0 1989.25 454.3 0.2  1 1 0.357861 1.64361 267.124 0.531044 0.449805 746.447 1
8 1990 0 0 1990.25 394.1 0.2  1 1 0.426359 1.95821 318.255 0.213753 0.181053 746.447 1
8 1991 0 0 1991.25 354.2 0.2  1 1 0.554163 2.5452 413.653 -0.155167 -0.131429 746.447 1
8 1992 0 0 1992.25 577.1 0.2  1 1 0.733752 3.37003 547.707 0.0522746 0.0442776 746.447 1
8 1993 0 0 1993.25 397.6 0.2  1 1 0.87292 4.00921 651.589 -0.493967 -0.4184 746.447 1
8 1994 0 0 1994.25 610 0.2  1 1 0.947501 4.35175 707.259 -0.147938 -0.125306 746.447 1
#------------
Survey_name ICNAF_and_USA_CPUE
Likelihood_weight: 0
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 26
Nobs_used_for_tuning= 0
Root_mean_square_residual_not_computed
#---
Survey_CVs_not_accessed
Min_survey_CV_not_computed
Max_survey_CV_not_computed
Mean_survey_CV_not_computed
CV_implied_by_goodness_of_fit_not_computed
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 0
#---
N_covariates_for_survey_Q 0
survey_covariate_names: NONE
Covariate_pars NONE
phase_estimation NA
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
```

```
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB
9 1960 0 0 1960.49 0.154094 1 na na na na na na na na
9 1961 0 0 1961.49 0.145542 1 na na na na na na na na
9 1963 0 0 1963.49 0.16747 1 na na na na na na na na
9 1964 0 0 1964.49 0.119432 1 na na na na na na na na
9 1965 0 0 1965.49 0.0503471 1 na na na na na na na na
9 1966 0 0 1966.49 0.0936122 1 na na na na na na na na
9 1967 0 0 1967.49 0.165301 1 na na na na na na na na
9 1968 0 0 1968.49 0.225098 1 na na na na na na na na
9 1969 0 0 1969.49 0.164017 1 na na na na na na na na
9 1970 0 0 1970.49 0.193137 1 na na na na na na na na
9 1971 0 0 1971.49 0.150286 1 na na na na na na na na
9 1972 0 0 1972.49 0.0931927 1 na na na na na na na na
9 1973 0 0 1973.49 0.103168 1 na na na na na na na na
9 1974 0 0 1974.49 0.0981641 1 na na na na na na na na
9 1975 0 0 1975.49 0.071347 1 na na na na na na na na
9 1976 0 0 1976.49 0.0731125 1 na na na na na na na na
9 1977 0 0 1977.49 0.103725 1 na na na na na na na na
9 1978 0 0 1978.49 0.12956 1 na na na na na na na na
9 1979 0 0 1979.49 0.177007 1 na na na na na na na na
9 1980 0 0 1980.49 0.128225 1 na na na na na na na na
9 1982 0 0 1982.49 0.0710141 1 na na na na na na na na
9 1983 0 0 1983.49 0.0437593 1 na na na na na na na na
9 1984 0 0 1984.49 0.0492521 1 na na na na na na na na
9 1985 0 0 1985.49 0.058507 1 na na na na na na na na
9 1986 0 0 1986.49 0.0724594 1 na na na na na na na na
9 1987 0 0 1987.49 0.0764225 1 na na na na na na na na
#------------
Survey_name Canadian_Larval_Survey
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 9
Nobs_used_for_tuning= 9
Root_mean_square_residual= 0.653692
#---
Survey_CVs NOT_USED
Min_survey_CV= 0.134717
Max_survey_CV= 0.428706
Mean_survey_CV=  0.23048
CV_implied_by_goodness_of_fit= 0.730159
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 26.4964
#---
N_covariates_for_survey_Q 0
survey_covariate_names: NONE
Covariate_pars NONE
phase_estimation NA
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB
10 1987 0 0 1987.85 12.5893 0.428706  1 1 0.237575 0.237575 6.29488 0.693111 1.0603 26.4964
10 1988 0 0 1988.85 6.05366 0.192931  1 1 0.285479 0.285479 7.56417 -0.22276 -0.340772 26.4964
10 1989 0 0 1989.83 7.3743 0.356369  1 1 0.320207 0.320207 8.48432 -0.140219 -0.214503 26.4964
10 1990 0 0 1990.84 10.214 0.186788  1 1 0.395716 0.395716 10.485 -0.02619 -0.0400647 26.4964
10 1991 0 0 1991.85 3.28665 0.258948  1 1 0.536979 0.536979 14.228 -1.46534 -2.24164 26.4964
10 1992 0 0 1992.91 12.172 0.148202  1 1 0.709656 0.709656 18.8033 -0.434895 -0.665291 26.4964
10 1993 0 0 1993.89 30.3514 0.134717  1 1 0.834605 0.834605 22.114 0.316631 0.484374 26.4964
10 1994 0 0 1994.89 52.2595 0.165629  1 1 0.902901 0.902901 23.9236 0.781356 1.1953 26.4964
10 1995 0 0 1995.89 41.294 0.202032  1 1 0.946864 0.946864 25.0885 0.498309 0.762299 26.4964
#------------
Survey_name Canadian_Age_2
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 17
Nobs_used_for_tuning= 15
Root_mean_square_residual= 1.69504
#---
```

```
Survey_CVs NOT_USED
Min_survey_CV= 0.286945
Max_survey_CV= 0.754251
Mean_survey_CV=  0.532836
CV_implied_by_goodness_of_fit= 4.08569
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 2.41618
#---
N_covariates_for_survey_Q 0
survey_covariate_names: NONE
Covariate_pars NONE
phase_estimation NA
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB
11 1986 0 0 1986.16 0.0962586 0.53915  1 1 0.0528574 0.0528574 0.127713 -0.282746 -0.166808 2.41618
11 1987 0 0 1987.16 0.0354864 0.625298  1 1 0.0990863 0.0990863 0.23941 -1.90903 -1.12624 2.41618
11 1988 0 0 1988.16 0.0137315 0.286945  1 1 0.0786107 0.0786107 0.189938 -2.627 -1.54982 2.41618
11 1989 0 0 1989.16 3.12522 0.50749  1 1 0.106567 0.106567 0.257485 2.4963 1.47271 2.41618
11 1990 0 0 1990.16 1.58928 0.42794  1 1 0.146236 0.146236 0.353332 1.50363 0.887075 2.41618
11 1991 0 0 1991.16 2.08539 0.568197  1 1 0.185793 0.185793 0.448908 1.53589 0.906109 2.41618
11 1992 0 0 1992.16 0.404232 0.548984  1 1 0.202316 0.202316 0.488833 -0.190031 -0.11211 2.41618
11 1993 0 0 1993.16 0.0192857 -0.69347 na na na na na na na na
11 1994 0 0 1994.16 0.0178963 -0.617265 na na na na na na na na
11 1995 0 0 1995.16 0.0975029 0.695333  1 1 0.132057 0.132057 0.319074 -1.18554 -0.699418 2.41618
11 1996 0 0 1996.16 1.72861 0.458356  1 1 0.394908 0.394908 0.954169 0.594232 0.350571 2.41618
11 1997 0 0 1997.16 0.988147 0.704324  1 1 0.212131 0.212131 0.512547 0.656439 0.38727 2.41618
11 1998 0 0 1998.16 0.0601231 0.754251  1 1 0.135711 0.135711 0.327901 -1.69632 -1.00075 2.41618
11 1999 0 0 1999.16 0.0322447 0.418691  1 1 0.10026 0.10026 0.242247 -2.0166 -1.18971 2.41618
11 2000 0 0 2000.16 28.4954 0.391581  1 1 0.384469 0.384469 0.928946 3.42345 2.01968 2.41618
11 2001 0 0 2001.16 0.124303 0.380895  1 1 0.107457 0.107457 0.259635 -0.736557 -0.434536 2.41618
11 2002 0 0 2002.16 0.5 0.685102  1 1 0.134093 0.134093 0.323991 0.433891 0.255977 2.41618
#------------
Survey_name Canadian_Age_3+
Likelihood_weight: 1
Biomass_in_goodness_of_fit_calcs_scaled_by 0.001
N_all_observations 17
Nobs_used_for_tuning= 15
Root_mean_square_residual= 1.56681
#---
Survey_CVs NOT_USED
Min_survey_CV= 0.229625
Max_survey_CV= 0.536046
Mean_survey_CV=  0.359279
CV_implied_by_goodness_of_fit= 3.2627
#---
Prior_Q_NOT_SPECIFIED
Emphasis 0
#---
Q_for_adj_biomass 4.18612
#---
N_covariates_for_survey_Q 0
survey_covariate_names: NONE
Covariate_pars NONE
phase_estimation NA
#---
Catchability_process_errors  OFF
N_survey_Q_process_errors 0
Mean_log_Q_process_error NA
Target_std_dev_log_Q_process_errors= NA
Obs_RMSE_log_Q_process_errors= NA
Target_arith_CV_Q_process_error NA
Obs_arith_CV_Q_process_error NA
#---
Linear_survey_with_I=qB
#---
SurvIdNum Year Sex Area Time Datum ArithCV LogStd LikelihoodWt_(1/LogStd^2) AvailB AvailB_Adj Yhat RawResid StdResid
Q=Yhat/AvailB
```

```
12 1986 0 0 1986.16 1.27675 0.536046  1 1 0.197714 0.197714 0.827654 0.433478 0.276663 4.18612
12 1987 0 0 1987.16 0.0135768 0.326106  1 1 0.21408 0.21408 0.896164 -4.18976 -2.67407 4.18612
12 1988 0 0 1988.16 0.556319 0.321023  1 1 0.278862 0.278862 1.16735 -0.741148 -0.47303 4.18612
12 1989 0 0 1989.16 0.479208 0.486534  1 1 0.310383 0.310383 1.2993 -0.997448 -0.636611 4.18612
12 1990 0 0 1990.16 0.220152 0.418123  1 1 0.357887 0.357887 1.49816 -1.91767 -1.22393 4.18612
12 1991 0 0 1991.16 8.19958 0.492509  1 1 0.463946 0.463946 1.94213 1.4403 0.919253 4.18612
12 1992 0 0 1992.16 4.99388 0.309343  1 1 0.635998 0.635998 2.66237 0.628998 0.401451 4.18612
12 1993 0 0 1993.16 30.0806 -0.430868 na na na na na na na na
12 1994 0 0 1994.16 0.298118 -0.344542 na na na na na na na na
12 1995 0 0 1995.16 4.83328 0.442822  1 1 0.958381 0.958381 4.0119 0.18626 0.118879 4.18612
12 1996 0 0 1996.16 2.41639 0.249246  1 1 0.995179 0.995179 4.16594 -0.544667 -0.347628 4.18612
12 1997 0 0 1997.16 31.0152 0.396522  1 1 1.35847 1.35847 5.6867 1.69635 1.08268 4.18612
12 1998 0 0 1998.16 3.16382 0.284036  1 1 1.50063 1.50063 6.28181 -0.685878 -0.437755 4.18612
12 1999 0 0 1999.16 41.2759 0.259872  1 1 1.50425 1.50425 6.29697 1.88021 1.20002 4.18612
12 2000 0 0 2000.16 7.04226 0.312992  1 1 1.43492 1.43492 6.00676 0.159043 0.101507 4.18612
12 2001 0 0 2001.16 47.8367 0.229625  1 1 1.72857 1.72857 7.23599 1.88873 1.20546 4.18612
12 2002 0 0 2002.16 15 0.324383  1 1 1.67039 1.67039 6.99245 0.763219 0.487116 4.18612
#-------------------------------------
Prior_survey_Q_details:
#-------------------------------------
emphasis_fpart_bayes_q  0 0 0 0 0 0 1 0 0 0 0 0
distn_prior_q  0 0 0 0 0 0 1 0 0 0 0 0
dist_name None None None None None None Log_Normal_Dist None None None None None
surveyq  0.109291 3.84788 0.608126 4.36407 0.00388664 0.43631 0.905171 162.523 0 26.4964 2.41618 4.18612
min_prior_q  1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06 1e-06
max_prior_q  99 99 99 99 99 99 99 99 99 99 99 99
mean_qprior  9 9 9 9 9 9 0.85 9 9 9 9 9
cv_qprior  9 9 9 9 9 9 0.429 9 9 9 9 9
q_parm_1  0 0 0 0 0 0 -0.246986 0 0 0 0 0
q_parm_2  0 0 0 0 0 0 0.411015 0 0 0 0 0
#-------------------------------------
Catch_goodness_of_fit_stuff:
#-------------------------------------
Assumed_CV_for_catch_data= 0.2
Sequence Year Obs_Landings Obs_Discard Obs_Catch Est_Catch Raw_Residual SD Scaled_Residual Weight
0 1959 94.001 0 94.001 94.001 -6.78853e-11 18.8002 -3.61088e-12 1
1 1960 93.955 0 93.955 93.955 5.90168e-08 18.791 3.14069e-09 1
2 1961 100.556 0 100.556 100.556 2.28998e-08 20.1112 1.13866e-09 1
3 1962 242.15 0 242.15 242.15 1.44701e-07 48.43 2.98784e-09 1
4 1963 194.344 0 194.344 194.344 -2.5618e-08 38.8688 -6.5909e-10 1
5 1964 187.445 0 187.445 187.445 -1.10196e-06 37.489 -2.93942e-08 1
6 1965 109.844 0 109.844 109.844 -6.41921e-07 21.9688 -2.92196e-08 1
7 1966 210.038 0 210.038 210.038 8.97517e-07 42.0076 2.13656e-08 1
8 1967 285.245 0 285.245 285.245 4.46882e-06 57.049 7.8333e-08 1
9 1968 469.978 0 469.978 469.978 -4.21371e-06 93.9956 -4.48288e-08 1
10 1969 392.655 0 392.655 392.655 -1.1603e-05 78.531 -1.4775e-07 1
11 1970 307.131 0 307.131 307.131 -2.89992e-06 61.4262 -4.72099e-08 1
12 1971 330.52 0 330.52 330.52 1.18598e-05 66.104 1.79411e-07 1
13 1972 271.744 0 271.744 271.744 2.08602e-05 54.3488 3.83821e-07 1
14 1973 258.551 0 258.551 258.551 -3.12134e-06 51.7102 -6.03623e-08 1
15 1974 209.886 0 209.886 209.886 -2.1806e-06 41.9772 -5.19472e-08 1
16 1975 216.957 0 216.957 216.957 2.14663e-05 43.3914 4.94712e-07 1
17 1976 121.925 0 121.925 121.925 4.51919e-06 24.385 1.85327e-07 1
18 1977 67.08 0 67.08 67.08 -1.38874e-06 13.416 -1.03513e-07 1
19 1978 88.165 0 88.165 88.165 -1.02525e-06 17.633 -5.81436e-08 1
20 1979 104.178 0 104.178 104.178 -6.03223e-06 20.8356 -2.89515e-07 1
21 1980 93.234 0 93.234 93.234 -4.45089e-06 18.6468 -2.38695e-07 1
22 1981 84.097 0 84.097 84.097 -4.05831e-06 16.8194 -2.41287e-07 1
23 1982 59.852 0 59.852 59.852 -4.3428e-06 11.9704 -3.62795e-07 1
24 1983 35.627 0 35.627 35.627 -4.09758e-08 7.1254 -5.75067e-09 1
25 1984 42.442 0 42.442 42.442 1.30825e-06 8.4884 1.54122e-07 1
26 1985 55.155 0 55.155 55.155 1.37516e-06 11.031 1.24663e-07 1
27 1986 56.202 0 56.202 56.202 -1.01001e-07 11.2404 -8.98555e-09 1
28 1987 66.846 0 66.846 66.846 1.48102e-06 13.3692 1.10778e-07 1
29 1988 73.95 0 73.95 73.95 -4.59041e-07 14.79 -3.10373e-08 1
30 1989 97.059 0 97.059 97.059 -1.47467e-06 19.4118 -7.59676e-08 1
31 1990 93.805 0 93.805 93.805 -1.7928e-07 18.761 -9.55602e-09 1
32 1991 79.943 0 79.943 79.943 3.71747e-07 15.9886 2.32507e-08 1
33 1992 93.191 0 93.191 93.191 1.28106e-06 18.6382 6.87333e-08 1
34 1993 88.667 0 88.667 88.667 -9.98006e-08 17.7334 -5.62783e-09 1
35 1994 76.821 0 76.821 76.821 6.04662e-07 15.3642 3.93553e-08 1
36 1995 102.253 0 102.253 102.253 1.05632e-06 20.4506 5.16523e-08 1
37 1996 126.852 0 126.852 126.852 1.25116e-06 25.3704 4.93157e-08 1
38 1997 119.553 0 119.553 119.553 1.27989e-07 23.9106 5.35282e-09 1
39 1998 125.829 0 125.829 125.829 1.31597e-08 25.1658 5.2292e-10 1
40 1999 124.101 0 124.101 124.101 9.95616e-08 24.8202 4.01131e-09 1
41 2000 125.818 0 125.818 125.818 2.69034e-06 25.1636 1.06914e-07 1
42 2001 133.165 0 133.165 133.165 -2.88905e-06 26.633 -1.08476e-07 1
43 2002 104.43 0 104.43 104.43 -6.51136e-06 20.886 -3.11757e-07 1
#-------------------------------------
natmat_devs_NOT_USED
```

```
#-------------------------------------
#Status_variables
#-------------------------------------
ID Fstatus Bstatus
First_Year 2000 2000
Last_Year 2002 2002
Status_value 0.0683743 1844.47
#-------------------------------------
#Population_dynamics
#-------------------------------------
small_biomass_(minimum_credible_biomass)= 0.005
big_biomass_(maximum_credible_biomass)= 50000
#---
Natural_mortality_(M)_process_errors: NONE
#---
Recruitment_devs: INDEPENDENT
#---
natmat_covariates_used: NONE
#---
min_M= 0.2
mean_M= 0.2
max_M= 0.2
#---
Sequence Year Recruits Escapement TotalBiom SpawnBiom CatHat F(t) M(t) IGR_recruits IGR_escapement IGR_all SurplusProd
Delta C_over_B
0 1959 NA NA 1216.61  NA 94.001 0.0806634 0.2  NA NA 0.193938 150.796 0.996932 0.0772646  <-Note:Biomass_constrained!
<-Note:IGR_assumed_same_as_1960!
1 1960 158.148 1115.55 1273.69 1115.55 93.955 0.0768667 0.2  0.587084 0.138203 0.193938 157.591 1.00922 0.0737658  <-
Note:IGR_escapement_constrained!
2 1961 149.687 1186.78 1336.46 1186.78 100.556 0.0784234 0.2  0.587084 0.145518 0.194974 161.253 1.00835 0.0752404
3 1962 153.427 1242.89 1396.32 1242.89 242.15 0.191084 0.2  0.587084 0.145312 0.193854 152.148 1.00756 0.17342
4 1963 145.771 1158.72 1304.49 1158.72 194.344 0.161832 0.2  0.587084 0.144553 0.194004 159.414 1.00784 0.148981
5 1964 153.009 1115.02 1268.03 1115.02 187.445 0.160119 0.2  0.587084 0.144755 0.198129 94.5504 1.0107 0.147823
6 1965 82.1544 1090.98 1173.13 1090.98 109.844 0.0994134 0.2  0.587084 0.147607 0.178383 111.929 0.996145 0.093633
7 1966 128.784 1046.86 1175.64 1046.86 210.038 0.198628 0.2  0.587084 0.133096 0.182828 173.415 1.00243 0.178658
8 1967 180.288 958.221 1138.51 958.221 285.245 0.286915 0.2  0.587084 0.138323 0.209386 199.102 1.01994 0.250543
9 1968 171.198 875.482 1046.68 875.482 469.978 0.586331 0.2  0.587806 0.156029 0.226652 167.479 1.02902 0.449018
10 1969 124.036 606.506 730.542 606.506 392.655 0.752497 0.2  0.587418 0.165365 0.237024 295.368 1.0351 0.537484
11 1970 257.324 362.149 619.473 362.149 307.131 0.624468 0.2  0.586951 0.170978 0.34377 266.809 1.10498 0.495794
12 1971 155.586 391.321 546.907 391.321 330.52 0.846061 0.2  0.586845 0.228859 0.3307 363.534 1.09138 0.604344
13 1972 278.589 271.129 549.718 271.129 271.744 0.597655 0.2  0.586399 0.219079 0.405231 224.894 1.13631 0.494334
14 1973 88.269 377.557 465.826 377.557 258.551 0.748704 0.2  0.585347 0.254185 0.316937 124.351 1.07696 0.555038
15 1974 61.8308 249.897 311.727 249.897 209.886 1.04994 0.2  0.583638 0.210133 0.284217 178.079 1.06289 0.6733
16 1975 146.621 120.1 266.721 120.1 216.957 1.3836 0.2  0.580872 0.195145 0.407185 146.756 1.15394 0.813423
17 1976 79.3695 83.7521 163.122 83.7521 121.925 1.15341 0.2  0.578181 0.255587 0.41255 106.352 1.14737 0.747449
18 1977 65.0841 64.4967 129.581 64.4967 67.08 0.632954 0.2  0.575629 0.255703 0.416391 89.2737 1.13922 0.517669
19 1978 55.9067 86.5287 142.435 86.5287 88.165 0.848096 0.2  0.573464 0.257228 0.381352 112.666 1.12093 0.618982
20 1979 82.2578 74.0169 156.275 74.0169 104.178 0.935167 0.2  0.571236 0.24176 0.415185 98.9131 1.14529 0.666634
21 1980 58.7796 77.0941 135.874 77.0941 93.234 1.0005 0.2  0.569328 0.256997 0.392113 75.8329 1.13024 0.686181
22 1981 45.0506 61.2789 106.33 61.2789 84.097 1.32909 0.2  0.567728 0.246492 0.382596 75.8413 1.13023 0.790909
23 1982 52.9024 34.2197 87.1221 34.2197 59.852 0.966926 0.2  0.566723 0.242582 0.439407 90.1943 1.16021 0.68699
24 1983 65.27 42.6057 107.876 42.6057 35.627 0.34689 0.2  0.566115 0.266591 0.447817 123.334 1.14909 0.33026
25 1984 91.5433 98.728 190.271 98.728 42.442 0.22444 0.2  0.566083 0.269315 0.412096 91.5978 1.12652 0.22306
26 1985 44.0426 190.015 234.057 190.015 55.155 0.252417 0.2  0.566341 0.254663 0.313311 81.899 1.06866 0.235647
27 1986 51.7366 205.278 257.014 205.278 56.202 0.236192 0.2  0.566573 0.207802 0.280022 121.272 1.0538 0.218673
28 1987 96.7559 222.304 319.06 222.304 66.846 0.221883 0.2  0.566666 0.192546 0.305999 117.893 1.07245 0.209509
29 1988 76.6895 288.575 365.264 288.575 73.95 0.216213 0.2  0.566737 0.207922 0.283257 140.734 1.05575 0.202456
30 1989 104.464 323.462 427.926 323.462 97.059 0.245464 0.2  0.566694 0.194388 0.285275 186.561 1.05935 0.226813
31 1990 142.098 369.57 511.668 369.57 93.805 0.191956 0.2  0.566578 0.196537 0.299303 240.181 1.06745 0.183332
32 1991 178.539 473.177 651.716 473.177 79.943 0.123936 0.2  0.566206 0.204083 0.303287 274.949 1.06821 0.122665
33 1992 194.054 647.216 841.27 647.216 93.191 0.112071 0.2  0.565733 0.20571 0.288756 203.422 1.05877 0.110774
34 1993 114.027 831.997 946.024 831.997 88.667 0.0962972 0.2  0.565119 0.197628 0.241923 174.705 1.0295 0.093726
35 1994 126.426 903.02 1029.45 903.02 76.821 0.0768083 0.2  0.564424 0.170431 0.218817 155.663 1.01892 0.0746236
36 1995 126.386 980.449 1106.83 980.449 102.253 0.0967065 0.2  0.563743 0.158223 0.204528 393.037 1.01159 0.0923833
37 1996 377.707 1018.73 1396.43 1018.73 126.852 0.0922326 0.2  0.563153 0.149968 0.261726 318.078 1.05025 0.09084
38 1997 202.411 1378.87 1581.28 1378.87 119.553 0.0772257 0.2  0.562572 0.186517 0.234654 199.535 1.0265 0.075605
39 1998 129.543 1528.55 1658.1 1528.55 125.829 0.0790143 0.2  0.561943 0.166843 0.197711 102.379 1.00514 0.0758875
40 1999 95.7335 1538.27 1634 1538.27 124.101 0.0802661 0.2  0.561338 0.144223 0.168661 324.761 0.98957 0.0759492
41 2000 366.544 1469.41 1835.96 1469.41 125.818 0.0705243 0.2  0.560971 0.126043 0.212875 157.116 1.0232 0.06853
42 2001 102.522 1761.81 1864.33 1761.81 133.165 0.0748295 0.2  0.56082 0.158942 0.181042 101.294 0.995137 0.0714276
43 2002 127.618 1705.49 1833.11 1705.49 104.43 0.0597691 0.2  0.56082 0.13325 0.163017 NA NA 0.0569687
#-------------------------------------
Recruit_model_and_spawning_biomass_info
Recruitment_model:_BEVERTON-HOLT_MODEL_(Code=3)
Recruitment_model_turned_ON_in_loglikelihood
Emphasis_on_recruit_model_fit 1
Beverton_Holt_parameter_alpha= 169.351
Beverton_Holt_parameter_beta= 120.28
Beverton_Holt_spawner_recruit_model:_R=(169.351*S)/(S+120.28)
Root_Mean_Square_Error_recruit_model_residuals= 0.389325
Corresponding_Arith_Scale_CV= 0.404555
```

