PATTERNS AND ENVIRONMENTAL DRIVERS OF JUVENILE SABLEFISH MOVEMENT IN SOUTHEAST ALASKA

By

Rhea K. Ehresmann, B.S.

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of

Master of Science

in

Fisheries

University of Alaska Fairbanks

August 2018

APPROVED:

Dr. Anne H. Beaudreau, Committee Chair
Dr. Andrew C. Seitz, Committee Member
Kristen M. Green, Committee Member
Milo D. Adkison, Chair
Department of Fisheries
S. Bradley Moran, Dean
College of Fisheries and Ocean Sciences
Michael Castellini, Dean
Graduate School

Abstract

Sablefish *Anoplopoma fimbria* are a long-lived, deep-dwelling groundfish that inhabit the North Pacific Ocean, ranging from northern Mexico to the Gulf of Alaska to Japan, supporting one of Alaska's most valuable commercial fisheries. After decades of heavy fishing, declines in the Sablefish population led to significant fishing restrictions but few strong year classes developed in recent years. Most Sablefish research has focused on the larval, near-surface juvenile, or adult life history stages, but few studies have examined post-settlement juvenile Sablefish in nearshore areas. This study used acoustic telemetry to understand the presence and movement of juvenile Sablefish in a nursery area in Southeast Alaska. Throughout the summer and fall of 2015 and 2016, 40 juvenile Sablefish implanted with acoustic transmitters were monitored using an array of eight fixed receivers in St. John Baptist Bay, Baranof Island, Alaska. We quantified the movement patterns of 28 juvenile Sablefish using displacement from the head of the bay, daily distance traveled, daily duration within the bay, unique movement types among individuals, and movement in relation to environmental variables. From these analyses, we show that juvenile Sablefish exhibit fidelity to the middle-head region of the bay, display relatively high rates of daily movement and residence, demonstrate three distinct movement patterns, and are influenced by environmental variables like water temperature, diel state, moon phase, and day of year. Our results show that juvenile Sablefish exhibit seasonality in movements as they progressively emigrate from the bay throughout the summer and fall. Certain factors were found to increase the likelihood of movement for juvenile Sablefish, perhaps allowing them to remain in suitable environmental conditions. This study fills a gap in our knowledge of Sablefish early life history and reinforces the importance of nursery areas like St. John Baptist Bay for juvenile Sablefish prior to recruitment into commercial fisheries.

Table of Contents

List of Figures

Chapter 1 Page

Chapter 2

List of Tables

Chapter 1 Page

Chapter 2

List of Appendices

Acknowledgements

I would like to acknowledge and thank my thesis advisor Dr. Anne Beaudreau of the College of Fisheries and Ocean Sciences (CFOS) at the University of Alaska Fairbanks (UAF) for her knowledge and support for me and for this project over the past four years. She has incredible drive and passion for her work and her students, and I appreciate her relentless encouragement via weekly check-ins, emails, and meetings. Dr. Beaudreau has inspired me to step out of my comfort zones many times throughout graduate school and has helped me shape the 3.9 million detections from this study into two chapters of which I am very proud.

I would also like to acknowledge and thank my other two committee members, Dr. Andy Seitz at the UAF Fairbanks campus and Kristen Green of Stanford University for their insightful discussions regarding telemetry work, comments on the individual chapters and analyses, and questions regarding the big-picture implications of this project.

The Alaska Department of Fish & Game (ADF&G) provided funding for this work and for my graduate studies, and I am grateful for receiving this opportunity. Many ADF&G coworkers provided countless hours of diving and boat operating to retrieve the receivers from St. John Baptist Bay, sometimes at a very short notice. I am indebted to them for their assistance, as this project would not have been possible without their help.

Finally, I would like to thank Dan O'Neill for his help with assembling receiver moorings and for dozens of weekly trips to St. John Baptist Bay for mobile tracking surveys. I owe many thanks to the past and present members of the Coastal Fisheries Ecology Lab for their feedback on topics ranging from presentations to academic challenges and for their comradery and friendship. I would also like to thank Justin Priest for his assistance with R code and analyses, editing and reviewing manuscripts, and overall support in the final months of graduate school.

General Introduction

Coastal habitats are ecologically important; they serve as feeding grounds, spawning areas, nursery areas, and migration routes and support the survival, growth, and reproduction of many species of fish (Beck et al. 2001; Seitz et al. 2014; Vasconcelos et al. 2014). For example, nursery grounds in coastal and estuarine ecosystems can provide prey resources, favorable environmental conditions, and refuge from predators for juvenile fishes, allowing for maximization of growth rates (Herke 1971; Weinstein 1979; Boesch and Turner 1984; Beck et al. 2001; Heck et al. 2003). Juvenile fishes may choose a post-settlement habitat that balances physiological requirements for survival and growth in varying environmental conditions while foraging for prey and avoiding predators (Hughes and Grand 2000; Adams et al. 2006; Fulford et al. 2011). Whether juvenile fishes move away from or remain in the location in which they settle during their nearshore residency is important for understanding the scale of their dependence on nursery areas (Saucerman and Deegan 1991). Furthermore, understanding how juveniles use nursery areas improves our understanding of this life history stage as well as their biological responses to changes in conditions. One way to examine how juvenile fishes use nursery areas is by examining their presence and movements, as such factors may be influenced by biotic and abiotic factors. In this study, we used acoustic telemetry to describe and evaluate juvenile Sablefish (*Anoplopoma fimbria*) presence and movement in a nearshore nursery area in Southeast Alaska.

Sablefish undergo an ontogenetic habitat shift in their early life history (Mason et al. 1983; Kendall and Matarese 1987). Adult Sablefish primarily live along the continental slope and spawn during the early spring in deep offshore waters at depths ranging from 300 to 500 m (Mason et al. 1983; McFarlane and Beamish 1983; Kendall and Matarese 1987). After hatching and drifting from offshore to nearshore, juvenile Sablefish settle in interior bays by the end of their first summer where they experience rapid growth in nearshore environments (Mason et al. 1983; McFarlane and Beamish 1983; Rutecki and Varosi 1997a, 1997b). Larvae are thought to move from deep, offshore waters to warmer, nearshore waters to maximize their growth rates and rapidly accumulate biomass (Rutecki and Varosi 1997a; Gao et al. 2004). Juvenile Sablefish remain in these protected areas for one to two years before returning to deeper waters where they remain as adults, typically recruiting to commercial fisheries by age 4 (Rutecki and Varosi 1997a; Sigler et al. 2003). Improving knowledge of the early life history of Sablefish, particularly their movement patterns during their first years of life, may lead to a better understanding of the importance of nursery grounds and the influence of environmental variables on juvenile Sablefish movement (Mason et al. 1983; Sigler et al. 2001, 2003).

Survival in the first year of life has been shown to be critical for juvenile Sablefish recruitment success, but relatively little is known about post-settlement juvenile Sablefish in nearshore bays prior to outmigration (Mason et al. 1983; Sigler et al. 2001, 2003). Juvenile Sablefish are capable of rapid growth, which may be a mechanism for enhancing their survival during their early life history (Rutecki and Varosi 1997a; Sogard and Olla 2001). During this period of rapid growth, factors that influence Sablefish nutritional status and body condition play an important role in determining year class strength (Mason et al. 1983; Sigler et al. 2001, 2003). Juvenile Sablefish may modify their movements to achieve a balance among food acquisition, predation risk, and preferred temperatures that promote rapid summertime growth, as found in an experimental setting (Sogard and Olla 1998). Water temperature influences juvenile Sablefish physiologically and behaviorally (Sogard and Olla 1998, 2001), while light levels impact the activity rates of juvenile Sablefish, perhaps due to a reduced ability for foraging during periods of low light (Sogard and Olla 1998; Ryer and Olla 1999). Movements related to foraging and habitat selection appear as shifts in horizontal and vertical distribution and may vary among individual fish based on hunger level and body size (Sogard and Olla 1998).

Juvenile Sablefish have been documented in bays and harbors throughout Southeast Alaska, but are consistently found in St. John Baptist Bay (SJBB), Baranof Island, which has been a focus of studies on juvenile Sablefish ecology since the 1990s (Rutecki and Varosi 1997a). While resident in SJBB, juvenile Sablefish feed on high-energy, seasonally-pulsed prey items, including Pacific Herring *Clupea pallasii* and carcasses of adult salmon *Oncorhynchus* spp. near freshwater sources (Coutré et al. 2015). A movement study of six juvenile Sablefish tagged in SJBB revealed that they spent most of their time near the bottom while embarking on periodic vertical excursions, with the highest frequency of excursions during dawn and day, but lowest at night (Coutré et al. 2017). Long-term tagging projects have identified large-scale patterns of movement and migration rates (Maloney and Sigler 2008); however, fine-scale movement patterns and habitat use of juvenile Sablefish in SJBB and other nursery grounds is not well understood. Beyond these studies of juvenile Sablefish feeding ecology and vertical movement patterns in SJBB (Coutré et al. 2015, 2017), little is known about post-settlement juvenile Sablefish within the bay over multiple seasons.

To examine the range of fine-scale movements that juvenile Sablefish undertake during their residence in coastal and estuarine nursery grounds, this thesis used acoustic telemetry to track individual fish movements. The overarching goals of this study were to collect and analyze acoustic telemetry data to (1) describe movement patterns of juvenile Sablefish during their nearshore residence and (2) evaluate patterns of movement in relation to variables such as temperature, tidal stage, diel period, moon phase, day of year, and year. In Chapter One, the fine-scale movements of 28 tagged juvenile Sablefish were examined from June through October in 2015 and 2016 in SJBB. To understand movement patterns and residence time of juvenile Sablefish within SJBB, we analyzed acoustic detections to quantify (1) daily presence; (2) residence within the bay; (3) displacement from the head of the bay; (4) duration of time spent within the bay; (5) distance traveled; (6) variation among individual movement patterns; and (7) variation in size. We used these metrics and analyses to address the hypotheses that juvenile Sablefish movements would occur throughout the entire bay but would be more common at the head of the bay and that individual Sablefish would exhibit variation in their movement and location within the bay.

Chapter Two of this thesis examined the influence of environmental variables on juvenile Sablefish movement. Juvenile Sablefish have exhibited patterns in movement in relation to temperature and diel state based on experimental research and studies in the wild (Sogard and Olla 1998, 2001; Coutré et al. 2017), and changes in other environmental conditions may also explain patterns in movement. In this chapter, we qualitatively examined fish presence in relation to environmental variables and quantitatively examined movement rates in relation to environmental variables. We modeled the relationship between the hourly movement probability for tagged juvenile Sablefish and mean water temperature, diel state, moon phase, and day of year for SJBB using a generalized linear mixed effects model. We used this model and other analyses to evaluate how environmental factors affect juvenile Sablefish movement in a nearshore nursery area. This research adds to existing studies of juvenile Sablefish (Rutecki and Varosi 1997a; Courtney and Rutecki 2011; Coutré et al. 2015, 2017) and contributes more broadly to our understanding of the temporal and spatial dynamics of juvenile Sablefish in nearshore bays.

References

Adams, A. J., C. P. Dahlgren, G. T. Kellison, M. S. Kendall, C. A. Layman, J. A. Ley, I. Nagelkerken, and J. E. Serafy. 2006. Nursery function of tropical back-reef systems. Marine Ecology Progress Series 318.

Beck, M. W., K. L. Heck, K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B. Halpern, C. G. Hays, K. Hoshino, T. J. Minello, R. J. Orth, P. F. Sheridan, and M. P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51(8).

Boesch, D. F., and R. E. Turner. 1984. Dependence of fishery species on salt marshes: the role of food and refuge. Estuaries 7(4A).

Courtney, D., and T. L. Rutecki. 2011. Inshore movement and habitat use by juvenile Sablefish, *Anoplopoma fimbria*, implanted with acoustic tags in Southeast Alaska. AFSC Processed Report 2011-01, 39 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar, Fish. Serv., Auke Bay Laboratories.

Coutré, K. M., A. H. Beaudreau, D. Courtney, F. J. Mueter, P. W. Malecha, and T. L. Rutecki. 2017. Vertical movements of juvenile Sablefish in coastal Southeast Alaska. Marine and Coastal Fisheries 9(1).

Coutré, K. M., A. H. Beaudreau, and P. W. Malecha. 2015. Temporal variation in diet composition and use of pulsed resource subsidies by juvenile Sablefish. Transactions of the American Fisheries Society 144(4).

Fulford, R. S., M. S. Peterson, and P. O. Grammer. 2011. An ecological model of the habitat mosaic in estuarine nursery areas: Part I-Interaction of dispersal theory and habitat variability in describing juvenile fish distributions. Ecological Modelling 222(17).

Gao, Y., S. H. Joner, R. A. Svec, and K. L. Weinberg. 2004. Stable isotopic comparison in otoliths of juvenile sablefish *Anoplopoma fimbria* from waters off the Washington and Oregon coast. Fisheries Research 68(1–3).

Heck, K. L., G. Hays, and R. J. Orth. 2003. Critical evaluation of nursery hypothesis for seagrasses. Marine Ecology Progress Series 253

Herke, W. 1971. Use of natural, and semi-impounded, Louisiana tidal marshes as nurseries for fishes and crustaceans (1971).

Hughes, N. F., and T. C. Grand. 2000. Physiological ecology meets the ideal free distribution: predicting the distribution of size-structured fish populations across temperature gradients. Environmental Biology of Fishes 59.

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

Maloney, N. E., and M. F. Sigler. 2008. Age-specific movement patterns of sablefish (*Anoplopoma fimbria*) in Alaska. Fishery Bulletin 106(3).

Mason, J. C., R. J. Beamish, and G. A. McFarlane. 1983. Sexual maturity, fecundity, spawning, and early life history of sablefish off the Pacific coast of Canada. Can. J. Fish. and Aquatic Sci. 40.

McFarlane, G. A., and R. J. Beamish. 1983. Preliminary observations on the juvenile biology of sable fish *Anoplopoma fimbria* in waters off the west coast of Canada. Proceedings of the International Sablefish Symposium, 29-31 March 1983, Anchorage, Alaska.

Rutecki, T. L., and E. R. Varosi. 1997a. Distribution, age, and growth of juvenile sablefish, *Anoplopoma fimbria*, in Southeast Alaska. NOAA Tech Rep NMFS 130.

Rutecki, T. L., and E. R. Varosi. 1997b. Migrations of juvenile sablefish, *Anoplopoma fimbria*, in Southeast Alaska. NOAA Technical Report NMFS 130.

Ryer, C., and B. Olla. 1999. Light-induced changes in the prey consumption and behavior of two juvenile planktivorous fish. Marine Ecology Progress Series 181.

Saucerman, S. E., and L. A. Deegan. 1991. Lateral and cross-channel movement of young-of-the-year winter flounder (*Pseudopleuronectes americanus*) in Waquoit Bay, Massachusetts. Estuaries 14(4).

Seitz, R. D., H. Wennhage, U. Bergström, R. N. Lipcius, and T. Ysebaert. 2014. Ecological value of coastal habitats for commercially and ecologically important species. ICES Journal of Marine Science 71(3).

Sigler, M. F., C. R. Lunsford, J. T. Fujioka, and S. A. Lowe. 2003. Alaska Sablefish assessment for 2004. Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska.

Sigler, M. F., T. L. Rutecki, D. L. Courtney, J. F. Karinen, and M.-S. Yang. 2001. Young of the year sablefish abundance, growth, and diet in the Gulf of Alaska. Alaska Fishery Research Bulletin 8(1).

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

Sogard, S. M., and B. L. Olla. 2001. Growth and behavioral responses to elevated temperatures by juvenile sablefish *Anoplopoma fimbria* and the interactive role of food availability. Marine Ecology Progress Series 217.

Vasconcelos, R. P., D. B. Eggleston, O. Le Pape, and I. Tulp. 2014. Patterns and processes of habitat-specific demographic variability in exploited marine species. ICES Journal of Marine Science 71(3).

Weinstein, M. P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fishery Bulletin 77(2).

Chapter 1: Movement patterns of juvenile Sablefish within a nursery area in Southeast Alaska[1]

Abstract

Sablefish *Anoplopoma fimbria* is a commercially important species that inhabits waters of the Pacific Ocean from Baja California, Mexico, to the Bering Sea, Alaska. Most studies have focused on the larval, neustonic (near-surface) juvenile, or the adult stages of the Sablefish life cycle, while much less is known about the post-settlement juvenile stage (ages 0 to 2 years) in nearshore nursery areas, even though survival of post-settlement juveniles is thought to be important for determining year class strength. We used acoustic telemetry to monitor movement of post-settlement juvenile Sablefish in a nursery area in Alaska to better describe their period of nearshore residency. Forty juvenile Sablefish were surgically implanted with acoustic transmitters and monitored using eight fixed receivers throughout the summer and fall of 2015 and 2016 in a small bay in Southeast Alaska. We quantified movement patterns in terms of displacement from the head of the bay, distance traveled, and duration of time spent within the bay for 28 individuals. Sablefish showed fidelity to the bay during the summer, with relatively high rates of movement within the bay. Juvenile Sablefish traveled 9.4 km/d and spent 20.2 h/d within the bay on average in 2015 and traveled 13.0 km/d and spent 17.9 h/d within the bay on average in 2016. Tagged Sablefish showed the greatest affinity for a region near the head of the bay, perhaps indicating an area of preferred habitat, prey resources, or environmental conditions. In addition, we assessed variation in horizontal movements among individuals and identified three distinct movement types. This study fills a gap in knowledge of Sablefish early life history

---

[1] Ehresmann, R. K., A. H. Beaudreau, and K. M. Green. In press (2018). Movement patterns of juvenile Sablefish within a nursery area in Southeast Alaska. Transactions of the American Fisheries Society.

by characterizing movement during nearshore residency before outmigration into deeper waters. The results of this study reinforce the importance of nearshore habitats like St. John Baptist Bay for juvenile Sablefish prior to recruitment into fisheries.

Introduction

Estuarine and coastal ecosystems have long been recognized as nursery grounds for crustaceans and fishes (Herke 1971; Weinstein 1979; Boesch and Turner 1984; Beck et al. 2001). Nursery habitats support ecological processes that contribute to recruitment success by improving growth and survival of juveniles, such as providing refuge habitat from predators, food resources, and favorable environmental conditions at a range of spatial and temporal scales (Heck et al. 2003; Nagelkerken et al. 2015; Sheaves et al. 2015). Assessing how juvenile fishes use nursery areas may contribute to understanding the connection between post-settlement habitat and the population's vital rates (e.g., survival, recruitment, emigration; Rutecki and Varosi 1997a; Hanselman et al. 2015; Pirtle et al. 2017). One way to assess how juvenile fishes use nursery areas is to examine their movements within such habitats. Fish movements within nearshore habitats may be related to ecological factors, such as competition among conspecifics for territories, foraging strategies, predator avoidance, and seasonal migrations (Boesch and Turner 1984; Roy et al. 2013; Finn et al. 2014; Henderson et al. 2014; Sheaves et al. 2015). Various methods can be used to investigate movement of fishes, including distributional studies that compare abundance and size structure of fishes among areas; conventional tagging studies that allow for greater spatial and temporal resolution; and electronic tagging and acoustic telemetry studies that provide more detailed information on movements (Furey et al. 2013).

In this study, we examined movement patterns of post-settlement juvenile Sablefish *Anoplopoma fimbria*, a commercially important species in the North Pacific, within a nearshore nursery habitat. Adult Sablefish inhabit waters of the Pacific Ocean along the continental slope at depths of 200 to 1000 m with a geographic distribution ranging from Baja California, Mexico, to the Bering Sea, Alaska, and west to Japan (Sasaki 1985; Wolotira et al. 1993). Mark-recapture studies suggest that there are southern and northern West Coast Sablefish populations, with some mixing near Vancouver Island (McDevitt 1990; Kimura et al. 1998). Sablefish of the northern population spawn offshore from February to March at depths up to 500 m (Mason et al. 1983; McFarlane and Nagata 1988; Wing 1997). After the eggs incubate and hatch, the larvae rise to the surface, reaching nearshore nursery habitats by the end of their first summer where they transition to demersal habitats (Mason et al. 1983; Kendall and Matarese 1987; Rutecki and Varosi 1997a; Wing 1997). Post-settlement juvenile Sablefish remain in nearshore waters for one to two years, reaching approximately 300 to 400 mm in length before they emigrate to deeper waters of the continental shelf, eventually arriving at adult habitats of the continental slope by ages 4 to 5 (Mason et al. 1983; Kendall and Matarese 1987; Rutecki and Varosi 1997a; Maloney and Sigler 2008). Bays and inlets from Southeast Alaska to British Columbia are thought to be important nursery grounds for juvenile Sablefish (Sasaki 1985; Rutecki and Varosi 1997a, 1997b).

Relatively little is known about juvenile Sablefish ecology in nearshore areas; however, it is during this post-settlement period when factors influencing Sablefish body condition and energy allocation strategy are thought to play an important role in determining year class strength (Mason et al. 1983; Sigler et al. 2001, 2003). Juvenile Sablefish growth rates are among the highest measured in juvenile teleosts; young-of-the-year Sablefish can grow at a rate of > 3 mm/d under optimal conditions (Sogard and Olla 2001). While residing in nearshore habitats, juvenile Sablefish are opportunistic feeders, eating high-energy, seasonally pulsed prey, including Pacific Herring *Clupea pallasii* and tissue from adult spawning Pacific salmon *Oncorhynchus* spp. (Coutré et al. 2015). Their vertical movements may be related to foraging, as suggested by a study of six juvenile Sablefish tagged in a Southeast Alaska bay, which found that individuals spent most of their time near the bottom while embarking on periodic vertical excursions primarily during dawn and day periods (Coutré et al. 2017). Beyond these studies of juvenile Sablefish feeding ecology and vertical distribution (Courtney and Rutecki 2011; Coutré et al. 2015, 2017), little is known about the occupancy of post-settlement juvenile Sablefish within nearshore areas over multiple seasons and their degree of movements within nearshore habitats prior to outmigration.

We used acoustic telemetry to examine movement patterns by juvenile Sablefish in a nursery habitat during their post-settlement stage. The first objective of the study was to describe movement of juvenile Sablefish throughout St. John Baptist Bay, Alaska, a known nursery area (Rutecki and Varosi 1997a). We hypothesized that juvenile Sablefish would move throughout the entire bay, but show stronger fidelity to the head of the bay, due to proximity to freshwater input that offers a potential food source of salmon carcasses during the late summer and fall and because this area of the bay has been found to produce higher catch rates of juvenile Sablefish (Rutecki and Varosi 1997a; Courtney and Rutecki 2011; Coutré et al. 2015, 2017). The second objective was to characterize differences in movement patterns among individual Sablefish, as individual variation in movement has been documented for other fishes and may be driven by dynamic ecological factors like foraging strategies, avoiding predators, and biological responses to environmental conditions (Boesch and Turner 1984; Beaudreau and Essington 2011; Roy et al.

2013; Finn et al. 2014; Henderson et al. 2014; Sheaves et al. 2015). We hypothesized that individual Sablefish would exhibit variation in their degree of movement and location within the bay, with some individuals showing fewer absences between detections and stronger site fidelity than others. We also expected that larger individuals, which may be closer to the age of outmigration, would show higher movement rates and lower residence time in the bay compared to smaller individuals.

