Young of the Year Sablefish Abundance, Growth, and Diet in the Gulf of Alaska

M. F. Sigler, T. L. Rutecki, D. L. Courtney, J. F. Karinen, and M.-S.Yang

Reprinted from the
Alaska Fishery Research Bulletin
Vol. 8 No. 1, Summer 2001

The Alaska Fishery Research Bulletin can found on the World Wide Web
at URL: http://www.state.ak.us/adfg/geninfo/pubs/afrb/afrbhome.htm .

Alaska Fishery Research Bulletin 8(1):57–70. 2001.

Young of the Year Sablefish Abundance, Growth, and Diet in the Gulf of Alaska

M. F. Sigler, T. L. Rutecki, D. L. Courtney, J. F. Karinen, and M.-S.Yang

ABSTRACT: Abundance is dependent on year class success, which is highly variable from year to year. We studied young of the year sablefish *Anoplopoma fimbria* to collect basic life history information on their abundance, growth, and diet and to determine whether forecasting year class abundance based on young of the year surveys was practical. Surface gillnet surveys were conducted annually from 1995 to 1999 along the seaward edge of the continental shelf of Alaska. Sablefish made up about one-third of the catch and were caught mostly in the central and eastern Gulf of Alaska. Growth averaged 1.2 mm·d^{-1}. The mean date the first otolith increment formed, April 30, implied an average spawning date of March 30. Diet was mainly euphausiids. Growth rate tended to be higher in years when gillnet catches were higher, but no relationship was apparent between diet and gillnet catches.

INTRODUCTION

Fish are highly susceptible to environmental changes during early life. Year class success varies greatly from year to year, indicating that one or more variables significantly affect survival and growth (Hagen and Quinn 1991; Hollowed and Wooster 1992; Clark et al. 1999). Our study focuses on young of the year sablefish *Anoplopoma fimbria.* Sablefish are a long-lived species inhabiting the North Pacific Ocean and Bering Sea. This species supports a valuable fishery in Alaskan waters, with annual catches averaging 21,000 t and exvessel values averaging $100 million during 1994 to 1997 (Hiatt and Terry 1999). The fishery uses mostly longline gear and occurs primarily on the upper continental slope and deep fjords inhabited by adult sablefish.

Several environmental factors could affect young of the year sablefish abundance. Laboratory studies have shown that very cold water (2°C) may be lethal for juvenile sablefish (63–109 mm); dives beneath the thermocline that exceeded 60 seconds resulted in loss of equilibrium and immediate death for 12°C-adapted fish that moved to 2°C (Sogard and Olla 1998). Food abundance is known to affect survival of sablefish larvae based on correlation of food abundance and year class strength (McFarlane and Beamish 1992).

Survival could be affected at several stages of the early life history of sablefish. Sablefish spawn below 300 m in offshore waters (Mason et al. 1983; Kendall and Matarese 1987), and eggs and larvae are subject to drift and export from the spawning location for an extended period. After hatching the larvae rise toward the surface as they develop, encountering more variable conditions in near-surface waters. Early juveniles are neuston-oriented, but potentially move downward in the water column during the day expanding their foraging area (Sogard and Olla 1998). McFarlane and Beamish (1992) provide evidence that sablefish year class strength is determined by larval survival at depth; the strongest year classes are associated with large-scale increases in copepod abundance and increases in sea surface temperatures following intense Aleutian lows. These findings agree with Sogard and Olla (1998) who report the sensitivity of juvenile sablefish to cold water. During some years cold Arctic water prevails along the northern coast of the Gulf of Alaska when sablefish larvae and juveniles occupy the neuston, whereas in other years the surface layers of this area are much warmer due to the influx of warmer water from the south (Francis et al. 1998). Water temperature and surface currents generated by wind drift (modified by prevailing currents) may determine the distribution of postlarval and juvenile sablefish in the Gulf of Alaska and thereby influence year class strength.

Our objectives were to: (1) collect a 5-year time series (1995–1999) of basic life history information

Authors: M. F. SIGLER, T. L. RUTECKI , and D. L. COURTNEY are fishery biologists and J. F. KARINEN is an oceanographer with the Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, 11305 Glacier Highway, Juneau, AK 99801-8626. M. F. Sigler's email: Mike.Sigler@noaa.gov. M.-S.YANG is a fishery biologist with the Alaska Fisheries Science Center, National Marine Fisheries Service, 7600 Sand Point Way NE, Seattle, WA 98115.
Acknowledgments: Noele Weemes — helped with otolith processing. Linda Cole — helped identify the tunicates. Ed Farley and Phil Rigby — reviewed our manuscript.

on young of the year sablefish abundance, growth, and diet from the Gulf of Alaska, and (2) evaluate the potential use of the time series in forecasting recruitment of sablefish. A better understanding of physical and biological determinants of juvenile growth and survival may contribute to recruitment forecasts 3–5 years before a year class enters the fishery.

METHODS

Survey

Sampling in the Gulf of Alaska, Aleutian Islands region, and eastern Bering Sea occurred during June, July, August, and early September of 1995 to 1999 (Figure 1). The Gulf of Alaska was sampled all years except that during 1995, the pilot year, only the eastern Gulf of Alaska was sampled. During the years 1996 to 1999 the Aleutian Islands region was sampled in even years and the eastern Bering Sea in odd years. The young of the year surveys were conducted using fishing vessels chartered to conduct annual longline surveys of the upper continental slope (Rutecki et al. 1997). The F/V *Ocean Prowler* (47 m) was used during odd years, and the F/V *Alaskan Leader* (46 m) was used during even years.

The upper 3 m of the water column was sampled with a lightweight, variable-mesh gillnet (Rutecki and Sigler 1999). A net 300 m long by 3 m deep with 3 stretched-mesh sizes of 25, 31, and 38 mm (100 m long each, arranged in sequence from smallest to largest mesh size) was used during 1995. During all other years, a net 200 m long by 3 m deep with 4 stretched-mesh sizes of 19, 25, 31, and 38 mm (50 m long each, arranged in sequence from smallest to largest mesh size) was used. On some sets 2 nets were tied together to make a 400-m net; one 200-m net was used if large numbers of fish were expected to be caught. A catch per unit of effort (CPUE) was calculated for each set as the number of fish captured per 200 m of net. The net was set between midnight and 0100 Alaska Daylight Time (AKDT) and fished until 0500 AKDT. Because the net was consistently fished for the same time period each night, fishing (soak) time was not incorporated into the CPUE. The net was allowed to drift freely while being monitored by vessel personnel. Upon retrieval of the net, all captured fish were counted and recorded by species. For small catches, less than 30 (50 in 1995) fish of any species, all fish were measured on board for fork length to the nearest centimeter, and all juvenile sablefish and juvenile salmon were preserved frozen for subsequent processing at the lab. For large catches, a random subsample of 30 (50 in 1995) fish of each species were measured on board for fork length to the nearest centimeter and preserved frozen for subsequent processing at the lab. Upon returning to the lab, frozen samples of young of the year sablefish were randomly subsampled for age determination and diet analyses. Processing otoliths into thin sections was time consuming, approximately one per day, and limited the number of otoliths we could process for age determinations. Consequently, fewer otoliths were processed for daily age determinations than stomachs for diet analyses.