```
Bias_correction= 1.07873
maturity_ogive=  0 1
year_lag_recruits= 2
mean_recruitment= 132.283
mean_log_recruitment= 4.74561
geometric_mean_recruitment= 115.078
Sequence SpawnYr SpawnBiom RecruitYr Weight Recruits Recruit_Model_(GM) Recruit_Model_Unbiased Raw_Resid Std_Resid
1 1958 NA 1960 1 158.148 0 0 0 0  <-Note:Recruitment_constrained_recruit_model_recruitment_in_1962
2 1959 NA 1961 1 149.687 0 0 0 0  <-Note:Recruitment_constrained_recruit_model_recruitment_in_1962
3 1960 1115.55 1962 1 153.427 152.869 164.905 0.00364522 0.00936291
4 1961 1186.78 1963 1 145.771 153.767 165.874 -0.0534031 -0.137168
5 1962 1242.89 1964 1 153.009 154.409 166.566 -0.00910619 -0.0233897
6 1963 1158.72 1965 1 82.1544 153.425 165.505 -0.624612 -1.60435
7 1964 1115.02 1966 1 128.784 152.862 164.897 -0.171397 -0.44024
8 1965 1090.98 1967 1 180.288 152.534 164.544 0.167165 0.42937
9 1966 1046.86 1968 1 171.198 151.899 163.858 0.119608 0.307217
10 1967 958.221 1969 1 124.036 150.464 162.311 -0.193152 -0.496121
11 1968 875.482 1970 1 257.324 148.895 160.618 0.547094 1.40524
12 1969 606.506 1971 1 155.586 141.324 152.451 0.0961405 0.246941
13 1970 362.149 1972 1 278.589 127.128 137.138 0.784538 2.01512
14 1971 391.321 1973 1 88.269 129.536 139.735 -0.38357 -0.985217
15 1972 271.129 1974 1 61.8308 117.31 126.546 -0.640416 -1.64494
16 1973 377.557 1975 1 146.621 128.435 138.547 0.132424 0.340137
17 1974 249.897 1976 1 79.3695 114.325 123.326 -0.364928 -0.937335
18 1975 120.1 1977 1 65.0841 84.6125 91.2743 -0.262401 -0.673988
19 1976 83.7521 1978 1 55.9067 69.5162 74.9894 -0.217875 -0.559622
20 1977 64.4967 1979 1 82.2578 59.1125 63.7666 0.330415 0.848686
21 1978 86.5287 1980 1 58.7796 70.8566 76.4353 -0.186862 -0.479965
22 1979 74.0169 1981 1 45.0506 64.514 69.5934 -0.359097 -0.922356
23 1980 77.0941 1982 1 52.9024 66.1485 71.3566 -0.223454 -0.573952
24 1981 61.2789 1983 1 65.27 57.1587 61.659 0.1327 0.340846
25 1982 34.2197 1984 1 91.5433 37.5092 40.4624 0.892225 2.29172
26 1983 42.6057 1985 1 44.0426 44.2969 47.7846 -0.00575788 -0.0147894
27 1984 98.728 1986 1 51.7366 76.343 82.3537 -0.389072 -0.999349
28 1985 190.015 1987 1 96.7559 103.705 111.871 -0.0693635 -0.178163
29 1986 205.278 1988 1 76.6895 106.783 115.19 -0.331035 -0.850279
30 1987 222.304 1989 1 104.464 109.893 118.545 -0.050659 -0.13012
31 1988 288.575 1990 1 142.098 119.53 128.941 0.172946 0.444219
32 1989 323.462 1991 1 178.539 123.447 133.167 0.368993 0.947776
33 1990 369.57 1992 1 194.054 127.768 137.828 0.417919 1.07344
34 1991 473.177 1993 1 114.027 135.028 145.659 -0.169045 -0.434199
35 1992 647.216 1994 1 126.426 142.811 154.055 -0.121869 -0.313026
36 1993 831.997 1995 1 126.386 147.961 159.61 -0.157608 -0.404824
37 1994 903.02 1996 1 377.707 149.446 161.212 0.927187 2.38152
38 1995 980.449 1997 1 202.411 150.846 162.722 0.294041 0.755258
39 1996 1018.73 1998 1 129.543 151.468 163.393 -0.156357 -0.40161
40 1997 1378.87 1999 1 95.7335 155.764 168.028 -0.486774 -1.2503
41 1998 1528.55 2000 1 366.544 156.997 169.358 0.847889 2.17784
42 1999 1538.27 2001 1 102.522 157.07 169.436 -0.42661 -1.09577
43 2000 1469.41 2002 1 127.618 156.538 168.862 -0.204255 -0.524639
44 2001 1761.81 2003 NA NA NA
45 2002 1705.49 2004 NA NA NA

Sorted_by_spawning_biomass_for_plotting:
 SpawnYr RecruitYr SpawnBiom Obs_R Predicted_R
 1982 1984 34.2197 91.5433 37.5092
 1983 1985 42.6057 44.0426 44.2969
 1981 1983 61.2789 65.27 57.1587
 1977 1979 64.4967 82.2578 59.1125
 1979 1981 74.0169 45.0506 64.514
 1980 1982 77.0941 52.9024 66.1485
 1976 1978 83.7521 55.9067 69.5162
 1978 1980 86.5287 58.7796 70.8566
 1984 1986 98.728 51.7366 76.343
 1975 1977 120.1 65.0841 84.6125
 1985 1987 190.015 96.7559 103.705
 1986 1988 205.278 76.6895 106.783
 1987 1989 222.304 104.464 109.893
 1974 1976 249.897 79.3695 114.325
 1972 1974 271.129 61.8308 117.31
 1988 1990 288.575 142.098 119.53
 1989 1991 323.462 178.539 123.447
 1970 1972 362.149 278.589 127.128
 1990 1992 369.57 194.054 127.768
 1973 1975 377.557 146.621 128.435
 1971 1973 391.321 88.269 129.536
 1991 1993 473.177 114.027 135.028
 1969 1971 606.506 155.586 141.324
 1992 1994 647.216 126.426 142.811
 1993 1995 831.997 126.386 147.961
 1968 1970 875.482 257.324 148.895
```

```
 1994 1996 903.02 377.707 149.446
 1967 1969 958.221 124.036 150.464
 1995 1997 980.449 202.411 150.846
 1996 1998 1018.73 129.543 151.468
 1966 1968 1046.86 171.198 151.899
 1965 1967 1090.98 180.288 152.534
 1964 1966 1115.02 128.784 152.862
 1960 1962 1115.55 153.427 152.869
 1963 1965 1158.72 82.1544 153.425
 1961 1963 1186.78 145.771 153.767
 1962 1964 1242.89 153.009 154.409
 1997 1999 1378.87 95.7335 155.764
 2000 2002 1469.41 127.618 156.538
 1998 2000 1528.55 366.544 156.997
 1999 2001 1538.27 102.522 157.07
#------------------------------------
Internal_surplus_production_turned_ON_in_likelihood
Emphasis_on_surplus_production_model_fit 0.0001
Biomass_and_production_scaled_by 0.001
Standard_deviation_for_production= 0.0644334
Fox_production_model_used_internally
Surplus_production_parameter_a= 0.221867
Surplus_production_parameter_b= 2.43446
P=-e*0.221867*(B/2.43446)*ln(B/2.43446)_(P_and_B_scaled_by_0.001)
K_(carrying_capacity)= 2.43446
Bmsy= 0.895883
MSY= 0.221867
Fmsy= 0.247651
Recent_F/Fmsy= 0.276091
Recent_B/Bmsy= 2.05883
ID Year Biomass SP_Observed SP_Model Residual Std_Residual
1 1959 1.21661 0.150796 0.209064 -0.0582687 -0.904325
2 1960 1.27369 0.157591 0.204406 -0.046815 -0.726564
3 1961 1.33646 0.161253 0.198552 -0.0372985 -0.57887
4 1962 1.39632 0.152148 0.192289 -0.0401411 -0.622986
5 1963 1.30449 0.159414 0.201627 -0.0422137 -0.655153
6 1964 1.26803 0.0945504 0.204896 -0.110346 -1.71256
7 1965 1.17313 0.111929 0.212169 -0.10024 -1.55571
8 1966 1.17564 0.173415 0.212001 -0.0385855 -0.598844
9 1967 1.13851 0.199102 0.214357 -0.0152544 -0.236747
10 1968 1.04668 0.167479 0.218873 -0.051394 -0.797631
11 1969 0.730542 0.295368 0.217844 0.0775244 1.20317
12 1970 0.619473 0.266809 0.210032 0.0567763 0.881163
13 1971 0.546907 0.363534 0.202309 0.161225 2.5022
14 1972 0.549718 0.224894 0.202651 0.0222435 0.345216
15 1973 0.465826 0.124351 0.190834 -0.0664831 -1.03181
16 1974 0.311727 0.178079 0.158725 0.0193542 0.300375
17 1975 0.266721 0.146756 0.146111 0.000644271 0.00999903
18 1976 0.163122 0.106352 0.109229 -0.00287712 -0.0446526
19 1977 0.129581 0.0892737 0.0941591 -0.00488538 -0.0758207
20 1978 0.142435 0.112666 0.100162 0.0125041 0.194063
21 1979 0.156275 0.0989131 0.106304 -0.00739129 -0.114712
22 1980 0.135874 0.0758329 0.0971355 -0.0213027 -0.330616
23 1981 0.10633 0.0758413 0.0824729 -0.00663161 -0.102922
24 1982 0.0871221 0.0901943 0.071875 0.0183193 0.284314
25 1983 0.107876 0.123334 0.0832864 0.0400479 0.62154
26 1984 0.190271 0.0915978 0.120152 -0.0285543 -0.443161
27 1985 0.234057 0.081899 0.135793 -0.0538937 -0.836425
28 1986 0.257014 0.121272 0.143154 -0.0218825 -0.339614
29 1987 0.31906 0.117893 0.160621 -0.0427272 -0.663122
30 1988 0.365264 0.140734 0.171643 -0.0309084 -0.479695
31 1989 0.427926 0.186561 0.184304 0.00225737 0.0350341
32 1990 0.511668 0.240181 0.197716 0.042465 0.659053
33 1991 0.651716 0.274949 0.212772 0.062177 0.964982
34 1992 0.84127 0.203422 0.22145 -0.0180278 -0.27979
35 1993 0.946024 0.174705 0.221521 -0.0468162 -0.726583
36 1994 1.02945 0.155663 0.219503 -0.0638407 -0.990802
37 1995 1.10683 0.393037 0.21613 0.176907 2.74559
38 1996 1.39643 0.318078 0.192276 0.125801 1.95242
39 1997 1.58128 0.199535 0.16903 0.0305057 0.473446
40 1998 1.6581 0.102379 0.157756 -0.0553776 -0.859455
41 1999 1.634 0.324761 0.16139 0.163371 2.5355
42 2000 1.83596 0.157116 0.128334 0.0287814 0.446685
43 2001 1.86433 0.101294 0.123234 -0.0219398 -0.340504

Production_results_sorted_by_biomass_for_plotting:
 Year Biomass SP_Observed SP_Model
 1982 0.0871221 0.0901943 0.071875
 1981 0.10633 0.0758413 0.0824729
 1983 0.107876 0.123334 0.0832864
 1977 0.129581 0.0892737 0.0941591
```

```
 1980 0.135874 0.0758329 0.0971355
 1978 0.142435 0.112666 0.100162
 1979 0.156275 0.0989131 0.106304
 1976 0.163122 0.106352 0.109229
 1984 0.190271 0.0915978 0.120152
 1985 0.234057 0.081899 0.135793
 1986 0.257014 0.121272 0.143154
 1975 0.266721 0.146756 0.146111
 1974 0.311727 0.178079 0.158725
 1987 0.31906 0.117893 0.160621
 1988 0.365264 0.140734 0.171643
 1989 0.427926 0.186561 0.184304
 1973 0.465826 0.124351 0.190834
 1990 0.511668 0.240181 0.197716
 1971 0.546907 0.363534 0.202309
 1972 0.549718 0.224894 0.202651
 1970 0.619473 0.266809 0.210032
 1991 0.651716 0.274949 0.212772
 1969 0.730542 0.295368 0.217844
 1992 0.84127 0.203422 0.22145
 1993 0.946024 0.174705 0.221521
 1994 1.02945 0.155663 0.219503
 1968 1.04668 0.167479 0.218873
 1995 1.10683 0.393037 0.21613
 1967 1.13851 0.199102 0.214357
 1965 1.17313 0.111929 0.212169
 1966 1.17564 0.173415 0.212001
 1964 1.26803 0.0945504 0.204896
 1960 1.27369 0.157591 0.204406
 1963 1.30449 0.159414 0.201627
 1961 1.33646 0.161253 0.198552
 1962 1.39632 0.152148 0.192289
 1996 1.39643 0.318078 0.192276
 1997 1.58128 0.199535 0.16903
 1999 1.634 0.324761 0.16139
 1998 1.6581 0.102379 0.157756
 2000 1.83596 0.157116 0.128334
 2001 1.86433 0.101294 0.123234
#---Done_with_Report---
```

Appendix III. Initial ADAPT Run.

```
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APL  Ver. 4.0.03

ADAPT_W  Ver. 3.0

Workspace size = 16000000

USA Total CAA Numbers x 10^6
               1       2       3       4       5       6       7       8       9      10
 1967.00     137     424     229     209     131     270     389      50      12      10
 1968.00      15    1392     277     181     397     267     465     356      25       9
 1969.00      71     582     398     234     301     310     217     215     130      29
 1970.00       6     494     190     493     296     152     128      79      51      32
 1971.00     155     233     410     328     333     222     136      69      26      30
 1972.00       8    1001      65     165     262     209     126      56      32      24
 1973.00      37     351    1301     294      77      47      36      20       5       6
 1974.00      35     429     147     750      79      18       9       6       3       0
 1975.00      45     646     118     112     610      46      17       9       6       1
 1976.00      75     531     249      47      49     209      10       3       3       1
 1977.00     597     579      83      71      21      18      50       3       1       0
 1978.00     270    1222     138      26      43       6       8      32       1       1
 1979.00       7    1174     423      58      16      17       6       5       7       0
 1980.00     343     230     363     185      22       6       8       1       1       4
 1981.00      62    1169      34      68      47       5       1       1       0       0
 1982.00      53     669     110       7      30      19       2       0       1       0
 1983.00      33     267      59      29       1       7       7       0       0       0
 1984.00      19     185     133      40      28       2       4       2       1       0
 1985.00      30     563      84      51      27      14       1       2       1       0
 1986.00      41     247     225      49      38      16       8       0       0       0
 1987.00      51     224     135     181      45      18       6       2       0       0
 1988.00      79     502     111      62     127      35       9       2       1       0
 1989.00      27     460     166     108      81     181      29       8       2       0
 1990.00      13     571     221      89      38      43      82      29      15       4
 1991.00       6     462     180     102      65      33      23      21      10       3
 1992.00       1     547     220      94      88      56      27      17      14       4
 1993.00       2     384     244     101      89      51      35      17       6       2
 1994.00       2     423     176      73      85      71      37      19       6       2
 1995.00      59     465     134      53      38      84      92      56      17       3
 1996.00       6     620     161      71      79     171     100      29       6       2
 1997.00      11     317     637      89      49      64      72      17       3       0
 1998.00       0     628     146     331      59      31      32      16       6       2
 1999.00       5     176     395     128     228      82      35      20       5       0
 2000.00       4     445      55     129     161     177      44      15       3       1
 2001.00       1     194     495      60     103     129     136      27       5       0
 2002.00

Herring Winter Catch Per Tow 1992-2002
               2       3       4       5       6       7       8
 1992.00    7.70   13.23    8.19    4.40    1.36    0.53    0.00
 1993.00    0.32   16.17   17.00    9.78    5.78    0.71    0.00
 1994.00    0.08    0.52    1.16    1.24    1.01    0.27    0.12
 1995.00    0.07    0.84    0.99    4.89    6.09    3.77    0.87
 1996.00   74.57    6.57    3.60    4.11   14.30    6.82    1.35
 1997.00    1.76    6.98    1.72    6.99   17.12   14.62    4.83
 1998.00    1.68   13.92   28.46    6.49    3.76    2.35    0.53
 1999.00    0.24    6.48    8.34   26.47    7.78    4.17    1.71
 2000.00   47.82    3.96    5.51    5.30    3.10    0.42    0.08
 2001.00    5.97   38.02    4.56    9.46    8.83    6.37    0.79
 2002.00    0.93    3.07   40.80    7.78    9.59    6.97    2.02
```

```
Spring survey index for 1968-2002
                2       3       4       5       6       7       8
 1968.25    1.54    8.70    3.44    3.57    2.89    4.50    1.35
 1969.25    0.12    1.32    0.50    1.00    1.74    4.06    1.76
 1970.25    3.85    1.48    1.04    0.83    0.55    0.43    0.04
 1971.25    0.20    0.45    0.50    0.21    0.22    0.15    0.05
 1972.25    0.47    0.94    0.48    0.57    0.32    0.02    0.02
 1973.25    0.07    2.27    3.46    0.57    1.15    0.57    0.12
 1974.25    0.03    0.10    4.44    0.76    0.19    0.07    0.04
 1975.25    0.04    0.10    0.04    0.83    0.08    0.04    0.01
 1976.25    0.04    0.23    0.06    0.12    0.31    0.23    0.02
 1977.25    0.06    0.12    0.38    0.13    0.07    0.23    0.01
 1978.25    0.12    1.99    0.33    0.30    0.05    0.05    0.19
 1979.25    4.53    0.37    1.12    0.81    0.24    0.12    0.17
 1980.25    0.11    1.46    3.71    0.68    0.08    0.11    0.01
 1981.25    0.02    0.01    0.51    1.34    0.19    0.06    0.03
 1982.25    0.40    0.05    0.05    0.05    0.04    0.01    0.00
 1983.25    0.15    0.03    0.06    0.01    0.05    0.09    0.00
 1984.25    1.93    0.41    0.30    0.14    0.01    0.02    0.01
 1985.25    1.95    0.94    0.42    0.48    0.11    0.02    0.02
 1986.25    1.69   27.17    3.37    1.17    0.56    0.41    0.00
 1987.25    1.30    2.13    3.83    0.23    0.14    0.00    0.00
 1988.25    3.23    3.97    3.49    3.30    0.31    0.01    0.00
 1989.25    1.66    1.66    2.89    1.99    1.37    0.13    0.00
 1990.25    2.97    2.38    2.67    1.16    0.16    0.00    0.00
 1991.25    4.58    6.81   10.91    0.96    0.30    0.06    0.00
 1992.25   11.00   15.99    6.50    2.05    0.58    0.19    0.00
 1993.25    7.24   32.70   25.61    5.72    0.91    0.07    0.00
 1994.25    4.35    3.38   12.11   11.00    3.31    0.52    0.04
 1995.25    6.06    3.77    3.23   11.66    2.84    0.52    0.01
 1996.25   40.91    8.48    5.06    2.80    4.48    2.52    0.64
 1997.25   21.28   33.05    5.70    2.68    2.42    1.42    0.35
 1998.25    4.68   10.74   27.77    5.88    1.58    0.83    0.17
 1999.25    2.35   16.35   14.38   42.77    7.06    2.92    0.90
 2000.25   15.11    3.42    5.03    4.97    3.67    0.80    0.19
 2001.25    5.01   19.21    1.91    2.68    2.87    2.54    0.51
 2002.00    5.99    2.05   13.44    2.40    1.72    1.17    0.38

Index Type and Model Form
ID# | Label                            |Age|Index Type| Model Form
 1 Herring Winter Catch Per Tow 1992-2002 2 Abundance Proportional
 2 Herring Winter Catch Per Tow 1992-2002 3 Abundance Proportional
 3 Herring Winter Catch Per Tow 1992-2002 4 Abundance Proportional
 4 Herring Winter Catch Per Tow 1992-2002 5 Abundance Proportional
 5 Herring Winter Catch Per Tow 1992-2002 6 Abundance Proportional
 6 Herring Winter Catch Per Tow 1992-2002 7 Abundance Proportional
 7 Herring Winter Catch Per Tow 1992-2002 8 Abundance Proportional
 8 Spring survey index for 1968-2002      2 Abundance Proportional
 9 Spring survey index for 1968-2002      3 Abundance Proportional
10 Spring survey index for 1968-2002      4 Abundance Proportional
11 Spring survey index for 1968-2002      5 Abundance Proportional
12 Spring survey index for 1968-2002      6 Abundance Proportional
13 Spring survey index for 1968-2002      7 Abundance Proportional
14 Spring survey index for 1968-2002      8 Abundance Proportional

Index Inclusion
ID# on same line have common catchability
 1
 2
 3
```

```
 4
 5
 6
 7
 8
 9
 10
 11
 12
 13
 14

VPA setup

Plus Group : No plus group

Population
             1       2       3       4       5       6       7       8       9      10
 2002.00  (5000)  (5000)                   3000    2000    1000
F ratios
             1       2       3       4       5       6       7       8       9      10
 1967.00                                                                   1.00 ********
 1968.00                                                                   1.00 ********
 1969.00                                                                   1.00 ********
 1970.00                                                                   1.00 ********
 1971.00                                                                   1.00 ********
 1972.00                                                                   1.00 ********
 1973.00                                                                   1.00 ********
 1974.00                                                                   1.00 ********
 1975.00                                                                   1.00 ********
 1976.00                                                                   1.00 ********
 1977.00                                                                   1.00 ********
 1978.00                                                                   1.00 ********
 1979.00                                                                   1.00 ********
 1980.00                                                                   1.00 ********
 1981.00                                                                   1.00 ********
 1982.00                                                                   1.00 ********
 1983.00                                                                   1.00 ********
 1984.00                                                                   1.00 ********
 1985.00                                                                   1.00 ********
 1986.00                                                                   1.00 ********
 1987.00                                                                   1.00 ********
 1988.00                                                                   1.00 ********
 1989.00                                                                   1.00 ********
 1990.00                                                                   1.00 ********
 1991.00                                                                   1.00 ********
 1992.00                                                                   1.00 ********
 1993.00                                                                   1.00 ********
 1994.00                                                                   1.00 ********
 1995.00                                                                   1.00 ********
 1996.00                                                                   1.00 ********
 1997.00                                                                   1.00 ********
 1998.00                                                                   1.00 ********
 1999.00                                                                   1.00 ********
 2000.00                                                                   1.00 ********
 2001.00         **wtd**           1.00    1.00    1.00
 2001.00                 **wtd**   1.00    1.00    1.00
 2001.00                           1.00    1.00    1.00  **wtd**
 2001.00                           1.00    1.00    1.00          **wtd**
 2001.00                           1.00    1.00    1.00                  **wtd**
 2001.00                                                                   1.00 ********
Natural Mortality
             1       2       3       4       5       6       7       8       9      10
```

```
 1967.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1968.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1969.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1970.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1971.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1972.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1973.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1974.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1975.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1976.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1977.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1978.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1979.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1980.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1981.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1982.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1983.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1984.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1985.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1986.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1987.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1988.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1989.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1990.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1991.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1992.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1993.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1994.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1995.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1996.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1997.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1998.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 1999.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 2000.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)
 2001.00  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)  (0.20)

