Factors Affecting Sablefish Recruitment in Alaska

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Executive Summary

Amendments to the EFH FMP text of Alaska sablefish included suggestions for future consideration of small, unobtrusive research closures in areas of intense fishing. This prompted a Council request to provide information regarding all factors influencing sablefish recruitment. This document responds to that request in the form of a review paper on a variety of aspects revolving around sablefish recruitment. The first two sections include a general overview of sablefish early life history and issues surrounding the estimation of recruitment in the stock assessment model. We follow this with a three stage rationale for defining sablefish recruitment, summaries of available data for each stage, and an evaluation of factors influencing the three stages. The document concludes with a discussion section that introduces three current research projects, identifies data gaps and research priorities, and considers implications for conservation efforts. We believe it is premature at this juncture to recommend habitat conservation measures specifically for sablefish. However, we continue to suggest that research closures are one effective tool for understanding effects of fishing, and we recommend that any new conservation measures be designed within a multi-species context as an effort by management to seek a better understanding of changes to the ecosystem and EFH.

Introduction

In 2009, stock assessment authors were requested to review current FMP text regarding Essential Fish Habitat (EFH) for each species or species complex and report any updates or changes since the 2005 EFH Environmental Impact Statement (EIS). The Plan Teams reviewed changes to the FMP text and any author recommendations for EFH conservation or Habitat Areas of Particular Concern (HAPC). The Alaska sablefish authors submitted changes to the Gulf of Alaska (GOA) FMP text on EFH description for early juveniles, known predators on adults, shifts in fishery gear type, information on food habits, and references or literature cited. Since sablefish are considered one stock for Alaska, the Bering Sea and Aleutian Islands (BSAI) text was changed substantially to be consistent with the GOA text. The authors stated that little is known about the early juvenile stage distribution, habitat requirements, and interaction with other components of the ecosystem, but that juveniles have been known to reside in habitat subject to potentially adverse fishing effects (NMFS 2005). An evaluation of the effects of fishing on habitat in these areas along with the role of these features in the ecosystem was suggested. The authors further clarified that an analysis of the recovery rates for sensitive habitat features in areas of intense fishing (NMFS 2005) and the role of those features on the growth and survival of juvenile sablefish and other species would be very useful. The EFH summary concluded that areas of persistent and intense bottom trawling could be a concern. The authors suggested a potential future step for NMFS is to consider implementing small, unobtrusive research closures to determine whether EFH for sablefish and other species in these areas were adversely affected.

Following review of the EFH updates, the Plan Teams submitted similar recommendations as that of the sablefish authors to the Council and recommended these statements as high priority for the Council to consider. In April 2010, the Council discussed this agenda item and issued a request that NMFS prepare a discussion paper on all factors that may affect sablefish recruitment. The request was issued to allow for the Council to determine what type of management tools or research efforts may be available for protecting juvenile sablefish and the resulting conservation measure required. This document is the response to the Council request. We first present known information on sablefish early life history (ELH) and a review of issues involving estimating recruitment for this species. We then put forward a three stage rationale for estimating sablefish recruitment and include a synopsis of available ELH data for each stage. Following this, we evaluate the main ecological factors influencing the three stages. We conclude the document with a discussion that introduces three current research projects, identifies data gaps and research priorities, and considers implications for conservation efforts.

Early Life History

Sablefish (*Anoplopoma fimbria*) are a fast growing, highly valuable commercial groundfish species distributed across the North Pacific from northern Mexico to the Bering Sea (Wolotira et al. 1993). Two populations exist within this range based on differences in growth rate, size at maturity, and tagging studies (McDevitt 1990, Saunders et al. 1996, Kimura et al. 1998). The northern or Alaska sablefish are assessed as a single population in Federal waters off Alaska due to their propensity for large scale movements (Heifetz and Fujioka 1991). Sablefish in northern BC and inside waters of Alaska (e.g., PWS, Chatham Strait, Clarence Strait) are generally considered part of the Alaska population but are assessed separately. Adults in Alaska are typically encountered between 200-1000 m along the continental slope, shelf gullies, and deep fjords. Spawning takes place in depths between 300-500 m and occurs between January and May, with later spawning at higher latitudes (Mason et al. 1983, McFarlane and Nagata 1988, Sigler et al. 2001). Average spawning date for Alaska is estimated to be March 30 from otolith analysis (Sigler et al. 2001) and peak spawning was observed in February for southeast Alaska (Hanselman et al. 2009). The eggs are pelagic and thought to incubate for several weeks, increasing in density and sinking to depths between 400-1000 m (Kendall and Matarese 1987). After hatch, larvae begin feeding at depth and immediately swim toward the surface, developing as far offshore as 160 km in southeast Alaska (Wing 1997) to 240 km in the Aleutians (Kendall and Matarese 1987). Sablefish larvae (<35 mm) grow very quickly, from 1.2 up to 2 mm per day (Kendall and Matarese 1987, Sigler et al. 2001). When larvae are small, diet consists mostly of copepod nauplii and eggs. As larvae grow, diet shifts to mainly copepods and euphausiids, but may also include amphipods, pelagic tunicates, and pteropods (Yang and Nelson 2000).