Growth

Sagittal otoliths were examined in the laboratory to determine daily age. The sagittal otoliths were chosen for age determination because they were the largest of the 3 otolith pairs. The transverse plane was chosen for otolith thin sections because it consistently provided detectable microgrowth increments (pairs of light translucent and dark opaque bands visible under a transmitted light microscope) from the center to the outside edge of each otolith thin section. Otolith thin sectioning in the transverse plane followed standard methods described by Stevenson and Campana (1992). Daily age was determined by counting the number of microgrowth increments encountered along a transect extending from the center to the outside edge of each otolith thin section. A daily periodicity in the formation of juvenile sablefish sagittal otolith microgrowth increments was assumed for this study. A single technician processed and read every otolith for age determinations. Magnifications for otolith examination ranged from 200x to 1,000x.

Daily age estimates were used to determine the date of first-increment formation and length-at-age for each specimen. Length-at-age was used to estimate growth rates for young of the year sablefish. The date of first-increment formation was calculated for each fish by subtracting the daily age estimate from the capture date of the fish. Growth appeared linear for the size range of these fish and was described with a linear regression estimated from individual fork length (FL) and daily age estimates pooled over all years. The young of the year catches obtained each year were limited in time and space. Pooling the data across years provided the widest range of lengths and ages for estimating a length-at-age relationship. Growth rates by year were estimated as the slope of the linear length-at-age relationship from each year. These calculations were made to compare a measure of growth rate with environmental data and abundance estimates for each year.

Table 1. Catch by species or species group and year.

Species	Number of Fish 1995	1996	1997	1998	1999	Total	Percent
Pacific saury	2,872	0	204	12	0	3,088	37%
Sablefish	742	392	802	955	36	2,927	35%
Salmon	187	268	108	799	720	2,082	25%
Other fish	4	57	164	85	31	341	4%
Total fish	3,805	717	1,278	1,851	787	8,438	100%

Diet

Sablefish stomach contents were examined in the laboratory to determine diet. The stomach was cut open, and the contents were removed and blotted with a paper towel. Wet weight was recorded to the nearest 0.01 g. The stomach contents were then placed in a petri dish and examined under a dissecting microscope. Each prey item was classified to the lowest practical taxonomic level. The prey items were weighed (to the nearest 0.001 g) and enumerated. The diet of juvenile sablefish was summarized to show the overall percent frequency of occurrence, percent of numbers (if available), and the percent of the total weight of each prey item found in the stomachs.

RESULTS

Abundance

Seven gillnet sets were completed in the eastern Gulf of Alaska in 1995, the pilot year. An average of 32 gillnet sets per year was completed throughout the survey area during 1996–1999 (Figure 1). Sablefish catches were highest in 1995, 1997, and 1998 and lowest in 1996 and 1999 (Figure 2a). Young of the year sablefish lengths ranged from 60- to 230-mm FL, with most between 90- and 220-mm FL. Young of the year sablefish caught during early July were about 100-mm FL, whereas fish caught in early September were about 200-mm FL. Age-1 sablefish also were caught; their lengths ranged from 310- to 390-mm FL.

Young of the year sablefish were caught exclusively east of 159°W longitude (Figure 1). Most were caught after mid July. Whether the lack of captures westward of 159°W is due to a time effect or an area effect is unknown because sampling was not synoptic. Areas west of 159°W were sampled during June, and areas east of this longitude were sampled during July and August. Some evidence suggests an area effect. The area between 159°W and 150°W was sampled in July during 1996 and 1997 and in August during 1998 and 1999, but sablefish catches in this area were uncommon regardless of sample timing. This indicates that young of the year sablefish may be more common

Table 2. Number of juvenile sablefish *Anoplopoma fimbria* processed for age determinations and diet analyses.

Analyses	Number of Fish 1995	1996	1997	1998	1999	All Years
Age Determinations						
Number of aged specimens	17	22	21	25	22	107
Number of unsuitable specimens	8	17	9	5	5	44
Number of hauls	4	7	8	9	8	31
Mean sablefish fork length (mm)	167	118	109	135	108	125
Sablefish size range (mm)	140–200	90–140	70–140	100–180	100–140	70–200
Diet Analyses						
Number of non-empty stomachs	50	23	43	23	25	164
Number of empty stomachs	1	5	15	7	1	29
Number of hauls	4	6	14	9	7	40
Mean sablefish fork length (mm)	173	121	114	141	108	136
Sablefish size range (mm)	140–200	100–140	90–160	90–180	100–140	90–200

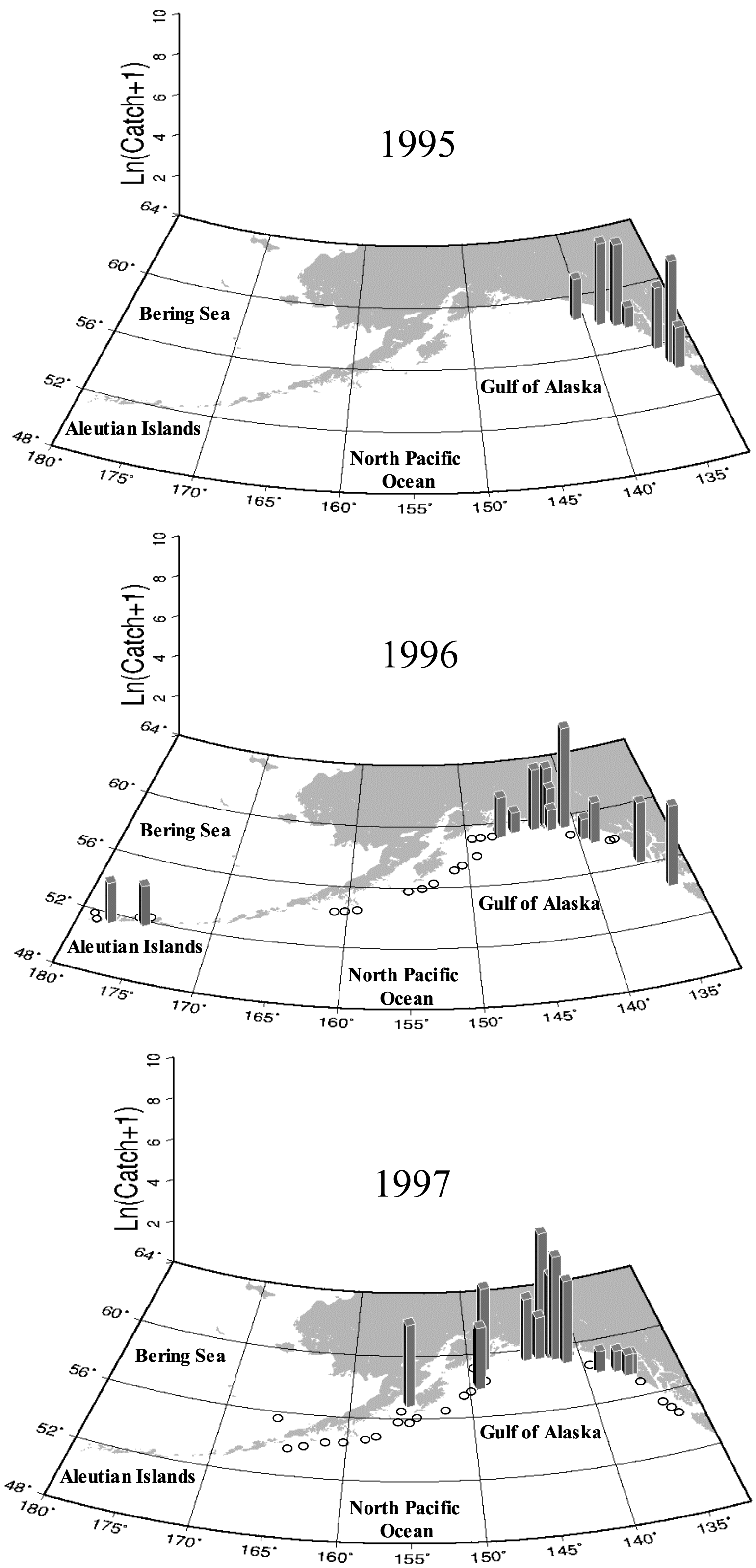

Figure 1. Maps of study area and young of the year sablefish catch per 200-m net by location, 1995–1999. The captures between 170° and 180°W longitude were age-1 sablefish. Circles on map represent hauls with no young of the year sablefish catch.

east of 150°W, in the central and eastern Gulf of Alaska. However, synoptic surveys are required for verification of the area effect, for example, by sampling the western, central, and eastern Gulf of Alaska after mid July and again during mid August.