Methods

Study area

The study was conducted from June 2015 to October 2016 in St. John Baptist Bay, Baranof Island, approximately 33 km north of Sitka, Alaska. St. John Baptist Bay (SJBB) is a small bay (about 3 km long and < 1 km wide) that opens to Salisbury Sound, has a freshwater input, and was historically a commercial log transfer facility (Miller et al. 2007; Figure 1.1). At the mouth of the bay, the depth ranges from 60 to 80 m and becomes gradually shallower toward the middle-head region of the bay, where the depth ranges from 20 to 30 m until nearing the freshwater source at the very head of the bay, at which the depth quickly shallows to less than 15 m. Bottom substrate is mostly soft sediment throughout, with the southern side of the bay near the mouth exhibiting rocky features and boulders. We selected SJBB as the study location for this research because it has been the focus of several juvenile Sablefish ecological studies across multiple seasons and years (e.g., Rutecki and Varosi 1997a; Maloney and Sigler 2008; Courtney and Rutecki 2011; Coutré et al. 2015, 2017) and continues to be sampled annually during the National Marine Fisheries Service (NMFS) juvenile Sablefish tagging survey (Dana Hanselman, NOAA, personal communication).

Tagging

We monitored juvenile Sablefish movements using acoustic telemetry. Acoustic telemetry is a technique in which fish tagged with acoustic transmitters are detected by submerged hydrophones to provide detailed observations of distribution and movements (Eiler and Bishop 2016). Twenty juvenile Sablefish were captured for tagging June 10, 2015, and twenty on June 11 and 12, 2016. Sample size was limited to twenty fish each year based on the size of bay, potential tag interference, and boat traffic within the bay (Jonathan Mulock, Vemco, personal communication). Based on length ranges reported in the literature, tagged juvenile Sablefish were likely age-1 (280–350 mm) and age-2 fish (390–510 mm; Rutecki and Varosi 1997a). Sablefish were caught using rod and reel with baited hooks near the head of the bay at depths ranging from 11.3 to 25.9 m. Date, time, geographic position, and depth were recorded for each fish upon capture. Fish were individually sedated using 10% eugenol (Aqui-S 20E) at a concentration of approximately 30 mg of Aqui-S/L of sea water (average temperature 10.3°C, nearest 0.001°C) and were weighed (round mass, nearest 10 g) and measured (fork length, nearest 5 mm) before tagging.

Acoustic transmitters (Vemco V9-2L 69kHz, 146dB re 1uPA @ 1m, 30 to 90 s delay, 9 mm diameter x 29 mm length, weighing 4.7 g in air and 2.9 g in water) were inserted through a ~1 cm incision through the midline of the ventral musculature of each juvenile Sablefish. The incision was closed by two simple interrupted sutures, performed following procedures outlined by Lowe et al. (2003) and Mulcahy (2003). All instruments and tags were thoroughly disinfected in a 10% betadine solution between surgeries. When transmitters are less than 2% of the weight of the fish, adverse effects of the tagging procedure are thought to be minimal (Gallepp and Magnuson 1972; Ross and McCormick 1981; Winter 1996); on average, transmitters were 1.4%

of the initial weight of individual tagged Sablefish. Each fish was also tagged externally with a unique T-bar anchor tag (Floy) for visual identification if fish were recaptured. After surgery, fish were immediately placed in a recovery tank of fresh seawater for observation until it was apparent that the fish had regained equilibrium and normal gill ventilation rate. On average, sedation and surgery took fewer than 10 minutes total for each fish, with post-surgical recovery time ranging from approximately 10 to 35 minutes. Fish not behaving normally or appearing in healthy condition after an extended recovery period were sacrificed, and all other fish were released at their approximate capture location near the head of the bay. The research was approved by the University of Alaska Fairbanks Institutional Animal Care and Use Committee (protocol no. 738825). Transmitters implanted in 2015 were set to expire after 370 days to avoid inference with the transmitters deployed the following year, and transmitter lifetime for those in 2016 was estimated to be 476 days.

Fixed receiver array and mobile surveys

Between June 9, 2015, and October 11, 2016, eight Vemco VR2W acoustic receivers were deployed and maintained in SJBB. Each acoustic receiver station was submerged and anchored using a 23-kg cement pier block, and receivers were suspended approximately 3 m off the bottom beneath a 20-cm trawl float on polypropylene line. The receivers were attached hydrophone-down below the trawl float to more effectively capture detections of the juvenile Sablefish, as they typically inhabit the area near the benthos. The receivers were positioned to provide the greatest coverage possible of the study area and remained in the bay throughout the duration of the study, except from March 25 to April 10, 2016, during a commercial herring sac roe fishery opening. Receivers 7 and 8 were removed from May 17 to June 13, 2016, due to entanglements with commercial troll gear. These gaps in coverage did not affect our results, as they occurred after fish tagged in 2015 were no longer detected in the bay and before fish were tagged in 2016.

The acoustic array was designed to monitor fish movement throughout the entire bay and to create an acoustic gate to capture movement in and out of the bay. To help determine the siting of the receiver array within SJBB, range testing was performed on receivers positioned at three different points between the head and mouth of the bay (approximately at receivers 1, 5, and 6; Figure 1.1) to ensure that receiver detection capabilities did not vary by location in the bay. For each receiver location, we drove transects (n = 6) from the receiver position to approximately 1,000 m away with a tag suspended from the boat. The geographic position of each transmission was recorded using the boat-based hydrophone equipped with GPS (Vemco VR100). Using a comparison of transmissions detected by the boat-based hydrophone to transmissions detected by the stationary receiver, we modeled the probability of detection for each receiver location using logistic regression. Range testing results showed a 50% probability of detection at distances from 295 to 695 m (mean = 440 m) from stationary receivers, depending on the position of the receiver and local conditions during range testing. Based on these detection capabilities, the receiver array provided nearly full coverage of the bay. One reference tag was deployed each year at the mouth of the bay between receivers 7 and 8 to test the functional performance of the receiver array, even when tagged fish were not present.

In addition to fixed receivers, individual fish were detected from a boat using the boat-based hydrophone once every 7 to 10 days from June through August of each year to ground truth presence/absence of tags in the bay against receiver data and to allow for movement observations in season.

Data analysis

We examined horizontal movement of juvenile Sablefish throughout SJBB and characterized variation in movement patterns among individuals. Prior to analysis, the first five days of each study year were excluded to account for acclimation of tagged fish. Tags that were assumed to have been expelled or were in fish that had died (i.e., tag did not change positions for 30 days or longer) were also excluded. The data were filtered to remove false detections by defining presence within the detection array for a given day as being detected at least twice on any receiver in that 24-hour period; absence from the detection array was defined as being detected only once or not at all in that 24-hour period. Next, we assigned the primary receiver location of each tagged fish to every 15-minute interval in the time series. Primary receiver location was determined as the receiver by which the fish was most frequently detected during that time interval; if more than one receiver was designated as primary for a given interval, a single receiver was randomly chosen from among those with the most detections. We used this method of assigning a primary receiver to each 15-minute interval because for any given transmission, a fish could have been detected at more than one receiver due to overlap in receiver range. While this approach does not generate a precise estimate of fish location, it provides a means of examining temporal patterns of movement across coarse regions of the bay.

Using primary receiver locations, we calculated residence indices (RI) for each receiver and fish. The RI was calculated as the number of intervals an individual fish was detected at each receiver station divided by the total number of intervals the fish was detected anywhere within the acoustic array, similar to Kessel et al. (2016), but using 15-minute intervals instead of days. We mapped the mean RI across fish for each receiver and each year.

To examine Sablefish movement throughout SJBB, we calculated three metrics for each fish: (1) daily displacement from the receiver in closest proximity to the head of the bay (receiver 1), (2) daily distance traveled within the receiver array, and (3) daily duration of presence within or absence from the receiver array. Displacement was calculated as the straight-line distance (km) between the receiver on which a fish was detected and receiver 1 for each 15-minute interval. This measurement allowed for visualization of movement from or toward the head of the bay over time. Daily displacement was calculated for each fish as the average displacement distance per 24-hour period, from the sixth day post-tagging to the last date of detection and then averaged by date for all fish. To calculate distance traveled and duration of time spent within the bay for each fish per 24-hour period, a unique number was assigned to each movement event. When a fish moved to a new receiver or out of the detection array, this marked a new event comprised of distance traveled to that receiver and duration spent at that receiver. For each movement event, distance was measured as the straight-line distance between the fish's previous primary receiver location and the new primary receiver location, and duration was the sum of 15-minute intervals for that movement event. Once the fish changed primary receiver locations, a new event began, and distance and duration were calculated for that movement event. Daily distance (km/d) traveled within the receiver array was calculated by summing distance across events for each 24-hour period, from the sixth day post-tagging to the last date of detection for each fish. Daily duration (h/d) was calculated by summing duration across events for each 24-hour period, from the sixth day post-tagging to the last date of detection for each fish. Box plots were created to show the median and range of estimated daily distance traveled and daily duration spent within the bay for individuals.

Because it was not possible to determine a tagged individual's precise location at any given time or movement path among receivers, these metrics are coarse scale indices of relative movement that allow for an examination of variation in the degree of movement among individuals. It is important to note that displacement and distance measurements account for travel in straight-line distances using only detections inside the range of the receiver array, and thus may over or underestimate movement depending on the actual location of the fish. Direct distances between two receivers were generated using package VTrack in R (Campbell et al. 2012; R Core Team 2017).

We used two complementary approaches to characterize variation in movement patterns among individuals. First, we visually categorized each fish's movement based on the overall shape of its time series of displacement distance from receiver 1. The three unique groups were identified and defined as follows: (1) fish with a greater proportion of detection intervals near the mouth of the bay, (2) fish with a greater proportion of detection intervals near the head of the bay, and (3) fish intermediate to these two types, with a more even distribution of detections between head and mouth (i.e., demonstrating more dispersive tendencies). To corroborate this qualitative assessment, we calculated the proportion of 15-minute detection intervals that fell into each of four regions of the bay: head (receivers 1 and 2), middle-head (receivers 3 and 4), middle-mouth (receivers 5 and 6), and mouth (receivers 7 and 8). We then used a kmeans cluster analysis (k=3; R Core Team 2017) to quantitatively categorize each fish into one of three groups based on similarities in their proportional frequency distributions across regions.

To evaluate the influence of body size on movement, we used separate linear regression models to test for relationships between fork length and days present within the bay, fork length and mean daily distance traveled, and fork length and mean daily duration. All analyses were conducted in R (R Core Team 2017).

Results

Summary of tagged individuals

A total of 40 juvenile Sablefish were implanted with acoustic transmitters in 2015 and 2016, and 28 of these fish were used for analyses. The remaining 12 fish were eliminated from analyses due to suspected tag loss or mortality, as no movement was detected for 30 days or longer (i.e., until the battery expired or the study ended) for each omitted tag. Fork lengths ranged from 300 to 420 mm for both study years (349 ± 24 mm [mean ± SD]), and weights ranged from 240 to 690 g (352 ± 89 g; Table 1.1). Based on fork lengths of tagged fish, we assume the tagged individuals were predominantly age-1, though some may have been age-2 (Rutecki and Varosi 1997a). Between June 11, 2015, and October 11, 2016, a total of 3,886,245 detections were logged for all 40 tagged juvenile Sablefish. The 28 tagged fish used for analyses were detected in the receiver array for at minimum five days during the period of analyses (i.e., after the first five days post-tagging were eliminated). The final dataset used for analyses contained a total of 1,494,963 detections for 28 individuals, which were subset into 15-minute intervals for a total of 106,793 detection intervals (Table 1.2). All eight receivers detected fish, and all fish were detected on every receiver, except for one individual (ID 43454) that was not detected again at receivers 1 and 2 after the initial five-day acclimation period. Only one fish (ID 34759) tagged in 2015 and used in the analyses was detected again after October 21, 2015, which was 195 times between December 7 and 10, 2015; however, these detections were not included in this study.

Presence/absence

Tagged Sablefish were present within the bay from 5 to 121 days (46 ± 39 days [mean ± SD]) between the date of first detection following the five-day acclimation period and date of last detection for each fish (Table 1.1). Absence from the bay ranged from 0 to 56 days (8 ± 12 days) over the same period. Individuals spent an average of 36 days in the receiver array in 2015 with 50% of tagged fish no longer detected within the bay by mid-July (Figure 1.2). Individuals spent an average of 61 days in the receiver array in 2016 with 50% of tagged fish no longer detected by early September (Figure 1.2). Mean daily absence for absences < 24 h ranged from 0.5 to 4.1 h/d (1.4 ± 1.0 h/d) across individuals in 2015 and from 0.8 to 5.5 h/d (2.3 ± 1.4 h/d) in 2016. Some of this short-term absence could be due to being outside the detection radius of the receiver array or within acoustic shadows, though still inside the bay. Absences occurred throughout the summer and fall with no obvious pattern among individuals (Figure 1.3). Receiver performance was generally stable over time, as the reference tags were detected throughout the study with minimal break between detections.

Residence index

Mean RI values for tagged juvenile Sablefish of both years indicated an affinity to receivers 2 and 3 located in middle-head region of the bay (Figure 1.1). Near the mouth of the bay, Sablefish favored the northern shoreline (receivers 5 and 7), with RI values for receivers 6 and 8 along the southern shoreline much lower for both study years. Across both years, receivers 2 and 3 had high mean RI values, while receivers 6 and 8 had the lowest mean RI values. Receivers 4 and 7 also had high mean RI values for 2016.

Displacement, distance, and duration

The mean daily displacement for fish tagged in 2015 ranged from 0.3 to 2.6 km/d (1.5 ± 0.5 km/d across all fish [mean ± SD]), and the mean daily displacement for fish tagged in 2016 ranged from 0.7 to 2.3 km/d (1.6 ± 0.3 km/d across all fish; Figure 1.4). The daily distance traveled for fish tagged in 2015 ranged from 8.6 to 18.2 km/d (13.0 ± 2.6 km/d), and the daily distance traveled for fish tagged in 2016 ranged from 1.3 to 14.5 km/d (9.4 ± 4.1 km/d; Figure 1.5). The daily duration of time spent within the receiver array for fish tagged in 2015 ranged from 17.2 to 22.7 h/d (20.2 ± 1.6 h/d), and the daily duration of time spent for fish tagged in 2016 ranged from 1.5 to 23.5 h/d (17.9 ± 5.8 h/d; Figure 1.6). Some fish moved more frequently throughout the bay while others remained stationary for longer periods of time, as measured using distance and duration spent within the receiver array (Figures 1.5 and 1.6).

Movement types

Movement varied among individuals, and three movement types were apparent from visual classification of individual plots of displacement distance from receiver 1 over time (Figure 1.7). Ten fish increased distance from receiver 1 over time, making few excursions back to the head, and were categorized as mouth residents. Six fish were consistently detected closer to receiver 1, spending more time near the head of the bay but making short-term excursions away before returning; these fish were categorized as head residents. Twelve individuals moved periodically between the head and the mouth of the bay and were categorized as dispersive individuals. Of the mouth residents, all but two were tagged in 2016, while the head residents were split evenly across tagging years. All but one of the dispersive type fish were tagged in 2015.

Visual classification of the individual plots was largely corroborated by the cluster analysis, but differed for six fish. One fish (ID 43447) was visually classified as a mouth resident, but was clustered as a head resident. Two fish (IDs 43443 and 43451) were visually classified as mouth residents, but were clustered into the dispersive group. The remaining three fish visually appeared to be dispersive fish (IDs 34757, 34772, and 43444), but were clustered with head residents. Overall, the analyses suggest that 25% to 36% of the fish were more closely associated with the mouth, 21% to 36% were more closely associated with the head, and 39% to 43% of the fish exhibited more dispersive movement patterns within the bay.

Body size and movement

Days present within the bay was significantly negatively related to fish length (linear regression: $F = 10.69$, df = 26, $P = 0.003$). No relationship was found between length of fish and mean daily distance traveled within the bay (linear regression: $F = 0.14$, df = 26, $P = 0.71$). There was a significant negative linear relationship between the length of fish and mean daily duration (linear regression: $F = 11.50$, df = 26, $P = 0.002$). The coefficients of determination for both significant effects were moderate ($R^2 = 0.29$, $R^2 = 0.31$, respectively).

Discussion

Juvenile Sablefish spend the first one to two years of life in nearshore habitats before emigrating to offshore habitats, but relatively little is known about the extent of their residence and movement within these nearshore areas (Mason et al. 1983; Kendall and Matarese 1987; Rutecki and Varosi 1997a; Maloney and Sigler 2008). Previous telemetry research conducted on juvenile Sablefish focused on vertical movements in a small area of SJBB over 40 days (Coutré et al. 2017). Other tagging studies have examined movement rates of over 34,000 juveniles that were tagged externally with plastic T-bar anchor tags and released in southeast Alaska (most in SJBB) from 1985 to 2005, with recoveries throughout the Gulf of Alaska (Rutecki and Varosi 1997b; Maloney and Sigler 2008; Hanselman et al. 2015). Why SJBB remains a consistent location where juvenile Sablefish may be found is unknown, as an earlier study revealed no significant differences in temperature and salinity from conductivity–temperature–depth (CTD) measurements in SJBB relative to nearby bays (Rutecki and Varosi 1997a). This study fills a gap in knowledge of Sablefish early life history by characterizing juvenile Sablefish movements during their summer and fall residency in SJBB, an important nursery area that has been a focus of ecological research since the 1980s (Rutecki and Varosi 1997a; Sigler et al. 2001; Maloney and Sigler 2008; Courtney and Rutecki 2011; Coutré et al. 2015, 2017).

Presence/absence of fish in the bay

According to Rutecki and Varosi (1997a), juvenile Sablefish emigrate out of the nearshore habitats by the end of the summer, which could explain the progression of absences we observed over the course of both study years. Half of the fish tagged in 2015 were no longer detected by mid-July, while half of the fish tagged in 2016 were no longer detected by early September, leading us to conclude that they had left the bay for adjacent nearshore waters like Salisbury Sound, perhaps en route to offshore habitats in the Gulf of Alaska. It is not known what triggers juvenile Sablefish to leave nearshore habitats; however, by ages 3 and 4, most juvenile Sablefish are found offshore on the continental shelf at depths > 100 m (Maloney and Sigler 2008). No clear trend was observed marking an exodus from the nursery area, but rather individuals left the bay over the course of the season, with few fish remaining by October of either year. The progression of likely emigration was more gradual in 2016 compared to 2015; reasons for this difference were not explored in this study but may be due to differences in water temperatures, prey availability, predator densities, or Sablefish nutritional condition between years. Transmitters implanted into fish in 2015 were expected to last 370 days; however, after all fish appeared to have left the receiver array by October 2015, only one fish was detected again for a period of four days in December, but was never detected after that. The 16 fish tagged in 2015 likely moved away from the receiver array within SJBB, although they could have experienced mortality or their tags could have malfunctioned. Transmitters inserted into fish in 2016 were expected to last approximately 476 days based on battery life, but the receivers were permanently removed from the bay in October 2016, although some fish were still detected daily in the weeks before the end of the study. Periods of time without detections in some fish may be related to use of areas beyond detection range of receivers or movement outside of the bay entirely. Future telemetry studies could tag age-0 juvenile Sablefish in late fall to examine movement patterns and occupancy in SJBB throughout the entirety of their nursery inhabitance, including the overwinter period. With current technology, age-0 Sablefish may be too small to successfully carry acoustic tags that would have sufficient battery life to cover this time frame, and a previous tagging study found that age-0 Sablefish experienced a high rate of mortality when tagged in October compared to summer (Rutecki and Varosi 1997b).

Movement patterns

We hypothesized that juvenile Sablefish would move throughout the entire bay, but show stronger fidelity to the head of the bay than the mouth. The highest RI values were not found at the very head of the bay at receivers 1 and 2, but rather in the middle-head of the bay at receivers 2 and 3. This is corroborated by hook-and-line tagging surveys conducted by NMFS in SJBB (Dana Hanselman, NOAA, personal communication), as well as several ecological studies of juvenile Sablefish (Rutecki and Varosi 1997a; Courtney and Rutecki 2011; Coutré et al. 2015, 2017; this study), that concentrated their sampling efforts in the middle-head area due to higher catch rates of juvenile Sablefish in that location. The affinity for the middle-head of the bay in late summer could be due to the presence of spawning salmon carcasses, which juvenile Sablefish have been documented to consume (Coutré et al. 2015). Displacement of Sablefish towards the head of SJBB from August 8 to 23, 2015, corresponded to the time in which large numbers of pink salmon were entering the freshwater system at the head of the bay, based on observations during mobile tracking surveys and Alaska Department of Fish & Game (ADF&G) aerial surveys (Aaron Dupuis, ADF&G, personal communication).

The middle-head area of the bay also could be more frequently occupied than other areas of the bay due to the habitat structure; for example, the southern shoreline near the mouth of the bay was notably rockier and steeper and produced the lowest RI values (receivers 6 and 8). Pirtle et al. (2017) found that juvenile Sablefish habitat was predicted to occur in low-lying areas with little rocky substrate and low-gradient slope, including deep, main channels of bays. The reference tag detection rate was similar between the two receivers at the mouth (receivers 7 and 8) and between the two at the middle-mouth (receivers 5 and 6), suggesting that differences in occupancy for those areas were more likely due to tagged fish traveling along the northern shoreline than a result of acoustic shadowing by rocky habitat along the southern shoreline. Though not examined in this study, Sablefish may move to navigate tradeoffs in their thermal experience, food availability, and the degree of predation risk in nursery habitats. For example, Sogard and Olla (1998) found that juvenile Sablefish displayed avoidance of cold water in thermally stratified lab tanks, but made potentially lethal vertical movements below the thermocline when food was present.

Variation in individual movements

Our results supported the hypothesis that individual Sablefish varied in their movement patterns and location within the bay. Displacement, distance, and duration were wide-ranging among individuals and varied between years. For the 28 fish that were used in analyses, there was individual variation in their horizontal movements, measured by displacement from receiver 1 over time. Individual variation in movement types has been documented for other fishes, including Lingcod *Ophiodon elongatus* (Beaudreau and Essington 2011), Pacific Halibut *Hippoglossus stenolepis* (Nielsen et al. 2014), wild juvenile Atlantic salmon *Salmo salar* (Roy et al. 2013), coral reef fishes *Lutjanus apodus* and *Sparisoma viride* (Garcia et al. 2015), and white croaker *Genyonemus lineatus* (family Sciaenidae) (Wolfe and Lowe 2015). Sources of variation in movement types among individuals could be related to ecological factors, such as competition among conspecifics for territories, foraging strategies, predator avoidance, seasonal migrations, and physiological responses to the environment (Boesch and Turner 1984; Roy et al. 2013; Finn et al. 2014; Henderson et al. 2014; Sheaves et al. 2015). Heterogeneity in movement patterns at a microhabitat scale illustrates the dynamic nature of foraging decisions, mortality risks, competition, and life history traits like sex-specific behaviors and movements (Roy et al. 2013; Garcia et al. 2015). Our tagging data may be used in combination with environmental data to identify potential mechanisms that contribute to variation in movement patterns among juvenile Sablefish.

We expected that larger individuals that are closer to outmigration would show higher movement rates and lower residence in the bay. A marked ontogenetic shift in displacement, distance, or duration was not obvious in the current study. Significant negative relationships were found between length of fish and days present within the bay, as well as between length of fish and daily duration, but the small sample size and limited size range of juveniles tagged were not sufficient to make a strong conclusion regarding the effects of length. Nevertheless, these relationships may explain some of the differences we observed between years, specifically the progression of emigration, as fish tagged in 2015 were slightly larger than those tagged in 2016 (Table 1.1). Although displacement, distance, and duration within the bay varied between years and among individuals, both study years exhibited a gradual trend of increasing displacement distance from the head over the late summer and fall as tagged individuals outmigrated from the bay.

