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ECONOMIC EFFECTS OF PACIFIC HALIBUT CLOSURES ON BUSINESSES
ON THE NORTH COAST AND THE AGE, GROWTH, AND REPRODUCTIVE
STATUS OF PACIFIC HALIBUT IN NORTHERN CALIFORNIA AND CENTRAL
OREGON

By

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A Thesis Presented to

The Faculty of Humboldt State University

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Natural Resources: Fisheries

Committee Membership

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ABSTRACT

ECONOMIC EFFECTS OF PACIFIC HALIBUT CLOSURES ON BUSINESSES ON THE NORTH COAST AND THE AGE, GROWTH, AND REPRODUCTIVE STATUS OF PACIFIC HALIBUT IN NORTHERN CALIFORNIA AND CENTRAL OREGON

Miki Tajima Takada

Traditionally, the recreational fishery for Pacific halibut has been open in California from 1 May through 31 October. In 2014, however, the Pacific halibut fishery was closed in California during the month of August for the first time in history in an effort to reduce harvest and bring total catch closer to what is allocated to our region by the Pacific Fisheries Management Council (PFMC) Catch Sharing Plan. To determine the effects that the closure had on businesses along the North Coast, I conducted an economic impact survey in 2014. The results of the survey showed that fishing-related businesses lost between zero percent and eight percent of their revenue in 2014, as a result of the closure; lodging and traveler service companies lost between 0.3 percent and one percent of their revenue in the same year. None of the businesses changed the number of employees as a result of the closure. We estimated a decrease in revenue for businesses on the North Coast to be between \$189,750 and \$222,250.

Age and growth are important components in stock assessment models, but biological data in general are scarce on populations of Pacific halibut found in northern California. For this reason, I conducted a study that examined the age and growth of

Pacific halibut landed in this region, expanding on a previous study to examine possible interannual variation in the age/growth structure, and broadened the study into central Oregon, to compare two distinct bioregions. Results from my study show that mean size-at-age of female Pacific halibut from northern California and central Oregon was larger than those from the IPHC setline surveys in most of Alaska, but similar to those from Oregon and Washington. In addition, fish from this study in northern California and central Oregon were smaller for a given age than those from the 2014 IPHC survey conducted in northern California. Possible reasons for the trend in size-at-age include poor oceanic conditions during my study, the movement of slower-growing halibut into northern Californian waters, and sampling error.

The maturity stage of female gonads is also an important component in stock assessment models, but these data are also scarce for Pacific halibut populations in northern California. For this reason, I conducted a study that characterized the maturation of Pacific halibut landed in northern California and central Oregon. I also compared the macroscopic maturity staging method currently utilized by the IPHC against the more rigorous microscopic methods (microscopic staging and measuring oocyte diameter). Results of this study and that of Perkins (2015) indicate that Pacific halibut caught in northern California and central Oregon matured three years earlier than those caught during IPHC setline surveys in waters off of Alaska, and about a year earlier than those caught by the IPHC in Oregon and Washington. The length-at-50%-maturity for Pacific halibut caught in northern California and central Oregon was smaller than that of fish caught in the IPHC setline survey. In addition, for all three stages of maturity observed in

females (immature, mature, and resting; spawning-stage females were not observed) there was at least 66 percent agreement between macroscopic and histological staging methods, with the highest level of agreement (94 percent) seen in mature ovaries. This study largely validated the macroscopic staging methods because of its high accuracy in identifying mature ovaries; the inaccuracy in distinguishing resting versus immature ovaries had little effect on length- and age-at-maturity analysis.

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INTRODUCTION

Basic Life History

Pacific halibut, *Hippoglossus stenolepis*, is the largest species in the Pleuronectidae family, growing up to 2.5 m in length (IPHC 2016a). They are diamond-shaped and laterally compressed, with a mottled dark-brown to green eyed side (top) and a white, blind side (bottom). Most Pacific halibut are dextral (right-eyed), though occasionally (about one in 20,000 or 0.005 percent) left-eyed Pacific halibut are encountered (ADFG 2016). Compared to other flatfishes, Pacific halibut are more elongated, with the length of the body approximately three times that of the width (IPHC 1987). Their mouths are smaller than those of the California halibut, with the maxillary only reaching the anterior portion of the eyes (Miller and Lea 1972). They have small scales embedded in their skin, which gives their skin a smooth appearance, and a lunate caudal fin (IPHC 1987).

P.J. Schmidt, a Russian scientist, proposed the scientific name for Pacific halibut, *Hippoglossus stenolepis*, from the Greek *Hippos* (horse), *glossa* (tongue), *steno* (narrow), and *lepis* (scale) in 1904 to differentiate it from *Hippoglossus hippoglossus*, the Atlantic halibut, noting differences in the body shape, pectoral fin length, and scale shape of the two species (IPHC 1987). While taxonomist M.F. Vernidub (1936) disagreed about the necessity to differentiate between the two, genetic research on the two halibuts has confirmed that they are, indeed, two separate species and that they diverged between 1.7 and 4.5 million years ago during the Pliocene (Grant et al. 1984).

Males mature at approximately eight years of age, while females are mature by 12. Fecundity is proportional to the size of the female; a 25 kg female will lay approximately 500,000 eggs, while a 115 kg female will produce four million eggs (PFMC 2016). Spawning occurs annually, from November through March, at 90 to 460 m in depth. The eggs are about three mm in diameter when released, and free floating. After external fertilization, the eggs hatch in 15 days during which time they drift with the ocean currents. Metamorphosis occurs when the halibut larvae are 2.5 cm long, when the left eye migrates to the right side of the head, and the blind side loses its color. Adult form is obtained when the fish are six months old, at which time they migrate down to the bottom of inshore areas (IPHC 1987).

Larval Pacific halibut feed on plankton as they drift over shallower continental shelves (IPHC 1987), while one to three year olds eat small shrimp and fish. Adult Pacific halibut consume other fishes, such as cod, sablefish, pollock, and rockfish, as well as other flatfishes, cephalopods (octopus), decapods (crabs), and mollusks (clams) (ADFG 2016).

While many commercially caught Pacific halibut weigh 10 to 90 kg, some may exceed 220 kg. Halibut weighing 315 kg and measuring 275 cm in length have reportedly been caught in the past, but the largest documented halibut caught was a 33-year-old female that weighed 225 kg and was 240 cm long. Most of the halibut caught by longline gear weigh between 4.5 and 90 kg (IPHC 1987).

Pacific halibut are also a long-living species, and have been known to live for 55 years, though most do not live past 40 (Wilén and Homans 1998, PFMC 2016). Size-at-

age for Pacific halibut increased from 1920 to 1970, but has been decreasing in recent years. In the 1980s, 12-year-old halibut were 75 percent longer and 50 percent heavier than they were in the early 2000s. The cause of this change in size-at-age continues to be unknown, although ocean temperature changes have been ruled out as a cause. On the other hand, intraspecific and interspecific competition, fishing impacts (both direct effects of targeted fisheries and bycatch, as well as indirect impacts on habitat from trawling), climatic effects, and differences in aging methods have been hypothesized as possible reasons for this change (ADFG 2016).

Pacific halibut have a wide distribution range, from the continental shelf off the coast of central California (Santa Barbara) to the Bering Sea and the eastern Pacific Ocean, and from Hokkaido, Japan to the Gulf of Anadyr in Russia in the western Pacific (Figure 0.1; IPHC 2016a). They are demersal and prefer a water temperature range of three to eight degrees Celsius. During the summer, halibut migrate from along the continental shelf to shallower coastal waters to feed, and then return to deeper waters in the winter to spawn. Most halibut caught in the summer are taken at depths of 27 to 275 m, though some have been captured at 1,100 m (IPHC 1987).



Figure 0.1. Range of Pacific halibut (Mmm, 2007).

While a commercial fishery for Pacific halibut was not established in the United States until 1888 (PFMC 2016), archaeological studies have shown that Native Americans from the Pacific Coast have been fishing for this species for thousands of years (Wilén and Homans 1998).

History of Fishing for Pacific Halibut

Pacific halibut have been a vital part of the culture and diet of indigenous tribes living along the eastern Pacific Coast for millennia. Humans have been occupying the Gulf of Alaska region for approximately 12,000 years, and have historically been heavily dependent upon marine resources, including intertidal and marine fishes and other organisms including marine birds and mammals. Aboriginal people in southeast Alaska have harvested halibut for more than 8,000 years (Ames and Maschner 1999).

Historically, many island and coastal tribes in Alaska and Washington traded smoked or dried halibut (and other items) for clothing and other food and household items. The Makah Tribe of Neah Bay, Washington, would club the halibut to kill them, and the women would cut the carcass into ribbon-like strips, sun-dry, smoke, and then pack them into boxes and blankets. Halibut were carefully processed in this manner because it was such an important commodity, to be traded with other coastal and mainland tribes (Reid 2015).

In exchange for dried halibut, the Puyallup Tribe of Tacoma, Washington traded spring salmon and clams that were dried especially for them (Reid 2015). The Tlingit Tribe of Alaska traded dried halibut and venison, seal oil, dried Chinook salmon, dried herring, dried algae, clams, mussels, sea urchin, preserved herring spawn, cedar bark, and yew wood for eulachon oil and dried eulachon, cranberries preserved in oil, spoons, Chilcat blankets, spruce root baskets, rabbit and marmot skin blankets, moose hide shirts, trousers with stockings attached, leggings, and moccasins (Oberg 1973).

Eventually, the Makah Tribe started selling their halibut catches; in 1880, they caught 720,000 kg of halibut, and by 1893, they were selling between 11,000 and 54,000 kg of halibut and cod weekly. Daily shipments of five tons of halibut were recorded by agents in Neah Bay in August of 1898, and in 1905, the Tribe made \$32,000 from the sales of halibut and other fishes (Collins 1996). Most of the halibut harvested was sold to steamships that were owned by fish companies on Puget Sound, or to buyers in Seattle when the Puget Sound fish companies were unavailable (Reid 2015). The income that the halibut fishery generated for the Makah Tribe allowed them a certain level of

independence, as small payments to the elderly and disabled were the only monies the tribe received from the federal government (Collins 1996).

The year 1888 was a pivotal year for halibut along the Pacific Northwest, as the first commercial halibut fishery was started in Tacoma, Washington. Pacific halibut started to experience intense fishing pressures in the 1890s, as vessels that were originally used to hunt seals switched to halibut fishing as seal populations declined (Wilens and Homans 1998, Clark and Hare 2006).

While competition was fierce, the Pacific halibut fishery was quite lucrative in the early years of the industry. In 1895, most successful operations were able to pay off their fishing vessels within the first year. Halibut was shipped from Tacoma and Seattle to large eastern cities, such as Minneapolis, Kansas City, Omaha, and Chicago. Fishers responded to high demands with multi-day trips that caught large hauls; for example, a four-day fishing trip by one fishing boat netted 9,100 kg of halibut (Collins 1996). Pacific halibut were also a popular fish species because they do not spoil easily (IPHC 2016b).

As Caucasian populations increased in the West, faster vessels were built, the railway system carried salted or frozen fish to markets on the East Coast, and Pacific halibut landings increased dramatically. Not surprisingly, population declines of halibut were observed in the United States and Canada by the start of World War I (Wilens and Homans 1998).

Regulations Surrounding Pacific Halibut
International Pacific Halibut Commission. Out of concern for the species, The

Convention for the Preservation of the Halibut Fishery of the Northern Pacific Ocean was bilaterally agreed to by the U.S. and Canada in 1923, creating the International Pacific Halibut Commission (IPHC), to continually assess stock populations and manage the fishery in North America (IPHC 1987, Wilen and Homans 1998).

The IPHC is composed of six commissioners – three from Canada, appointed by the Governor General of Canada, and three from the United States, appointed by the President. The three commissioners from each nation are usually a fisher, a buyer or processor, and a federal fisheries agency employee. A director, chosen by the commissioners, supervises the IPHC staff, and is responsible for collecting and analyzing the data used to manage the halibut fishery. The Commission's chairperson alternates between a Canadian and American citizen. The commissioners are responsible for reviewing the regulations proposed by both IPHC staff and the Conference Board, which represents anglers and fishing vessel owners; the regulations approved by the commissioners are then submitted to the American and Canadian governments for final approval (IPHC 1987).

Stock assessments conducted annually by the IPHC include information pertaining to harvest levels, risks associated with each harvest level, and fishing trends. Each regulatory area is given its own catch limits, which are set by the IPHC, based on the stock assessment that is conducted for the entire coastwide fishery. The area being fished and the catch rates from IPHC setline surveys are used to allocate certain

proportions of the total biomass to specific regulatory areas; the timing and the catch of other fish species competing for hooks are taken into consideration as part of this analysis. These, and current harvest policies are reviewed before the IPHC makes a final determination on catch targets for the year. The IPHC determines the total catch for the year, which is then divided among treaty tribes, the recreational fishery, and the commercial fishery, which includes Pacific halibut bycatch caught in pot fisheries, groundfish trawl, and hook and line, all of which are managed by the federal government (NPFMC n.d., PFMC 2016).

The Fishery Constant Exploitation Yield (FCEY) is used by governmental agencies to help determine how much catch is allocated to each regulatory area. This takes into account the Total Constant Exploitation Yield (TCEY, based on the harvest rate targets), and the non-directed removals, which may include removals by the recreational fishery or personal or subsistence fishers, wastage from the commercial fishery, and bycatch (PFMC 2016). TCEY is calculated by multiplying the IPHC's target harvest rate by the coastwide exploitable biomass, defined as the fraction of the total biomass that is catchable by hook and line ($TCEY = \text{biomass} * \text{harvest rate}$). FCEY is calculated by subtracting all O26 (all Pacific halibut with a fork length greater than 26 inches, or 66.04 cm) bycatch and wastage, in addition to all halibut caught in the tribal, charter, recreational, and Community Development Quota fisheries, from the TCEY ($FCEY = TCEY - (\text{O26 bycatch/wastage} + \text{non Catch-Sharing Plan removal})$); IPHC 2012, 2015).

The first action that the IPHC took in managing the declining Pacific halibut stock was to implement a three-month closure in the winter of 1924 to protect spawning stocks (PFMC 2016), an action deemed necessary to protect the fishery (St-Pierre 1984). In 1930, an update to the convention gave the IPHC authorization to “define regulatory areas, set catch limits, and adopt other regulations,” and quotas were put in place in 1932 (IPHC 1987).

Historically, the IPHC has adjusted catch limits in response to fluctuations in the Pacific halibut populations, for instance, by buying back vessels to reduce fishing effort. However, the primary means by which catch has been limited has been to shorten the fishing season, which has led to derby fishing. Recognizing the inherent dangers and the effects that derby fishing has on the fishery and the economy, both the Canadian and United States government instated quota systems that replaced derby fishing in some areas (Clark and Hare 2006). The Individual Fishing Quota (IFQ) system was put in place in 1995 by the North Pacific Fishery Management Council (NPFMC; Pautzke and Oliver 1997). The NPFMC is a regional council created under the Magnuson-Stevens Fishery Conservation and Management Act of 1976 to manage fisheries within the United States’ Exclusive Economic Zone (EEZ; NPFMC 2009) off of Alaska (Pautzke and Oliver 1997). The IFQ system was similar to the individual vessel quota (IVQ) system established by Canada four years prior, but the quota was set for individuals, not vessels (PFMC 2016).

Derby Fishing. Until the 1990s, the main management system utilized to regulate the Pacific halibut fishery in North America was the Total Allowable Catch (TAC)

system, wherein the entire fishery was allotted a quota, which was adjusted by the IPHC in response to increases or decreases in the halibut population (Hartley and Fina, 2001). There is a difference between “pure open access fisheries,” such as the one experienced by the Alaskan Bering Sea pollock fishery, and a “regulated open access fishery,” in which the fishery is regulated as to prevent excessive harvesting – the TAC system falls into the latter category (Munro 2001). While Pacific halibut population levels have varied during the time that the IPHC has been managing the fishery, declines were noted starting in the 1960s, due to an increase in the number of vessels and technological advancements that improved harvest yields. While attempts were made by the governments of Canada and the United States to reduce the number of vessels by initiating “buy-back” programs, the number of halibut vessels remained high (Clark and Hare 2006).

Eventually, drastic measures were taken to reduce the catch, by shortening the Pacific halibut fishery season. By 1979, the fishing season in some areas was reduced to 16 days a year, down from 150 in 1970 (Carothers 2013). In Alaska, the season was reduced from 96 days in 1976 to two in 1994 (Hermann and Criddle 2006). Fishing for Pacific halibut during this era was known as “derby fishing,” as fishers competed in a “race to the fish,” to maximize their share of the quota (Carothers 2013). This created an “appropriation externality,” because each fisher’s take reduced the availability of fish for other fishers (Hackett 2011).

Today, the non-tribal commercial Pacific halibut fisheries in Regulatory Area 2A (the area that includes California, Oregon, and Washington) remain on the derby system, with 10-hour season openings, and other limits on fishing duration (PFMC 2016).

Individual Quota System (IQS). In the 1990s, management of some of the regional Pacific halibut fisheries changed from an open access, derby-style fishery to one in which quotas were assigned to individuals or groups. The Canadian government instated an individual transferable quota (ITQ) system in 1991, and the state of Alaska followed suit in 1995 with an individual fishing quota (IFQ) system (Clark and Hare 2006).

When the IFQ system was first implemented in Alaska, individual quota shares were distributed to fishers in each regulatory area by the National Marine Fisheries Service (NMFS) (Hartley and Fina 2001). All fishing vessel owners that had fished from 1988 to 1990 were given quota shares. Furthermore, they were allocated shares proportional to catch for their five best years during the seven-year period between 1984 and 1990. At the beginning of each Pacific halibut season, a TAC is allocated, and each fisher gets a proportion of that TAC as their individual quota, thereby removing the appropriation externality (Hackett 2011). The fisher may choose to fish the quota allowed to them, or sell their quota, though restrictions were put into place to prevent over-consolidation of quotas (Hartley and Fina 2001). For example, all sales and transfers of quota shares are monitored by NMFS and must be approved by the Commerce Secretary. If an individual goes over their quota, the overage is taken out of their quota for the following year, provided that the overage is under 10 percent. Random checks are performed at ports that do not have NMFS enforcement agents monitoring the landings (Pautzke and Oliver 1997). Under the new management system, the fishing season was extended from what it was under open access, and fishers could fish at any point during

the fishing season (Hartley and Fina 2001). Since the inception of the IQS in both Alaska and British Columbia, the number of fishing days has increased to 245 days, from March until November (Hermann and Criddle 2006). However, some, including Carothers et al. (2010), have written about the unintentional negative impacts that IFQ implementation has had, such as reduced indigenous participation in fisheries and the likelihood of residents of small remote fishing communities (SRFC) and Alaska Native villages selling quotas, rather than buying them.

Gear Used for Pacific Halibut Fishing. In California, there are specific requirements for gear used for Pacific halibut fishing. Only one line with up to two hooks attached to the main long line can be used when fishing for Pacific halibut recreationally. Once a halibut is legally caught, an angler may use a harpoon, gaff, or net to bring in the fish (CDFW 2016). However, harpoons may not be used within 100 yards of any stream or river mouth or waters north of Ventura County, and may not be used on any boats on which broadbill swordfish or marlin have been caught (California Fish and Game Commission 2015). In the commercial fishery, Pacific halibut are most commonly caught using longlines (PFMC 2016).

Subsistence Fishing and Tribal Take of Pacific Halibut. Alaskan native tribes are treated differently than those in the contiguous 48 states because treaties that protect subsistence rights have not been signed between Alaskan tribes and the United States federal government, except for the right to hunt marine mammals, such as whales (Ristroph 2010). In fact, the Alaska Native Claims Settlement Act (ANCSA) of 1971 took fishing and hunting rights away from aboriginal Alaskans; subsistence was,

however, addressed in the Alaska National Interest Lands Conservation Act (ANILCA) of 1980, but subsistence rights were given to all rural Alaskans, not just native tribes, because the Alaskan Constitution states that the state's natural resources belong to everybody, not just native Alaskans (Haycox 2002).

For this reason, indigenous tribes of Alaska are treated differently from native tribes in California, Oregon, and Washington, collectively known as Regulatory Area 2A. In Area 2A, native tribes are given catch limits within the overall catch limit of the regulatory area; within allocations to tribes, there are separate limits for commercial and ceremonial/subsistence uses. The 2016 catch sharing plan for Area 2A designated 35 percent of the total allowable catch to treaty native American tribes, and the remaining 65 percent to non-tribal fisheries. In 2016, the "treaty Indian commercial" limit was 165,606 kg, and the "treaty Indian ceremonial and subsistence (year-round)" limit was 15,376 kg (IPHC 2016b).

Pacific Halibut Fishery in California

While Pacific halibut was utilized as a food source by aboriginal people in northwestern Washington, British Columbia, and Alaska, tribes along coastal northern California mainly depended on other marine and freshwater organisms, such as Chinook salmon, steelhead trout, Pacific lamprey, smelt, sturgeon, shellfish, and marine mammals for sustenance. Furthermore, the Klamath River and the adjoining forests provided abundant food for tribes living in the region (Roberts 1932). However, some coastal tribes, including the Yurok and Tolowa Tribes, occasionally harvested halibut, off

Trinidad Head and near the Snake River, respectively (Kroeber and Barrett 1960, Bell and Best 1968).

Halibut were reportedly first sold in markets in San Francisco in 1855, when 40 to 50 pound fish were caught off of the Farallon Islands (Ayres 1855). This was the extent of the local halibut market at this time as there was not a large demand for this fish, though shipments of halibut were delivered from Vancouver and Puget Sound (Lockington 1881, Collins 1892).