The catch was dominated by 3 species groups, which together made up 96% of the catches from 1995 to 1999 (Table 1). Pacific saury *Cololabis saira* was the most common species caught but only because catches were high in 1995. Sablefish was almost as abundant, making up about one-third of the catch. Salmonids *Oncorhynchus* spp. (both juveniles and adults of pink *O. gorbuscha*, chum *O. keta*, sockeye *O. nerka*, coho *O. kisutch*, and chinook *O. tshawytscha* salmon) were the third most common species group. Pink salmon (juvenile and adult) were the most common salmonid.

Growth

A total of 151 young of the year sablefish otoliths were processed into transverse thin sections, of which 107 (71%) were suitable for the determination of daily age (Table 2). Some (29%) of the thin sections were ground too thin, missed the central primordium, or were unreadable over some section of the otolith and consequently were unsuitable for the determination of daily age. The aged fish ranged in size from 70- to

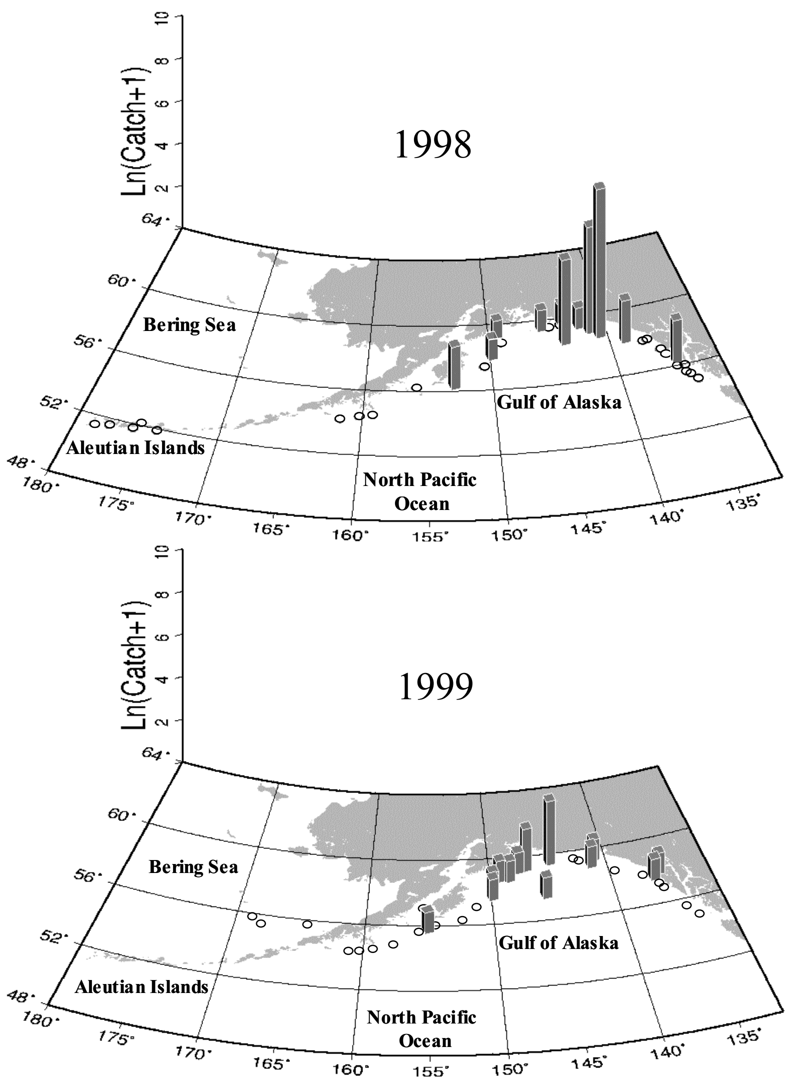

Figure 1. (continued)

200-mm FL, mean = 125 mm (SE = 2.7). Ages ranged from 53 to 147 days, median = 93 days (mean = 95 days, SE = 1.5). The day of the year of first-increment formation was estimated for aged fish as capture date (day of the year as numbered from January 1) minus daily age. Capture dates for aged fish ranged from day 193 (July 11) to day 249 (September 5), with median day = 213 (July 31) and mean day = 216 (August 3, SE = 1.5). Estimated dates of first-increment formation for aged fish were dispersed widely and ranged from day 93 (April 2) to day 158 (June 6), with median day = 121 (April 30) and mean day also 121 (SE = 1.3; Figure 3).

We initially pooled the length and estimated age data over all years. The linear relationship between pooled length and age was significant ($P < 0.001$, $n = 107$), indicating a growth rate of 1.19 mm·d^{-1} (SE = 0.13; Figure 4). We then separated the age data

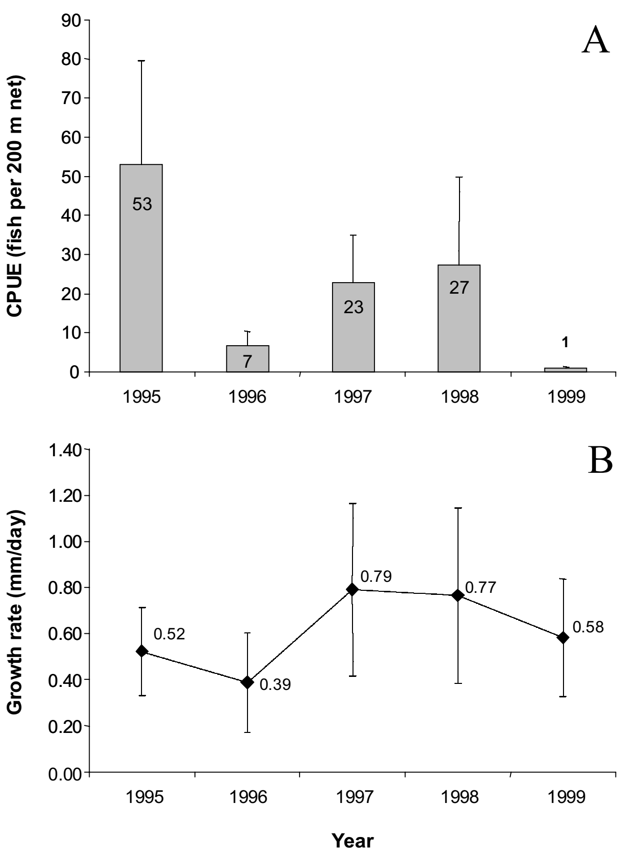

Figure 2. Panel A: Average catch per unit of effort (CPUE) of young of the year sablefish by survey year (+ standard error bars). CPUE for each haul was estimated as the average number of sablefish per 200-m net. Panel B: growth rates (mm·d^{-1}) for young of the year sablefish estimated as the slope of a linear regression by year, 1995–1999 (± standard error bars).

by year and estimated a regression relationship for each year. The annual regression relationships differed significantly from the pooled regression relationship (likelihood ratio test, $P < 0.01$; Hilborn and Mangel 1997). We did not test for significant differences in growth rates among years. However, the growth rates were fastest in 1997 (0.79 mm·d^{-1}, SE = 0.38, $n = 21$) and 1998 (0.77 mm·d^{-1}, SE = 0.38, $n = 25$), intermediate in 1995 (0.52 mm·d^{-1}, SE = 0.19, $n = 17$) and 1999 (0.58 mm·d^{-1}, SE = 0.26, $n = 22$), and slowest in 1996 (0.39 mm·d^{-1}, SE = 0.21, $n = 22$) (Figure 2b).