Passive acoustic telemetry allows researchers to study long-term movement monitoring, though not without caveats. Some disadvantages of using acoustic telemetry include the invasive nature of the implantation of the transmitter, which may adversely affect the fish and its behavior (Eiler and Bishop 2016). While it is sometimes apparent when a tag is expelled or mortality occurs, one may not be able to tell if a tagged fish was consumed by a predator; however, methods to identify probable predation events using predation tags are in development (Halfyard et al. 2017). For the 12 tagged fish that were excluded from analyses, we inferred that tags were expelled or the fish did not survive the tagging procedure because the location of the tags ceased to change for over 30 days. Additionally, receiver orientation, placement of receivers in relation to habitat structure, and depth of receiver affect the detection range and detectability of the transmitters (Huveneers et al. 2016). Range testing can provide insight on potential placement issues; however, the risk of entanglement with fishing gear or anchor lines is also of concern. At least three receivers over the course of the study were encountered and had groundlines cut by fishing gear, but all receivers were either returned to researchers or eventually recovered via grappling. Cost of acoustic telemetry, confinements of the study area, and limited battery life of the transmitters may further restrict study time and sample sizes (Eiler and Bishop 2016). For this study, the small size of the bay and expected level of acoustic interference from vessel traffic restricted our sample size to 20 fish in each study year (Jonathan Mulock, Vemco, personal communication).

Adult Sablefish that were tagged as juveniles in coastal bays of Southeast Alaska, namely in SJBB, have been recovered as far west as the Aleutian Islands, as far north as the Bering Sea, as far south as off Vancouver Island and even inland in the Chatham Strait fishery, illustrating the considerable movement Sablefish are capable of as adults (Rutecki and Varosi 1997b; Maloney and Sigler 2008). This study found that juvenile Sablefish traveled 9.4 km/d on average in 2015 and 13.0 km/d on average in 2016, suggesting that they are making substantial movements early in their lives, even in a small nearshore bay. Sablefish populations depend on recruitment from strong year classes, and widespread abundance of age-1 juvenile Sablefish is indicative of a strong year class (Rutecki and Varosi 1997a). Knowing the extent to which juvenile fish use nursery habitat and describing ranges of movements during their residence are critical for defining juvenile life history, for establishing habitat suitability models, and for understanding the importance of nearshore nursery habitat in Southeast Alaska to recruitment success in both federal and state managed fisheries in the North Pacific.

Acknowledgements

This project was part of the Alaska Department of Fish and Game (ADF&G) Graduate Studies Program in conjunction with the University of Alaska Fairbanks College of Fisheries and Ocean Sciences (UAF CFOS), funded by ADF&G and UAF. We thank S. Kelley, D. Duncan, and many other ADF&G staff and divers for their logistical and field help, as well as D. O'Neill for his weekly transportation to SJBB for mobile surveys and J. Priest for his assistance with analyses. The authors would like to thank A. Seitz and two anonymous reviewers whose comments greatly improved this manuscript.

Figures

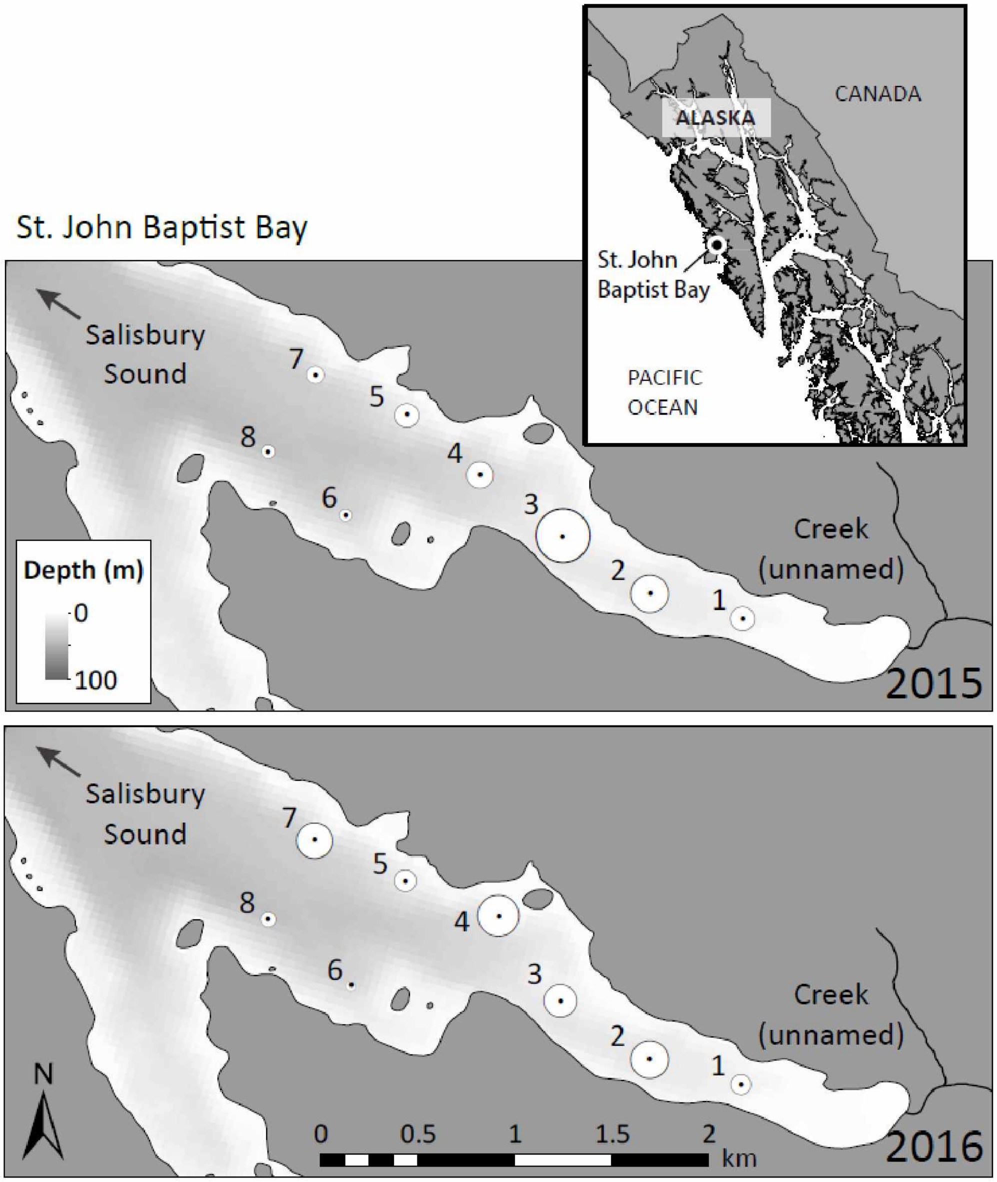


Figure 1.1 Map of St. John Baptist Bay, Alaska, showing receiver placement (solid points) and mean residence index (RI; open circles) for 2015 (top) and 2016 (bottom). Open circles are proportional to the mean RI across all fish for each receiver in each study year (see Table 1.2 for mean RI values). The bay has a freshwater source at the head (unnamed creek) and the mouth opens into Neva Strait, toward Salisbury Sound. A 40-m raster dataset showing depth in the bay was provided by NOAA/TNC (Source: http://seakgis.alaska.edu/data/bathy_40m.zip).

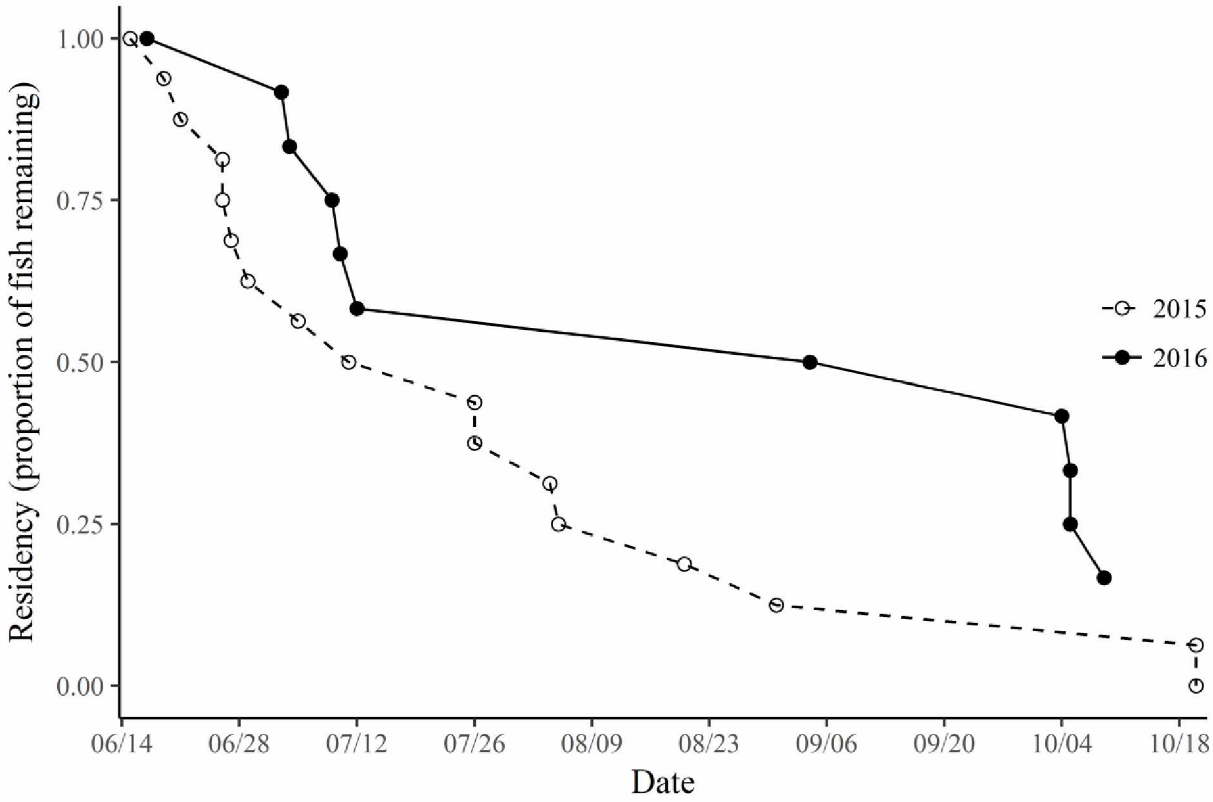


Figure 1.2 Residency in St. John Baptist Bay, Alaska, of juvenile Sablefish from mid-June to mid-October of each study year. Lines show proportion of fish remaining within receiver array over time.

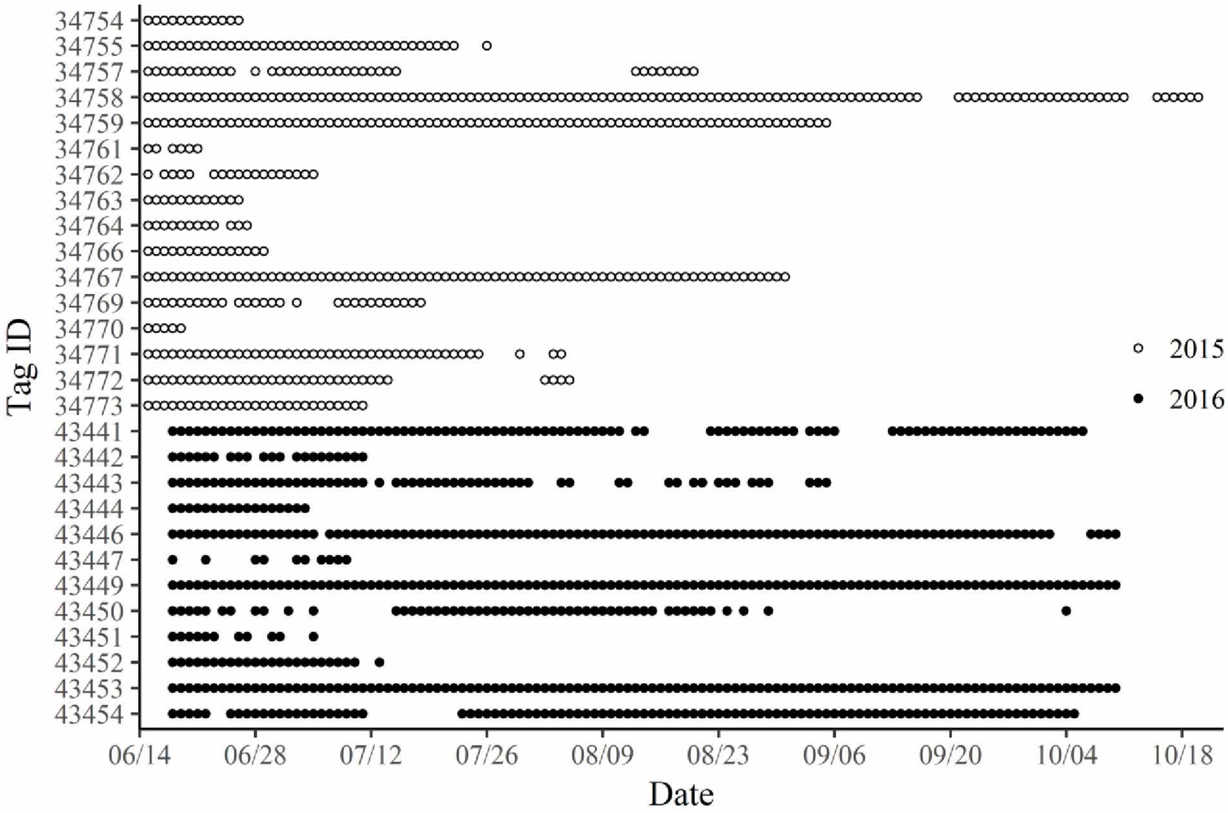


Figure 1.3 Calendar plot of juvenile Sablefish detections in St. John Baptist Bay, Alaska, by tag ID from mid-June to mid-October of each study year. Each dot represents presence for each day a fish was detected.

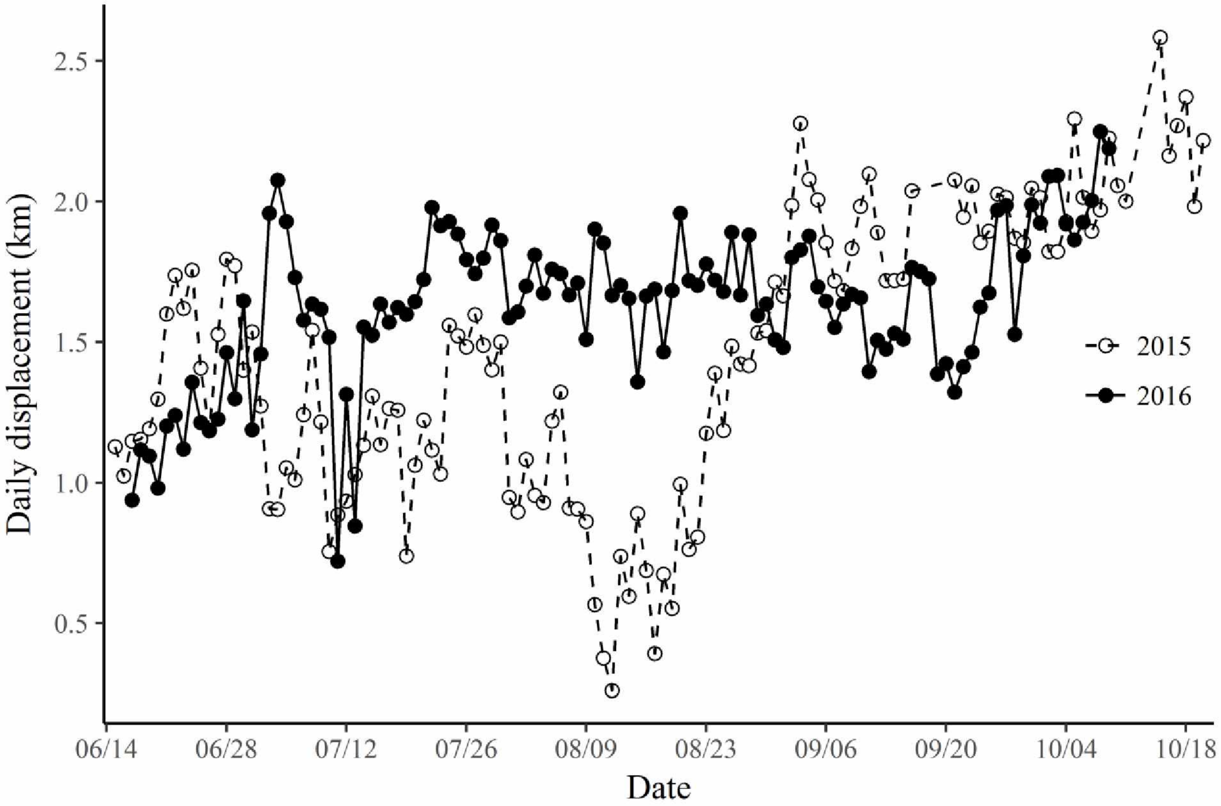


Figure 1.4 Plot comparing mean daily displacement (km) from receiver 1 at the head of St. John Baptist Bay, Alaska, over time for tagged juvenile Sablefish of each study year.

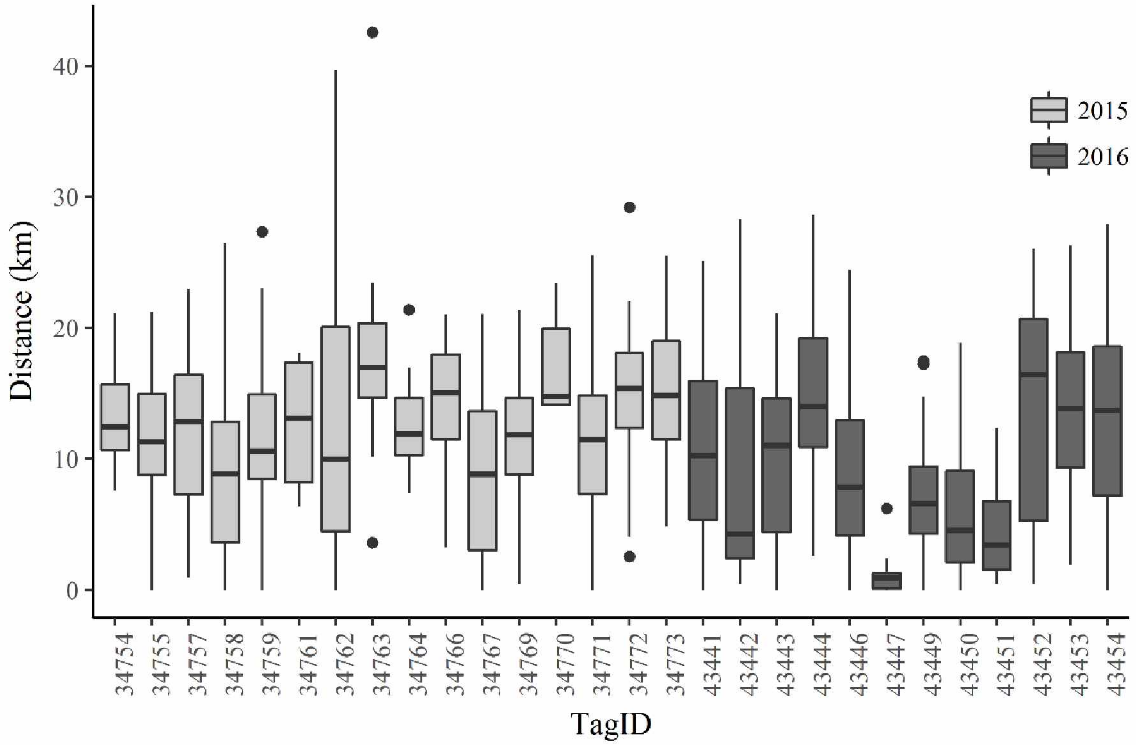


Figure 1.5 Daily distance traveled (km) in St. John Baptist Bay, Alaska, for tagged juvenile Sablefish, for all days detected of each study year. The black line within boxes represents median daily distance traveled while the lower and upper edges of the box correspond to the first and third quartiles. The upper whisker extends to the greatest distance traveled no larger than 1.5·interquartile range, and the lower whisker extends to the smallest distance traveled at most 1.5·interquartile range. Dots beyond the whiskers represent outlier points.

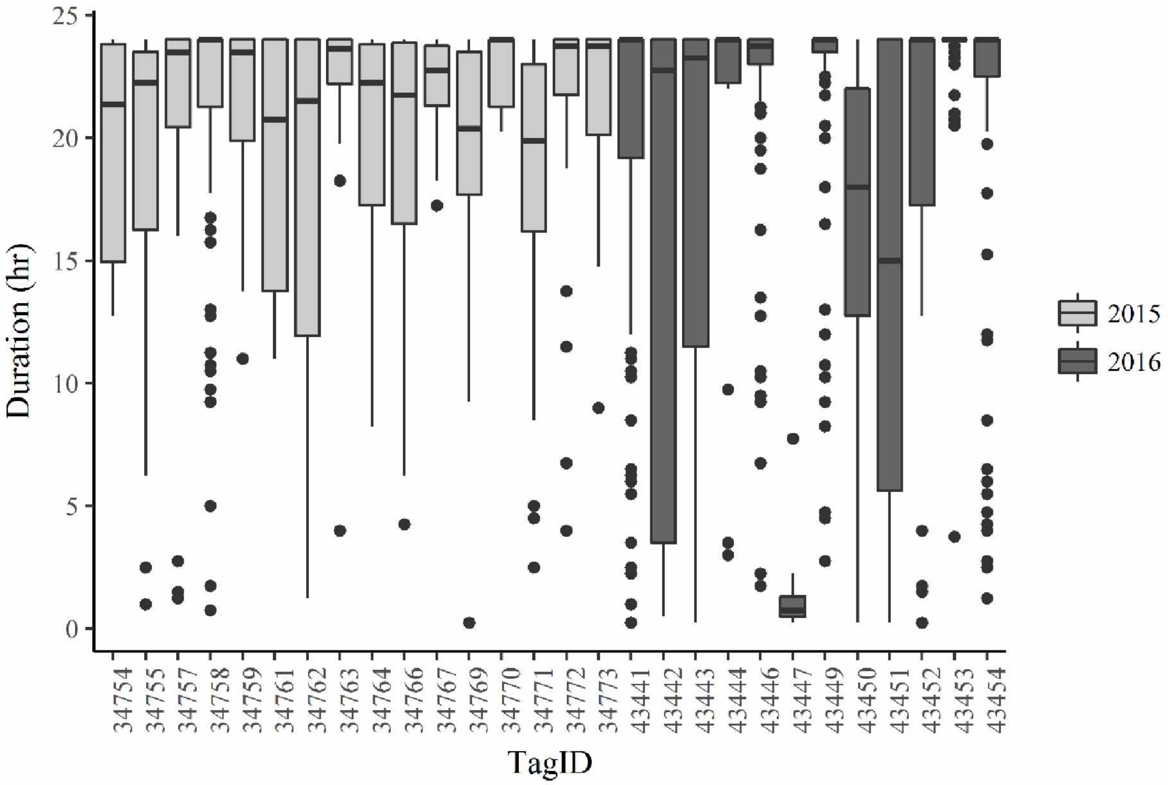


Figure 1.6 Daily duration (hr) spent within the receiver array in St. John Baptist Bay, Alaska, for tagged juvenile Sablefish, for all days detected of each study year. The black line within boxes represent median daily duration while the lower and upper edges of the box correspond to the first and third quartiles. The upper whisker extends to the greatest duration no larger than 1.5·interquartile range, and the lower whisker extends to the smallest duration no further than 1.5·interquartile range. Dots beyond the whiskers represent outlier points.