There is no clear transition from larvae to young-of-the-year (YOY) juveniles. However, large, pigmented pectoral fins are a diagnostic feature of larvae as they grow and both stages appear to be obligate surface dwellers as they drift inshore (Kendall and Matarese 1987). Juvenile sablefish may also exhibit some thermal intolerance to very cold water. Laboratory studies on early juveniles in Oregon indicate avoidance of cold water except when food was present and a potential lethal risk for extended dives below the thermocline (Sogard and Olla 1998). In Alaska, samples of YOY sablefish are primarily collected near the continental shelf break in the central and eastern Gulf of Alaska (GOA) and have been caught in some years on the Bering Sea shelf (Grover and Olla 1990, Sigler et al. 2001). YOY sablefish (35-200 mm) mainly consume euphausiids, but also ingest pelagic tunicates, pteropods, and polychaetes (Sigler et al. 2001). Typically by the end of the summer YOY less than 200 mm reach nearshore bays where they spend the winter and following summer reaching 300-400 mm. At this time juveniles begin offshore movement to deeper water with younger fish (ages 3-4) inhabiting the continental shelf and older fish migrating to the slope habitat (Rutecki and Varosi 1997a). Juvenile sablefish (400-600 mm) are opportunistic feeders with fish (e.g. pollock, eulachon, herring), squid, jellyfish, and euphausiids comprising the majority of their diet (Yang and Nelson 2000). As they age, sablefish tend to move counterclockwise through the GOA reaching adult habitat within 4 to 5 years (Maloney and Sigler 2008, Rutecki and Varosi 1997a, Heifetz and Fujioka 1991). Sablefish, therefore, do not recruit to the fishery until they are around four years old.

Issues Estimating Recruitment

Often considered the fundamental driver of fluctuations in stock size, recruitment is generally defined as the abundance of the youngest fish entering a population that can be estimated successfully (Myers 1998, Maunder and Watters 2003). Developing a reliable estimate of recruitment has been a long standing problem for fisheries management. Variability in recruitment results from fluctuations in spawning stock size (i.e. egg production) and variability in egg-to-recruit survival. Factors influencing the egg to recruit survival may include natural or anthropogenic changes in the physical environment, shifts in populations of prey, and changes in competition and/or predation. The difficulty in estimating recruitment is in understanding the underlying processes that influence recruitment and then estimating the most recent years of recruitment where there is a dearth of information.

The Alaska sablefish assessment model incorporates a variety of survey and fishery information (e.g. biomass indices, catch, age and length compositions) in a maximum likelihood framework to simultaneously estimate spawning biomass, recruitment, fishing mortality, and a projection of future harvests. Recruitment is not modeled with a stock-recruitment relationship; rather it is computed as mean recruitment and annual recruitment deviations. Recruits are estimated as 2-year-old fish because very little information is available in the age/length compositions for age-0 to age-1 fish. Annual estimated recruitment is extremely episodic and appears unrelated to spawning biomass over the range of observed abundances (Hanselman et al. 2009).

Recruitment estimates based on information from the 1960s are extremely uncertain as they are based only on limited fishery catch rate data. Additionally, estimates of the most recent years of recruitment are highly uncertain since there is no catch-at-age data available for the most recent years. Therefore, recent recruitment estimates are not used in projections. Average recruitment is reported as 18.0 million 2-year-old sablefish per year based on estimates from 1979-2007 (Hanselman et al. 2009). Estimates of annual recruitment vary widely but large year classes can be clearly tracked in the survey and fishery age composition data. The top 25% of recruitment values are considered strong year classes and occurred in the early 1960s, 1971, 1977-1978, early 1980s, 1989, 1991, 1997, and 2000 (Hanselman et al. 2009). Additionally, the extremely large 1977-78 and 1980-81 year classes occurred when sablefish biomass was near historic lows. More recently, the 1997 and 2000 larger than average year classes were also produced when the population was at a recent low. Conversely, weak or average year classes have been produced when the sablefish population was at historic highs. This information suggests that sablefish recruitment may be highly influenced by environmental conditions.

Several of these successful recruitment years for sablefish coincide with strong year classes for many northeast Pacific groundfish stocks (Hollowed and Wooster 1992). The high survival synchrony in 1977 has been attributed to a major regime shift in the north Pacific and associated with a phase change in the Pacific Decadal Oscillation (PDO) to warmer conditions (Hare and Mantua 2000). Other potential climate-recruit relationships have been suggested for the Alaska sablefish such as water mass movements and temperature changes. Above-average recruitment was somewhat more likely with northerly winter currents and much less likely for years when the drift was southerly (Sigler et al. 2001). One study on the west coast sablefish population showed significant relationships between Ekman transport and sea-level height with sablefish recruitment (Schirripa and Colbert 2006).

Stages of Recruitment

Typically, the two primary factors affecting recruitment are the level of adult spawning and the ecological processes influencing egg to recruit survival. As discussed previously, the level of adult spawners seems to be a secondary factor. Fishing on pre-recruits may also affect survival to the adult stage. Sablefish have been targeted since the 19th century, but were not heavily exploited until the directed Japanese longline fishery began in the 1960s. Heavy fishing in the 1970s lead to a large decrease in the population and strict fishery regulations in Alaska were imposed to sharply reduce catches since this time (Hanselman et al.