Diet

A total of 193 young of the year sablefish stomachs were analyzed, of which 164 (85%) contained food. Fish size ranged from 90- to 200-mm FL, with a mean of 136 mm (SE = 2.3). They fed mainly on euphausiids (73% by weight) and pelagic tunicates (9% by weight; Table 3). Other food items, pteropods, calanoid copepods, amphipods, and crab zoeae and megalopae (mainly *Cancer* spp.) were found frequently, but were relatively less important (< 6% by weight). Small amounts of larval capelin *Mallotus villosus* and Scorpaenidae were also found.

Euphausiids dominated the diet every year except 1998 (Table 4). Euphausiids made up more than 65% of sablefish diet by weight in 1995, 1996, and 1997, and 45% in 1999, but only 26% in 1998. In 1998 pelagic tunicates (*Ascidia* sp. and *Salpa* sp.) replaced euphausiids as the dominant prey (67% by weight). Pelagic tunicates also were a significant dietary item in 1997 (13% by weight). Pteropods were a frequent food item every year, but their biomass was important only in 1999 (21% by weight). Polychaetes also were an important dietary item only in 1999, 15% by weight compared to only about 1% in other years. Brachyuran zoeae and megalopae were frequent dietary items (<1% to 8% by weight) in those 5 years. Squid were a dietary item (< 1% by weight) every year except 1998.

DISCUSSION

Abundance

The gillnet catch rates may provide an index of recruitment strength based on young of the year relative abundance. Their annual pattern implies that sablefish recruitment was above average in 1995, 1997, and 1998 and below average in 1996 and 1999 (Figure 2a). Other data are available to estimate recruitment strength independently, including longline survey catch rates, age and length data, and fishery catch rates and length data. These data sets have been used to estimate sablefish recruitment using an age-structured analysis (Sigler et al. 1999), which provides recruitment estimates at age 2, whereas the gillnet survey provides earlier estimates for young of the year sablefish abundance. Thus, the gillnet survey may be useful for forecasting recruitment strength. We tested its usefulness by comparing the log-transformed gillnet catch rate residuals to the log-transformed recruitment estimate residuals from age-structured analysis where they overlapped in the 1995–1997 year classes (Figure 5a). Like the pattern of gillnet catches, the recruitment estimates from age-structured analysis also indicated the 1995 and 1997 year classes were above average, and the 1996 year class was below average.

Growth

A daily periodicity of otolith microgrowth-increment formation was assumed in this study. Otolith microgrowth increments were first described for young of the year sablefish by Beamish et al. (1983). Otolith increment analyses were subsequently used to estimate growth rates and first-increment formation dates of larval and juvenile sablefish captured off the Pacific coast of Oregon and Washington (Boehlert and Yoklavich 1985). Support for the daily deposition of increments has been provided by Boehlert and Yoklavich (1985) who examined 3 juvenile sablefish, 53–110-mm standard length at death, held in the laboratory. In that study a check mark was identified on each sagittal otolith and was assumed to have been induced by the stress of capture. The number of increments counted from the check mark to the edge of each otolith approximated the number of days in captivity. Beamish et al. (1983) also conducted daily age determinations from the sagittal otoliths of 9 juvenile sablefish to determine the location of the first winter annulus. The fish (230- to 270-mm FL) were assumed to be approximately 1 year old based upon their time of capture in February. Daily increment counts ranged from 270 to 350 and approximated the assumed age of the fish in days. Boehlert and Yoklavich (1985) and Beamish et al. (1983) noted that the interpretation of daily increments becomes more difficult in older specimens due to changes in sagittal otolith structure and to the progressively smaller distance between increments. Beamish et al. (1983) ground their sagittal otoliths in a sagittal thin section to view daily increments but were

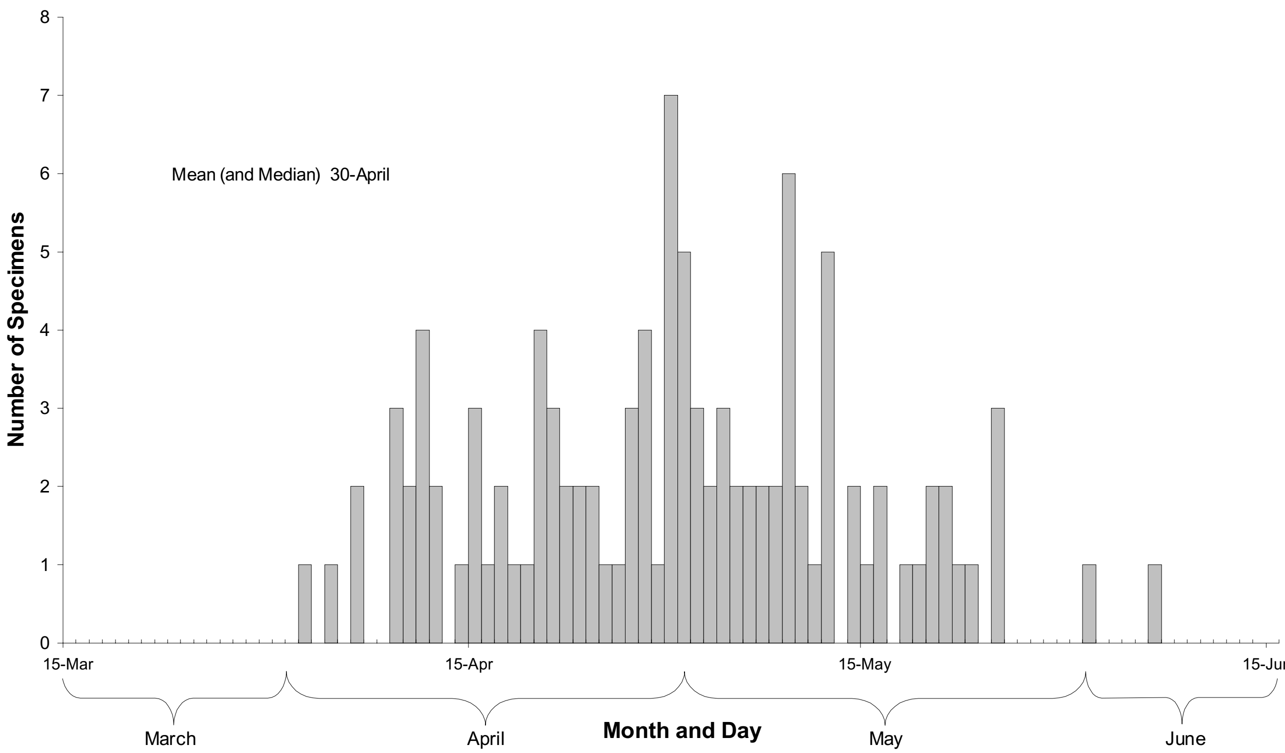

Figure 3. Distribution of estimated dates of first-increment formation for Gulf of Alaska young of the year sablefish, 1995–1999, determined by back-calculations using estimated age and capture date.

unable to view all increments at one time. A transverse section was introduced for older specimens by Boehlert and Yoklavich (1985). In our study, a transverse thin section was also required to detect increments from the center to the outside edge of a sagittal otolith.

