NOAA Technical Memorandum NMFS-AFSC-254

Report to Industry on the Alaska Sablefish Tag Program, 1972-2012

by
K. Echave, D. H. Hanselman, and N. E. Maloney

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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PREFACE

The National Marine Fisheries Service (NMFS) Alaska Sablefish Tag Program has released over 360,000 tagged sablefish in Alaska waters since 1972, and over 33,500 of those fish have been recovered by members of the fishing industry. Data from the releases and recoveries are maintained in the Sablefish Tag Database. These data have been used to examine movement patterns, evaluate areal apportionment strategies of annual catch quota, validate ageing methods, and to examine growth.

Although a small reward (hat) is offered for return of the tags to NMFS, many people are more interested in the brief letter which accompanies the reward and describes the history of the fish in terms of movement and growth. This demonstrates the support and interest from industry for the tagging program.

This report summarizes release and recovery data within the tag database and describes the results of studies utilizing these tag data by NMFS and others on sablefish age, growth, and migration. Hopefully it will prove both interesting and informative for those who have contributed the largest share of the data: individual members of the fishing industry.

CONTENTS

INTRODUCTION

The purpose of this report is to inform the fishing community of the knowledge gained on sablefish (*Anoplopoma fimbria*) age, growth, and migration now available because of the industry's participation in the Alaska Fisheries Science Center's (AFSC) Sablefish Tag Program. Sablefish have been extensively tagged in the northeast Pacific Ocean using a variety of methods over the years in order to determine or estimate spatial distribution within a geographic range, migratory patterns, abundance, and growth. Sablefish is a long lived, highly mobile demersal species which inhabits the northeastern Pacific Ocean from Baja Mexico to the Gulf of Alaska (GOA), westward to the Aleutian Islands (AI), and into the eastern Bering Sea (BS; Hanselman et al. 2012)). Sablefish is one of the deepest dwelling commercially valuable species, with an ex-vessel value of over $100 million in 2010. Adult sablefish are generally found along the continental slope, shelf gullies, and in deep fjords. In contrast, juvenile sablefish (< 40 cm) spend their first 2-3 years on the continental shelf and in interior bays, moving into deeper waters along the slope as they age (McDevitt 1990). Based on evidence from tagging studies and differences in growth rate and size at maturity, it is thought that there are two populations of sablefish (McDevitt 1990): the Alaska population (found in Alaska and northern British Columbia waters) and the West Coast population (found in southern British Columbia, Washington, Oregon, and California waters).

Since sablefish have a long-term time series of tag-recovery data, they may be a candidate for a spatially explicit stock assessment. Few stocks have the necessary quality of data to reasonably estimate a spatially explicit stock assessment because estimates of movement between areas, and good estimates of areal abundance are preferred. Spatially explicit stock

assessment has been identified as a goal, and a step toward realizing ecosystem-based management. In order to estimate movement and examine appropriate scales of spatial management, the AFSC Auke Bay Laboratories (ABL) has been tagging sablefish since 1972 using a variety of methods including traditional anchor tags, electronic archival tags, and most recently pop-off satellite tags.

As a major contributor to the history of sablefish tagging in the North Pacific, ABL has deployed traditional anchor tags on over 360,000 sablefish, recovering more than 33,500. Beginning in 2003, electronic archival tags were deployed inside approximately 1,460 juvenile and adult sablefish and 141 of those have been recovered. Upon release and recapture of the archival tagged fish, geo-position, depth, and biological data may be collected. Beginning in 2011, exploratory work using pop-off satellite tags on sablefish was initiated. These tags are similar to archival tags in that they collect depth and temperature data at pre-determined sampling intervals, but they also record an estimated location. Satellite tags release from the fish at a pre-programmed date and float to the surface where they upload recorded data to passing satellites.

Although sablefish are assessed as one population in Federal waters off Alaska (seaward of the 3-mile state line), harvest is allocated to discrete geographic regions (management areas) to distribute exploitation throughout their wide geographic range. Harvest is managed by the National Marine Fisheries Service (NMFS) under regulations recommended by North Pacific Fishery Management Council. A total harvest quota, called the acceptable biological catch (ABC), is calculated for the entire Gulf of Alaska, Bering Sea and Aleutian Islands (GOA, BS, and AI), and then this ABC is apportioned among six management areas (Fig. 1). These annual

quotas for each area are based on the distribution of biomass among the areas, estimated from annual longline surveys and commercial catches. Because of the high movement rates determined by the tag data, it has been shown that apportionments can be flexible to achieve other objectives, while still maintaining spawning biomass (Heifetz et al. 1997). The total ABC is derived from a population model which incorporates age composition, growth rates, and survey and commercial catches (Hanselman et al. 2010). Much of the biological information for estimates of these factors comes from annual sablefish longline surveys, observer samples of the fishery, and fishery logbooks, but tagging results can be used as an independent check on these results.

The following is a report is to inform the fishing community of the knowledge gained on sablefish age, growth, and migration now available because of the industry's participation in the AFSC Sablefish Tag Program.

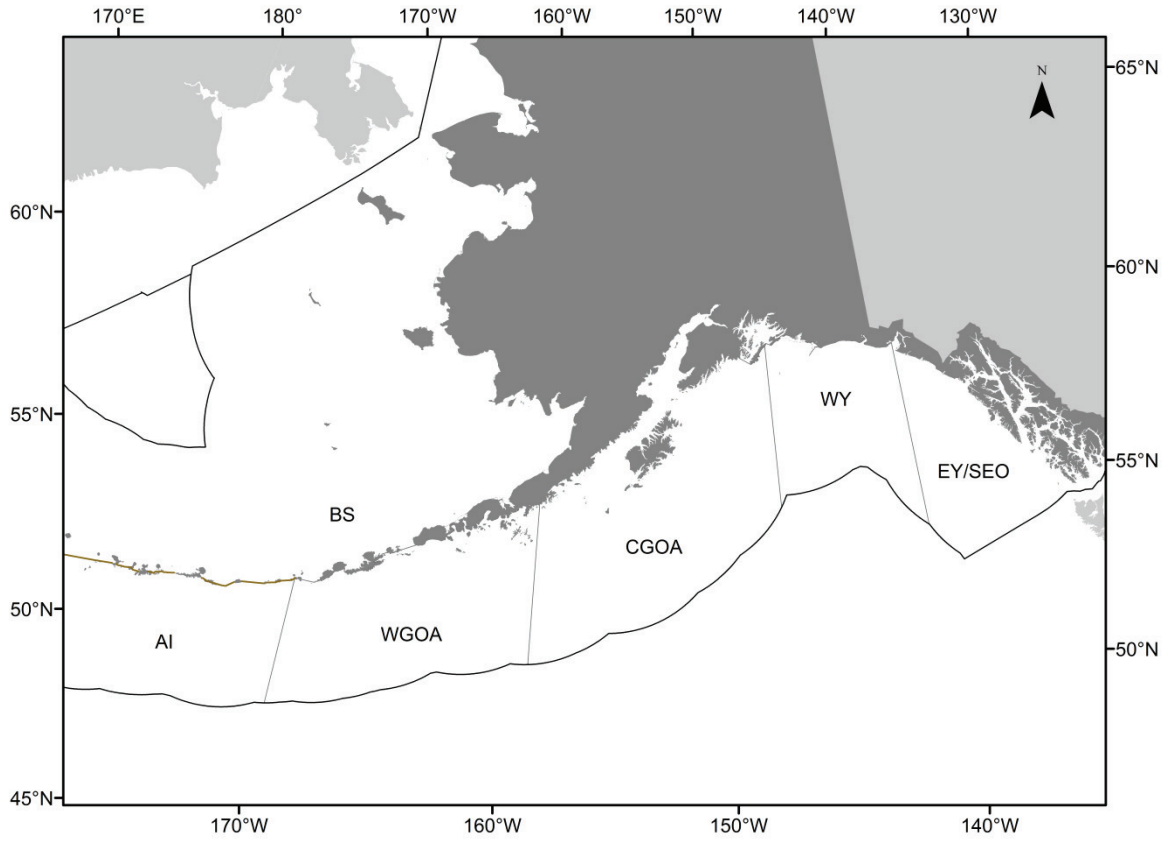

Figure 1. -- Map of the six management areas sablefish harvest is geographically apportioned. BS (Bering Sea); AI (Aleutian Islands); WGOA (Western Gulf of Alaska (GOA)); CGOA (Central GOA); WY (West Yakutat); and EY/SEO (East Yakutat/Southeast Outside).

TAG RELEASES

The AFSC has been tagging and releasing sablefish in Alaska waters since 1972. Tagging effort in Alaska has been centered in three main areas: 1) adult sablefish in offshore waters of the GOA, BS, and AI; 2) adult sablefish in the inside waters of Chatham and Clarence Straits; and 3) juvenile sablefish in interior bays of southeast Alaska. To date, approximately 360,000 sablefish have been tagged and released (Table 1).

Adult Tag Releases in Offshore Waters

Almost all GOA, BS, and AI tags have been released during the NMFS annual longline surveys or the Japan-U.S. cooperative longline surveys. Figure 2 shows the major release and recovery areas discussed in this document, as well as the location of the annual longline survey stations. During the years of the Japan-U.S. cooperative longline survey (1978-94), all tagging was done aboard Japanese vessels by Japanese and U.S. scientists working together. The NMFS annual longline survey began in 1987 and replaced the cooperative survey in 1995. Since 1997, tagging in offshore waters has been conducted aboard chartered commercial vessels during the annual domestic longline survey. Approximately 5% of the longline survey catch of sablefish are tagged and released each year, which generally equals about 3,000 – 3,500 fish per year. Offshore tagging utilizes conventional anchor tags, internally implanted electronic archival tags, and externally attached pop-off satellite tags. To date, 322,263 adult fish have been tagged with conventional anchor tags in offshore waters, 619 electronic archival tags have been implanted in adult sablefish, and 43 sablefish have been tagged with pop off satellite tags on the NMFS annual longline surveys in offshore waters.

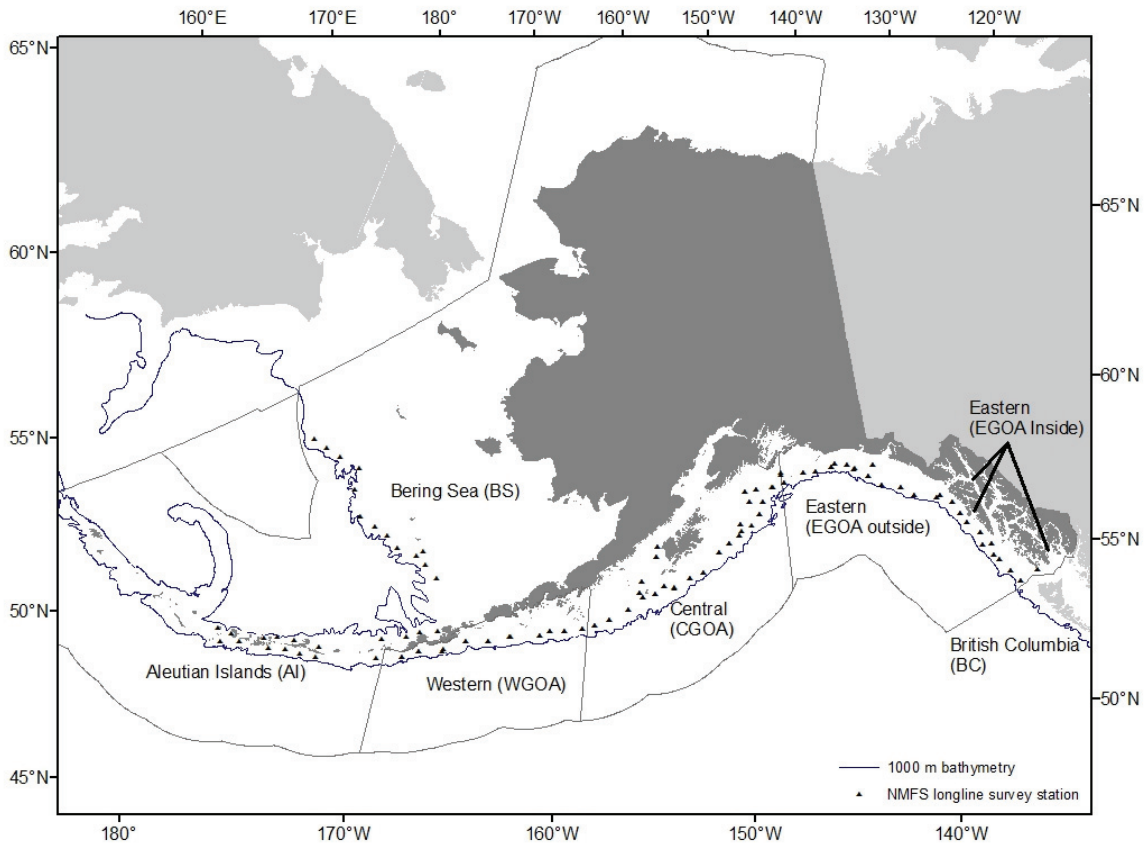

Figure 2. -- Map of the NMFS annual longline survey stations (triangles) and Fishery Management Plan (FMP) areas: the Bering Sea (BS), Aleutian Islands (AI) and the Gulf of Alaska (GOA) subareas. Tags are deployed at all stations in the GOA each year, and in alternating years in the BS and AI. Eastern GOA Inside consists of Chatham and Clarence Straits.