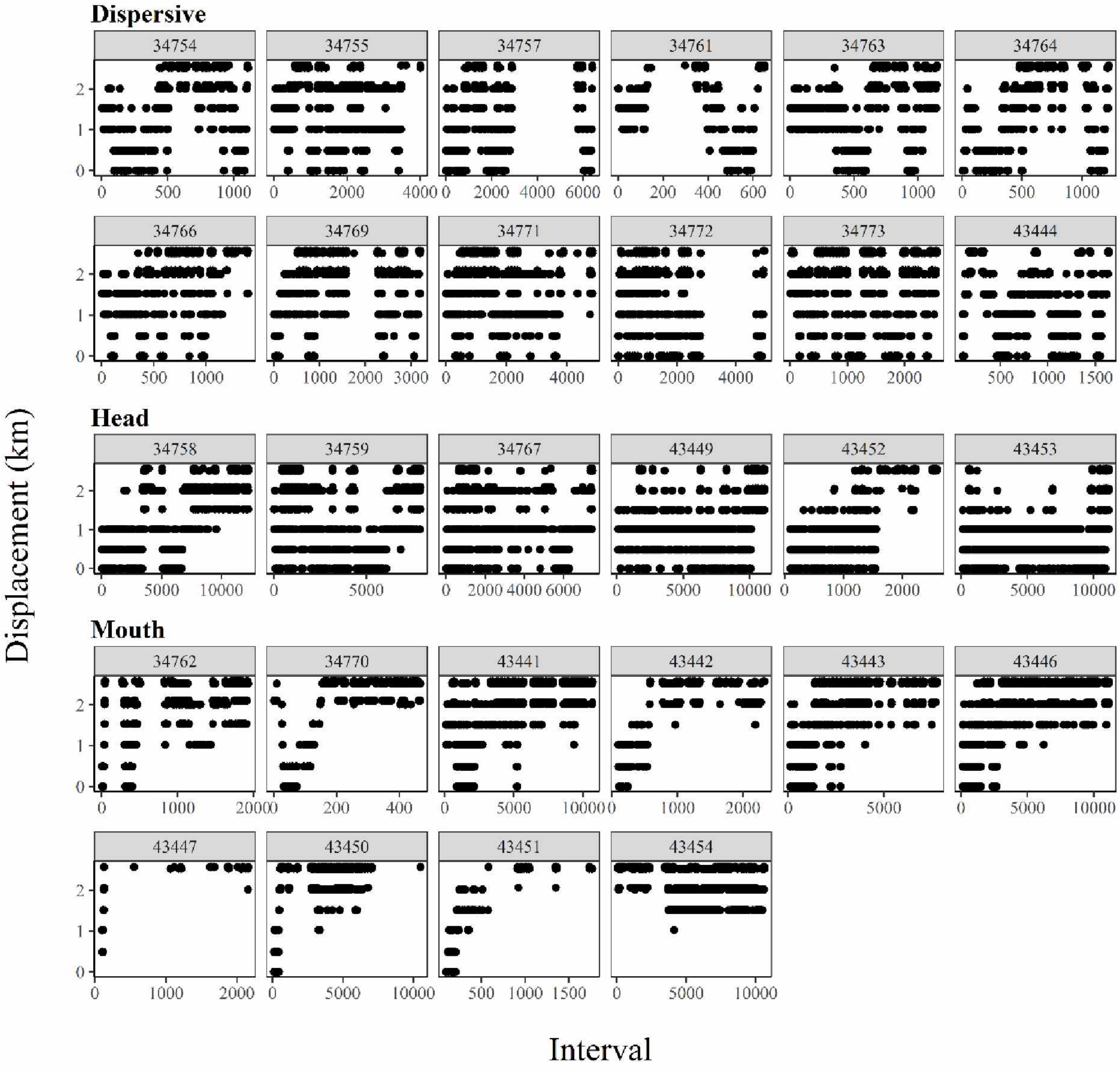


Figure 1.7 Movement plots for individual Sablefish showing displacement distance (km) from receiver 1 in St. John Baptist Bay, Alaska, over all 15-minute intervals, organized by movement type. Dispersive fish movement plots are shown in the top two rows, head resident movement plots in the middle row, and mouth resident movement plots in the bottom two rows. Movement types shown are based on visual assessment. Visual assessments differed from cluster analysis results for six fish: 43443 and 43451 were assigned to the dispersive group, while 34757, 34772, 43444, and 43447 were identified as head residents based on cluster analysis.

Tables

Table 1.1 Summary information for individual tagged Sablefish in St. John Baptist Bay, Alaska. Study start marks the sixth day post-tagging while the last detection is the date of last detection or end of study. Range is the total number of days between the study start and last detection. Association in bay (d) are the days each fish was detected in the detection array at least twice, while out of bay (d) are the days each fish was not detected in the detection array at all or only once. The presence rate was found by dividing days in bay by range.

Release			Monitoring				Association with bay		
Tag ID	Length (mm)	Weight (g)	Release date	Study start	Last detection	Range (d)	In (d)	Out (d)	Presence rate
34754	350	450	6/10/2015	6/15/2015	6/26/2015	12	12	0	100%
34755	355	350	6/10/2015	6/15/2015	7/26/2015	42	39	3	93%
34756	350	340	6/10/2015	6/15/2015	–	–	–	–	–
34757	380	410	6/10/2015	6/15/2015	8/20/2015	67	36	31	54%
34758	345	300	6/10/2015	6/15/2015	10/20/2015	128	121	7	95%
34759	360	380	6/10/2015	6/15/2015	9/5/2015	83	83	0	100%
34761	370	400	6/10/2015	6/15/2015	6/21/2015	7	6	1	86%
34762	360	370	6/10/2015	6/15/2015	7/5/2015	21	18	3	86%
34763	360	360	6/10/2015	6/15/2015	6/26/2015	12	12	0	100%
34764	360	360	6/10/2015	6/15/2015	6/27/2015	13	12	1	92%
34765	350	330	6/10/2015	6/15/2015	–	–	–	–	–
34766	370	400	6/10/2015	6/15/2015	6/29/2015	15	15	0	100%
34767	340	300	6/10/2015	6/15/2015	8/31/2015	78	78	0	100%
34768	340	300	6/10/2015	6/15/2015	–	–	–	–	–
34769	380	420	6/10/2015	6/15/2015	7/18/2015	34	28	6	82%
34770	350	320	6/10/2015	6/15/2015	6/19/2015	5	5	0	100%
34771	340	320	6/10/2015	6/15/2015	8/4/2015	51	44	7	86%
34772	360	350	6/10/2015	6/15/2015	8/5/2015	52	34	18	65%
34773	360	350	6/10/2015	6/15/2015	7/11/2015	27	27	0	100%
34774	335	290	6/10/2015	6/15/2015	–	–	–	–	–
43438	325	280	6/12/2016	6/17/2016	–	–	–	–	–
43439	345	310	6/12/2016	6/17/2016	–	–	–	–	–
43440	400	580	6/12/2016	6/17/2016	–	–	–	–	–
43441	365	420	6/12/2016	6/17/2016	10/5/2016	111	96	15	86%
43442	365	370	6/11/2016	6/17/2016	7/10/2016	24	21	3	88%
43443	340	370	6/11/2016	6/17/2016	9/4/2016	80	59	21	74%
43444	360	420	6/11/2016	6/17/2016	7/3/2016	17	17	0	100%
43445	345	350	6/12/2016	6/17/2016	–	–	–	–	–

Table 1.1 continued…

Release			Monitoring				Association with bay		
Tag ID	Length (mm)	Weight (g)	Release date	Study start	Last detection	Range (d)	In (d)	Out (d)	Presence rate
43446	300	240	6/12/2016	6/17/2016	10/9/2016	115	110	5	96%
43447	420	690	6/12/2016	6/17/2016	7/8/2016	22	10	12	45%
43448	315	260	6/12/2016	6/17/2016	–	–	–	–	–
43449	355	430	6/12/2016	6/17/2016	10/9/2016	115	115	0	100%
43450	335	280	6/12/2016	6/17/2016	10/3/2016	109	53	56	49%
43451	330	310	6/12/2016	6/17/2016	7/4/2016	18	11	7	61%
43452	365	390	6/12/2016	6/17/2016	7/12/2016	26	24	2	92%
43453	310	240	6/12/2016	6/17/2016	10/9/2016	115	115	0	100%
43454	330	320	6/12/2016	6/17/2016	10/4/2016	110	97	13	88%
43455	320	250	6/12/2016	6/17/2016	–	–	–	–	–
43456	310	240	6/12/2016	6/17/2016	–	–	–	–	–
43457	310	240	6/12/2016	6/17/2016	–	–	–	–	–

Table 1.2 Summary information for acoustic receivers placed in St. John Baptist Bay, Alaska, with bottom depth, displacement distance, total number of 15-minute intervals, and mean residence index (RI) for each study year for the 28 fish used in analyses.

	2015 Receiver data				2016 Receiver data			
Receiver	Depth (m)	Displacement from R1 (km)	Number of detection intervals	Mean RI	Depth (m)	Displacement from R1 (km)	Number of detection intervals	Mean RI
1	13.23	0.00	5,567	0.114	13.02	0.00	4,418	0.098
2	23.90	0.49	10,892	0.179	23.78	0.49	10,819	0.181
3	18.35	1.02	13,869	0.256	17.07	1.02	10,003	0.157
4	42.07	1.53	3,598	0.128	18.90	1.51	10,141	0.196
5	22.07	2.01	7,138	0.118	23.48	2.02	7,780	0.105
6	52.74	2.10	1,972	0.061	46.04	2.07	1,496	0.042
7	47.26	2.52	2,239	0.082	46.95	2.53	11,425	0.172
8	71.65	2.58	1,918	0.063	71.34	2.57	3,518	0.072

References

Beaudreau, A. H., and T. E. Essington. 2011. Use of pelagic prey subsidies by demersal predators in rocky reefs: insight from movement patterns of lingcod. Marine Biology 158:471–483.

Beck, M. W., K. L. Heck, Jr., K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B. Halpern, C. G. Hays, K. Hoshino, T. J. Minello, R. J. Orth, P. F. Sheridan, and M. P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51:633–641.

Boesch, D. F., and R. E. Turner. 1984. Dependence of fishery species on salt marshes: the role of food and refuge. Estuaries 7:460–468.

Campbell, H. A., M. E. Watts, R. G. Dwyer, and C. E. Franklin. 2012. V-Track: software for analysing and visualising animal movement from acoustic telemetry detections. Marine and Freshwater Research 63:815–820.

Courtney, D., and T. L. Rutecki. 2011. Inshore movement and habitat use by juvenile Sablefish, *Anoplopoma fimbria*, implanted with acoustic tags in Southeast Alaska. National Marine Fisheries Service, AFSC Processed Report 2011-01, Juneau.

Coutré, K. M., A. H. Beaudreau, D. Courtney, F. J. Mueter, P. W. Malecha, and T. L. Rutecki. 2017. Vertical movements of juvenile Sablefish in coastal Southeast Alaska. Marine and Coastal Fisheries 9:161–169.

Coutré, K. M., A. H. Beaudreau, and P. W. Malecha. 2015. Temporal variation in diet composition and use of pulsed resource subsidies by juvenile Sablefish. Transactions of the American Fisheries Society 144:807–819.

Eiler, J. H., and M. A. Bishop. 2016. Tagging response and postspawning movements of Pacific herring, a small pelagic forage fish sensitive to handling. Transactions of the American Fisheries Society 145:427–439.

Finn, J. T., J. W. Brownscombe, C. R. Haak, S. J. Cooke, R. Cormier, T. Gagne, and A. J. Danylchuk. 2014. Applying network methods to acoustic telemetry data: modeling the movements of tropical marine fishes. Ecological Modelling 293:139–149.

Furey, N. B., M. A. Dance, and J. R. Rooker. 2013. Fine-scale movements and habitat use of juvenile southern flounder *Paralichthys lethostigma* in an estuarine seascape. Journal of Fish Biology 82:1469–1483.

Gallepp, G. W., and J. J. Magnuson. 1972. Effects of negative buoyancy on the behavior on the bluegill, *Lepomis macrochirus Rafinesque*. Transactions of the American Fisheries Society 101:507–512.

Garcia, J., J. Mourier, and P. Lenfant. 2015. Spatial behavior of two coral reef fishes within a Caribbean marine protected area. Marine Environmental Research 109:41–51.

Halfyard, E. A., D. Webber, J. Del Papa, T. Leadley, S. T. Kessel, S. F. Colborne, and A. T. Fisk. 2017. Evaluation of an acoustic telemetry transmitter designed to identify predation events. Methods in Ecology and Evolution 8:1063–1071.

Hanselman, D. H., C. R. Lunsford, and C. J. Rodgveller. 2015. Assessment of the sablefish stock in Alaska. Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, Anchorage, Alaska.

Heck, K. L., G. Hays, and R. J. Orth. 2003. Critical evaluation of nursery hypothesis for seagrasses. Marine Ecology Progress Series 253:123–136.

Henderson, M. J., M. C. Fabrizio, and J. A. Lucy. 2014. Movement patterns of summer flounder near an artificial reef: effects of fish size and environmental cues. Fisheries Research 153.

Herke, W. 1971. Use of natural, and semi-impounded, Louisiana tidal marshes as nurseries for fishes and crustaceans. Doctoral dissertation. Louisiana State University, Baton Rouge, Louisiana.

Huveneers, C., C. A. Simpfendorfer, S. Kim, J. M. Semmens, A. J. Hobday, H. Pederson, T. Stieglitz, R. Vallee, D. Webber, M. R. Heupel, V. Peddemors, and R. G. Harcourt. 2016. The influence of environmental parameters on the performance and detection range of acoustic receivers. Methods in Ecology and Evolution 7:825–835.

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

Kessel, S. T., N. E. Hussey, R. E. Crawford, D. J. Yurkowski, C. V. O'Neill, and A. T. Fisk. 2016. Distinct patterns of Arctic cod (*Boreogadus saida*) presence and absence in a shallow high Arctic embayment, revealed across open-water and ice-covered periods through acoustic telemetry. Polar Biology 39:1057–1068.

Kimura, D. K., A. M. Shimada, and F. R. Shaw. 1998. Stock structure and movement of tagged sablefish, *Anoplopoma fimbria*, in offshore northeast Pacific waters and the effects of el nino-southern oscillation on migration and growth. Fishery Bulletin 96(3):462-481.

Lowe, C. G., D. T. Topping, D. P. Cartamil, and Y. P. Papastamatiou. 2003. Movement patterns, home range, and habitat utilization of adult kelp bass. Mar. Ecol. Progress Series 256.

Maloney, N. E., and M. F. Sigler. 2008. Age-specific movement patterns of sablefish (*Anoplopoma fimbria*) in Alaska. Fishery Bulletin 106:305–316.

Mason, J. C., R. J. Beamish, and G. A. McFarlane. 1983. Sexual maturity, fecundity, spawning, and early life history of sablefish off the Pacific coast of Canada. Can. J. Fish. and Aquat. Sci. 40:2126-2134.

McDevitt, S. A. 1990. Growth analysis of sablefish from mark-recapture data from the northeast Pacific. Master's thesis. University of Washington, Seattle, Washington.

McFarlane, G. A., and W. D. Nagata. 1988. Overview of Sablefish mariculture and its potential for industry. Alaska Sea Grant Report 88-4. University of Alaska Fairbanks, Fairbanks, Alaska.

Miller, K., S. D. Rice, and J. Hudson. 2007. Evaluation of essential fish habitat recovery at log transfer facilities in southeastern Alaska. Essential fish habitat project status report 2016. National Oceanic and Atmospheric Administration. Alaska Fisheries Science Center.

Mulcahy, D. M. 2003. Surgical implantation of transmitters into fish. ILAR Journal 44.

Nagelkerken, I., M. Sheaves, R. Baker, and R. M. Connolly. 2015. The seascape nursery: A novel spatial approach to identify and manage nurseries for coastal marine fauna. Fish and Fisheries 16:362–371.

Nielsen, J. K., P. N. Hooge, S. J. Taggart, and A. C. Seitz. 2014. Characterizing Pacific halibut movement and habitat in a marine protected area using net squared displacement analysis methods. Marine Ecology Progress Series 517:229–250.

Pirtle, J. L., S. K. Shotwell, M. Zimmermann, J. A. Reid, and N. Golden. 2017. Habitat suitability models for groundfish in the Gulf of Alaska. Deep Sea Research Part II: Topical Studies in Oceanography. https://doi.org/10.1016/j.dsr2.2017.12.005.

R Core Team. 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Ross, M. J., and J. H. McCormick. 1981. Effects of external radio transmitters on fish. The Progressive Fish-Culturist 43:67-72.

Roy, M. L., A. G. Roy, J. W. A. Grant, and N. E. Bergeron. 2013. Individual variability of wild juvenile Atlantic salmon activity patterns: effect of flow stage, temperature, and habitat use. Canadian Journal of Fisheries and Aquatic Sciences 70:1082–1091.

Rutecki, T. L., and E. R. Varosi. 1997a. Distribution, age, and growth of juvenile sablefish, *Anoplopoma fimbria*, in Southeast Alaska. NOAA Technical Report NMFS 130:45–54.

Rutecki, T. L., and E. R. Varosi. 1997b. Migrations of juvenile sablefish, *Anoplopoma fimbria*, in Southeast Alaska. NOAA Technical Report NMFS 130:123–130.

Sasaki, T. 1985. Studies on the sablefish resources of the North Pacific Ocean. Bull. Far Seas Fish. Res. Lab. Bulletin 22:1–108. Simizu, 424, Japan.

Sheaves, M., R. Baker, I. Nagelkerken, and R. M. Connolly. 2015. True value of estuarine and coastal nurseries for fish: incorporating complexity and dynamics. Estuaries and Coasts 38:401–414.

Sigler, M. F., C. R. Lundsford, J. T. Fujioka, and S. A. Lowe. 2003. Alaska Sablefish Assessment for 2004. Stock assessment and evaluation report for the groundfish resources of the Bering Sea, Aleutian Islands, and Gulf of Alaska. North Pacific Fishery Management Council, Anchorage, Alaska.

Sigler, M. F., T. L. Rutecki, D. L. Courtney, J. F. Karinen, and M.-S. Yang. 2001. Young of the year Sablefish abundance, growth, and diet in the Gulf of Alaska. Alaska Fishery Research Bulletin 8:57–70.

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

Sogard, S. M., and B. L. Olla. 2001. Growth and behavioral responses to elevated temperatures by juvenile sablefish *Anoplopoma fimbria* and the interactive role of food availability. Marine Ecology Progress Series 217:121–134.

Weinstein, M. P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fishery Bulletin 77:339–357.

Wing, B. L. 1997. Distribution of sablefish, *Anoplopoma fimbria*, larvae in the Eastern Gulf of Alaska. Proceedings of the International Symposium on the Biology and Management of Sablefish. NOAA Technical Report NMFS 130:13–26.

Winter, J. D. 1996. Advances in underwater biotelemetry. Pages 555-590 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Wolfe, B. W., and C. G. Lowe. 2015. Movement patterns, habitat use and site fidelity of the white croaker (*Genyonemus lineatus*) in the Palos Verdes Superfund Site, Los Angeles, California. Marine Environmental Research 109:69–80.

Wolotira, R. J., Jr., T. M. Sample, S. F. Noel, and C. R. Iten. 1993. Geographic and bathymetric distributions for many commercially important fishes and shellfishes off the west coast of North America, based on research survey and commercial catch data, 1912-84. U.S. Dep. Commer., NOAA Technical Memo. NMFS-AFSC-6:1–184.

Chapter 2: Influence of environmental factors on juvenile Sablefish movement

Abstract

In early life stages, juvenile fishes are influenced by environmental factors such as salinity, turbidity, temperature, diel cycles, and tidal changes. The importance of nursery habitats to settlement-stage juveniles for optimizing physiological needs and maximizing growth has been documented for many species, including Sablefish *Anoplopoma fimbria*. During their post-settlement stage, juvenile Sablefish inhabit nearshore nursery areas where they experience fluctuations in environmental conditions. This study used acoustic telemetry to examine the influence of environmental conditions on the movement of juvenile Sablefish in a nearshore nursery area. Forty juvenile Sablefish ranging in size from 300 to 420 mm FL were surgically implanted with acoustic transmitters, and their movements were monitored within an array of eight fixed receivers throughout the summer and fall of 2015 and 2016 in St. John Baptist Bay, Baranof Island, Alaska. The 28 fish used in analyses were present for an average of 46 days across study years and moved an average of 0.99 km/hr within the bay. We examined relationships between distance traveled per hour and select environmental variables. A generalized linear mixed-effects model with a binomial response of movement evaluated the relationships between movement probability and environmental conditions. Tagged Sablefish exhibited a decline in distance traveled per hour and probability of movement in relation to increases in temperature and day of year, and no relationship with movement in relation to tidal stage. Distance traveled per hour and movement probability were greatest during the daytime and last quarter moon phase, and lowest at night. Though juvenile Sablefish are physiologically adapted to survive in a range of environmental conditions, we have identified certain conditions

in which it appears that they undergo more movement or have increased likelihood of movement, perhaps to remain in optimal environmental conditions.

Introduction

Environmental factors have considerable effects on the behavior, movement, and survival of fishes throughout their life history. Variability in abiotic and biotic conditions may influence fishes to undergo movement to areas that offer more favorable conditions (Szedlmayer and Able 1993; Whitfield 1994; Almeida 1996; Childs et al. 2008). Settlement-stage larvae and early-juvenile fish may be especially vulnerable and move to suitable habitats to meet their physiological and energetic needs (Dodson 1997; Nagelkerken et al. 2015). For example, juvenile fish movements are driven by environmental conditions that fluctuate over short-term cycles, (e.g., tidal phase or diel periodicity; Szedlmayer and Able 1993; Furey et al. 2013; Coutré et al. 2017), while seasonal changes in environmental conditions influence juvenile fish movements over a longer time (e.g., seasonal variation in turbidity or temperature; Blaber and Blaber 1980; Roy et al. 2013; Amorim et al. 2016). Understanding how environmental variables affect activity patterns of juvenile fishes in nursery habitats improves our understanding of their biology and our knowledge of factors affecting movement.

Sablefish *Anoplopoma fimbria* is one of the highest valued commercial groundfish species in Southeast Alaska and supports important fisheries in both state and federal waters (Fissel et al. 2013). As adults, Sablefish are a deep-dwelling demersal species found in the North Pacific Ocean and are adapted to the low oxygen levels and limited food availability of the outer shelf and continental slope (Allen and Smith 1988; Wolotira et al. 1993). They spawn during the early spring in offshore waters at depths of 300–500 m, and after eggs hatch at depths deeper than 200 m, the larvae drift inshore while swimming to the surface (Mason et al. 1983; Kendall and Matarese 1987). By the end of their first summer, age-0 Sablefish settle in coastal bays where they inhabit warmer waters with a higher abundance of prey, allowing them to grow at rapid rates when prey availability is sufficient (Mason et al. 1983; Boehlert and Yoklavich 1985; Shenker and Olla 1986; Rutecki and Varosi 1997b). While residing in these nearshore nursery areas, post-settlement juvenile Sablefish (>200 mm) undergo substantial growth before emigrating offshore to deeper waters at ages 1–2, and typically recruit to commercial fisheries by age-4 (Rutecki and Varosi 1997b; Sigler et al. 2001, 2003).

There are limited data on the juvenile life history stage of Sablefish and relatively little information on the environmental mechanisms that affect Sablefish survival in nearshore areas. Juvenile Sablefish in captivity modify their movements to achieve a balance among predation risk, food acquisition, and preferred temperatures, which is thought to be a mechanism for enhancing their survival during their early life history (Sogard and Olla 1998, 2001). Movements related to foraging and habitat selection appear as shifts in horizontal and vertical distribution and vary among individual fish based on hunger level and body size (Sogard and Olla 1998). The extent to which juvenile Sablefish occupy and move within nearshore bays has been examined for one nursery area (Coutré et al. 2017; Ehresmann et al. in press), but how environmental variables affect their movement patterns is unknown. Understanding how juvenile fishes use nearshore areas improves our understanding of their life history as well as factors that affect their survival and growth. Documenting the relationship between fish movement and environmental conditions requires movement data collected concurrently with environmental data.