The interpretation of otolith microgrowth-increment banding patterns can be subjective (Campana 1992; Neilson 1992;). Beamish et al. (1983) suggested their increment counts were most likely underestimates of true daily age. Boehlert and Yoklavich (1985) found no evidence of subdaily increments in their specimens, suggesting it would be difficult to overestimate the daily age of young of the year sablefish. In this study, the increment banding patterns near the center and near the outside edge of many transverse sections could be subject to multiple interpretations. However, without the availability of known-age juvenile sablefish otoliths, it is difficult to advocate any particular interpretation. Our approach in this case was to be as consistent as possible in our interpretation of increment banding patterns between otolith specimens. In this way, relative ages and growth rates could be compared between specimens and corrections to estimates of daily age can be applied at a later date if ongoing validation experiments indicate that they are necessary. The preparation of sagittal otolith thin sections in the transverse plane also provided for the maintenance of a complete record of the increment banding patterns from each otolith specimen, which can be reevaluated at a later date if warranted.

The growth rate of young of the year sablefish in the Gulf of Alaska from this study (1.19 mm·d^{-1}, $n = 107$, all years 1995–1999, $r^2 = 0.45$, SE = 0.13; Figure 4) was somewhat lower than that found in a similar study of juvenile sablefish captured off the Pacific

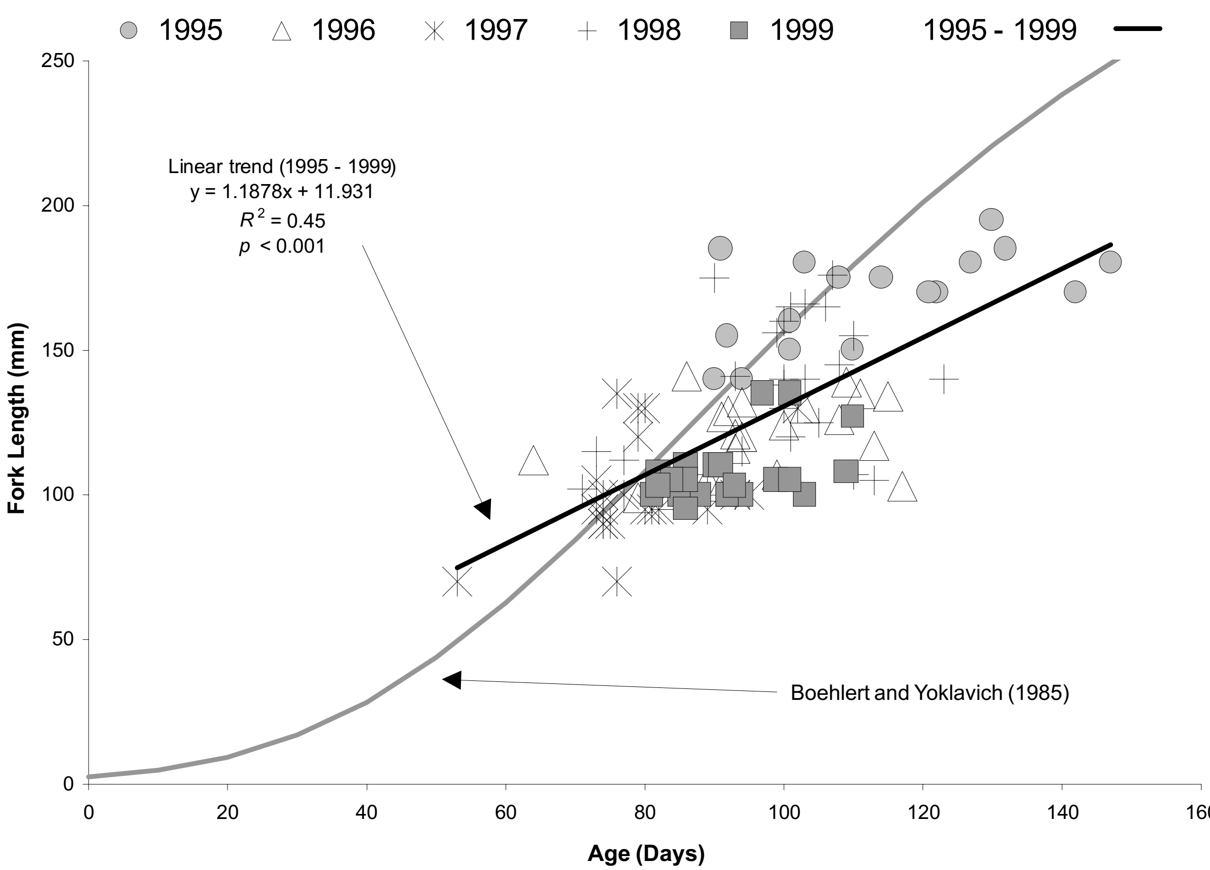

Figure 4. Length (mm) at estimated age (days) of young of the year sablefish from otolith daily age determinations. The solid line and equation represent the linear trend of the 1995–1999 Gulf of Alaska length-at-age data collected in this study. The shaded line represents the least squares fit of the Laird–Gompertz growth model reported by Boehlert and Yoklavich (1985) for standard length-at-age data from larval and juvenile sablefish collected in 1981–1983 off the Pacific coast of Oregon and Washington. Standard length was converted to fork length for this plot of the Laird–Gompertz growth curve using the relationship provided by Boehlert and Yoklavich (1985).

Table 3. Percent frequency of occurrence (%FQ), percent of number (%CT), and percent weight (%WT) of the prey of juvenile sablefish *Anoplopoma fimbria* collected in 40 hauls over all years.

Prey	%FQ	%CT	%WT
Polychaeta (worm)	6.71	0.20	0.90
Gastropoda (snail)	0.61	0.02	0.00
Pteropoda (Thecosomata or Gymnosomata)	22.56	17.90	3.83
Thecosomata (pteropod)	4.88	0.26	0.98
Cephalopoda (squid or octopus)	1.22	0.03	0.02
Teuthoidea (squid)	1.83	0.07	0.14
Crustacea	1.83	0.59	0.59
Calanoida (copepod)	10.98	0.46	0.58
Calanus sp.	1.83	0.03	0.32
Neocalanus cristatus	0.61	0.38	0.14
Amphipoda	1.22	0.02	0.03
Gammaridea	5.49	0.42	0.27
Hyperiidea	12.20	13.35	1.34
Themisto sp.	14.02	0.42	0.40
Euphausiacea (euphausiid)	33.54	0.64	14.38
Euphausiidae	9.15	25.79	21.11
Euphausia pacifica	0.61	0.00	0.54
Thysanoessa sp.	18.29	27.23	34.76
Thysanoessa inermis	0.61	0.02	0.02
Thysanoessa spinifera	5.49	0.42	1.90
Reptantia (crab)	2.44	0.20	0.13
Decapoda Brachyura (crab)	1.22	0.08	0.02
Majidae (spider crab)	0.61	0.02	0.00
Cancridae	26.22	8.46	5.13
Cancer sp.	2.44	2.32	0.67
Urochordata (tunicate)	1.22	0.00	0.03
Ascidia sp. (tunicate)	10.37	0.00	7.78
Salpa sp. (pelagic salp)	0.61	0.00	0.82
Osteichthyes Teleostei-unidentified (fish)	3.05	0.20	0.08
Non-gadoid fish remains	1.22	0.03	0.09
Mallotus villosus (capelin)	1.22	0.08	0.47
Scorpaenidae	1.22	0.07	0.34
Unidentified organic material	11.59	0.31	2.19

coast of Oregon and Washington (1.47 mm·d^{-1}, $n = 21$ juveniles captured in 1981, $r^2 = 0.822$; Boehlert and Yoklavich 1985). Boehlert and Yoklavich (1985) also fit the Laird–Gompertz growth curve to a broader size (and age) range of larval and juvenile sablefish captured off the Pacific coast of Oregon and Washington from 1981 to 1983. The majority of Gulf of Alaska young of the year sablefish from this study fall to the right of that curve graphically indicating that Gulf of Alaska sablefish in 1995–1999 grew slower than those captured off Oregon and Washington in 1981–1983 (Figure 4).