Adult Tag Releases in Inshore Waters

Most of the nearly 70,000 tags released by NMFS in Chatham and Clarence Straits (Fig. 2) have been released from various NOAA research vessels. The State of Alaska has jurisdiction over fisheries in these waters, and many of the tag releases were made in cooperation with the Alaska Department of Fish and Game (ADFG).

Tag Releases of Juvenile Sablefish

Juvenile sablefish in southeast Alaska make up a third group of NMFS tag releases. Beginning in 1985, juvenile sablefish were tagged and released in a number of bays and inlets in southeast Alaska, ranging from Ketchikan to Juneau. Most of these fish were tagged from NOAA ships or from docks in Sitka, Ketchikan, and Juneau. Approximately 37,100 juvenile sablefish have been tagged and released to date (Table 1). The majority of juvenile tagging efforts have centered in St. John Baptist Bay outside of Sitka on Baranof Island (Fig. 3).

To date, 852 electronic archival tags have been implanted and released in juvenile sablefish from the 2003-2012 year classes in St. John Baptist Bay. These tags should be available for recovery as the fish recruit to the commercial fishery. The first three of these archival tags were recovered in 2008, and five more have been recovered since 2009. These tags store depth and temperature data recorded at preset time intervals throughout each day. Data from these tags provide information about inshore-offshore migration, daily depth movements, and habitat temperature.

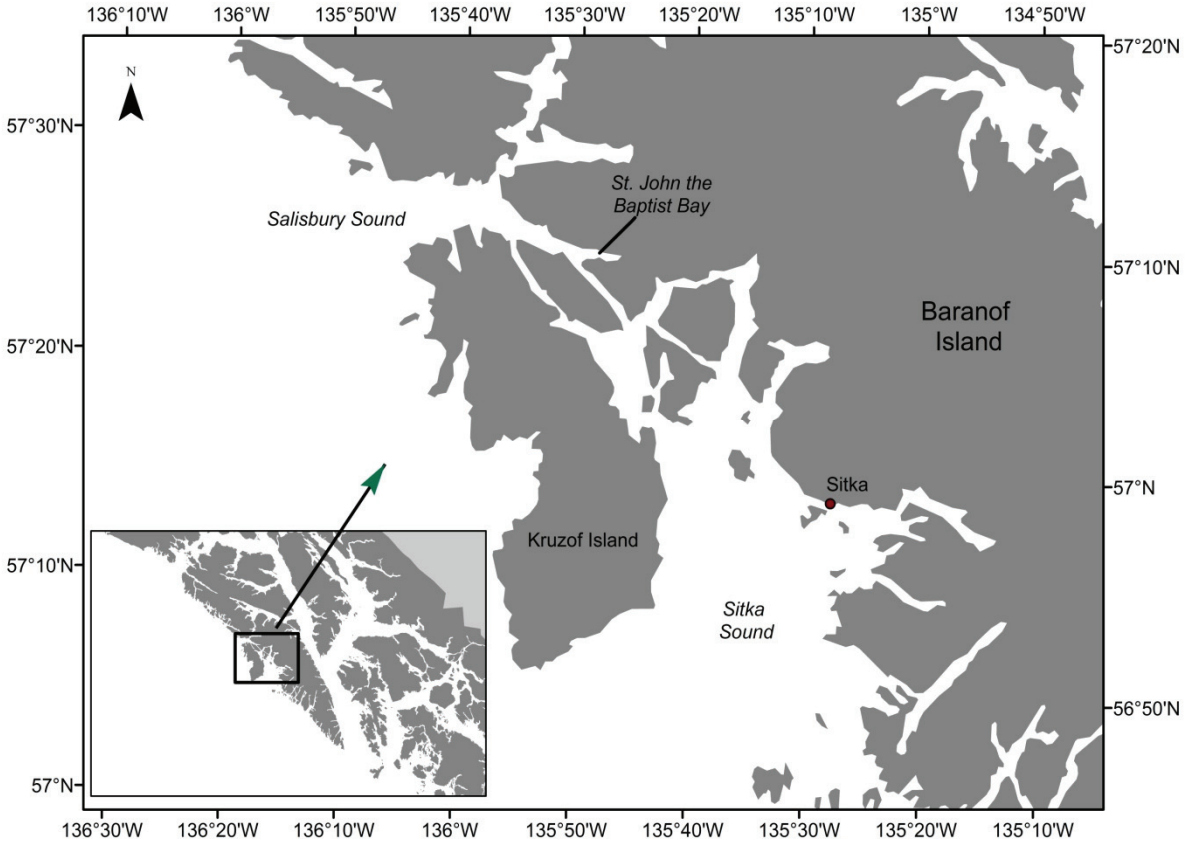

Figure 3. -- Map of location of juvenile sablefish tagging in St. John Baptist Bay on Baranof Island in Southeast Alaska.

TAG RECOVERIES AND MIGRATION

Accurate tag recovery position information helps identify major migration routes. If recovery dates are available, it is possible to calculate movement rates as well as routes. Analysis of tag data is the primary method used to study sablefish movement.

Several tagging studies have shown sablefish to be highly migratory for at least part of their life cycle (Bracken 1983, Sasaki 1985, Fujioka et al. 1988, Heifetz and Fujioka 1991, Maloney and Heifetz 1997, Hanselman et al. in review), with the pattern of movement related to fish size and progression of maturity. It had previously been reported that sablefish traveled

primarily in a counter-clockwise direction around the GOA (Fig. 4); small, immature fish tagged in shallow inshore waters of the eastern GOA travel north and westward from their release sites out on the continental shelf and eventually end up as an adult in the deeper waters of the continental slope throughout the distribution, where spawning takes place (Heifetz and Fujioka 1991, Maloney and Heifetz 1997, Maloney 2002). Large fish tagged in the western areas of the GOA would move eastward, and large fish tagged in the eastern areas of the GOA had a tendency to remain there (Fig. 4; Heifetz and Fujioka 1991, Maloney 2002). Young sablefish would routinely undertake migrations of a thousand miles or more, and older fish would commonly travel the same distance on a return journey. However, recent work by Hanselman et al. (in review) has reported that sablefish mobility has increased over time, that the directionality of movement has changed since previously reported, and that annual movement probabilities differ greatly between areas. Hanselman et al. (in review) re-estimated annual movement rates for all three size groups of tagged sablefish among regulatory areas using tag recovery data (over 300,000 tag releases in Alaska and 27,000 recoveries) from 1979 to 2009, as well as tag release data from the inside waters of Southeast Alaska from the Alaska Department of Fish and Game (ADFG). Direction of movement changed the most for small sablefish. Small sablefish (41-56 cm) were more likely, than previously shown, to move out of their current area in all areas except the Eastern Gulf of Alaska (EGOA), and to move predominately eastward; whereas previous studies showed that they moved westward. Medium (57-66 cm) and large (> 66 cm) fish moved more than in previous years, and large sablefish still displayed a tendency to move east rather west. So overall, if one considers the Central Gulf of Alaska (CGOA) the center of distribution of Alaska sablefish, it is more likely for all size groups to move east than west.

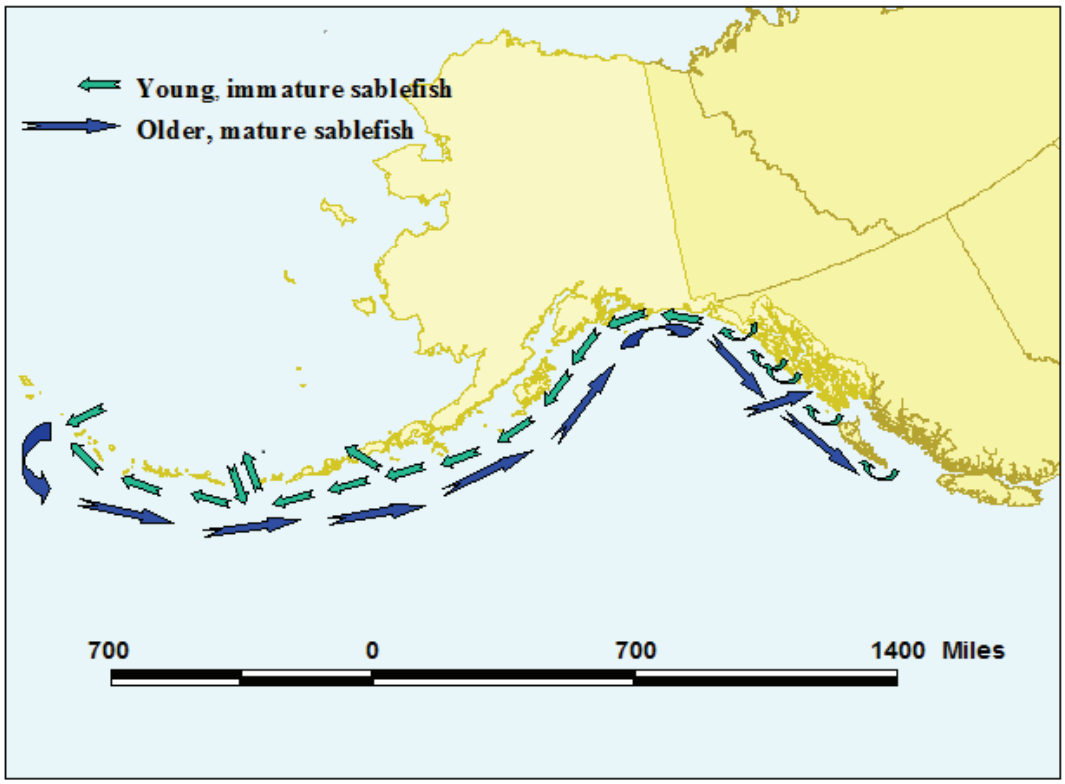

Figure 4. -- The basic migration pattern of sablefish in the northeast Pacific Ocean. Young, immature fish travel north and west from inshore nursery areas in Canada and the Eastern Gulf of Alaska (GOA) to the Western GOA, Bering Sea, and Aleutian Islands. Older, mature fish move offshore and return eastward (Maloney 2002).

Tag data from the NMFS Alaska Sablefish Tag Database for sablefish are summarized in the following sections by region, with reference to the migration patterns reported by Hanselman et al. (in review). Release size categories are based on length frequency data: small (41-56 cm), medium (57-66 cm), and large (> 66 cm). In general, these size ranges correspond to ages 3-4 (small), 5-7 (medium), and 8 and over (large), although, males grow more slowly than females; for example, a 5-year-old female would probably have reached “medium” size while a 5-year-old

male might still be of “small” size. The size categories “small”, “medium”, and “large” refer to the size of the fish at release and not the actual size at recovery unless otherwise stated.

Eastern Gulf of Alaska Tag Releases

The majority of tag releases have been in the EGOA (approximately 217, 050; Fig. 5, Table 2). This number includes releases in “inside” waters (Chatham Strait, Clarence Strait, and juveniles tagged in Southeast Alaska), as well as “outside”, or offshore waters (during the annual longline survey).

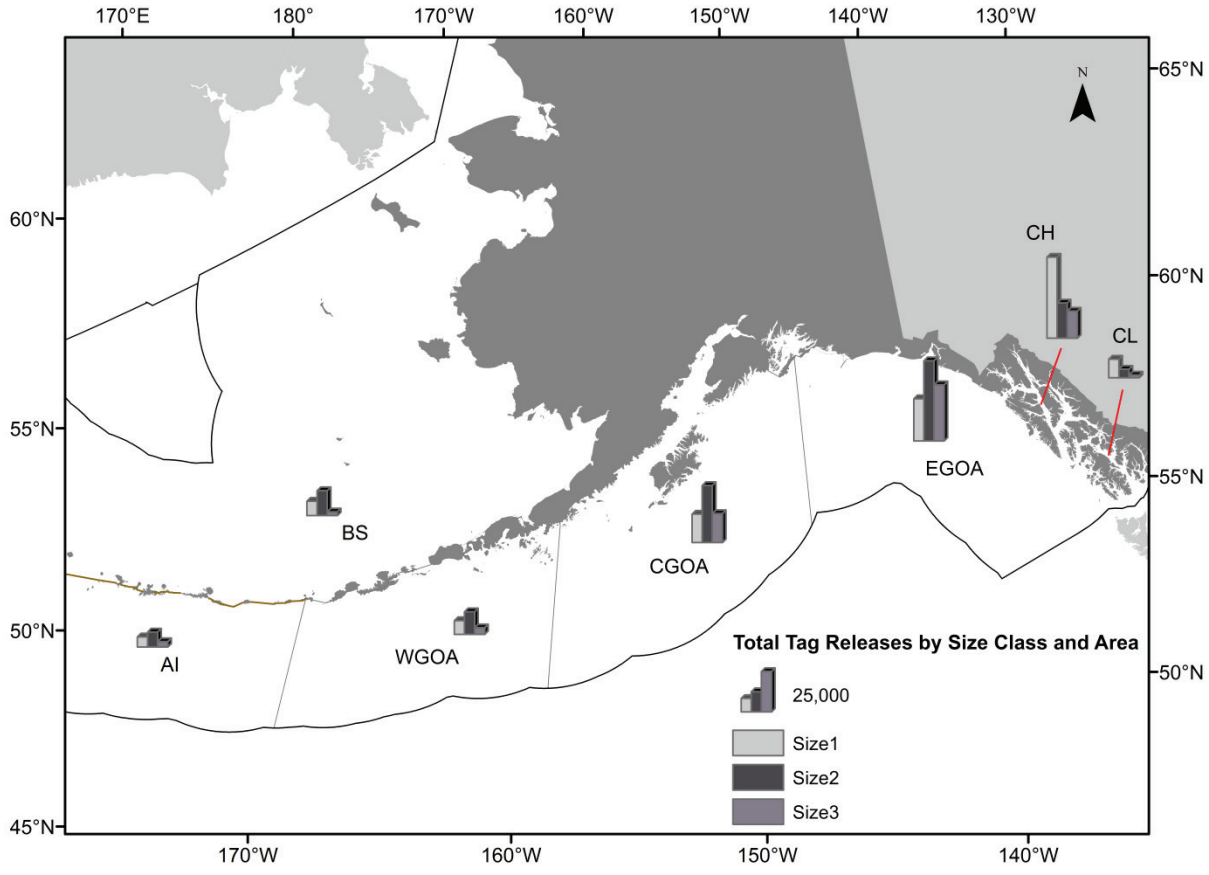

Figure 5. -- Total number of tag releases by NMFS by size and area during years 1972–2012; Bering Sea (BS); Aleutian Islands (AI); Western Gulf of Alaska (GOA)(WGOA); Central GOA (CGOA); Eastern GOA (EGOA); Chatham Strait (CH); and Clarence Strait (CL). Size 1 = 41-56 cm; size 2 = 57-66 cm; and size 3 > 66 cm.