2009). Large fluctuations in recruitment and stock size have occurred in spite of precautionary fishing levels since the 1980s. Given the highly variable recruitment during levels of high/low spawning biomass and fishing, it seems likely that sablefish recruitment is primarily driven by ecosystem process. We therefore rationalize that a critical window for sablefish survival is bound by the egg/larval development in the offshore pelagic zone through nearshore settlement and subsequent juvenile migration to the adult slope habitat approximately four years later.

We partition this early life history (ELH) into three distinct sequential steps or stages (Figure 1). Each successive stage mediates the output from the previous stage with the net output of all three stages resulting in recruitment to the adult population on the continental slope and deep gullies. We have provided a brief overview of sablefish ELH and draw upon this general information to define each stage. Egg, larval, and early juveniles in the pelagic oceanic offshore ecosystem define stage I. Juveniles from their first late summer to their second winter settling in nearshore waters define stage II. Early recruit two-year-olds to four-year-olds on the continental shelf and shallow gullies prior to migrating to the adult habitat define stage III. Stage I probably has the highest annual variability in survival due to highly complex interactions in the pelagic open ocean environment. Stages II and III likely have small annual variation within locale but may have long-term temporal or spatial trends due to changes in the benthic habitat or density dependent effects. In the following three sections, we list potential factors influencing survival in each stage and any available ELH data for sablefish.

Stage I: Pelagic Offshore to Nearshore

This first stage is spatially bound by egg and larval development in the offshore pelagic zone to early juvenile settlement in the nearshore zone. Timing of this stage occurs from late winter, early spring through late summer, early fall of the first year. Survival during this period is dependent on factors related to transport, productivity, and predation from the offshore to the nearshore. Larvae and early juvenile sablefish have protective coloration or countershading (dark on dorsal surface, light on ventral surface) which may aid in predator avoidance (Kendall and Matarese 1987). However, the rapid growth requirements and high consumption rates of larval and YOY sablefish result in a strong dependence on encounter of highly productive environments. Growth rate of young-of-the-year sablefish is higher in years when recruitment is above average (Sigler et al. 2001). Food shortage and adverse drift may be a significant source of mortality for this stage. (Kendall and Matarese1987).

Previous surveys have been successful in capturing egg, larvae, and YOY sablefish; however, sampling has been periodic and gear types differed between surveys. The Recruitment Processes Program at the Alaska Fisheries Science Center (AFSC) has successfully sampled eggs, larvae, and YOY sablefish from the Bering Sea through the central and western GOA since the early 1970s. Sampling primarily occurred during April and May and included bongo nets and Tucker trawls for vertical tows and neuston nets for surface tows (Matarese et al. 2003). The U.S. Global Ocean Ecosystem Dynamics (GLOBEC) program performed surface trawls along transects at various locations in the GOA from Yakutat to southwest Kodiak Island. YOY sablefish were captured during summer from 1999 through 2003 (J. Moss, pers. comm.). The Southeast Alaska Coastal Monitoring (SECM) program at the AFSC has conducted surface trawling at four coastal stations off Icy Point in southeast Alaska (7 to 65 km offshore) from spring to fall during 1997-1999. YOY sablefish were captured at various years, sometimes in large quantities such as in summer 1997 (Orsi et al. 2000). A survey was conducted by scientists at the AFSC in May 1990 to investigate sablefish and associated ichthyoplankton distribution in the eastern GOA. Neuston, bongo, and CTD (conductivity, temperature, depth) sampling occurred on stations along transects extending as far as 160 km offshore. Larval sablefish were caught at most stations (except nearshore) with a potential three-fold increase during night-time sampling (Wing 1995). As part of a voluntary logbook program in southeastern Alaska, commercial salmon trollers identified prey in stomachs of chinook and coho salmon from 1977-1991 along the outer coast of Alaska from Dixon Entrance to Yakutat. Sablefish YOY were common prey during September (Wing 1985). The Marine Ecology and Stock Assessment (MESA) program at the AFSC conducted nighttime sets using a variable-mesh gillnet during the annual AFSC sablefish longline survey from 1995-2004. Large numbers of YOY sablefish were captured from 1995 through 1998 generally in the eastern GOA. Numbers declined substantially from 1999 to 2004 when the gillnet survey ended.

Stage II: Nearshore Settlement

Timing and location of settlement is largely unknown for sablefish and likely includes a range of depths and benthic habitats. Generally, settlement is thought to be before the first overwinter period, although sablefish perform vertical migrations throughout their nearshore existence (Sogard and Olla 2001). Opportunistic surveys performed in nearshore bays and inlets throughout southeast Alaska suggests that YOY sablefish occur consistently in only a few locations. However, during years of high recruitment YOY sablefish were found throughout the area (Rutecki and Varosi 1997b). This suggests that YOY sablefish may utilize a variety of benthic habitats in the nearshore, but specific features of a few locations may be unique and critical to maintain a base level of recruitment. When they were encountered, YOY juveniles were collected using many different gear types at a variety of depths and times of year (Rutecki and Varosi 1997b). Therefore, ecological processes occurring in both the pelagic and benthic habitats of shallow nearshore coastal bays may influence survival for this stage. Upon arrival in the nearshore in late summer, early fall, YOY sablefish must acquire prey, compete with other species, avoid predation, and settle to suitable benthic habitat in order to recruit successfully to the next stage. Juveniles overwinter in the nearshore for one to three years before they begin offshore movement (Rutecki and Varosi 1997a). Accounts of widespread, abundant age-1 juveniles likely indicate a strong year class and have been reported for the 1960 (J. Fujioka & H. Zenger, pers. comm.), 1977 (Bracken 1983), 1980, 1984, and 1998 year classes in southeast Alaska, the 1997 and 1998 year classes in Prince William Sound (W. Bechtol, pers. comm.), and the 1998 year class near Kodiak Island (D. Jackson, ADFG, pers. comm.).