Virtual Population Analysis using initial values

Population Numbers
                1        2        3        4        5        6        7        8        9       10
 1967.00     5263     2809     1798     1805     1161     1540     1287      176       56       51
 1968.00     2627     4186     1918     1266     1290      833     1018      704       99       36
 1969.00     2067     2137     2178     1320      874      700      442      418      259       58
 1970.00     1396     1628     1227     1426      870      446      296      169      151       96
 1971.00     7652     1138      889      834      726      447      229      128       68       78
 1972.00     1173     6125      722      361      389      296      168       67       43       32
 1973.00      993      953     4114      533      148       87       58       27        6        7
 1974.00     1639      779      466     2201      174       53       29       15        4        1
 1975.00     1004     1310      256      249     1129       72       27       16        7        1
 1976.00     1269      781      497      104      104      381       18        7        4        1
 1977.00     3545      971      170      184       43       41      126        6        2        1
 1978.00     2701     2365      280       65       88       17       17       59        2        1
 1979.00      396     1968      847      106       29       34        8        7       19        1
 1980.00     2309      319      568      316       36       10       12        1        1       10
 1981.00     1328     1582       58      143       94       10        3        3        0        1
 1982.00     1070     1032      265       17       57       36        4        1        1        0
 1983.00     1053      828      252      118        8       19       12        1        0        0
 1984.00     2846      832      438      153       71        5       10        3        1        0
 1985.00     1247     2313      515      239       89       33        2        4        1        0
 1986.00     1168      994     1388      346      150       48       15        1        1        0
 1987.00     1823      919      591      934      239       89       25        5        0        1
 1988.00     2047     1446      552      363      602      156       56       15        2        0
 1989.00     2187     1605      734      352      241      379       96       38       11        1
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 1990.00    2123    1766     901     452     191     125     149      52      23       7
 1991.00    2276    1727     934     539     289     122      63      49      18       6
 1992.00    1586    1859     999     602     350     178      70      31      21       6
 1993.00    2004    1298    1031     620     408     207      96      33      11       5
 1994.00    4443    1639     718     625     417     255     124      47      12       4
 1995.00   15426    3636     962     430     446     264     144      68      21       4
 1996.00    5032   12576    2557     667     304     331     141      37       7       2
 1997.00    7454    4114    9737    1949     482     178     119      28       5       0
 1998.00    7123    6093    3082    7397    1515     351      88      34       7       2
 1999.00   19739    5832    4422    2392    5757    1187     259      44      13       1
 2000.00    6142   16157    4616    3264    1843    4508     898     180      18       7
 2001.00    6108    5025   12826    3730    2556    1364    3531     695     134      12
 2002.00    5000    5000    3939   10054    3000    2000    1000    2768     545     105

Fishing Mortality
               1       2       3       4       5       6       7       8       9      10
 1967.00   0.029   0.182   0.151   0.136   0.132   0.214   0.403   0.375   0.254   0.254
 1968.00   0.007   0.453   0.173   0.171   0.412   0.432   0.689   0.800   0.326   0.326
 1969.00   0.039   0.355   0.224   0.217   0.473   0.660   0.763   0.821   0.791   0.791
 1970.00   0.005   0.405   0.187   0.476   0.466   0.466   0.639   0.716   0.460   0.460
 1971.00   0.023   0.255   0.700   0.562   0.695   0.778   1.034   0.890   0.557   0.557
 1972.00   0.008   0.198   0.104   0.690   1.297   1.435   1.645   2.202   1.632   1.632
 1973.00   0.042   0.516   0.426   0.917   0.829   0.895   1.135   1.580   1.978   1.978
 1974.00   0.024   0.913   0.424   0.467   0.678   0.478   0.420   0.515   1.355   1.355
 1975.00   0.051   0.770   0.696   0.674   0.886   1.177   1.205   1.050   1.641   1.641
 1976.00   0.068   1.327   0.791   0.682   0.729   0.906   0.961   0.803   0.959   0.959
 1977.00   0.205   1.042   0.767   0.542   0.750   0.674   0.564   0.695   0.361   0.361
 1978.00   0.117   0.827   0.771   0.583   0.761   0.518   0.745   0.905   0.719   0.719
 1979.00   0.018   1.042   0.785   0.895   0.899   0.808   1.659   1.325   0.509   0.509
 1980.00   0.178   1.503   1.177   1.008   1.092   1.136   1.288   1.280   0.717   0.717
 1981.00   0.053   1.587   1.028   0.730   0.778   0.783   0.849   0.642   0.308   0.308
 1982.00   0.056   1.211   0.605   0.566   0.872   0.893   1.043   0.705   1.359   1.359
 1983.00   0.035   0.437   0.298   0.312   0.191   0.469   1.108   0.421   0.831   0.831
 1984.00   0.007   0.280   0.405   0.342   0.577   0.576   0.645   0.870   3.408   3.408
 1985.00   0.027   0.311   0.198   0.267   0.408   0.604   0.741   0.939   1.221   1.221
 1986.00   0.039   0.319   0.196   0.168   0.326   0.458   0.855   0.529   0.461   0.461
 1987.00   0.031   0.311   0.288   0.239   0.231   0.259   0.287   0.702   0.684   0.684
 1988.00   0.044   0.478   0.250   0.208   0.263   0.282   0.198   0.169   0.844   0.844
 1989.00   0.014   0.378   0.286   0.411   0.461   0.733   0.406   0.281   0.257   0.257
 1990.00   0.007   0.437   0.313   0.245   0.247   0.477   0.920   0.896   1.152   1.152
 1991.00   0.003   0.347   0.239   0.232   0.285   0.355   0.514   0.656   0.928   0.928
 1992.00   0.001   0.389   0.276   0.189   0.323   0.422   0.539   0.876   1.280   1.280
 1993.00   0.001   0.392   0.300   0.198   0.272   0.313   0.505   0.838   0.853   0.853
 1994.00   0.000   0.333   0.314   0.137   0.255   0.367   0.400   0.592   0.841   0.841
 1995.00   0.004   0.152   0.166   0.147   0.098   0.425   1.158   2.121   2.006   2.006
 1996.00   0.001   0.056   0.072   0.125   0.334   0.825   1.432   1.745   4.868   4.868
 1997.00   0.002   0.089   0.075   0.052   0.119   0.501   1.061   1.106   0.729   0.729
 1998.00   0.000   0.121   0.054   0.051   0.044   0.103   0.503   0.738   1.768   1.768
 1999.00   0.000   0.034   0.104   0.061   0.045   0.079   0.163   0.670   0.472   0.472
 2000.00   0.001   0.031   0.013   0.044   0.101   0.044   0.056   0.099   0.186   0.186
 2001.00   0.000   0.043   0.043   0.018   0.045   0.110   0.043   0.043   0.043   0.043

LAMBDA       1.00000E-2
RSS          6.41053E2
NPHI         6.41053E2

Parameters
   8.00637E0      7.60090E0      6.90776E0

LAMBDA       1.00000E-3
RSS          6.17042E2
NPHI         6.17042E2
```

```
Parameters
   6.93510E0      7.00363E0      6.79881E0

LAMBDA       1.00000E-4
RSS          6.15639E2
NPHI         6.15639E2

Parameters
   6.61876E0      6.84056E0      6.76905E0

LAMBDA       1.00000E-5
RSS          6.15598E2
NPHI         6.15598E2

Parameters
   6.56623E0      6.80548E0      6.76283E0

LAMBDA       1.00000E-5
RSS          6.15597E2
NPHI         6.15597E2

Parameters
   6.55943E0      6.79885E0      6.76199E0

RELATIVE CHANGE IN RESIDUAL SUM OF SQUARES LESS THAN 0.00001

LAMBDA       1.00000E-2
RSS          6.15597E2
NPHI         6.15597E2

Parameters
   6.55943E0      6.79885E0      6.76199E0     -7.46704E0     -5.69737E0     -5.23259E0
  -4.63987E0     -4.31706E0     -4.44733E0     -4.62808E0     -7.23062E0     -6.12161E0
  -5.48995E0     -5.35359E0     -5.49276E0     -5.59022E0     -6.23013E0

LAMBDA       1.00000E-3
RSS          6.15597E2
NPHI         6.15597E2

Parameters
   6.55861E0      6.79761E0      6.76190E0     -7.46673E0     -5.69701E0     -5.23226E0
  -4.63957E0     -4.31681E0     -4.44716E0     -4.62784E0     -7.23052E0     -6.12149E0
  -5.48984E0     -5.35349E0     -5.49268E0     -5.59016E0     -6.23005E0

RELATIVE CHANGE IN RESIDUAL SUM OF SQUARES LESS THAN 0.00001

Estimated VPA (biased)

Population Numbers
               1       2       3       4       5       6       7       8       9      10
 1967.00    5263    2809    1798    1805    1161    1540    1287     176      56      51
 1968.00    2627    4186    1918    1266    1290     833    1018     704      99      36
 1969.00    2067    2137    2178    1320     874     700     442     418     259      58
 1970.00    1396    1628    1227    1426     870     446     296     169     151      96
 1971.00    7652    1138     889     834     726     447     229     128      68      78
 1972.00    1173    6125     722     361     389     296     168      67      43      32
 1973.00     993     953    4114     533     148      87      58      27       6       7
 1974.00    1639     779     466    2201     174      53      29      15       4       1
 1975.00    1004    1310     256     249    1129      72      27      16       7       1
 1976.00    1269     781     497     104     104     381      18       7       4       1
 1977.00    3545     971     170     184      43      41     126       6       2       1
 1978.00    2701    2365     280      65      88      17      17      59       2       1
 1979.00     396    1968     847     106      29      34       8       7      19       1
```

```
 1980.00    2309     319     568     316      36      10      12       1       1      10
 1981.00    1328    1582      58     143      94      10       3       3       0       1
 1982.00    1070    1032     265      17      57      36       4       1       1       0
 1983.00    1053     828     252     118       8      19      12       1       0       0
 1984.00    2846     832     438     153      71       5      10       3       1       0
 1985.00    1247    2313     515     239      89      33       2       4       1       0
 1986.00    1168     994    1388     346     150      48      15       1       1       0
 1987.00    1823     919     591     934     239      89      25       5       0       1
 1988.00    2047    1446     552     363     602     156      56      15       2       0
 1989.00    2187    1605     734     352     241     379      96      38      11       1
 1990.00    2121    1766     901     452     191     125     149      52      23       7
 1991.00    2256    1725     934     539     289     122      63      49      18       6
 1992.00    1543    1842     998     602     350     178      70      31      21       6
 1993.00    1632    1263    1018     619     408     207      96      33      11       5
 1994.00    2862    1335     689     614     416     254     124      47      12       4
 1995.00    8857    2342     713     406     437     264     144      68      21       4
 1996.00    4581    7198    1499     463     284     324     141      37       7       2
 1997.00    4449    3745    5335    1082     315     162     113      27       5       0
 1998.00    2016    3633    2780    3793     806     214      75      29       7       2
 1999.00    9023    1650    2409    2144    2807     606     147      33       9       1
 2000.00    2705    7383    1193    1616    1641    2093     422      89      10       4
 2001.00    6108    2211    5643     927    1207    1198    1554     306      59       5
 2002.00    5000    5000    1635    4174     705     896     864    1149     226      43

Fishing Mortality
               1       2       3       4       5       6       7       8       9      10
 1967.00   0.029   0.182   0.151   0.136   0.132   0.214   0.403   0.375   0.254   0.254
 1968.00   0.007   0.453   0.173   0.171   0.412   0.432   0.689   0.800   0.326   0.326
 1969.00   0.039   0.355   0.224   0.217   0.473   0.660   0.763   0.821   0.791   0.791
 1970.00   0.005   0.405   0.187   0.476   0.466   0.466   0.639   0.716   0.460   0.460
 1971.00   0.023   0.255   0.700   0.562   0.695   0.778   1.034   0.890   0.557   0.557
 1972.00   0.008   0.198   0.104   0.690   1.297   1.435   1.645   2.202   1.632   1.632
 1973.00   0.042   0.516   0.426   0.917   0.829   0.895   1.135   1.580   1.978   1.978
 1974.00   0.024   0.913   0.424   0.467   0.678   0.478   0.420   0.515   1.355   1.355
 1975.00   0.051   0.770   0.696   0.674   0.886   1.177   1.205   1.050   1.641   1.641
 1976.00   0.068   1.327   0.791   0.682   0.729   0.906   0.961   0.803   0.959   0.959
 1977.00   0.205   1.042   0.767   0.542   0.750   0.674   0.564   0.695   0.361   0.361
 1978.00   0.117   0.827   0.771   0.583   0.761   0.518   0.745   0.905   0.719   0.719
 1979.00   0.018   1.042   0.785   0.895   0.899   0.808   1.659   1.325   0.509   0.509
 1980.00   0.178   1.503   1.177   1.008   1.092   1.136   1.288   1.280   0.717   0.717
 1981.00   0.053   1.587   1.028   0.730   0.778   0.783   0.849   0.642   0.308   0.308
 1982.00   0.056   1.211   0.605   0.566   0.872   0.893   1.043   0.705   1.359   1.359
 1983.00   0.035   0.437   0.298   0.312   0.191   0.469   1.108   0.421   0.831   0.831
 1984.00   0.007   0.280   0.405   0.342   0.577   0.576   0.645   0.870   3.408   3.408
 1985.00   0.027   0.311   0.198   0.267   0.408   0.604   0.741   0.939   1.221   1.221
 1986.00   0.039   0.319   0.196   0.168   0.326   0.458   0.855   0.529   0.461   0.461
 1987.00   0.031   0.311   0.288   0.239   0.231   0.259   0.287   0.702   0.684   0.684
 1988.00   0.044   0.478   0.250   0.208   0.263   0.282   0.198   0.169   0.844   0.844
 1989.00   0.014   0.378   0.286   0.411   0.461   0.733   0.406   0.281   0.257   0.257
 1990.00   0.007   0.437   0.313   0.245   0.247   0.477   0.920   0.896   1.152   1.152
 1991.00   0.003   0.348   0.239   0.232   0.285   0.355   0.514   0.656   0.928   0.928
 1992.00   0.001   0.394   0.277   0.189   0.323   0.422   0.539   0.876   1.280   1.280
 1993.00   0.001   0.405   0.305   0.199   0.272   0.313   0.505   0.838   0.853   0.853
 1994.00   0.001   0.427   0.329   0.140   0.255   0.368   0.400   0.592   0.841   0.841
 1995.00   0.007   0.246   0.231   0.156   0.100   0.427   1.162   2.121   2.006   2.006
 1996.00   0.001   0.100   0.126   0.185   0.362   0.854   1.446   1.767   4.894   4.894
 1997.00   0.003   0.098   0.141   0.095   0.187   0.566   1.162   1.142   0.757   0.757
 1998.00   0.000   0.211   0.060   0.101   0.085   0.174   0.621   0.931   2.058   2.058
 1999.00   0.001   0.125   0.199   0.068   0.094   0.161   0.307   1.021   0.753   0.753
 2000.00   0.002   0.069   0.052   0.092   0.115   0.098   0.122   0.212   0.381   0.381
 2001.00   0.000   0.102   0.102   0.073   0.098   0.126   0.102   0.102   0.102   0.102

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION
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ORTHOGONALITY OFFSET.........        0.001063
MEAN SQUARE RESIDUALS .......        2.072718

  Parameter              Est.     Std. Err.    Rel. Err.    Bias       Rel. Bias
  ---------            ---------  ---------    ---------  ---------    ---------
N[2002 5]               7.05E2     3.84E2         0.545   7.07E1          0.100
N[2002 6]               8.96E2     4.61E2         0.514   5.96E1          0.067
N[2002 7]               8.64E2     4.24E2         0.490   5.21E1          0.060
q ID#[1]                5.72E-4    2.57E-4        0.449   5.27E-5         0.092
q ID#[2]                3.36E-3    1.52E-3        0.453   3.23E-4         0.096
q ID#[3]                5.34E-3    2.41E-3        0.451   5.35E-4         0.100
q ID#[4]                9.66E-3    4.32E-3        0.447   1.00E-3         0.104
q ID#[5]                1.33E-2    5.94E-3        0.445   1.35E-3         0.101
q ID#[6]                1.17E-2    5.19E-3        0.443   1.11E-3         0.095
q ID#[7]                9.78E-3    4.77E-3        0.488   1.04E-3         0.106
q ID#[8]                7.24E-4    1.78E-4        0.246   2.01E-5         0.028
q ID#[9]                2.20E-3    5.42E-4        0.247   6.29E-5         0.029
q ID#[10]               4.13E-3    1.02E-3        0.246   1.24E-4         0.030
q ID#[11]               4.73E-3    1.16E-3        0.246   1.50E-4         0.032
q ID#[12]               4.12E-3    1.01E-3        0.245   1.27E-4         0.031
q ID#[13]               3.73E-3    9.29E-4        0.249   1.11E-4         0.030
q ID#[14]               1.97E-3    5.21E-4        0.264   6.10E-5         0.031

VPA using analytical bias adjusted parameters (linear scale)
Population Numbers
                1       2       3       4       5       6       7       8       9      10
 1967.00     5263    2809    1798    1805    1161    1540    1287     176      56      51
 1968.00     2627    4186    1918    1266    1290     833    1018     704      99      36
 1969.00     2067    2137    2178    1320     874     700     442     418     259      58
 1970.00     1396    1628    1227    1426     870     446     296     169     151      96
 1971.00     7652    1138     889     834     726     447     229     128      68      78
 1972.00     1173    6125     722     361     389     296     168      67      43      32
 1973.00      993     953    4114     533     148      87      58      27       6       7
 1974.00     1639     779     466    2201     174      53      29      15       4       1
 1975.00     1004    1310     256     249    1129      72      27      16       7       1
 1976.00     1269     781     497     104     104     381      18       7       4       1
 1977.00     3545     971     170     184      43      41     126       6       2       1
 1978.00     2701    2365     280      65      88      17      17      59       2       1
 1979.00      396    1968     847     106      29      34       8       7      19       1
 1980.00     2309     319     568     316      36      10      12       1       1      10
 1981.00     1328    1582      58     143      94      10       3       3       0       1
 1982.00     1070    1032     265      17      57      36       4       1       1       0
 1983.00     1053     828     252     118       8      19      12       1       0       0
 1984.00     2846     832     438     153      71       5      10       3       1       0
 1985.00     1247    2313     515     239      89      33       2       4       1       0
 1986.00     1168     994    1388     346     150      48      15       1       1       0
 1987.00     1823     919     591     934     239      89      25       5       0       1
 1988.00     2047    1446     552     363     602     156      56      15       2       0
 1989.00     2187    1605     734     352     241     379      96      38      11       1
 1990.00     2121    1766     901     452     191     125     149      52      23       7
 1991.00     2255    1725     934     539     289     122      63      49      18       6
 1992.00     1541    1841     997     602     350     178      70      31      21       6
 1993.00     1612    1261    1017     619     408     207      96      33      11       5
 1994.00     2779    1319     688     614     416     254     124      47      12       4
 1995.00     8513    2274     700     405     437     264     144      68      21       4
 1996.00     4408    6916    1443     453     283     324     141      37       7       2
 1997.00     4287    3603    5104    1037     307     161     113      27       5       0
 1998.00     1858    3500    2664    3604     768     207      75      29       7       2
 1999.00     8461    1521    2300    2049    2652     575     141      33       9       1
 2000.00     2525    6923    1087    1527    1563    1966     397      84       9       3
 2001.00     6108    2063    5267     841    1134    1134    1450     285      55       5
 2002.00     5000    5000    1515    3866     635     836     812    1064     210      40
```

```
Fishing Mortality
               1        2        3        4        5        6        7        8        9       10
 1967.00   0.029    0.182    0.151    0.136    0.132    0.214    0.403    0.375    0.254    0.254
 1968.00   0.007    0.453    0.173    0.171    0.412    0.432    0.689    0.800    0.326    0.326
 1969.00   0.039    0.355    0.224    0.217    0.473    0.660    0.763    0.821    0.791    0.791
 1970.00   0.005    0.405    0.187    0.476    0.466    0.466    0.639    0.716    0.460    0.460
 1971.00   0.023    0.255    0.700    0.562    0.695    0.778    1.034    0.890    0.557    0.557
 1972.00   0.008    0.198    0.104    0.690    1.297    1.435    1.645    2.202    1.632    1.632
 1973.00   0.042    0.516    0.426    0.917    0.829    0.895    1.135    1.580    1.978    1.978
 1974.00   0.024    0.913    0.424    0.467    0.678    0.478    0.420    0.515    1.355    1.355
 1975.00   0.051    0.770    0.696    0.674    0.886    1.177    1.205    1.050    1.641    1.641
 1976.00   0.068    1.327    0.791    0.682    0.729    0.906    0.961    0.803    0.959    0.959
 1977.00   0.205    1.042    0.767    0.542    0.750    0.674    0.564    0.695    0.361    0.361
 1978.00   0.117    0.827    0.771    0.583    0.761    0.518    0.745    0.905    0.719    0.719
 1979.00   0.018    1.042    0.785    0.895    0.899    0.808    1.659    1.325    0.509    0.509
 1980.00   0.178    1.503    1.177    1.008    1.092    1.136    1.288    1.280    0.717    0.717
 1981.00   0.053    1.587    1.028    0.730    0.778    0.783    0.849    0.642    0.308    0.308
 1982.00   0.056    1.211    0.605    0.566    0.872    0.893    1.043    0.705    1.359    1.359
 1983.00   0.035    0.437    0.298    0.312    0.191    0.469    1.108    0.421    0.831    0.831
 1984.00   0.007    0.280    0.405    0.342    0.577    0.576    0.645    0.870    3.408    3.408
 1985.00   0.027    0.311    0.198    0.267    0.408    0.604    0.741    0.939    1.221    1.221
 1986.00   0.039    0.319    0.196    0.168    0.326    0.458    0.855    0.529    0.461    0.461
 1987.00   0.031    0.311    0.288    0.239    0.231    0.259    0.287    0.702    0.684    0.684
 1988.00   0.044    0.478    0.250    0.208    0.263    0.282    0.198    0.169    0.844    0.844
 1989.00   0.014    0.378    0.286    0.411    0.461    0.733    0.406    0.281    0.257    0.257
 1990.00   0.007    0.437    0.313    0.245    0.247    0.477    0.920    0.896    1.152    1.152
 1991.00   0.003    0.348    0.239    0.232    0.285    0.355    0.514    0.656    0.928    0.928
 1992.00   0.001    0.394    0.277    0.189    0.323    0.422    0.539    0.876    1.280    1.280
 1993.00   0.001    0.406    0.305    0.199    0.272    0.313    0.505    0.838    0.853    0.853
 1994.00   0.001    0.434    0.330    0.140    0.255    0.368    0.400    0.592    0.841    0.841
 1995.00   0.008    0.255    0.235    0.157    0.101    0.427    1.162    2.121    2.006    2.006
 1996.00   0.001    0.104    0.131    0.190    0.363    0.855    1.447    1.768    4.896    4.896
 1997.00   0.003    0.102    0.148    0.100    0.193    0.570    1.168    1.144    0.759    0.759
 1998.00   0.000    0.220    0.062    0.107    0.089    0.181    0.629    0.945    2.077    2.077
 1999.00   0.001    0.136    0.209    0.071    0.099    0.170    0.322    1.051    0.778    0.778
 2000.00   0.002    0.073    0.057    0.097    0.121    0.105    0.131    0.225    0.403    0.403
 2001.00   0.000    0.109    0.109    0.081    0.105    0.134    0.109    0.109    0.109    0.109

Herring Winter Catch Per Tow 1992-2002
Age :   2
Ln calibration constant :      -7.46673

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1992.00       2.04182       0.05203       1.98979       7.51876
  1993.00      -1.14413      -0.32585      -0.81829       7.14089
  1994.00      -2.51331      -0.27038      -2.24293       7.19635
  1995.00      -2.61456       0.29189      -2.90645       7.75862
  1996.00       4.31175       1.41485       2.89690       8.88158
  1997.00       0.56594       0.76143      -0.19549       8.22816
  1998.00       0.51927       0.73111      -0.21184       8.19784
  1999.00      -1.42628      -0.05818      -1.36810       7.40855
  2000.00       3.86737       1.44021       2.42717       8.90694
  2001.00       1.78685       0.23445       1.55239       7.70118
  2002.00      -0.07246       1.05046      -1.12293       8.51719

          Average squared residual :        3.45599

Herring Winter Catch Per Tow 1992-2002
Age :   3
Ln calibration constant :      -5.69701
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```
     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1992.00      2.58238       1.20825       1.37413       6.90526
   1993.00      2.78337       1.22817       1.55520       6.92518
   1994.00     -0.65220       0.83855      -1.49075       6.53556
   1995.00     -0.17459       0.87217      -1.04676       6.56918
   1996.00      1.88318       1.61525       0.26793       7.31226
   1997.00      1.94318       2.88493      -0.94175       8.58194
   1998.00      2.63313       2.23313       0.40000       7.93014
   1999.00      1.86821       2.08992      -0.22171       7.78693
   2000.00      1.37506       1.38695      -0.01190       7.08396
   2001.00      3.63799       2.94118       0.69682       8.63818
   2002.00      1.12168       1.70263      -0.58095       7.39964

          Average squared residual :        0.87418

Herring Winter Catch Per Tow 1992-2002
Age :   4
Ln calibration constant :      -5.23226

     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1992.00      2.10339       1.16805       0.93534       6.40030
   1993.00      2.83346       1.19627       1.63719       6.42852
   1994.00      0.14479       1.18818      -1.04339       6.42043
   1995.00     -0.01339       0.77424      -0.78763       6.00649
   1996.00      1.28143       0.90632       0.37512       6.13857
   1997.00      0.54412       1.75445      -1.21032       6.98670
   1998.00      3.34842       3.00873       0.33969       8.24099
   1999.00      2.12057       2.43829      -0.31772       7.67055
   2000.00      1.70613       2.15568      -0.44955       7.38793
   2001.00      1.51699       1.59984      -0.08285       6.83210
   2002.00      3.70873       3.10439       0.60434       8.33664