Analysis of released tags from the EGOA verifies the movement pattern presented by Hanselman et al. (in review): all size groups of both male and female tagged sablefish from the EGOA have a tendency to remain in the EGOA (Figs. 6, 7; Tables 3, 4). Fish released in outside EGOA waters moved less than fish in other areas: 55% of fish released in the EGOA were recovered in outside EGOA waters, 15% recovered in the CGOA, and 14% recovered in BC (Fig. 6, Table 3). The same holds true for fish released in Chatham Strait. Over half of the recovered fish that were released in Chatham Strait were later recovered in Chatham (Table 3); therefore, it is no surprise that fish in Chatham Strait have a low annual probability of moving (10-14%; Table 4). Clarence Strait sablefish appear to be more directly connected geographically to the GOA than Chatham Strait, showing about a 30% chance of moving, mainly into the EGOA and BC waters (Table 4). Close to half (47%) of the recovered fish from Clarence Strait releases were recovered in Clarence Strait, however, a high percentage (26%) were also recovered in BC (Table 3). In summary, the EGOA is the largest recipient of fish moving out of inside waters (Hanselman et al. in review).

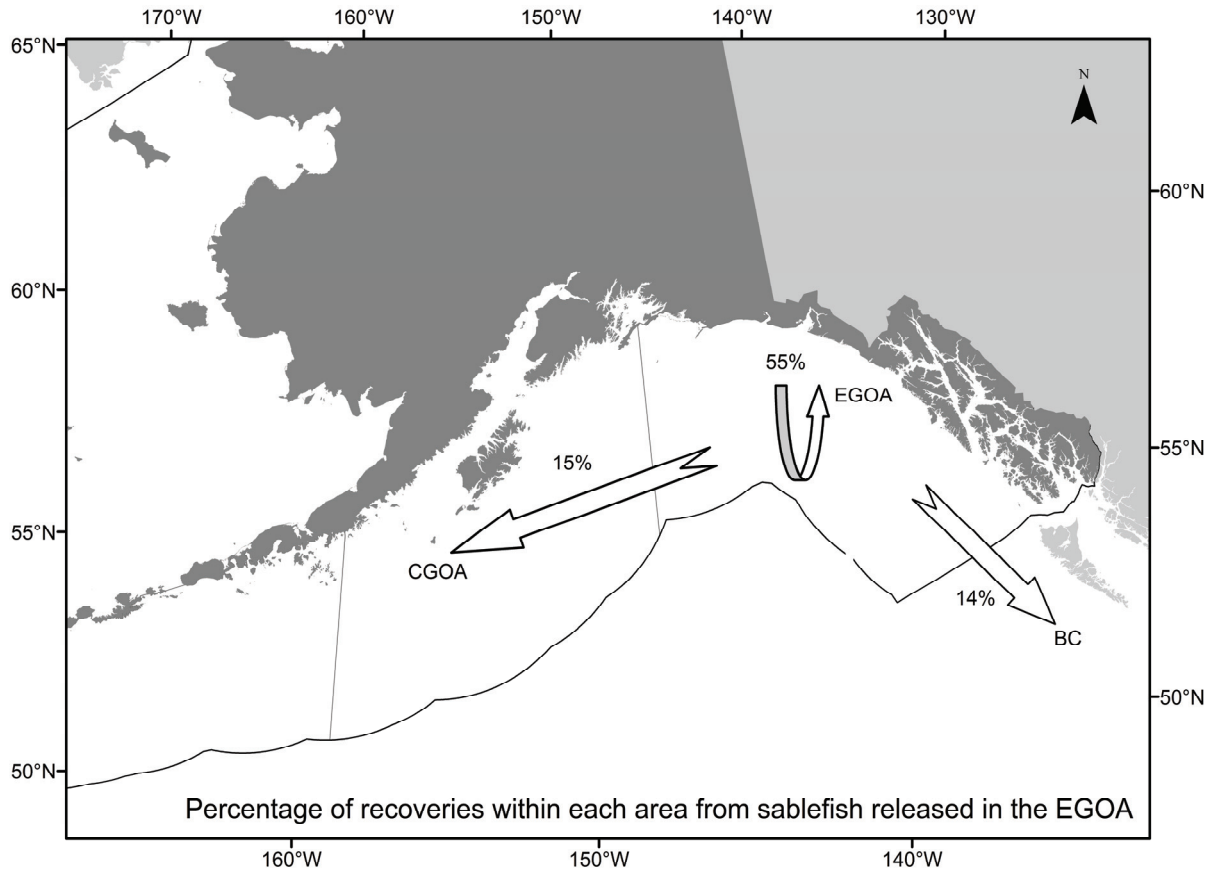

Figure 6. -- The percentage of tagged sablefish recovered within each area from fish released in outside Eastern Gulf of Alaska (EGOA) waters; 55% of fish were recovered in outside EGOA waters; 15% were recovered in the Central GOA (CGOA); and 14% were recovered in British Columbia (BC).

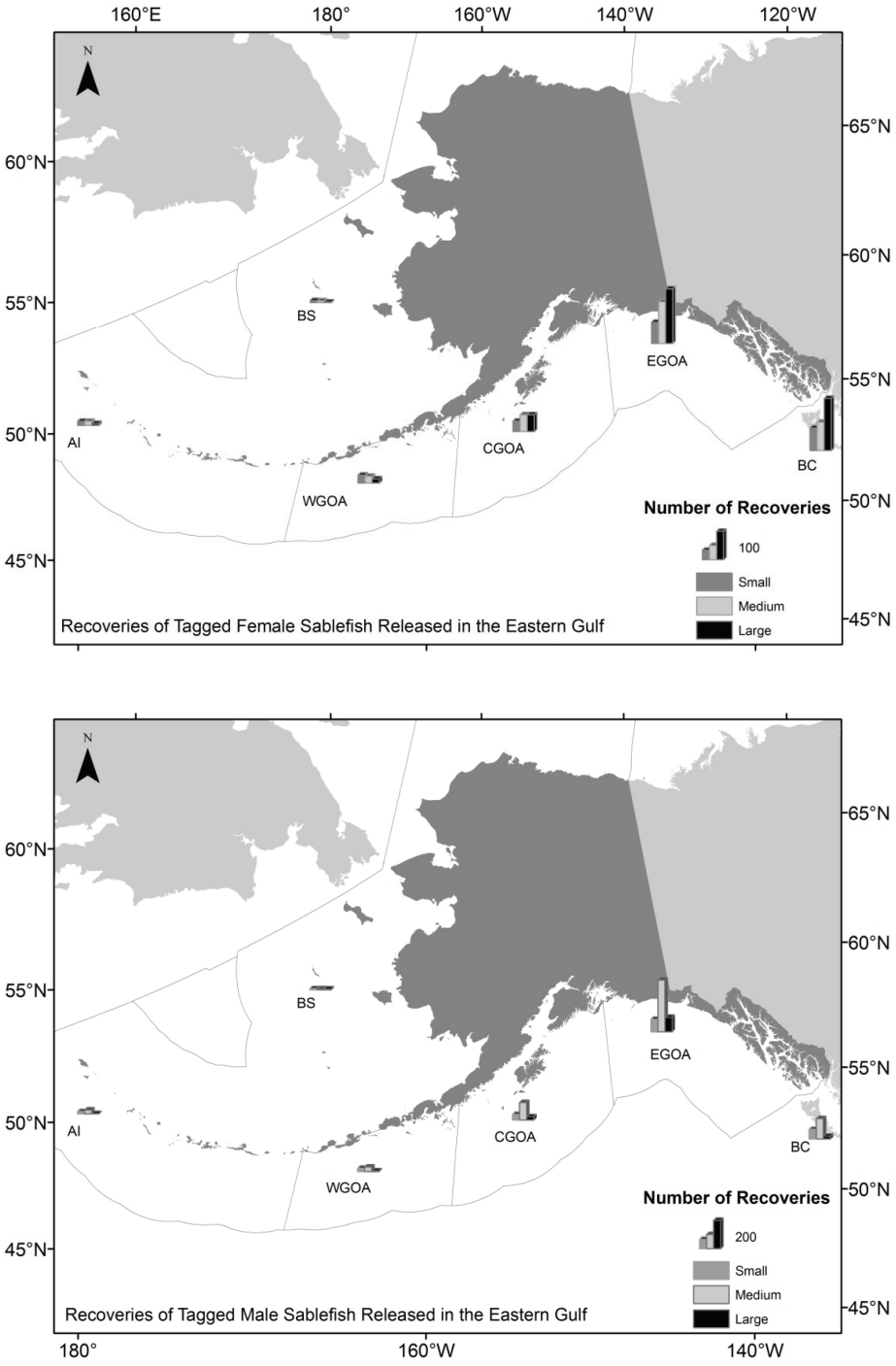

Figure 7. -- Recoveries of tagged female (top panel) and male (bottom panel) sablefish released in the Eastern Gulf of Alaska (GOA), by release size and recovery area. Please note the different scale between the two panels. BC = British Columbia, EGOA = Eastern GOA, CGOA = Central GOA, WGOA = Western GOA, AI = Aleutian Islands, and BS = Bering Sea. Small = 41-56 cm, medium = 57-66 cm, and large > 66 cm.

Central Gulf of Alaska Tag Releases

The CGOA is considered a mixing zone of small and large sablefish, as well as being the location of the second highest number of tag releases in federal waters (Fig. 5, Table 2). In the CGOA, it is more likely for all size groups to move east than west; however, the probability of fish moving west is higher from this area than others (Hanselman et al. in review). This coincides with the original movement model describing a counterclockwise movement by sablefish around the GOA (Fig. 4; Maloney 2002). The probability of fish moving west or east from the CGOA is 29% and 39% for small sablefish, respectively, and 22% and 47% for large sablefish, respectively (Hansleman et al. in review). Fish recovered in the CGOA may have originated in the EGOA and were still traveling westward or they may have already been out west and were returning east when captured. Fish tagged (all sizes combined) in the CGOA were most likely to be recovered in the CGOA (44%) and EGOA (26%; Figs. 8, 9; Table 3).

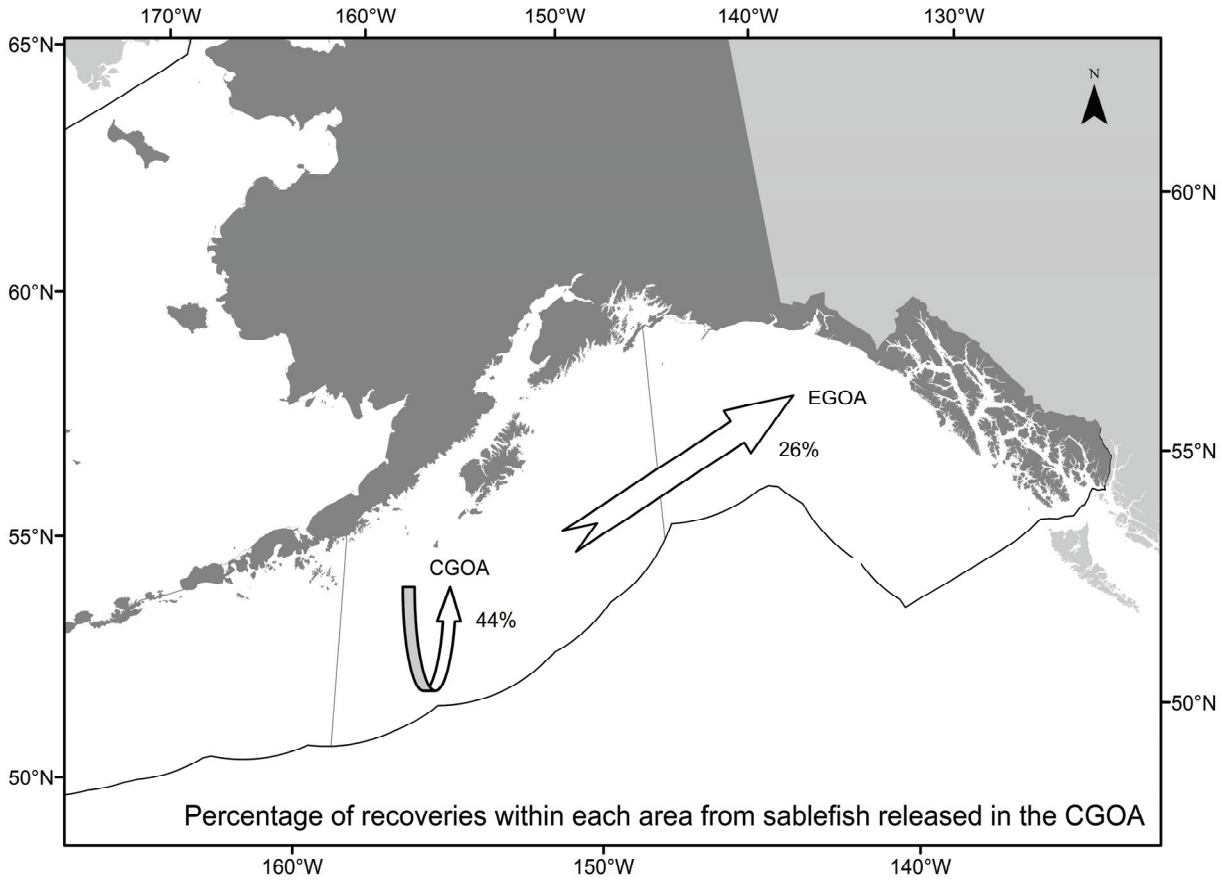

Figure 8. -- The percentage of tagged sablefish recovered within each area from fish released in the Central Gulf of Alaska (CGOA); 44% of fish were recovered in the CGOA; and 26% recovered in the Eastern GOA (EGOA).