A few consistent surveys in central and eastern GOA have successfully sampled YOY to age-1+ juvenile sablefish during the nearshore settlement stage. Small mesh trawl surveys for shrimp and forage fish around Kodiak Island have been conducted by the AFSC and the Alaska Department of Fish and Game (ADFG) since 1953. Catch is dominated by shrimp, Pacific cod, pollock, and flatfish. A shorter time series of rockfishes and sablefish are available (Anderson and Piatt 1999). The SECM program at the AFSC has conducted surface trawling at nine stations sampling inshore, strait, and coastal habitats in the northern region of southeast Alaska from June to September 1997-present. Relatively large numbers of age-1+ sablefish were caught in the strait habitat in 1999 (between Chatham and Icy Strait) co-occurring with juvenile salmon which were the primary prey item for the juvenile sablefish. During years of high recruitment, sablefish in Stage II may be a significant predator of juvenile salmon during their offshore migration (Sturdevant et al. 2009). The MESA program at the AFSC performed opportunistic surveys in southeast Alaska from 1985 to present to sample and tag age-1+ sablefish in nearshore bays. One location, St. John Baptist Bay (SJBB) consistently produces large amounts of age-1+ sablefish. Limited oceanographic sampling and diet analysis on age-1+ sablefish was conducted in SJBB during various years. However, analysis of this data was not unique when compared to nearby bays (Rutecki and Varosi 1997b). Persistent oceanographic events offshore combined with bathymetric steering may contribute to the uniqueness of SJBB. Additionally, 726 electronic archival tags have been implanted and released in YOY sablefish since 2003. Five of these archival tags were recovered in the commercial fishery since 2008 (D. Hanselman pers. comm.).

Another potential source of information for this stage is data that may be used to define habitat suitability for stage II sablefish. Benthic habitat data exists at varying resolutions from detailed bottom mapping and actual bottom observations (e.g. Shotwell et al. 2008) to general low resolution bathymetry and regional sediment distribution paper maps (e.g. Carlson et al. 1977). Three main types of bathymetric data exist in the GOA and BSAI: low resolution remotely sensed data of broad regional extent, high-resolution multibeam bathymetry of limited areal extent, and National Ocean Service (NOS) point data of variable resolution. Scientists at the AFSC are currently constructing a highly detailed bathymetric map of the GOA seafloor so that seafloor measures (e.g. topographic roughness) can be analyzed (M. Zimmermann

AFSC pers. comm.). Since 2000, the US Geological Survey (USGS) and its collaborators have compiled seabed data from existing reports and datasets into usSEABED, which is a nation-wide integrated seafloor characterization database (Reid et al. 2006). Preliminary analysis of these data in central GOA shows muddy sediment in bathymetric lows such as Shelikof Strait with coarser sediment (to gravel) on bathymetric highs such as Albatross Bank. These data may be used to create continuous gridded surfaces of sediment and rock distributions. In combination, the highly detailed bathymetry with sediment distribution grids could provide regional contextual three-dimensional observations of sediment distributions in the GOA and BSAI. This information could provide an informative, scalable, basis for developing stage II juvenile sablefish habitat suitability models.

Stage III: Pre-recruit Migration to Adult Habitat

Juvenile sablefish begin offshore movement following their second summer and are found in varying concentrations on the continental shelf as sub-adults before recruiting to adult habitat on the slope and deep gullies. Length samples from the AFSC bottom trawl survey suggest that the spatial range of juvenile sablefish on the shelf varies dramatically from year to year. In particular, juveniles utilize the Bering Sea shelf extensively in some years, while not at all in others (S.K. Shotwell, unpublished report). On the continental shelf, juvenile sablefish share residence with a large variety of piscivorous groundfish in the GOA. Euphausiids are a common prey item for many juvenile groundfish species and density dependent effects on the continental shelf habitat may increase competition for this resource. Additionally, spatial overlap with adult groundfish may cause increased predation on juvenile sablefish (Yang et al. 2006). Survival through this final stage may largely depend on the density of other groundfish species throughout the continental shelf and their influence on the level of competition with and predation on pre-recruit sablefish.

A variety of surveys sample pre-recruit juveniles after settlement on their return to adult habitat. We define pre-recruits as individuals 45 cm or less because this is the average size of two-years-olds which are rarely seen in fisheries. The AFSC biennial trawl survey has captured pre-recruit juvenile sablefish in the GOA, Aleutian Islands and Bering Sea from 1984 through present. This survey has the most extensive coverage over the range of potential juvenile sablefish distribution. The domestic AFSC sablefish longline survey has conducted annual surveys in the GOA since 1987 and biennial surveys in the Aleutian Islands and Bering Sea since 1996 and 1997, respectively (Rutecki et al. 1987, Hanselman et al. 2009). This survey, which likely provides an accurate index of adult sablefish abundance, includes a set of 27 gully stations throughout the central and eastern GOA. Catches in the gully stations typically consist of smaller fish than nearby slope stations. Data from these stations are thought to be potential indicators of recruitment signals since the stations are typically at shallower depths and sample smaller fish. Results from a preliminary analysis of gully station catch rates suggests that gullies may show recruitment signals and strength earlier and better then slope stations (Hanselman et al. 2009). The International Pacific Halibut Commission (IPHC) performs a halibut longline survey each year utilizing a systematic grid to consistently sample the continental shelf from 1-500 m (Soderlund et al. 2009). The survey catches substantial amounts of sablefish which are likely smaller and younger than those caught on the AFSC sablefish longline survey which samples from 200 to 1000 m. However, only sablefish catch in numbers is available from this survey (Hanselman et al. 2009).