          Average squared residual :        0.69640

Herring Winter Catch Per Tow 1992-2002
Age :   5
Ln calibration constant :      -4.63957

     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1992.00      1.48115       1.21829       0.26286       5.85786
   1993.00      2.28075       1.37183       0.90892       6.01140
   1994.00      0.21777       1.39024      -1.17247       6.02981
   1995.00      1.58664       1.44126       0.14538       6.08083
   1996.00      1.41347       1.01081       0.40266       5.65038
   1997.00      1.94481       1.11404       0.83077       5.75361
   1998.00      1.86995       2.05192      -0.18196       6.69149
   1999.00      3.27617       3.30028      -0.02411       7.93985
   2000.00      1.66778       2.76320      -1.09542       7.40277
   2001.00      2.24697       2.45653      -0.20957       7.09610
   2002.00      2.05219       1.91904       0.13314       6.55861

          Average squared residual :        0.40351

Herring Winter Catch Per Tow 1992-2002
Age :   6
Ln calibration constant :      -4.31681

     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1992.00      0.30557       0.86622      -0.56065       5.18303
```

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  1993.00       1.75432       1.01769       0.73663       5.33450
  1994.00       0.00568       1.22232      -1.21664       5.53913
  1995.00       1.80601       1.25757       0.54844       5.57438
  1996.00       2.66041       1.46360       1.19681       5.78041
  1997.00       2.84019       0.77196       2.06824       5.08877
  1998.00       1.32538       1.04962       0.27576       5.36643
  1999.00       2.05183       2.08984      -0.03801       6.40665
  2000.00       1.13160       3.32938      -2.19779       7.64619
  2001.00       2.17839       2.77130      -0.59290       7.08811
  2002.00       2.26114       2.48080      -0.21966       6.79761

          Average squared residual :        1.24140

Herring Winter Catch Per Tow 1992-2002
Age :   7
Ln calibration constant :      -4.44716

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1992.00      -0.63111      -0.19656      -0.43455       4.25061
  1993.00      -0.34348       0.11349      -0.45697       4.56065
  1994.00      -1.32539       0.37465      -1.70004       4.82182
  1995.00       1.32800       0.52415       0.80385       4.97132
  1996.00       1.91990       0.50050       1.41940       4.94767
  1997.00       2.68247       0.27951       2.40296       4.72667
  1998.00       0.85484      -0.12403       0.97887       4.32314
  1999.00       1.42782       0.54508       0.88274       4.99224
  2000.00      -0.87443       1.59828      -2.47271       6.04545
  2001.00       1.85107       2.90114      -1.05007       7.34830
  2002.00       1.94139       2.31460      -0.37322       6.76177

          Average squared residual :        1.89241

Herring Winter Catch Per Tow 1992-2002
Age :   8
Ln calibration constant :      -4.62784

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1994.00      -2.16282      -0.77238      -1.39045       3.85546
  1995.00      -0.14018      -0.40569       0.26551       4.22215
  1996.00       0.29877      -1.01821       1.31698       3.60963
  1997.00       1.57557      -1.32635       2.90192       3.30149
  1998.00      -0.63469      -1.26314       0.62845       3.36470
  1999.00       0.53825      -1.12547       1.66371       3.50238
  2000.00      -2.48651      -0.14286      -2.34364       4.48498
  2001.00      -0.22979       1.09519      -1.32498       5.72303
  2002.00       0.70156       2.41892      -1.71736       7.04676

          Average squared residual :        2.83554

Spring survey index for 1968-2002
Age :   2
Ln calibration constant :      -7.23052

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1968.25       0.43224       0.94562      -0.51339       8.17614
  1969.25      -2.12863       0.29802      -2.42666       7.52854
  1970.25       1.34802       0.01331       1.33471       7.24383
  1971.25      -1.60594      -0.30741      -1.29854       6.92311
  1972.25      -0.75290       1.39013      -2.14302       8.62064
  1973.25      -2.70755      -0.55017      -2.15738       6.68035
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  1974.25      -3.65738      -0.85034      -2.80704       6.38018
  1975.25      -3.26492      -0.29508      -2.96984       6.93544
  1976.25      -3.13041      -0.95186      -2.17854       6.27866
  1977.25      -2.83191      -0.66274      -2.16917       6.56778
  1978.25      -2.10210       0.28103      -2.38313       7.51155
  1979.25       1.51119       0.04359       1.46760       7.27410
  1980.25      -2.17772      -1.89210      -0.28561       5.33842
  1981.25      -3.95284      -0.31104      -3.64181       6.91948
  1982.25      -0.90609      -0.64443      -0.26166       6.58609
  1983.25      -1.87797      -0.67039      -1.20758       6.56013
  1984.25       0.65856      -0.62622       1.28477       6.60430
  1985.25       0.66921       0.38815       0.28106       7.61867
  1986.25       0.52615      -0.45857       0.98471       6.77195
  1987.25       0.26236      -0.53464       0.79701       6.69588
  1988.25       1.17208      -0.12335       1.29543       7.10716
  1989.25       0.50555       0.00581       0.49974       7.23633
  1990.25       1.08900       0.08653       1.00247       7.31705
  1991.25       1.52194       0.08550       1.43644       7.31602
  1992.25       2.39804       0.13985       2.25819       7.37036
  1993.25       1.97977      -0.24097       2.22074       6.98955
  1994.25       1.46990      -0.19096       1.66086       7.03956
  1995.25       1.80232       0.41651       1.38581       7.64703
  1996.25       3.71144       1.57615       2.13529       8.80667
  1997.25       3.05772       0.92314       2.13458       8.15366
  1998.25       1.54281       0.86459       0.67821       8.09511
  1999.25       0.85586       0.09689       0.75898       7.32740
  2000.25       2.71540       1.60923       1.10617       8.83975
  2001.25       1.61195       0.39528       1.21668       7.62580
  2002.00       1.79083       1.28667       0.50415       8.51719

          Average squared residual :        2.96779

Spring survey index for 1968-2002
Age :   3
Ln calibration constant :      -6.12149

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1968.25       2.16341       1.34407       0.81934       7.46556
  1969.25       0.27960       1.45889      -1.17929       7.58038
  1970.25       0.38893       0.89438      -0.50545       7.01587
  1971.25      -0.79629       0.44375      -1.24004       6.56525
  1972.25      -0.05922       0.38411      -0.44333       6.50560
  1973.25       0.81868       2.04418      -1.22550       8.16567
  1974.25      -2.26240      -0.13442      -2.12798       5.98707
  1975.25      -2.34758      -0.80018      -1.54740       5.32131
  1976.25      -1.48678      -0.16140      -1.32537       5.96009
  1977.25      -2.12779      -1.22981      -0.89798       4.89168
  1978.25       0.69029      -0.72803       1.41833       5.39346
  1979.25      -0.99101       0.37351      -1.36453       6.49500
  1980.25       0.38069      -0.12330       0.50399       5.99819
  1981.25      -4.44817      -2.36758      -2.08059       3.75391
  1982.25      -2.96423      -0.74331      -2.22093       5.37818
  1983.25      -3.62684      -0.71832      -2.90852       5.40317
  1984.25      -0.89624      -0.18998      -0.70626       5.93151
  1985.25      -0.06219       0.02327      -0.08546       6.14476
  1986.25       3.30201       1.01506       2.28695       7.13655
  1987.25       0.75730       0.13909       0.61821       6.26058
  1988.25       1.37869       0.07878       1.29991       6.20027
  1989.25       0.50634       0.35559       0.15075       6.47708
  1990.25       0.86748       0.55344       0.31404       6.67493
  1991.25       1.91835       0.60788       1.31047       6.72937
  1992.25       2.77204       0.66459       2.10746       6.78608
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   1993.25      3.48725      0.67750      2.80975      6.79899
   1994.25      1.21929      0.28180      0.93750      6.40329
   1995.25      1.32731      0.34004      0.98728      6.46153
   1996.25      2.13773      1.10938      1.02835      7.23087
   1997.25      3.49814      2.37521      1.12293      8.49670
   1998.25      2.37396      1.74375      0.63020      7.86524
   1999.25      2.79401      1.56569      1.22832      7.68718
   2000.25      1.22926      0.89950      0.32976      7.02100
   2001.25      2.95561      2.44131      0.51430      8.56280
   2002.00      0.71920      1.27815     -0.55894      7.39964

           Average squared residual :        1.87527

 Spring survey index for 1968-2002
 Age :   4
 Ln calibration constant :      -5.48984

      Year      Observed     Predicted      Residual       Ln Pop.
   -------      --------     ---------      --------       -------
   1968.25      1.23689      1.56085     -0.32396      7.05069
   1969.25     -0.69917      1.59158     -2.29074      7.08142
   1970.25      0.03517      1.60372     -1.56855      7.09356
   1971.25     -0.68458      1.04554     -1.73013      6.53538
   1972.25     -0.74087      0.17784     -0.91871      5.66768
   1973.25      1.24008      0.50860      0.73148      5.99844
   1974.25      1.48978      2.03984     -0.55007      7.52968
   1975.25     -3.20153     -0.18957     -3.01196      5.30027
   1976.25     -2.87884     -1.06112     -1.81772      4.42872
   1977.25     -0.95581     -0.45870     -0.49711      5.03114
   1978.25     -1.10624     -1.51874      0.41250      3.97109
   1979.25      0.11288     -1.09875      1.21163      4.39109
   1980.25      1.31038     -0.03531      1.34569      5.45453
   1981.25     -0.67668     -0.75698      0.08029      4.73286
   1982.25     -3.04282     -2.84876     -0.19406      2.64108
   1983.25     -2.75514     -0.84361     -1.91153      4.64623
   1984.25     -1.19073     -0.59585     -0.59488      4.89399
   1985.25     -0.86488     -0.12868     -0.73620      5.36115
   1986.25      1.21346      0.26417      0.94929      5.75401
   1987.25      1.34315      1.23964      0.10351      6.72948
   1988.25      1.25105      0.30260      0.94845      5.79244
   1989.25      1.06063      0.22041      0.84022      5.71025
   1990.25      0.98065      0.51179      0.46887      6.00163
   1991.25      2.38922      0.69224      1.69698      6.18208
   1992.25      1.87254      0.81324      1.05930      6.30308
   1993.25      3.24299      0.83901      2.40399      6.32884
   1994.25      2.49386      0.84569      1.64816      6.33553
   1995.25      1.17350      0.42763      0.74588      5.91746
   1996.25      1.62109      0.55249      1.06860      6.04233
   1997.25      1.74082      1.42306      0.31776      6.91290
   1998.25      3.32402      2.67586      0.64816      8.16570
   1999.25      2.66614      2.11377      0.55237      7.60361
   2000.25      1.61466      1.82513     -0.21047      7.31497
   2001.25      0.64558      1.27389     -0.62830      6.76373
   2002.00      2.59829      2.84680     -0.24851      8.33664

           Average squared residual :        1.46897

 Spring survey index for 1968-2002
 Age :   5
 Ln calibration constant :      -5.35349

      Year      Observed     Predicted      Residual       Ln Pop.
   -------      --------     ---------      --------       -------
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  1968.25       1.27290       1.65592      -0.38302       7.00941
  1969.25       0.00419       1.25092      -1.24673       6.60441
  1970.25      -0.18284       1.24859      -1.43143       6.60208
  1971.25      -1.56590       1.00965      -2.57555       6.36314
  1972.25      -0.56651       0.23602      -0.80254       5.58951
  1973.25      -0.56352      -0.61064       0.04712       4.74285
  1974.25      -0.26971      -0.41191       0.14220       4.94158
  1975.25      -0.18284       1.40411      -1.58695       6.75760
  1976.25      -2.15675      -0.94137      -1.21539       4.41212
  1977.25      -2.00842      -1.82359      -0.18483       3.52990
  1978.25      -1.20065      -1.11935      -0.08129       4.23414
  1979.25      -0.21505      -2.24408       2.02903       3.10941
  1980.25      -0.37848      -2.10678       1.72829       3.24671
  1981.25       0.29617      -1.04963       1.34580       4.30386
  1982.25      -3.01798      -1.58586      -1.43212       3.76763
  1983.25      -4.72170      -3.38490      -1.33681       1.96860
  1984.25      -1.94771      -1.28542      -0.66229       4.06807
  1985.25      -0.73002      -1.01784       0.28782       4.33565
  1986.25       0.15649      -0.47405       0.63054       4.87944
  1987.25      -1.47666       0.01717      -1.49383       5.37067
  1988.25       1.19247       0.93120       0.26127       6.28469
  1989.25       0.68808      -0.03251       0.72059       5.32098
  1990.25       0.14885      -0.21303       0.36188       5.14046
  1991.25      -0.04239       0.19309      -0.23548       5.54658
  1992.25       0.71950       0.37353       0.34597       5.72702
  1993.25       1.74383       0.53984       1.20399       5.89333
  1994.25       2.39781       0.56246       1.83535       5.91595
  1995.25       2.45619       0.65224       1.80395       6.00573
  1996.25       1.03001       0.15649       0.87352       5.50998
  1997.25       0.98753       0.30332       0.68421       5.65681
  1998.25       1.77132       1.26679       0.50453       6.62028
  1999.25       3.75573       2.51294       1.24279       7.86643
  2000.25       1.60404       1.97062      -0.36657       7.32411
  2001.25       0.98440       1.66799      -0.68359       7.02148
  2002.00       0.87489       1.20512      -0.33024       6.55861

          Average squared residual :        1.24849

Spring survey index for 1968-2002
Age :   6
Ln calibration constant :       -5.49268

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1968.25       1.05994       1.07408      -0.01413       6.56675
  1969.25       0.55555       0.84308      -0.28753       6.33576
  1970.25      -0.60148       0.44039      -1.04187       5.93307
  1971.25      -1.50238       0.36520      -1.86758       5.85788
  1972.25      -1.14917      -0.20979      -0.93938       5.28289
  1973.25       0.14254      -1.30000       1.44254       4.19268
  1974.25      -1.66919      -1.69132       0.02214       3.80135
  1975.25      -2.50226      -1.55364      -0.94861       3.93903
  1976.25      -1.16059       0.17359      -1.33419       5.66627
  1977.25      -2.63946      -1.99591      -0.64355       3.49677
  1978.25      -3.07046      -2.85474      -0.21572       2.63794
  1979.25      -1.42047      -2.23134       0.81087       3.26134
  1980.25      -2.48891      -3.54105       1.05214       1.95163
  1981.25      -1.66284      -3.46082       1.79798       2.03186
  1982.25      -3.20893      -2.19554      -1.01338       3.29713
  1983.25      -2.92062      -2.69628      -0.22435       2.79640
  1984.25      -4.34281      -4.01161      -0.33119       1.48107
  1985.25      -2.23213      -2.20860      -0.02352       3.28407
  1986.25      -0.58322      -1.77742       1.19420       3.71526
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  1987.25      -1.95829      -1.12225      -0.83603       4.37042
  1988.25      -1.15964      -0.56551      -0.59413       4.92717
  1989.25       0.31693       0.21169       0.10523       5.70437
  1990.25      -1.85790      -0.83626      -1.02164       4.65642
  1991.25      -1.20131      -0.82596      -0.37535       4.66672
  1992.25      -0.55026      -0.46524      -0.08502       5.02744
  1993.25      -0.09003      -0.28635       0.19632       5.20633
  1994.25       1.19547      -0.09550       1.29097       5.39718
  1995.25       1.04289      -0.07498       1.11787       5.41770
  1996.25       1.50049       0.02430       1.47620       5.51698
  1997.25       0.88311      -0.59532       1.47843       4.89736
  1998.25       0.45938      -0.21980       0.67918       5.27288
  1999.25       1.95487       0.82367       1.13120       6.31635
  2000.25       1.30144       2.07904      -0.77760       7.57172
  2001.25       1.05372       1.51384      -0.46012       7.00652
  2002.00       0.54482       1.30493      -0.76011       6.79761

          Average squared residual :        0.88803

Spring survey index for 1968-2002
Age :   7
Ln calibration constant :      -5.59016

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1968.25       1.50488       1.11296       0.39192       6.70312
  1969.25       1.40118       0.26139       1.13980       5.85155
  1970.25      -0.83425      -0.10876      -0.72549       5.48140
  1971.25      -1.92964      -0.46538      -1.46426       5.12478
  1972.25      -3.72140      -0.92703      -2.79438       4.66314
  1973.25      -0.55513      -1.86758       1.31245       3.72259
  1974.25      -2.71507      -2.37356      -0.34152       3.21660
  1975.25      -3.14656      -2.64854      -0.49802       2.94163
  1976.25      -1.48017      -2.97427       1.49410       2.61589
  1977.25      -1.47011      -0.94450      -0.52561       4.64566
  1978.25      -2.97397      -2.98494       0.01096       2.60523
  1979.25      -2.09557      -3.95508       1.85951       1.63509
  1980.25      -2.24526      -3.45677       1.21151       2.13339
  1981.25      -2.81175      -4.90250       2.09075       0.68766
  1982.25      -4.64599      -4.60616      -0.03983       0.98400
  1983.25      -2.38380      -3.43981       1.05601       2.15036
  1984.25      -4.03419      -3.50654      -0.52765       2.08362
  1985.25      -3.85375      -4.92663       1.07287       0.66354
  1986.25      -0.88455      -3.17320       2.28865       2.41696
  1988.25      -4.32754      -1.66350      -2.66404       3.92666
  1989.25      -2.04253      -1.17621      -0.86632       4.41395
  1990.25      -6.26590      -0.86561      -5.40029       4.72455
  1991.25      -2.85077      -1.61974      -1.23103       3.97042
  1992.25      -1.66866      -1.52438      -0.14427       4.06578
  1993.25      -2.72114      -1.20580      -1.51533       4.38436
  1994.25      -0.66359      -0.91826       0.25467       4.67190
  1995.25      -0.65105      -0.95926       0.30822       4.63090
  1996.25       0.92287      -1.05404       1.97691       4.53612
  1997.25       0.34889      -1.20398       1.55288       4.38618
  1998.25      -0.18392      -1.47222       1.28829       4.11795
  1999.25       1.07045      -0.72474       1.79519       4.86542
  2000.25      -0.22540       0.37468      -0.60008       5.96484
  2001.25       0.93232       1.68276      -0.75044       7.27292
  2002.00       0.15572       1.17161      -1.01589       6.76177

          Average squared residual :        2.58143

Spring survey index for 1968-2002
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Age :   8
Ln calibration constant :      -6.23005

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1968.25       0.30025       0.07704       0.22321       6.30709
  1969.25       0.56406      -0.44926       1.01333       5.78079
  1970.25      -3.11903      -1.33012      -1.78891       4.89993
  1971.25      -2.98578      -1.65017      -1.33562       4.57989
  1972.25      -3.79869      -2.63102      -1.16768       3.59903
  1973.25      -2.11362      -3.39542       1.28181       2.83463
  1974.25      -3.21638      -3.68721       0.47083       2.54284
  1975.25      -4.54690      -3.79059      -0.75631       2.43946
  1976.25      -3.82585      -4.59280       0.76696       1.63725
  1977.25      -4.24750      -4.70908       0.46159       1.52097
  1978.25      -1.65078      -2.43338       0.78260       3.79667
  1979.25      -1.76902      -4.71486       2.94584       1.51519
  1980.25      -4.97623      -6.35891       1.38267      -0.12886
  1981.25      -3.51661      -5.42347       1.90687       0.80658
  1982.25      -6.81245      -6.55563      -0.25681      -0.32558
  1983.25      -6.90776      -6.33387      -0.57389      -0.10382
  1984.25      -4.84089      -5.32799       0.48710       0.90206
  1985.25      -3.74651      -5.06493       1.31842       1.16512
  1988.25      -9.21034      -3.58733      -5.62301       2.64272
  1992.25      -5.62682      -3.06423      -2.56259       3.16582
  1993.25      -7.13090      -2.97821      -4.15269       3.25184
  1994.25      -3.17486      -2.57257      -0.60229       3.65748
  1995.25      -4.32754      -2.58820      -1.73934       3.64185
  1996.25      -0.44863      -3.11209       2.66346       3.11796
  1997.25      -1.06334      -3.26412       2.20077       2.96594
  1998.25      -1.74698      -3.14818       1.40121       3.08187
  1999.25      -0.10148      -3.03291       2.93144       3.19714
  2000.25      -1.65810      -1.84800       0.18990       4.38205
  2001.25      -0.66787      -0.58241      -0.08546       5.64764
  2002.00      -0.96653       0.81671      -1.78324       7.04676

          Average squared residual :        3.74689

Work file G:\Mike\5zdir\VPA\NoPlusFinalRuns\USA_1968-2002noplus10avg9.aw3 saved
```

Appendix III Final ADAPT Run.

```
THURSDAY, FEBRUARY 13, 2003  9:07:24.940 PM

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APL  Ver. 4.0.03

ADAPT_W  Ver. 3.0

Workspace size = 16000000

Complex Total CAA Numbers x 10^6
               1       2       3       4       5       6       7       8       9      10
 1967.00     137     424     229     209     131     270     389      50      12      10
 1968.00      15    1392     277     181     397     267     465     356      25       9
 1969.00      71     582     398     234     301     310     217     215     130      29
 1970.00       6     494     190     493     296     152     128      79      51      32
 1971.00     155     233     410     328     333     222     136      69      26      30
 1972.00       8    1001      65     165     262     209     126      56      32      24
 1973.00      37     351    1301     294      77      47      36      20       5       6
 1974.00      35     429     147     750      79      18       9       6       3       0
 1975.00      45     646     118     112     610      46      17       9       6       1
 1976.00      75     531     249      47      49     209      10       3       3       1
 1977.00     597     579      83      71      21      18      50       3       1       0
 1978.00     270    1222     138      26      43       6       8      32       1       1
 1979.00       7    1174     423      58      16      17       6       5       7       0
 1980.00     343     230     363     185      22       6       8       1       1       4
 1981.00      62    1169      34      68      47       5       1       1       0       0
 1982.00      53     669     110       7      30      19       2       0       1       0
 1983.00      33     267      59      29       1       7       7       0       0       0
 1984.00      19     185     133      40      28       2       4       2       1       0
 1985.00      30     563      84      51      27      14       1       2       1       0
 1986.00      41     247     225      49      38      16       8       0       0       0
 1987.00      51     224     135     181      45      18       6       2       0       0
 1988.00      79     502     111      62     127      35       9       2       1       0
 1989.00      27     460     166     108      81     181      29       8       2       0
 1990.00      13     571     221      89      38      43      82      29      15       4
 1991.00       6     462     180     102      65      33      23      21      10       3
 1992.00       1     547     220      94      88      56      27      17      14       4
 1993.00       2     384     244     101      89      51      35      17       6       2
 1994.00       2     423     176      73      85      71      37      19       6       2
 1995.00      59     465     134      53      38      84      92      56      17       3
 1996.00       6     620     161      71      79     171     100      29       6       2
 1997.00      11     317     637      89      49      64      72      17       3       0
 1998.00       0     628     146     331      59      31      32      16       6       2
 1999.00       5     176     395     128     228      82      35      20       5       0
 2000.00       4     445      55     129     161     177      44      15       3       1
 2001.00       1     194     495      60     103     129     136      27       5       0
 2002.00      44     252     115     260      85      70      72      34       3       0
 2003.00

1-US fall 1967-1984
               2       3       4       5       6       7       8
 1967.83    0.07    0.13    0.36    0.19    0.59    0.40    0.01
 1968.83    0.02    0.06    0.06    0.05    0.37    0.11    0.00
 1969.83    0.02    0.04    0.06    0.04    0.06    0.10    0.00
 1970.83    0.03    0.03    0.07    0.06    0.11    0.01    0.00
 1971.83    0.02    0.31    0.26    0.58    0.34    0.02    0.00
 1972.83    0.13    0.06    0.08    0.06    0.06    0.05    0.02
 1973.83    0.00    0.04    0.00    0.00    0.00    0.00    0.00
 1974.83    0.00    0.00    0.06    0.01    0.01    0.00    0.01
```

```
 1975.83    0.01    0.00    0.02    0.10    0.05    0.03    0.03
 1976.83    0.00    0.00    0.01    0.01    0.07    0.01    0.00
 1977.83    0.01    0.00    0.01    0.00    0.00    0.01    0.00
 1978.83    0.01    0.06    0.08    0.16    0.01    0.02    0.08
 1979.83    0.01    0.02    0.00    0.00    0.00    0.00    0.00
 1980.83    0.00    0.01    0.00    0.00    0.00    0.00    0.00
 1981.83    0.00    0.00    0.00    0.00    0.00    0.00    0.00
 1982.83    0.00    0.01    0.01    0.03    0.02    0.00    0.00
 1983.83    0.04    0.04    0.02    0.00    0.01    0.02    0.00
 1984.83    0.01    0.12    0.15    0.15    0.05    0.21    0.17

2-US fall 1985-2002
               2       3       4       5       6       7       8
 1985.83    0.03    0.05    0.99    0.31    0.32    0.05    0.16
 1986.83    0.02    0.43    0.23    0.19    0.06    0.00    0.00
 1987.83    2.02    3.83    3.01    0.39    0.22    0.03    0.01
 1988.83    1.02    3.56    4.54    1.77    0.19    0.06    0.00
 1989.83    1.40    4.32    4.02    2.01    2.11    0.25    0.09
 1990.83    2.60    8.92    1.90    0.42    0.09    0.05    0.00
 1991.83    2.70   11.55    5.44    0.86    0.17    0.02    0.00
 1992.83    2.24   25.44   16.56    9.99    1.78    0.45    0.00
 1993.83    0.35    1.80    6.79    6.09    1.47    0.29    0.01
 1994.83    0.63    1.03    4.11    3.63    2.97    0.89    0.23
 1995.83    0.58    7.80    8.81   23.60   20.96    7.17    0.75
 1996.83   10.81    6.72    6.75    2.83    6.27    3.21    0.80
 1997.83    1.82   17.38    4.65    4.16    4.30    3.61    0.65
 1998.83    1.60    2.84    8.36    2.82    2.10    2.02    0.60
 1999.83    0.22    2.86    2.81    5.22    1.20    0.81    0.31
 2000.83    1.10    1.01    4.19    6.79    5.18    1.69    0.64
 2001.83    0.30    8.50    1.61    2.57    4.56    5.02    1.25
 2002.83    2.45    6.19   37.45    9.80   10.00    7.54    3.32

3-US Spring 1968-1984
               2       3       4       5       6       7       8
 1968.25    1.54    8.70    3.44    3.57    2.89    4.50    1.35
 1969.25    0.12    1.32    0.50    1.00    1.74    4.06    1.76
 1970.25    3.85    1.48    1.04    0.83    0.55    0.43    0.04
 1971.25    0.20    0.45    0.50    0.21    0.22    0.15    0.05
 1972.25    0.47    0.94    0.48    0.57    0.32    0.02    0.02
 1973.25    0.07    2.27    3.46    0.57    1.15    0.57    0.12
 1974.25    0.03    0.10    4.44    0.76    0.19    0.07    0.04
 1975.25    0.04    0.10    0.04    0.83    0.08    0.04    0.01
 1976.25    0.04    0.23    0.06    0.12    0.31    0.23    0.02
 1977.25    0.06    0.12    0.38    0.13    0.07    0.23    0.01
 1978.25    0.12    1.99    0.33    0.30    0.05    0.05    0.19
 1979.25    4.53    0.37    1.12    0.81    0.24    0.12    0.17
 1980.25    0.11    1.46    3.71    0.68    0.08    0.11    0.01
 1981.25    0.02    0.01    0.51    1.34    0.19    0.06    0.03
 1982.25    0.40    0.05    0.05    0.05    0.04    0.01    0.00
 1983.25    0.15    0.03    0.06    0.01    0.05    0.09    0.00
 1984.25    1.93    0.41    0.30    0.14    0.01    0.02    0.01

4-US Spring 1985-2002
               2       3       4       5       6       7       8
 1985.25    1.95    0.94    0.42    0.48    0.11    0.02    0.02
 1986.25    1.69   27.17    3.37    1.17    0.56    0.41    0.00
 1987.25    1.30    2.13    3.83    0.23    0.14    0.00    0.00
 1988.25    3.23    3.97    3.49    3.30    0.31    0.01    0.00
 1989.25    1.66    1.66    2.89    1.99    1.37    0.13    0.00
 1990.25    2.97    2.38    2.67    1.16    0.16    0.00    0.00
 1991.25    4.58    6.81   10.91    0.96    0.30    0.06    0.00
 1992.25   11.00   15.99    6.50    2.05    0.58    0.19    0.00
 1993.25    7.24   32.70   25.61    5.72    0.91    0.07    0.00
```