Between the late 1800s and the mid 1910s, increasing numbers of halibut were landed in Oregon and Washington; this does not appear to be the case in California, though there was a reasonably successful commercial halibut fishery off the mouth of the Smith River around 1915 (Rankin 1915; Figure 0.2). Fishing for halibut continued at various locations in northern California through World War I and continued for a period after the war (Bell and Best 1968).

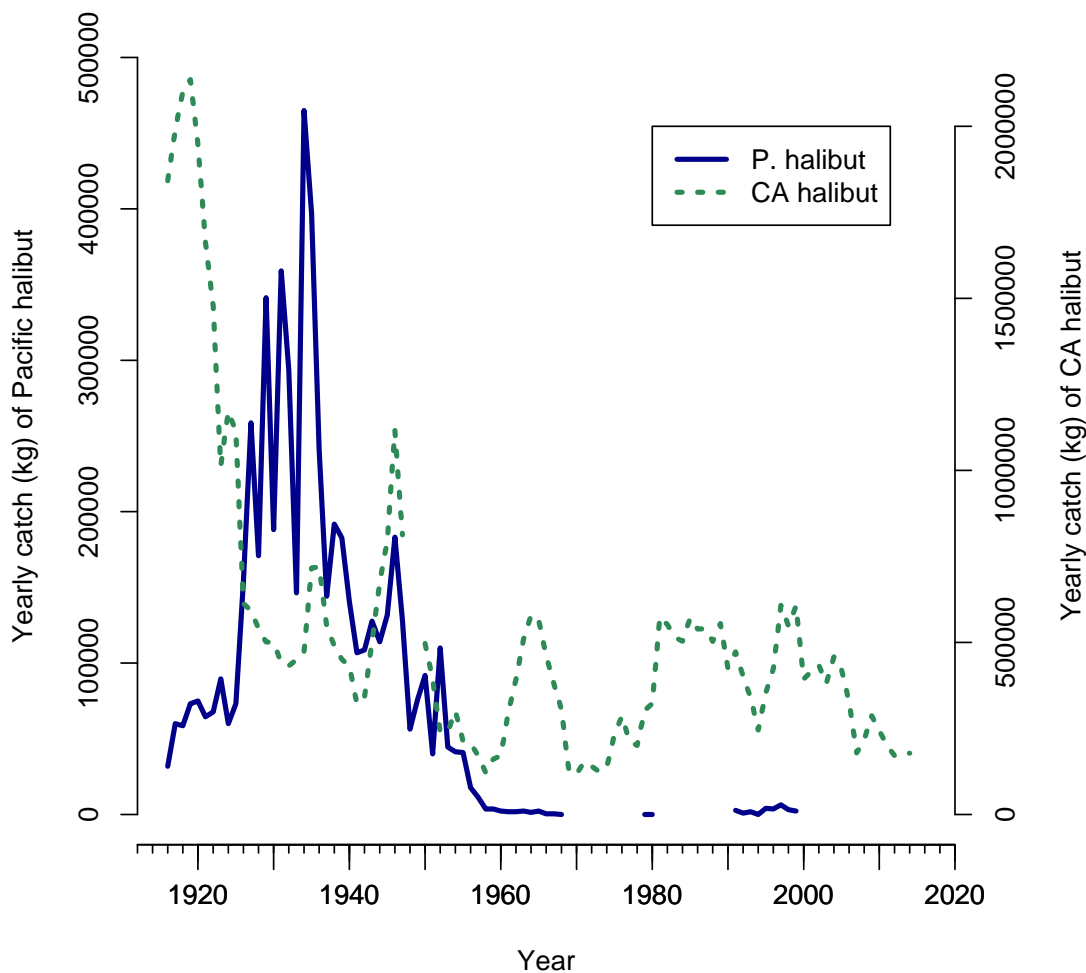


Figure 0.2. Yearly catch (in kg) of Pacific halibut and California halibut in the commercial fishery from 1916 to 2014 for California (Bureau of Marine Fisheries 1949 (1916 to 1947), Bell and Best 1968 (1948, 1949), NOAA n.d. (1950-2014)).

A commercial Pacific halibut fishery was created in Eureka in 1923 to augment the quantities that were being supplied to the markets in San Francisco by off-season salmon trawlers. Although fog and unprotected harbors made halibut fishing somewhat dangerous, setline vessels from Oregon and Washington nevertheless arrived in northern California during this time to fish for halibut. The result was a large spike in halibut landings in California, with more than 340 million kg of halibut caught, mostly in

northern California; this increase was short-lived, however, as landings were reduced to 90,000 kg in 1940. Shortened seasons and reduced interest in the fish led to the continued drop in landings thereafter (Bell and Best 1968). Halibut became overfished along the entire coast in the 1950s, and regulations were instated in order to reduce the strain on the fishery (CDFW 2016).

These regulations have maintained California's commercial take at a minimum level (CDFW 2016). The 2016 catch limit for the directed commercial and incidental commercial catch during the salmon troll fishery in Regulatory Area 2A, of which California is a part, was 103,000 kg. The incidental commercial limit for the sablefish fishery was 22,500 kg. Vessels that wish to participate in the commercial halibut fishery in California must submit a license application to the IPHC. This license, when approved, allows a vessel to operate as either a recreational charter or commercial vessel (not both) to catch halibut as part of the directed fishery or as incidental catch in the salmon or sablefish fishery (IPHC 2016c).

While commercial take of Pacific halibut in California has been reduced, the recreational fishery has experienced an increase in landings in recent years (Figure 0.3). The recreational fishery became popular in the 1950s and 1960s, especially during the summer months and on weekends (Bell and Best 1968), and this popularity led the IPHC to officially adopt laws regulating the recreational Pacific halibut fishery in 1973 (IPHC 1987), after the U.S. and Canadian governments determined that the IPHC had the authority to regulate the recreational fishery. In 1973, the recreational fishery was open from 1 March to 31 October with a daily catch limit of three fish of any size; this was

reduced to one fish in 1974, and then increased again to two in 1975. During the 1973-1974 season, a total of 1,000 fish (5,443 kg) were caught in waters surrounding California and Oregon. Recreational catch in IPHC Regulatory Area 2A, (which includes California, Oregon, and Washington), increased dramatically from 9,072 kg in 1981 to 188,241 kg in 1987. In response, there was an unsuccessful attempt to establish a minimum size limit (76.2 cm), to close the recreational fishery early (September 30), and to limit the total catch to 90,718 kg. In 1988 and 1989, a Catch Sharing Plan was adopted for Area 2A, in which the recreational fishery was allocated 122,470 kg in 1988 and 101,604 kg in 1989 (this allocation only applied to Oregon and Washington, not California). While still small compared to landings in Oregon and Washington, the increase in California landings in the 1980s has been attributed to the increase in the abundance of Pacific halibut, and in more recent years, to reduced fishing opportunities for salmon and groundfish, but also to the hopes of catching a trophy-sized fish (IPHC 1991).

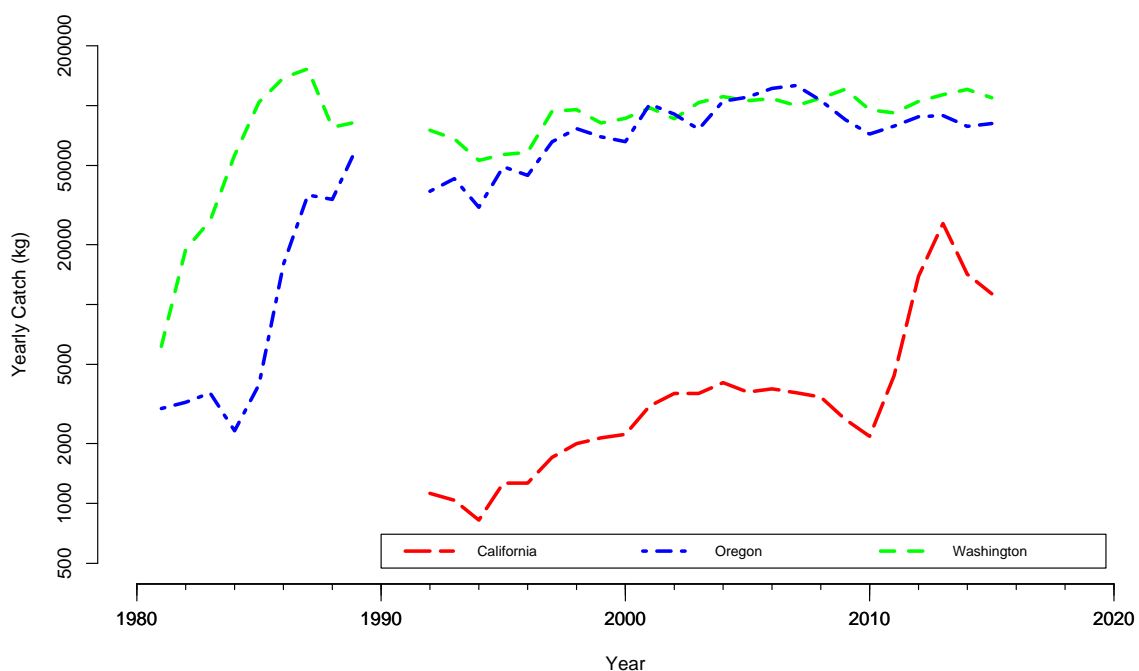


Figure 0.3. Yearly catch (in kg) of Pacific halibut in the recreational fishery from 1980 to 2015 for California (IPHC n.d. (1992-2015)), Oregon (IPHC 1991 (1980-1989), IPHC 2017 (1992-2001), ODFW 2017 (2002-2015)), and Washington (IPHC 1991 (1980-1989), IPHC 2017 (1992-2005), WDFW 2017 (2006-2015)). Note that the y-axis is log transformed.

The total allowable catch (TAC) of Pacific halibut in California is determined by the Halibut Catch Sharing Plan, which determines the percentages of allowable catch allocated to the three states, California, Oregon, and Washington, that make up Area 2A. The annual TAC is established in January by the IPHC, after the Pacific Fishery Management Council (PFMC) receives feedback from the public on proposed changes made public in the fall, and then makes final recommendations on these changes (PFMC 2016).

From 2001 to 2013, California and Southern Oregon (California/Oregon border to Humbug Mountain) had a combined allocation of about 2,700 kg under the Catch Sharing

Plan of the PFM. In 2014, a separate subarea was created for California, to which 2,800 kg was allocated (California Fish and Game Commission 2014). In 2016, 35 percent of the TAC of Area 2A was apportioned to Native American tribes in Washington state, with the rest allocated to non-native American fisheries in Washington, Oregon, and California. Of the 65 percent allocated to non-tribal fisheries, the Washington recreational fishery (north of the Columbia River) was allocated 34.6 percent, while 29.7 percent was allocated to the Oregon recreational fishery, and four percent to the California recreational fishery, up from one percent in 2014 (Federal Register 2015); the remaining 30.7 percent was allocated to the commercial fishery (NOAA 2016b). The four percent that was allocated to California translated to 13,444 kg (CDFW 2016). In 2016, the recreational Pacific halibut fishery in California had no minimum size limit, and a bag limit of one halibut per day (NOAA 2016b).

It is important to note the ambiguity of historical landings data for halibut in California. In the earlier years of the halibut fishery in California, before the state had created its catch statistics system, purchase invoices did not indicate whether the halibut being purchased was Pacific halibut (*Hippoglossus stenolepis*) or California halibut (*Paralichthys californicus*). California Department of Fish and Wildlife (CDFW) has reviewed the catch data, and has deemed that prior to 1946, the differentiation between the two species were reasonably accurate. However, the CDFW prorated the statistics for the years 1947 to 1954 so that 90 percent of the catch was deemed to be California halibut, with the remaining 10 percent being Pacific halibut (Marine Resources

Operations 1958). A directive from the CDFW in the 1950s explained how this affected landings data for these two halibut species:

Halibut delivered to the San Francisco region in previous years was prorated and published as 90 percent Pacific halibut and 10 percent California halibut. Recent investigation indicates that 90 to 99 percent of the landings are California halibut, instead of Pacific halibut. Hence, all halibut landed in the San Francisco region is published as California halibut except when the variety is specifically designated as Pacific or Northern by the fish dealers (Marine Resources Operations 1958).

Because of this directive, most of the halibut sold in San Francisco between 1955 and 1965 were listed as California halibut, except for 30 pounds that were specifically labeled as Pacific halibut in 1961. Another reason for the confusion is that fish were labeled as California halibut, regardless of whether it was California or Pacific halibut, if the halibut was caught in California waters (Bell and Best 1968).

Commercial and Recreational Value of Pacific Halibut in California. Reports from 1855 show that halibut caught off the Farallon Islands were sold in markets in San Francisco for 50 cents a pound, though there appear to be discrepancies as to whether there was just a single halibut sold in the San Francisco market, or multiple (Ayres 1855, Lockington 1880). Pacific halibut shipped down from Puget Sound to San Francisco reportedly sold for 10 to 15 cents per pound (Lockington 1881). In 1899, 8,820 pounds of halibut from an unknown origin were sold in San Francisco for 30 cents per pound (Wilcox 1902).

Figure 0.4 shows the trend in yearly catch values (in dollars) for Pacific halibut and California halibut sold in California. The yearly values appear to be volatile; there

was a large spike in the value of Pacific halibut in 1987. The value of California halibut appears to be consistently higher than the value of Pacific halibut for all years.

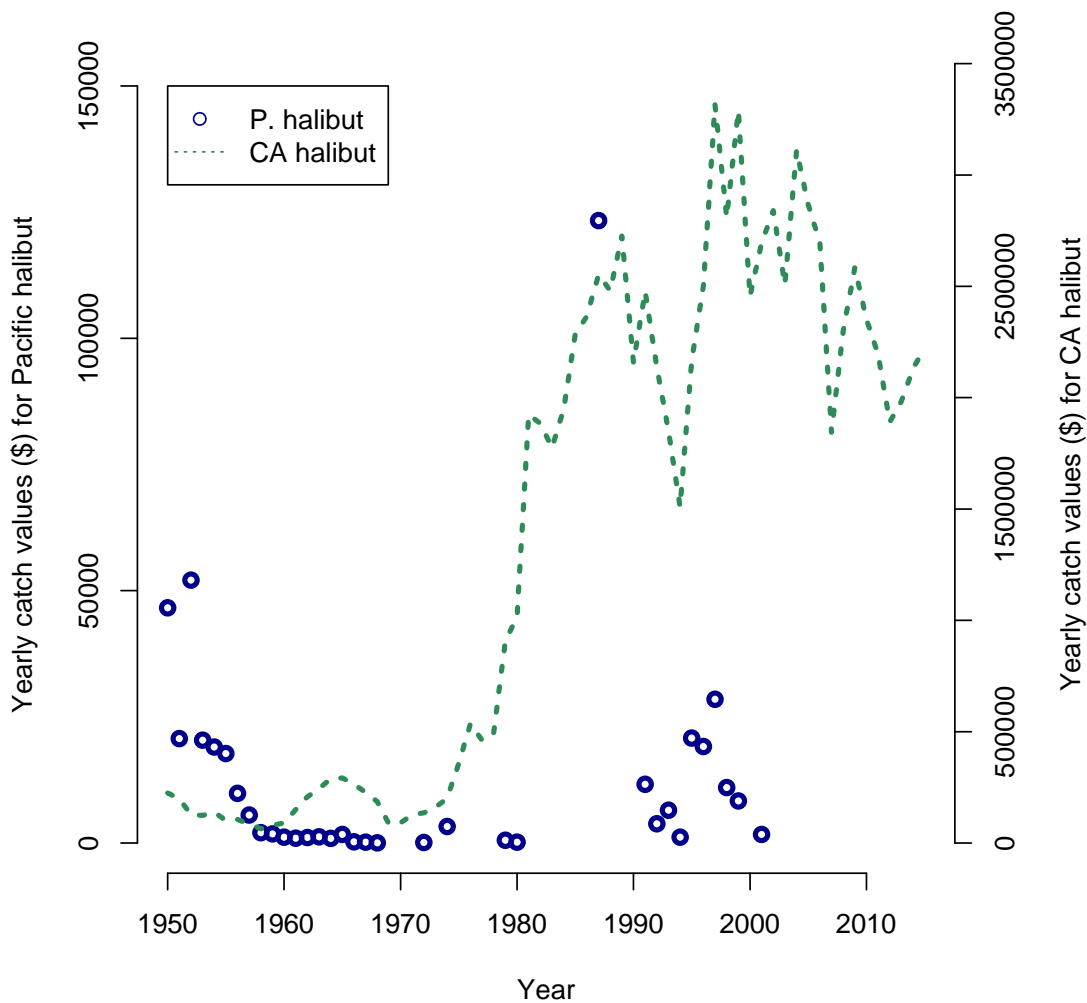


Figure 0.4. Yearly catch values (in dollars) of Pacific and California halibut in the commercial fishery from 1950 to 2014 (NOAA n.d.)



Figure 0.5. Blacky Silvaggi (left) and Joe Sabella (right) at the foot of Commercial Street on the Eureka waterfront, circa 1938. Photo courtesy of the Humboldt County Historical Society.



Figure 0.6. Axel Lindgren I with two friends with halibut. Photo courtesy of the HSU Boyle Collection.

Objectives of this Study

Age/growth and reproductive status are the two most important components in stock assessment models, which are used to estimate population abundance and ultimately, harvest limits. However, to date, little biological data have been gathered on Pacific halibut found in northern California. Data gathered on Pacific halibut in all areas may influence the allocation of Pacific halibut catch by the IPHC and PFMCC, and can assist the IPHC in refining their stock assessment model, which will help maintain the health and sustainability of the Pacific halibut fishery in North America.

Despite the lack of data on the abundance of Pacific halibut in northern California, the fishery was closed to recreational anglers for the first time in August 2014,

and was shortened by a month and a half in 2015. These closures were instated in order to reduce the recreational take in northern California to bring it into compliance with the allocation assigned by the PFMC (roughly 40 to 60 percent of the average catch during the previous five years). However, the closures were very controversial, especially among recreational fishers residing along the North Coast, primarily because the Pacific halibut fishery provided fishing opportunities in an area that has recently seen a reduction in the opportunities for salmon and groundfish fishing, and because of negative economic effects of the closures. For instance, many individuals who provided public comments to the CDFW, the California Fish and Game Commission, PFMC, and NMFS on the closure of the Pacific halibut fishery stated that the allocations were inequitable, and the closures unnecessary. Many anglers preferred a shorter fishery that was open seven days a week over a longer fishery with closures on certain days of the week; however, businesses, such as the Trinidad Rancheria, owner and operator of the Trinidad Pier and boat launch, lamented the financial effect of the month-long closure (CDFW 2015).

The objectives of this study were:

- i. Objective I: Pacific halibut closure economic survey – conduct a survey to determine the economic impact of the August 2014 Pacific halibut closure on businesses along the northern California coast, from Shelter Cove to Crescent City.
- ii. Objective II: Biological analysis – work collaboratively with local anglers to characterize the age and growth of Pacific halibut landed off northern California and central Oregon.

- iii. Objective III: Biological analysis – compare macroscopic and microscopic analyses of maturity stages of female Pacific halibut.

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CHAPTER 1

PACIFIC HALIBUT CLOSURE ECONOMIC SURVEY

ABSTRACT

Prior to 2014, the recreational fishery for Pacific halibut in California had been open from 1 May through 31 October. In 2014, however, the Pacific halibut fishery was closed in California during the month of August for the first time in history in an effort to reduce harvest and bring total catch closer to what is allocated to our region by the Pacific Fisheries Management Council (PFMC) Catch Sharing Plan. To determine the effects of the closure on businesses along the North Coast, I conducted an economic impact survey in 2014. The results of the survey showed that fishing-related businesses lost between zero percent and eight percent of their revenue in 2014, as a result of the closure; lodging and traveler service companies lost between 0.3 percent and one percent of their revenue in the same year. None of the businesses changed the number of employees as a result of the closure. We estimated a decrease in revenue for businesses on the North Coast to be between \$189,750 and \$222,250.

INTRODUCTION

Prior to 2014, the recreational fishery for Pacific halibut in California had been open annually from 1 May through 31 October. In 2014, however, the Pacific halibut fishery was closed in California during the month of August for the first time in history in an effort to reduce harvest and bring total catch closer to what is allocated to our region by the Pacific Fisheries Management Council (PFMC) Catch Sharing Plan (Federal Register 2014).

To determine the effects of the August 2014 Pacific halibut fishery closure on the North Coast, the Humboldt Area Saltwater Anglers (HASA), a non-profit organization created on the North Coast to promote the sustainable stewardship of the region's fisheries and protect the interests of local anglers, commissioned Ecotrust, a Portland-based non-profit organization, to conduct an economic impact survey of recreational anglers and charter boats (Hesselgrave et al. 2014, Appendices B and C). I conducted a complementary survey (Appendix A) in order to obtain economic impact information directly from businesses along the North Coast that were impacted by the fishery closure.

METHODS

Data Collection

Data on the economic impact of the Pacific halibut fishery closure were obtained by sending surveys to businesses frequented by both local and out-of-town Pacific halibut anglers; business type and proximity to the nearest port or marina were the main selection criteria. The survey was a questionnaire that could be either filled out online or completed on paper and returned via mail; confidentiality was assured. A cover letter was provided to all participants, that included information on the organizations involved in the study, the contact information of the primary researcher, how and why the participants were selected for the study, and the goals of the study. The questionnaire was composed of both open-ended questions, in which the respondents composed their own responses, and closed (multiple choice and true or false) questions. Because of time constraints, we were unable to conduct a pilot survey (Kelley et al. 2003). The launch date of the survey was 22 September 2014, and participants were given until 7 October, 2014 (16 days) to complete the questionnaire. However, because we received so few responses, the closing date was extended in order to obtain as many responses as possible. The estimated total time commitment required from the participants was 40 minutes.