Potential Factors Affecting Recruitment

We have defined a critical window for sablefish survival bounded by the aforementioned three stages. Successful recruitment likely depends on several linked ecological processes influencing transport to the nearshore, prey availability, competition with other species, and predator avoidance. In addition to ecological effects, fishing activities represents another factor which may influence recruitment of sablefish throughout these stages. These processes control the quantity and condition of pre-recruit sablefish as they enter each stage. While the level of success at the end of stage I may determine the maximum potential for each year class, subsequent survival during stages II and III likely modulate that potential causing additional limits to survival. In the next four sections, we define the potential factors influencing sablefish recruitment at each stage through the main concepts of the environment, competition, predation, and fishing.

Environment

The physical structure, transport processes, and biology of the Northeast Pacific Ocean respond strongly to forcing at several time and space scales that can result in large interannual changes for both offshore and coastal regions (Batcheldor 2002). Cross-shelf and along-shore transport are influenced by several physical mechanisms including mesoscale eddies, episodic upwelling, freshwater runoff, tidal mixing, and complex bottom topography (Weingartner et al. 2002, 2005, Ladd et al. 2005, Bailey et al. 2008). Some of these mesoscale features (e.g. large fronts or anticyclonic eddies) persist for several years in the GOA and Aleutian Islands, traveling hundreds of kilometers and transporting heat and nutrients from the formation region (Belkin et al. 2002, Ladd et al. 2007).These physical properties additionally impact the stability of the water column influencing the timing and size of spring phytoplankton blooms. Secondary producers such as zooplankton and euphausiids respond to these seasonal and interannual fluctuations in prevailing oceanographic conditions and the primary producers (Coyle and Pinchuk 2005, Conners and Guttormsen 2005). Each of these factors may have compounding affects on the abundance, distribution, and condition of egg, larval, and YOY sablefish during the first recruitment stage. Since larval and YOY sablefish feed almost primarily on copepods and euphausiids (Grover and Olla 1990, Sigler et al. 2001), this stage may be particularly dependent on the fluctuations in the food web dynamics. Anomalous meanders and fluctuating intensities of mesoscale features directly impact the transport of YOY sablefish to the nearshore environment (Okkonen et al. 2003, Ladd et al. 2005).

Competition

Juvenile sablefish during stage I and II are typically less than 40 cm and have a relatively narrow diet consisting of copepods and euphausiids. As they grow and enter stage III they begin to feed more opportunistically (Yang and Nelson 2000) on fish, squid, jellyfish, and euphausiids. Diets in stage I and II overlap with several other species of juvenile groundfish and forage fish such as arrowtooth flounder (*Atheresthes stomias*), pollock (*Theragra chalcogramma*), Pacific ocean perch (*Sebastes alutus*), herring (*Clupea pallasii*), and capelin (*Mallotus villosus*). As sablefish juveniles approach the nearshore environment and space becomes limiting, the potential for interaction between sablefish and these other species increases. This can lead to increased competition for resources. During stage III, juvenile sablefish also share residence with many other groundfish species on the continental shelf. Diet of sablefish at this stage is known to overlap with arrowtooth flounder (Yang and Nelson 2000). Abundance of arrowtooth flounder has increased four-fold from 1976 to the present (Wilderbuer et al. 2009, Turnock and Wilderbuer 2009). Sharing a trophic level with such an abundant stock indicates potential for competitive effects on sablefish recruitment (Hanselman et al. 2009).

Predation

There are few reports of sablefish egg and larval predation. Generally samples of sablefish YOY are rare and few are captured at one time suggesting that predators are not keying in on stage I as a primary source of food (Kendall and Matarese 1987). However, YOY juveniles entering the nearshore environment are commonly reported in adult coho (*Oncorhynchus kisutch*) and chinook (*O. tshawytscha*) salmon stomachs in southeast Alaska. Juvenile sablefish were the fourth most commonly reported prey species in the salmon troll logbook program from 1977 to 1984 (Wing 1985). However the effect of salmon predation on sablefish survival during stage II is unknown. Although juvenile sablefish may not be a prominent prey item because of their relatively low and sporadic abundance compared to other prey items, during stage III they share residence with the main piscivorous groundfishes in the Gulf of Alaska (Yang et al. 2006). An additional source of predation may be piscivorous seabirds with an estimated 7.2 million breeding pairs in the GOA (Stephensen and Irons 2003). A recent paper from Thayer et al. 2008 discusses the diets of piscivorous seabirds at two major colonies in the GOA. Sablefish and rockfish are included in the top species of prey for juvenile predatory fishes in the GOA. Predation from piscivorous fish and seabirds during stage II and III may be an important influence on sablefish recruitment.