This study used acoustic telemetry to examine the influence of water temperature, tidal stage, diel state, moon phase, day of year, and year on the movements of tagged fish within an acoustic array to understand how these variables affect juvenile Sablefish movement in a nearshore nursery. Water temperature interacts with juvenile Sablefish physiologically and behaviorally, as juveniles in a laboratory setting exhibited faster growth as water temperatures increased and demonstrated a clear avoidance of cold water (Sogard and Olla 1998, 2001); thus, we hypothesized that juvenile Sablefish would exhibit higher movement rates and a greater probability of movement at warmer temperatures. Second, as tidal stage was found to influence rates of vertical movement for some juvenile Sablefish (Coutré et al. 2017), we hypothesized that we would observe higher movement rates and a greater probability of movement during flood tides. Third, because previous studies found that juvenile Sablefish have the greatest frequency of excursions during the dawn and day periods and the lowest frequency of excursions at night, perhaps due to reduced ability for foraging during periods of low light (Sogard and Olla 1998; Ryer and Olla 1999; Coutré et al. 2017), we hypothesized that we would observe juvenile Sablefish exhibiting higher movement rates and a greater probability of movement during dawn and day periods and lowest at night. Fourth, lower moon illumination (new moon and crescent moon phases) may reduce the ability for foraging during low light periods (Sogard and Olla 1998; Ryer and Olla 1999), so we hypothesized that Sablefish would exhibit lower movement rates and a lower probability of movement during moon phases of diminished moonlight. Finally, as proportion of night (i.e., reduced ability for foraging during low light conditions; Sogard and Olla 1998; Ryer and Olla 1999) increased over the season (e.g., from summer to fall), we hypothesized that juvenile Sablefish would display lower probability of movement over time but would not exhibit differences between years (Table 2.1).

Methods

Study site

This study was conducted in St. John Baptist Bay, Baranof Island, from June 2015 to October 2016. St. John Baptist Bay (SJBB) is a small bay located 33 km north of Sitka, Alaska, approximately three km long and less than one km wide, that opens to Neva Strait and Salisbury Sound with a freshwater input at the head of the bay. Though juvenile Sablefish have been documented in bays and harbors throughout Southeast Alaska, juvenile Sablefish are reliably found in SJBB based on tagging surveys and other studies conducted in the bay (Rutecki and Varosi 1997a; Maloney and Sigler 2008; Courtney and Rutecki 2011; Coutré et al. 2015, 2017; Ehresmann et al. in press).

Acoustic array and tagging

We used acoustic telemetry to monitor movements of juvenile Sablefish within SJBB. Field methods, including receiver schematics and range testing, are described in detail by Ehresmann et al. (in press). Eight acoustic receivers (Vemco VR2W) were deployed and maintained in an array to provide nearly complete coverage throughout the bay. Temperature data loggers (HOBO TidbiT v2) were attached to four receivers in 2015 and five receivers in 2016 (Figure 2.1). In addition to fixed receivers, mobile surveys using a hydrophone and Vemco VR100 receiver were conducted every 7–10 days from June through August of each study year. These surveys were used to validate presence/absence of tagged fish against receiver data. Range testing was conducted to ensure proper spacing between receivers and adequate coverage of the bay. Receivers were deployed June 2015 and were maintained within the bay for the duration of the study until they were removed in October 2016, except from March 25–April 10, 2016, and from May 17–June 13, 2016, due to gear conflicts with commercial fisheries. These gaps in coverage occurred after fish tagged in 2015 were no longer detected in the array and prior to tagging in 2016.

Juvenile Sablefish were captured for telemetry tagging by hand jigging using rod and reel with baited hooks near the head of the bay. Twenty juvenile Sablefish were captured for tagging on June 10, 2015, and twenty on June 11–12, 2016. Sample size was limited to twenty fish per year to prevent tag interference based upon bay size and acoustic noise within the bay (Jonathan Mulock, Vemco, personal communication). Immediately upon capture, date, time, location, and depth were recorded for each fish. Fish that appeared healthy and without signs of stress or injury were individually sedated, measured (fork length; mm), and weighed (g) before being placed on their dorsal side in a V-shaped foam trough. Acoustic transmitters (Vemco V9-2L 69kHz, 146dB re 1uPA @ 1m, 30 to 90 s delay, 9 mm diameter x 29 mm length, weighing 4.7 g in air and 2.9 g in water) were inserted through a 1-cm incision through the midline of the ventral musculature, and the incision was closed by two simple interrupted sutures. Post-surgery, each fish was tagged externally with a uniquely numbered t-bar anchor tag (Floy) for visual identification before being placed in a tank of fresh seawater for observation. Once the fish regained equilibrium and normal gill ventilation rate, typically after 10–35 minutes, it was released at or near the site of capture. Fish behaving abnormally or appearing in unhealthy condition after an extended recovery period were sacrificed and discarded according to permit requirements, while tagged fish were released at or near their capture location. All research followed protocols approved by the University of Alaska Fairbanks Institutional Animal Care and Use Committee (protocol no. 738825).

Data analysis

Tag data were prepared for analysis following Ehresmann et al. (in press). Briefly, the first five days of tag data were excluded for each fish to account for acclimation of tagged fish. Tagged fish that did not change positions for 30 days or longer were assumed to be mortalities or expelled tags and were also excluded. False detections, or tagged fish detected only once in a 24-hour period, were removed from the dataset. A primary receiver location was assigned to each fish for every 15-minute interval it was present in the receiver array, defined as the receiver on which the fish was most frequently detected during that time interval. If a fish was detected equally by two or more receivers during that interval, a single receiver was randomly chosen among the receivers with the most detections. We assigned a primary receiver location to each 15-minute interval for each fish because for any given transmission, a fish may have been detected at more than one receiver due to spatial overlap in receiver detection range. While this approach does not generate a precise location for each fish, it does allow for a coarse-scale examination of movement within the bay.

Environmental variables

We examined juvenile Sablefish movement in relation to four environmental variables: water temperature, tidal stage, diel state, and moon phase. The mean water temperature for SJBB was determined by averaging temperatures collected every 15 minutes by temperature loggers at three locations (receivers 1, 2, and 6; Figure 2.1), from June 2015 through October 2016. Predicted tidal current velocities for Zeal Point at the mouth of SJBB were extracted from the National Oceanic and Atmospheric Administration (NOAA) Current Prediction archives (NOAA 2013) and used to assign three tidal categories: (1) Slack (predicted current velocity $\geq$ -0.12 m/s and $\leq$ 0.12 m/s); (2) Ebb (predicted current velocity < -0.12 m/s); and (3) Flood (predicted current velocity > 0.12 m/s) for every 15-minutes during the study period. Each 15-minute interval during a 24-hour period was categorized as one of five diel states: (1) Dawn, nautical dawn to sunrise; (2) Day AM, sunrise to the midpoint between sunrise and sunset; (3) Day PM, from the midpoint between sunrise and sunset to sunset; (4) Dusk, sunset to nautical dusk; and (5) Night, nautical dusk to nautical dawn (e.g., Beaudreau and Essington 2011). Sunrise, sunset, and nautical twilight data were accessed from the U.S. Naval Observatory (2003) for SJBB. The proportion of night was also calculated for each 24-hour period to examine the influence of night as a continuous variable. Moon illumination was summarized from the U.S. Naval Observatory (2003) as a continuous variable from 0–1, with 0 representing a new moon and 1 a full moon. The moon phases were acquired from the lunar.phase function in the R package "lunar" to assign one of eight moon cycle stages (new, waxing crescent, first quarter, waxing gibbous, full, waning gibbous, third quarter, waning crescent) for each 24-hour period (Lazaridis 2014). Hourly and daily mean values of continuous environmental variables were calculated as necessary for plots. Continuous variables of temperature, tidal velocity, proportion night, and moon illumination were used to graphically visualize daily temporal patterns in environmental conditions, while temperature, tidal stage, diel state, and moon phase were used as categorical variables in examining DPH. When modeling relationships between movement and environmental factors, we used temperature as a continuous variable, and tidal stage, diel state, and moon phase as categorical variables.

Presence and movement

We used two metrics to analyze detections of juvenile Sablefish: presence in the receiver array and distance traveled per hour. On a daily timescale, a fish was determined to be present within the receiver array if it was detected at least twice on any receiver in that 24-hour period.

Presence was examined by plotting days present for each fish over time alongside temperature, tidal velocity, proportion of night, and moon illumination to provide a visual depiction of temporal presence and absence in relation to environmental data. Movement was calculated on an hourly timescale using distance traveled per hour (DPH). Distance traveled per hour was calculated by identifying the receiver at which the fish was detected most frequently during a given hour using and calculating the straight-line distance between successive hourly primary receiver locations. If the fish did not change primary receiver location within a given hour or from one hour to the next, the DPH returned was zero. Boxplots of DPH (using only hours in which movement occurred) and of daily hours stationary (using only hours in which no movement occurred) were created for each fish to evaluate variation in movement among individuals. We averaged DPH across all fish to examine variability in DPH over temperature, tidal stage, diel state, and moon phase and used one-way ANOVA and Tukey HSD tests to evaluate if pairs of means within each variable were significantly different from each other.

Modeling movement with environmental variables

A generalized linear mixed-effects model (GLMM) was used to evaluate the probability of movement of individual juvenile Sablefish in SJBB as a function of environmental variables using the glmer function from the package "lme4" (Bates et al. 2015) with a logit link function in R (R Core Team 2018). A GLMM was fitted to binomial movement data, where a value of 1 was assigned to each hour interval with a positive DPH and a value of 0 assigned to hour intervals in which no movement was detected. Because fish locations, and therefore measures of DPH, are imprecise, modeling movement as a binary variable was a more robust approach to relating environmental factors to movement. GLMMs are useful for modeling repeated measures as they account for within-subject correlation using random effects (Littell et al. 1998; Gillies et al.

2006). Incorporating fish identity as a random effect in the model allows the intercept to vary among individuals, thereby isolating the effects of environmental factors (modeled as fixed effects) that are operating on all individuals (Gillies et al. 2006).

We constructed a set of candidate models to estimate the probability that movement occurred within a given 1-hour interval. The full model consisted of all fixed effects (specified below) with fish identity as a random effect. Fixed effects included continuous variables temperature and day of year, and categorical variables tidal stage, diel state, moon phase, and year. Interaction terms were not included as potential predictors because incorporating interaction terms tends to complicate interpretation of the relationship due to the log link function (Tsai and Gill 2013). Prior to modeling, predictor variables were examined for independence and collinearity using pairwise plots of the variables and a correlation matrix.

Next, we used an information-theoretic approach to select the best model from the set of candidate models (i.e., most parsimonious and best fit to the data; Burnham and Anderson 2002). The information-theoretic approach allows for comparison of multiple models relative to each other using Akaike's Information Criterion (AIC) (Boyce et al. 2002; Burnham and Anderson 2002; Bolker et al. 2009). The top models were determined using ΔAIC, the difference between the best model with the lowest AIC and each candidate model. Models with a $\Delta\text{AIC} \leq 6$ were identified as the top models; using a cut-off of $\Delta \leq 6$ has shown to be necessary to be 95% sure that the most parsimonious model is retained in the set (Richards 2005, 2008; Richards et al. 2011). Model weight was also found using the Akaike weight (w_i) for each model, which represents the relative likelihood that model i is the best approximating model for the dataset (Burnham and Anderson 2002). Model fit was assessed using a marginal R^2 (only fixed effects) and conditional R^2 (fixed and random effects) using the function r.squaredGLMM in the

“MuMIn” package (Nakagawa and Schielzeth 2013; Barton 2018). We also calculated the Nagelkerke/Cragg and Uhler’s pseudo-R^2 value using the nagelkerke function in the “rcompanion” package (Mangiafico 2018). Due to the nature of binary response data, model diagnostic tests are limited in assessing overall fit. All analyses were performed using R.

Results

Acoustic tagging

We recorded movements of 40 tagged juvenile Sablefish in this study, ranging in fork length from 300–420 mm (mean = 349 ± 24 SD) and weight from 240–690 g (mean = 352 ± 89 SD). Individuals were likely age-1, though some may have been age-2, based on length at age estimates from the literature (Rutecki and Varosi 1997a). Tag detection data showed that 12 fish evidently died or expelled their tags as they had not changed position for 30 days or longer and were subsequently removed from analyses. Of the remaining 28 tagged fish used for analyses, all but one individual (ID 43454) moved throughout the entirety of the bay and were detected on every receiver during the study period, with all receivers detecting tagged fish. Range testing results showed a 50% detection probability for range testing tags that were 295–695 m (mean = 440 m) from stationary receivers (Ehresmann et al. in press). Based on the results of the range testing and the comprehensive array grid design, it was unlikely that a tagged fish would be present for long within the bay before being detected. The final dataset for the 28 tagged juvenile Sablefish contained 1,494,963 detections, which were subset into 106,793 15-minute detection intervals and used for subsequent analysis.

Presence and movement with environmental variables

Presence within the detection array in the bay on a daily scale varied among individuals, ranging from 5–121 days (mean = 46 ± 39 SD) during the period of analyses (i.e., after eliminating the first five days post-tagging; Table 2.2). Fish that were tagged in 2015 spent an average of 36 days in the receiver array, while fish that were tagged in 2016 spent an average of 61 days in the receiver array, with an overall affinity for the middle-head region of the bay for both years (Ehresmann et al. in press). A calendar plot of daily presence for individuals in relation to plots of temperature, tidal velocity, proportion of night, and moon illumination over time did not demonstrate any obvious broad-scale trends between presence and environmental variables (Figure 2.2).

Individuals displayed variation in hourly movement, as DPH ranged from 0.46–4.04 km/hr (mean = 0.99 ± 0.52 SD; Figure 2.3), while hours individuals remained stationary in a day ranged from 1.00–24.00 hr/day (mean = 10.82 ± 5.82 SD; Figure 2.4). Plots of DPH averaged across all fish showed DPH varied among factor levels of temperature, tidal stage, diel state, and moon phase (Figure 2.5). Juvenile Sablefish were detected in temperatures ranging from 8.46–12.48°C (mean = 10.11 ± 0.77 SD) for both years. The average bay temperature for 2015 ranged from 8.46–11.47°C (mean = 9.67 ± 0.66 SD) while the average bay temperature for 2016 ranged from 9.11–12.48°C (mean = 10.45 ± 0.68 SD). Using a post hoc Tukey HSD test, we found significant differences in DPH for fish among temperature bins: at higher average temperatures within the bay, the DPH for tagged fish was significantly lower than at cooler temperatures (i.e., fish were more sedentary at higher temperatures, $p < 0.05$), as all temperature bins except the warmest bins differed significantly from one another. DPH at temperature bins 10.5–11.5°C (mean = 0.42 ± 0.58 SD) and 11.5–12.5°C (mean = 0.42 ± 0.55 SD) were not significantly different from each other (p = 0.99). Tidal velocity within SJBB ranged from -0.46–0.41 m/s (mean = -0.04 ± 0.21 SD), but the average DPH values for tagged juvenile Sablefish were not significantly different among tidal stages (one-way ANOVA, F-value = 1.08, p = 0.34). We also found significant differences in DPH for juvenile Sablefish across diel states, as DPH was lowest at night (mean 0.39 ± 0.58 SD) and greatest during day AM (mean 0.53 ± 0.63 SD). The post hoc Tukey HSD test showed that DPH at night was significantly different than all other diel states, as was DPH during day AM compared to dusk (mean 0.49 ± 0.60 SD) ($p < 0.05$). Finally, juvenile Sablefish exhibited significant differences in DPH among moon phases; last quarter (mean = 0.54 ± 0.63 SD) and new moon (mean = 0.54 ± 0.61 SD) were significantly greater than waxing crescent (mean = 0.47 ± 0.59 SD), waxing gibbous (mean = 0.48 ± 0.68 SD), full (mean = 0.48 ± 0.63 SD), waning gibbous (mean = 0.49 ± 0.61 SD), and waning crescent moons (mean = 0.49 ± 0.60 SD) ($p < 0.05$), but were not significantly different than first quarter (mean = 0.50 ± 0.60 SD).

Movement model with environmental variables

Based on the model selection procedure, we found four models with ΔAIC of 6 or less (models 1–4; Table 2.3). Because models 2, 3, and 4 added predictors to the best AIC model (model 1), with little gained by increasing model complexity, we selected model 1 as the best model for inference based on parsimony (Richards 2008; Richards et al. 2011). The generalized linear mixed-effects model with the highest weight and lowest AIC included the covariates temperature, diel state, moon phase, and day of year, as well as a random effect for individual fish, while tidal stage and year were not included in the final model. The model selected was:

$$\begin{aligned}\text{logit}(\pi_{ijklm}) = \mu + \beta_1(Temperature)_i + \beta_2(Diel\ State)_j + \beta_3(Moon\ Phase)_k \\ + \beta_4(Day\ of\ Year)_l + \gamma_m + \varepsilon_{ijklm}\end{aligned}$$

using the logit link function and binomial family. The response, π_{ijklm}, is the binomial probability of movement for individual fish (m) during temperature (i), diel state (j), moon phase (k), and day of year (l); μ is the overall mean logit intercept; β values are the parameter estimates for each of the fixed effects; γ is the random effect for fish (m), and ε is the residual error.

There was a negative relationship between hourly probability of movement and temperature; as temperature increased, the probability of hourly movement decreased (Figure 2.6). The probability of juvenile Sablefish movement varied during the day with hourly movement probability peaking during day AM, and the probability of movement lowest at night. Probability of movement was highest during last quarter moon stage, and lowest during full and waxing gibbous moon phases. The probability of movement also showed seasonality, with movement probabilities decreasing as the day of year increased. Temperature and day of year were positively correlated but were not omitted from the model as $r < 0.70$ ($r = 0.55$, $p < 0.05$; Dormann et al. 2013).

Model fit using marginal R^2 (fixed effects only; $R^2 = 0.048$), conditional R^2 (both fixed and random effects; $R^2 = 0.086$), and the Nagelkerke/Cragg and Uhler's pseudo-R^2 ($R^2 = 0.034$) was within the range commonly reported for ecological models (Møller and Jennions 2002).

Discussion

Prior to our study, juvenile Sablefish were known to associate with SJBB (Rutecki and Varosi 1997a; Courtney and Rutecki 2011; Coutré et al. 2015, 2017), but the extent of their association and how environmental conditions affect their movement was unknown. The temporal and spatial extent of our study allowed for continuous observations of juvenile Sablefish movements over several months in two study years throughout nearly the entire bay, which revealed behaviors that were not apparent in previous studies. This is the most comprehensive study to discern movement patterns of juvenile Sablefish in relation to environmental conditions in the wild.

In the analysis of presence, we found that individuals were detected within the array for an average of 46 days across both years during the study period, but we did not see clear trends in daily presence and environmental conditions. A visual comparison of presence and absence of individual fish against water temperature, tidal velocity, proportion of night, and moon illumination did not show a common trend, perhaps because the scale was too broad for finding relationships.

Evaluating the data on a finer scale using DPH and modeled responses, juvenile Sablefish movements were influenced by temperature, diel state, moon phase, and day of year, but not by tidal stage or year. Temperature had a significant influence on movement of juvenile Sablefish. Temperature is one of the primary abiotic factors that controls the biological processes of fishes, ultimately affecting how fish use and interact with their habitat (Beitinger and Fitzpatrick 1979). Fish have a thermal preference that allows for optimization of physiological processes, as lower temperatures may reduce metabolism and growth; as a result, fish will occupy areas that optimize their physiological needs while providing suitable resources (Beitinger and Fitzpatrick 1979; Childs et al. 2008). In the present study, we found that at colder temperatures juvenile Sablefish exhibited higher DPH rates, as well as a higher probability of movement. Temperature variability observed in SJBB during this study fell within the known physiological tolerances of juvenile Sablefish (Sogard and Olla 2001), with mean water temperatures ranging from 8.46–12.48°C across both study years. In a laboratory study with juvenile Sablefish, food availability appeared to play a considerable role in utilization of temperature zones: higher growth rates and higher activity levels were observed when feeding levels were unrestricted, and when fish were deprived of food, they reduced their activity levels as an energy conservation maneuver (Sogard and Olla 1998, 2001). One explanation for our results is that prey availability varied over temperature: during cooler periods within the bay, movement increased (e.g., more foraging activity), or perhaps insufficient food resources at warmer temperatures led to less movement activity (e.g., conservation maneuver). Alternatively, pulsed prey items like salmon carcasses during the warmer periods may not have required much movement. However, this telemetry study did not observe prey availability or diets of juveniles, and thus we are uncertain the effect that prey availability may have had upon movement patterns.

In this study, the relationships between diel state and moon phase with movement activity were significant, but the relationship between tidal stage and movement was not significant. Cyclical environmental variables controlled by solar and lunar rhythms have been found to influence movements and behaviors of fish and many other animals (Gibson 1994, 2003; Wilcockson and Zhang 2008; Næsje et al. 2012). Juvenile Sablefish exhibited higher DPH and greater probability of movement during the daytime, while DPH and probability of movement were lowest at night. Our results are supported by previous research that found vertical excursion frequency for tagged juvenile Sablefish was highest during dawn and day periods and lowest at night (Coutré et al. 2017). Ryer and Olla (1999) also documented reduced swimming speeds of juvenile Sablefish at night in a laboratory setting, which may suggest that slower swimming speeds leads to a reduction in foraging opportunities during periods of low light. Moon phase did have an influence on juvenile Sablefish movement: DPH was greatest in the last quarter and new moon stages, while the probability of movement occurring was greatest for the first and last quarter moon stages, which could be linked to neap tides. Ryer and Olla (1999) found that greater illumination resulted in increased swimming speed, but we observed lower DPH values during the full moon stage, perhaps as juvenile Sablefish are avoiding predators during these times. Estuarine-associated fishes are influenced by tides in various ways, such as to minimize predation risks (Gibson 2003), to alter depths of habitat use in nearshore systems (Sakabe and Lyle 2010; Furey et al. 2013), and to minimize energy costs by moving with tidal currents (Almeida 1996). However, we did not observe a significant influence of tidal stage on DPH or probability of movement in this study. Some individual juvenile Sablefish vertical excursions were influenced by tidal stage in a prior study, but tide did not have a significant effect on vertical excursions across all fish (Coutré et al. 2017).

Juvenile Sablefish also exhibited seasonal movement patterns. As the day of year increased, the DPH and probability of movement decreased for tagged juveniles in SJBB. The seasonal trend we observed in juvenile Sablefish in SJBB could be due a reduction in seasonally-pulsed prey, or perhaps less foraging activity was necessary as salmon carcasses may have been prevalent in SJBB in the fall (Coutré et al. 2015).

Our findings from the movement analysis fit with existing literature on juvenile Sablefish movements. In an experimental setting, swimming speeds for age-1+ Sablefish ranged from 25–30 cm/s (Ryer et al. 2004), which is 0.90–1.08 km/hr and corroborates our finding of average DPH of 0.99 km/hr for juvenile Sablefish in the wild. It is important to note that the measurements of DPH are coarse scale as we were only able to measure the direct distance between receivers to estimate distance traveled, and not the precise locations of the fish.

While we found plausible relationships between Sablefish movement and environmental factors, certain issues should be considered. Limitations of the study include the relatively small sample size of juvenile Sablefish in each study year and that the temperatures we measured in this study may not accurately reflect the experience of the fish, as we were unable to collect depth data for tagged fish. Depth could play a role in how the variables we examined affect fish movement. Fish may be moving to meet physiological needs at a small spatial/temporal scale; however, we were not able to measure such fine-scale environmental data in this study. Furthermore, the correlation between certain variables (e.g., temperature and day of year) confound interpretation of the effects of individual factors. Telemetry studies with multiple observations of each fish can cause pseudoreplication; such serial autocorrelation may affect statistical comparisons and analyses that use standard errors or confidence intervals, limiting the ability to make statistically significant conclusions (Gillies et al. 2006; Koper and Manseau 2009). Given the limitations of a binomial GLMM, we had few options for dealing with effects of autocorrelation. We pooled data to an hourly scale instead of 15-minute intervals, and we did not have an ecological basis to suspect that fish, once moving, would continue in such a state (other than the same environmental conditions that caused movement still existed). While pseudo-R^2 values were low in this study, such values are common in ecological models (Møller and Jennions 2002), though we cannot rule out that variance in movement probability may have been poorly explained by the model. Model fit may be improved with the inclusion of additional physiochemical factors that were not measured in this study.