These businesses were then prioritized into two groups – Priority A and B. Priority A businesses were those businesses that were believed to have been most impacted by the Pacific halibut closure (examples include boat repair companies and

sporting goods stores); Priority B businesses were those that were not believed to be as heavily impacted by the closure (examples include most hotels/motels and gasoline/fuel stations). I distributed questionnaires to a total of 158 businesses, 59 Priority A businesses and 99 Priority B businesses. Tables 1.1 and 1.2 outline the types of businesses and the number of businesses that made up the Priority A (Table 1.1) and Priority B (Table 1.2) groups.

Table 1.1. Types of businesses and the number of businesses in each business type for Priority A businesses.

Priority A Businesses (<i>n</i>=59)	
Business Type	Number of Businesses
Boat Repair Company	1
Casino	2
Gasoline/fuel company	2
Lodging facilities	24
Marina/boat launch/port	1
Market	2
Sporting goods store	5
Restaurants/bars/coffee shops	12
Storage facility	1
Tackle shop	9

Table 1.2. Type of businesses and the number of businesses in each business type for Priority B businesses.

Priority B Businesses (<i>n</i>=99)	
Business Type	Number of Businesses
Automobile repair shop	1
Boat-related businesses	2
Gasoline/fuel station	21
Lodging facilities	41
Market	4
Hardware store	1
Sporting goods store	3
Restaurants/bars/coffee shop	26

Half of the surveys were hand-delivered, and the other half were mailed via USPS. Members of the HASA board assisted in hand-delivering the business surveys, and were given talking points (included as Appendix D), which were used when introducing the survey to the business owners or employees. Anonymization numbers were used to determine which businesses had their surveys hand delivered, and which were mailed. An electronic copy of the survey was also e-mailed to the businesses for which we had e-mail addresses. Unique e-mail links were created for each of the e-mail addresses to which this survey was sent, which enabled us to track which businesses had submitted responses.

To increase the likelihood of businesses completing and submitting the survey, we offered respondents four options for submitting the surveys:

- a) a stamped return envelope was included in each survey envelope, enabling businesses to submit a hard copy of the survey.
- b) a fax number was provided that businesses could use to submit their surveys.
- c) a general web address link was included in the letter accompanying the survey – this allowed businesses to complete the survey online. To keep track of responses, businesses were asked to fill in their assigned anonymization numbers from the paper survey when completing the online survey.
- d) unique web address links were e-mailed to businesses for which we had an e-mail address, which allowed for tracking.

Ethical Statement

Institutional Review Board for the Protection of Human Subjects (IRB, IRB# 14-

020) was approved for this study, per university requirements (Appendix E).

RESULTS

Business Survey

Of the 158 surveys that were distributed, 29 were completed and returned, but three were unusable because completed consent forms were not submitted, leaving 26 usable surveys. Of the 79 businesses to whom the surveys were mailed, 14 were returned undelivered for various reasons. Of the 26 usable responses that were submitted, 17 of the original surveys had been hand-delivered, and nine had been mailed (Table 1.3). One survey response, from a fish processor, was omitted from the analyses, as our prediction that the Pacific halibut closure had little effect on their business was confirmed by their responses, and because it would have been difficult to assign them to any of the business categories. This aggregation of responses into categories was necessary to help maintain the anonymity and confidentiality of survey participants. Therefore, the results below are based upon responses from 25 businesses (overall response rate of 15.8 percent). Response rates for postal questionnaires are generally quite low (approximately 20 percent; Kelley et al. 2003), although the response rate for our survey was lower than this average.

Table 1.3. Table showing method of survey distribution and response rates by distribution method

Number of surveys distributed: 158		Number of surveys completed/returned: 29		
Number of mailed surveys: 79	Number of hand-delivered surveys: 79	Number of usable surveys: 26		Number of unusable surveys: 3
		Number of hand-delivered usable surveys: 17	Number of mailed usable surveys: 9	

To maintain anonymity, business types were consolidated and re-categorized. The business types were re-classified into three groups:

- Recreational fishing-related businesses, including tackle and marine supply shops, other sporting goods stores, and boat repair shops (7 responses out of 19 businesses, or 36.8 percent response rate).
- Traveler services, such as gasoline/fuel, market/sundries, and restaurants (6 responses out of 67 businesses, or 9.0 percent response rate).
- Lodging facilities, including hotels, motels, and RV parks (12 responses out of 65 businesses, or 18.5 percent response rate).

Response by City. Of the twenty-five responses used in the analysis, nine of the businesses are located in Eureka, seven are in Trinidad, five are in Arcata, three in McKinleyville, and one is in Fortuna (Figure 1.1). No responses were received from Crescent City or Shelter Cove.

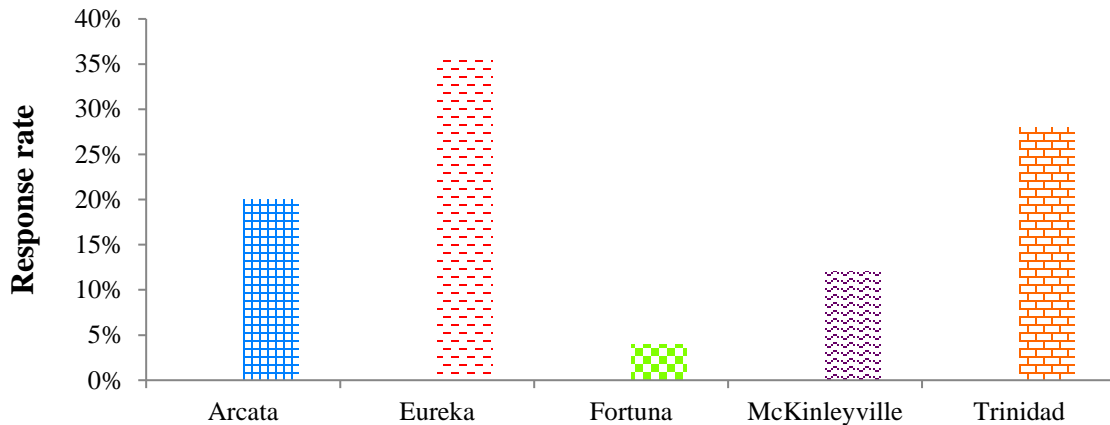


Figure 1.1. Response rate by city.

Question #1: Business Type. Of the surveys that were distributed, 65 went to lodging facilities, 67 to traveler services, and 19 to recreational fishing goods and services. Of the businesses that responded to the survey, 12 were lodging facilities, six were traveler services, and seven were tackle and sporting goods stores. Although the overall response rate was 15.8 percent, it varied widely among cities (Figure 1.1) and business type (Figure 1.2).

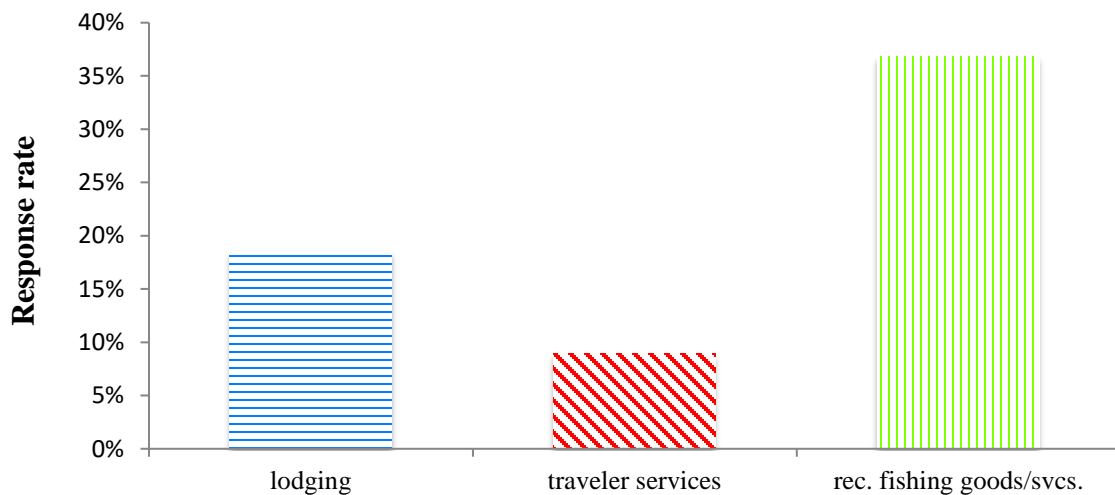


Figure 1.2. Response rate by business type.

Question #2: Importance of Recreational Fishing to Business. Of the 25 businesses that responded to the survey, 13 responded that recreational fishing was either “extremely important” or “very important,” seven responded that it was “somewhat important,” four responded that it was either “not at all important” or “not very important,” and one responded that they “did not know” (Figure 1.3).

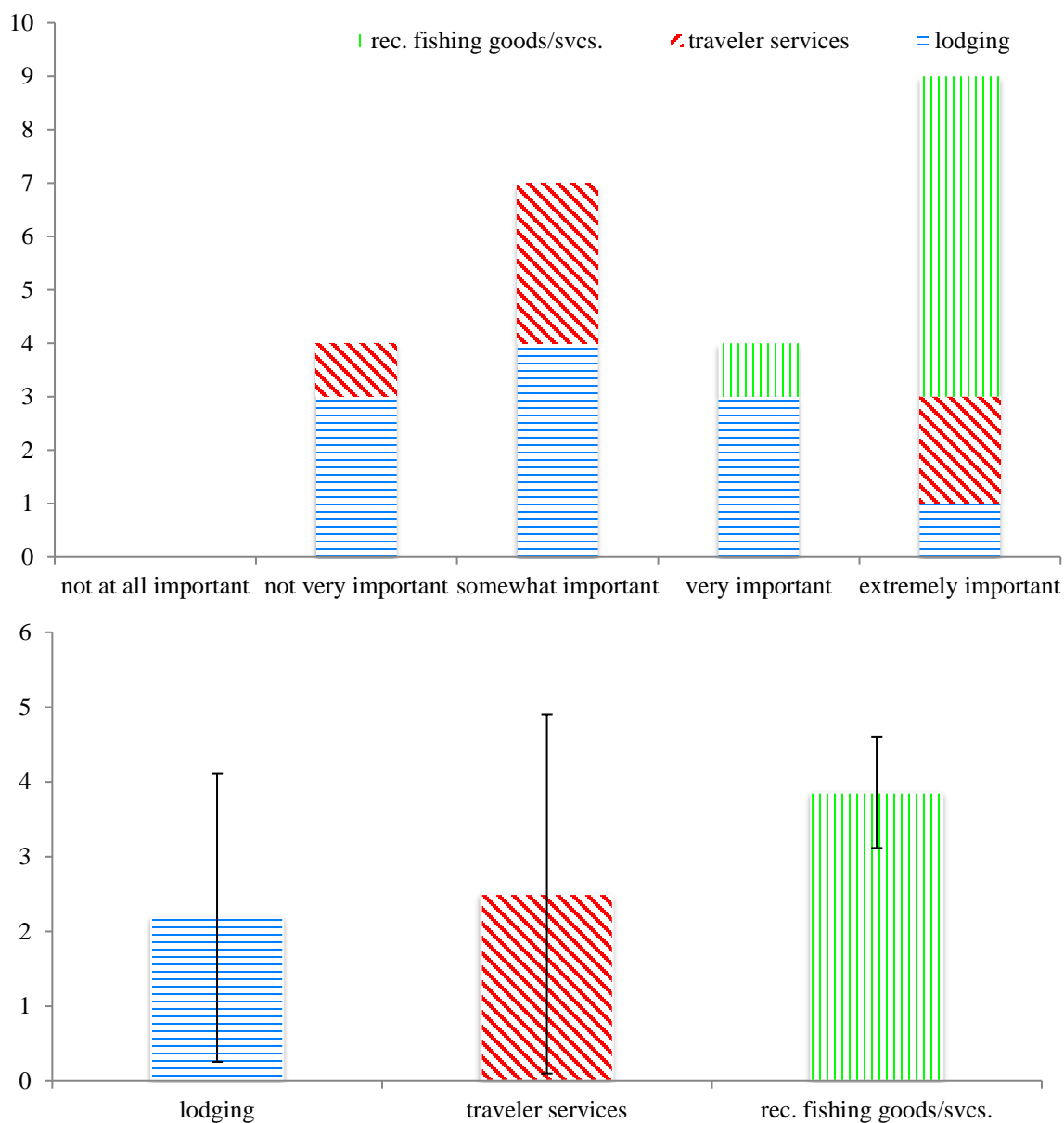


Figure 1.3. Importance of recreational fishing to businesses. Top) Individual responses by business type. Bottom) Average responses by business type, coded with “not at all important” = 0, and “extremely important” = 4. Error bars are 95% confidence intervals.

Business type appears to be the primary factor that determines the relative importance of recreational fishing to businesses. Of the lodging facilities that responded

to the survey, three responded that recreational fishing was “not very important,” four responded that it was “somewhat important,” and four responded that it was either “very important” or “extremely important.” One traveler service business stated that recreational fishing was “not very important,” three stated that it was “somewhat important” to their business, and two responded that it was “extremely important” to their business. Not surprisingly, all seven recreational fishing-related respondents stated that recreational fishing was either “very important” or “extremely important” (Figure 1.3).

Question #3: Importance of Recreational Pacific Halibut Fishing to Businesses.

Of the 25 businesses that responded to the survey, eight businesses responded that recreational Pacific halibut fishing was “extremely important” or “very important,” seven responded that it was “somewhat important,” and nine responded that it was “not very important,” or “not at all important,” and one responded that they “did not know” (Figure 1.4).

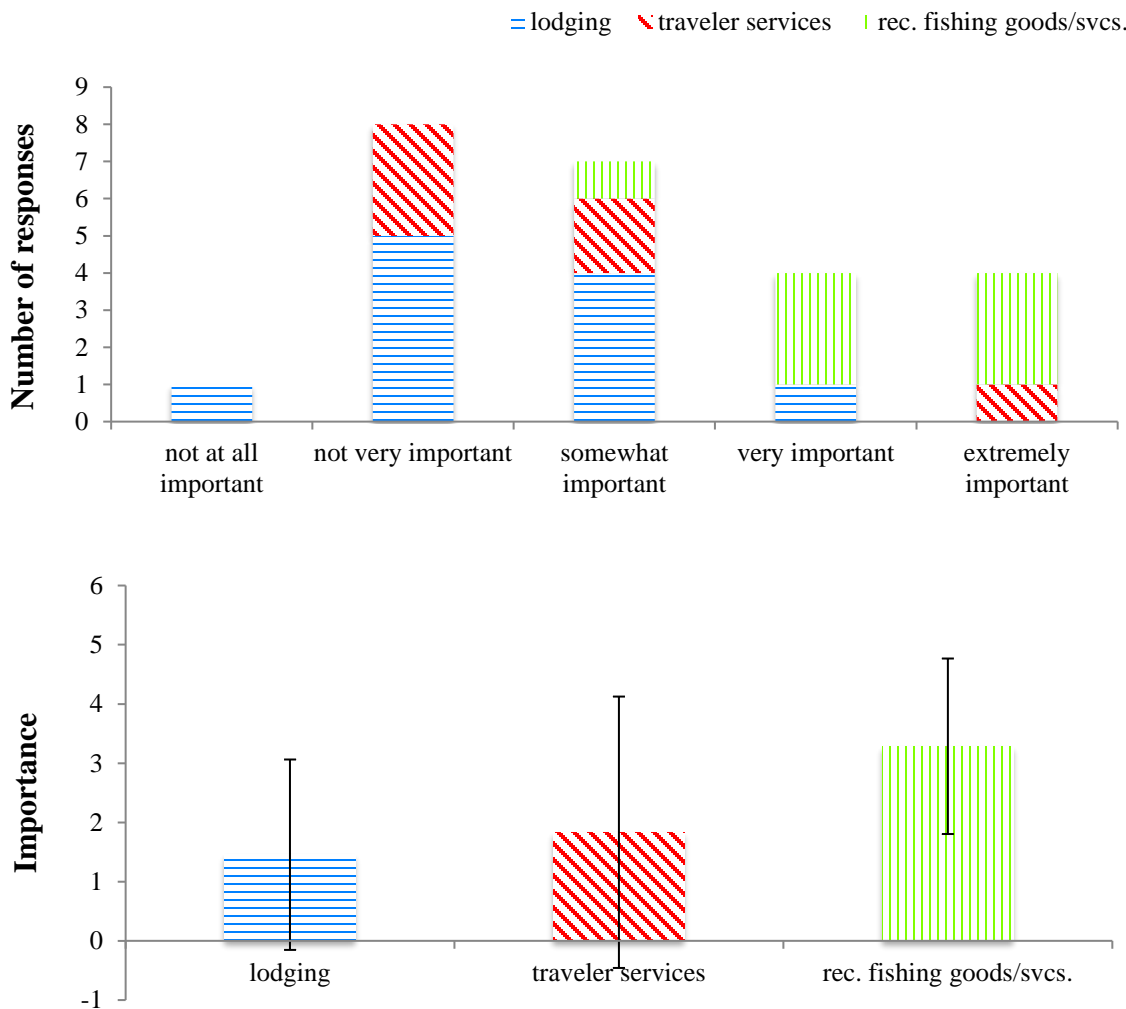


Figure 1.4. Importance of Pacific halibut fishing to businesses. Top) Individual responses by business type. Bottom) Average responses by business type, coded with “not at all important” = 0, and “extremely important” =4. Error bars are 95% confidence intervals.

Of the 12 lodging facilities that responded, six stated that recreational Pacific halibut fishing was “not at all important” or “not very important,” four said that it was “somewhat important,” one reported that it was “very important,” and one “did not know.” Three of the traveler services stated that Pacific halibut fishing was “not very

important,” two reported that it was “somewhat important,” and one stated that it was “extremely important.” One of the recreational fishing-related businesses stated that Pacific halibut fishing was “somewhat important” to their business, and six stated that it was either “very important,” or “extremely important.”

Question #4: Specific Goods/Services Provided to Recreational Anglers. Of the 12 responses from lodging businesses, 50 percent reported that they provide no specific goods or services to recreational anglers, and 50 percent stated that they provide goods and services. The specific goods and services provided by these businesses were: ice, beer, snacks, maps, brochures, pamphlets of the area, barbequing and fish cleaning facilities, disposal of fish remains, and of course, lodging accommodations. All six traveler service businesses reported that they provided specific goods and services to recreational anglers. Fuel, bait, ice, food, and beer were provided by these businesses. Five of the six recreational fishing-related businesses reported that they provided specific goods and services to recreational anglers – they provided lures, weights, spreader bars, bait, rods/reels, line, fuel, tackle, fishing licenses and tags, boat repair, and electronics (Figure 1.5).

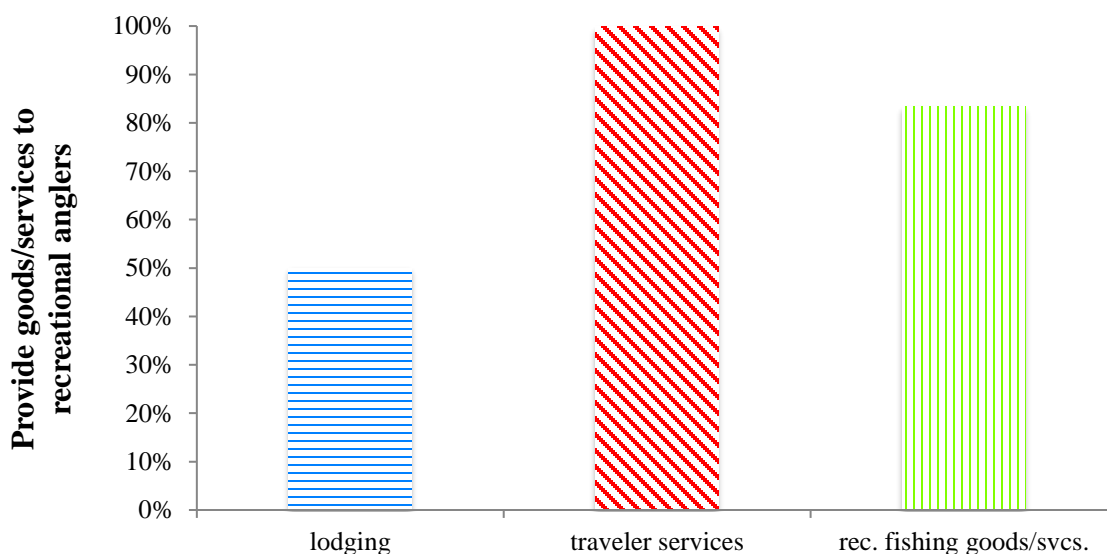


Figure 1.5. Percentage of each business type that provide specific goods/services to recreational anglers.

Question #5: Distance from the Nearest Boat Launch, Marina, or Port. Twenty-five percent of the lodging facility respondents reported that their business was less than one mile away from the nearest boat launch, marina, or port; 50 percent of them were within one to five miles from the nearest launch facility, and 25 percent were between 5 and 20 miles away. Four of the six traveler services were less than one mile from the nearest launch facility, one was between one and five miles away, and one was between five and 20 miles away. Three of the seven recreational fishing-related businesses were less than one mile away from the nearest boat launch, marina, or port, two were between one and five miles away, and two were between five and 20 miles away (Figure 1.6).