Estimated mean date of first-increment formation for Gulf of Alaska sablefish from this study was April 30, approximately one month later than the peak of first-increment formation for sablefish off the coast of Oregon and Washington (early April, Boehlert and Yoklavich 1985). These results are consistent with recent surveys that catch large numbers of neustonic sablefish larvae off the Pacific coast of Vancouver Island in April (McFarlane et al. 1997) and off the Pacific coast of southeastern Alaska in May (Wing 1997). Spawning is thought to occur approximately one month before first feeding of sablefish larvae (Boehlert and Yoklavich 1985; Kendall and Matarese 1987), when the first otolith increments may begin to form. Consequently, our results suggest that sablefish may spawn up to one month later in the Gulf of Alaska than off the coast of Oregon and Washington.

Some relationship may exist between year class strength and growth. A graphical comparison of estimated young of the year sablefish growth rates with estimates of young of the year sablefish gillnet catch rates showed some agreement in trends. The lowest gillnet catch rates occurred in 1996 and 1999, and sablefish growth rates were also the slowest in 1996

Table 4. Comparisons of the percent weight (%WT) by year of the main prey groups of juvenile sablefish *Anoplopoma fimbria* in the Gulf of Alaska.

Prey	Percent Weight (%WT)				
	1995	1996	1997	1998	1999
Polychaeta	0.14	1.18	0.00	0.00	15.25
Pteropoda	5.23	1.35	4.07	0.78	21.08
Teuthoidea (squid)	0.10	0.93	0.15	0.00	0.42
Crustacea (unidentified)	0.96	0.00	0.01	0.00	0.00
Calanoida (copepod)	0.00	0.08	8.55	0.13	2.84
Amphipoda	2.34	0.39	1.37	0.29	7.68
Euphausiacea (euphausiid)	80.51	90.08	65.54	26.18	44.72
Brachyura (crab) zoea & megalops	7.93	2.23	0.37	4.02	7.01
Urochordata (tunicate)	0.00	0.00	13.17	66.72	0.00
Osteichthyes Teleostei (fish)	0.04	0.00	6.78	1.88	1.00
Unidentified organic material	2.85	3.37	0.00	0.00	0.00
Total prey weight (g)	81.41	16.91	13.78	14.39	5.73

and 1999. However, the highest gillnet catch rate occurred in 1995, but sablefish growth rate was only moderate in 1995 (Figures 2a and 2b). Alternatively, a graphical examination of the fit to the linear trend in growth pooled across all years, 1995–1999, revealed that the majority of young of the year sablefish captured in 1995 were above the pooled linear growth estimate, and the majority of sablefish captured in 1999 were below the pooled linear growth estimate (linear trend, Figure 4). This may indicate that young of the year sablefish had already attained a larger size for a given age in 1995 (relative to 1999) before the time period covered by the gillnet survey (primarily June–August).

Diet

Sablefish are planktivores in their larval and early juvenile stages and piscivores during late juvenile and adult stages. Sablefish larvae consume primarily planktonic copepods and amphipods (Grover and Olla 1990). Our young of the year sablefish consumed zooplankton, primarily euphausiids. Sablefish ≥ 400-mm FL consumed fish and invertebrates; 400–600-mm FL sablefish consumed more euphausiids, shrimp, and cephalopods, whereas larger sablefish (≥600-mm FL) consumed mainly fish (Yang and Nelson 2000).

Young of the year sablefish are zooplankton feeders, consuming mainly euphausiids; pelagic tunicates were important only in 1998, and pteropods and polychaetes were important only in 1999. This pattern is unrelated to above-average gillnet catch rates in 1995, 1997, and 1998 and below-average gillnet catch rates in 1996 and 1999 (Figure 2), indicating that year class strength may be unrelated to diet composition. These differences in prey-item importance may be due to patchy prey distribution. Pelagic tunicates occurred in only 2 of 9 stations sampled in 1998 (100% and 67% by weight). Similarly, pteropods were found at only 2 of 7 stations in 1999 (95% and 92% by weight).

Forecasting Recruitment

Age 2 is the earliest age for which recruitment strength currently can be estimated because age 2 is the earliest age available from survey and fishery data. Age-structured analysis is used to interpret these data and infer absolute abundance of 2-year-olds. These recruitment estimates are imprecise for the most recent year classes because these year classes have been observed only 1 or 2 times and are only partially available to the survey and fishery. Thus a young of the year index would be useful to forecast the number of fish < 2 years old and improve the precision of estimates for recent year classes.

Methods for developing recruitment indices typically include attempts to correlate recruitment with environmental time series. For illustrative purposes we collected several physical oceanographic time series available for the northern Pacific Ocean and compared them with sablefish recruitment estimates from age-structured analysis. Relative sea surface drift strengths and direction were plotted with OSCURS, (a model developed by W. James Ingraham, Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, <http://www.refm.noaa.gov/docs/oscurs/get_to_know.htm>). The starting point was Ocean Papa Weather Station, which is within subarctic water but is located near the boundary of the more productive