Despite the limitations of the analyses used here, this study offers a glimpse into potential relationships between movement of juvenile Sablefish and environmental variables. Further studies are necessary to understand juvenile Sablefish directionality of movement and position within the receiver array in relation to environmental variables. For example, directionality or position could be examined at finer temporal and spatial scales of temperature (e.g., day ranges of extreme temperatures, head vs. mouth temperatures), and though tide did not affect DPH or probability of movement, it could potentially affect directionality or position within the bay. In the first year of life, juvenile Sablefish are faced with balancing physiological needs while avoiding predators and locating prey in an environment that is spatially variable as well as environmentally fluctuating. The balance among these factors is achieved at the level of the individual, which may result in a trade-off among several functions. Understanding how juvenile Sablefish respond to changes in environmental conditions improves our understanding of their biological tolerances, which in turn contributes to understanding how anthropogenic impacts or changes in climate may affect these fish while in a nearshore nursery area.

Acknowledgements

This project was financially supported by the Alaska Department of Fish and Game (ADF&G) Graduate Studies Program in conjunction with the University of Alaska Fairbanks College of Fisheries and Ocean Sciences (UAF CFOS). We would like to thank S. Kelley, D. Duncan, and many other ADF&G staff and divers for their logistical support in the field, as well as J. Priest for his assistance with analyses.

Figures

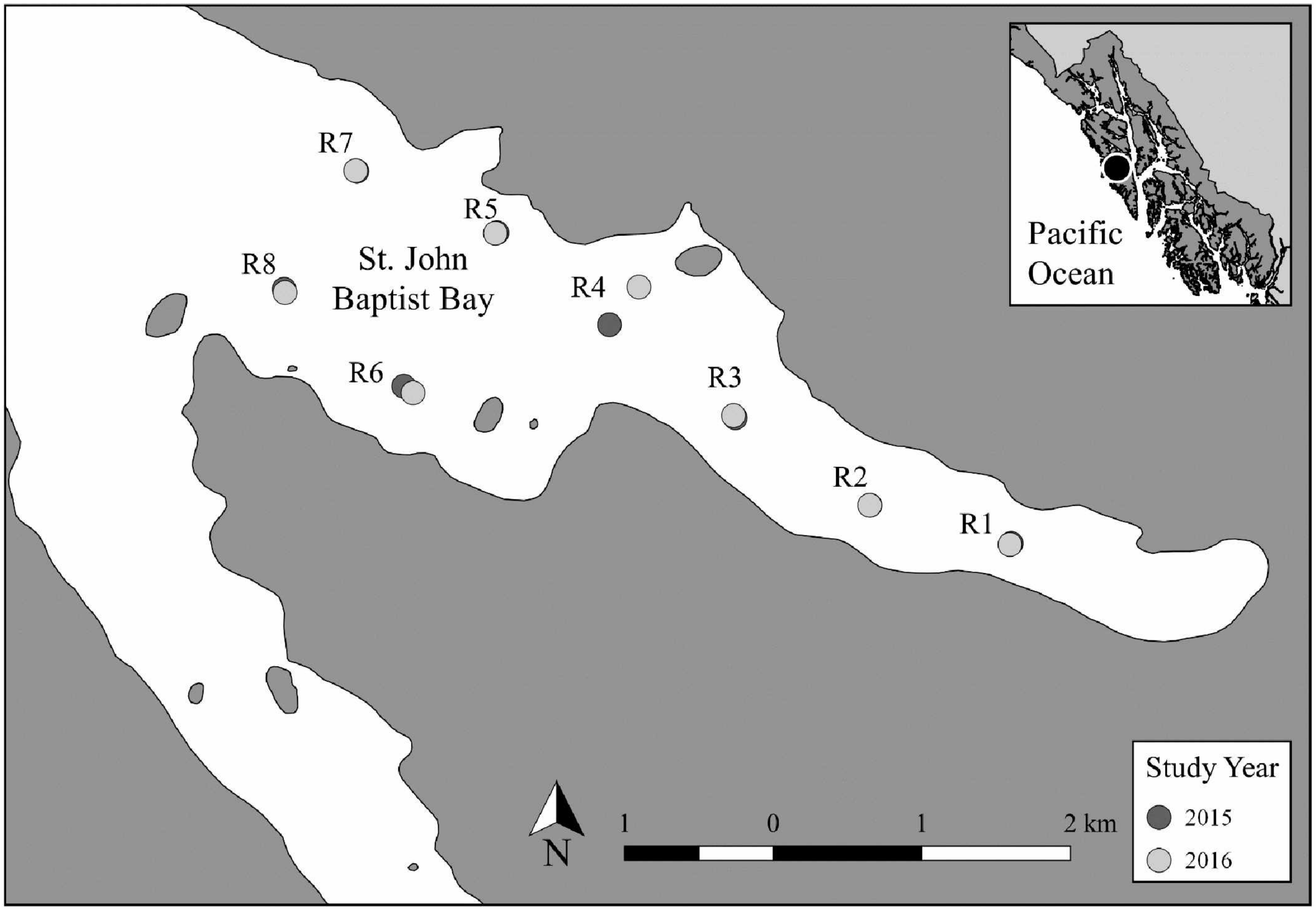


Figure 2.1 Map of study area in St. John Baptist Bay, Alaska, showing receiver placement and bay orientation. Areas shaded gray represent land; dots represent receivers, shaded for the year in which they were deployed in each location. The map inset shows the location of the bay (black dot) in relation to Southeast Alaska.

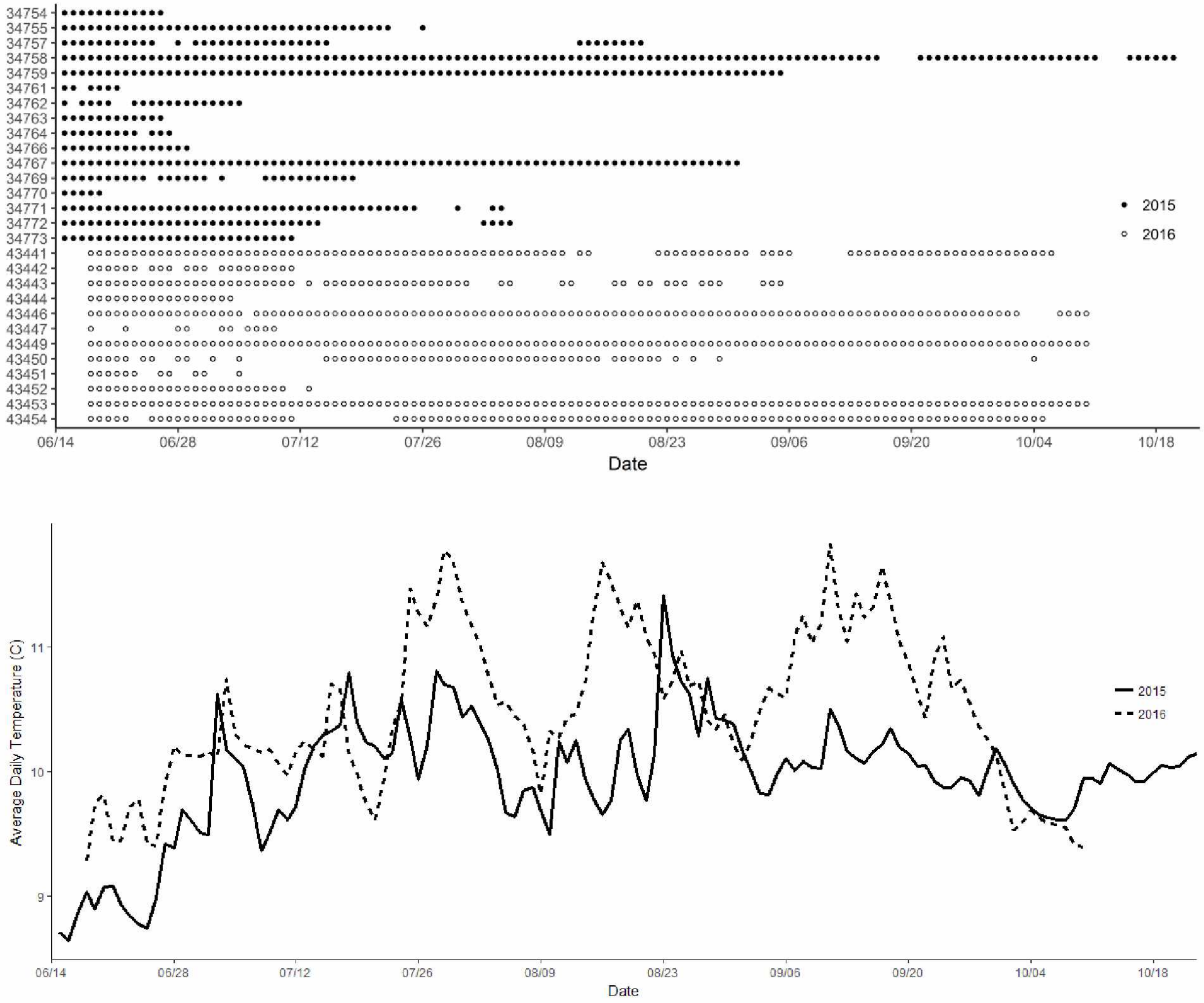


Figure 2.2 Calendar plot of juvenile Sablefish detections in St. John Baptist Bay, Alaska, by tag ID from mid-June to mid-October of each study year, with each dot representing the day in which a fish was present within the bay. Also shown are plots describing mean water temperature, tidal velocity, proportion of night, and proportion of moon illumination by year.

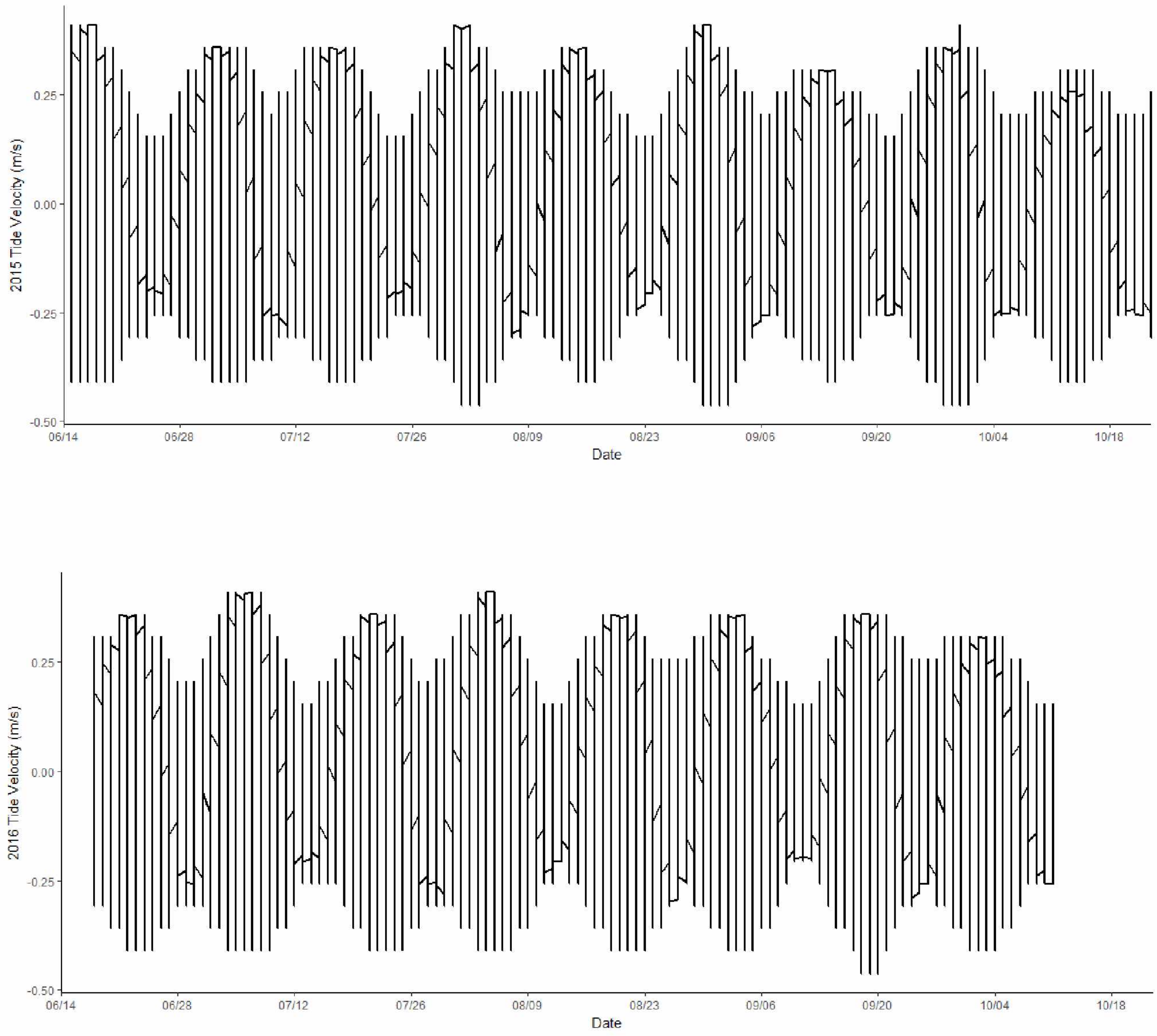


Figure 2.2 continued…

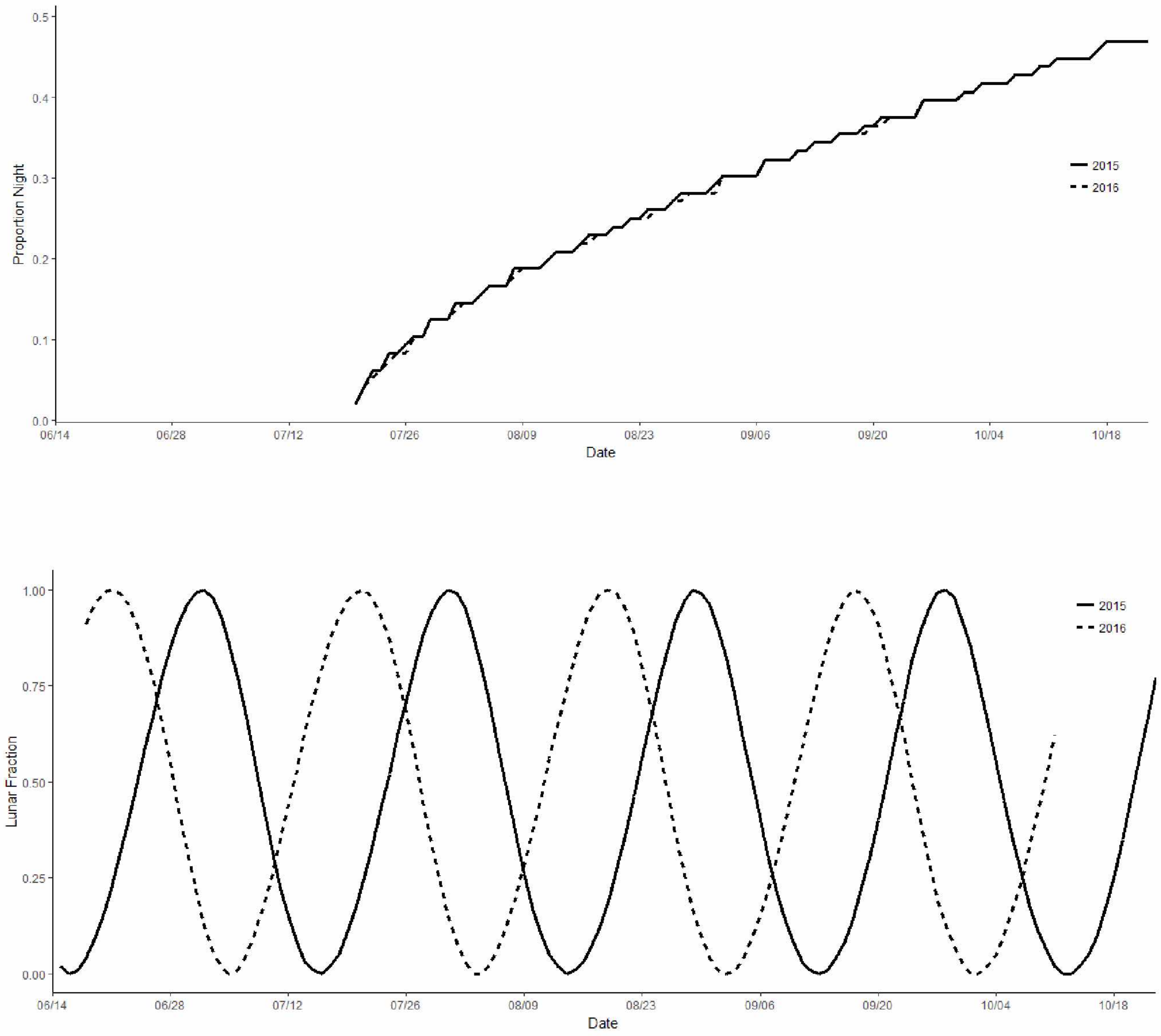


Figure 2.2 continued…

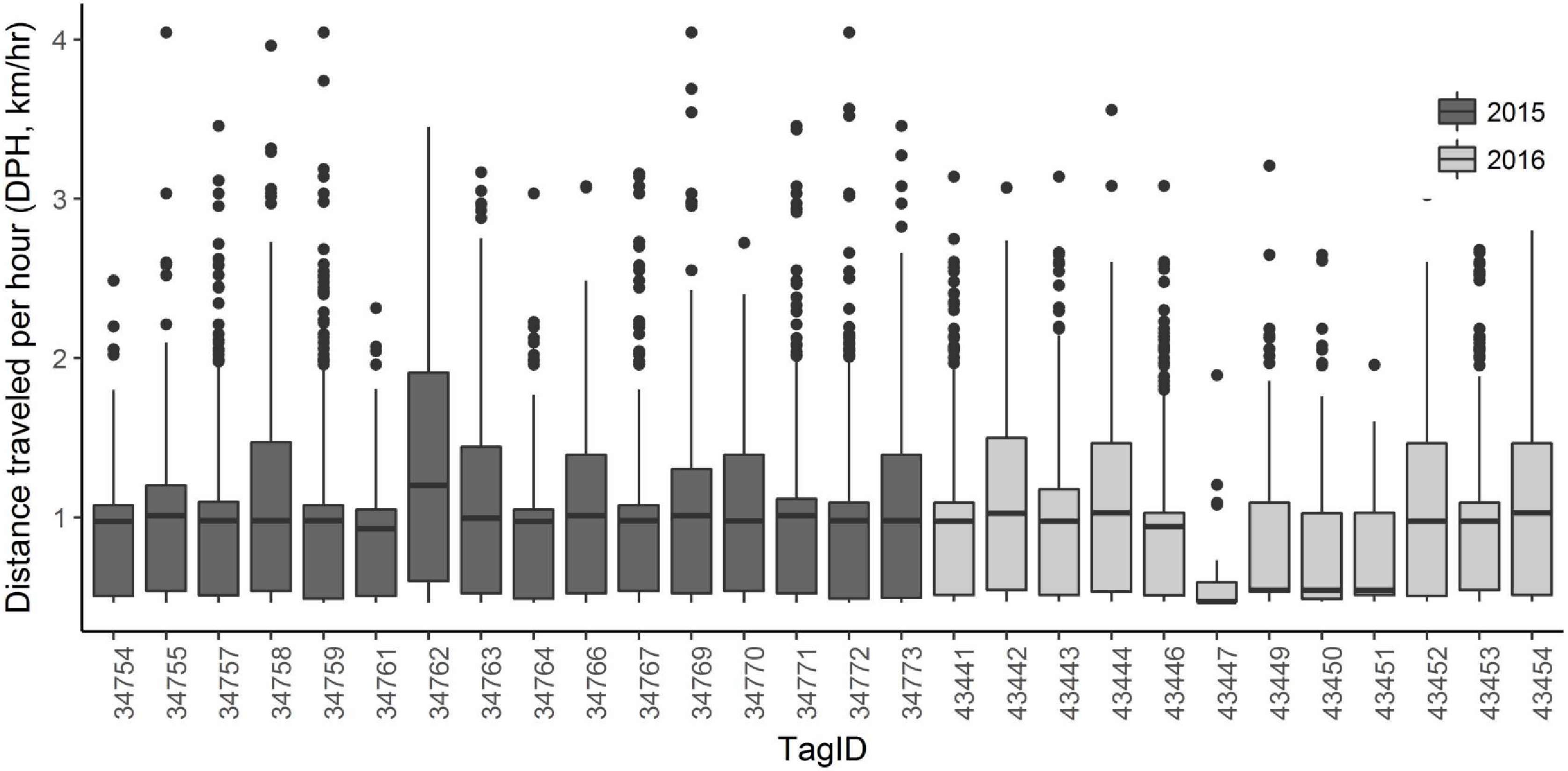


Figure 2.3 Distance traveled per hour using only hours in which movement occurred for each tagged juvenile Sablefish in St. John Baptist Bay, Alaska. The black line within boxes represents median distanced traveled per hour, while the lower and upper edges of the box represent the first and third quartiles. The upper whisker extends to the greatest distance traveled per hour no larger than 1.5·interquartile range, and the lower whisker extends to the smallest distance traveled per hour no further than 1.5·interquartile range. Dots beyond the whiskers represent outlier points.