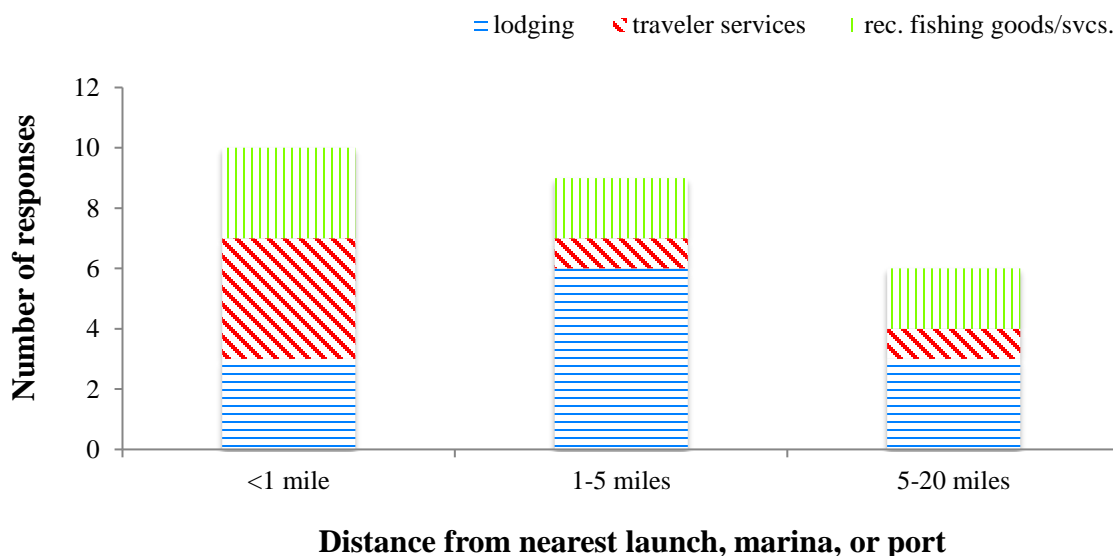


Figure 1.6. Distance from business to nearest boat launch/marina/port.

Though the small sample size precludes statistical analysis, it appeared that among lodging businesses, the Pacific halibut sport fishery and recreational fishing in general were more important for those located within a mile of a port, boat launch, or marina (Figures 1.7 and 1.8). Distance from port did not appear to be a major factor for

fishing-related businesses (for whom halibut and sport fishing in general were of high importance), nor for traveler service businesses. Data in Figures 1.7 and 1.8 were jittered along the x -axis to prevent the data points from overlapping.

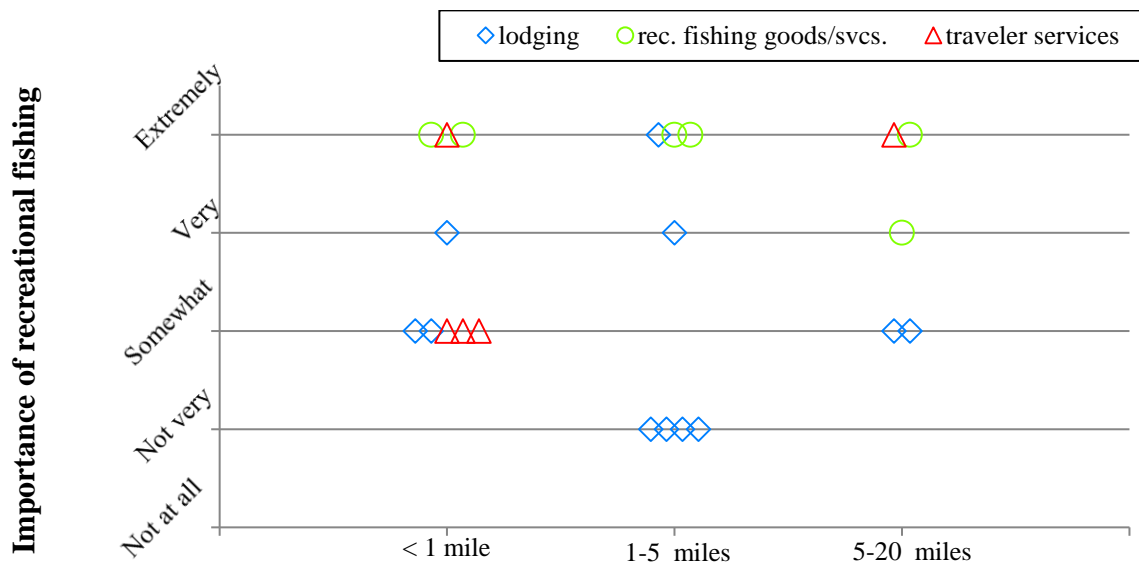


Figure 1.7. Importance of recreational fishing versus distance from port by business type. Data have been jittered along the distance category axis to show all data points; one “Don’t know” response not plotted.

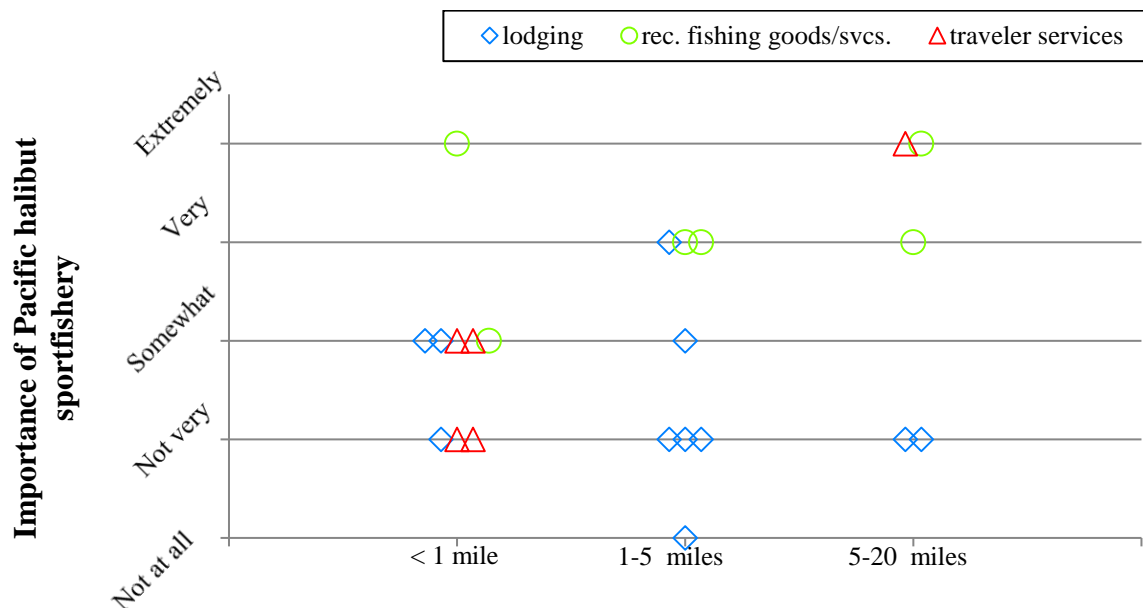


Figure 1.8. Importance of Pacific halibut sport fishing versus distance from port by business type. Data have been jittered along the distance category axis to show all data points; one “Don’t know” response not plotted.

Question #6: Awareness of the August Pacific Halibut Closure. Five of the 12 lodging facilities responded that they were aware of the August Pacific halibut closure; seven responded that they were unaware. Five traveler service businesses were not aware of the closure, and one was aware. All seven recreational fishing-related businesses were aware of the halibut closure (Figure 1.9).

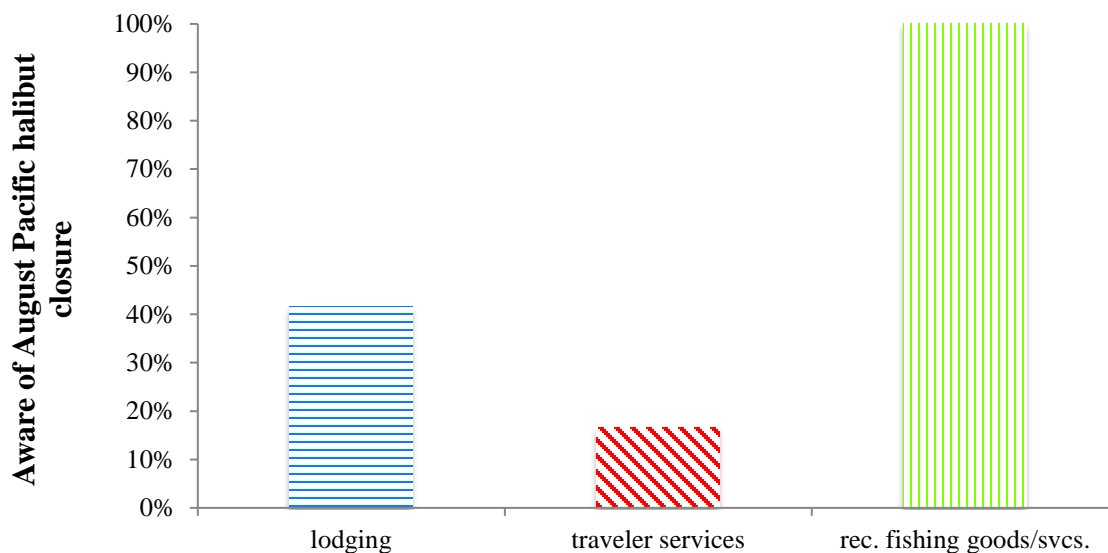


Figure 1.9. Percentage of businesses that were aware of the Pacific halibut closure.

Question #7: How Much the August Pacific Halibut Closure Negatively Affected Business. Six lodging facilities believed the closure had “no effect” (or reported that it had neither positive nor negative effects) on their business, three believed it had a “minor effect,” two believed it had “moderate effects,” and one facility answered that they “did not know” whether the closure had a negative effect on their business. Four traveler services reported that the halibut closure had “minor effects,” and two reported “moderate effects.” Five recreational fishing-related businesses stated that the closure had “moderate effects,” and two reported “major effects” (Figure 1.10).

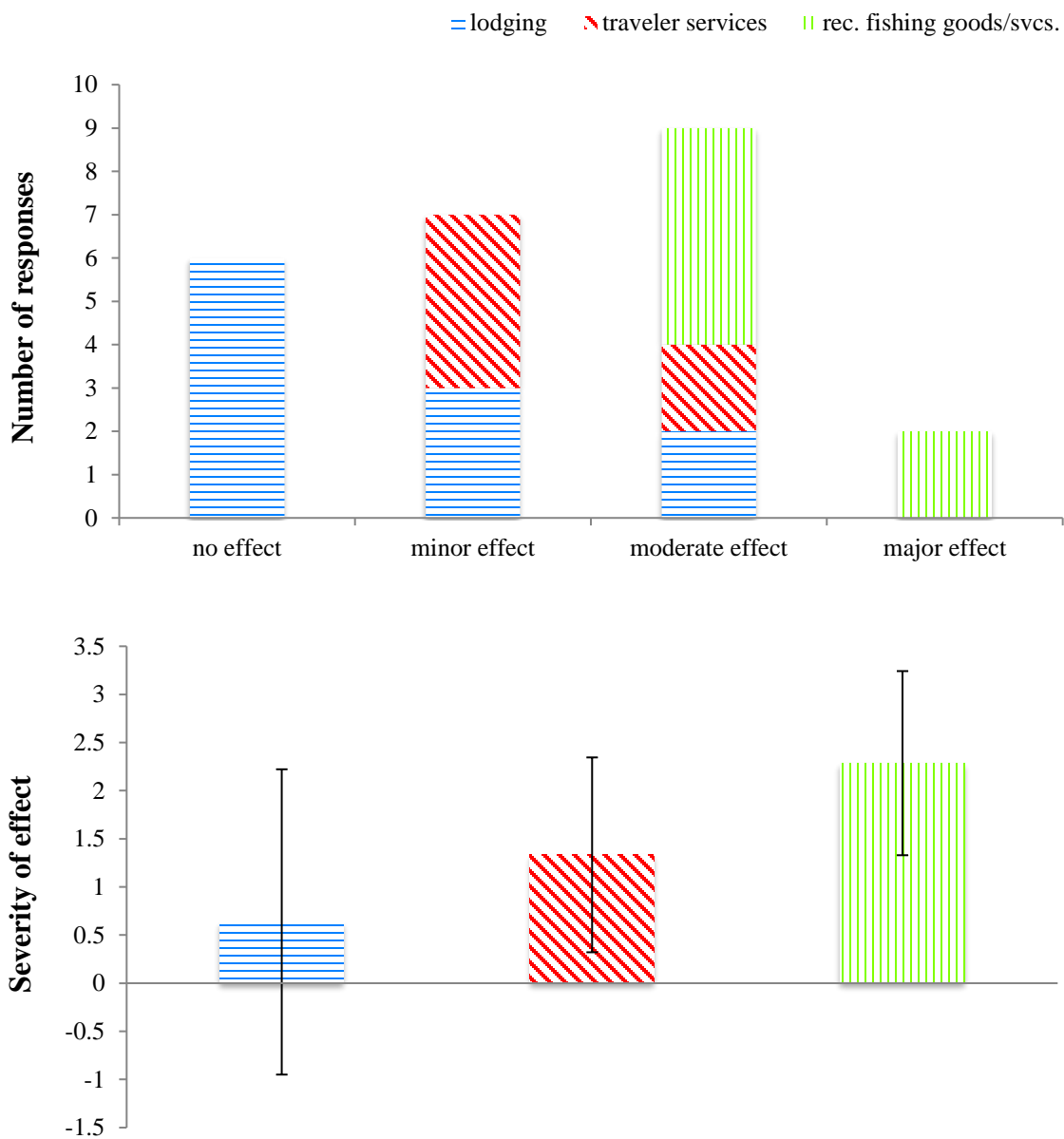


Figure 1.10. Perceived effects of Pacific halibut closure. Top) Individual responses by business type. Bottom) Average responses by business type, coded with “no effect” = 0, and “major effect” = 3. Error bars are 95% confidence intervals.

Question #8: How the Closure Affected Business. Although seven of the lodging facilities either did not answer this question, or believed that the closure did not affect their business, some of the businesses stated that the closure led to “less market traffic,” and “reduction of travelers.” Traveler service businesses responded similarly, stating that the closure led to “reduced sales,” and “fewer customers.” Fishing-related businesses also responded that the closure led to a “loss of sales” and “less late season customers than usual.”

Question #9: Familiarity with Sport Fishing Management. Five of the lodging facilities stated that they were “not at all familiar” with the management of sport fishing; two were “slightly familiar,” three were “somewhat familiar,” one was “moderately familiar,” and one was “extremely familiar.” Three traveler service businesses were “slightly familiar” with sport fishing management, and two were “moderately familiar.” One recreational fishing-related business was “somewhat familiar” with the management of sport fishing, four were “moderately familiar,” and two were “extremely familiar” (Figure 1.11).

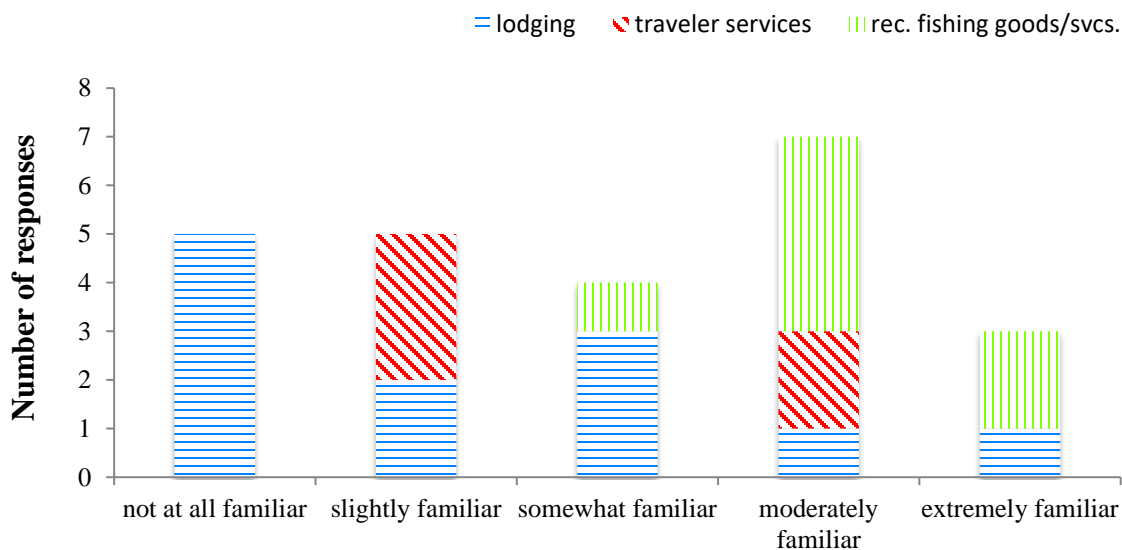


Figure 1.11. Familiarity with recreational fishing management.

Question #10: Familiarity with Pacific Halibut Sport Fishing Management. Six of the twelve lodging facilities responded that they were “not at all familiar” with Pacific halibut sport fishing management, three stated that they were “slightly familiar,” two were “somewhat familiar,” and one was “extremely familiar.” Two traveler service businesses were “not at all familiar” with the management of Pacific halibut sport fishing, and three were “slightly familiar.” One recreational fishing-related business was “somewhat familiar” with Pacific halibut sport fishing management, five were “moderately familiar,” and one was “extremely familiar” (Figure 1.12).

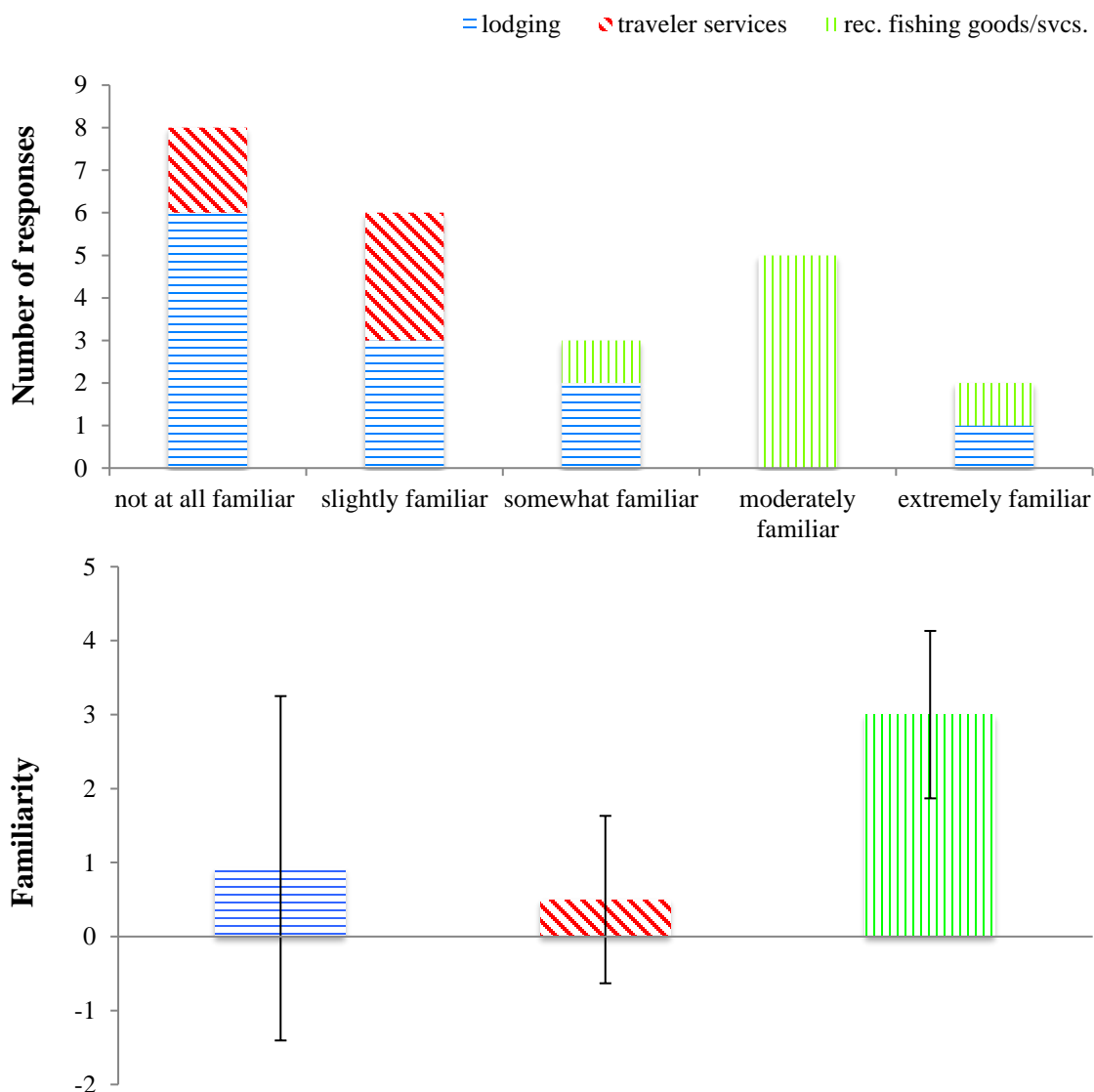


Figure 1.12. Familiarity with Pacific halibut sport fishing management. A) Individual responses by business type. B) Average responses by business type, coded with “not familiar” = 0, and “very familiar” =3. Error bars are 95% confidence intervals.

Question #13: Number of Employees Working Year-Round (2013). Eight lodging facilities stated that they had between zero and five part-time employees year-round in 2013, and two had between six and ten. Six of the lodging businesses had between zero and five full-time employees in 2013 working year-round, one had between six and ten,

and two had between 11 and 15. Three traveler service businesses had between zero and five part-time employees, and one had between six and 10. Four of the traveler service businesses had between zero and five full-time employees, and one had between 16 and 20. Three of the recreational fishing businesses had three part-time employees working year-round in 2013, five had between zero and five full-time employees, and one had over 21 employees working full time (Figure 1.13).