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 1994.25    4.35    3.38   12.11   11.00    3.31    0.52    0.04
 1995.25    6.06    3.77    3.23   11.66    2.84    0.52    0.01
 1996.25   40.91    8.48    5.06    2.80    4.48    2.52    0.64
 1997.25   21.28   33.05    5.70    2.68    2.42    1.42    0.35
 1998.25    4.68   10.74   27.77    5.88    1.58    0.83    0.17
 1999.25    2.35   16.35   14.38   42.77    7.06    2.92    0.90
 2000.25   15.11    3.42    5.03    4.97    3.67    0.80    0.19
 2001.25    5.01   19.21    1.91    2.68    2.87    2.54    0.51
 2002.25    5.99    2.05   13.44    2.40    1.72    1.17    0.38

5-US Winter 1992-2002
               2       3       4       5       6       7       8
 1992.00    7.70   13.23    8.19    4.40    1.36    0.53    0.00
 1993.00    0.32   16.17   17.00    9.78    5.78    0.71    0.00
 1994.00    0.08    0.52    1.16    1.24    1.01    0.27    0.12
 1995.00    0.07    0.84    0.99    4.89    6.09    3.77    0.87
 1996.00   74.57    6.57    3.60    4.11   14.30    6.82    1.35
 1997.00    1.76    6.98    1.72    6.99   17.12   14.62    4.83
 1998.00    1.68   13.92   28.46    6.49    3.76    2.35    0.53
 1999.00    0.24    6.48    8.34   26.47    7.78    4.17    1.71
 2000.00   47.82    3.96    5.51    5.30    3.10    0.42    0.08
 2001.00    5.97   38.02    4.56    9.46    8.83    6.37    0.79
 2002.00    0.93    3.07   40.80    7.78    9.59    6.97    2.02

6a-US larval 1971-1988 (weighted mean)
               3       4       5       6       7       8       9      10
 1971.83   89.70
 1972.83   81.40
 1973.83  355.20
 1974.83  304.50
 1975.83   55.90
 1976.83    2.20
 1977.83   19.20
 1978.83    2.40
 1979.83    6.00
 1980.83    1.90
 1981.83   29.70
 1982.83   18.20
 1983.83    3.70
 1984.83    2.30
 1985.83   95.40
 1986.83   60.40
 1987.83   31.40
 1988.83  184.90

Fishery Midyr Wts at age
               3       4       5       6       7       8       9      10
 1971.83    0.12    0.18    0.23    0.33    0.29    0.29    0.33    0.33
 1972.83    0.12    0.19    0.23    0.27    0.31    0.36    0.27    0.29
 1973.83    0.11    0.17    0.23    0.26    0.29    0.33    0.34    0.26
 1974.83    0.11    0.17    0.20    0.23    0.25    0.27    0.29    0.29
 1975.83    0.10    0.17    0.19    0.23    0.27    0.27    0.30    0.29
 1976.83    0.11    0.18    0.21    0.21    0.26    0.28    0.32    0.33
 1977.83    0.10    0.16    0.19    0.22    0.23    0.26    0.30    0.29
 1978.83    0.12    0.19    0.23    0.26    0.27    0.28    0.32    0.35
 1979.83    0.09    0.20    0.26    0.28    0.18    0.33    0.33    0.31
 1980.83    0.10    0.17    0.27    0.32    0.34    0.24    0.31    0.39
 1981.83    0.11    0.19    0.23    0.29    0.32    0.34    0.47    0.30
 1982.83    0.13    0.19    0.25    0.27    0.30    0.32    0.34    0.42
 1983.83    0.14    0.22    0.22    0.31    0.35    0.37    0.39    0.40
 1984.83    0.13    0.18    0.23    0.26    0.31    0.34    0.31    0.40
 1985.83    0.14    0.18    0.20    0.23    0.28    0.27    0.29    0.29
 1986.83    0.12    0.17    0.22    0.23    0.25    0.26    0.30    0.29
```

```
 1987.83    0.09    0.14    0.18    0.22    0.23    0.23    0.25    0.27
 1988.83    0.09    0.13    0.16    0.19    0.23    0.24    0.25    0.29


6b-US larval 1971-1988 (weighted mean)
               3       4       5       6       7       8       9      10
 1989.83  454.30
 1990.83  394.10
 1991.83  354.20
 1992.83  577.10
 1993.83  397.60
 1994.83  610.00

Fishery Midyr Wts at age
               3       4       5       6       7       8       9      10
 1989.83    0.10    0.14    0.17    0.20    0.24    0.25    0.24    0.31
 1990.83    0.10    0.15    0.18    0.19    0.21    0.23    0.24    0.26
 1991.83    0.09    0.13    0.17    0.19    0.21    0.23    0.23    0.24
 1992.83    0.09    0.13    0.15    0.18    0.20    0.22    0.23    0.26
 1993.83    0.10    0.13    0.16    0.18    0.21    0.24    0.26    0.28
 1994.83    0.09    0.12    0.14    0.16    0.18    0.21    0.24    0.26

7-CAN larval 1987-1995 mean
               3       4       5       6       7       8       9      10
 1987.83   22.00
 1988.83    6.50
 1989.83    7.40
 1990.83   10.20
 1991.83    3.30
 1992.83   12.60
 1993.83   30.80
 1994.83   52.90
 1995.83   47.30

Fishery Midyr Wts at age
               3       4       5       6       7       8       9      10
 1987.83    0.09    0.14    0.18    0.22    0.23    0.23    0.25    0.27
 1988.83    0.09    0.13    0.16    0.19    0.23    0.24    0.25    0.29
 1989.83    0.10    0.14    0.17    0.20    0.24    0.25    0.24    0.31
 1990.83    0.10    0.15    0.18    0.19    0.21    0.23    0.24    0.26
 1991.83    0.09    0.13    0.17    0.19    0.21    0.23    0.23    0.24
 1992.83    0.09    0.13    0.15    0.18    0.20    0.22    0.23    0.26
 1993.83    0.10    0.13    0.16    0.18    0.21    0.24    0.26    0.28
 1994.83    0.09    0.12    0.14    0.16    0.18    0.21    0.24    0.26
 1995.83    0.10    0.12    0.14    0.16    0.17    0.19    0.22    0.26

8-US acoustic 1999-2002
               3       4       5       6       7       8       9      10
 1999.83********
 2000.83********
 2001.83********
 2002.83********

Fishery Midyr Wts at age
               3       4       5       6       7       8       9      10
 1999.83    0.08    0.11    0.14    0.16    0.18    0.20    0.29    0.30
 2000.83    0.11    0.13    0.16    0.17    0.20    0.21    0.29    0.30
 2001.83    0.10    0.13    0.15    0.17    0.19    0.21    0.29    0.30
 2002.83    0.09    0.13    0.15    0.17    0.18    0.20    0.22    0.21