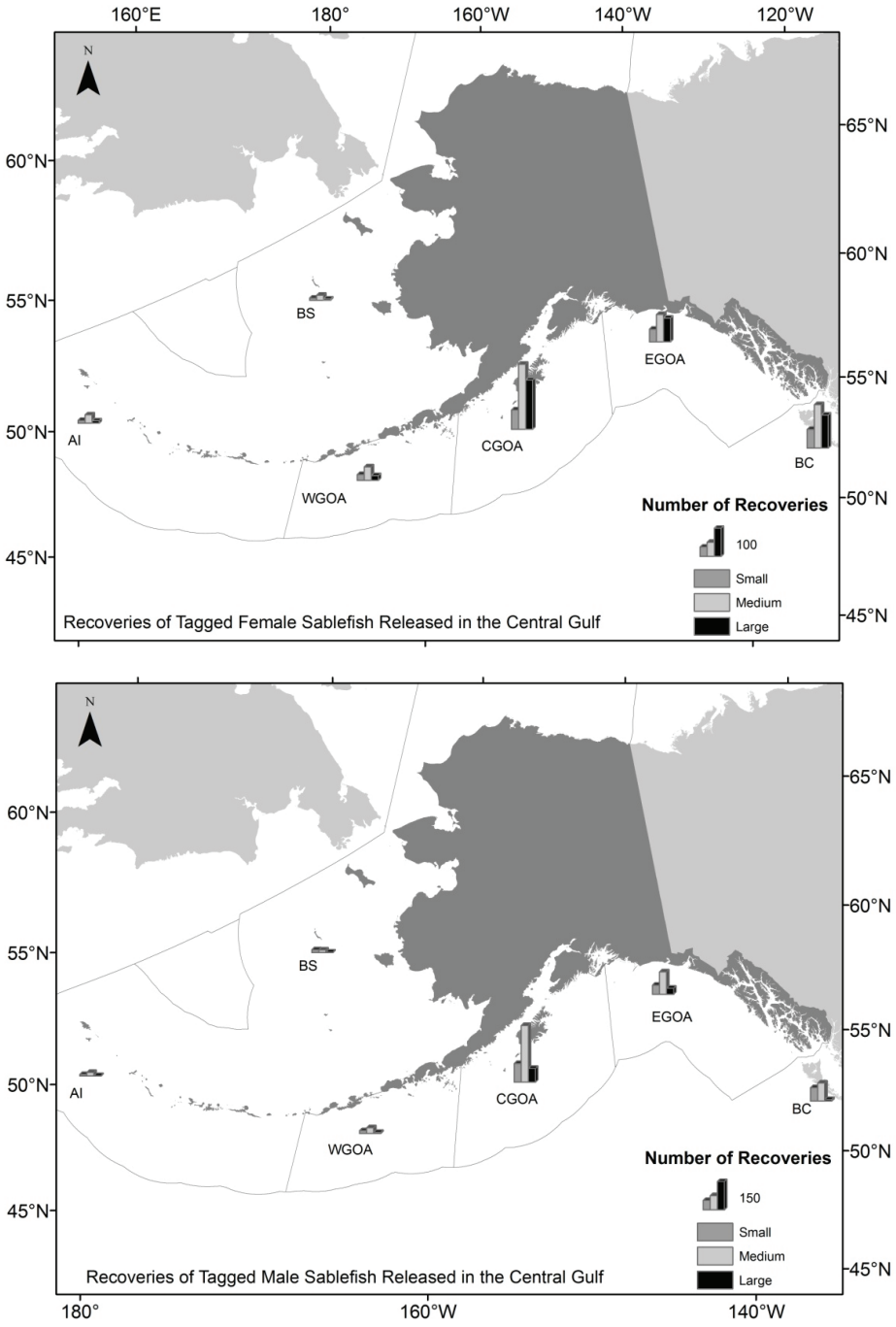

Figure 9. -- Recoveries of tagged female (top panel) and male (bottom panel) sablefish released in the Central Gulf of Alaska (GOA), by release size and recovery area. Please note the different scale between the two panels. BC = British Columbia, EGOA = Eastern GOA, CGOA = Central GOA, WGOA = Western GOA, AI = Aleutian Islands, and BS = Bering Sea. Small = 41-56 cm, medium = 57-66 cm, and large > 66 cm.

Western Gulf of Alaska Tag Releases

Fish of all sizes that are tagged in the western GOA are more likely (than previously reported by Heifetz and Fujioka 1991) to move from this area (Hanselman et al. in review). It appears that the Western Gulf of Alaska (WGOA) is a transition zone for all sizes of sablefish, as there is between an 80-90% probability that a sablefish will leave the WGOA 1 year after arriving (Hanselman et al. in review). However, fish tagged at a small size in the WGOA tend to remain in the western areas (WGOA, AI, BS) longer than large fish before heading east (Maloney 2002). The majority of small-sized sablefish released in the WGOA were caught in the WGOA, AI, and BS 0-3 years following tagging. However, the majority of small fish recovered 5+ years following tagging were primarily caught in the CGOA, EGOA, and BC, reinforcing the movement model of their eventual eastward movement. Large-sized sablefish have a tendency to move from the WGOA immediately, and appear to move eastward. The majority of large tagged sablefish from the WGOA were immediately (1-4 years following tagging) recovered in the CGOA, EGOA, and BC. Since sablefish tagging was initiated, only eight large tagged fish in the WGOA have been recovered in the BS and only nine in the AI.

Similar percentages of recoveries from WGOA released fish (all size groups and years at liberty combined) were found in the WGOA (25%), EGOA (24%), and CGOA (21%; Figs. 10, 11; Table 3). The pattern of movement from this area is strikingly different from other areas in the GOA, where the majority of fish remained in their release area. It should be noted, as is evident in Figure 5, that there are not as many large-sized sablefish tagged in the WGOA. Length frequency data from the longline survey show that there are an increased number of smaller-sized sablefish caught in the WGOA than in other areas. For example, during the longline survey

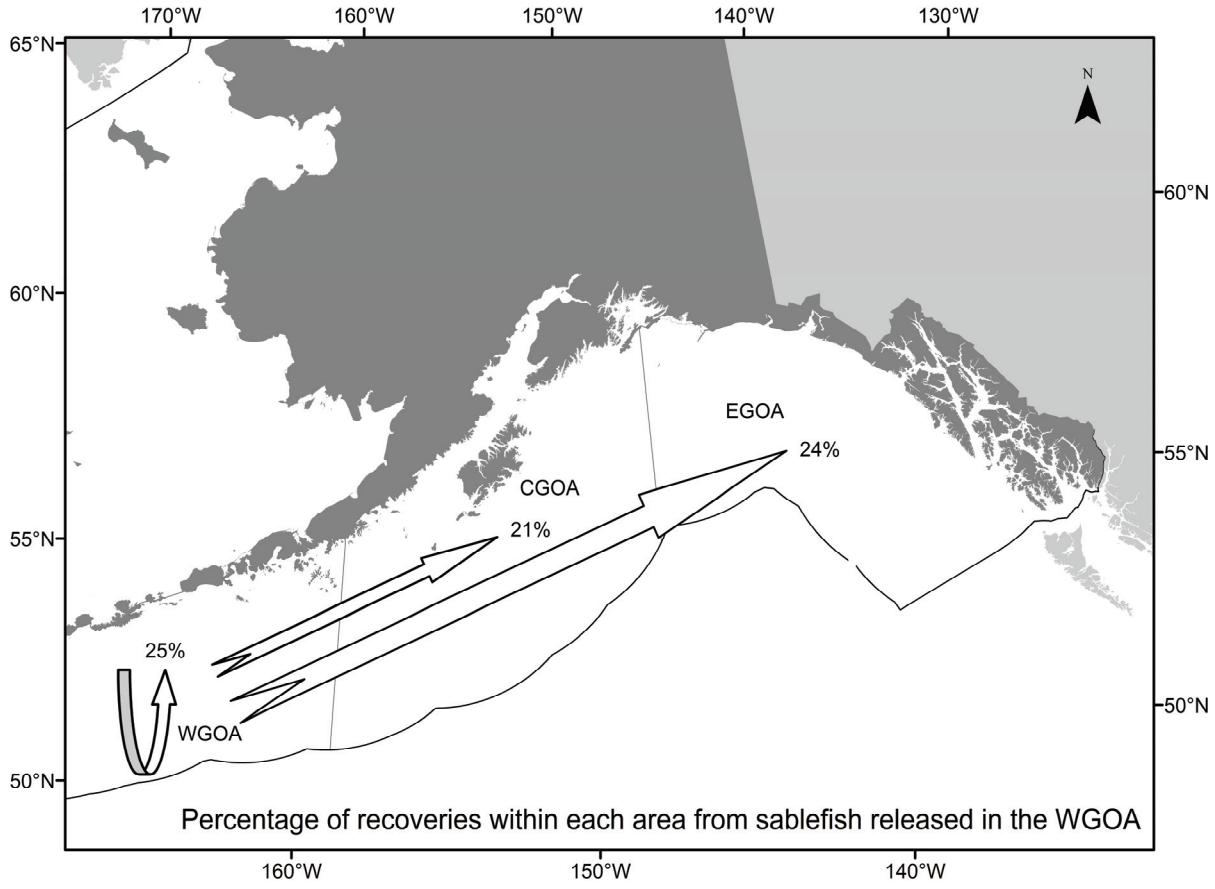

Figure 10. -- The percentage of tagged sablefish recovered within each area from fish released in the Western Gulf of Alaska (WGOA): 25% of fish were recovered in the WGOA; 24% were recovered in the Eastern GOA (EGOA); and 21% were recovered in the Central GOA (CGOA).