Fishing

Direct effects such as removals and indirect effects such as habitat degradation are the most likely influence of fishing activities on juvenile sablefish. These activities should only impact sablefish in stages II and III. Little is known about the distribution or the habitat requirements of stage II sablefish in the nearshore. Only a few surveys (such as SJBB) consistently sample sablefish during this stage and other reports are sparse and generally anecdotal. Preliminary analysis of AFSC bottom trawl survey data suggests the range of distribution of Stage III sablefish varies dramatically from year to year across the continental shelf. Furthermore, juveniles utilize specific areas such as the Bering Sea extensively in some years while not at all in others (Hanselman et al. 2009).

It is difficult to discern the direct or indirect effects that fishing activities may have on these stages due to the sparse and inconsistent nature of available data. However, direct effects by fisheries are likely limited in Stage II as nearshore areas are not heavily impacted by fishing activities. Stage III sablefish discards in other fisheries are relatively low and have decreased in recent years (Hanselman et al. 2009). These low discard rates correspond to years of poor recruitment which suggests that incidental bycatch mortality is unlikely to be a direct contributor to sablefish recruitment failure. Furthermore, the majority of sablefish discards are adults and not the pre-recruit stages discussed here. Since little is known about juvenile sablefish habitat requirements, indirect effects from fishing on benthic substrates are unknown and probably confounded by influences of competition and predation. Yet, the widespread occurrence of juvenile sablefish on the continental shelf suggests that these fish interact or are indirectly impacted by multiple gear types and fisheries occurring in these waters. Unfortunately, given the available data, any hypothesis of a substantial effect of these impacts can be neither proven nor disproven.

Discussion

Throughout this document we present the known information on sablefish early life history (ELH) and put forth a rationale for a three stage approach to describing sablefish recruitment. Included in this review are the available sources of sablefish ELH data. We discuss potential factors affecting recruitment during these three stages that manifest in the ecological processes of the biophysical environment, competition, and predation along with anthropogenic effects caused by fishing. A logical next step is to combine the sources of sablefish ELH data with hypotheses on mechanisms for influencing sablefish recruitment. Scientists at the AFSC Auke Bay Laboratories (ABL) have recently initiated three new research projects investigating the utility of ecological information for reducing recruitment uncertainty in the sablefish stock assessment. A complete description of these projects is presented in the **Ongoing and Future Sablefish Recruitment Research** section at the end of the document. Two of these studies focus specifically on sablefish recruitment in stage I. Mechanisms of offshore transport and prey availability represented by satellite-derived environmental variables (Project 1) and large-scale polar front dynamics (Project 2) are examined. Project 3 is a larger GOA integrated ecosystem research program (GOA-IERP) with sablefish as one of five focal groundfish species. Oceanographic and ichthyoplankton surveys will be conducted in an attempt to learn more about stage I sablefish distribution and condition. Ecosystem modeling will combine information from these surveys to gain understanding about potential mechanisms influencing recruitment through stage II.

These three current research projects are a first step toward understanding the ecological factors influencing sablefish recruitment. Data from these projects will supplement the current information on sablefish early life history and will develop environmental time series for potential integration into the sablefish stock assessment. Model evaluations within these projects may identify forcing mechanisms that cause the highly variable recruitment and potentially allow for reduction of uncertainty in the most recent recruitment estimates. However, there remain significant gaps in our current knowledge and future research projects should strive to improve our understanding in these areas. One specific item is the general lack of data on spawning locations. While there appears to be no clear relationship between spawning biomass and recruitment at the observed abundances, the spatial distribution of spawning females may provide insight on the highly specific nearshore settlement areas. Females may perform spawning migrations that situate them at the entrances of gullies throughout the GOA which may influence the pelagic dispersal pathway to the nearshore environment. Bailey et al. (2008) suggest this mechanism for some species of juvenile flatfish in the central GOA. The complex bathymetry of submarine canyons potentially amplifies the strong tidal signals in this region creating vertical instabilities which subsequently increase the upward movement of nutrients and larvae (Ladd et al. 2005, Bailey et al. 2008). Another significant data gap is information on juvenile sablefish benthic habitat preferences. Several studies have considered preferences and growth potential under different temperature regimes and food availability (e.g. Sogard and Olla 2001). However, habitat requirements are relatively unexplored. Controlled laboratory experiments could be conducted to test juvenile sablefish preference on a variety of benthic habitats. The influence of predator introduction on habitat selection could also be tested in this environment. Similar experiments on quillback rockfish (*Sebastes maliger*) and Pacific ocean perch have been successfully performed by the MESA program at ABL (Malecha pers. comm.). Information on benthic habitat preferences may be combined with bathymetric and substrate maps to develop habitat suitability models. High priority should be placed for projects that strive to enhance these specific data gaps in the sablefish early life history.

Conservation Concerns

Historically, periods of relatively intense fishing may have limited the sablefish population, but poor recruitment has also occurred during periods of precautionary fishing measures and relatively high spawning biomass. This suggests that ecological factors that manifest in the forms of transport, food availability, competition, predation, and habitat suitability are the main influences on sablefish recruitment. It is generally difficult to implement conservation measures that successfully mediate these ecological conditions. The previously mentioned research projects are designed to provide insight on the dominant mechanisms governing sablefish recruitment. Results from these studies may highlight critical seasons or areas that could respond well to protection.