9-CAN spring BT 86-92,95-02
               2       3       4       5       6       7       8
 1986.12    1.82    9.68    0.38    0.42    0.00    0.00    0.00
```

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 1987.12    0.81    0.09    0.04    0.00    0.00    0.00    0.00
 1988.12    0.40    0.23    0.45    1.44    0.61    0.48    0.03
 1989.12   67.94    3.98    0.32    0.13    0.06    0.00    0.00
 1990.12   36.12    1.80    0.21    0.06    0.00    0.00    0.00
 1991.12   39.35   50.30   25.36    1.86    0.63    0.09    0.00
 1992.12    8.79   14.50   11.64    8.75    3.45    1.24    0.03
 1995.12    1.74   38.59    1.52    4.34    1.51    0.36    0.01
 1996.12   32.01    3.71    2.62    3.13    4.72    2.13    0.30
 1997.12   21.48  168.13   16.18   19.29   27.54   21.46    9.75
 1998.12    1.47    6.38   11.31    4.03    2.22    1.36    0.36
 1999.12    0.60   16.23   25.88  110.93   62.08   37.12   18.83
 2000.12  467.14   29.91   11.11    8.37    4.84    0.92    0.32
 2001.12    2.04  203.91   33.50   56.65   44.04   30.34    4.96
 2002.12    0.02    3.34   12.85    1.85    2.05    1.32    0.46

Index Type and Model Form
ID# | Label                              |  Age Group(s)  |Index Type| Model Form
 1 1-US fall 1967-1984                                   2  Abundance Proportional
 2 1-US fall 1967-1984                                   3  Abundance Proportional
 3 1-US fall 1967-1984                                   4  Abundance Proportional
 4 1-US fall 1967-1984                                   5  Abundance Proportional
 5 1-US fall 1967-1984                                   6  Abundance Proportional
 6 1-US fall 1967-1984                                   7  Abundance Proportional
 7 1-US fall 1967-1984                                   8  Abundance Proportional
 8 2-US fall 1985-2002                                   2  Abundance Proportional
 9 2-US fall 1985-2002                                   3  Abundance Proportional
10 2-US fall 1985-2002                                   4  Abundance Proportional
11 2-US fall 1985-2002                                   5  Abundance Proportional
12 2-US fall 1985-2002                                   6  Abundance Proportional
13 2-US fall 1985-2002                                   7  Abundance Proportional
14 2-US fall 1985-2002                                   8  Abundance Proportional
15 3-US Spring 1968-1984                                 2  Abundance Proportional
16 3-US Spring 1968-1984                                 3  Abundance Proportional
17 3-US Spring 1968-1984                                 4  Abundance Proportional
18 3-US Spring 1968-1984                                 5  Abundance Proportional
19 3-US Spring 1968-1984                                 6  Abundance Proportional
20 3-US Spring 1968-1984                                 7  Abundance Proportional
21 3-US Spring 1968-1984                                 8  Abundance Proportional
22 4-US Spring 1985-2002                                 2  Abundance Proportional
23 4-US Spring 1985-2002                                 3  Abundance Proportional
24 4-US Spring 1985-2002                                 4  Abundance Proportional
25 4-US Spring 1985-2002                                 5  Abundance Proportional
26 4-US Spring 1985-2002                                 6  Abundance Proportional
27 4-US Spring 1985-2002                                 7  Abundance Proportional
28 4-US Spring 1985-2002                                 8  Abundance Proportional
29 5-US Winter 1992-2002                                 2  Abundance Proportional
30 5-US Winter 1992-2002                                 3  Abundance Proportional
31 5-US Winter 1992-2002                                 4  Abundance Proportional
32 5-US Winter 1992-2002                                 5  Abundance Proportional
33 5-US Winter 1992-2002                                 6  Abundance Proportional
34 5-US Winter 1992-2002                                 7  Abundance Proportional
35 5-US Winter 1992-2002                                 8  Abundance Proportional
36 6a-US larval 1971-1988 (weighted mean) 3 4 5 6 7 8 9 10  Biomass   Proportional
37 6b-US larval 1971-1988 (weighted mean) 3 4 5 6 7 8 9 10  Biomass   Proportional
38 7-CAN larval 1987-1995 mean            3 4 5 6 7 8 9 10  Biomass   Proportional
39 8-US acoustic 1999-2002                3 4 5 6 7 8 9 10  Biomass   Proportional
40 9-CAN spring BT 86-92,95-02                           2  Abundance Proportional
41 9-CAN spring BT 86-92,95-02                           3  Abundance Proportional
42 9-CAN spring BT 86-92,95-02                           4  Abundance Proportional
43 9-CAN spring BT 86-92,95-02                           5  Abundance Proportional
44 9-CAN spring BT 86-92,95-02                           6  Abundance Proportional
45 9-CAN spring BT 86-92,95-02                           7  Abundance Proportional
46 9-CAN spring BT 86-92,95-02                           8  Abundance Proportional
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Index Inclusion
ID# on same line have common catchability
 1
 2
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Index Intrinsic Weighting
ID# on same line have common weighting
 1
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VPA setup

Plus Group : No plus group

Population
             1       2       3       4       5       6       7       8       9      10
 2002.00  (2000)
 2003.00  (2000)            4000    3000    2000    1000    1000
F ratios
             1       2       3       4       5       6       7       8       9      10
 1967.00                                                    1.00    1.00    1.00  **wtd**
 1968.00                                                    1.00    1.00    1.00  **wtd**
 1969.00                                                    1.00    1.00    1.00  **wtd**
 1970.00                                                    1.00    1.00    1.00  **wtd**
 1971.00                                                    1.00    1.00    1.00  **wtd**
 1972.00                                                    1.00    1.00    1.00  **wtd**
 1973.00                                                    1.00    1.00    1.00  **wtd**
 1974.00                                                    1.00    1.00    1.00  **wtd**
 1975.00                                                    1.00    1.00    1.00  **wtd**
 1976.00                                                    1.00    1.00    1.00  **wtd**
 1977.00                                                    1.00    1.00    1.00  **wtd**
 1978.00                                                    1.00    1.00    1.00  **wtd**
 1979.00                                                    1.00    1.00    1.00  **wtd**
 1980.00                                                    1.00    1.00    1.00  **wtd**
 1981.00                                                    1.00    1.00    1.00  **wtd**
 1982.00                                                    1.00    1.00    1.00  **wtd**
 1983.00                                                    1.00    1.00    1.00  **wtd**
```

```
 1984.00                                                          1.00     1.00     1.00   **wtd**
 1985.00                                                          1.00     1.00     1.00   **wtd**
 1986.00                                                          1.00     1.00     1.00   **wtd**
 1987.00                                                          1.00     1.00     1.00   **wtd**
 1988.00                                                          1.00     1.00     1.00   **wtd**
 1989.00                                                          1.00     1.00     1.00   **wtd**
 1990.00                                                          1.00     1.00     1.00   **wtd**
 1991.00                                                          1.00     1.00     1.00   **wtd**
 1992.00                                                          1.00     1.00     1.00   **wtd**
 1993.00                                                          1.00     1.00     1.00   **wtd**
 1994.00                                                          1.00     1.00     1.00   **wtd**
 1995.00                                                          1.00     1.00     1.00   **wtd**
 1996.00                                                          1.00     1.00     1.00   **wtd**
 1997.00                                                          1.00     1.00     1.00   **wtd**
 1998.00                                                          1.00     1.00     1.00   **wtd**
 1999.00                                                          1.00     1.00     1.00   **wtd**
 2000.00                                                          1.00     1.00     1.00   **wtd**
 2001.00                                                          1.00     1.00     1.00   **wtd**
 2002.00                               1.00     1.00     1.00   **wtd**
 2002.00                               1.00     1.00     1.00            **wtd**
 2002.00                               1.00     1.00     1.00                     **wtd**
 2002.00                                                          1.00     1.00     1.00   **wtd**

Natural Mortality
              1        2        3        4        5        6        7        8        9       10
 1967.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1968.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1969.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1970.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1971.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1972.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1973.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1974.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1975.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1976.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1977.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1978.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1979.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1980.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1981.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1982.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1983.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1984.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1985.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1986.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1987.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1988.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1989.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1990.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1991.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1992.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1993.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1994.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1995.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1996.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1997.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1998.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 1999.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 2000.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 2001.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)
 2002.00   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)   (0.20)

Virtual Population Analysis using initial values
```

```
Population Numbers
                1        2        3        4        5        6        7        8        9       10
 1967.00     5263     2809     1800     1810     1159     1489     1245      171       35       33
 1968.00     2624     4185     1918     1268     1294      831      976      670       95       19
 1969.00     2065     2135     2178     1321      875      703      441      384      232       55
 1970.00     1394     1627     1225     1426      870      447      299      168      123       74
 1971.00     7634     1136      888      832      725      447      230      130       67       55
 1972.00     1171     6110      720      361      388      296      168       68       45       31
 1973.00      993      951     4101      531      148       86       58       27        7        8
 1974.00     1638      779      464     2191      173       52       28       15        5        1
 1975.00     1004     1310      256      248     1121       72       26       15        7        1
 1976.00     1269      782      496      105      103      374       18        6        4        1
 1977.00     3544      971      170      184       43       40      121        5        2        1
 1978.00     2704     2364      280       65       88       17       17       54        2        1
 1979.00      399     1971      846      106       30       33        8        6       16        1
 1980.00     2308      321      571      316       36       10       12        1        1        7
 1981.00     1336     1581       60      145       94       10        3        3        0        0
 1982.00     1085     1038      264       18       58       35        4        1        1        0
 1983.00     1069      841      256      118        9       21       12        1        1        0
 1984.00     2855      846      448      157       71        6       11        3        1        0
 1985.00     1259     2321      526      248       92       32        3        5        1        0
 1986.00     1171     1004     1394      355      157       51       14        2        2        0
 1987.00     1827      922      600      939      247       94       27        5        1        1
 1988.00     2047     1450      554      370      606      162       61       17        2        1
 1989.00     2193     1604      737      354      247      382      101       41       12        1
 1990.00     2120     1771      900      454      192      129      152       56       26        8
 1991.00     2253     1724      938      539      291      123       67       51       21        8
 1992.00     1522     1839      997      606      350      180       71       34       22        8
 1993.00     1393     1246     1015      619      411      207       97       34       13        6
 1994.00     1954     1139      675      612      415      257      124       48       13        6
 1995.00     5948     1598      553      395      436      263      146       68       22        5
 1996.00     4764     4817      891      333      275      323      141       39        7        3
 1997.00     5545     3896     3385      585      209      155      112       27        6        0
 1998.00     3373     4530     2903     2198      399      127       69       28        7        3
 1999.00     6389     2761     3143     2245     1501      273       76       28        9        1
 2000.00     5921     5227     2102     2217     1723     1024      150       30        6        3
 2001.00     6308     4844     3878     1672     1699     1265      679       83       11        2
 2002.00     2000     5163     3791     2729     1315     1298      920      433       44        5
 2003.00     2000     1598     4000     3000     2000     1000     1000      688      324       33

Fishing Mortality
                1        2        3        4        5        6        7        8        9       10
 1967.00    0.029    0.182    0.151    0.136    0.132    0.223    0.419    0.389    0.442    0.416
 1968.00    0.007    0.453    0.173    0.170    0.410    0.434    0.732    0.863    0.344    0.761
 1969.00    0.039    0.355    0.224    0.217    0.472    0.655    0.767    0.938    0.941    0.867
 1970.00    0.005    0.405    0.187    0.476    0.466    0.465    0.631    0.723    0.598    0.650
 1971.00    0.023    0.256    0.701    0.564    0.695    0.777    1.025    0.866    0.567    0.905
 1972.00    0.008    0.199    0.104    0.692    1.307    1.437    1.639    2.106    1.488    1.728
 1973.00    0.042    0.517    0.427    0.920    0.835    0.913    1.138    1.554    1.502    1.287
 1974.00    0.024    0.913    0.426    0.470    0.684    0.485    0.436    0.518    1.270    0.542
 1975.00    0.051    0.770    0.696    0.678    0.897    1.205    1.245    1.141    1.672    1.278
 1976.00    0.068    1.325    0.792    0.681    0.737    0.932    1.028    0.878    1.224    1.022
 1977.00    0.205    1.042    0.763    0.543    0.748    0.689    0.597    0.813    0.424    0.603
 1978.00    0.116    0.827    0.771    0.578    0.762    0.515    0.780    1.027    1.019    0.970
 1979.00    0.018    1.040    0.785    0.895    0.882    0.811    1.632    1.522    0.663    1.101
 1980.00    0.179    1.479    1.168    1.010    1.091    1.081    1.302    1.201    1.083    1.277
 1981.00    0.052    1.589    0.976    0.716    0.781    0.781    0.751    0.660    0.271    0.682
 1982.00    0.055    1.198    0.607    0.508    0.837    0.901    1.037    0.550    1.469    1.031
 1983.00    0.034    0.429    0.292    0.313    0.164    0.434    1.135    0.416    0.520    1.054
 1984.00    0.007    0.275    0.394    0.332    0.582    0.463    0.566    0.928    3.105    0.743
 1985.00    0.027    0.310    0.194    0.257    0.390    0.613    0.505    0.720    1.493    0.728
 1986.00    0.039    0.315    0.196    0.163    0.309    0.428    0.881    0.282    0.287    0.760
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 1987.00   0.031   0.310   0.284   0.237   0.223   0.242   0.260   0.749   0.264   0.332
 1988.00   0.044   0.477   0.249   0.204   0.261   0.270   0.181   0.150   0.978   0.193
 1989.00   0.014   0.378   0.284   0.408   0.448   0.724   0.382   0.252   0.223   0.335
 1990.00   0.007   0.436   0.313   0.244   0.245   0.456   0.894   0.800   0.934   0.876
 1991.00   0.003   0.348   0.237   0.232   0.283   0.351   0.479   0.617   0.718   0.566
 1992.00   0.001   0.394   0.277   0.188   0.324   0.418   0.529   0.763   1.098   0.692
 1993.00   0.001   0.412   0.306   0.199   0.270   0.313   0.497   0.808   0.635   0.583
 1994.00   0.001   0.522   0.337   0.140   0.256   0.364   0.400   0.575   0.775   0.471
 1995.00   0.011   0.384   0.308   0.161   0.101   0.427   1.132   2.130   1.802   1.482
 1996.00   0.001   0.153   0.221   0.268   0.376   0.859   1.450   1.589   5.835   1.635
 1997.00   0.002   0.094   0.232   0.184   0.298   0.603   1.183   1.153   0.557   1.149
 1998.00   0.000   0.166   0.057   0.181   0.179   0.314   0.699   0.979   2.162   0.873
 1999.00   0.001   0.073   0.149   0.065   0.183   0.400   0.714   1.384   0.846   0.892
 2000.00   0.001   0.099   0.029   0.066   0.109   0.211   0.391   0.801   0.763   0.469
 2001.00   0.000   0.045   0.151   0.040   0.069   0.119   0.249   0.437   0.700   0.276
 2002.00   0.024   0.055   0.034   0.111   0.074   0.061   0.090   0.090   0.090   0.090

LAMBDA       1.00000E-2
RSS          7.86832E2
NPHI         7.86832E2

Parameters
   8.29405E0      8.00637E0      7.60090E0      6.90776E0      6.90776E0

LAMBDA       1.00000E-3
RSS          7.05692E2
NPHI         7.05692E2

Parameters
   7.02722E0      6.20535E0      7.92684E0      5.61114E0      5.76001E0

LAMBDA       1.00000E-4
RSS          6.97951E2
NPHI         6.97951E2

Parameters
   6.98825E0      6.08334E0      7.70755E0      5.36968E0      5.52235E0

LAMBDA       1.00000E-5
RSS          6.95648E2
NPHI         6.95648E2

Parameters
   6.97929E0      6.03800E0      7.63251E0      5.33981E0      5.49973E0

LAMBDA       1.00000E-5
RSS          6.94903E2
NPHI         6.94903E2

Parameters
   6.97611E0      6.02034E0      7.60899E0      5.33357E0      5.49667E0

LAMBDA       1.00000E-5
RSS          6.94667E2
NPHI         6.94667E2

Parameters
   6.97501E0      6.01448E0      7.60164E0      5.33168E0      5.49581E0

LAMBDA       1.00000E-5
RSS          6.94593E2
NPHI         6.94593E2
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Parameters
   6.97465E0      6.01262E0      7.59934E0      5.33109E0      5.49555E0

LAMBDA       1.00000E-5
RSS          6.94570E2
NPHI         6.94570E2

Parameters
   6.97453E0      6.01203E0      7.59861E0      5.33091E0      5.49547E0

LAMBDA       1.00000E-5
RSS          6.94563E2
NPHI         6.94563E2

Parameters
   6.97450E0      6.01185E0      7.59839E0      5.33085E0      5.49544E0

LAMBDA       1.00000E-5
RSS          6.94560E2
NPHI         6.94560E2

Parameters
   6.97449E0      6.01179E0      7.59832E0      5.33083E0      5.49543E0

RELATIVE CHANGE IN RESIDUAL SUM OF SQUARES LESS THAN 0.00001
RELATIVE CHANGE IN EACH PARAMETER LESS THAN 0.00001

LAMBDA       1.00000E-2
RSS          6.94560E2
NPHI         6.94560E2

Parameters
   6.97449E0      6.01179E0      7.59832E0      5.33083E0      5.49543E0     -1.12648E1
  -9.85447E0     -8.72095E0     -8.35651E0     -7.50457E0     -7.18076E0     -6.97986E0
  -7.21699E0     -5.31461E0     -4.67431E0     -4.59818E0     -4.52000E0     -4.61259E0
  -4.69301E0     -8.54856E0     -7.12842E0     -6.18135E0     -5.81252E0     -5.72533E0
  -5.37330E0     -5.86172E0     -5.72062E0     -4.93300E0     -4.62739E0     -4.70840E0
  -5.07557E0     -5.60577E0     -6.34483E0     -7.05224E0     -5.31888E0     -4.88754E0
  -4.28792E0     -3.98071E0     -4.12466E0     -4.14393E0     -1.36018E0      9.40678E-1
  -2.46360E0      1.68094E1     -5.87556E0     -4.79538E0     -5.34079E0     -5.24915E0
  -4.82073E0     -4.56542E0     -4.52768E0

LAMBDA       1.00000E-3
RSS          6.94560E2
NPHI         6.94560E2

Parameters
   6.97448E0      6.01177E0      7.59829E0      5.33083E0      5.49543E0     -1.12648E1
  -9.85447E0     -8.72095E0     -8.35651E0     -7.50457E0     -7.18076E0     -6.97986E0
  -7.21699E0     -5.31460E0     -4.67431E0     -4.59818E0     -4.52000E0     -4.61259E0
  -4.69301E0     -8.54856E0     -7.12842E0     -6.18135E0     -5.81252E0     -5.72533E0
  -5.37330E0     -5.86172E0     -5.72062E0     -4.93299E0     -4.62739E0     -4.70840E0
  -5.07556E0     -5.60577E0     -6.34483E0     -7.05223E0     -5.31888E0     -4.88754E0
  -4.28792E0     -3.98071E0     -4.12466E0     -4.14392E0     -1.36018E0      9.40678E-1
  -2.46360E0      1.68094E1     -5.87556E0     -4.79538E0     -5.34079E0     -5.24914E0
  -4.82073E0     -4.56542E0     -4.52767E0

ORTHOGONALITY OFFSET LESS THAN 0.001
RELATIVE CHANGE IN RESIDUAL SUM OF SQUARES LESS THAN 0.00001
RELATIVE CHANGE IN EACH PARAMETER LESS THAN 0.00001

Estimated VPA (biased)
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Population Numbers
               1       2       3       4       5       6       7       8       9      10
 1967.00    5263    2809    1800    1810    1159    1489    1245     171      35      33
 1968.00    2624    4185    1918    1268    1294     831     976     670      95      19
 1969.00    2065    2135    2178    1321     875     703     441     384     232      55
 1970.00    1394    1627    1225    1426     870     447     299     168     123      74
 1971.00    7634    1136     888     832     725     447     230     130      67      55
 1972.00    1171    6110     720     361     388     296     168      68      45      31
 1973.00     993     951    4101     531     148      86      58      27       7       8
 1974.00    1638     779     464    2191     173      52      28      15       5       1
 1975.00    1004    1310     256     248    1121      72      26      15       7       1
 1976.00    1269     782     496     105     103     374      18       6       4       1
 1977.00    3544     971     170     184      43      40     121       5       2       1
 1978.00    2704    2364     280      65      88      17      17      54       2       1
 1979.00     399    1971     846     106      30      33       8       6      16       1
 1980.00    2308     321     571     316      36      10      12       1       1       7
 1981.00    1336    1581      60     145      94      10       3       3       0       0
 1982.00    1085    1038     264      18      58      35       4       1       1       0
 1983.00    1069     841     256     118       9      21      12       1       1       0
 1984.00    2855     846     448     157      71       6      11       3       1       0
 1985.00    1259    2321     526     248      92      32       3       5       1       0
 1986.00    1171    1004    1394     355     157      51      14       2       2       0
 1987.00    1827     922     600     939     247      94      27       5       1       1
 1988.00    2047    1450     554     370     606     162      61      17       2       1
 1989.00    2193    1604     737     354     247     382     101      41      12       1
 1990.00    2120    1771     900     454     192     129     152      56      26       8
 1991.00    2250    1724     938     539     291     123      67      51      21       8
 1992.00    1518    1837     997     606     350     180      71      34      22       8
 1993.00    1383    1242    1013     619     411     207      97      34      13       6
 1994.00    1874    1130     673     611     415     257     124      48      13       6
 1995.00    5307    1533     546     393     434     263     146      68      22       5
 1996.00    3656    4292     837     327     273     322     141      39       7       3
 1997.00    3028    2988    2956     541     204     153     111      27       6       0
 1998.00    1215    2469    2160    1847     363     123      68      27       7       3
 1999.00    6378     994    1457    1637    1214     243      73      27       8       1
 2000.00    1197    5217     656     838    1225     789     126      28       5       3
 2001.00    1935     977    3870     488     570     858     487      63       9       2
 2002.00    2000    1583     625    2723     346     374     586     276      28       3
 2003.00    2000    1598    1069     408    1995     207     244     415     196      20

Fishing Mortality
               1       2       3       4       5       6       7       8       9      10
 1967.00   0.029   0.182   0.151   0.136   0.132   0.223   0.419   0.389   0.442   0.416
 1968.00   0.007   0.453   0.173   0.170   0.410   0.434   0.732   0.863   0.344   0.761
 1969.00   0.039   0.355   0.224   0.217   0.472   0.655   0.767   0.938   0.941   0.867
 1970.00   0.005   0.405   0.187   0.476   0.466   0.465   0.631   0.723   0.598   0.650
 1971.00   0.023   0.256   0.701   0.564   0.695   0.777   1.025   0.866   0.567   0.905
 1972.00   0.008   0.199   0.104   0.692   1.307   1.437   1.639   2.106   1.488   1.728
 1973.00   0.042   0.517   0.427   0.920   0.835   0.913   1.138   1.554   1.502   1.287
 1974.00   0.024   0.913   0.426   0.470   0.684   0.485   0.436   0.518   1.270   0.542
 1975.00   0.051   0.770   0.696   0.678   0.897   1.205   1.245   1.141   1.672   1.278
 1976.00   0.068   1.325   0.792   0.681   0.737   0.932   1.028   0.878   1.224   1.022
 1977.00   0.205   1.042   0.763   0.543   0.748   0.689   0.597   0.813   0.424   0.603
 1978.00   0.116   0.827   0.771   0.578   0.762   0.515   0.780   1.027   1.019   0.970
 1979.00   0.018   1.040   0.785   0.895   0.882   0.811   1.632   1.522   0.663   1.101
 1980.00   0.179   1.479   1.168   1.010   1.091   1.081   1.302   1.201   1.083   1.277
 1981.00   0.052   1.589   0.976   0.716   0.781   0.781   0.751   0.660   0.271   0.682
 1982.00   0.055   1.198   0.607   0.508   0.837   0.901   1.037   0.550   1.469   1.031
 1983.00   0.034   0.429   0.292   0.313   0.164   0.434   1.135   0.416   0.520   1.054
 1984.00   0.007   0.275   0.394   0.332   0.582   0.463   0.566   0.928   3.105   0.743
 1985.00   0.027   0.310   0.194   0.257   0.390   0.613   0.505   0.720   1.493   0.728
 1986.00   0.039   0.315   0.196   0.163   0.309   0.428   0.881   0.282   0.287   0.760
 1987.00   0.031   0.310   0.284   0.237   0.223   0.242   0.260   0.749   0.264   0.332
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 1988.00   0.044   0.477   0.249   0.204   0.261   0.270   0.181   0.150   0.978   0.193
 1989.00   0.014   0.378   0.284   0.408   0.448   0.724   0.382   0.252   0.223   0.335
 1990.00   0.007   0.436   0.313   0.244   0.245   0.456   0.894   0.800   0.934   0.876
 1991.00   0.003   0.348   0.238   0.232   0.283   0.351   0.479   0.617   0.718   0.566
 1992.00   0.001   0.395   0.277   0.188   0.324   0.418   0.529   0.763   1.098   0.692
 1993.00   0.001   0.413   0.306   0.199   0.270   0.313   0.497   0.808   0.635   0.583
 1994.00   0.001   0.527   0.339   0.140   0.256   0.364   0.400   0.575   0.775   0.471
 1995.00   0.012   0.405   0.312   0.162   0.101   0.427   1.134   2.130   1.803   1.484
 1996.00   0.002   0.173   0.237   0.273   0.379   0.864   1.452   1.598   5.842   1.638
 1997.00   0.004   0.124   0.270   0.200   0.306   0.611   1.200   1.156   0.565   1.164
 1998.00   0.000   0.327   0.077   0.220   0.199   0.325   0.717   1.020   2.200   0.898
 1999.00   0.001   0.216   0.353   0.090   0.231   0.460   0.759   1.490   0.938   0.956
 2000.00   0.004   0.099   0.096   0.185   0.157   0.283   0.485   0.916   0.948   0.575
 2001.00   0.001   0.246   0.152   0.144   0.221   0.181   0.367   0.619   0.949   0.405
 2002.00   0.024   0.192   0.226   0.111   0.315   0.230   0.144   0.144   0.144   0.144

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION

ORTHOGONALITY OFFSET.........          0.000017
MEAN SQUARE RESIDUALS .......          1.105987

  Parameter              Est.     Std. Err.    Rel. Err.    Bias       Rel. Bias
  ---------            ---------  ---------    ---------  ---------    ---------
N[2003 3]               1.07E3     7.11E2          0.665   2.13E2          0.199
N[2003 4]               4.08E2     2.10E2          0.515   4.40E1          0.108
N[2003 5]               1.99E3     5.42E2          0.272   4.85E1          0.024
N[2003 6]               2.07E2     8.28E1          0.401   1.16E1          0.056
N[2003 7]               2.44E2     1.01E2          0.414   1.41E1          0.058
q ID#[1]                1.28E-5    3.99E-6         0.311   6.20E-7         0.048
q ID#[2]                5.25E-5    2.05E-5         0.391   4.01E-6         0.076
q ID#[3]                1.63E-4    5.49E-5         0.336   9.23E-6         0.057
q ID#[4]                2.35E-4    1.04E-4         0.444   2.32E-5         0.099
q ID#[5]                5.51E-4    2.17E-4         0.395   4.28E-5         0.078
q ID#[6]                7.61E-4    3.23E-4         0.425   6.86E-5         0.090
q ID#[7]                9.30E-4    6.30E-4         0.677   2.13E-4         0.229
q ID#[8]                7.34E-4    2.52E-4         0.343   4.26E-5         0.058
q ID#[9]                4.92E-3    1.69E-3         0.343   2.90E-4         0.059
q ID#[10]               9.33E-3    2.18E-3         0.234   2.53E-4         0.027
q ID#[11]               1.01E-2    2.58E-3         0.256   3.37E-4         0.033
q ID#[12]               1.09E-2    3.46E-3         0.317   5.54E-4         0.051
q ID#[13]               9.93E-3    4.22E-3         0.425   8.89E-4         0.090
q ID#[14]               9.16E-3    6.28E-3         0.686   2.14E-3         0.234
q ID#[15]               1.94E-4    7.48E-5         0.386   1.44E-5         0.074
q ID#[16]               8.02E-4    2.22E-4         0.277   3.07E-5         0.038
q ID#[17]               2.07E-3    6.26E-4         0.303   9.48E-5         0.046
q ID#[18]               2.99E-3    9.16E-4         0.306   1.40E-4         0.047
q ID#[19]               3.26E-3    8.00E-4         0.245   9.81E-5         0.030
q ID#[20]               4.64E-3    1.46E-3         0.314   2.28E-4         0.049
q ID#[21]               2.85E-3    8.78E-4         0.308   1.35E-4         0.048
q ID#[22]               3.28E-3    5.47E-4         0.167   3.75E-5         0.011
q ID#[23]               7.20E-3    1.36E-3         0.189   1.21E-4         0.017
q ID#[24]               9.78E-3    1.74E-3         0.177   1.47E-4         0.015
q ID#[25]               9.02E-3    1.89E-3         0.210   1.95E-4         0.022
q ID#[26]               6.25E-3    1.38E-3         0.221   1.52E-4         0.024
q ID#[27]               3.68E-3    1.80E-3         0.491   4.39E-4         0.120
q ID#[28]               1.76E-3    1.34E-3         0.765   5.12E-4         0.292
q ID#[29]               8.65E-4    5.15E-4         0.595   1.48E-4         0.171
q ID#[30]               4.90E-3    1.39E-3         0.283   1.84E-4         0.038
q ID#[31]               7.54E-3    1.96E-3         0.260   2.44E-4         0.032
q ID#[32]               1.37E-2    3.10E-3         0.226   3.30E-4         0.024
q ID#[33]               1.87E-2    5.88E-3         0.315   9.12E-4         0.049
q ID#[34]               1.62E-2    6.14E-3         0.380   1.14E-3         0.071
q ID#[35]               1.59E-2    7.25E-3         0.457   1.63E-3         0.103
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q ID#[36]              2.57E-1     7.88E-2         0.307   1.21E-2         0.047
q ID#[37]              2.56E0      2.32E-1         0.090   1.04E-2         0.004
q ID#[38]              8.51E-2     2.61E-2         0.307   4.00E-3         0.047
q ID#[39]              2.00E7      4.66E6          0.234   3.19E5          0.016
q ID#[40]              2.81E-3     1.65E-3         0.588   4.76E-4         0.169
q ID#[41]              8.27E-3     3.98E-3         0.481   9.44E-4         0.114
q ID#[42]              4.79E-3     2.48E-3         0.517   6.37E-4         0.133
q ID#[43]              5.25E-3     3.54E-3         0.675   1.19E-3         0.227
q ID#[44]              8.06E-3     5.53E-3         0.686   1.90E-3         0.235
q ID#[45]              1.04E-2     7.56E-3         0.727   2.73E-3         0.263
q ID#[46]              1.08E-2     9.42E-3         0.872   4.09E-3         0.378

VPA using analytical bias adjusted parameters (linear scale)
Population Numbers
                1        2        3        4        5        6        7        8        9       10
 1967.00     5263     2809     1800     1810     1159     1489     1245      171       35       33
 1968.00     2624     4185     1918     1268     1294      831      976      670       95       19
 1969.00     2065     2135     2178     1321      875      703      441      384      232       55
 1970.00     1394     1627     1225     1426      870      447      299      168      123       74
 1971.00     7634     1136      888      832      725      447      230      130       67       55
 1972.00     1171     6110      720      361      388      296      168       68       45       31
 1973.00      993      951     4101      531      148       86       58       27        7        8
 1974.00     1638      779      464     2191      173       52       28       15        5        1
 1975.00     1004     1310      256      248     1121       72       26       15        7        1
 1976.00     1269      782      496      105      103      374       18        6        4        1
 1977.00     3544      971      170      184       43       40      121        5        2        1
 1978.00     2704     2364      280       65       88       17       17       54        2        1
 1979.00      399     1971      846      106       30       33        8        6       16        1
 1980.00     2308      321      571      316       36       10       12        1        1        7
 1981.00     1336     1581       60      145       94       10        3        3        0        0
 1982.00     1085     1038      264       18       58       35        4        1        1        0
 1983.00     1069      841      256      118        9       21       12        1        1        0
 1984.00     2855      846      448      157       71        6       11        3        1        0
 1985.00     1259     2321      526      248       92       32        3        5        1        0
 1986.00     1171     1004     1394      355      157       51       14        2        2        0
 1987.00     1827      922      600      939      247       94       27        5        1        1
 1988.00     2047     1450      554      370      606      162       61       17        2        1
 1989.00     2193     1604      737      354      247      382      101       41       12        1
 1990.00     2120     1771      900      454      192      129      152       56       26        8
 1991.00     2250     1724      938      539      291      123       67       51       21        8
 1992.00     1518     1837      997      606      350      180       71       34       22        8
 1993.00     1382     1242     1013      619      411      207       97       34       13        6
 1994.00     1871     1130      673      611      415      257      124       48       13        6
 1995.00     5276     1530      546      392      434      263      146       68       22        5
 1996.00     3602     4266      835      327      273      321      141       38        7        3
 1997.00     2981     2944     2935      539      204      153      111       27        6        0
 1998.00     1183     2431     2124     1830      361      123       68       27        7        3
 1999.00     6270      968     1426     1607     1200      242       73       27        8        1
 2000.00     1117     5129      635      812     1201      778      125       28        5        3
 2001.00     1616      911     3798      470      549      838      477       62        9        2
 2002.00     2000     1322      571     2664      331      357      570      269       27        3
 2003.00     2000     1598      856      364     1946      195      229      402      189       19

Fishing Mortality
                1        2        3        4        5        6        7        8        9       10
 1967.00    0.029    0.182    0.151    0.136    0.132    0.223    0.419    0.389    0.442    0.416
 1968.00    0.007    0.453    0.173    0.170    0.410    0.434    0.732    0.863    0.344    0.761
 1969.00    0.039    0.355    0.224    0.217    0.472    0.655    0.767    0.938    0.941    0.867
 1970.00    0.005    0.405    0.187    0.476    0.466    0.465    0.631    0.723    0.598    0.650
 1971.00    0.023    0.256    0.701    0.564    0.695    0.777    1.025    0.866    0.567    0.905
 1972.00    0.008    0.199    0.104    0.692    1.307    1.437    1.639    2.106    1.488    1.728
 1973.00    0.042    0.517    0.427    0.920    0.835    0.913    1.138    1.554    1.502    1.287
 1974.00    0.024    0.913    0.426    0.470    0.684    0.485    0.436    0.518    1.270    0.542
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 1975.00   0.051   0.770   0.696   0.678   0.897   1.205   1.245   1.141   1.672   1.278
 1976.00   0.068   1.325   0.792   0.681   0.737   0.932   1.028   0.878   1.224   1.022
 1977.00   0.205   1.042   0.763   0.543   0.748   0.689   0.597   0.813   0.424   0.603
 1978.00   0.116   0.827   0.771   0.578   0.762   0.515   0.780   1.027   1.019   0.970
 1979.00   0.018   1.040   0.785   0.895   0.882   0.811   1.632   1.522   0.663   1.101
 1980.00   0.179   1.479   1.168   1.010   1.091   1.081   1.302   1.201   1.083   1.277
 1981.00   0.052   1.589   0.976   0.716   0.781   0.781   0.751   0.660   0.271   0.682
 1982.00   0.055   1.198   0.607   0.508   0.837   0.901   1.037   0.550   1.469   1.031
 1983.00   0.034   0.429   0.292   0.313   0.164   0.434   1.135   0.416   0.520   1.054
 1984.00   0.007   0.275   0.394   0.332   0.582   0.463   0.566   0.928   3.105   0.743
 1985.00   0.027   0.310   0.194   0.257   0.390   0.613   0.505   0.720   1.493   0.728
 1986.00   0.039   0.315   0.196   0.163   0.309   0.428   0.881   0.282   0.287   0.760
 1987.00   0.031   0.310   0.284   0.237   0.223   0.242   0.260   0.749   0.264   0.332
 1988.00   0.044   0.477   0.249   0.204   0.261   0.270   0.181   0.150   0.978   0.193
 1989.00   0.014   0.378   0.284   0.408   0.448   0.724   0.382   0.252   0.223   0.335
 1990.00   0.007   0.436   0.313   0.244   0.245   0.456   0.894   0.800   0.934   0.876
 1991.00   0.003   0.348   0.238   0.232   0.283   0.351   0.479   0.617   0.718   0.566
 1992.00   0.001   0.395   0.277   0.188   0.324   0.418   0.529   0.763   1.098   0.692
 1993.00   0.001   0.414   0.306   0.199   0.270   0.313   0.497   0.808   0.635   0.583
 1994.00   0.001   0.527   0.339   0.140   0.256   0.364   0.400   0.575   0.775   0.471
 1995.00   0.012   0.406   0.313   0.162   0.101   0.427   1.134   2.130   1.803   1.484
 1996.00   0.002   0.174   0.238   0.273   0.379   0.864   1.452   1.598   5.842   1.639
 1997.00   0.004   0.126   0.272   0.201   0.306   0.611   1.200   1.157   0.565   1.164
 1998.00   0.000   0.334   0.079   0.222   0.200   0.326   0.718   1.022   2.202   0.900
 1999.00   0.001   0.222   0.363   0.091   0.234   0.463   0.761   1.495   0.943   0.960
 2000.00   0.004   0.100   0.100   0.192   0.160   0.288   0.491   0.923   0.959   0.582
 2001.00   0.001   0.266   0.155   0.150   0.230   0.186   0.375   0.632   0.966   0.414
 2002.00   0.024   0.235   0.250   0.114   0.330   0.242   0.149   0.149   0.149   0.149

1-US fall 1967-1984
Age :   2
Ln calibration constant :     -11.26485

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
   1967.83      -2.68092      -3.64084       0.83812       7.62401
   1968.83      -3.80317      -3.46755      -0.29303       7.79729
   1969.83      -3.76360      -4.05963       0.25847       7.20522
   1970.83      -3.48024      -4.37290       0.77940       6.89194
   1971.83      -4.18646      -4.60807       0.36812       6.65677
   1972.83      -2.06593      -2.87799       0.70902       8.38685
   1973.83      -7.26443      -5.00234      -1.97507       6.26251
   1974.83      -8.51719      -5.52982      -2.60832       5.73503
   1975.83      -4.89285      -4.89233      -0.00045       6.37251
   1977.83      -5.09947      -5.41729       0.27750       5.84755
   1978.83      -4.53751      -4.34948      -0.16417       6.91536
   1979.83      -4.43122      -4.70753       0.24126       6.55731
   1982.83      -5.65499      -5.48012      -0.15268       5.78472
   1983.83      -3.31044      -5.05224       1.52079       6.21261
   1984.83      -4.68855      -4.91884       0.20107       6.34601

          Average squared residual :        1.02292

1-US fall 1967-1984
Age :   3
Ln calibration constant :      -9.85447

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
   1967.83      -2.04176      -2.64983       0.38549       7.20464
   1968.83      -2.80511      -2.60502      -0.12685       7.24944
   1969.83      -3.32424      -2.52007      -0.50981       7.33439
   1970.83      -3.40521      -3.06484      -0.21578       6.78963
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    1971.83      -1.17798      -3.81346       1.67079       6.04100
    1972.83      -2.82852      -3.52773       0.44327       6.32673
    1973.83      -3.14191      -2.05589      -0.68850       7.79858
    1974.83      -5.99146      -4.23314      -1.11471       5.62132
    1975.83      -6.31997      -5.05206      -0.80380       4.80240
    1976.83      -8.51719      -4.46987      -2.56584       5.38459
    1977.83      -6.90776      -5.51746      -0.88139       4.33700
    1978.83      -2.75829      -5.02424       1.43652       4.83022
    1979.83      -3.80317      -3.93138       0.08128       5.92309
    1980.83      -5.08321      -4.64365      -0.27866       5.21082
    1981.83      -5.95224      -6.73873       0.49860       3.11574
    1982.83      -4.33514      -4.94740       0.38815       4.90706
    1983.83      -3.23399      -4.71545       0.93918       5.13902
    1984.83      -2.12444      -4.24136       1.34204       5.61310

            Average squared residual :        1.02292

  1-US fall 1967-1984
  Age :   4
  Ln calibration constant :      -8.72095

       Year      Observed     Predicted      Residual       Ln Pop.
    -------      --------     ---------      --------       -------
    1967.83      -1.01971      -1.49839       0.36290       7.22256
    1968.83      -2.89498      -1.88335      -0.76695       6.83760
    1969.83      -2.74731      -1.88101      -0.65677       6.83994
    1970.83      -2.62970      -2.01936      -0.46272       6.70159
    1971.83      -1.35829      -2.63085       0.96477       6.09011
    1972.83      -2.58362      -3.57383       0.75071       5.14712
    1973.83      -5.44914      -3.37587      -1.57182       5.34509
    1974.83      -2.76939      -1.58511      -0.89785       7.13585
    1975.83      -4.19971      -3.93488      -0.20078       4.78608
    1976.83      -4.41455      -4.80188       0.29365       3.91907
    1977.83      -4.94766      -4.12142      -0.62640       4.59953
    1978.83      -2.51331      -5.19315       2.03169       3.52780
    1979.83      -6.43775      -4.96449      -1.11693       3.75646
    1981.83      -6.07485      -4.50317      -1.19154       4.21778
    1982.83      -5.08321      -6.39271       0.99278       2.32825
    1983.83      -3.80766      -4.37727       0.43184       4.34368
    1984.83      -1.91257      -4.10668       1.66343       4.61427

            Average squared residual :        1.02292

  1-US fall 1967-1984
  Age :   5
  Ln calibration constant :      -8.35651

       Year      Observed     Predicted      Residual       Ln Pop.
    -------      --------     ---------      --------       -------
    1967.83      -1.65339      -1.57713      -0.04514       6.77937
    1968.83      -2.91139      -1.69740      -0.71865       6.65910
    1969.83      -3.25450      -2.13944      -0.66009       6.21707
    1970.83      -2.78709      -2.14023      -0.38293       6.21628
    1971.83      -0.54697      -2.51291       1.16379       5.84360
    1972.83      -2.76780      -3.64674       0.52031       4.70977
    1973.83      -6.16582      -4.22042      -1.15163       4.13608
    1974.83      -4.66705      -3.93547      -0.43307       4.42104
    1975.83      -2.25666      -2.24467      -0.00709       6.11184
    1976.83      -4.29036      -4.49771       0.12275       3.85880
    1977.83      -6.07485      -5.37400      -0.41489       2.98251
    1978.83      -1.85470      -4.68207       1.67373       3.67444
    1981.83      -8.51719      -4.62496      -2.30411       3.73155
    1982.83      -3.52337      -5.15533       0.96608       3.20118
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  1983.83      -6.50229      -6.45066      -0.03056       1.90585
  1984.83      -1.87471      -4.74899       1.70150       3.60752

          Average squared residual :        1.02292

1-US fall 1967-1984
Age :   6
Ln calibration constant :      -7.50457

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1967.83      -0.52442      -0.54916       0.01649       6.95541
  1968.83      -0.98430      -1.30752       0.21540       6.19705
  1969.83      -2.78547      -1.65902      -0.75070       5.84555
  1970.83      -2.23213      -1.95334      -0.18579       5.55123
  1971.83      -1.08501      -2.21266       0.75150       5.29191
  1972.83      -2.81842      -3.17157       0.23535       4.33300
  1973.83      -7.60090      -3.97491      -2.41647       3.52966
  1974.83      -5.20301      -4.11276      -0.72657       3.39181
  1975.83      -2.96423      -4.39970       0.95664       3.10487
  1976.83      -2.67510      -2.51866      -0.10425       4.98591
  1977.83      -6.31997      -4.54292      -1.18428       2.96165
  1978.83      -4.27587      -5.27658       0.66690       2.22799
  1981.83      -7.26443      -6.03935      -0.81643       1.46522
  1982.83      -3.82585      -4.85369       0.68499       2.65088
  1983.83      -4.21991      -5.00605       0.52391       2.49853
  1984.83      -3.00983      -6.21094       2.13331       1.29364

          Average squared residual :        1.02292

1-US fall 1967-1984
Age :   7
Ln calibration constant :      -7.18076

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1967.83      -0.92256      -0.56768      -0.21971       6.61308
  1968.83      -2.16718      -1.07066      -0.67885       6.11010
  1969.83      -2.29363      -1.89399      -0.24742       5.28678
  1970.83      -4.31250      -2.17021      -1.32630       5.01056
  1971.83      -4.01184      -2.75919      -0.77552       4.42158
  1972.83      -3.03447      -3.58154       0.33869       3.59923
  1973.83      -6.11930      -4.23644      -1.16568       2.94433
  1974.83      -5.40368      -4.36835      -0.64097       2.81241
  1975.83      -3.45144      -5.10477       1.02358       2.07600
  1976.83      -4.72170      -5.33402       0.37909       1.84675
  1977.83      -4.54690      -3.04876      -0.92750       4.13201
  1978.83      -3.87762      -5.18330       0.80835       1.99747
  1981.83      -8.51719      -6.93739      -0.97806       0.24338
  1982.83      -5.65499      -6.90901       0.77636       0.27176
  1983.83      -3.83506      -5.82520       1.23210       1.35556
  1984.83      -1.54646      -5.42605       2.40186       1.75471

          Average squared residual :        1.02292

1-US fall 1967-1984
Age :   8
Ln calibration constant :      -6.97986

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1967.83      -4.55638      -2.32850      -0.99855       4.65136
  1972.83      -4.07454      -4.68053       0.27161       2.29932
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  1973.83      -7.26443      -5.14936      -0.94798       1.83050
  1974.83      -4.84089      -4.85863       0.00795       2.12123
  1975.83      -3.63819      -5.38885       0.78466       1.59100
  1976.83      -9.21034      -6.04401      -1.41916       0.93585
  1977.83      -8.11173      -6.18283      -0.86454       0.79703
  1978.83      -2.47456      -4.00133       0.68431       2.97853
  1981.83      -8.51719      -6.69563      -0.81643       0.28423
  1982.83      -5.71383      -7.52071       0.80985      -0.54085
  1983.83      -6.90776      -7.42933       0.23377      -0.44947
  1984.83      -1.75736      -6.78749       2.25453       0.19237

          Average squared residual :        1.02292

2-US fall 1985-2002
Age :   2
Ln calibration constant :      -7.21699

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.83      -3.37553       0.10970      -2.55115       7.32669
  1986.83      -3.78981      -0.73317      -2.23742       6.48381
  1987.83       0.70424      -0.81354       1.11100       6.40344
  1988.83       0.01597      -0.49960       0.37739       6.71738
  1989.83       0.33511      -0.31588       0.47652       6.90111
  1990.83       0.95520      -0.26523       0.89334       6.95176
  1991.83       0.99429      -0.21913       0.88821       6.99785
  1992.83       0.80844      -0.19496       0.73447       7.02203
  1993.83      -1.03761      -0.60146      -0.31926       6.61553
  1994.83      -0.45460      -0.79026       0.24570       6.42672
  1995.83      -0.53683      -0.38384      -0.11199       6.83315
  1996.83       2.38001       0.83789       1.12881       8.05488
  1997.83       0.60103       0.51601       0.06224       7.73299
  1998.83       0.46775       0.15686       0.22757       7.37385
  1999.83      -1.50103      -0.66014      -0.61552       6.55685
  2000.83       0.09613       1.09484      -0.73104       8.31182
  2001.83      -1.20098      -0.70316      -0.36440       6.51383
  2002.83       0.89739      -0.17579       0.78556       7.04120

          Average squared residual :        1.02292

2-US fall 1985-2002
Age :   3
Ln calibration constant :      -5.31460

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.83      -2.93935       0.62370      -2.59745       5.93830
  1986.83      -0.83910       1.59718      -1.77604       6.91179
  1987.83       1.34344       0.68021       0.48349       5.99481
  1988.83       1.27046       0.62982       0.46702       5.94443
  1989.83       1.46416       0.88576       0.42165       6.20037
  1990.83       2.18785       1.06241       0.82044       6.37702
  1991.83       2.44646       1.16594       0.93349       6.48055
  1992.83       3.23621       1.19428       1.48856       6.50888
  1993.83       0.58629       1.18608      -0.43724       6.50068
  1994.83       0.02966       0.74956      -0.52481       6.06417
  1995.83       2.05411       0.56314       1.08691       5.87774
  1996.83       1.90475       1.05333       0.62068       6.36794
  1997.83       2.85539       2.28660       0.41465       7.60120
  1998.83       1.04525       2.13304      -0.79300       7.44764
  1999.83       1.05117       1.51041      -0.33478       6.82501
  2000.83       0.01134       0.92562      -0.66651       6.24022
  2001.83       2.13978       2.65461      -0.37530       7.96921
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  2002.83       1.82353       0.76963       0.76829       6.08423

          Average squared residual :        1.02291

2-US fall 1985-2002
Age :   4
Ln calibration constant :      -4.67431

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.83      -0.01157       0.45870      -0.50559       5.13301
  1986.83      -1.46924       0.89569      -2.54259       5.57000
  1987.83       1.10081       1.80720      -0.75945       6.48151
  1988.83       1.51262       0.90273       0.65571       5.57704
  1989.83       1.39021       0.68904       0.75384       5.36336
  1990.83       0.64359       1.07543      -0.46428       5.74974
  1991.83       1.69367       1.25659       0.46992       5.93090
  1992.83       2.80706       1.41007       1.50193       6.08438
  1993.83       1.91575       1.42244       0.53037       6.09675
  1994.83       1.41418       1.45771      -0.04680       6.13202
  1995.83       2.17583       0.99788       1.26644       5.67219
  1996.83       1.90990       0.72384       1.27515       5.39816
  1997.83       1.53788       1.28735       0.26935       5.96166
  1998.83       2.12315       2.49867      -0.40374       7.17298
  1999.83       1.03454       2.48571      -1.56019       7.16002
  2000.83       1.43301       1.73702      -0.32684       6.41133
  2001.83       0.47834       1.22964      -0.80773       5.90395
  2002.83       3.62293       2.97688       0.69459       7.65119

          Average squared residual :        1.02291

2-US fall 1985-2002
Age :   5
Ln calibration constant :      -4.59818

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.83      -1.17215      -0.56410      -0.59463       4.03407
  1986.83      -1.68740       0.03458      -1.68397       4.63276
  1987.83      -0.95011       0.55904      -1.47583       5.15722
  1988.83       0.56877       1.42662      -0.83892       6.02480
  1989.83       0.69694       0.37236       0.31742       4.97053
  1990.83      -0.85590       0.29280      -1.12335       4.89098
  1991.83      -0.15117       0.67556      -0.80849       5.27374
  1992.83       2.30206       0.82468       1.44478       5.42285
  1993.83       1.80681       1.03013       0.75953       5.62831
  1994.83       1.28868       1.05254       0.23093       5.65072
  1995.83       3.16118       1.22602       1.89245       5.82420
  1996.83       1.04183       0.53167       0.49889       5.12985
  1997.83       1.42513       0.29981       1.10048       4.89799
  1998.83       1.03663       0.96445       0.07059       5.56263
  1999.83       1.65263       2.14575      -0.48224       6.74393
  2000.83       1.91501       2.21659      -0.29493       6.81477
  2001.83       0.94554       1.39833      -0.44279       5.99650
  2002.83       2.28258       0.82013       1.43017       5.41830

          Average squared residual :        1.02291

2-US fall 1985-2002
Age :   6
Ln calibration constant :      -4.52000

     Year      Observed     Predicted      Residual       Ln Pop.
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   -------      --------     ---------      --------       -------
   1985.83      -1.13538      -1.72036       0.45970       2.79963
   1986.83      -2.83191      -1.10775      -1.35490       3.41224
   1987.83      -1.53201      -0.34053      -0.93631       4.17946
   1988.83      -1.66654       0.17491      -1.44707       4.69491
   1989.83       0.74726       0.65963       0.06886       5.17963
   1990.83      -2.41800      -0.20416      -1.73970       4.31583
   1991.83      -1.79517      -0.16161      -1.28370       4.35839
   1992.83       0.57835       0.15886       0.32965       4.67885
   1993.83       0.38737       0.38813      -0.00060       4.90813
   1994.83       1.08769       0.56049       0.41429       5.08049
   1995.83       3.04271       0.53260       1.97253       5.05259
   1996.83       1.83586       0.37023       1.15174       4.89022
   1997.83       1.45820      -0.16168       1.27295       4.35831
   1998.83       0.74122      -0.14388       0.69554       4.37611
   1999.83       0.18465       0.42706      -0.19049       4.94706
   2000.83       1.64463       1.74965      -0.08253       6.26965
   2001.83       1.51658       1.91790      -0.31537       6.43789
   2002.83       2.30247       1.04836       0.98552       5.56836

          Average squared residual :        1.02292

 2-US fall 1985-2002
 Age :   7
 Ln calibration constant :      -4.61259

      Year      Observed     Predicted      Residual       Ln Pop.
   -------      --------     ---------      --------       -------
   1985.83      -3.04073      -4.01665       0.57071       0.59594
   1986.83      -5.47267      -2.84855      -1.53456       1.76404
   1987.83      -3.43579      -1.68934      -1.02130       2.92325
   1988.83      -2.77740      -0.82480      -1.14186       3.78779
   1989.83      -1.40364      -0.48104      -0.53953       4.13155
   1990.83      -3.07478      -0.49766      -1.50707       4.11493
   1991.83      -3.78981      -0.97193      -1.64787       3.64066
   1992.83      -0.78812      -0.95322       0.09655       3.65937
   1993.83      -1.23066      -0.61706      -0.35883       3.99553
   1994.83      -0.12172      -0.28974       0.09826       4.32285
   1995.83       1.97053      -0.73510       1.58223       3.87749
   1996.83       1.16661      -1.03740       1.28889       3.57519
   1997.83       1.28343      -1.06490       1.37328       3.54769
   1998.83       0.70344      -1.15299       1.08563       3.45960
   1999.83      -0.21456      -1.12148       0.53036       3.49111
   2000.83       0.52360      -0.34632       0.50872       4.26627
   2001.83       1.61373       1.10465       0.29771       5.71724
   2002.83       2.01965       1.47464       0.31872       6.08723

          Average squared residual :        1.02292

 2-US fall 1985-2002
 Age :   8
 Ln calibration constant :      -4.69301

      Year      Observed     Predicted      Residual       Ln Pop.
   -------      --------     ---------      --------       -------
   1985.83      -1.85726      -3.83244       0.78334       0.86057
   1987.83      -5.05146      -3.90084      -0.45632       0.79217
   1989.83      -2.43497      -1.34520      -0.43219       3.34781
   1990.83      -6.16582      -1.49069      -1.85412       3.20231
   1991.83      -7.13090      -1.44238      -2.25602       3.25063
   1993.83      -5.25910      -1.99403      -1.29490       2.69898
   1994.83      -1.45672      -1.45919       0.00098       3.23382
   1995.83      -0.28316      -2.40612       0.84195       2.28689
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  1996.83      -0.21704      -2.53444       0.91906       2.15857
  1997.83      -0.42327      -2.52435       0.83327       2.16866
  1998.83      -0.50650      -2.39590       0.74932       2.29711
  1999.83      -1.17022      -2.79173       0.64308       1.90128
  2000.83      -0.45303      -2.29127       0.72903       2.40174
  2001.83       0.22010      -1.22317       0.57239       3.46984
  2002.83       1.19963       0.64202       0.22115       5.33503

          Average squared residual :       1.02292

3-US Spring 1968-1984
Age :   2
Ln calibration constant :      -8.54856

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1968.25       0.43224      -0.37249       0.53183       8.17607
  1969.25      -2.12863      -1.02134      -0.73179       7.52722
  1970.25       1.34802      -1.30564       1.75377       7.24293
  1971.25      -1.60594      -1.62739       0.01417       6.92117
  1972.25      -0.75290       0.06950      -0.54351       8.61807
  1973.25      -2.70755      -1.87001      -0.55352       6.67855
  1974.25      -3.65738      -2.16811      -0.98424       6.38045
  1975.25      -3.26492      -1.61331      -1.09153       6.93525
  1976.25      -3.13041      -2.26852      -0.56961       6.28005
  1977.25      -2.83191      -1.98073      -0.56254       6.56784
  1978.25      -2.10210      -1.03727      -0.70373       7.51129
  1979.25       1.51119      -1.27233       1.83959       7.27623
  1980.25      -2.17772      -3.19694       0.67359       5.35162
  1981.25      -3.95284      -1.63006      -1.53510       6.91850
  1982.25      -0.90609      -1.95317       0.69200       6.59539
  1983.25      -1.87797      -1.97141       0.06176       6.57715
  1984.25       0.65856      -1.92714       1.70885       6.62142

          Average squared residual :       1.02292

3-US Spring 1968-1984
Age :   3
Ln calibration constant :      -7.12842

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1968.25       2.16341       0.33744       1.68368       7.46586
  1969.25       0.27960       0.45186      -0.15884       7.58028
  1970.25       0.38893      -0.11434       0.46405       7.01409
  1971.25      -0.79629      -0.56467      -0.21356       6.56375
  1972.25      -0.05922      -0.62521       0.52189       6.50321
  1973.25       0.81868       1.03388      -0.19843       8.16230
  1974.25      -2.26240      -1.14425      -1.03101       5.98417
  1975.25      -2.34758      -1.80650      -0.49891       5.32192
  1976.25      -1.48678      -1.16874      -0.29326       5.95969
  1977.25      -2.12779      -2.23282       0.09684       4.89560
  1978.25       0.69029      -1.73482       2.23612       5.39360
  1979.25      -0.99101      -0.63399      -0.32920       6.49443
  1980.25       0.38069      -1.12393       1.38737       6.00449
  1981.25      -4.44817      -3.33045      -1.03061       3.79798
  1982.25      -2.96423      -1.75313      -1.11672       5.37530
  1983.25      -3.62684      -1.70423      -1.77278       5.42419
  1984.25      -0.89624      -1.17105       0.25339       5.95737

          Average squared residual :       1.02292

3-US Spring 1968-1984
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Age :   4
Ln calibration constant :      -6.18135

     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1968.25      1.23689       0.87109       0.30816       7.05244
   1969.25     -0.69917       0.90042      -1.34753       7.08177
   1970.25      0.03517       0.91208      -0.73872       7.09343
   1971.25     -0.68458       0.35160      -0.87291       6.53295
   1972.25     -0.74087      -0.51666      -0.18888       5.66469
   1973.25      1.24008      -0.18644       1.20174       5.99491
   1974.25      1.48978       1.34311       0.12356       7.52446
   1975.25     -3.20153      -0.88592      -1.95072       5.29543
   1976.25     -2.87884      -1.75142      -0.94977       4.42993
   1977.25     -0.95581      -1.15101       0.16444       5.03034
   1978.25     -1.10624      -2.20249       0.92351       3.97886
   1979.25      0.11288      -1.78994       1.60298       4.39141
   1980.25      1.31038      -0.72820       1.71735       5.45316
   1981.25     -0.67668      -1.43220       0.63647       4.74915
   1982.25     -3.04282      -3.44254       0.33673       2.73881
   1983.25     -2.75514      -1.53989      -1.02376       4.64147
   1984.25     -1.19073      -1.25880       0.05735       4.92255

          Average squared residual :        1.02292

3-US Spring 1968-1984
Age :   5
Ln calibration constant :      -5.81252

     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1968.25      1.27290       1.20044       0.06031       7.01296
   1969.25      0.00419       0.79418      -0.65756       6.60669
   1970.25     -0.18284       0.79004      -0.80980       6.60256
   1971.25     -1.56590       0.55039      -1.76155       6.36291
   1972.25     -0.56651      -0.22888      -0.28104       5.58364
   1973.25     -0.56352      -1.07593       0.42651       4.73659
   1974.25     -0.26971      -0.87885       0.50704       4.93366
   1975.25     -0.18284       0.93530      -0.93071       6.74781
   1976.25     -2.15675      -1.41007      -0.62153       4.40245
   1977.25     -2.00842      -2.28018       0.22620       3.53234
   1978.25     -1.20065      -1.57987       0.31565       4.23265
   1979.25     -0.21505      -2.68751       2.05801       3.12501
   1980.25     -0.37848      -2.56495       1.81996       3.24756
   1981.25      0.29617      -1.51202       1.50509       4.30050
   1982.25     -3.01798      -2.00977      -0.83920       3.80274
   1983.25     -4.72170      -3.69559      -0.85411       2.11693
   1984.25     -1.94771      -1.75156      -0.16327       4.06096

          Average squared residual :        1.02292

3-US Spring 1968-1984
Age :   6
Ln calibration constant :      -5.72533

     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1968.25      1.05994       0.83916       0.22968       6.56449
   1969.25      0.55555       0.61625      -0.06314       6.34158
   1970.25     -0.60148       0.21138      -0.84561       5.93671
   1971.25     -1.50238       0.13340      -1.70168       5.85874
   1972.25     -1.14917      -0.44310      -0.73452       5.28223
   1973.25      0.14254      -1.55000       1.76073       4.17533
```