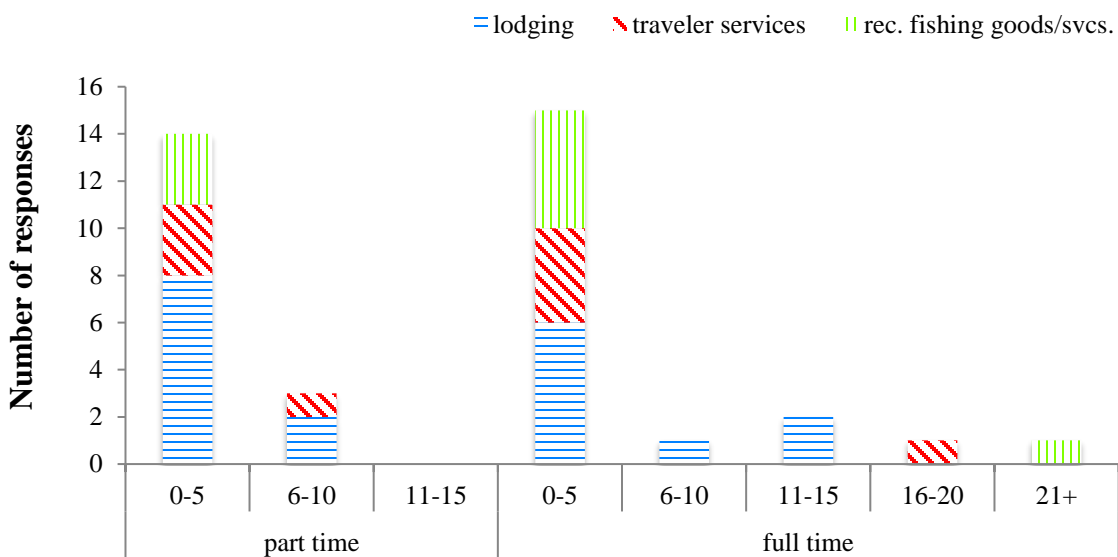


Figure 1.13. Number of part time and full time employees (year-round 2013).

Question #14: Number of Employees Working Seasonally (2013). Six of the lodging facilities reported having between zero and five part-time seasonal workers in 2013, and one reported having between six and 10. Six lodging facilities had between zero and five full-time seasonal employees in 2013, and one had between 11 and 15. Two of the traveler service businesses had between zero and five part-time seasonal workers in 2013, and one had between six and 10. One traveler service had between zero and five full-time seasonal workers in 2013, and one had between 16 and 20. Four of the

recreational fishing businesses had between zero and five part-time seasonal workers in 2013, and four had between zero and five full-time seasonal workers (Figure 1.14).

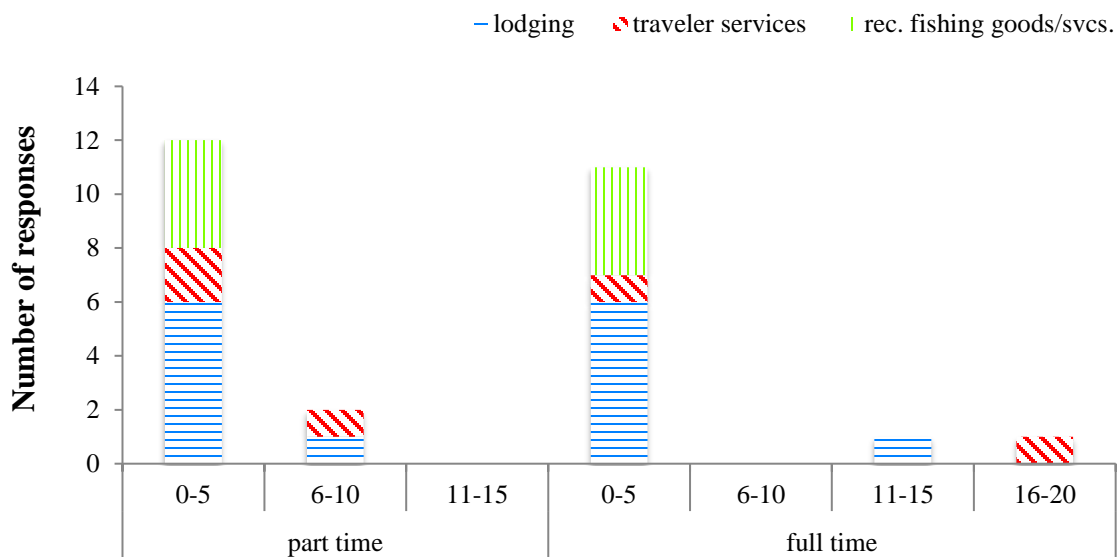


Figure 1.14. Number of part time and full time employees (seasonal, 2013).

Lodging businesses reported having three part-time employees and four full-time employees. Traveler service businesses reported having four part-time employees and 10 full-time employees. Recreational fishing businesses had three part-time and three full-time employees (Figure 1.15).

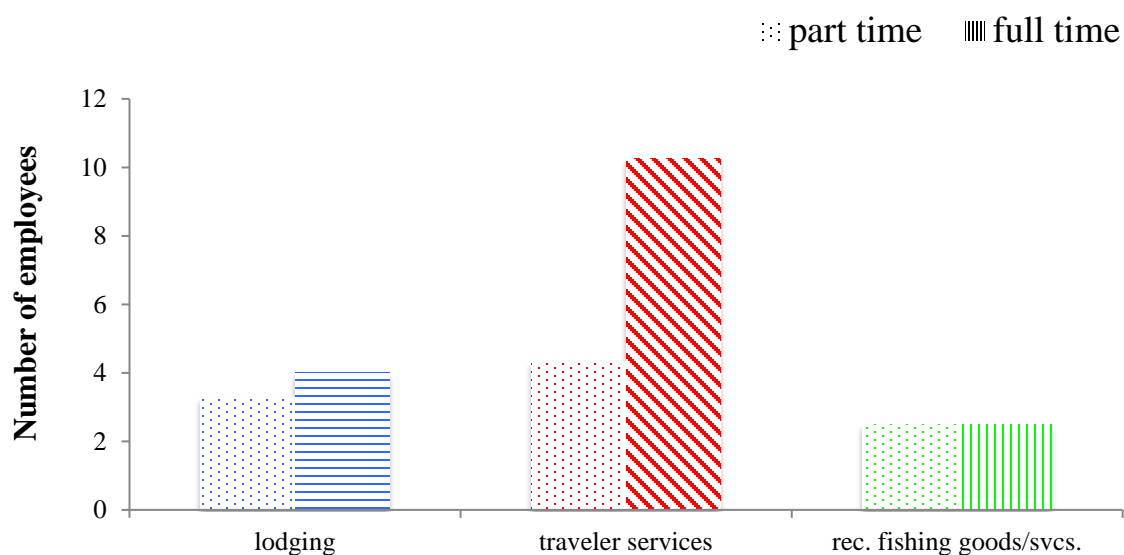


Figure 1.15. Average number of part time and full time employees. These averages were calculated using the median value for each range, e.g. 0-5 employees counted as 2.5, 6-10 employees counted as 8, etc.

Question #15: Staff Changes in August 2014. Eight of the lodging facilities had no staff changes in August 2014; three of them had either an increase or decrease in part-time positions by between zero and five positions, and two had either an increase or decrease in full-time positions by between zero and five positions. All four traveler service businesses reported that they had no staff changes in August 2014. Six of the recreational fishing businesses reported having no staff changes in August 2014, and one reported having a change in the number of part-time positions during that time (Figure 1.16). The question, as it was asked in the survey, was not specific enough to distinguish between increases and decreases.



Figure 1.16. Staff changes in August 2014.

Question #16: Staff Changes Because of Business Lost Due to the Pacific Halibut Closure. All 25 businesses reported that none of the staff changes they made during 2014 were due to the Pacific halibut closure.

Question #17: Business' Gross Revenue for 2013. Of the seven lodging facilities that responded to this question, most (five) had gross revenues of less than \$500,000 in 2013. Two of the traveler service businesses made less than \$500,000, and two made between \$500,001 and \$1,000,000. Two of the five recreational fishing businesses made less than \$500,000, while three made over \$1,000,000. Average gross revenue was calculated using the mean of each gross revenue range, so <\$500,000 was counted as \$250,000; \$500,000-\$1,000,000 counted as \$750,000; and >\$1,000,000 was counted as \$1,250,000. Average gross revenue for lodging facilities was \$567,858; for traveler services, it was \$512,500, and for recreational fishing goods and services, it was \$2,670,000 (Figure 1.17).

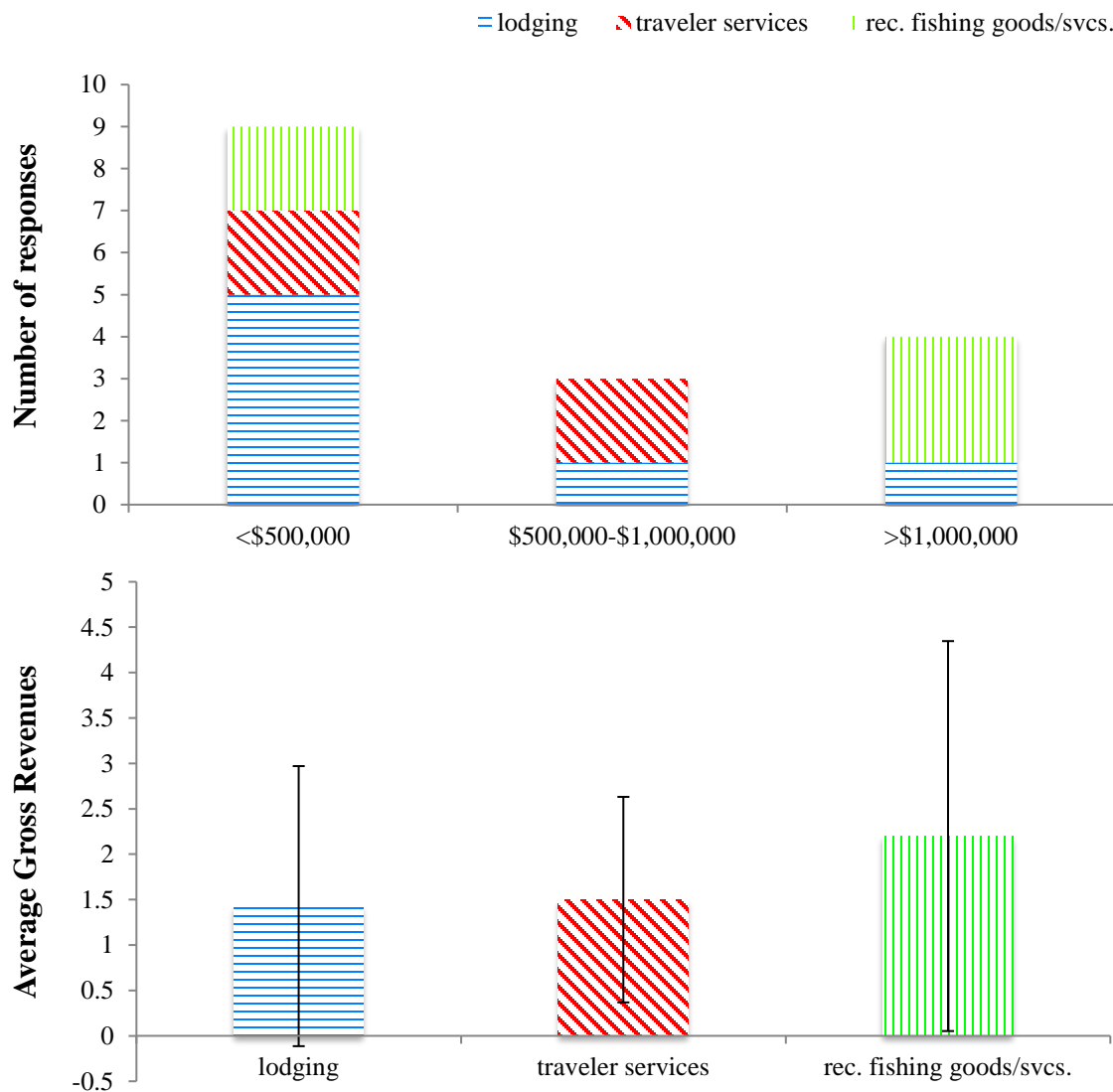


Figure 1.17. Business' 2013 gross revenue. Top) Individual responses by business type. Bottom) Average responses by business type, coded with <\$500,000 = 1, \$500,000-\$1,000,000 = 2, and >\$1,000,000 =3. Error bars are 95% confidence intervals.

Question #18: Business' 2013 Gross Revenue Relative to a Typical Year.

Businesses were asked how their 2013 gross revenue compared to a typical year. This was intended to serve as a baseline with which impacts from the August 2014 closure could be compared. Of the 10 lodging facilities that responded to this question, one reported that their 2013 gross revenue was somewhat worse relative to a typical year, four reported that it was about the same, four reported that it was somewhat better, and one reported that it was much better. One traveler service business reported that their 2013 gross revenue was much worse compared to a typical year, two reported that it was somewhat worse, and three reported that it was about the same. One of the recreational fishing businesses reported that their 2013 gross revenue relative to a typical year somewhat worse, three reported that it was about the same, and three reported that it was somewhat better (Figure 1.18).

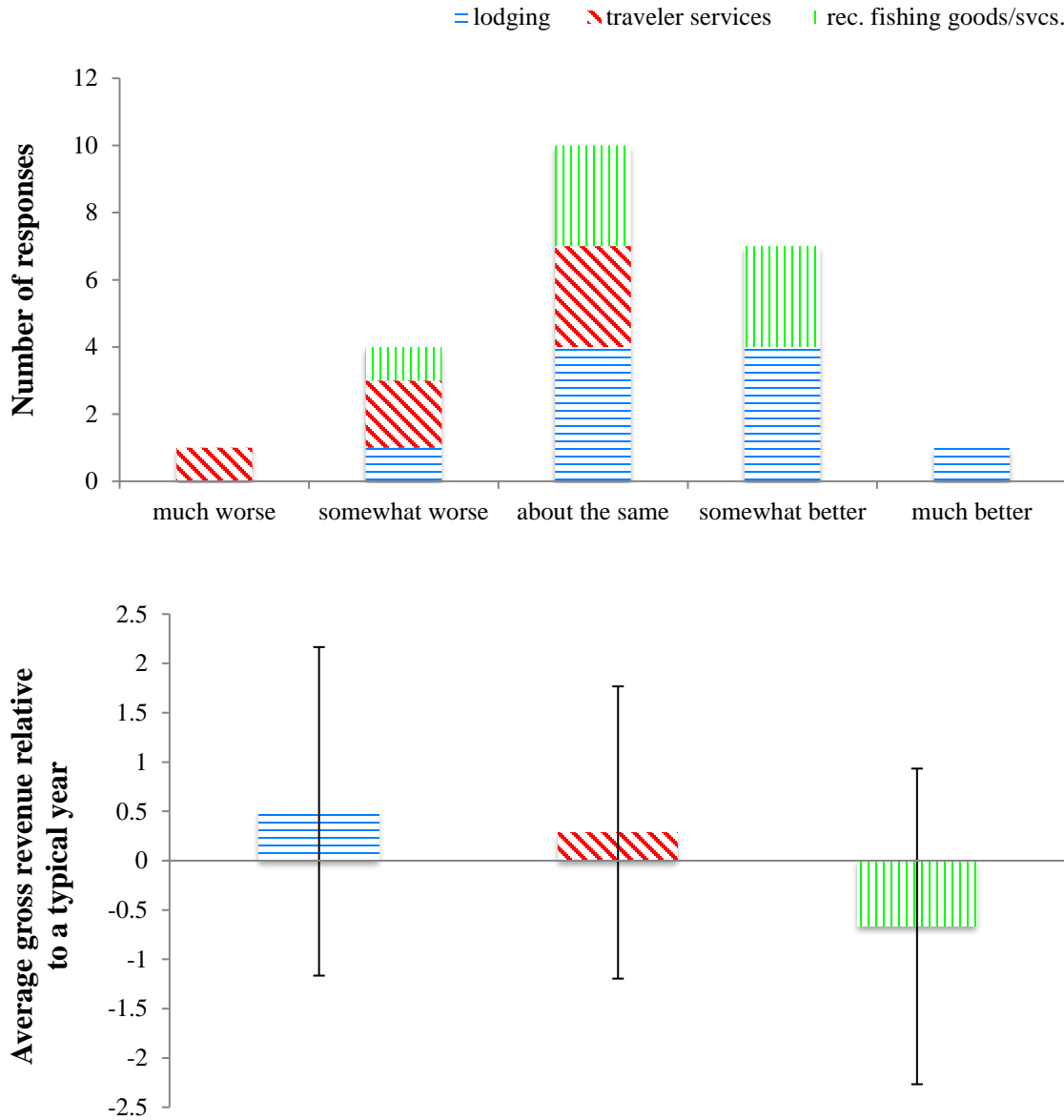


Figure 1.18. Business' 2013 gross revenue relative to a typical year. A) Individual responses by business type. B) Average responses by business type, coded with “about the same” = 0, “somewhat worse” = -1, “somewhat better” = 1, “much worse” = -2, “much better” = 2. Error bars are 95% confidence intervals.

Question #19: Percentage of Gross Revenue Earned in July and August in a Typical Year. Businesses were asked what percentage of gross annual revenue was earned in July and August in a typical year. Because the closure occurred in August of 2014, this question was intended to help determine how much of an economic impact the Pacific halibut closure had on revenue during the summer months. Annual gross revenue earned in July and August varied considerably. Lodging companies reportedly earned between 11 percent and 60 percent of their annual gross revenue in July and August. Traveler services reportedly earned between 11 percent and 40 percent of their annual gross revenue in July, and 11 percent and 30 percent in August. Fishing-related businesses reported earnings of between 21 percent and 50 percent of their annual gross revenue in July and August (Figures 1.19 and 1.20).

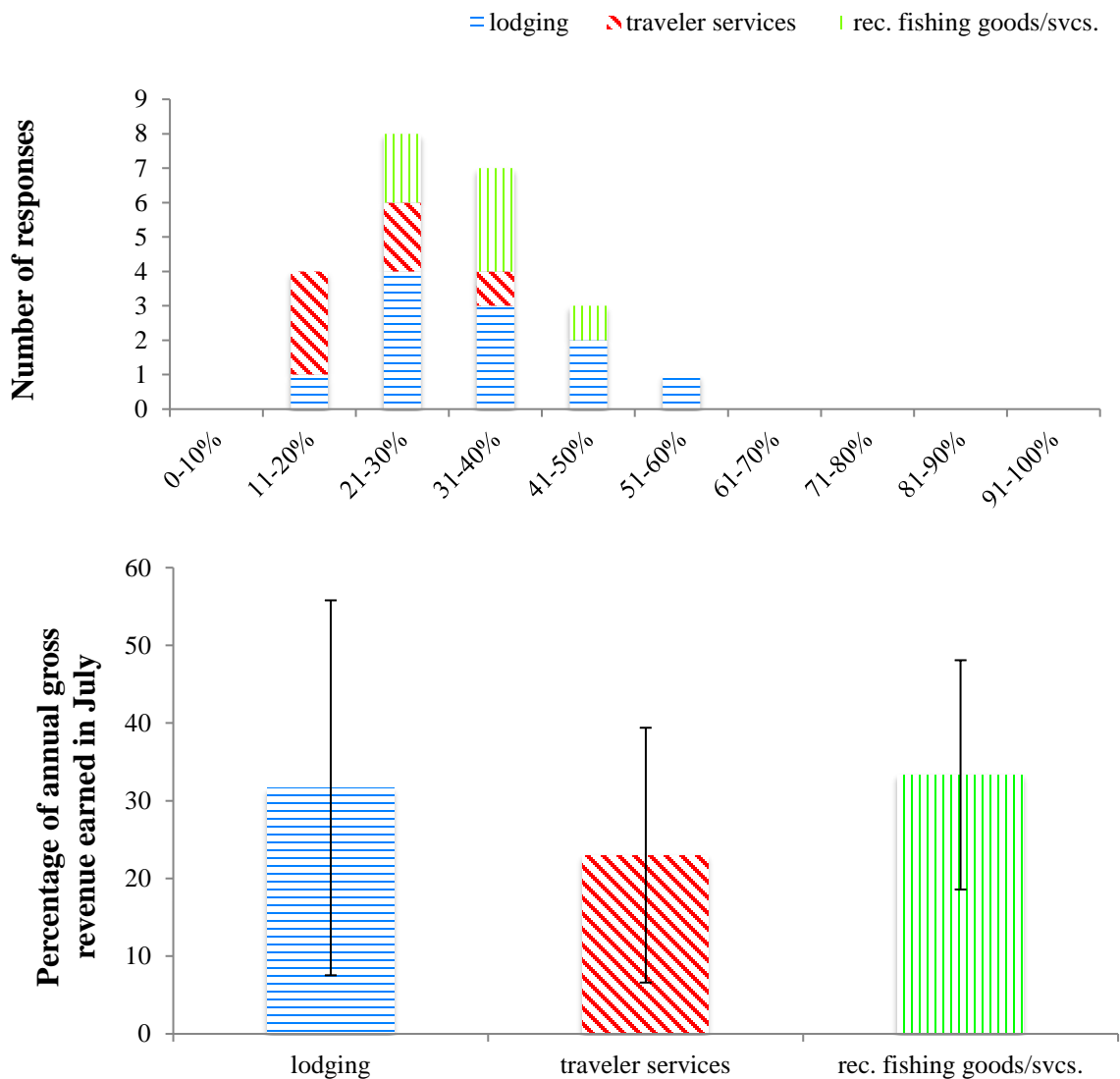


Figure 1.19. Percentage of annual gross revenue earned in July. Top) Individual responses by business type. Bottom) Average responses by business type, coded with 0-10% = 5, 11-20% = 15, 21-30% = 25, 31-40% = 35, 41-50% = 45, 51-60% = 55. Error bars are 95% confidence intervals.