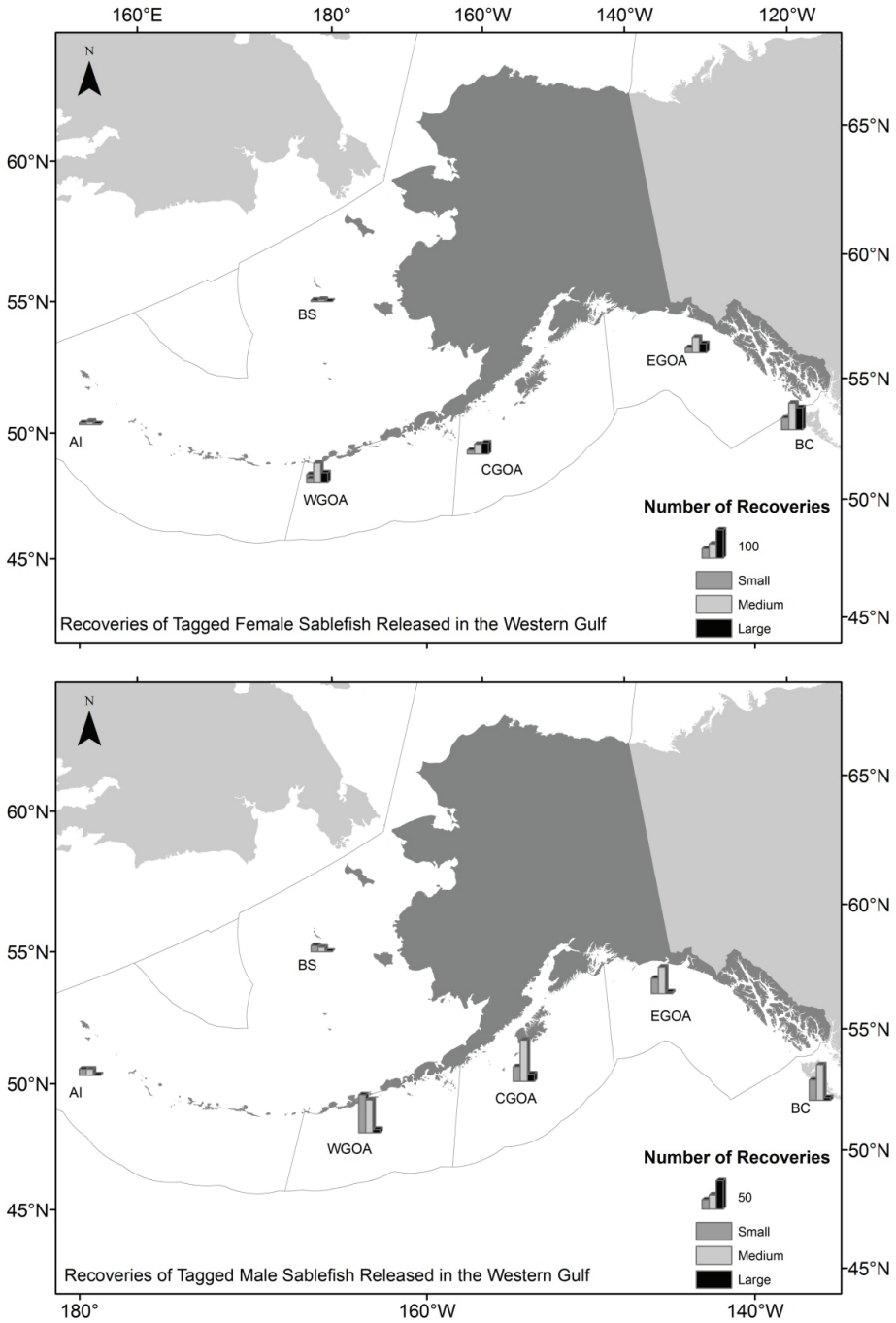

Figure 11. -- Recoveries of tagged female (top panel) and male (bottom panel) sablefish released in the Western Gulf of Alaska (GOA), by release size and recovery area. Please note the different scale between the two panels. BC = British Columbia, EGOA = Eastern GOA, CGOA = Central GOA, WGOA = Western GOA, AI = Aleutian Islands, and BS = Bering Sea. Small = 41-56 cm, medium = 57-66 cm, and large > 66 cm.

59 cm is the most frequent length of sablefish caught within the Shumagin management area (within the WGOA) compared to 67 cm within the Kodiak management area (within the CGOA).

Aleutian Islands and Eastern Bering Sea Tag Releases

Fish that are tagged farther west in the BS and AI are more likely to move out of the area in which they were tagged and into areas farther east (Figs. 12, 13, 14, 15; Tables 3, 4). Equally high percentages of recoveries from AI released fish were found in the EGOA (27%), AI (26%), and BC (18%; Fig. 12, Table 3), and a high percentage of recoveries from BS released fish were found in the EGOA (29%), CGOA (20%), and BS (19%, Fig. 13, Table 3). Small fish appear to remain in the BS the first 3 years following tagging and then move east from the area. Five to 10 years following tagging in the BS, an increasing proportion of small fish appear in the CGOA and EGOA. Large fish tagged in the BS are more likely to stay there, but a large proportion of fish are still recovered in the EGOA and BC within 10 years of tagging. Small fish in the AI show a high probability of remaining in the area during the first 5 years following tagging. Five to 10 years following tagging, there are increasing numbers of small sablefish recovered in the EGOA. Unlike large sablefish tagged in the BS, the majority of large sablefish tagged in the AI move immediately. Tag data indicates that most fish (small and large-sized) leaving the AI do not move eastward by way of the BS. Only 3.5% of the recoveries of AI releases were made in the BS (Table 3). Tagged sablefish released in the AI traveled the furthest, on average, before being recaptured (Table 5).

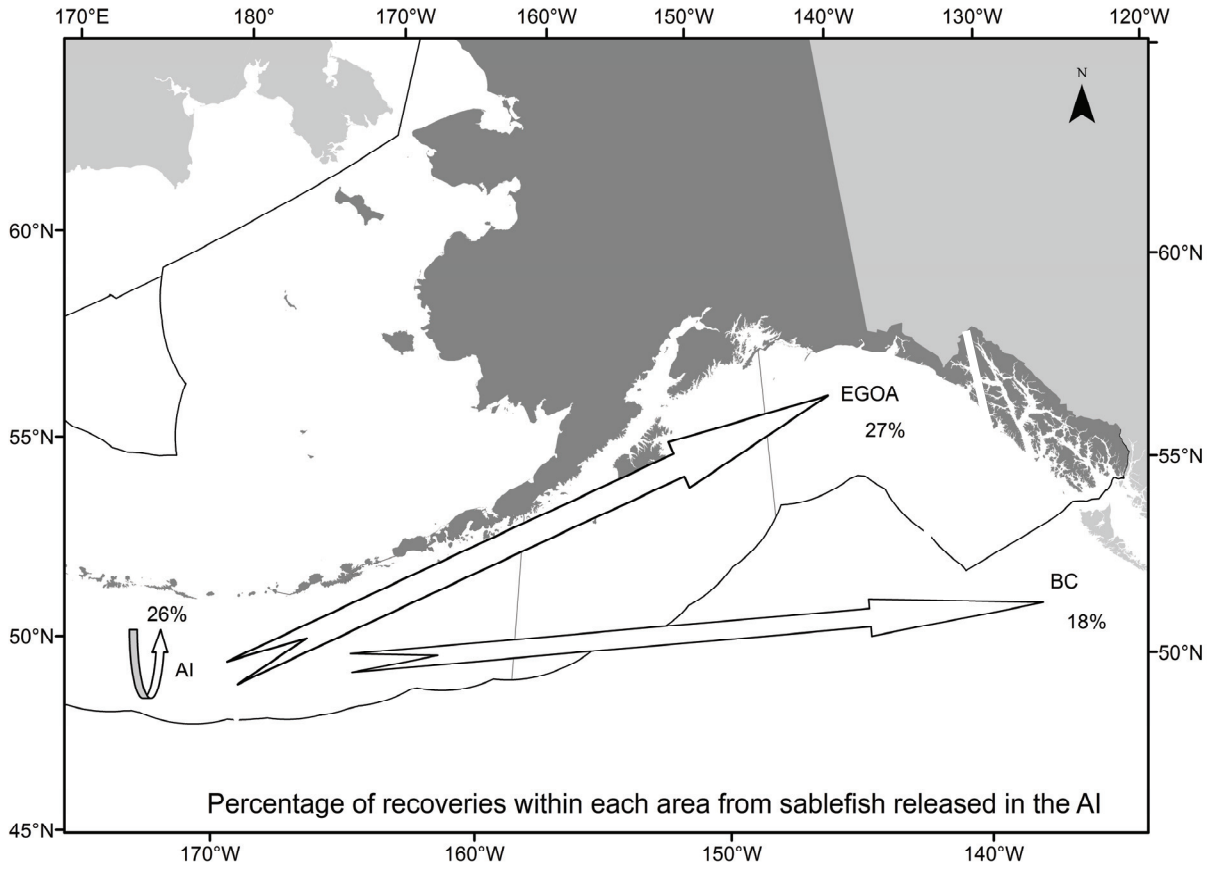

Figure 12. -- The percentage of tagged sablefish recovered within each area from fish released in Aleutian Islands (AI): 27% of fish were recovered in the Eastern GOA (EGOA); 26% were recovered in the AI; and 18% were recovered in British Columbia (BC).

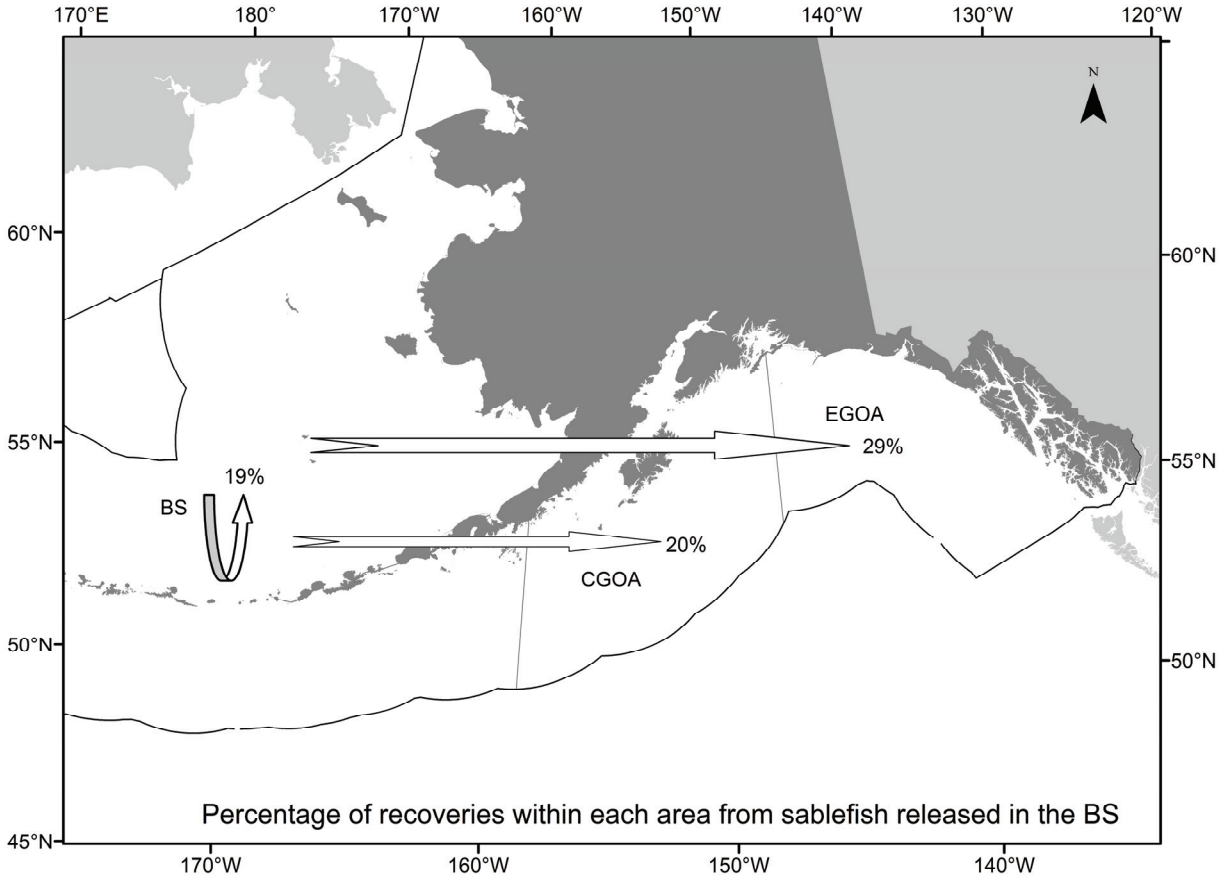

Figure 13. -- The percentage of tagged sablefish recovered within each area from fish released in outside the Bering Sea (BS): 29% of fish were recovered in the Eastern Gulf of Alaska (EGOA); 20% were recovered in the Central GOA (CGOA); and 19% were recovered in the BS.

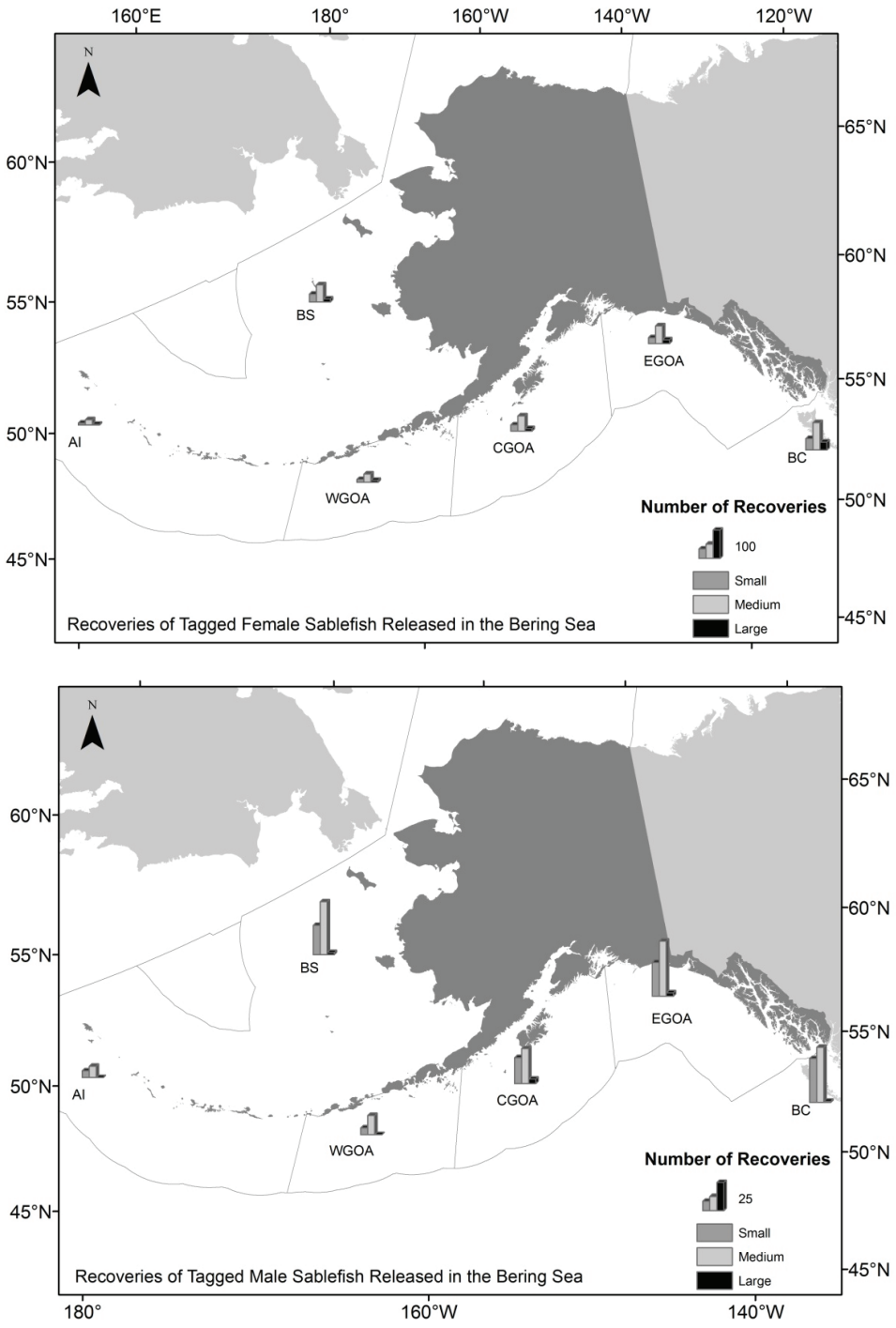

Figure 14. -- Recoveries of tagged female (top panel) and male (bottom panel) sablefish released in the Bering Sea, by release size and recovery area. Please note the different scales between the two panels. BC = British Columbia, EGOA = Eastern Gulf of Alaska (GOA), CGOA = Central GOA, WGOA = Western GOA, AI = Aleutian Islands, and BS = Bering Sea. Small = 41-56 cm, medium = 57-66 cm, and large > 66 cm.