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  1974.25      -1.66919      -1.93642       0.27800       3.78891
  1975.25      -2.50226      -1.80573      -0.72459       3.91960
  1976.25      -1.16059      -0.08289      -1.12112       5.64244
  1977.25      -2.63946      -2.24811      -0.40711       3.47722
  1978.25      -3.07046      -3.08270       0.01274       2.64263
  1979.25      -1.42047      -2.46721       1.08891       3.25812
  1980.25      -2.48891      -3.73230       1.29348       1.99303
  1981.25      -1.66284      -3.69131       2.11019       2.03403
  1982.25      -3.20893      -2.43582      -0.80425       3.28951
  1983.25      -2.92062      -2.85901      -0.06410       2.86633
  1984.25      -4.34281      -4.04712      -0.30760       1.67821

          Average squared residual :        1.02292

3-US Spring 1968-1984
Age :   7
Ln calibration constant :      -5.37330

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1968.25       1.50488       1.27731       0.18497       6.65061
  1969.25       1.40118       0.47432       0.75335       5.84761
  1970.25      -0.83425       0.11916      -0.77492       5.49245
  1971.25      -1.92964      -0.24128      -1.37229       5.13202
  1972.25      -3.72140      -0.70733      -2.44983       4.66597
  1973.25      -0.55513      -1.65299       0.89234       3.72030
  1974.25      -2.71507      -2.19192      -0.42522       3.18138
  1975.25      -3.14656      -2.45915      -0.55872       2.91414
  1976.25      -1.48017      -2.81425       1.08434       2.55905
  1977.25      -1.47011      -0.77906      -0.56168       4.59424
  1978.25      -2.97397      -2.80766      -0.13517       2.56563
  1979.25      -2.09557      -3.72490       1.32431       1.64840
  1980.25      -2.24526      -3.24886       0.81572       2.12444
  1981.25      -2.81175      -4.57860       1.43609       0.79470
  1982.25      -4.64599      -4.38405      -0.21290       0.98924
  1983.25      -2.38380      -3.24338       0.69867       2.12992
  1984.25      -4.03419      -3.17414      -0.69904       2.19915