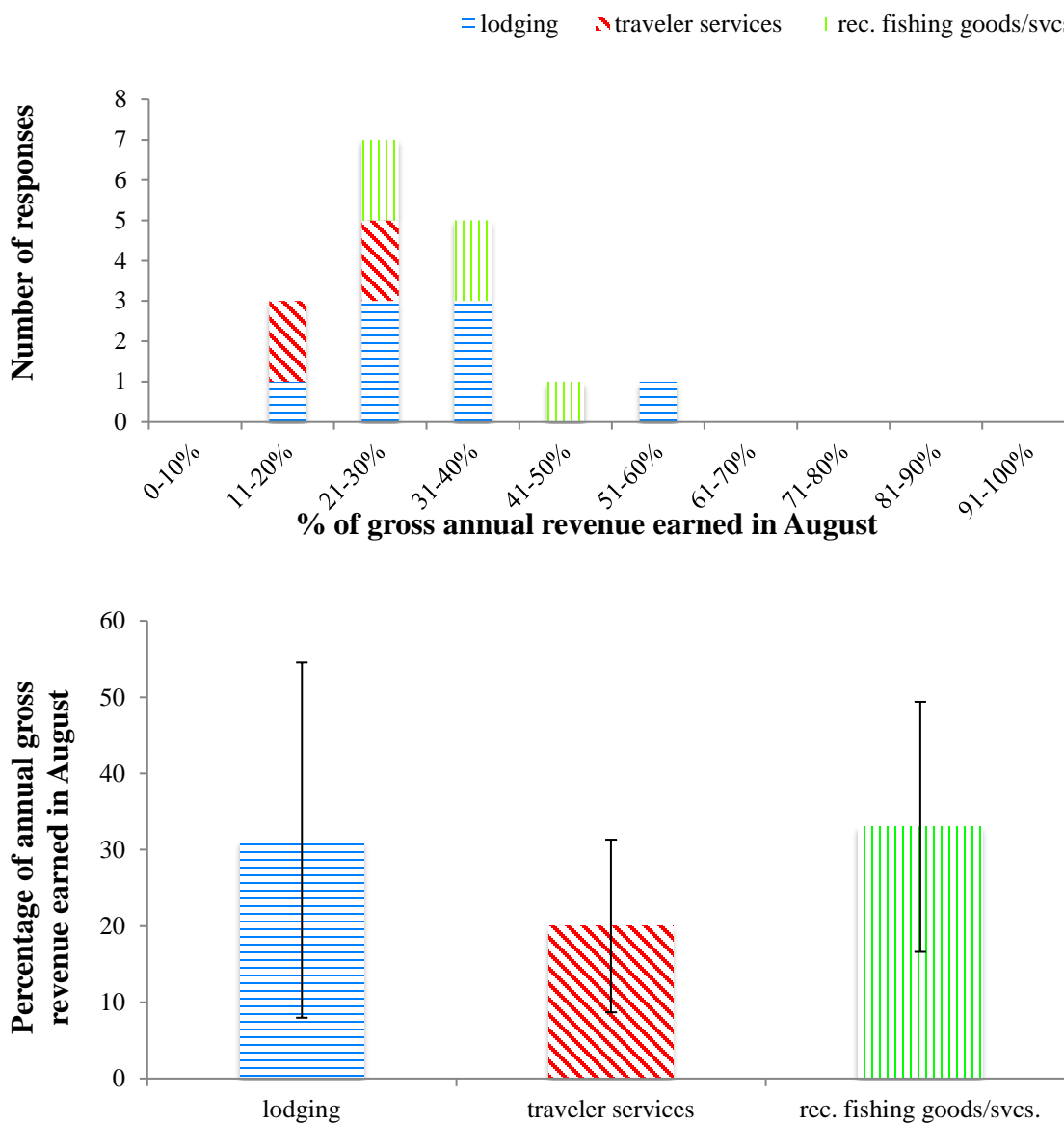


Figure 1.20. Percentage of annual gross revenue earned in August. Top) Individual responses by business type. Bottom) Average responses by business type, coded with 0-10% = 5, 11-20% = 15, 21-30% = 25, 31-40% = 35, 41-50% = 45, 51-60% = 55. Error bars are 95% confidence intervals.

Question #20: Business' Gross Revenues for July 2014 vs. July 2013. Six of the

12 lodging facility respondents stated that July 2014 gross revenue was approximately the same as July 2013 gross revenue, six reported having higher gross revenue in 2014, and

none having lower gross revenue. Two of the six traveler service businesses reported that the gross revenue across the two years were about the same, four reported having lower gross revenue in July 2014 than in July 2013. Three of the seven recreational fishing-related businesses reported that 2014 and 2013 July gross revenue were about the same, and four reported that they were lower in 2014 than in 2013 (Figure 1.21).

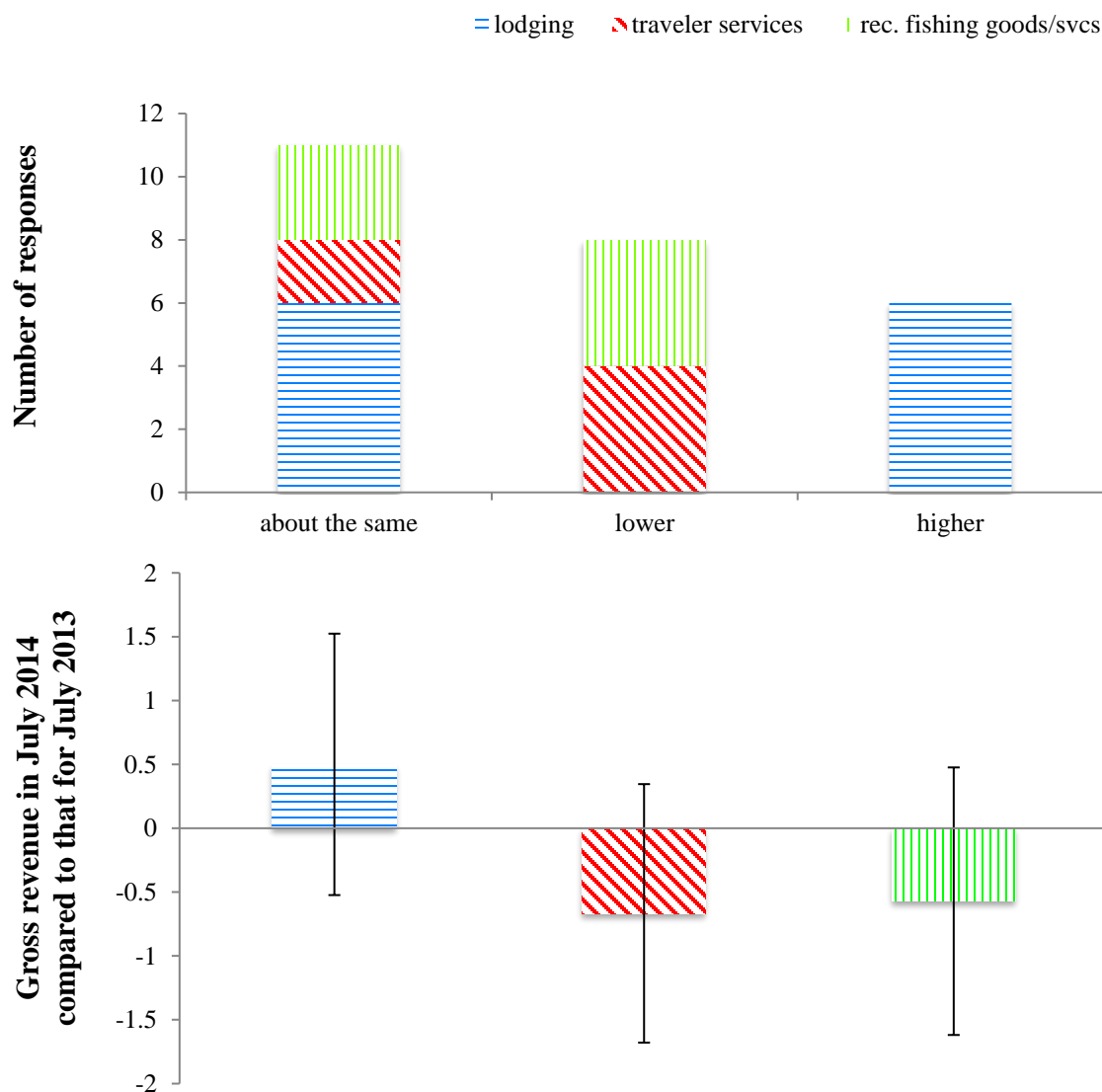


Figure 1.21. Gross revenue in July 2014 compared to that for July 2013. Top) Individual responses by business type. Bottom) Average responses by business type, coded with “about the same” = 0, “lower” = -1, “higher” = 1. Error bars are 95% confidence intervals.

Question #21: Business’ Gross Revenues for August 2014 vs. August 2013. This

survey question was intended to provide insight into whether there was a change in revenue between August 2014, when the Pacific halibut closure was in place, and August

2013, before the closure was implemented; therefore, this was one of the most important questions in the survey.

Five of the 12 lodging facilities stated that the August 2014 gross revenue was about the same as August 2013 gross revenue; one stated that August 2014 gross revenue was lower, and six facilities reported that it was higher. Three of the six traveler service respondents stated that the August 2014 gross revenue was approximately the same as gross revenue in August 2013, three reported that their gross revenue in August 2014 was lower than August 2013. Two of the seven recreational fishing-related services reported that August 2013 gross revenue was about the same as August 2014, and five stated that August 2014 revenue was higher than August 2013 (Figure 1.22).

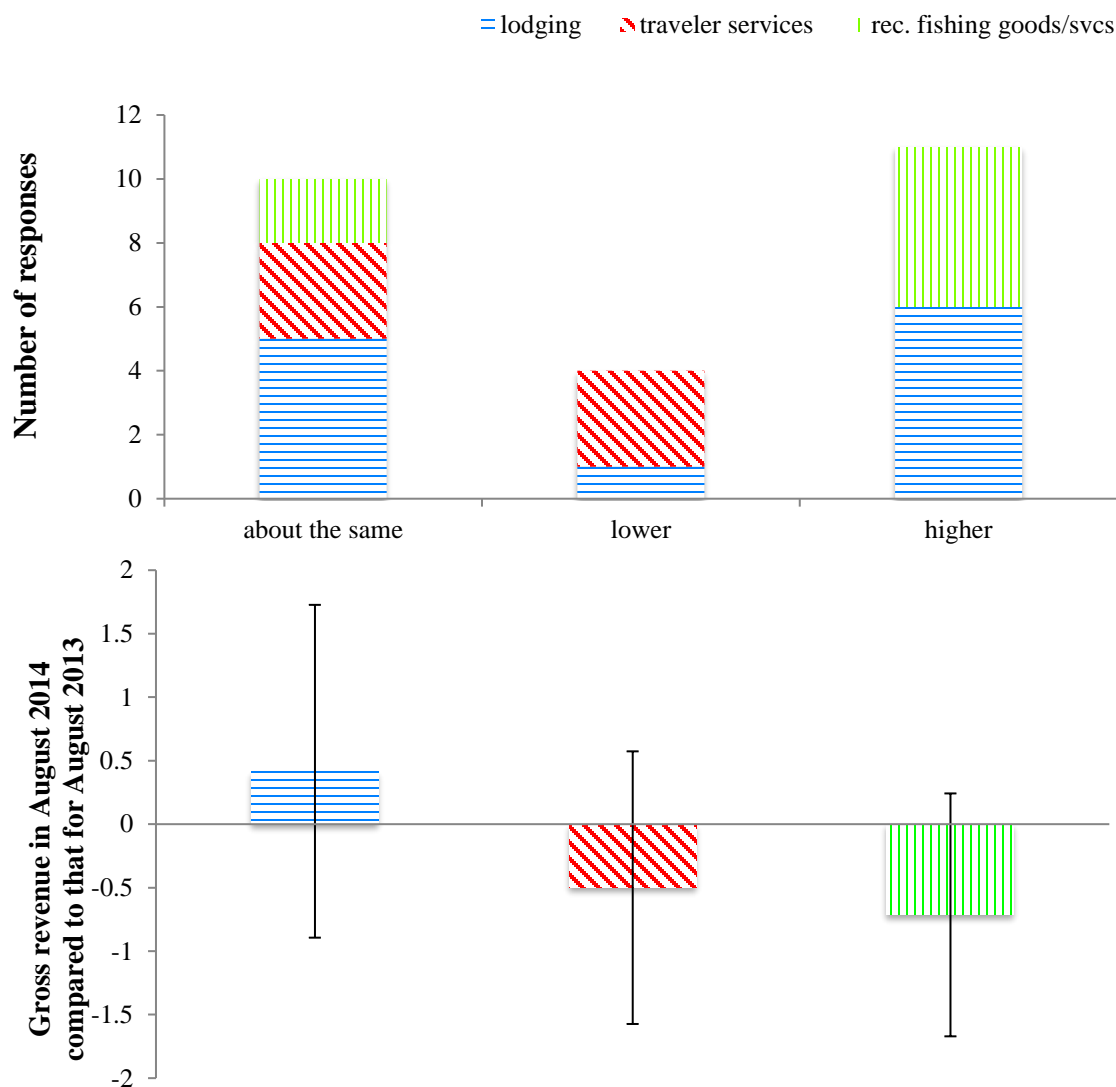


Figure 1.22. Gross revenue in August 2014 compared to that for August 2013. Top) Individual responses by business type. Bottom) Average responses by business type, coded with “about the same” = 0, “lower” = -1, “higher” = 1. Error bars are 95% confidence intervals.

Question #22: Revenue Lost Due to the August 2014 Closure. The business types that were likely impacted the most by the August 2014 Pacific halibut closure were recreational fishing-related businesses, with two of the seven businesses reporting a loss

of between \$1,000 and \$10,000, and two businesses reporting losing between zero percent and 15 percent of revenue; this is not surprising given that they provide goods and services directly utilized by anglers. One of the traveler services reported a loss of between \$1,000 and \$5,000, and of the eight lodging businesses that responded to this question, two appear to have been affected, with a loss of between \$1,000 and \$10,000. Six of the lodging facilities stated that the halibut closure did not result in any loss of revenue; one of the traveler service businesses also reported zero loss (Figure 1.23). One respondent indicated losses of \$200,000, but this data point was such an extreme outlier that we deemed it safest to exclude it from the figure below and from further analysis (including loss estimates).

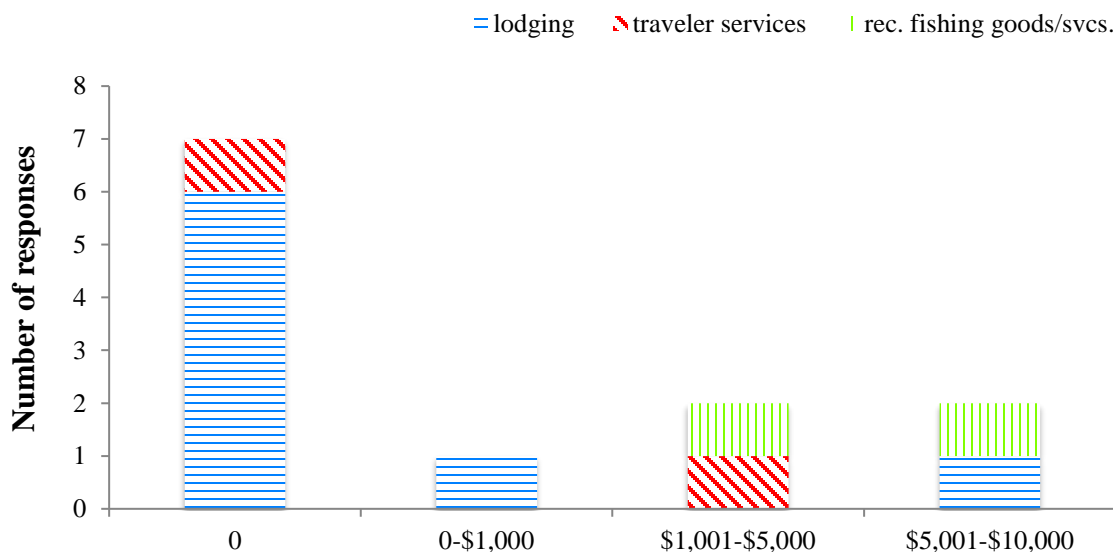


Figure 1.23. Revenue lost in 2014 due to the Pacific halibut closure.

Businesses were asked to estimate their gross revenue for 2013 (Appendix A, Question #17), and responses were categorical (e.g., less than \$50,000, \$50,001-\$100,000). Therefore, while we were unable to pinpoint revenue lost as a percentage of

gross annual revenue, we were able to calculate a range. Two lodging businesses lost from 0.4 percent to 1.0 percent of their annual revenue due to the August 2014 Pacific halibut closure, and one traveler service business lost between 0.3 percent and 0.6 percent of their annual revenue. Four fishing-related stores lost between zero percent and eight percent of their annual revenue due to the closure.

Question #23: Difference Between August 2013 and 2014 Revenues. One of the 10 lodging facility respondents reported that their August 2014 revenue was 11 percent to 20 percent lower than August 2013, seven reported that the revenues for these two periods were the same, one reported that August 2014 revenues were 11 percent to 20 percent higher than in August 2013, and one reported that they were 21 percent to 30 percent higher. One of the six traveler services reported that their August 2014 revenues were 21 percent to 30 percent lower, and five reported that their revenues during these two time periods were approximately the same. All five fishing-related businesses that responded reported their August 2013 and August 2014 revenues were about the same (Figure 1.24).



Figure 1.24. Percent difference between August 2013 and August 2014 revenue.

Monetary Effects of the Pacific Halibut Closure. While it is difficult to determine the exact economic impact that the Pacific halibut closure had on businesses on the North Coast, a rough estimate can be made based on the responses that were received. To help deal with the low sample size, these estimates were based on quartiles, which are resistant to the influence of outliers. High, low, and median estimates of the impact were made using the following equations:

- Low estimate: first quartile loss for each business category x number of businesses in each category
- High estimate: third quartile loss for each business category x number of businesses in each category
- Median estimate: median loss for each business category x number of businesses in each category

Table 1.4 summarizes the estimate of the economic impact that the August 2014 Pacific halibut closure had on businesses that responded to our survey, while Figure 1.25 shows the high, median, and low estimates of the decrease in revenue from the closure of the Pacific halibut fishery in August 2014. The first quartile is calculated as the median of the data that is less than the overall median, while the third quartile is the median of the data greater than the overall median.

Table 1.4. Estimate of the economic impact of the August 2014 Pacific halibut closure on businesses on the North Coast.

Business Type	Estimated Revenue Lost Due to Halibut Closure	Low estimate calculation	High estimate calculation	Median estimate Calculation
Lodging	\$0	Median (0,0,0,0) x # of businesses (65) = \$0	Median (0,0,1000,10000) x # of businesses (65) = \$32,500	Median (0,0,0,0,0,0,1000,10000) x # of businesses (65) = \$0
	\$0			
	\$0			
	\$0			
	\$0			
	\$1,000			
	\$10,000			
Traveler services	\$0	Median (1500) x # of businesses (67) = \$100,500	Median (1500) x # of businesses (67) = \$100,500	Median (1500) x # of businesses (67) = \$100,500
	\$3,000			
Rec. fishing goods/svcs.	\$3,000	Median (5250) x # of businesses (17) = \$89,250	Median (5250) x # of businesses (17) = \$89,250	Median (5250) x # of businesses (17) = \$89,250
	\$7,500			
Total		\$189,750	\$222,250	\$189,750

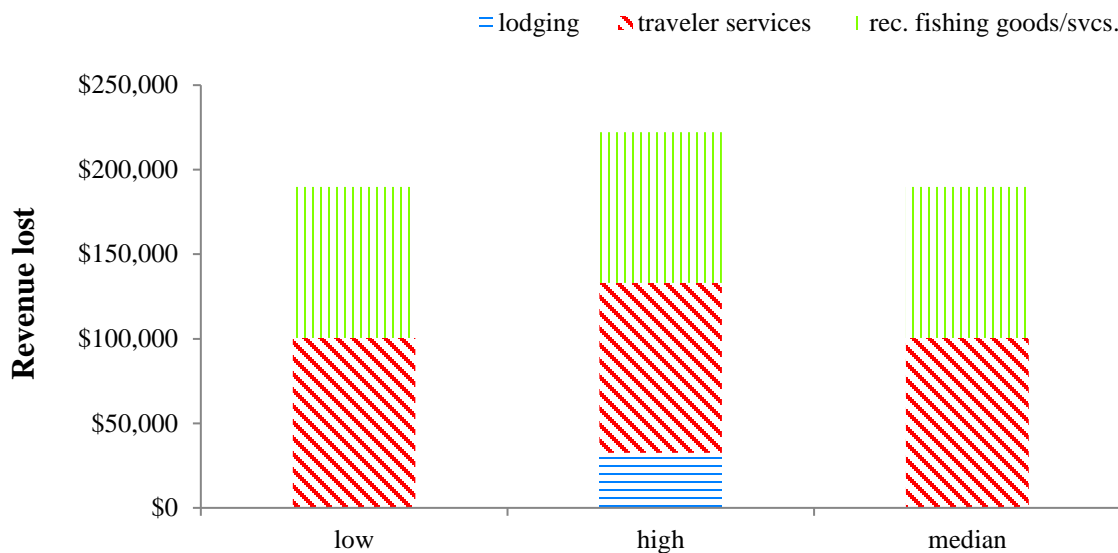


Figure 1.25. High, median, and low estimates of decrease in revenue from August closure.