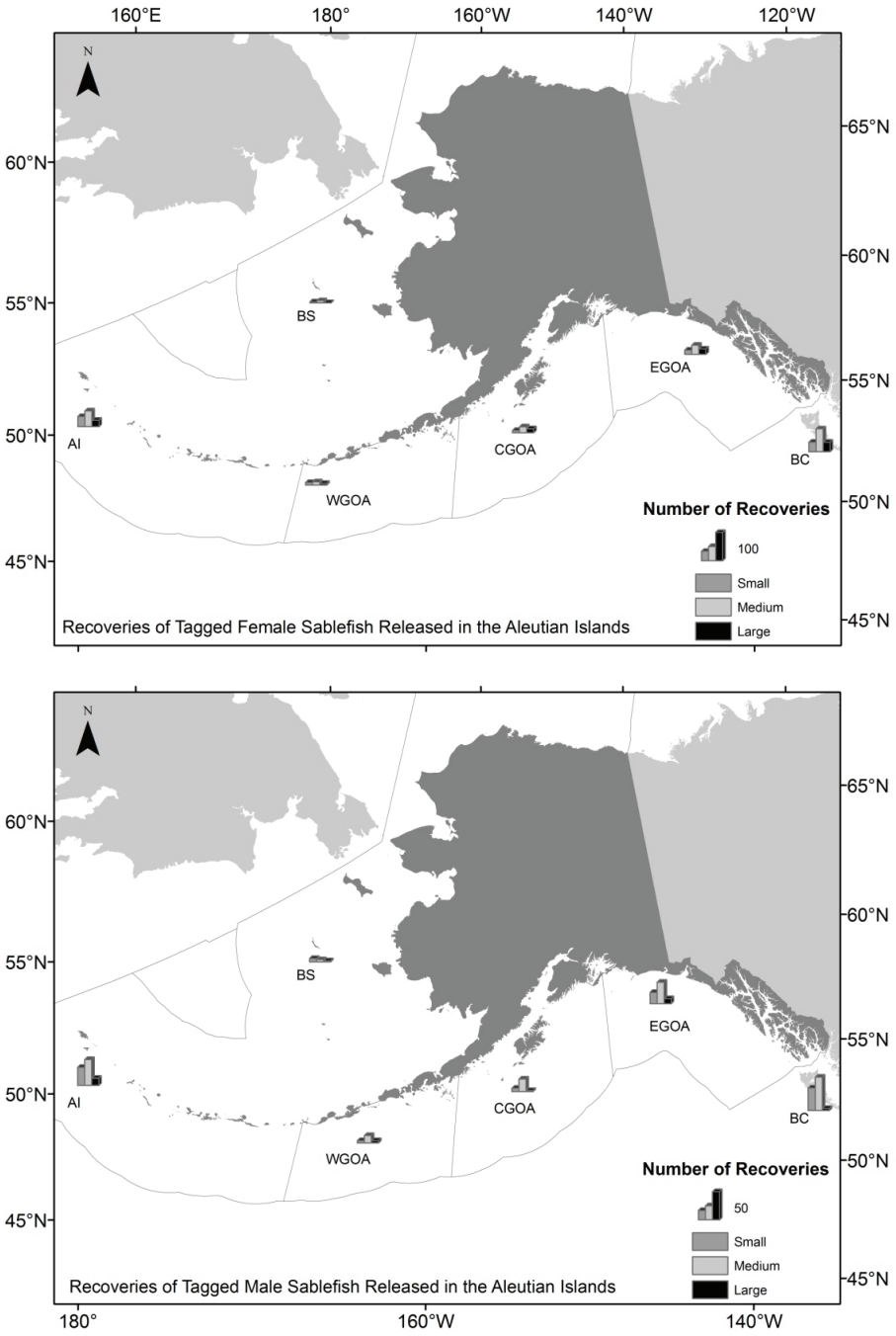

Figure 15. -- Recoveries of tagged female (top panel) and male (bottom panel) sablefish released in the Aleutian Islands, by release size and recovery area. Please note the different scales between the two panels. BC = British Columbia, EGOA = Eastern Gulf of Alaska (GOA), CGOA = Central GOA, WGOA = Western GOA, AI = Aleutian Islands, and BS = Bering Sea. Small = 41-56 cm, medium = 57-66 cm, and large > 66 cm.

MOVEMENT RATES

Estimated movement rates are essential in the management of a species in which quota are geographically apportioned, especially for a species such as sablefish, in which movement rates are great enough to affect the amount of fish available for harvest in an area. Rates of movement from one area to another are affected by a wide range of environmental and biological factors and may vary greatly between years, areas, and individual fish. In addition, the use of traditional anchor tag release/recapture data are not without problems. The length of time a fish was in an area before being captured and tagged, and the length of time a fish was in an area before being recovered, are both unknown. The longer a fish is at liberty and the farther it has traveled, the more uncertain the estimates of between-area movement rates become. For example, if a fish is recovered more than one area distant from the release area (i.e., released in the EGOA and recovered in the AI), it is impossible to know how much time was spent in each of the areas between release and recovery (Maloney 2002). In addition, if a fish is released and recaptured in the same area, it is impossible to know if the fish left the tagging area and returned after some time, or in fact remained in the tagging area without ever leaving. Regardless, analysis of all available conventional tag data are useful for providing overall patterns of movement and for estimating migration rates.

Heifetz and Fujioka (1991) estimated annual movement rates of tagged sablefish among regulatory areas using tag recovery data from 1979 to 1987. These results were presented in the 2001 Report to Industry on the Alaska Sablefish Tag Program, 1972-2001 (Maloney 2002). As previously mentioned, Hanselman et al. (in review) has since re-estimated annual movement rates for all three size groups of tagged sablefish among regulatory areas using tag recovery data

from 1979 to 2009, as well as tag data from the Alaska Department of Fish and Game (ADFG). The ADFG tag releases are all from the inside waters of Southeast Alaska and are in addition to the EGOA Inside releases by NMFS that were previously discussed. This updated analysis was done with hopes of incorporating these tag recovery and movement data into a fully age-structured spatial stock assessment model in the future. Hanselman et al. (in review) reported that movement rates were high (annual movement rates ranged from 10 to 80% depending on area and size group), and that estimated movement in all areas were higher than previously calculated by Heifetz and Fujioka (1991). Table 4 lists the annual percentage of small, medium, and large sablefish from each regulatory area which moved into another area or remained in the same regulatory area. The increase in annual probability of movement in the majority of areas and size groups from the original Heifetz and Fujioka (1991) estimates was substantial. The largest differences in movement rates (in comparison to results previously reported by Heifetz and Fujioka 1991), were related to the area they occupied and not because of the fish size, meaning that sablefish movement appears to be more directly influenced by the geographic location of the fish and not the size (or age) of the fish.

Overall, fish of all size groups are more likely to move than stay. This behavior change was most evident in fish that are farther west: annual movement rates for fish in the BS and AI were estimated to be almost 80% higher than previously estimated. Heifetz and Fujioka (1991) did not calculate movement rates for fish in Chatham and Clarence Straits, but Hanselman et al. (in review) showed that fish in Chatham Strait have a high probability of remaining in the same area, whereas fish in Clarence Strait have a high probability of leaving (Table 4). The directionality of movement in comparison to earlier studies has changed as well. New results show that it is more likely for a fish from all size groups to move east than west. Regarding

movement with relation to the size of fish, Hanselman et al. (in review) showed that small fish are more likely to move out of their current area and eastward, in all areas except the EGOA, while medium and large fish move more than previously thought in all areas except the BS. Large fish did show a large increase in annual probability of movement out of the EGOA and WGOA.

Sablefish moved large distances throughout the 39 years of tagging. Mean great-circle distance moved in one year over all size groups was 148 km (80 nautical miles (nmi)), and 626 km (338 nmi) over all time at liberty. These distances are calculated as point-to-point, so they surely are minimum distances. Female sablefish moved slightly farther on average than male fish. The longest a recaptured tagged fish has been at liberty is slightly over 37 years from a fish tagged in 1973 and recovered in 2010. Over half of all recovered tagged fish were recovered within 10 years of being tagged: 33% of tagged fish were recovered within 2 years of their release, 28% were recovered 3-5 years following their releases, and 24% were recovered 6-10 years following their release (Table 6).

Juvenile sablefish

Juvenile sablefish (mostly age-1) have been tagged in varying numbers since 1985 with traditional anchor tags and internal electronic archival tags in a number of bays and inlets in Southeast Alaska, ranging from Ketchikan to Juneau. Since 1987, the majority of the tagging has occurred in St. John Baptist Bay near Sitka, Alaska, on Baranof Island because juvenile sablefish have consistently been found there (Fig. 3). Through 2012, there have been over 36,200 tagged juveniles with traditional anchor tags and 852 juveniles tagged with internal electronic archival tags.

Researchers have generally thought that most young-of-the year (YOY; 0-age) sablefish occur east of Kodiak Island (Sigler et al. 2001), and that most sablefish recruitment takes places in the northeastern Pacific in the coastal waters of BC and the EGOA (Bracken 1983, Sasaki 1985, Beamish and McFarlane 1988). However, there has been recent documentation by ABL researchers of YOY sablefish in the BS. Adult sablefish spawn offshore in deep-water below 300 m in late winter/early spring. Eggs and larvae are subject to drift as they rise to the surface after hatching, drifting inshore. By late summer, juveniles are found in coastal bays and inlets. These 0-age ("young-of-the-year") fish usually remain in the bays and inlets until early fall of the year following entrance (about a year), although some remain for 2 years (Rutecki and Varosi 1997). The average length of an age-1 juvenile sablefish tagged in southeast Alaska is 31-35 cm.

Because of the known-age (age-1) of juvenile sablefish that are tagged in St. John Baptist Bay, these tagging studies are especially unique and provide valuable information that differs from info derived from the tagging of adults on the longline survey. Tagging of known-age juveniles before they leave coastal areas offers an opportunity to document age-specific movement; that is, recoveries of known-age fish provide information on the age at which fish become available to the fishery (Maloney and Sigler 2008). Recoveries of electronic archival tags from known-age juveniles are especially useful for this purpose. These tags store depth and temperature readings taken at preset time intervals, providing information about inshore-offshore migration at known ages, daily depth movements, and habitat temperature. Recoveries of known-age fish can also provide evaluation of ageing methods, such as otolith reading (Heifetz et al. 1999, Hanselman et al. 2012).

Results of studies on known-age tagged fish confirm that sablefish move to deeper water with age. Sablefish availability to the commercial fishery increases rapidly for fish of younger

ages, peaking at age 5 to 6, and then gradually declines as sablefish move deeper with age (Maloney and Sigler 2008). The average time at liberty of a tagged juvenile sablefish recovered in the commercial fishery is 4 years, which equates to a 5-year-old fish. This number is slightly low because of the inclusion of Chatham and Clarence Strait recoveries, which are generally much sooner following release than in outside waters, approximately 1.3 and 1.8 years, respectively. If we remove Chatham and Clarence Strait juvenile tag recoveries from this analysis, the average time at liberty of tagged juvenile sablefish recovered in the commercial fishery (in offshore waters) becomes 6.3 years (approximately 7 years old).