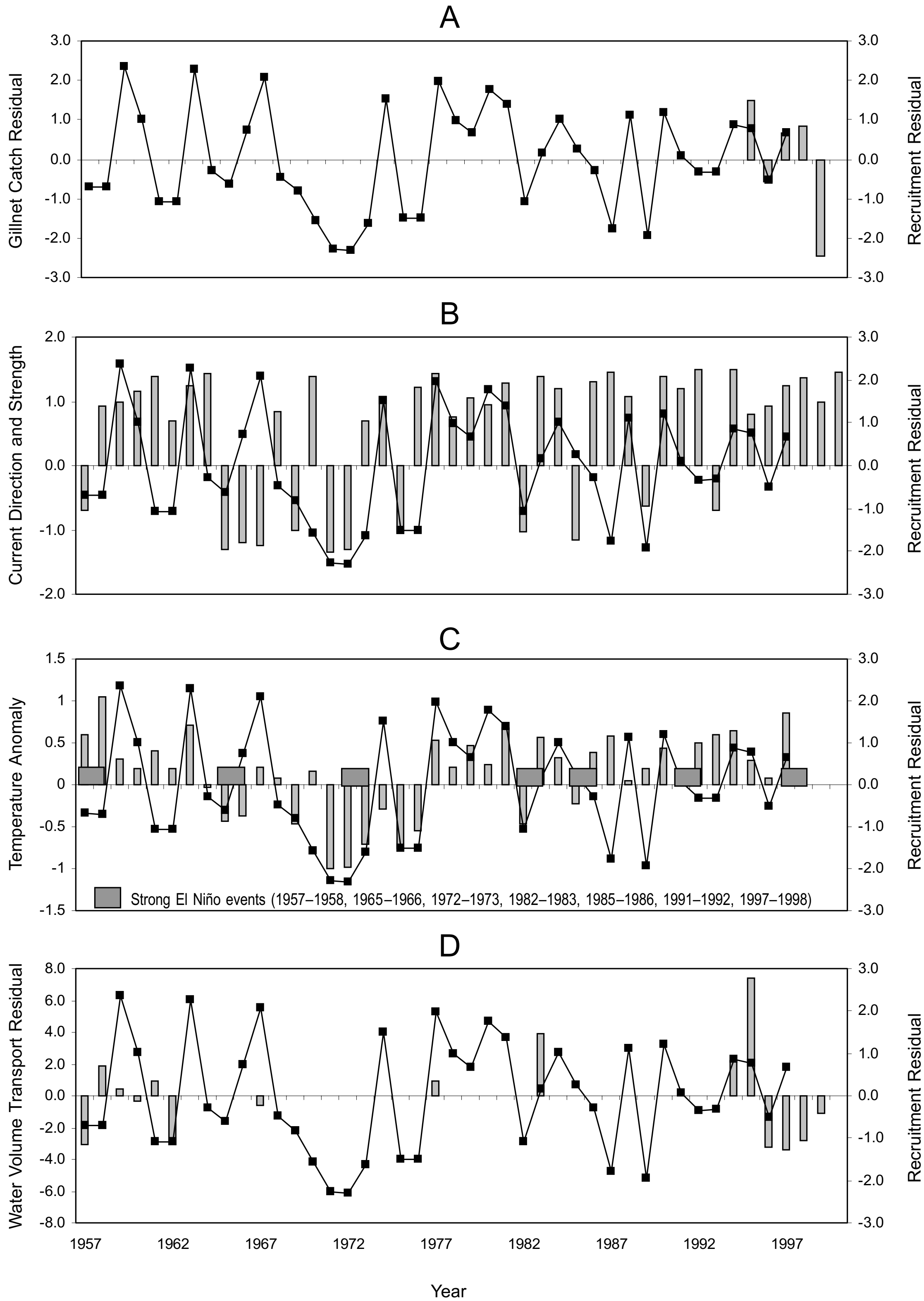

Figure 5. Log-transformed sablefish recruitment residual from age-structured analysis (Sigler et al. 1999; —■—) and log-transformed gillnet catch residual (A), current direction and strength (+ is north, – is south; B), temperature residual (strong El Niño events indicated by a box along the x-axis; C), and water volume transport residual (D).

oceanic subarctic water and the less productive oceanic subtropic water. Fifty years of surface current data were available to compare with 40 years of sablefish recruitment estimates (Sigler et al. 1999). The starting date was December 1 each year, and the duration was 90 days. Simulated drift was most often toward the northeast. Weak flows tended to move eastward toward Vancouver Island while the strongest flows reached 60°N latitude. Recruitment estimates were also compared with the annual occurrence, size, and strength of the Sitka or Tabata Eddy for 1954–1983 (Mysak 1985) and 1994–1999 (Onishi et al. 2000). Eddy intensities were expressed in baroclinic transport (millions of cubic meters per second) across line P (Mysak 1985) and volume transport (millions of cubic meters per second) of the eddy (Onishi et al. 2000). Values for 1954, 1956, 1957, and 1983 were estimated from winter atmospheric circulation. Mysak (1995) transport values were used to calculate the mean and annual residuals. Data from Onishi et al. (2000) were analyzed in a similar manner. Sablefish age-structured analysis recruitment residuals also were compared with sea surface temperature anomalies for 1950 to 1995 and strong El Niño events up to 1998 (departures from mean degrees Celsius, 1950 to 1979; Downton and Miller 1998, their figure 4–Region B: Gulf of Alaska and British Columbia Coast).

Estimates of sablefish recruitment success from age-structured analysis varied greatly from year to year (Sigler et al. 1999; Figure 5a). Recruitment success appeared related to winter current direction (Figure 5b); greater-than-average years of recruitment were more common for years with a northerly drift (17 of 29, 59%) than for years with an easterly or southerly drift (3 of 12, 25%) (χ^2 test, $P = 0.05$). Less-than-average years were distributed throughout both north and south modes. Recruitment success also appeared related to temperature anomalies (Figure 5c). Recruitment was above average in 17 of 29 years (59%) when temperature was above average, but in only 3 of 12 years (25%) when temperature was below average (χ^2 test, $P = 0.05$). Residuals of drift direction and magnitude and temperature anomaly appeared related, especially for 1957 to 1987, and showed an interdecadal oscillation from 1957 to 1981 (Figures 5b and 5c). Recruitment followed the trend generally, but there were several years when it did not, particularly 1986–1989. Strong El Niños occurred 7 times during the study period (Figure 5c). The presence of El Niños did not appear to improve recruitment success during the year that they occurred. Above-average recruitments occurred in 5 of 13 years (38%) when El Niños were present and in 15 of 28 years (54%) when they were absent (χ^2 test, $P > 0.25$). Above-average recruitments did occur the year following an El Niño in 4 of 7 instances. El Niños are reported to induce eddies in the Gulf of Alaska that are reported to have major effects on the local fisheries (Melsom et al. 2000). The incidence and relative strengths of anticyclonic eddies had no obvious effect on recruitment strength (Figure 5d). For years when eddy data were available, above-average recruitments occurred in 5 of 7 years (71%) when eddies occurred and 3 of 6 years (50%) when eddies were absent (χ^2 test, $P > 0.25$). These eddies propagate slowly into the Gulf of Alaska and last for years, and therefore may affect recruitment for several adjacent years.

Hollowed and Wooster (1992) reported on the variability of winter ocean conditions and strong year classes of northeastern Pacific Ocean groundfish from 1945 to 1984. Since 1932 warm and cool eras of 6 to 12 years duration have alternated. They reported that 50% or more of the groundfish stocks had strong year classes in 1951, 1961, 1970, 1977, and 1984. For sablefish only the 1977 and 1984 cohorts were strong. Francis et al. (1998) compared Hollowed and Wooster's (1992) peak recruitment years to sea surface temperature anomalies by year and found that warm water was present in the northern reaches of the northeastern Pacific Ocean during most of these years. Hollowed and Wooster (1995) revisited the synchronous strong year classes identified earlier (1961, 1970, 1977, and 1984) and found that the identity of stocks participating in this synchrony differed with time. Temperature was identified as a major variable in determining year class strength along with El Niño, periods of intense Aleutian lows, enhanced circulation in the Gulf of Alaska, and weakened coastal upwelling farther south.

From our brief examination of 40 years of sablefish recruitment data and selected environmental variables it appears that several factors may collectively influence recruitment success. Water mass movements and temperature appear related to recruitment success. Above-average recruitment was somewhat more likely with northerly winter currents and much less likely for years when the drift was southerly. Recruitment success also appeared related to water temperature. Recruitment was above average in 61% of the years when temperature was above average, but was above average in only 25% of the years when temperature was below average. Recruitment success did not appear directly related to the presence of El Niños or eddies, but they potentially could influence recruitment indirectly in years following their occurrence. Temperature, current strength and direction, and eddy strength residuals all were positive during the regime shift year of 1977, correlating with the very strong sablefish recruitment of that year. Although we cannot draw conclusions, we believe an in-depth study of sablefish recruitment as related to oceanographic effects is warranted. However, such a study will be constrained by the lack of consistent and long-term oceanographic data for the eastern Gulf of Alaska.