          Average squared residual :        1.02292

3-US Spring 1968-1984
Age :   8
Ln calibration constant :      -5.86172

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1968.25       0.30025       0.38043      -0.06633       6.24215
  1969.25       0.56406      -0.19444       0.62749       5.66727
  1970.25      -3.11903      -0.97002      -1.77781       4.89170
  1971.25      -2.98578      -1.25899      -1.42852       4.60273
  1972.25      -3.79869      -2.22489      -1.30196       3.63683
  1973.25      -2.11362      -3.01373       0.74463       2.84799
  1974.25      -3.21638      -3.32424       0.08923       2.53747
  1975.25      -4.54690      -3.49277      -0.87205       2.36895
  1976.25      -3.82585      -4.30081       0.39292       1.56091
  1977.25      -4.24750      -4.47704       0.18990       1.38467
  1978.25      -1.65078      -2.17182       0.43104       3.68990
  1979.25      -1.76902      -4.46138       2.22731       1.40033
  1980.25      -4.97623      -5.93780       0.79547      -0.07608
  1981.25      -3.51661      -5.07893       1.29246       0.78278
  1982.25      -6.81245      -5.96747      -0.69902      -0.10576
  1983.25      -6.90776      -5.95415      -0.78889      -0.09243
  1984.25      -4.84089      -5.01512       0.14413       0.84660
```

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          Average squared residual :        1.02292

4-US Spring 1985-2002
Age :   2
Ln calibration constant :      -5.72062

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.25       0.66921       1.90158      -1.91059       7.62220
  1986.25       0.52615       1.06216      -0.83100       6.78278
  1987.25       0.26234       0.97851      -1.11030       6.69913
  1988.25       1.17208       1.38931      -0.33678       7.10993
  1989.25       0.50555       1.51549      -1.56576       7.23612
  1990.25       1.08900       1.59983      -0.79196       7.32045
  1991.25       1.52194       1.59497      -0.11323       7.31560
  1992.25       2.39804       1.64649       1.16516       7.36711
  1993.25       1.97977       1.25071       1.13031       6.97133
  1994.25       1.46990       1.12790       0.53022       6.84852
  1995.25       1.80232       1.46314       0.52584       7.18376
  1996.25       3.71144       2.55059       1.79971       8.27122
  1997.25       3.05772       2.20053       1.32894       7.92115
  1998.25       1.54281       1.95915      -0.64547       7.67977
  1999.25       0.85586       1.07740      -0.34346       6.79802
  2000.25       2.71540       2.76444      -0.07603       8.48506
  2001.25       1.61195       1.05189       0.86829       6.77251
  2002.25       1.79083       1.54818       0.37618       7.26880

          Average squared residual :        1.02291

4-US Spring 1985-2002
Age :   3
Ln calibration constant :      -4.93299

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.25      -0.06219       1.23380      -1.74245       6.16679
  1986.25       3.30201       2.20820       1.47061       7.14119
  1987.25       0.75730       1.34230      -0.78653       6.27529
  1988.25       1.37869       1.27163       0.14395       6.20462
  1989.25       0.50634       1.54826      -1.40085       6.48125
  1990.25       0.86748       1.74164      -1.17530       6.67463
  1991.25       1.91835       1.80131       0.15735       6.73431
  1992.25       2.77204       1.85250       1.23632       6.78549
  1993.25       3.48725       1.86132       2.18605       6.79432
  1994.25       1.21929       1.44358      -0.30155       6.37658
  1995.25       1.32731       1.24198       0.11473       6.17498
  1996.25       2.13773       1.68821       0.60437       6.62121
  1997.25       3.49814       2.94092       0.74918       7.87392
  1998.25       2.37396       2.67551      -0.40543       7.60850
  1999.25       2.79401       2.21288       0.78133       7.14588
  2000.25       1.22926       1.47909      -0.33589       6.41208
  2001.25       2.95561       3.24015      -0.38256       8.17314
  2002.25       0.71920       1.39845      -0.91324       6.33145

          Average squared residual :        1.02292

4-US Spring 1985-2002
Age :   4
Ln calibration constant :      -4.62739

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
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  1985.25      -0.86488       0.77059      -2.33478       5.39798
  1986.25       1.21346       1.15318       0.08605       5.78057
  1987.25       1.34315       2.10781      -1.09161       6.73520
  1988.25       1.25105       1.18414       0.09552       5.81153
  1989.25       1.06063       1.08872      -0.04010       5.71611
  1990.25       0.98065       1.37972      -0.56969       6.00710
  1991.25       2.38922       1.55430       1.19193       6.18169
  1992.25       1.87254       1.68185       0.27222       6.30924
  1993.25       3.24299       1.70070       2.20175       6.32809
  1994.25       2.49386       1.70210       1.13030       6.32949
  1995.25       1.17350       1.25472      -0.11595       5.88211
  1996.25       1.62109       1.04502       0.82239       5.67241
  1997.25       1.74082       1.56630       0.24914       6.19369
  1998.25       3.32402       2.78897       0.76383       7.41636
  1999.25       2.66614       2.70067      -0.04930       7.32806
  2000.25       1.61466       2.00730      -0.56052       6.63469
  2001.25       0.64558       1.47635      -1.18598       6.10374
  2002.25       2.59829       3.20426      -0.86507       7.83165

          Average squared residual :        1.02291

4-US Spring 1985-2002
Age :   5
Ln calibration constant :      -4.70840

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.25      -0.73002      -0.33203      -0.47630       4.37637
  1986.25       0.15649       0.21966      -0.07560       4.92806
  1987.25      -1.47666       0.69415      -2.59793       5.40254
  1988.25       1.19247       1.58359      -0.46808       6.29199
  1989.25       0.68808       0.63793       0.06002       5.34633
  1990.25       0.14885       0.44043      -0.34895       5.14882
  1991.25      -0.04239       0.84526      -1.06230       5.55365
  1992.25       0.71950       1.01811      -0.35737       5.72651
  1993.25       1.74383       1.19256       0.65974       5.90095
  1994.25       2.39781       1.20662       1.42557       5.91502
  1995.25       2.45619       1.29046       1.39510       5.99885
  1996.25       1.03001       0.75745       0.32620       5.46584
  1997.25       0.98753       0.48293       0.60388       5.19133
  1998.25       1.77132       1.08555       0.82070       5.79394
  1999.25       3.75573       2.28551       1.75950       6.99390
  2000.25       1.60404       2.31322      -0.84871       7.02161
  2001.25       0.98440       1.53224      -0.65563       6.24063
  2002.25       0.87489       1.00836      -0.15973       5.71675

          Average squared residual :        1.02291

4-US Spring 1985-2002
Age :   6
Ln calibration constant :      -5.07556

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.25      -2.23213      -1.80426      -0.48355       3.27131
  1986.25      -0.58322      -1.29890       0.80882       3.77667
  1987.25      -1.95829      -0.63982      -1.49005       4.43574
  1988.25      -1.15964      -0.10784      -1.18867       4.96772
  1989.25       0.31693       0.63994      -0.36505       5.71551
  1990.25      -1.85790      -0.37920      -1.67114       4.69637
  1991.25      -1.20131      -0.39781      -0.90806       4.67775
  1992.25      -0.55026      -0.03834      -0.57854       5.03723
  1993.25      -0.09003       0.13006      -0.24873       5.20562
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  1994.25       1.19547       0.33190       0.97595       5.40746
  1995.25       1.04289       0.34086       0.79339       5.41643
  1996.25       1.50049       0.43154       1.20806       5.50711
  1997.25       0.88311      -0.24692       1.27709       4.82864
  1998.25       0.45938      -0.39485       0.96541       4.68071
  1999.25       1.95487       0.25427       1.92191       5.32983
  2000.25       1.30144       1.47431      -0.19536       6.54988
  2001.25       1.05372       1.58332      -0.59853       6.65889
  2002.25       0.54482       0.74198      -0.22281       5.81754

          Average squared residual :        1.02291

4-US Spring 1985-2002
Age :   7
Ln calibration constant :      -5.60577

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.25      -3.85375      -4.60105       0.38904       1.00472
  1986.25      -0.88455      -3.21467       1.21305       2.39110
  1988.25      -4.32754      -1.59677      -1.42163       4.00900
  1989.25      -2.04253      -1.13642      -0.47172       4.46935
  1990.25      -6.26590      -0.85659      -2.81606       4.74918
  1991.25      -2.85077      -1.57124      -0.66612       4.03453
  1992.25      -1.66866      -1.52334      -0.07565       4.08243
  1993.25      -2.72114      -1.20614      -0.78870       4.39963
  1994.25      -0.66359      -0.93486       0.14122       4.67091
  1995.25      -0.65105      -0.95460       0.15803       4.65117
  1996.25       0.92287      -1.07270       1.03888       4.53307
  1997.25       0.34889      -1.24627       0.83044       4.35950
  1998.25      -0.18392      -1.61448       0.74474       3.99128
  1999.25       1.07045      -1.55861       1.36868       4.04716
  2000.25      -0.22540      -0.94217       0.37315       4.66360
  2001.25       0.93232       0.44010       0.25625       6.04587
  2002.25       0.15572       0.68124      -0.27358       6.28701

          Average squared residual :        1.02292

4-US Spring 1985-2002
Age :   8
Ln calibration constant :      -6.34483

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1985.25      -3.74651      -4.95047       0.45942       1.39436
  1988.25      -9.21034      -3.58742      -2.14564       2.75741
  1992.25      -5.62682      -3.06044      -0.97930       3.28439
  1993.25      -7.13090      -3.06138      -1.55288       3.28345
  1994.25      -3.17486      -2.66150      -0.19589       3.68333
  1995.25      -4.32754      -2.70651      -0.61857       3.63832
  1996.25      -0.44863      -3.14355       1.02835       3.20128
  1997.25      -1.06334      -3.38948       0.88763       2.95535
  1998.25      -1.74698      -3.34009       0.60791       3.00474
  1999.25      -0.10148      -3.46350       1.28291       2.88133
  2000.25      -1.65810      -3.29573       0.62490       3.04910
  2001.25      -0.66787      -2.39983       0.66089       3.94500
  2002.25      -0.96653      -0.81003      -0.05972       5.53480

          Average squared residual :        1.02292

5-US Winter 1992-2002
Age :   2
Ln calibration constant :      -7.05223
```

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     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1992.00       2.04182       0.46362       0.84832       7.51586
  1993.00      -1.14413       0.07246      -0.65395       7.12469
  1994.00      -2.51331      -0.02191      -1.33919       7.03032
  1995.00      -2.61456       0.28266      -1.55733       7.33489
  1996.00       4.31175       1.31223       1.61232       8.36446
  1997.00       0.56594       0.95003      -0.20646       8.00226
  1998.00       0.51927       0.75940      -0.12908       7.81163
  1999.00      -1.42628      -0.15025      -0.68590       6.90198
  2000.00       3.86737       1.50750       1.26849       8.55974
  2001.00       1.78685      -0.16822       1.05090       6.88402
  2002.00      -0.07246       0.31468      -0.20810       7.36691

          Average squared residual :        1.02292

5-US Winter 1992-2002
Age :   3
Ln calibration constant :      -5.31888

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1992.00       2.58238       1.58584       1.14654       6.90472
  1993.00       2.78337       1.60200       1.35919       6.92088
  1994.00      -0.65220       1.19236      -2.12221       6.51124
  1995.00      -0.17459       0.98422      -1.33324       6.30310
  1996.00       1.88318       1.41150       0.54268       6.73038
  1997.00       1.94318       2.67259      -0.83921       7.99147
  1998.00       2.63313       2.35896       0.31544       7.67784
  1999.00       1.86821       1.96530      -0.11170       7.28418
  2000.00       1.37506       1.16728       0.23905       6.48616
  2001.00       3.63799       2.94217       0.80057       8.26105
  2002.00       1.12168       1.11912       0.00294       6.43800

          Average squared residual :        1.02291

5-US Winter 1992-2002
Age :   4
Ln calibration constant :      -4.88754

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1992.00       2.10339       1.51863       0.73004       6.40617
  1993.00       2.83346       1.54027       1.61448       6.42781
  1994.00       0.14479       1.52707      -1.72570       6.41461
  1995.00      -0.01339       1.08506      -1.37135       5.97260
  1996.00       1.28143       0.90308       0.47235       5.79062
  1997.00       0.54412       1.40616      -1.07621       6.29370
  1998.00       3.34842       2.63372       0.89226       7.52126
  1999.00       2.12057       2.51295      -0.48987       7.40049
  2000.00       1.70613       1.84343      -0.17141       6.73097
  2001.00       1.51699       1.30231       0.26802       6.18985
  2002.00       3.70873       3.02190       0.85747       7.90944

          Average squared residual :        1.02291

5-US Winter 1992-2002
Age :   5
Ln calibration constant :      -4.28792

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
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  1992.00       1.48115       1.56947      -0.12732       5.85739
  1993.00       2.28075       1.73055       0.79316       6.01847
  1994.00       0.21777       1.74102      -2.19592       6.02894
  1995.00       1.58664       1.78622      -0.28771       6.07414
  1996.00       1.41347       1.32274       0.13079       5.61067
  1997.00       1.94481       1.02985       1.31900       5.31777
  1998.00       1.86995       1.60573       0.38091       5.89365
  1999.00       3.27617       2.81373       0.66666       7.10165
  2000.00       1.66778       2.82285      -1.66514       7.11077
  2001.00       2.24697       2.05794       0.27250       6.34586
  2002.00       2.05219       1.55747       0.71318       5.84539

          Average squared residual :        1.02292

5-US Winter 1992-2002
Age :   6
Ln calibration constant :       -3.98071

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1992.00       0.30557       1.21099      -0.92254       5.19170
  1993.00       1.75432       1.35315       0.40876       5.33385
  1994.00       0.00568       1.56769      -1.59154       5.54840
  1995.00       1.80601       1.59255       0.21750       5.57325
  1996.00       2.66041       1.79230       0.88452       5.77301
  1997.00       2.84019       1.05067       1.82336       5.03137
  1998.00       1.32538       0.83130       0.50342       4.81201
  1999.00       2.05183       1.51412       0.54787       5.49483
  2000.00       1.13160       2.68996      -1.58782       6.67066
  2001.00       2.17839       2.77344      -0.60630       6.75414
  2002.00       2.26114       1.94424       0.32289       5.92495

          Average squared residual :        1.02292

5-US Winter 1992-2002
Age :   7
Ln calibration constant :       -4.12466

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1992.00      -0.63111       0.14012      -0.64747       4.26478
  1993.00      -0.34348       0.44915      -0.66543       4.57381
  1994.00      -1.32539       0.69627      -1.69724       4.82093
  1995.00       1.32800       0.85999       0.39291       4.98465
  1996.00       1.91990       0.82129       0.92232       4.94595
  1997.00       2.68247       0.58475       1.76109       4.70941
  1998.00       0.85484       0.09580       0.63724       4.22046
  1999.00       1.42782       0.16217       1.06255       4.28683
  2000.00      -0.87443       0.71020      -1.33034       4.83486
  2001.00       1.85107       2.06285      -0.17780       6.18752
  2002.00       1.94139       2.24846      -0.25779       6.37312

          Average squared residual :        1.02291

5-US Winter 1992-2002
Age :   8
Ln calibration constant :       -4.14392

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1994.00      -2.16282      -0.26683      -1.45942       3.87709
  1995.00      -0.14018       0.07691      -0.16711       4.22084
  1996.00       0.29877      -0.49320       0.60961       3.65072
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  1997.00       1.57557      -0.84949       1.86666       3.29443
  1998.00      -0.63469      -0.83417       0.15355       3.30975
  1999.00       0.53825      -0.84016       1.06102       3.30376
  2000.00      -2.48651      -0.81579      -1.28602       3.32813
  2001.00      -0.22979       0.00589      -0.18141       4.14981
  2002.00       0.70156       1.47699      -0.59688       5.62092

          Average squared residual :        1.02291

6a-US larval 1971-1988 (weighted mean)
Age :   3  4  5  6  7  8  9 10
Ln calibration constant :      -1.36018

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1971.83       4.49647       4.44668       0.04020       5.80686
  1972.83       4.39938       3.75137       0.52317       5.11155
  1973.83       5.87268       4.44183       1.15520       5.80201
  1974.83       5.71867       4.24916       1.18641       5.60934
  1975.83       4.02356       3.49022       0.43060       4.85040
  1976.83       0.78846       2.98878      -1.77644       4.34896
  1977.83       2.95491       2.49334       0.37265       3.85352
  1978.83       0.87547       2.34429      -1.18586       3.70447
  1979.83       1.79176       2.59765      -0.65063       3.95782
  1980.83       0.64185       2.44657      -1.45704       3.80674
  1981.83       3.39115       1.95135       1.16242       3.31152
  1982.83       2.90142       2.04783       0.68915       3.40800
  1983.83       1.30833       2.49340      -0.95676       3.85357
  1984.83       0.83291       2.83496      -1.61636       4.19513
  1985.83       4.55808       3.24366       1.06120       4.60384
  1986.83       4.10099       3.89358       0.16745       5.25376
  1987.83       3.44681       3.83148      -0.31056       5.19165
  1988.83       5.21982       3.77656       1.16522       5.13673

          Average squared residual :        1.02292

6b-US larval 1971-1988 (weighted mean)
Age :   3  4  5  6  7  8  9 10
Ln calibration constant :       0.94068

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1989.83       6.11876       6.02656       0.43771       5.08588
  1990.83       5.97660       6.04791      -0.33851       5.10723
  1991.83       5.86986       6.08567      -1.02453       5.14499
  1992.83       6.35802       6.15556       0.96112       5.21489
  1993.83       5.98545       6.28175      -1.40664       5.34107
  1994.83       6.41346       6.12470       1.37086       5.18402

          Average squared residual :        1.02292

7-CAN larval 1987-1995 mean
Age :   3  4  5  6  7  8  9 10
Ln calibration constant :      -2.46360

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1987.83       3.09104       2.72805       0.41510       5.19165
  1988.83       1.87180       2.67313      -0.91637       5.13673
  1989.83       2.00148       2.62228      -0.70992       5.08588
  1990.83       2.32239       2.64363      -0.36736       5.10723
  1991.83       1.19392       2.68139      -1.70102       5.14499
  1992.83       2.53370       2.75128      -0.24882       5.21489
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   1993.83       3.42751       2.87747       0.62902       5.34107
   1994.83       3.96840       2.72042       1.42715       5.18402
   1995.83       3.85651       2.56911       1.47223       5.03271

          Average squared residual :        1.02292

8-US acoustic 1999-2002
Age :   3  4  5  6  7  8  9 10
Ln calibration constant :      16.80939

     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1999.83      22.90097      22.73123       0.51033       5.92184
   2000.83      23.01524      22.76641       0.74813       5.95702
   2001.83      23.31557      23.15446       0.48439       6.34507
   2002.83      22.46329      23.04291      -1.74268       6.23352

          Average squared residual :        1.02293

9-CAN spring BT 86-92,95-02
Age :   2
Ln calibration constant :      -5.87556

     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1986.12       0.59675       0.97424      -0.17512       6.84979
   1987.12      -0.21504       0.88984      -0.51257       6.76540
   1988.12      -0.90667       1.32236      -1.03408       7.19792
   1989.12       4.21862       1.43565       1.29106       7.31120
   1990.12       3.58685       1.52753       0.95534       7.40309
   1991.12       3.67242       1.51126       1.00259       7.38682
   1992.12       2.17335       1.56890       0.28041       7.44446
   1995.12       0.55453       1.38679      -0.38610       7.26235
   1996.12       3.46609       2.44415       0.47409       8.31970
   1997.12       3.06719       2.08777       0.45437       7.96333
   1998.12       0.38282       1.87278      -0.69121       7.74834
   1999.12      -0.51563       0.97652      -0.69223       6.85208
   2000.12       6.14663       2.64834       1.62291       8.52389
   2001.12       0.71185       0.95494      -0.11277       6.83049
   2002.12      -3.89438       1.44426      -2.47667       7.31982

          Average squared residual :        1.02291

9-CAN spring BT 86-92,95-02
Age :   3
Ln calibration constant :      -4.79538

     Year      Observed     Predicted      Residual       Ln Pop.
   -------     --------     ---------      --------       -------
   1986.12       2.26972       2.39723      -0.07232       7.19261
   1987.12      -2.45133       1.54277      -2.26549       6.33816
   1988.12      -1.46889       1.46756      -1.66557       6.26294
   1989.12       1.38023       1.74883      -0.20907       6.54421
   1990.12       0.58728       1.94596      -0.77065       6.74134
   1991.12       3.91795       1.99581       1.09025       6.79119
   1992.12       2.67436       2.05211       0.35295       6.84749
   1995.12       3.65300       1.44622       1.25170       6.24160
   1996.12       1.31190       1.88260      -0.32371       6.67798
   1997.12       5.12473       3.13966       1.12595       7.93504
   1998.12       1.85247       2.84918      -0.56534       7.64456
   1999.12       2.78715       2.42241       0.20688       7.21779
   2000.12       3.39809       1.65522       0.98857       6.45060
   2001.12       5.31769       3.42347       1.07442       8.21885
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  2002.12       1.20620       1.59147      -0.21853       6.38686

          Average squared residual :        1.02292

9-CAN spring BT 86-92,95-02
Age :   4
Ln calibration constant :      -5.34079

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1986.12      -0.96985       0.48698      -0.76722       5.82777
  1987.12      -3.26721       1.45127      -2.48491       6.79206
  1988.12      -0.78780       0.52330      -0.69047       5.86409
  1989.12      -1.12745       0.45439      -0.83305       5.79518
  1990.12      -1.57363       0.72400      -1.21001       6.06479
  1991.12       3.23336       0.89711       1.23035       6.23790
  1992.12       2.45423       1.01886       0.75592       6.35964
  1995.12       0.42183       0.58838      -0.08771       5.92916
  1996.12       0.96180       0.39309       0.29950       5.73388
  1997.12       2.78355       0.90491       0.98935       6.24570
  1998.12       2.42570       2.13012       0.15566       7.47091
  1999.12       3.25349       2.02494       0.64699       7.36573
  2000.12       2.40740       1.34397       0.56004       6.68475
  2001.12       3.51154       0.80773       1.42392       6.14852
  2002.12       2.55348       2.53131       0.01167       7.87210

          Average squared residual :        1.02292

9-CAN spring BT 86-92,95-02
Age :   5
Ln calibration constant :      -5.24914

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1986.12      -0.85633      -0.25490      -0.24252       4.99425
  1987.12      -6.85186       0.20839      -2.84689       5.45753
  1988.12       0.36732       1.10273      -0.29654       6.35187
  1989.12      -2.04534       0.18141      -0.89789       5.43056
  1990.12      -2.85825      -0.04253      -1.13538       5.20661
  1991.12       0.62269       0.36725       0.10300       5.61639
  1992.12       2.16896       0.54542       0.65466       5.79457
  1995.12       1.46769       0.78886       0.27372       6.03800
  1996.12       1.14051       0.29201       0.34214       5.54115
  1997.12       2.95959       0.00794       1.19019       5.25708
  1998.12       1.39491       0.59665       0.32188       5.84579
  1999.12       4.70894       1.80079       1.17265       7.04993
  2000.12       2.12493       1.81883       0.12343       7.06797
  2001.12       4.03693       1.04621       1.20594       6.29535
  2002.12       0.61294       0.53450       0.03163       5.78364

          Average squared residual :        1.02292

9-CAN spring BT 86-92,95-02
Age :   6
Ln calibration constant :      -4.82073

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1988.12      -0.49309       0.20814      -0.29850       5.02887
  1989.12      -2.87412       1.01489      -1.65546       5.83562
  1990.12      -5.41283      -0.03907      -2.28748       4.78166
  1991.12      -0.46195      -0.07139      -0.16625       4.74933
  1992.12       1.23813       0.29683       0.40069       5.11755
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  1995.12       0.40911       0.67725      -0.11414       5.49798
  1996.12       1.55109       0.82465       0.30923       5.64537
  1997.12       3.31562       0.11334       1.36314       4.93406
  1998.12       0.79906      -0.07174       0.37068       4.74899
  1999.12       4.12840       0.59490       1.50412       5.41563
  2000.12       1.57625       1.79196      -0.09182       6.61269
  2001.12       3.78510       1.88769       0.80768       6.70842
  2002.12       0.71946       1.05267      -0.14184       5.87339

          Average squared residual :        1.02292

9-CAN spring BT 86-92,95-02
Age :   7
Ln calibration constant :      -4.56542

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1988.12      -0.73576      -0.50684      -0.09575       4.05858
  1989.12      -5.67146      -0.02036      -2.36370       4.54506
  1991.12      -2.41081      -0.44261      -0.82324       4.12281
  1992.12       0.21797      -0.38816       0.25353       4.17725
  1995.12      -1.03183       0.25916      -0.53998       4.82458
  1996.12       0.75682       0.18235       0.24028       4.74777
  1997.12       3.06627      -0.02396       1.29256       4.54145
  1998.12       0.30444      -0.45496       0.31764       4.11045
  1999.12       3.61418      -0.39363       1.67635       4.17179
  2000.12      -0.07814       0.18724      -0.11100       4.75266
  2001.12       3.41231       1.55411       0.77723       6.11952
  2002.12       0.27476       1.76637      -0.62390       6.33178

          Average squared residual :        1.02292

9-CAN spring BT 86-92,95-02
Age :   8
Ln calibration constant :      -4.52767

     Year      Observed     Predicted      Residual       Ln Pop.
  -------      --------     ---------      --------       -------
  1988.12      -3.45883      -1.72473      -0.66229       2.80294
  1992.12      -3.47030      -1.11805      -0.89837       3.40962
  1995.12      -5.19064      -0.58644      -1.75845       3.94123
  1996.12      -1.20912      -1.09269      -0.04447       3.43499
  1997.12       2.27701      -1.39600       1.40280       3.13167
  1998.12      -1.02429      -1.36433       0.12987       3.16335
  1999.12       2.93562      -1.42668       1.66606       3.10099
  2000.12      -1.14112      -1.33348       0.07346       3.19420
  2001.12       1.60223      -0.47617       0.79379       4.05150
  2002.12      -0.78720       1.05191      -0.70240       5.57958

          Average squared residual :        1.02292

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