Figure 16 displays movement by age and size of 862 juvenile sablefish tagged in Southeast Alaska, for which recovery size was available. In the panel displaying recoveries 0-2 years following release (2-3 year olds), the majority of fish are still in the small size group, and very few fish have been recaptured in outside waters. Most fish captured within 2 years following tagging are sport-caught in inside Southeast Alaska waters. Over half of the tagged juvenile sablefish recaptured 3-4 years following tagging (4-5 year olds) have become medium-sized fish, and 33% remain small-sized fish (Fig. 16). These small fish are likely males, as they grow slower than females (Echave et al. 2012). By this age/size, most of the sablefish have moved out of the shallow inshore bays into offshore waters where they have become vulnerable to commercial fishing gear. The majority of recoveries are in the EGOA and CGOA. By the time fish are recovered 5-6 years following tagging (6-7-year-old fish; Fig. 16), the great majority are in the medium to large size class. At this point, the number of recoveries in the WGOA, AI, and BS are increasing, but the EGOA and CGOA still have the highest recoveries of these fish. This could also be a result of higher fishing effort in these areas. At age 8 and older, the majority of

recoveries were large fish (Fig. 16). In addition, there were far more recoveries of tagged juveniles 7+ years following tagging than in the earlier years, re-emphasizing the size and age when the majority of sablefish are caught in the commercial fishery.

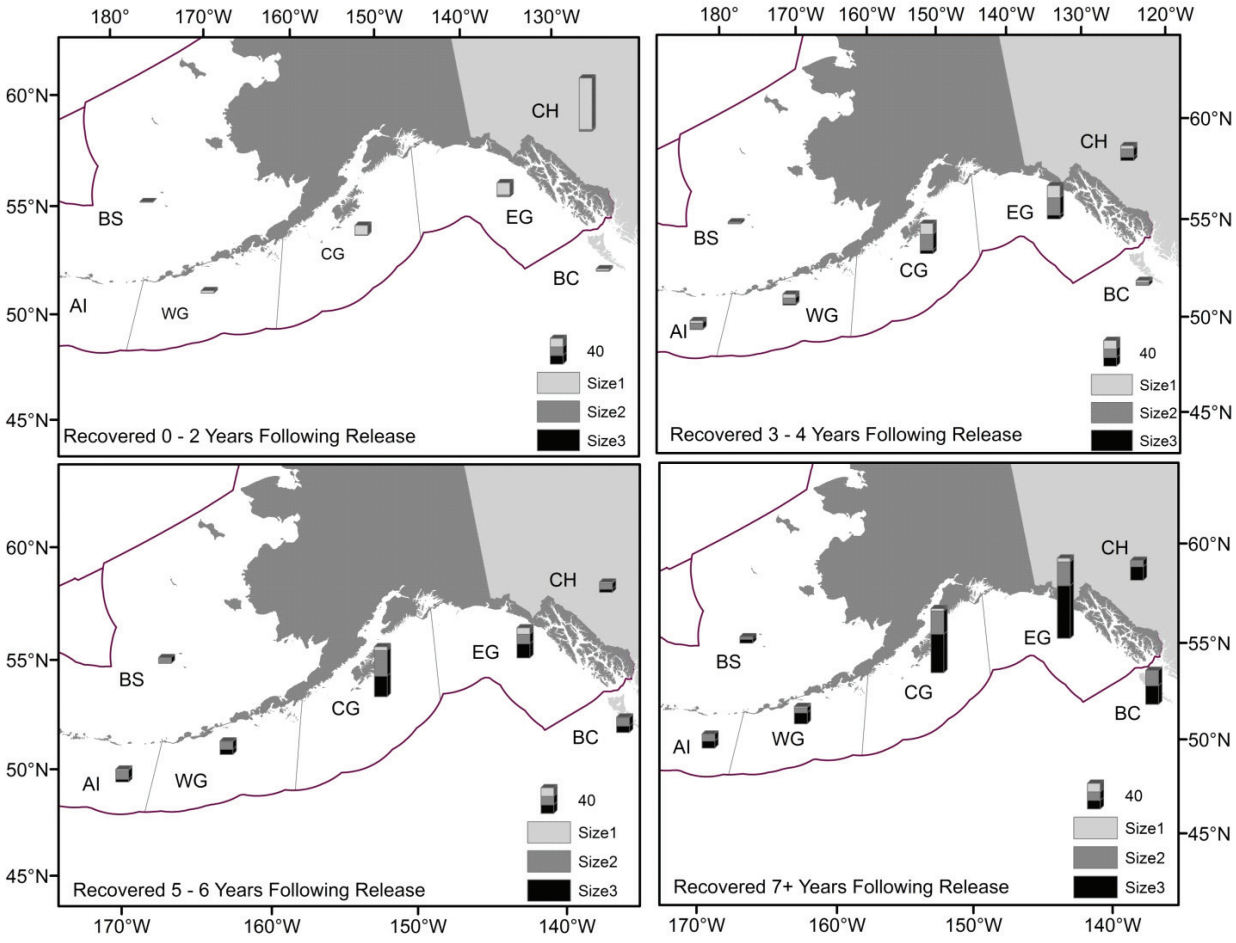

Figure 16. -- Recoveries of known-age tagged juveniles by recovery size and recovery area, recovered 0-2 years following release (top left panel), recovered 3-4 years following release (top right panel), recovered 5-6 years following release (bottom left panel), and recovered 7+ years following release (bottom right panel). BC = British Columbia, EG = Eastern Gulf of Alaska (GOA), CG = Central GOA, WG = Western GOA, AI = Aleutian Islands, and BS = Bering Sea. Size 1 = 41-56 cm, size 2 = 57-66 cm, and size 3 > 66 cm.

RELATED STUDIES

Recruitment

The abundance of sablefish depends heavily on annual recruitment. Recruitment is generally defined as the abundance of the youngest fish entering a population that can be estimated successfully (Maunder and Watters 2003). Recruitment of sablefish, in particular, is characterized by great variation in year class strength. Often a single strong year class dominates fishery catches for 5 or more years. There are many factors that may affect annual recruitment: fluctuations in spawning stock size (i.e., egg production), environmental conditions (such as water temperature and currents), food availability, and predation on larvae, to name a few. For example, above-average recruitment success was more likely with northerly winter currents (59%) than with a southerly or easterly winter current (25%) (Sigler et al. 2001).

Historically, strong year classes have been signaled by the presence of large numbers of juvenile sablefish in many parts of the migration range. This has been true for the 1959, 1971, 1977, 1980, 1984, 1989, 1991, 1997, and 2000 year classes, which have all proved to be above average in size (Hanselman et al. 2010).

Tag-Reporting Rate

An essential part of estimating migration rates from tagging data is the tag-reporting rate, or the estimate of the percentage of recovered tags that are returned. The tag-reporting rate for the sablefish fishery during 1980-1998 was estimated by Heifetz and Maloney (2001) by comparing tag returns from the commercial fishery with tag returns from the annual longline survey. The primary assumption of this method is that all tagged fish caught on the longline

survey are reported. Reporting rates were highest in the CGOA (38.5%) and EGOA (31.5%), intermediate in the WGOA (26.9%), and lowest in the AI (17.4%) and BS (16.9%). Heifetz and Maloney (2001) reported that the overall reporting rate had increased over time. This increased rate was coincidental with the implementation of the IFQ system, and may have been a result of the number of tags available for recovery, the length of the commercial fishing season, increased observer coverage, the implementation of the tag reward program, and an increased interest of fishermen in the management of sablefish. Hanselman et al. (in review) recalculated tag-reporting rates for an updated look at sablefish movement by pooling data in 3 year increments. Figure 17 shows how these rates have fluctuated over time (Hanselman et al. in review). The 90% British Columbia (BC) value is the Fisheries and Oceans Canada assumed tag reporting rate (Beamish and McFarlane 1988).

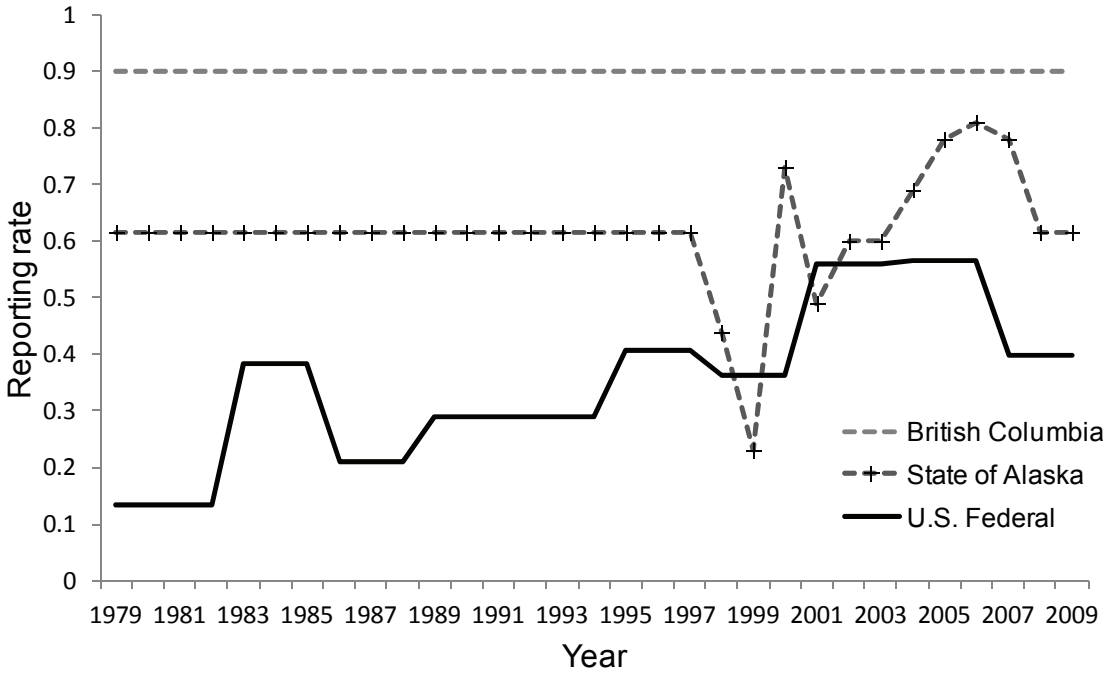

Figure 17. -- Values for tag reporting rates in Alaska federal waters, State of Alaska, and British Columbia used in the sablefish movement model (Hanselman et al. in press). We used the assumed 90% tag reporting value from British Columbia (Department of Fisheries and Oceans).

Age and Growth

Length measurements and otoliths (the ear bone) of sablefish have been collected since the inception of the Japan-U.S. cooperative longline survey in 1981, and data collection has continued as part of the current NMFS domestic longline survey that began in 1988. The annular growth zones found on sablefish otoliths (similar to reading rings on a tree) and the size of the fish at the time of sampling provide a means to age the fish and estimate growth rates. These data are used in the assessment of the stock. Tagging data, consisting of release and recovery sizes and the length of time fish were at liberty, provide an independent estimate of growth rates and a means to validate otolith ages. Fork length measurements are made on all tagged fish when they are released. A fork length measurement taken at recovery, together with the recovery date, provides a direct growth observation for the period that the fish was free (McDevitt 1990, Maloney 2002). If the sex of the fish is also provided together with date, position, depth, and size, then comparisons between migration and growth rates of males and females can be made.

Data from tagged fish show that sablefish grow rapidly for the first 3 to 4 years of their life, after which growth rates slow and remain low for the remainder of their lives. Females grow faster, larger, and mature at a larger size than males (McDevitt 1990, Echave et al. 2012). An updated growth analysis of Alaska sablefish (Echave et al. 2012) revealed that sablefish are growing to a larger maximum size at a faster rate in more recent years (1996-2004 compared against 1981-1993). In addition, it has been determined that significant differences in growth patterns exist among management regions; the GOA regions consistently display the largest and fastest growing sablefish for both sexes (McDevitt 1990, Sigler et al. 1997, Echave et al. 2012). As more studies continue to point towards the development of a spatially explicit age-structured

stock assessment model, these different growth patterns among management regions will become particularly important for the management of the stock.

Pop-off Satellite Tagging

Sablefish spawn in the winter between January and March (Mason et al. 1983), when the fishery is closed. For this reason, there is little knowledge of sablefish distribution during the winter spawning season. To overcome the shortcomings of fishery-dependent recovery of tagged fish, sablefish were tagged with geomagnetic pop-off satellite tags (Desert Star Co.) off of Kodiak Island in December 2011 and on the summer AFSC longline survey in 2012. Tagging will also continue on the AFSC longline survey in 2013, 2014, and 2015. These tags measure the strength of the earth's magnetic field along three axes in order to provide an estimated location of the fish. The tag is programmed to release on a predetermined date, and once surfaced, archived data are uploaded by a passing satellite. We targeted mature females by tagging fish with a fork length > 85 cm and programmed tags to release during spawning times in hopes of determining spawning locations.