We believe it is premature at this time to recommend any specific habitat conservation measures for sablefish. As results of current research projects become available, management will have an opportunity to utilize this information to make informed decisions for conservation measures. If research results identify, for example, a specific canyon entrance as a main pathway for transport to the nearshore (Stage I) or migration to adult habitat (Stage III), then these specific areas could be designated as HAPC for sablefish. Fishing in part of this corridor could be restricted during certain times of the year. If habitat suitability models for juvenile sablefish (Stage II) provide maps of preferred habitat, then research closures could be imposed on sections of this habitat. This progressive approach to implementing conservation allows management to utilize scientific research to base decisions and choose the most appropriate tool for protection. In a multispecies context, we continue to suggest that small, unobtrusive research closures in heavily fished areas are one effective tool for understanding the effects of fishing, especially on benthic habitat. We recommend that any new conservation measures be designed within a multi-species context as an effort by the management agency to seek a better understanding of changes to the ecosystem and EFH.

Ongoing and Future Sablefish Research

We conclude this document with a brief synopsis of the previously mentioned three new research projects initiated by the MESA program of the AFSC. These projects have potential to elucidate some of the data gaps in understanding sablefish recruitment mechanisms.

Project 1: Utilizing environmental information to reduce recruitment uncertainty in the Alaska sablefish stock assessment

Project Investigators: S. Kalei Shotwell, Dana H. Hanselman, David G. Foley, Anthony J. Booth

This research project uses Alaska sablefish and the associated stock assessment as a case study for investigating underlying mechanisms influencing recruitment. Objectives are to evaluate the various sources of early life history data for stage I sablefish and explore integration of NASA Earth Science satellite time series within the sablefish stock assessment model to understand recruitment variability. We collected all available early life history survey data to describe the spatial distribution of larval and YOY sablefish. A qualitative comparison with model recruitment estimates reveals potential critical spatial pathways during high recruitment years. Following this we considered potential mechanisms influencing recruitment and selected environmental indices representing these mechanisms. We considered several high resolution satellite measures and generated subset regions based on sablefish life history and management areas. Twenty-three indices of sea surface temperature, eddy kinetic energy, and chlorophyll *a* passed our model selection criteria and explain some of the recruitment variability in sablefish. Comparisons of satellite series time lapse visualizations suggest that the position of large scale eddies as they translate through the Gulf of Alaska and into the Aleutian Islands influence the survivability of young-of-the-year sablefish through offshore food availability and nearshore transport. Development of a modeling framework for sablefish that successfully incorporates NASA Earth Science data establishes a foundation for future ecosystem based management. Reducing uncertainty in recruitment estimates may increase efficiency in harvest decisions, improve geographic catch apportionment, and allow for more reliable future harvest projections.

Project 2: In the Path of the Polar Front: Reducing recruitment uncertainty through integration of large scale climate indices within the Alaska sablefish stock assessment

Project Investigators: S. Kalei Shotwell, Igor M. Belkin, Dana H. Hanselman, Lisa B. Eisner, Mark Zimmermann

The North Pacific Polar Front (NPPF) is associated with the North Pacific (or Subarctic) Current and therefore is a convenient proxy for the Subarctic Current and its extension, the Alaska Current. We propose that advection along the NPPF plays a key role in shaping the oceanographic climate of Alaskan waters. This would directly influence the cross-shelf transport of larval fish to their essential nearshore habitat and the productivity of the ocean environment. We use the Alaska sablefish and the associated stock assessment as a case study for investigating the influence of the NPPF. Analysis of temporal changes in the NPPF mechanism will allow for development of environmental time series for use in the sablefish stock assessment to reduce recruitment uncertainty. The primary objective of our research project is to estimate the NPPF and its variability and integrate this information into the sablefish stock assessment. We will first collect, process, and analyze both historic and recent satellite oceanographic and *in situ* hydrographic data to estimate the parameters of the NPPF (e.g. front location and cross-frontal ranges of temperature, salinity, density, nutrients, and chlorophyll *a*). We use two front detection algorithms (Cayula-Cornillon and Belkin-O'Reilly, Belkin and O'Reilly 2009) on satellite images of sea surface temperature and chlorophyll *a* to properly characterize the NPPF. Following the satellite mapping, oceanographic *in situ* data are analyzed across and along the front's path to generate time series representing properties of the NPPF. We will then analyze the propagation of temperature-salinity-nutrient anomalies along the NPPF path to estimate variability. The proximity of these anomalies to the shelf break provides a relative measure of the pelagic environment in which YOY sablefish must survive. Relevant time series are then incorporated into the sablefish stock assessment through the recruitment dynamics equations. Estimates using the NPPF are then compared to random simulations to determine if there is a reduction in recruitment uncertainty. We will also run a cross-validation exercise to calculate estimates of prediction error for recruitment estimates over time. This will determine if information from the Polar Front would have allowed for early detection of recruitment trends.