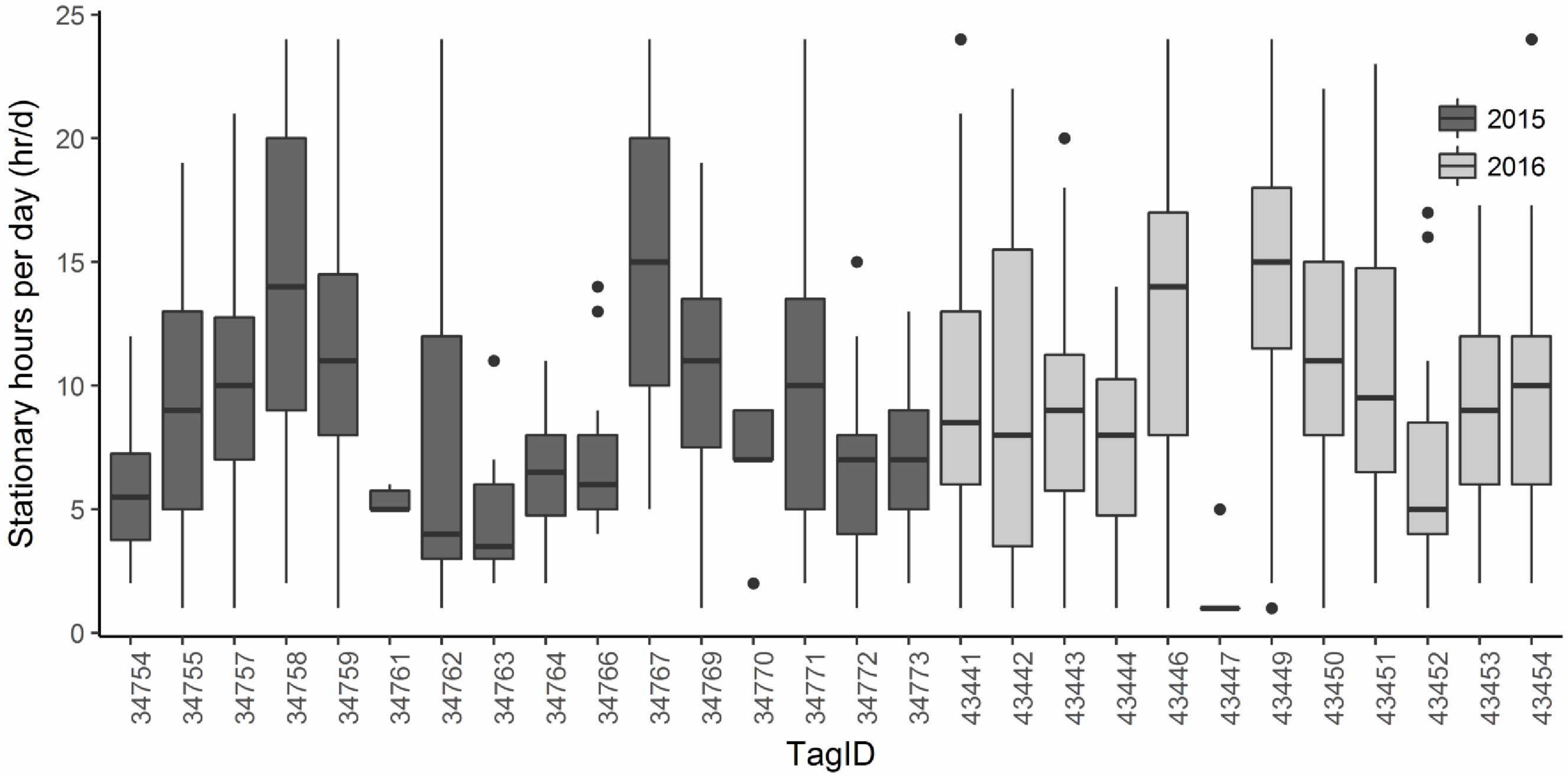


Figure 2.4 Hours per day in which no movement occurred (i.e., stationary hours per day) for each tagged juvenile Sablefish in St. John Baptist Bay, Alaska, of each study year. The black line within boxes represents median hours per day of no movement, while the lower and upper edges of the box represent the first and third quartiles. The upper whisker extends to the most stationary hours per day no larger than 1.5·interquartile range, and the lower whisker extends to the least stationary hours per day no further than 1.5·interquartile range. Dots beyond the whiskers represent outlier points.

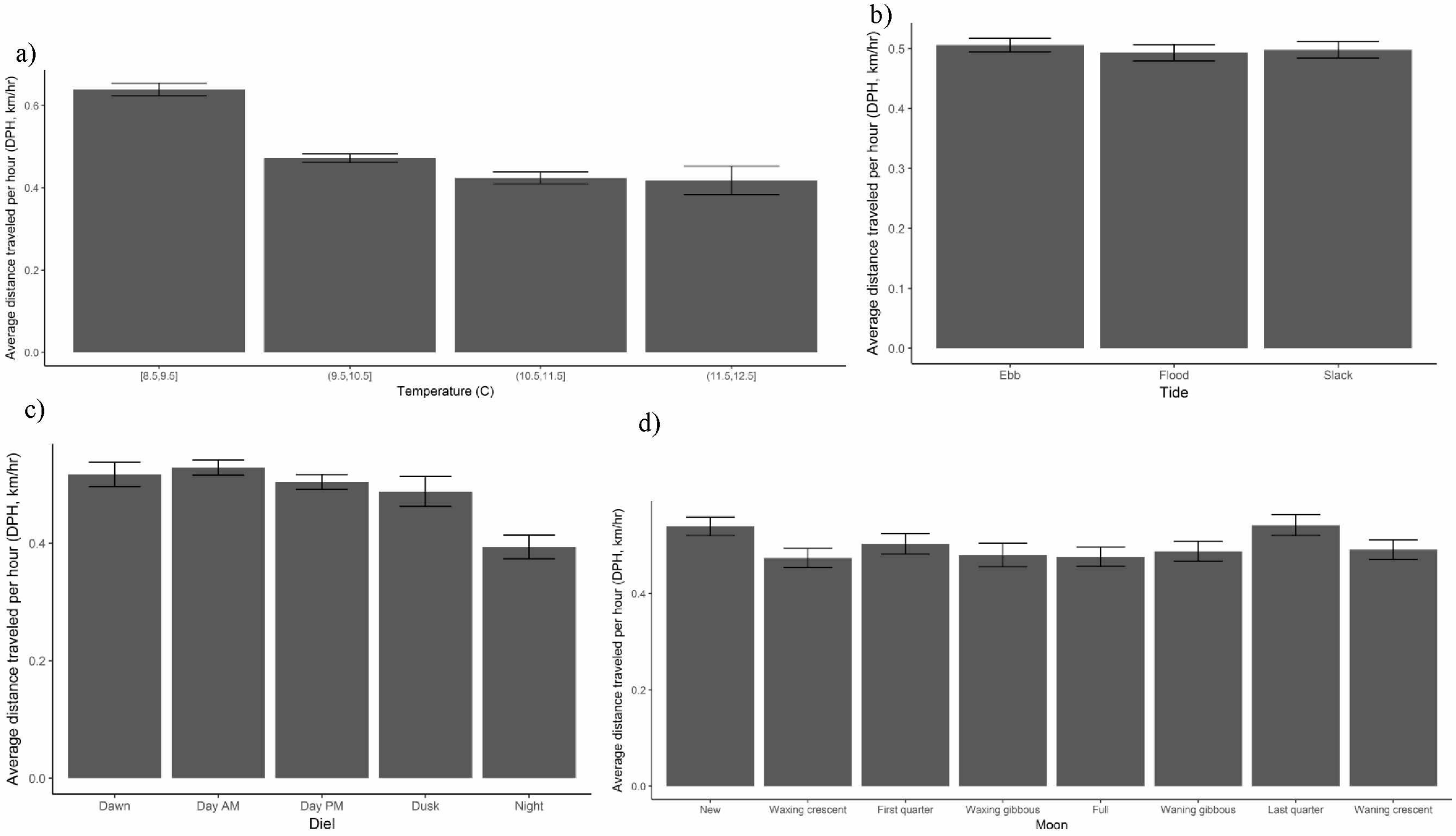


Figure 2.5 Mean (± 2 SEs) movement plots for all tagged juvenile Sablefish showing distance traveled per hour in relation to a) temperature, b) tide stage, c) diel state, and d) moon phase in St. John Baptist Bay, Alaska.

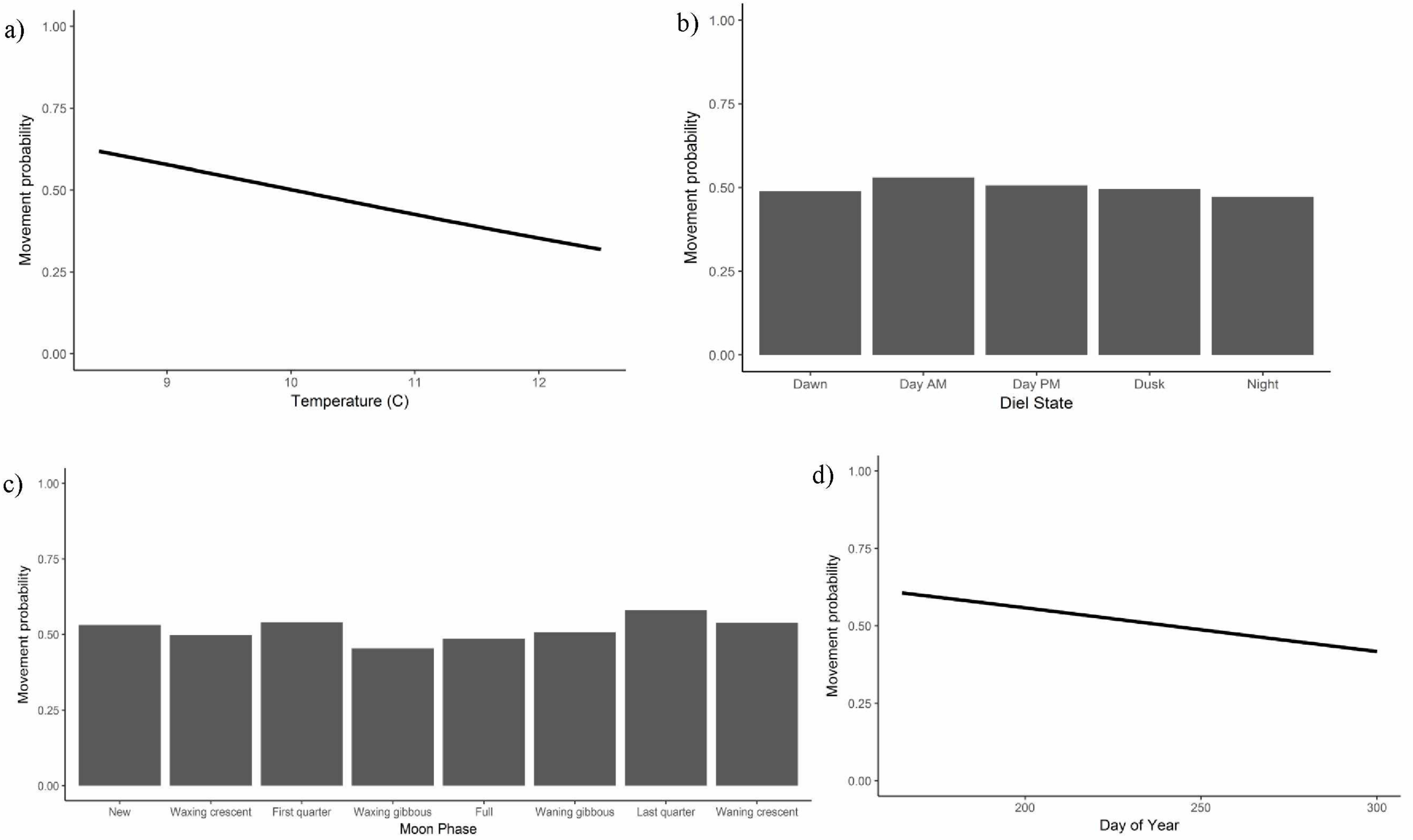


Figure 2.6 Mean predicted probability of movement plots for all tagged juvenile Sablefish showing movement probability in relation to a) temperature, b) diel state, c) moon phase, and d) day of year in St. John Baptist Bay, Alaska., based on the best-fit binomial generalized linear mixed model.

Tables

Table 2.1 Variables examined in this study with supporting literature and hyptheses for movement rate and probability of movement occuring.

Variable	Literature	Hypothesis (rate or probability of movement)
Water temperature	Faster growth at higher water temperatures; avoidance of cold water (Sogard and Olla 1998; 2001)	Higher at warmer temperatures
Tidal stage	Influx of prey during flood tide; some juvenile Sablefish influenced by tide (Coutré et al. 2017)	Higher during flood tide
Diel state	Greatest frequency of excursions during dawn and day; lowest at night (Sogard and Olla 1998; Ryer and Olla 1999; Coutré et al. 2017)	Higher during dawn and day; lowest at night
Moon phase	Reduced ability for foraging during low light periods (Sogard and Olla 1998; Ryer and Olla 1999)	Lower during decreased moon illumination
Day of year	Reduced ability for foraging during low light periods (Sogard and Olla 1998; Ryer and Olla 1999)	Lower over time as days grow shorter
Year	N/A	No difference between years

Table 2.2 Biological and telemetry data for each fish used in analyses. The In bay (d) column shows the number of days each fish was detected within the receiver array. The average DPH column shows the mean distance (km) traveled per hour, while the mean hrs/day stationary column shows the average hours in a given day in which fish did not change primary receivers.

Release			Monitoring				Movement in Bay	
Tag ID	Length (mm)	Weight (g)	Release date	Study start	Last detection	In bay (d)	Mean DPH	Mean hrs/day stationary
34754	352	450	6/10/2015	6/15/2015	6/26/2015	12	0.90	5.83
34755	354	350	6/10/2015	6/15/2015	7/26/2015	39	1.05	9.41
34757	380	410	6/10/2015	6/15/2015	8/20/2015	36	1.01	9.39
34758	344	300	6/10/2015	6/15/2015	10/20/2015	121	1.07	14.08
34759	362	380	6/10/2015	6/15/2015	12/10/2015	88	0.97	11.63
34761	370	400	6/10/2015	6/15/2015	6/21/2015	6	0.92	5.33
34762	358	370	6/10/2015	6/15/2015	7/5/2015	18	1.30	7.76
34763	358	360	6/10/2015	6/15/2015	6/26/2015	12	1.05	4.67
34764	358	360	6/10/2015	6/15/2015	6/27/2015	12	0.91	6.50
34766	372	400	6/10/2015	6/15/2015	6/29/2015	15	1.02	7.00
34767	340	300	6/10/2015	6/15/2015	8/31/2015	78	1.03	15.19
34769	380	420	6/10/2015	6/15/2015	7/26/2015	29	1.09	10.26
34770	352	320	6/10/2015	6/15/2015	6/19/2015	5	1.05	6.80
34771	340	320	6/10/2015	6/15/2015	8/4/2015	44	1.07	9.91
34772	360	350	6/10/2015	6/15/2015	8/5/2015	34	0.98	6.65
34773	362	350	6/10/2015	6/15/2015	7/11/2015	27	1.01	7.37
43441	365	420	6/12/2016	6/17/2016	10/5/2016	95	0.97	9.69
43442	365	370	6/11/2016	6/17/2016	7/10/2016	20	1.09	9.68
43443	340	370	6/11/2016	6/17/2016	9/4/2016	58	0.98	8.43
43444	360	420	6/11/2016	6/17/2016	7/3/2016	16	1.07	7.69
43446	300	240	6/12/2016	6/17/2016	10/9/2016	109	0.91	12.80
43447	420	690	6/12/2016	6/17/2016	7/9/2016	15	0.67	1.57
43449	355	430	6/12/2016	6/17/2016	10/9/2016	114	0.85	14.32
43450	335	280	6/12/2016	6/17/2016	10/5/2016	53	0.81	11.15
43451	330	310	6/12/2016	6/17/2016	7/4/2016	10	0.81	10.80
43452	365	390	6/12/2016	6/17/2016	7/12/2016	23	1.04	6.31
43453	310	240	6/12/2016	6/17/2016	10/9/2016	114	0.98	9.62
43454	330	320	6/12/2016	6/17/2016	10/4/2016	96	1.05	9.95

Table 2.3 Top ten GLMM analyses model comparison results and null model.

	Model covariates	df	logLik	AIC	ΔAIC	Weight
1	Movement ~ Temp + DOY + Diel + Moon + (1 | TagID)	15	-18,349.82	36,729.64	0.00	0.48
2	Movement ~ Temp + DOY + Tide + Diel + Moon + (1 | TagID)	17	-18,348.54	36,731.08	1.44	0.24
3	Movement ~ Temp + DOY + Diel + Moon + Year + (1 | TagID)	16	-18,349.75	36,731.50	1.87	0.19
4	Movement ~ Temp + DOY + Tide + Diel + Moon + Year + (1 | TagID)	18	-18,348.48	36,732.95	3.31	0.09
5	Movement ~ Temp + DOY + Tide + Moon + (1 | TagID)	13	-18,364.76	36,755.51	25.88	0.00
6	Movement ~ Temp + DOY + Tide + Moon + Year + (1 | TagID)	14	-18,364.71	36,757.41	27.77	0.00
7	Movement ~ Temp + DOY + Moon + (1 | TagID)	11	-18,367.81	36,757.61	27.97	0.00
8	Movement ~ Temp + DOY + Moon + Year + (1 | TagID)	12	-18,367.75	36,759.50	29.86	0.00
9	Movement ~ Temp + Diel + Moon + (1 | TagID)	14	-18,403.30	36,834.61	104.97	0.00
10	Movement ~ Temp + Diel + Moon + Year + (1 | TagID)	15	-18,403.28	36,836.56	106.92	0.00
Null	Movement ~ (1 | TagID)	2	-18,706.82	37,471.65	688.01	0.00

References

Allen, M. J., and G. B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. NOAA Technical Report 66.

Almeida, P. R. 1996. Estuarine movement patterns of adult thin-lipped grey mullet, *Liza ramada* (Risso) (Pisces, Mugilidae), observed by ultrasonic tracking. Journal of Experimental Marine Biology and Ecology 202(2).

Amorim, E., S. Ramos, M. Elliott, and A. A. Bordalo. 2016. Immigration and early life stages recruitment of the European flounder (*Platichthys flesus*) to an estuarine nursery: The influence of environmental factors. Journal of Sea Research 107(1).

Barton, K. 2018. MuMIn: Multi-Model Inference. R package version 1.40.4.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67(1).

Beaudreau, A. H., and T. E. Essington. 2011. Use of pelagic prey subsidies by demersal predators in rocky reefs: insight from movement patterns of lingcod. Marine Biology 158(2).

Beitinger, T. L., and L. C. Fitzpatrick. 1979. Physiological and ecological correlates of preferred temperature in fish. American Zoology 19.

Blaber, S. J. M., and T. G. Blaber. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. Journal of Fish Biology 17(2).

Boehlert, G. W., and M. M. Yoklavich. 1985. Larval and juvenile growth of Sablefish, *Anoplopoma fimbria*, as determined from otolith increments. Fishery Bulletin 83(3).

Bolker, B. M., M. E. Brooks, C. J. Clark, S. W. Geange, J. R. Poulsen, M. H. H. Stevens, and J. S. S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24(3).

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157(2–3).

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach (2nd ed). Springer, New York.

Childs, A. R., P. D. Cowley, T. F. Næsje, A. J. Booth, W. M. Potts, E. B. Thorstad, and F. Økland. 2008. Do environmental factors influence the movement of estuarine fish? A case study using acoustic telemetry. Estuarine, Coastal and Shelf Science 78(1).

Courtney, D., and T. L. Rutecki. 2011. Inshore movement and habitat use by juvenile Sablefish, *Anoplopoma fimbria*, implanted with acoustic tags in Southeast Alaska. AFSC Processed Report 2011-01, 39 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar, Fish. Serv., Auke Bay Laboratories,17109 Lena Point Loop Road Juneau, AK 99801 (March).

Coutré, K. M., A. H. Beaudreau, D. Courtney, F. J. Mueter, P. W. Malecha, and T. L. Rutecki. 2017. Vertical movements of juvenile Sablefish in coastal Southeast Alaska. Marine and Coastal Fisheries 9(1).

Coutré, K. M., A. H. Beaudreau, and P. W. Malecha. 2015. Temporal variation in diet composition and use of pulsed resource subsidies by juvenile Sablefish. Transactions of the American Fisheries Society 144(4).

Dodson, J. J. 1997. Fish migration: an evolutionary perspective. In: Behavioural Ecology of Teleost Fishes, ed. J.G.J. Godin. 10-36. Oxford: Oxford University Press.

Dormann, C. F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carré, J. R. G. Marquéz, B. Gruber, B. Lafourcade, P. J. Leitão, T. Münkemüller, C. Mcclean, P. E. Osborne, B. Reineking, B. Schröder, A. K. Skidmore, D. Zurell, and S. Lautenbach. 2013. Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. Ecography 36(1).

Ehresmann, R., A. B. Beaudreau, and K. M. Green. In Press. Movement patterns of juvenile Sablefish within a nursery area in Southeast Alaska. Transactions of the American Fisheries Society.

Fissel, B., M. Dalton, R. Felthoven, B. Garber-Yonts, A. Haynie, A. HimesCornell, S. Kasperski, J. Lee, D. Lew, L. Pfeiffer, and C. Seung. 2013. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands areas: economic status of the groundfish fisheries off Alaska, 2012. North Pacific Fishery Management Council, Anchorage, Alaska.

Furey, N. B., M. A. Dance, and J. R. Rooker. 2013. Fine-scale movements and habitat use of juvenile southern flounder *Paralichthys lethostigma* in an estuarine seascape. Journal of Fish Biology 82(5).

Gibson, R. N. 1994. Impact of habitat quality and quantity on the recruitment of juvenile flatfishes. Netherlands Journal of Sea Research.

Gibson, R. N. 2003. Go with the flow tidal migrations in marine animals. Hydrobiologia 503.

Gillies, C. S., M. Hebblewhite, S. E. Nielsen, M. A. Krawchuk, C. L. Aldridge, J. L. Frair, D. J. Saher, C. E. Stevens, and C. L. Jerde. 2006. Application of random effects to the study of resource selection by animals. Journal of Animal Ecology 75(4).

Kendall, A. W., and A. C. Matarese. 1987. Biology of eggs, larvae and epipelagic juveniles of Sablefish, *Anoplopoma fimbria*, in relation to their potential use in management. Marine Fisheries Review 49 (1).

Koper, N., and M. Manseau. 2009. Generalized estimating equations and generalized linear mixed-effects models for modelling resource selection. Journal of Applied Ecology 46(3).

Lazaridis, E. 2014. lunar: Lunar Phase & Distance, Seasons and Other Environmental Factors. Version 0.1-04. Available from http://statistics.lazaridis.eu

Littell, R. C., P. R. Henry, and C. B. Ammerman. 1998. Statistical analysis of repeated measures data using SAS procedures. Journal of Animal Science 76(4).

Maloney, N. E., and M. F. Sigler. 2008. Age-specific movement patterns of Sablefish (*Anoplopoma fimbria*) in Alaska. Fishery Bulletin 106(3).

Mangiafico, S. 2018. rcompanion: Functions to support extension education program evaluation. R package version 1.13.0.

Mason, J.C., Beamish, R.J., & McFarlane, G. A. 1983. Sexual maturity, fecundity, spawning, and early life history of Sablefish off the Pacific coast of Canada. Can. J. Fish. and Aquatic Sci. 40(12).

Møller, A. P., and M. D. Jennions. 2002. How much variance can be explained by ecologists and evolutionary biologists? Oecologia 132(4).

Næsje, T. F., P. D. Cowley, O. H. Diserud, A. R. Childs, S. E. Kerwath, and E. B. Thorstad. 2012. Riding the tide: Estuarine movements of a sciaenid fish, *Argyrosomus japonicus*. Marine Ecology Progress Series 460.

Nagelkerken, I., M. Sheaves, R. Baker, and R. M. Connolly. 2015. The seascape nursery: A novel spatial approach to identify and manage nurseries for coastal marine fauna. Fish and Fisheries 16(2).

Nakagawa, S., and H. Schielzeth. 2013. A general and simple method for obtaining R2 from generalized linear mixed-effects models. Methods in Ecology and Evolution 4(2).

National Oceanic and Atmospheric Administration (NOAA). 2013. Current Predictions.

R Core Team. 2018. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Richards, S. A. 2005. Testing ecological theory using the information-theoretic approach: examples and cautionary results. Ecology 86(10).

Richards, S. A. 2008. Dealing with overdispersed count data in applied ecology. Journal of Applied Ecology 45(1).

Richards, S. A., M. J. Whittingham, and P. A. Stephens. 2011. Model selection and model averaging in behavioural ecology: The utility of the IT-AIC framework. Behavioral Ecology and Sociobiology 65(1).

Roy, M. L., A. G. Roy, J. W. A. Grant, and N. E. Bergeron. 2013. Individual variability of wild juvenile Atlantic salmon activity patterns: effect of flow stage, temperature, and habitat use. Canadian Journal of Fisheries and Aquatic Sciences 70(7).

Rutecki, T. L., and E. R. Varosi. 1997a. Distribution, age, and growth of juvenile Sablefish, *Anoplopoma fimbria*, in Southeast Alaska. NOAA Technical Report NMFS 130.

Rutecki, T. L., and E. R. Varosi. 1997b. Migrations of juvenile Sablefish, *Anoplopoma fimbria*, in Southeast Alaska. NOAA Technical Report NMFS 130.