Pop-off satellite tags were placed on five large sablefish off of Kodiak Island to monitor their movements during the spawning season in December 2011. Four of the five tags successfully released on their respective programmed dates in mid-January and early February with known pop-off locations. The two fish that were initially captured, tagged, and released nearshore on the edge of Amatuli Trough northeast of Kodiak Island (Fig. 18) remained within 1 km of their tagging location on the shelf. The two fish that were initially captured offshore but released nearshore traveled approximately 75 km (great circle distance) back to the slope within

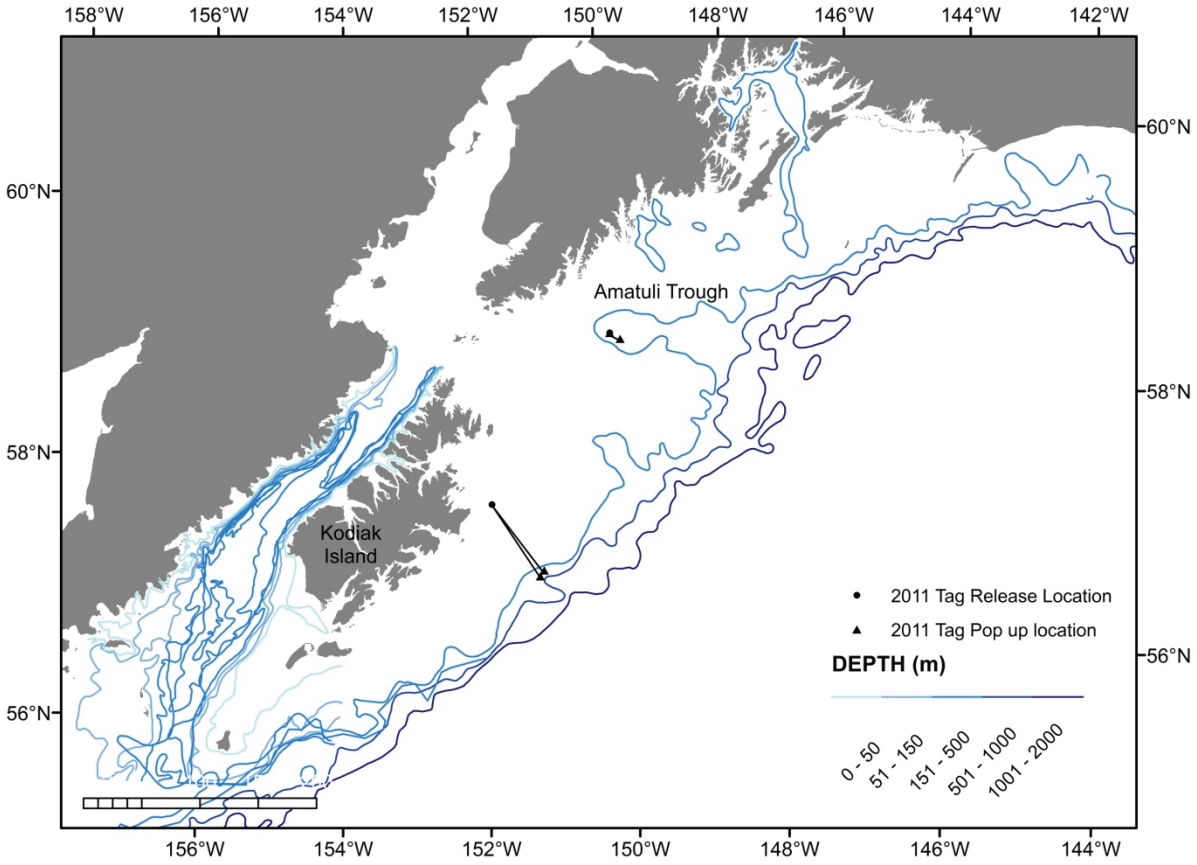

Figure 18. -- Release and pop-off locations of four satellite tags released on sablefish off Kodiak Island in December 2011.

10 km of their initial capture location. Future work will look at the daily tracking calculated by magnetic field measurements once the raw data are fully acquired.

Pop-off satellite tags were also deployed on 43 sablefish throughout the geographic range of the 2012 AFSC longline survey to study daily and large-scale movements. These tags were programmed to release from the fish 1 January 2013 and 1 February 2013, in hopes of determining spawning locations and ultimately areas which may be used to help assess recruitment. Data from these tags will also provide an improved picture of the daily movements and behavior patterns of sablefish. Approximately half of the tags were successful releasing from

the fish on their respective dates, and have been successfully transmitting data via satellite. With just one year of data acquired and still in the early stages of analysis of the data that has been received, it is still too early to determine if there is a directed movement by sablefish for spawning purposes. However, just having the release location of the tag and the pop-off location (location of the fish when the tag released) has provided great insight into (relatively) short-term and winter behavior of sablefish. Movement has ranged from < 5 km in the approximate 6 month period to a Gulf crossing from the WGOA to the EGOA.

FUTURE STUDIES

The use of pop-off satellite tags remains relatively new, and all the applications and benefits from the data acquired from these tags are still unknown. We hope that the information they provide will give us insight into the behavior and movement of fish during the times of year when the fishery is closed. For instance, there is hope that patterns of spawning behavior will be identified in addition to the location of possible spawning aggregations. This information would help with future work looking at recruitment. In addition, the reason for sablefish movement is still unknown. It could be the result of density overcrowding, a spawning migration, physiologically driven, or just random movement. The use of archival and satellite tag data will hopefully shed some light onto these questions.

Although we did find trends in movement direction, based on anchor and archival tag data, not all tagged fish followed the general movement trends, and it is not completely understood what factors influence the variability in migration rates from year to year and between individuals. Several pairs of sablefish, tagged and released at the same time and place,

have been recovered together at a new location several years later, indicating that their respective migration rates were very similar. On the other hand, some fish starting from the same area at the same time have been recovered at approximately the same time hundreds of miles apart, indicating vastly different migration rates. Our tag database, in addition to increasing amount of archival data and satellite data soon to be acquired, will continue to be used to help answer questions about the purpose and timing of movement patterns.

ACKNOWLEDGMENTS

Many individuals have contributed to the success of the Sablefish Tag Program, from the biologists and crews of chartered vessels who have spent endless hours tagging sablefish, to the many fishermen, observers, and processors who have taken the time to take measurements and return recovered tags. In addition, we would like to thank the Alaska Department of Fish and Game for providing sablefish tag data for the updated movement analyses reported in this article, in addition to their cooperation throughout the years with the exchange of tag recoveries and recovery information. Lastly, we gratefully thank all those who have been involved and continue to help this project succeed and we hope you enjoy your hats!

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Table 1. -- Total number of adult and juvenile sablefish tag releases by year.

Year	Adults	Juveniles	Total
1972	2,402		2,402
1973	6,999		6,999
1975	476		476
1976	162		162
1978	7,705		7,705
1979	24,397		24,397
1980	16,904		16,904
1981	27,526		27,526
1982	26,342		26,342
1983	26,449		26,449
1984	14,160	1	14,161
1985	17,285	6,179	23,464
1986	17,164	1,178	18,342
1987	16,546	7,918	24,464
1988	12,892	3,904	16,796
1989	15,115	531	15,646
1990	5,984		5,984
1991	10,052	3,370	13,422
1992	4,231	1,659	5,735
1993	4,016	613	4,629
1994	3,489	1,199	4,688
1995	2	987	989
1996	1	1,737	1,738
1997	3,857	58	3,915
1998	3,491	1,174	4,665
1999	4,650	869	5,519
2000	4,191	737	4,927
2001	5,362	106	5,468
2002	4,504	477	4,981
2003	4,079	760	4,839
2004	4,184	291	4,474
2005	3,539	697	4,236
2006	3,931	84	4,013
2007	3,825	164	3,988
2008	3,295	459	3,754
2009	3,388	312	3,700
2010	3,739	227	3,966
2011	4,323	948	5,264
2012	3,041	497	3,538

Table 2. -- Number of sablefish releases by release area and size, and the total number of recoveries from those releases. AI = Aleutian Islands, BS = Bering Sea, WGOA = Western Gulf of Alaska (GOA), CGOA = Central GOA, and EGOA = the outside waters of the Eastern GOA, and EG inside = the inside waters of southeast Alaska in the Eastern GOA. Small = 41-56 cm, medium = 57-66 cm, and large >66 cm. The sum of releases of each of the three sizes for each area won't match the total release number due to missing size data.

		Release Size					
		Small		Medium		Large	
Release Area	Total Releases	Release	Recovery	Release	Recovery	Release	Recovery
AI	18,906	6,325	516	9,229	984	3,352	362
BS	26,404	8,815	755	15,283	1,566	2,278	257
WGOA	26,796	8,631	809	14,014	1,630	4,142	523
CGOA	70,851	17,211	1,346	35,397	3,129	18,031	1,501
EGOA	110,472	25,678	1,696	49,435	4,225	34,916	2,908
EG inside	106,578	61,460	1,785	26,812	1,470	18,187	986

Table 3. -- Percentage of fish recovered in each area from each tagging area. AI = Aleutian Islands, BS = Bering Sea, WGOA = Western Gulf of Alaska, CGOA = Central Gulf of Alaska, EGOA = Eastern Gulf of Alaska (outside), CH = Chatham Strait (inside southeast Alaska waters in the EGOA), CL = Clarence Strait (inside southeast Alaska waters in the EGOA), Outside reporting waters = water beyond the Alaska Exclusive Economic Zone, BC = British Columbia, and WC = West Coast. Totals for each release area don't equal 100 due to rounding.

		Recovery Area									
Release Area	Total Recoveries	AI	BS	WGOA	CGOA	EGOA	CH	CL	Outside reporting waters	BC	WC
AI	1,865	26%	4%	6%	13%	27%	2%	<1%	3%	18%	2%
BS	2,582	4%	19%	7%	20%	29%	3%	<1%	3%	13%	<1%
WGOA	2,961	4%	4%	24%	21%	24%	3%	<1%	3%	16%	1%
CGOA	5,994	3%	2%	5%	44%	26%	2%	0	3%	13%	<1%
EGOA	8,849	3%	2%	4%	15%	55%	4%	1%	3%	14%	1%
CH	7,287	1%	1%	2%	7%	15%	62%	<1%	2%	11%	1%
CL	1,545	1%	1%	1%	3%	16%	4%	47%	1%	26%	<1%

Table 4. -- Annual movement probability estimates by area, $a \neq k$ is the total probability of moving to any other area. BC = British Columbia, CL = Clarence Strait, CH = Chatham Straight, EGOA = Eastern Gulf of Alaska (GOA), CGOA = Central GOA, WGOA = Western GOA, BS = Bering Sea, and AI = Aleutian Islands. From Hanselman et al. (in review).

Area	BC	CL	CH	EGOA	CGOA	WGOA	BS	AI	$a \neq k$
				Small (< 57 cm)					
CL	20%	69.7%	1.4%	18.6%	6.1%	1.8%	0.2%	0.2%	30.3%
CH	1.2%	0.2%	89.6%	6.3%	2%	0.6%	0.1%	0%	10.4%
EGOA	2.5%	0.1%	1%	50.3%	29.4%	12.7%	2.1%	1.9%	49.7%
CGOA	1%	0%	0.4%	37.2%	32.5%	18%	5.7%	5.3%	67.5%
WGOA	0.55	0%	0.2%	27.1%	30.4%	19.6%	11.2%	11%	80.4%
BS	0.1%	0%	0%	7%	14.8%	17.2%	56.7%	4.2%	43.3%
AI	0%	0%	0%	3.8%	8.5%	10.5%	4.9%	72.2%	27.8%
				Medium (57-66 cm)					
CL	5.8%	72.3%	1.8%	15.4%	3.6%	0.8%	0.1%	0.1%	27.7%
CH	2.3%	0.1%	85.7%	9.2%	2..1%	0.5%	0%	0.1%	14.3%
EGOA	2.5%	0.1%	1.5%	58.4%	26.1%	7.9%	1.4%	2.1%	41.6%
CGOA	0.8%	0%	0.5%	36.9%	35.6%	13.9%	4.9%	7.5%	61.4%
WGOA	0.4%	0%	0.3%	27.1%	33.9%	15.1%	9.1%	14%	84.9%
BS	0.1%	0%	0%	8.1%	20%	15.1%	50.2%	6.5%	49.8%
AI	0.1%	0%	0%	7.3%	18.3%	14.1%	5.4%	54.8%	45.2%
				Large (> 66 cm)					
CL	10.8%	67.8%	3.6%	12.7%	3.6%	1.1%	0.2%	0.2%	32.2%
CH	1.6%	0.2%	90.3%	5.7%	1.6%	0.5%	0.1%	0.1%	9.7%
EGOA	2.3%	0%	1.4%	55%	27.2%	9.4%	2.3%	2.4%	45%
CGOA	1%	0%	0.6%	45.8%	30.6%	11.4%	5%	5.5%	69.4%
WGOA	0.8%	0%	0.5%	42.3%	30.4%	11.7%	6.7%	7.6%	88.3%
BS	0.2%	0%	0.1%	17.2%	22.7%	11.5%	39.5%	8.7%	60.5%
AI	0.2%	0%	0.1%	15.3%	20.7%	10.6%	3%	50.1%	49.9%

Table 5. -- Average distance traveled (km) of each size type from each release area of both females (Sex 2) and males (Sex 1). EGOA = Eastern Gulf of Alaska (GOA), CH = Chatham Strait, CL = Clarence Strait, CGOA = Central GOA, WGOA = Western GOA, BS = Bering Sea, and AI = Aleutian Islands. Small = 41-56 cm, medium = 57-66 cm, and large > 66 cm.

		Release Area						
Release Size	Sex	EGOA	CH	CL	CGOA	WGOA	BS	AI
All	2	231	121	120	355	586	722	972
Small	2	267	257	177	328	626	738	1,009
Medium	2	324	281	191	433	557	766	1,001
Large	2	199	92	102	334	586	702	946
All	1	359	229	180	369	533	673	869
Small	1	396	454	246	415	514	771	980
Medium	1	453	486	308	443	574	730	845
Large	1	319	158	158	324	521	624	825

Table 6. -- The percentage of tag recoveries after so many years at liberty.

Number of years at liberty	Percentage of recoveries
0 – 2	33 %
3 – 5	28 %
6 – 10	24 %
11 – 15	9 %
16 – 20	4 %
21 – 25	2 %
26 – 30	< 1 %
30+	< 1 %

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