Project 3: Surviving the Gauntlet: A comparative study of the pelagic, demersal, and spatial linkages that determine groundfish recruitment and diversity in the Gulf of Alaska ecosystem (GOA-IERP)

Project Investigators: Jamal Moss, S. Kalei Shotwell, Franz Mueter, Shannon Atkinson

The overall goal of the proposed research focuses on identifying and quantifying the major ecosystem processes that regulate recruitment strength of key groundfish species in the Gulf of Alaska (GOA). We concentrate on a functional grouping of five top predatory groundfish species that are commercially or ecologically valuable and account for most of the predatory fish biomass in the GOA: arrowtooth flounder (*Atheresthes stomias*), Pacific cod (*Gadus macrocephalus*), Pacific ocean perch (*Sebastes alutus*), sablefish (*Anoplopoma fimbria*), and walleye pollock (*Theragra chalcogramma*). Taken together these species encompass a range of life history strategies and geographic distributions that provide contrast to explore regional ecosystem processes. Early life of these key species begins with an offshore pelagic phase (Stage I) followed by a nearshore settlement phase (Stage II). Spatial distribution, food preference, and habitat suitability of these two life history stages are poorly known. Four main components that are part of this integrated ecosystem research program (IERP) funded by the North Pacific Research Board (NPRB) will examine different aspects of the processes influencing recruitment of these five species. Research activities include retrospective analysis, offshore and nearshore field sampling, diet and health analysis, habitat suitability characterization, top predator tagging, and ecosystem modeling.

The retrospective analysis is a four component effort to provide a synopsis of available spatial and temporal datasets for understanding climatic, oceanographic, and biological drivers of the GOA ecosystem. Fieldwork conducted by the lower, middle, and upper trophic level components will include offshore pelagic to nearshore benthic sampling utilizing a variety of gear types to quantify the abundance, distribution, and condition of the key groundfish species. This information combined with concurrent sampling of the biophysical environment (i.e. oceanography, prey, competitors, and predators) will define a critical environmental window for these five focal species as they cross the gauntlet from offshore spawning to nearshore settlement areas. The upper trophic level will use samples from the field to develop growth curves and consumption rates as a measure of health during the two life history stages. High resolution bathymetry and substrate data will be combined with species specific habitat preferences to create benthic habitat suitability maps. The modeling component will develop a hydrographic model linked to a nutrient-phytoplankton-zooplankton (NPZ) model that will utilize data generated in the afore-mentioned research activities for calibration. Results from this model will be integrated into individual based models for each of the key groundfish species to predict recruitment. Forecasts will be compared with recruitment estimates from current single-species assessment models as a diagnostic check. Regional and seasonal recruitment estimates for each species will be evaluated to infer the relative influence of ecological processes. Finally, regional differences will be linked to dietary preference and movements of top level predators to infer causal mechanisms for population trends and influence of climate change on ecosystem structure and diversity.

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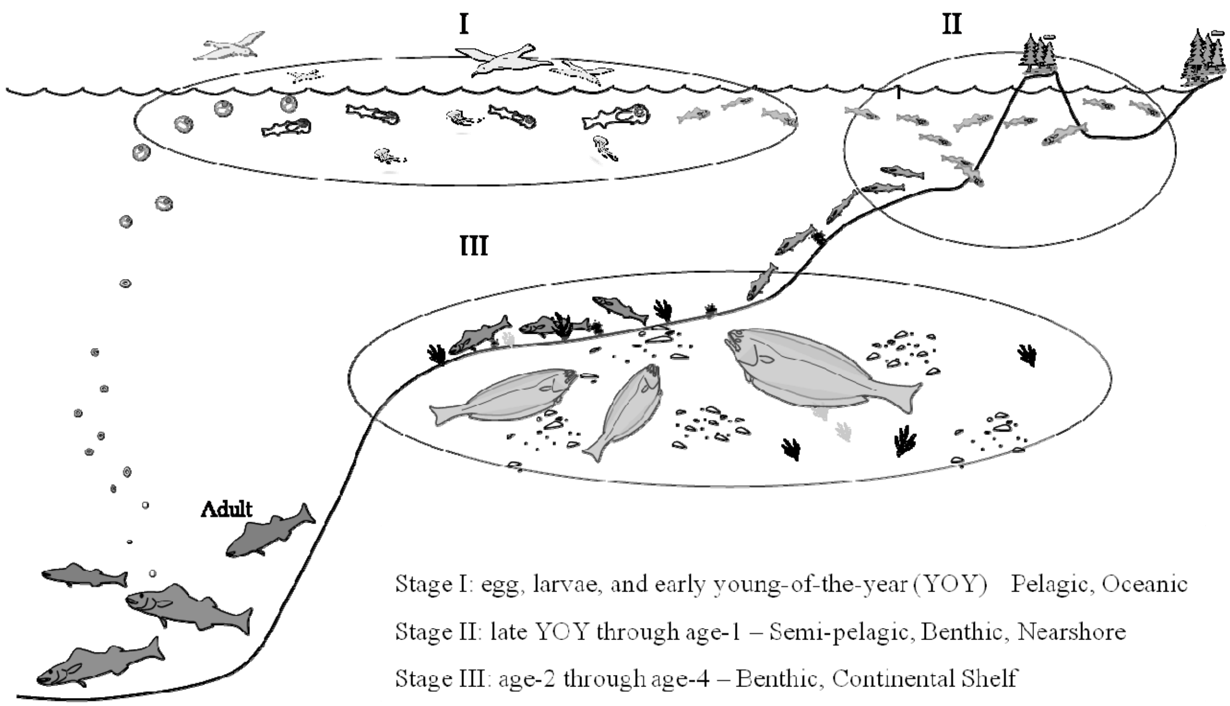

Figure 1: Sablefish pre-recruit life history depicting three critical stages.