Ryer, C. H., M. L. Ottmar, and E. A. Sturm. 2004. Behavioral impairment after escape from trawl codends may not be limited to fragile fish species. Fisheries Research 66(2–3).

Ryer, C., and B. Olla. 1999. Light-induced changes in the prey consumption and behavior of two juvenile planktivorous fish. Marine Ecology Progress Series 181.

Sakabe, R., and J. M. Lyle. 2010. The influence of tidal cycles and freshwater inflow on the distribution and movement of an estuarine resident fish *Acanthopagrus butcheri*. Journal of Fish Biology 77(3).

Shenker, J. M., and B. L. Olla. 1986. Laboratory feeding and growth of juvenile Sablefish, *Anoplopoma fimbria*. Canadian Journal of Fisheries and Aquatic Sciences 43(5).

Sigler, M. F., C. R. Lunsford, J. T. Fujioka, and S. A. Lowe. 2003. Alaska Sablefish assessment for 2004. Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska.

Sigler, M. F., T. L. Rutecki, D. L. Courtney, J. F. Karinen, and M.-S. Yang. 2001. Young of the year Sablefish abundance, growth, and diet in the Gulf of Alaska. Alaska Fishery Research Bulletin 8(1).

Sogard, S. M., and B. L. Olla. 1998. Behavior of juvenile Sablefish, *Anoplopoma fimbria* (Pallas), in a thermal gradient: Balancing food and temperature requirements. Journal of Experimental Marine Biology and Ecology 222(1–2).

Sogard, S. M., and B. L. Olla. 2001. Growth and behavioral responses to elevated temperatures by juvenile Sablefish *Anoplopoma fimbria* and the interactive role of food availability. Marine Ecology Progress Series 217.

Szedlmayer, S., and K. Able. 1993. Ultrasonic telemetry of age-0 summer flounder, *Paralichthys dentatus*, movements in a Southern New Jersey estuary. Copeia 1993(3).

Tsai, T., and J. Gill. 2013. Interactions in generalized linear models: theoretical issues and an application to personal vote-earning attributes. Social Sciences 2(2).

U.S. Naval Observatory. 2003. Sunrise, sunset, and nautical twilight tables for Sitka, Alaska.

Whitfield, A. K. 1994. Abundance of larval and 0+ juvenile marine fishes in the lower reaches of 3 southern African estuaries with differing freshwater inputs. Marine Ecology Progress Series 105(3).

Wilcockson, D., and L. Zhang. 2008. Circatidal clocks. Current Biology 18(17).

Wolotira, R. J., T. M. Sample, S. F. Noel, and C. R. Iten. 1993. Geographic and bathymetric distributions for many commercially important fishes and shellfishes off the West Coast of North America, based on research survey and commercial catch data, 1912-84. U.S. Dep. Commer., NOAA Technical Memo. NMFS-AFSC-6.

General Conclusion

Sablefish is one of the highest valued groundfish species targeted in Alaska's commercial fisheries; however, after decades of heavy exploitation, a declining trend in Sablefish relative abundance has been observed since 1988, with few strong year classes in recent years (Fissel et al. 2012; Hanselman et al. 2015). The strength of a year class is important because it is the fundamental driver behind fluctuations in stock size, but estimating the abundance of the youngest fish entering a population (recruitment) is challenging as the underlying processes that influence recruitment are highly variable (Hanselman et al. 2015). Though recruitment is difficult to estimate, an early indicator of a strong year class is the widespread abundance of age-1 juvenile Sablefish in nearshore waters of Southeast Alaska (Rutecki and Varosi 1997; Hanselman et al. 2015). With limited data on early life history stages and relatively little information on environmental mechanisms that affect juvenile Sablefish survival, identifying factors that influence juvenile Sablefish during the first years of life is crucial. This study is the most comprehensive account to date of movement patterns for juvenile Sablefish in a nearshore habitat. The results show that Sablefish demonstrate site fidelity in their early life history, move substantial distances per day, and exhibit a relationship between movement and water temperature, diel state, moon phase, and day of year. This thesis, in combination with previous studies, provides insights into nursery space use and movement patterns of juvenile Sablefish in Southeast Alaska and presents a foundation for future studies of this life stage. It also provides a reference for methods in analyzing telemetry data and for comparing species with similar life histories.

Results from Chapter One revealed that juvenile Sablefish were present for an average of 46 days during the study period across both study years. While present within the bay, we found that juvenile Sablefish moved throughout the entire bay, but spent more time near the middle-head region of the bay. This location of higher residence is corroborated by previous studies of juvenile Sablefish in SJBB (Rutecki and Varosi 1997; Courtney and Rutecki 2011; Coutré et al. 2015, 2017). Juvenile Sablefish may have an affinity for this region of the bay due to ecological or environmental factors, including habitat characteristics (Pirtle et al. 2017). We also found that juvenile Sablefish made considerable daily movements and spent much of the day within the bay; fish tagged in 2015 traveled 13.0 km/d and spent 20.2 h/d within the bay on average, and fish tagged in 2016 traveled 9.4 km/d and spent 17.9 h/d within the bay on average. Three distinct movement types were identified among all 28 tagged juvenile Sablefish, illustrating the dynamic nature of individual movement due to factors like foraging decisions, predation risk, competition, and individual variation in life history traits (Roy et al. 2013; Garcia et al. 2015). Juvenile Sablefish progressively emigrated from SJBB throughout the summer and fall. It is unclear what marked the exodus for juvenile Sablefish from SJBB to adjacent waters, but few tagged fish remained in the bay by October of either study year. Reasons for differences in emigration among individuals and between years may have been due to measured variables such as temperature, size of fish, or other factors outside the scope of this study, such as prey availability.

In Chapter Two, we found that juvenile Sablefish movements are related to environmental conditions. Generalized linear mixed effects model results showed that the hourly probability of movement was significantly influenced by mean water temperature, diel state, moon phase, and day of year, while movement was not significantly affected by differences in tidal stage or between years. Increases in mean water temperature and day of year resulted in a lower predicted probability of movement, perhaps due to seasonality in prey availability, as juvenile Sablefish are known to feed on seasonally-pulsed prey items (Coutré et al. 2015). Predicted probability of movement was greatest in the day AM diel state and lowest at night, which aligns with previous findings in both experimental and laboratory settings (Sogard and Olla 1998, 2001; Coutré et al. 2017). Juvenile Sablefish movements were significantly influenced by moon phase, with the last quarter moon phase associated with the highest probability of movement. Understanding how moon phase affects juvenile Sablefish movements necessitates further research but could be due to predator avoidance during higher moon illumination conditions. Moonlight increases the ability of visual predators to locate prey but also increases the ability of visual prey to detect and avoid predators (e.g., Fallows et al. 2016). Juvenile Sablefish exhibited seasonality in their movement; the predicted probability of movement decreased over day of year. This trend may have been due to changes in seasonal prey resources (Coutré et al. 2015); however, it is likely that environmental factors not examined in this study (e.g., precipitation, salinity, etc.) also influenced the movements of individuals.

Prior to this study, SJBB was recognized as a nursery habitat for juvenile Sablefish (Rutecki and Varosi 1997; Courtney and Rutecki 2011; Coutré et al. 2015, 2017), but the extent of their residence and drivers of their movements in the bay were unknown. It remains unclear why SJBB is a consistently reliable area for juvenile Sablefish, but findings from this study corroborate its role as a nursery area. Very little is known about the bycatch implications of juvenile Sablefish in herring and salmon seine fisheries that are conducted within SJBB; however, this is a potential management concern given the residence time of juvenile Sablefish in the bay and its role as a nursery habitat. Understanding how local conditions affect movement improves the overall understanding of the biology of a species and the factors that influence their movements, as juvenile fishes rely on nursery areas for suitable habitat to meet their physiological and energetic needs (Beck et al. 2001; Heck et al. 2003; Nagelkerken et al. 2015). There is growing evidence of links between nursery habitat quality, juvenile fitness, and subsequent recruitment success because the associations between fish and their habitats are strongest at these early stages (Gibson 1994; Levin and Stunz 2005; Vasconcelos et al. 2014; Le Pape and Bonhommeau 2015). As a result, juvenile life history stages need to be more closely examined.

Future studies could examine the movements of age-0 juvenile Sablefish in nearshore areas to gain a better understanding of the entire nearshore stage. Additionally, repeating this study in multiple juvenile Sablefish nursery areas would improve our understanding of their occurrence and inhabitance at this life stage, as we currently rely on studies in SJBB and local knowledge of fishermen. Potential physiological triggers of migration out of nearshore habitats could be better understood by pairing a telemetry study with an analysis of juvenile Sablefish body condition (e.g., energy allocation) and their thermal experience during the summer and fall months. Further research is required to identify specific mechanisms that contribute to variations in movement patterns, as this behavioral diversity may contribute to greater resiliency and stability in the population through a “portfolio effect” (Schindler et al. 2010).

References

Beck, M. W., K. L. Heck, K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B. Halpern, C. G. Hays, K. Hoshino, T. J. Minello, R. J. Orth, P. F. Sheridan, and M. P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51(8):633–641.

Courtney, D., and T. L. Rutecki. 2011. Inshore movement and habitat use by juvenile Sablefish, *Anoplopoma fimbria*, implanted with acoustic tags in Southeast Alaska. AFSC Processed Report 2011-01. Alaska Fisheries Science Center, NOAA, National Marine Fisheries Service, Auke Bay Laboratories.

Coutré, K. M., A. H. Beaudreau, D. Courtney, F. J. Mueter, P. W. Malecha, and T. L. Rutecki. 2017. Vertical movements of juvenile Sablefish in coastal Southeast Alaska. Marine and Coastal Fisheries 9(1):161–169.

Coutré, K. M., A. H. Beaudreau, and P. W. Malecha. 2015. Temporal variation in diet composition and use of pulsed resource subsidies by juvenile Sablefish. Transactions of the American Fisheries Society 144(4):807–819.

Fallows, C., M. Fallows, and N. Hammerschlag. 2016. Effects of lunar phase on predator-prey interactions between white shark (*Carcharodon carcharias*) and Cape fur seals (*Arctocephalus pusillus pusillus*). Environmental Biology of Fishes 99(11):805–812. Environmental Biology of Fishes.

Fissel, B., M. Dalton, R. Felthoven, B. Garber-yonts, A. Haynie, S. Kasperski, J. Lee, D. Lew, L. Pfeiffer, and C. Seung. 2012. Stock Assessment and Fishery Evaluation Report for the Groundfish Fisheries of the Gulf of Alaska and Bering Sea / Aleutian Islands Area : NPFMC Economic SAFE (December 2013).

Garcia, J., J. Mourier, and P. Lenfant. 2015. Spatial behavior of two coral reef fishes within a Caribbean marine protected area. Marine Environmental Research 109:41–51.

Gibson, R. N. 1994. Impact of habitat quality and quantity on the recruitment of juvenile flatfishes. Netherlands Journal of Sea Research.

Hanselman, D. H., C. R. Lunsford, and C. J. Rodgveller. 2015. Assessment of the Sablefish stock in Alaska. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska 2014:576–717.

Heck, K. L., G. Hays, and R. J. Orth. 2003. Critical evaluation of nursery hypothesis for seagrasses. Marine Ecology Progress Series 253:123–136.

Levin, P. S., and G. W. Stunz. 2005. Habitat triage for exploited fishes: Can we identify essential "Essential Fish Habitat?" Estuarine, Coastal and Shelf Science 64:70–78.

Nagelkerken, I., M. Sheaves, R. Baker, and R. M. Connolly. 2015. The seascape nursery: A novel spatial approach to identify and manage nurseries for coastal marine fauna. Fish and Fisheries 16(2):362–371.

Le Pape, O., and S. Bonhommeau. 2015. The food limitation hypothesis for juvenile marine fish. Fish and Fisheries 16(3):373–398.

Pirtle, J. L., S. K. Shotwell, M. Zimmermann, J. A. Reid, and N. Golden. 2017. Habitat suitability models for groundfish in the Gulf of Alaska. Deep Sea Research Part II: Topical Studies in Oceanography.

Roy, M. L., A. G. Roy, J. W. A. Grant, and N. E. Bergeron. 2013. Individual variability of wild juvenile Atlantic salmon activity patterns: effect of flow stage, temperature, and habitat use. Canadian Journal of Fisheries and Aquatic Sciences 70(7):1082–1091.

Rutecki, T. L., and E. R. Varosi. 1997. Distribution, age, and growth of juvenile Sablefish, *Anoplopoma fimbria*, in Southeast Alaska. NOAA Tech Rep NMFS 130:45–54.

Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. A. Rogers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465(7298):609–612. Nature Publishing Group.

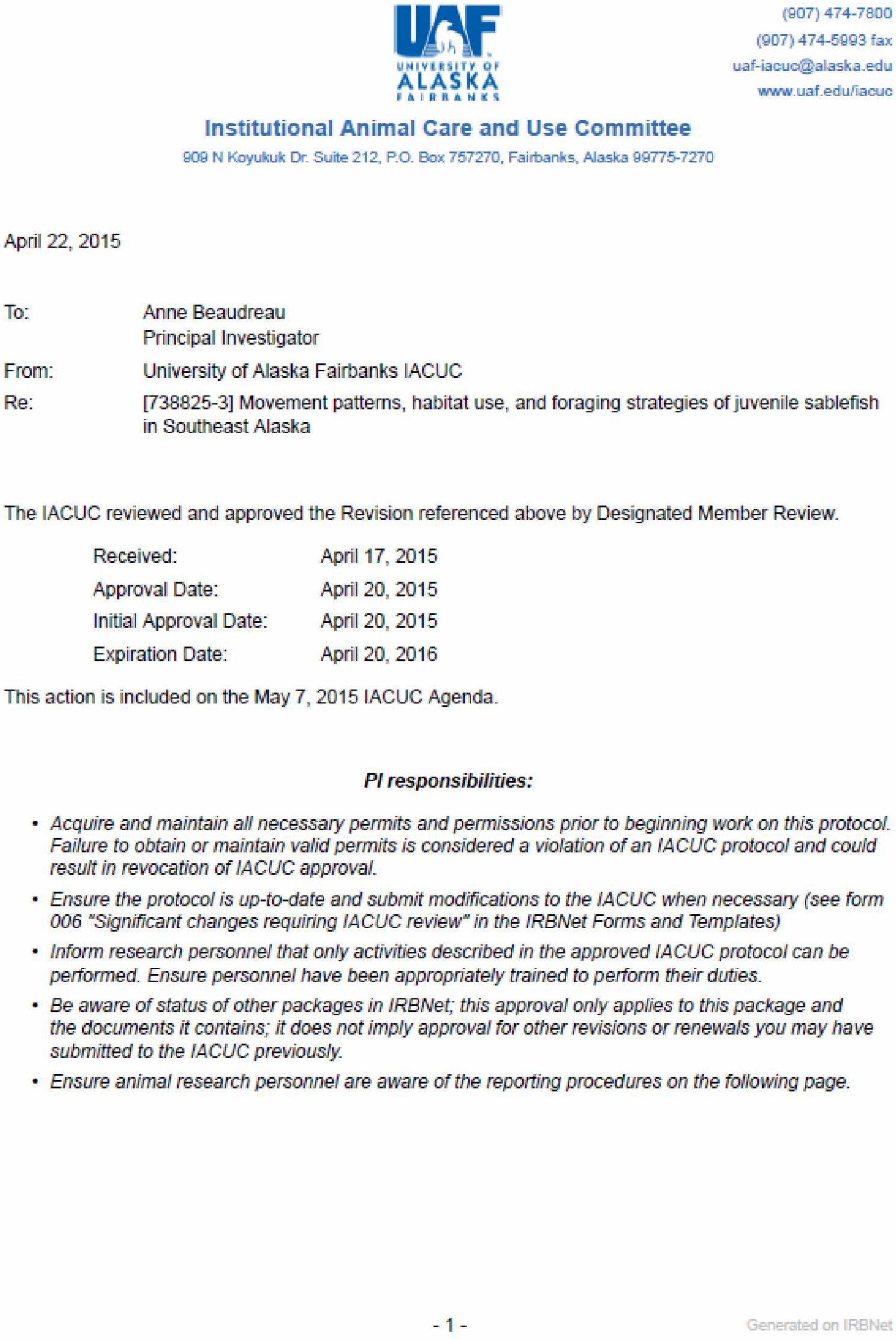
Sogard, S. M., and B. L. Olla. 1998. Behavior of juvenile Sablefish, *Anoplopoma fimbria* (Pallas), in a thermal gradient: Balancing food and temperature requirements. Journal of Experimental Marine Biology and Ecology 222(1–2):43–58.

Sogard, S. M., and B. L. Olla. 2001. Growth and behavioral responses to elevated temperatures by juvenile Sablefish *Anoplopoma fimbria* and the interactive role of food availability. Marine Ecology Progress Series 217:121–134.

Vasconcelos, R. P., D. B. Eggleston, O. Le Pape, and I. Tulp. 2014. Patterns and processes of habitat-specific demographic variability in exploited marine species. ICES Journal of Marine Science 71(3):638–647.

Appendices

Appendix A: 2015 IACUC Approval Letter



UNIVERSITY OF ALASKA FAIRBANKS

(907) 474-7800
(907) 474-5993 fax
uaf-iacuc@alaska.edu
www.uaf.edu/iacuc

Institutional Animal Care and Use Committee
909 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

April 22, 2015

To: Anne Beaudreau
Principal Investigator
From: University of Alaska Fairbanks IACUC
Re: [738825-3] Movement patterns, habitat use, and foraging strategies of juvenile sablefish in Southeast Alaska

The IACUC reviewed and approved the Revision referenced above by Designated Member Review.

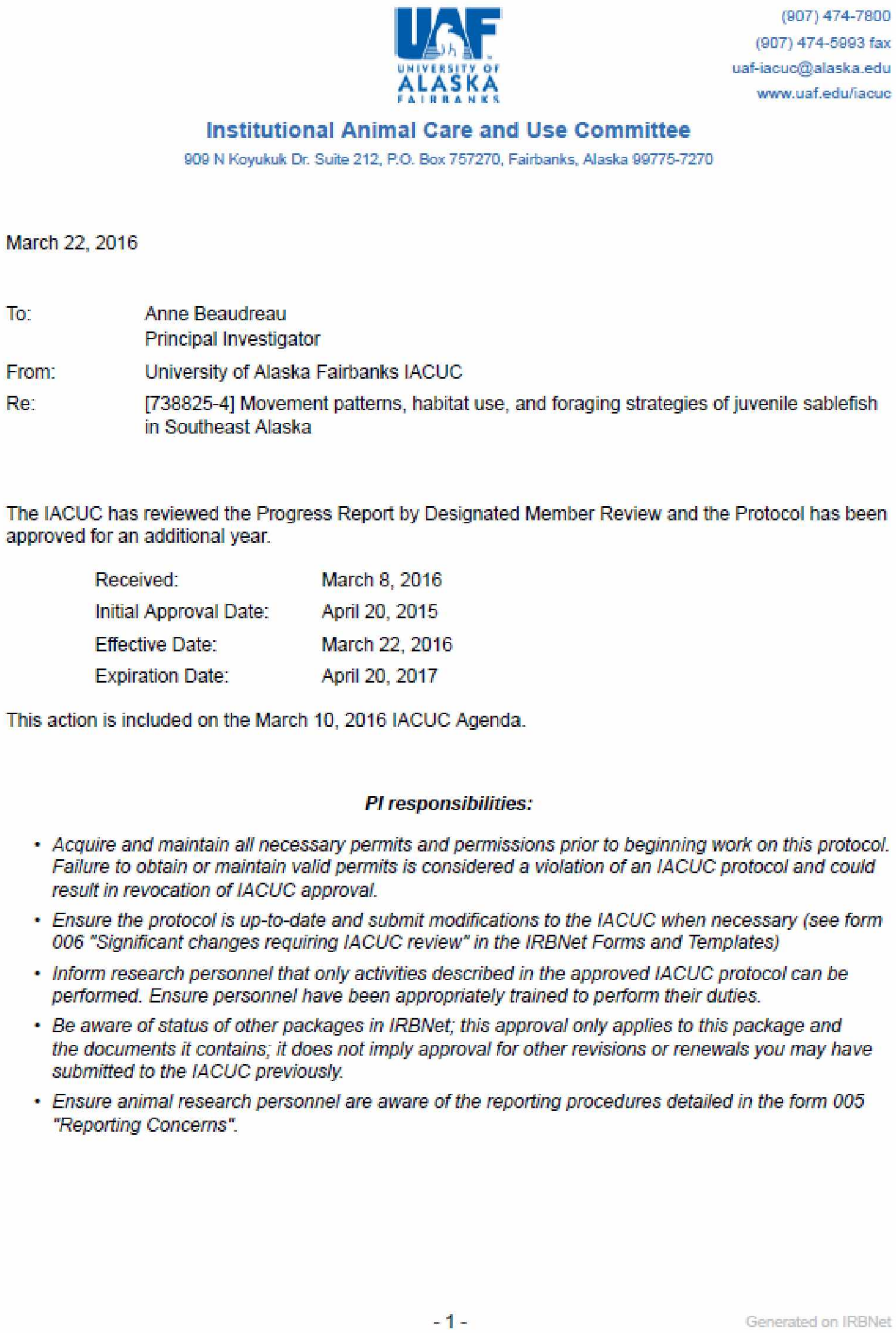
Received: April 17, 2015
Approval Date: April 20, 2015
Initial Approval Date: April 20, 2015
Expiration Date: April 20, 2016

This action is included on the May 7, 2015 IACUC Agenda.

PI responsibilities:

- *Acquire and maintain all necessary permits and permissions prior to beginning work on this protocol. Failure to obtain or maintain valid permits is considered a violation of an IACUC protocol and could result in revocation of IACUC approval.*
- *Ensure the protocol is up-to-date and submit modifications to the IACUC when necessary (see form 006 "Significant changes requiring IACUC review" in the IRBNet Forms and Templates)*
- *Inform research personnel that only activities described in the approved IACUC protocol can be performed. Ensure personnel have been appropriately trained to perform their duties.*
- *Be aware of status of other packages in IRBNet; this approval only applies to this package and the documents it contains; it does not imply approval for other revisions or renewals you may have submitted to the IACUC previously.*
- *Ensure animal research personnel are aware of the reporting procedures on the following page.*

Appendix B: 2016 IACUC Approval Letter



(907) 474-7800
(907) 474-5993 fax
uaf-iacuc@alaska.edu
www.uaf.edu/iacuc

Institutional Animal Care and Use Committee
909 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

March 22, 2016

To: Anne Beaudreau
Principal Investigator
From: University of Alaska Fairbanks IACUC
Re: [738825-4] Movement patterns, habitat use, and foraging strategies of juvenile sablefish in Southeast Alaska

The IACUC has reviewed the Progress Report by Designated Member Review and the Protocol has been approved for an additional year.

Received:	March 8, 2016
Initial Approval Date:	April 20, 2015
Effective Date:	March 22, 2016
Expiration Date:	April 20, 2017

This action is included on the March 10, 2016 IACUC Agenda.

PI responsibilities:

- *Acquire and maintain all necessary permits and permissions prior to beginning work on this protocol. Failure to obtain or maintain valid permits is considered a violation of an IACUC protocol and could result in revocation of IACUC approval.*
- *Ensure the protocol is up-to-date and submit modifications to the IACUC when necessary (see form 006 "Significant changes requiring IACUC review" in the IRBNet Forms and Templates)*
- *Inform research personnel that only activities described in the approved IACUC protocol can be performed. Ensure personnel have been appropriately trained to perform their duties.*
- *Be aware of status of other packages in IRBNet; this approval only applies to this package and the documents it contains; it does not imply approval for other revisions or renewals you may have submitted to the IACUC previously.*
- *Ensure animal research personnel are aware of the reporting procedures detailed in the form 005 "Reporting Concerns".*