The young of the year index provided by surveys sampling near-surface waters may be the best approach for forecasting recruitment, at least for the present. The gillnet surveys implied that the 1998 year class was above average and that the 1999 year class was below average. Other information also indicated that the 1998 year class was above average. One-year-old fish were abundant in many coastal areas of Alaska in 1999, an observation that in the past has occurred only for above-average year classes. The patterns of gillnet catch rates and recruitment estimates from age-structured analysis matched for the albeit short time series of 3 years that they overlapped (Figure 5a). If trends in these time series continue to overlap, then the young of the year index provided by surveys sampling near-surface waters could prove to be a valuable predictor of future recruitment strength.

Sablefish spawn during winter, with the spawning peak in mid February in British Columbia (Mason et al. 1983). Young of the year sablefish are captured during June–August during the gillnet surveys near the continental shelf break, and at least some of the young of the year reach the nearshore by September in southeastern Alaska (Rutecki and Varosi 1997). If the young of the year index provided by gillnet surveys is in fact a good forecast of recruitment strength, then year class strength is already established by the June–August sampling period of the young of the year surveys.

LITERATURE CITED

Beamish, R. J., G. A. McFarlane, and D. E. Chilton. 1983. Use of oxytetracycline and other methods to validate a method of age determination for sablefish. Pages 95–116 *in* B. R. Meteff, editor. Proceedings of the International Sablefish Symposium. University of Alaska Sea Grant College Program Report 83-8, Fairbanks.

Boehlert, G. W., and M. M. Yoklavich. 1985. Larval and juvenile growth of sablefish, *Anoplopoma fimbria*, as determined from otolith increments. Fishery Bulletin 83:475–481.

Campana, S. E. 1992. Measurement and interpretation of the otolith microstructure of fish otoliths. Pages 59–71 *in* D. K. Stevensen and S. E. Campana, editors. Otolith microstructure examination and analysis. Canadian Special Publication of Fisheries and Aquatic Sciences 117.

Clark, W. G., S. R. Hare, A. M. Parma, P. J. Sullivan, and R. J. Trumble. 1999. Decadal changes in growth and recruitment of Pacific halibut. Canadian Journal of Fisheries and Aquatic Sciences 56:242–252.

Downton, M. W., and K. A. Miller. 1998. Relationships between Alaskan salmon catch and North Pacific climate on interannual and interdecadal time scales. Canadian Journal of Fisheries and Aquatic Sciences 55:2255–2265.

Francis, R. C., S. R. Hare, A. B. Hollowed, and W. S. Wooster. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. Fisheries Oceanography 7:1–21.

Grover, J. J., and B. L. Olla. 1990. Food habits of larval sablefish *Anoplopoma fimbria* from the Bering Sea. Fishery Bulletin 88:811–814.

Hagen, P. T., and T. J. Quinn II. 1991. Long-term growth dynamics of young Pacific halibut: evidence of temperature-induced variation. Fisheries Research 11:283–306.

Hiatt, T., and J. Terry. 1999. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Island area: economic status of the groundfish fisheries off Alaska, 1999. Available from North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, Alaska 99510-2252.

Hilborn, R., and M. Mangel. 1997. The ecological detective: confronting models with data. Princeton University Press, Princeton.

Hollowed, A. B., and W. S. Wooster. 1992. Variability of winter ocean conditions and strong year classes of Northeast Pacific groundfish. ICES Marine Science Symposium 195:433–444.

Hollowed, A. B., and W. S. Wooster. 1995. Decadal-scale variations in the eastern subarctic Pacific: B. Response of Northeast Pacific fish stocks. Pages 373–385 *in* R. J. Beamish, editor. Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121.

Kendall, A. W. Jr., and A. C. Matarese. 1987. Biology of eggs, larvae, and epipelagic juveniles of sablefish, *Anoplopoma fimbria*, in relation to their potential use in management. Marine Fisheries Review 49:1–13.

Mason, J. C., R. J. Beamish, and G. A. McFarlane. 1983. Sexual maturity, fecundity, spawning, and early life history of sablefish (*Anoplopoma fimbria*) off the Pacific coast of Canada. Canadian Journal of Fisheries and Aquatic Sciences 40:2126–2134.

McFarlane, G. A., M. W. Saunders, R. E. Thomson, and R. I. Perry. 1997. Distribution and abundance of larval sablefish, *Anoplopoma fimbria*, off the west coast of Vancouver Island, and linkages to physical oceanography. Pages 27–38 *in* M. E. Saunders and M. W. Wilkins, editors. Biology and management of sablefish. U.S. Department of Commerce, NOAA Technical Report NMFS-130.

McFarlane, G. A., and R. J. Beamish. 1992. Climatic influence linking copepod production with strong year-classes in sablefish, *Anoplopoma fimbria*. Canadian Journal of Fisheries and Aquatic Sciences 49:743–753.

Melsom, A., H. E. Hurlburt, E. J. Metzger, S. D. Meyers, and J. J. O'Brien. No date. El Niño induced ocean eddies in the Gulf of Alaska. <http://www.coaps.fsu.edu/~meyers/papers/ALASKA/goa.html>.

Mysak, L. A. 1985. On the interannual variability of eddies in the northeast Pacific Ocean. Page 97 *in* W. S. Wooster and D. L. Fluharty, editors. El Niño North: Niño effects in the eastern subarctic Pacific Ocean, University of Washington Sea Grant Report 85-3, Seattle.

Neilson, J. D. 1992. Sources of error in otolith microstructure examination. Pages 115–125 *in* D. K. Stevensen and S. E. Campana, editors. Otolith microstructure examination and analysis. Canadian Special Publication of Fisheries and Aquatic Sciences 117.

Onishi, H., S. Ohtsuka, and G. Anma. 2000. Anticyclonic, baroclinic eddies along 145°W in the Gulf of Alaska in 1994–1999. Bulletin of the Faculty of Fisheries, Hokkaido University 51:31–43.

Rutecki, T. L., M. F. Sigler, and H. H. Zenger Jr. 1997. Data report: National Marine Fisheries Service longline surveys, 1991–96. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-83.

Rutecki, T. L., and M. F. Sigler. 1999. Surveys of juvenile sablefish in Alaskan waters, 1995–1997. North Pacific Anadromous Fish Commission Document 393. Available from Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 11305 Glacier Highway, Juneau, Alaska 99801-8626.

Rutecki, T. L., and E. R. Varosi. 1997. Distribution, age, and growth of juvenile sablefish, *Anoplopoma fimbria*, in Southeast Alaska. Pages 45–54 *in* M. E. Saunders and M. W. Wilkins, editors. Biology and management of sablefish. U.S. Department of Commerce, NOAA Technical Report NMFS-130.

Sigler, M. F., J. T. Fujioka, and S. A. Lowe. 1999. Alaska sablefish assessment for 2000. Pages 255–305 *in* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2000. Available from North Pacific Fishery Management Council, 605 West 4th Avenue, Suite 306, Anchorage, Alaska 99501-2252.

Sogard, S. M., and B. L. Olla. 1998. Behavior of juvenile sablefish, *Anoplopoma fimbria* (Pallas), in a thermal gradient: balancing food and temperature requirements. Journal of Experimental Marine Biology and Ecology 222:43–58.

Stevenson, D. K., and S. E. Campana, editors. 1992. Otolith microstructure examination and analysis. Canadian Special Publication of Fisheries and Aquatic Sciences 117.

Wing, B. L. 1997. Distribution of sablefish, *Anoplopoma fimbria*, larvae in the Eastern Gulf of Alaska: neuston-net tows versus oblique tows. Pages 27–28 *in* M. E. Saunders and M. W. Wilkins, editors. Biology and management of sablefish. U.S. Department of Commerce, NOAA Technical Report NMFS-130.

Yang, M.-S., and M. W. Nelson. 2000. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-112.