Note that while the estimated amount of losses for travelers' services businesses is slightly more than double that for fishing-related businesses, there were roughly four times as many traveler service businesses than fishing-related businesses, suggesting a much greater impact on individual fishing-related businesses.

Comments About the Pacific Halibut Closure from North Coast Businesses. Many of the respondents provided comments on how they viewed the Pacific halibut closure; this provided additional insight into the personal opinions of the business owners. Comments on the Pacific halibut closure varied greatly, from some businesses voicing concern that it has negatively affected their business, to those who were generally supportive of the closure.

Against the Closure

Lodging establishment:

“Please keep [the halibut fishery] open all summer, it helps attract visitors.”

Fuel supplier:

“Sport and commercial fishing provide revenue that we don’t want to lose.”

Sporting goods store:

“... Let us fish! The weather keeps us off the water enough without having to deal with politics!”

Tackle and marine supply store:

“Was the closure even necessary? Halibut numbers have been [increasing] for the last several years.”

Supportive of the Closure

There were multiple comments supportive of the closure; many were conditional on the closure being necessary for the health of the Pacific halibut populations.

Hotel:

“I applaud any moves that help Pacific halibut recover.”

Hotel:

“We are hoping that the halibut closures are to help the halibut regain their numbers...and come back next year stronger than ever.”

Tackle and marine supply store:

“We are willing to accept [the] closure if it keeps fishery robust.”

Boat repair and marine supply business:

“.... If there is something to fish for, our regular customers would be here regardless of what they could fish for. They just want to fish for something. Preferably salmon, but all other legal and available species they fish for. As long as there is something to fish for, I don't think our business will be negatively impacted by selective closures.”

Business Impacts

Fishing-related store:

It [affects] all of our local businesses, hotels, restaurants, charter boats. It totally killed my August halibut tackle [sales].”

Lodging facility:

“Many homes were only half full during stays. We typically fill each house to capacity.”

Restaurant:

“Overall, salmon was a major impact, but halibut, I'm not sure of.”

Ecotrust's Angler and Charter Boat Surveys

HASA also commissioned Ecotrust to survey anglers and charter boat captains to determine the economic impact that the August 2014 Pacific halibut closure had on them. Between August and October 2014, 265 recreational fishers and 11 charter boat businesses from Crescent City, Trinidad, Eureka, and Shelter Cove completed Ecotrust's SurveyMonkey survey (Hesselgrave et al. 2014). The recreational fisher and charter boat surveys are included as Appendices B and C, respectively.

Figure 1.26 illustrates the area of study and statistics gathered from the survey. The majority of trips to the North Coast were to Eureka or Humboldt Bay, with approximately 4,200 total trips, and an average of 20 trips per angler. Trinidad was the second most visited, with 1,200 trips and approximately six trips per angler. Seven percent of fishing trips made to the North Coast were to Crescent City, with 484 total trips, and an average of 2.3 trips per angler. Shelter Cove made up five percent of total visits to the area, with 318 total trips, and an average of 5.7 trips per angler. For all of the locations surveyed, between 30 percent and 40 percent of the fishing trips were for Pacific halibut (Hesselgrave et al. 2014).

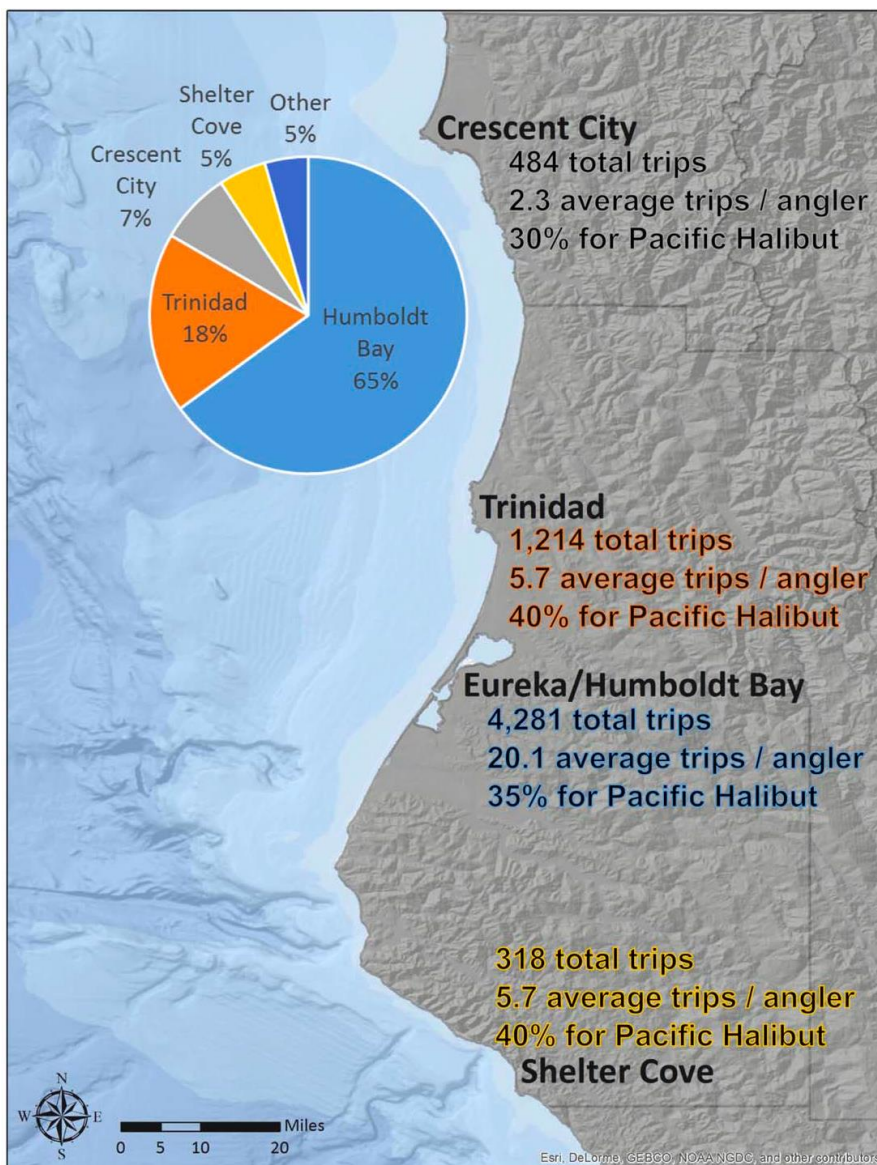


Figure 1.26. Ecotrust's area of study and survey statistics (Hesselgrave et. al 2014).

Preferred Days of the Week for Recreational Fishing. Two hundred and two responses were received for this question, in which respondents were asked to select the two days they preferred to fish recreationally. Saturday and Sunday were chosen more often than any other day of the week (Figure 1.27) (Hesselgrave et al. 2014).

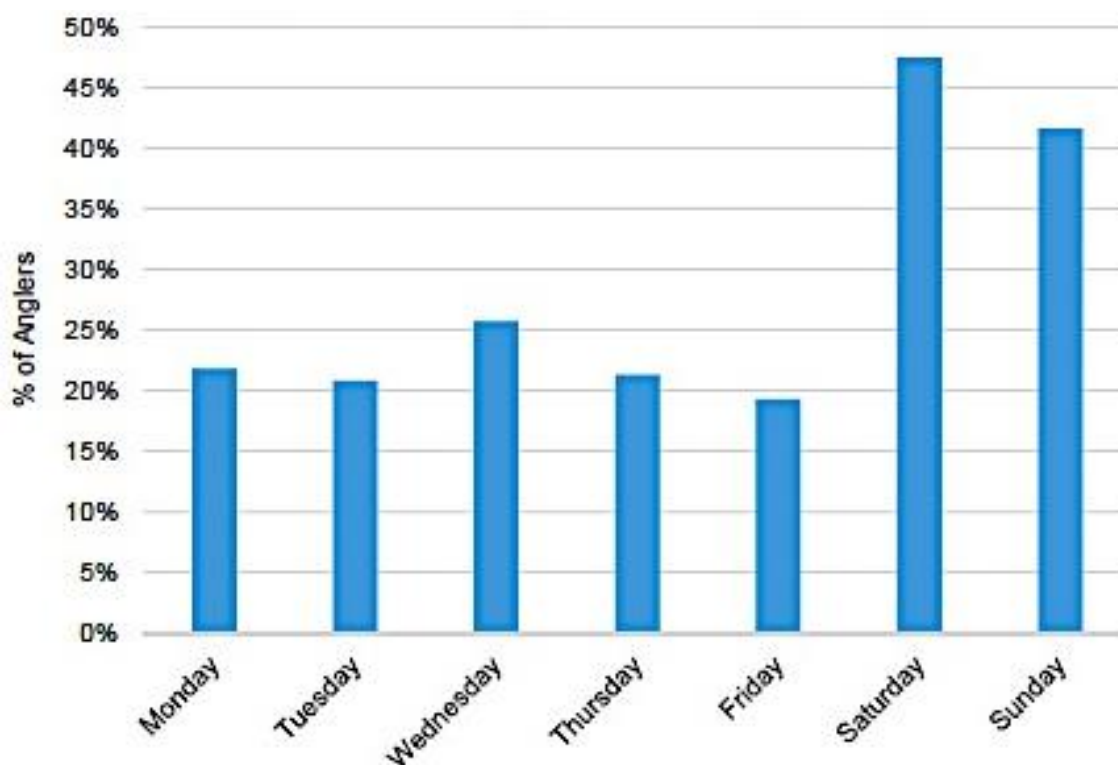


Figure 1.27. Ecotrust’s survey results on preferences by anglers for day of the week to go recreational fishing (Hesselgrave et al. 2014).

Species Ranked by Importance to Anglers. Two hundred and eleven fishers responded to this question, in which they were asked to rank their targeted fish species. Pacific halibut was the second most popular, both in the “most important” and “second most important” categories, after salmon. When these two categories are combined, 72 percent of anglers stated that Pacific halibut was their first or second choice (Figure 1.28) (Hesselgrave et al. 2014).

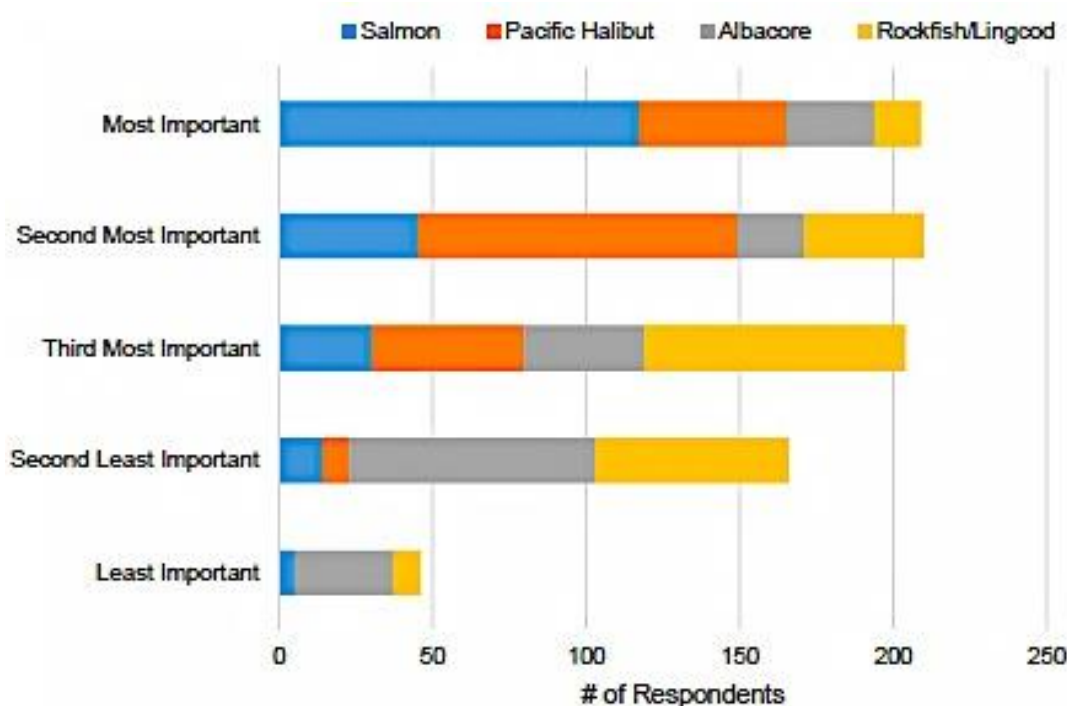


Figure 1.28. Ecotrust’s survey results on fish species level of importance (Hesselgrave et al. 2014).

Average Trip Expenditures Per Person by Item Across All Respondents. Table 1.5

shows average fishing trip expenditures, based on responses from 184 anglers. The column titled “among those who spent on item” lists the average expenditures, per item, for individuals who indicated costs associated with the listed items. Charter fishing fees, lodging, and entertainment/casinos were the top three items on which monies were spent, with \$296.92 spent on charter fishing fees, \$217.21 spent on lodging, and \$193.70 spent on entertainment and casinos. When these costs were averaged across all anglers, regardless of whether they indicated purchasing the listed items, the total expenditure spent per angler per trip was approximately \$254 (Hesselgrave et al. 2014).

Table 1.5. Average trip expenditures per person by item (Hesselgrave et al. 2014).

Item	% Occurrence	Averages	
		Among those who spent on item	Across all anglers
Car fuel	86%	\$33.77	\$29.18
Boat fuel	85%	\$55.01	\$46.94
Bait and tackle	85%	\$28.77	\$24.39
Store-bought food and beverages	82%	\$30.26	\$24.67
Sundries	53%	\$10.27	\$5.41
Restaurant-purchased food and beverages	48%	\$56.42	\$27.29
Ramp fees	24%	\$34.05	\$8.14
Lodging	14%	\$217.21	\$30.69
Souvenirs	13%	\$30.83	\$3.85
Entertainment / casinos	10%	\$193.70	\$18.95
Parking	8%	\$7.07	\$0.54
Charter fishing fee	7%	\$296.92	\$20.98
Car rental	1%	\$83.33	\$0.45
Boat rental	1%	\$40.00	\$0.22
Other	10%	\$121.12	\$12.51
Total average expenditure per angler per trip			\$254.21

Relative Average Recreational Fishing Trip Expenditures. Figure 1.29 shows, on average, the relative expenditures for each of the items listed in Table 1.5. Items not directly related to fishing, such as lodging (12.2 percent), car fuel (11.6 percent), food and beverage (9.8 percent), and entertainment/casinos (7.5 percent) made up approximately 40 percent of the total (Hesselgrave et al. 2014).

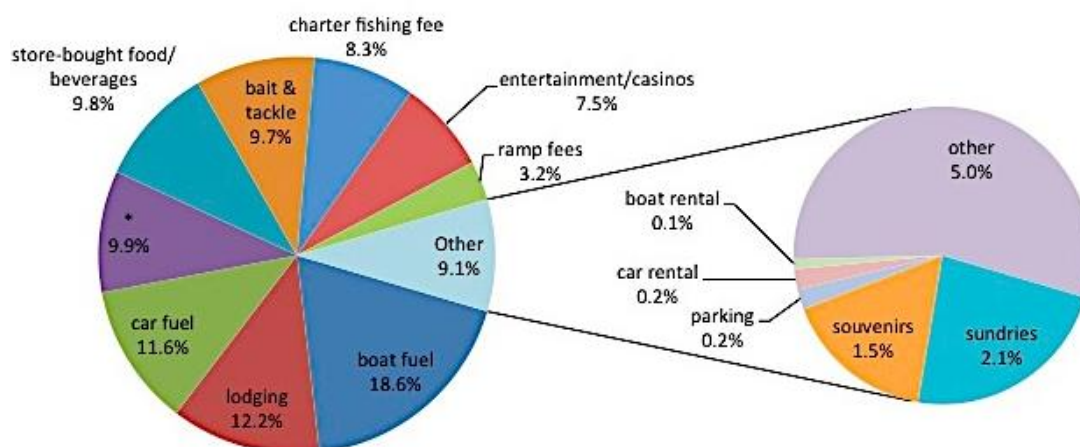


Figure 1.29. Ecotrust's survey results on relative average recreational fishing trip expenditures (Hesselgrave et al. 2014).

Reported Change in Usual Fishing Behavior Due to Closure. Of the 183 anglers who responded to the question of whether they changed their usual fishing behavior in response to the closure, 109 anglers reported that they pursued other fish species, and 97 fished less frequently overall. Sixty-five responded that they fished more heavily early in the season, in anticipation of the August closure. Seventeen respondents fished for halibut elsewhere, where there were no closures, and 12 did not fish at all during the month of August (Figure 1.30) (Hesselgrave et al. 2014).

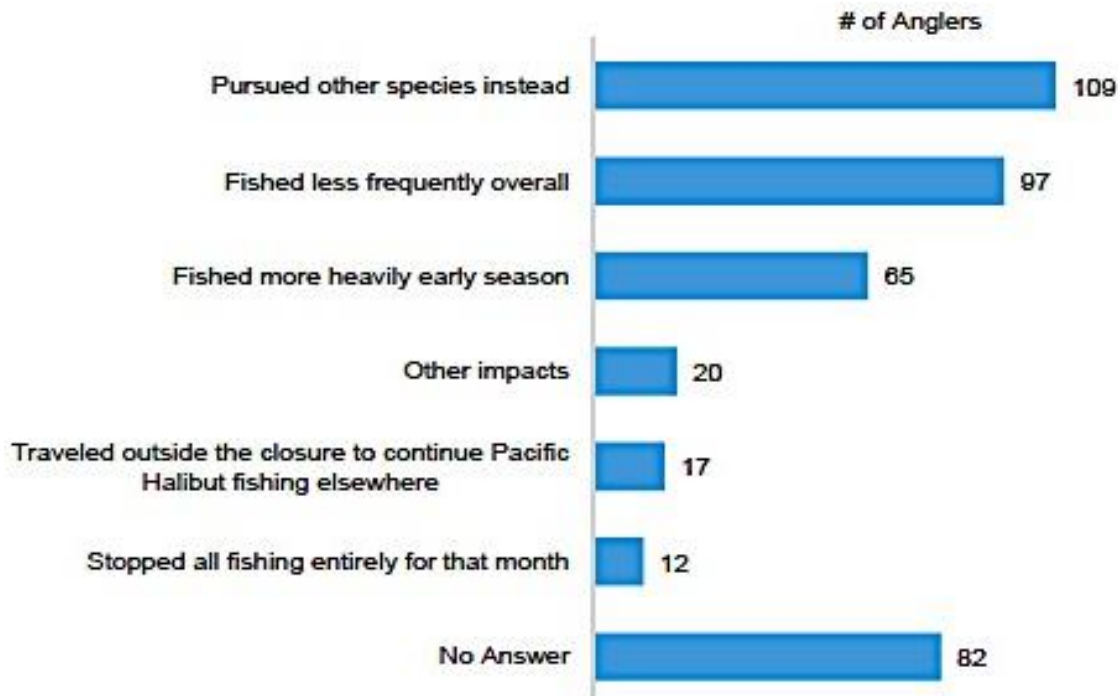


Figure 1.30. Ecotrust's survey results on reported change in usual fishing behavior due to closure (Hesselgrave et al. 2014).

Additional Foregone Fishing Trips Due to Pacific Halibut Closure Among Respondents. Of the 179 anglers who responded to the question of how many fishing trips were missed due to the August closure, 18 respondents indicated one trip, 71 respondents indicated two to three trips, 75 respondents indicated four to eight, 20 respondents indicated nine to 14 trips, and three responded that 15 or more trips were foregone due to the closure (Figure 1.31) (Hesselgrave et al. 2014).

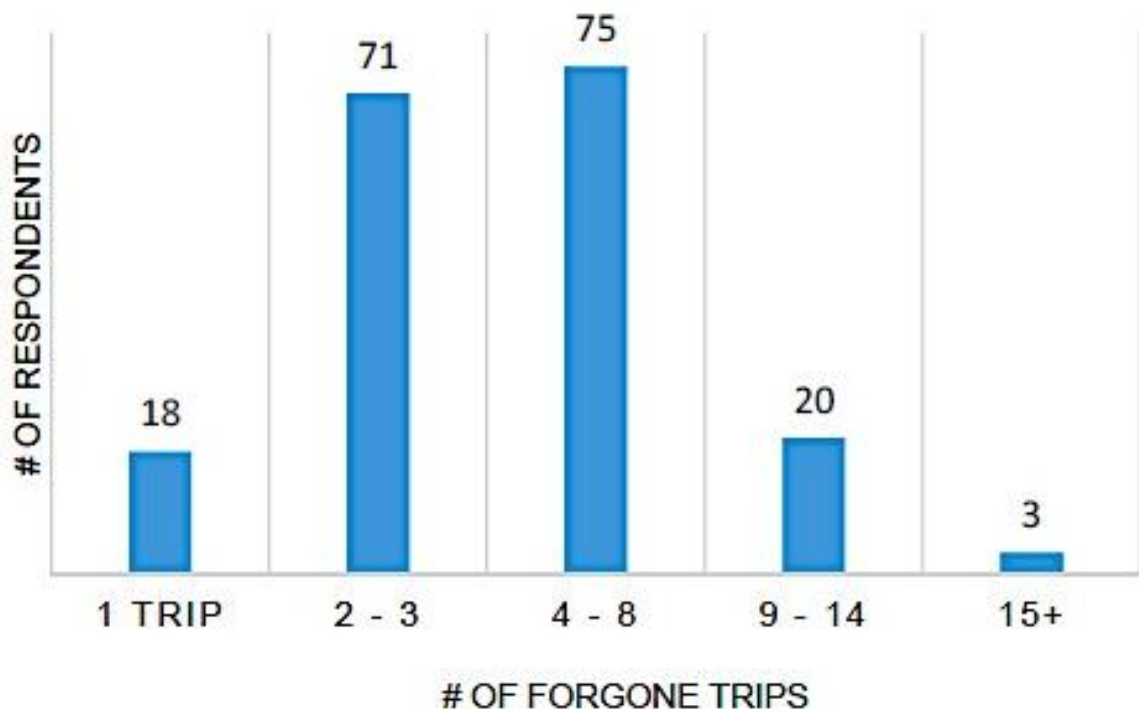


Figure 1.31. Ecotrust’s survey results on the number of forgone trips due to the August closure (Hessegrave et al. 2014).

Angler Willingness to Return to North Coast Once Pacific Halibut Fishery is Re-opened. Of the 183 anglers who responded to the question of whether they would return to the North Coast once the Pacific halibut fishery was re-opened, 97.8 percent responded that they would either “likely” or “very likely” return. Approximately one percent was “neutral,” and one percent responded that the chances were “unlikely” or “very unlikely” that they would return (Figure 1.32) (Hesselgrave et al. 2014).

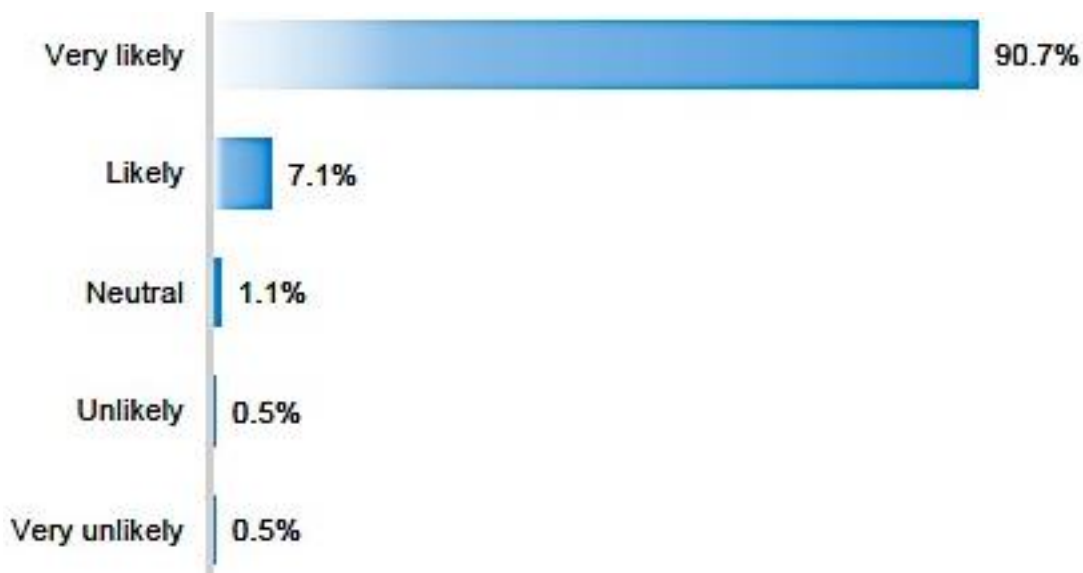


Figure 1.32. Ecotrust’s survey results on anglers’ willingness to return to the North Coast once Pacific halibut fishery is re-opened (Hesselgrave et al. 2014).

Total Estimated Foregone Recreational Trip Expenditures. Figure 1.33 shows the calculation that was used by Ecotrust to estimate the amount of recreational fishing expenditures that were lost due to the August 2014 Pacific halibut closure. They estimate that \$244,857 was lost due to the closure (Hesselgrave et al. 2014).

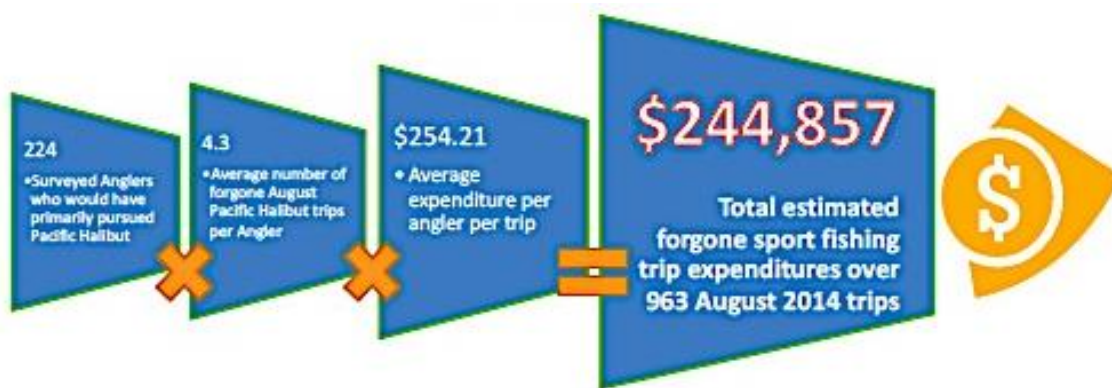


Figure 1.33. Ecotrust’s survey results on expenditure related to forgone fishing trips due to the August 2014 Pacific halibut closure (Hesselgrave et al. 2014).

Importance of Pacific Halibut Availability to Charter Business Success. For the 11 charter boats that responded to the question of whether Pacific halibut availability was important to the success of their business, 82 percent indicated that it was either “enormously” important or very important. Eighteen percent indicated that it was either “a little” important or “not at all” important (Figure 1.34) (Hesselgrave et al. 2014).

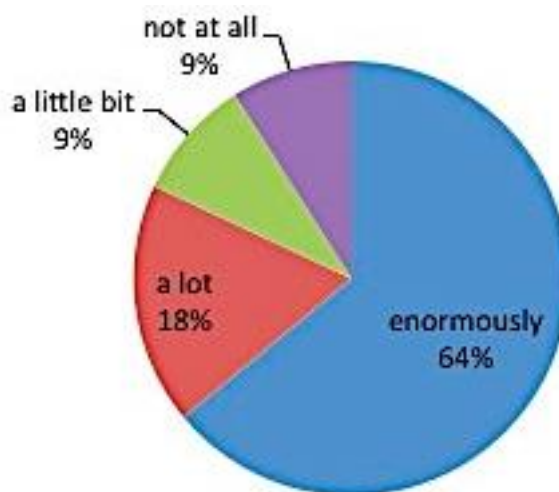


Figure 1.34. Ecotrust’s survey results on the importance of Pacific halibut availability to charter business success (Hesselgrave et al. 2014).

The Number of Charter Businesses Experiencing Changes in July and August Revenue from 2013 to 2014. Charter boats that responded to questions in the survey about their finances indicated that approximately one third of their annual revenue was earned in August. For the 10 that responded to questions about changes in revenue between July 2013 and July 2014, and between August 2013 and August 2014, 10 percent indicated that August 2014 revenue was higher than August 2013, 20 percent stated that it was the same during those two months, and 70 percent indicated that August

2014 revenue was lower than August 2013 (Figure 1.35) (Hesselgrave et al. 2014). It is unclear whether this was due to the Pacific halibut closure.



Figure 1.35. Ecotrust's survey results on the number of charter businesses experiencing changes in July and August revenue from 2013 to 2014 (Hesselgrave et al. 2014).

Estimate of Losses to the Total Charter Industry Due to the August 2014 Pacific Halibut Closure. Figure 1.36 shows the calculation used by Ecotrust to estimate the economic impact that the August 2014 Pacific halibut closure had on charter businesses on the North Coast. They estimate that approximately \$294,766 was lost by charter boat businesses due to the closure (Hesselgrave et al. 2014).

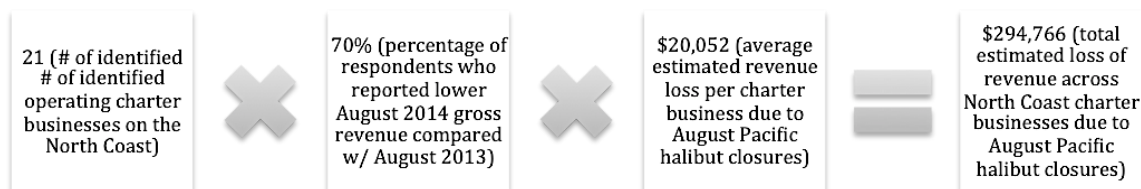


Figure 1.36. Charter business impact estimates of August 2014 Pacific halibut closure (Hesselgrave et al. 2014).

Comments about the Pacific Halibut Closure from Recreational Fishers and

Charter Boats. Below are comments from recreational anglers and charter boat captains regarding the August 2014 Pacific halibut closure (Hesselgrave et al. 2014). While all of the comments are against the closure, it is unknown whether all of the comments that were provided by fishers and charter boat captains were of this nature, or whether Ecotrust chose to only include these types of comments in their report.

Comments from Recreational Anglers.

- “There is something really special about the experience of halibut fishing; I always enjoy drifting out in the ocean with the engine off listening to and seeing all that is out there even if I don’t catch anything.”
- “When the fishery is closed my parents are less likely to come visit.”
- “Employment opportunities on the north coast are so limited that many people have grown to rely on sportfishing as a means of keeping healthy food on the table yet each year lately it seems opportunities for fishing become more restricted.”
- “The northern California coast pacific halibut [*sic*] is a special fishery to me my friends and family [*sic*].”
- “I would have invited friends from out of the area to fish with me.”
- “Halibut fishing is wonderful [*sic*] draw for out of area [*sic*] fishermen and women – I have many friends and relatives come to our area during the summer to fish for salmon and halibut, [*sic*] I’m not sure they would come with the same frequency if it was just to visit me instead of going fishing.”
- “I will not be fishing the saltwater for the remainder of the August closure period because without Pacific Halibut there is nothing worth fishing.”
- “The Pacific’s [*sic*] are the only reason I can justify spending the extra time and money [*sic*] I can fish a lot closer to home for salmon and lingcod.”
- “Block closures create unfair economic harm to the Trinidad and shelter cove [*sic*] ports that rely heavily on tourism since august [*sic*] used to be their busiest month.”
- “The fishery is extremely important to me and the economy of the north coast [*sic*].”

Comments from Charter Boat Captains.

- “August is typically a very busy month for me. The opportunity to catch a Pacific Halibut on the north coast draws a lot of people here... People who would have ordinarily traveled here to fish for salmon and halibut from out of the area who did not come this year as a result of the closure [*sic*]. Most of my business is from people who travel more than a hundred miles and stay the night in Eureka as part of their vacation... Had the month of August been open to halibut [*sic*] I believe my business would have been double what it was. That directly affects the whole area. From ice to beer and dining out to hotels, fish smoking and packaging, fuel sales and so on.....”
- “I own the local bait company closing [*sic*] halibut season more would cost me thousands of dollars in sales.”
- “We rely on combo trips to fill the boat and with no Pacific Halibut were [*sic*] forced to lower our prices to target only one species.”
- “We manufacture a fishing lure that is used for Pacific Halibut fishing on the north coast and have had a decrease in income because of this closure.”
- “As a charter boat operator I didn’t receive income that is important to be made in the summer season to make it through the winter when there is no fishing season open.”
- “Pacific Halibut are our biggest draw that differs our port from any other in California.”
- “The impact of a Pacific Halibut closure extends far beyond the obvious numbers. While we actually spend relatively little time actually targeting them, the potential to catch one is a huge draw to our port and encourages anglers to travel into our area.”

DISCUSSION

Despite the low response rate of businesses along the North Coast, some general trends on the impact of the August Pacific halibut closure are discernable. Fishing-related businesses, which we had predicted would be the most seriously impacted, reported losing between zero percent and eight percent of their 2014 revenue as a result of the halibut closure. Lodging and traveler service companies reported that they lost between 0.3 percent and one percent of their 2014 revenue due to the closure (based on estimates of gross revenue and losses from the closure, survey items 17 and 22). None of the businesses surveyed indicated changes in the number of employees as a result of the closure. For many businesses, the summer months of July and August made up a large proportion of their annual income (between 11 percent and 60 percent); consequently, lost business may have been detrimental to their bottom line. Based on the data that were gathered from the survey, the decrease in revenue for businesses on the North Coast as a result of the August Pacific halibut closure was estimated to be between \$189,750 and \$222,250.

For many businesses, like hotels, restaurants, and gas stations, it was difficult to determine whether the halibut closure had an effect on their business, or if it did, to determine the dollar value of the effect. And, as one restaurant pointed out (see comment above), if the salmon run was good, it was difficult to determine whether and how the halibut closure increased or decreased business. Conversely, in years when the recreational salmon fishing opportunities were limited, the impact of the August closure

of Pacific halibut fishing was likely to be much greater. Attitudes toward and impacts from the Pacific halibut closure may be closely linked to the success of other fisheries, particularly salmon. Given the drought California currently faces, declines in salmon and salmon fishing opportunities are a distinct possibility. In the last decade, there were two salmon season closures in California; it was during these periods that fishing for Pacific halibut became much more popular as an alternative. It is likely that if both salmon and Pacific halibut fisheries are closed simultaneously, it will have a much greater impact on the northern California economy than the halibut closure in 2014 when salmon fishing was quite good. As one recreational fishing-related business commented (see above), “[customers] just want to fish for something.” In response to comments like these, the PFMC in 2016 adopted regulations that allow fishing for Pacific halibut during the first two weeks of each summer month, and for salmon during the second two.

There also appeared to be myriad reasons for an increase or decrease in revenues, from August 2013 to August 2014. While some of this may have been due to the closure of the Pacific halibut fishery to recreational anglers in August 2014, other business-specific reasons may have been the cause of this change. For instance, some lodging facilities cited “increases in room rates,” “renovated rooms,” and “new management” as reasons for increased revenues in 2014. Similarly, a gasoline/fuel station credited “higher fuel costs” for their increase in revenue. Fishing-related businesses noted that weather and rough seas may have contributed to lower sales figures. There may also have been a positive correlation between the strength of the salmon fishery for that particular season and revenue; years when salmon were plentiful, earnings may also have improved. This

may also have contributed to the large variation in business revenue reportings, and in the difficulties that businesses experienced in determining the actual effects of the month-long halibut closure.

Our estimate of the economic impact on local businesses should be regarded as very approximate since it was extrapolated from a very small sample size. That said, our estimate (\$189,750 to \$222,250) was reasonably close to the estimate by Ecotrust of reduced expenditures by members of the Humboldt Area Saltwater Anglers (HASA) as a result of fewer halibut trips (\$244,857; Hesselgrave et al. 2014). This complementary study by Ecotrust also estimated lost revenue by local charter boat operators of \$294,766 (Hesselgrave et al. 2014). While reduced expenditures by HASA members likely contributed to the reduction in revenue for both charter boats and other local businesses, the impacts on these latter two (charter boats and other local businesses) are likely largely independent and therefore additive (though some amount of lost charter boat revenue would probably have been spent at local businesses). It is also important to note that HASA members probably would not have had a considerable financial impact on lodging and travel services, due to the fact that they mostly live locally. Assuming losses to charter boats and other businesses were independent would have produced a combined loss estimate of \$484,516 to \$517,016. Even if the losses to charter boats and other businesses were not considered to be independent, the economic impact on the study region certainly exceeds any of these single estimates (charter boats, other businesses, HASA member expenditures). The economic impact on the region was greater than the estimate of charter boat operator losses because this excludes losses at all other

businesses. Similarly, the regional impact was greater than the estimate of reduced revenue at other businesses because this excluded charter boat operators. Lastly, the impact was greater than the estimate of reduced expenditures by HASA members because though numerous, HASA members were just a subset of the anglers who fished in this region. While Ecotrust attempted to survey all local anglers, they were only able to reliably estimate reduced spending by HASA members due to very limited response from non-HASA fishers (Hesselgrave et al. 2014).

Results of the Ecotrust survey show that recreational anglers that responded to the questionnaire took approximately 6,600 fishing trips in the 2013-2014 fishing season, with one third of these trips taken primarily to fish for Pacific halibut. Approximately 75 percent of recreational anglers named Pacific halibut as either the most important or second most important species for which they fish. Approximately \$244,857 was lost to the local economy as a result of the August closure, which equated to almost 1,000 cancelled trips (Hesselgrave et al. 2014).

Approximately 90 percent of the surveyed charter boat businesses stated that the recreational Pacific halibut fishery was very to extremely important to their business, with 70 percent of the businesses reporting that their August 2014 revenue was lower than their August 2013 revenue. Ecotrust's estimate of the loss in revenue to charter boat businesses as a result of the Pacific halibut fishery closure was \$294,766 (Hesselgrave et al. 2014).

CONCLUSIONS

The short turnaround time required for this project was at least partly responsible for the low response rate to the business questionnaire. Another obstacle was the well-known reluctance of many business owners to share economic data – even when they are assured of confidentiality and anonymity. As with many surveys, there was likely a bias toward increased responses from those who experienced the greatest impacts (non-response bias). This expectation was borne out by the much higher response rate of the most impacted business category (37 percent for the fishing-related businesses).

It is recommended that this survey project be repeated in the future, to determine if there is a trend in the economic impact that the Pacific halibut closure has over time. Prior notification, via announcements through the relevant chambers of commerce or communicating with the businesses in advance would alert the businesses that the surveys were forthcoming, thereby perhaps leading to a higher response rate. Allowing for more time to develop the survey and giving businesses more time to complete them may also increase the number of respondents.

Ecotrust explained (Hesselgrave et al. 2014) that despite the results from their survey, a lot remains uncertain and unknown, primarily because the data below are unavailable:

- The angler population size on the North Coast that targets Pacific halibut, which would have helped determine whether the survey respondents were representative of the total population of anglers

- The number of Pacific halibut targeted trips made by these anglers, of which some may have shifted to early in the season, before the August closure
- Catch-per-unit-effort (CPUE) estimates for the Pacific halibut recreational fishery
- The economic multiplier effect on the local economy of the Pacific halibut closure.

Ecotrust also described the significance of the thousands of dollars lost to the local economy, based on the results of their survey. The multiplier effect mentioned above affects the local economy in many ways. Additionally, as opportunities for salmon decline on the North Coast, closures of the Pacific halibut fishery in the area may have an increasingly large negative effect (Hesselgrave et al. 2014). Negative impacts may be mitigated by alternating closures of Pacific halibut and salmon during the season, as was done in 2016, so that anglers have the opportunity to fish for at least one of these prized fishes at any point (until the catch limit is reached).

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Appendix A

Appendix A: California North Coast Business Survey

Waiver: I understand that neither my name nor the name of my business(es) will ever be associated directly with my responses and survey information will only be presented in an aggregated form. By participating in this survey I confirm I am at least 18 years of age and that my participation in the survey is voluntary.

General Question

1) What type is your business? (Please rank all that apply, with 1 being most important.)

- | | |
|--|---|
| <input type="checkbox"/> Tackle and Marine Supply
<input type="checkbox"/> Other Sporting Goods
<input type="checkbox"/> Rentals
<input type="checkbox"/> Tours
<input type="checkbox"/> Restaurant/Bar/Coffee Shop
<input type="checkbox"/> Lodging (hotel, motel, RV park, etc.)
<input type="checkbox"/> Marina / Launch / Port | <input type="checkbox"/> Market / Sundries
<input type="checkbox"/> Casino
<input type="checkbox"/> Boat Repair
<input type="checkbox"/> Gasoline /Fuel
<input type="checkbox"/> Other (please specify)
<hr style="width: 100%;"/> |
|--|---|

Recreational Fishing Questions

2) In your opinion, how important is recreational fishing to your business? (Please check one):

- | | | |
|--|---|---|
| <input type="checkbox"/> Extremely important | <input type="checkbox"/> Somewhat important | <input type="checkbox"/> Not at all important |
| <input type="checkbox"/> Very important | <input type="checkbox"/> Not very important | <input type="checkbox"/> Don't know |

3) In your opinion, how important is recreational Pacific halibut fishing, in particular, to your business? (Please check one):

- | | | |
|--|---|---|
| <input type="checkbox"/> Extremely important | <input type="checkbox"/> Somewhat important | <input type="checkbox"/> Not at all important |
| <input type="checkbox"/> Very important | <input type="checkbox"/> Not very important | <input type="checkbox"/> Don't know |

4) What specific goods/services does your business provide for recreational fishing activities, especially recreational fishing for Pacific halibut?

a) Do fishermen buy your goods/services directly? Yes No

5) How long is the drive from your business to the nearest boat launch, marina, or port that is often used by sport fishermen (private or charter)?

- Less than 1 miles 1 to 5 miles Between 5 and 20 miles More than 20 mile

6) Were you aware that the Pacific halibut recreational fishery was closed in August of this year (federal and state regulations mandated that the Pacific halibut fishery in California be closed this August)?

- Yes No

7) How much do you believe the August 2014 Pacific halibut closure negatively affected your business?

- | | | |
|--|---------------------------------------|---------------------------------------|
| <input type="checkbox"/> Major effect | <input type="checkbox"/> Neutral | <input type="checkbox"/> No effect |
| <input type="checkbox"/> Moderate effect | <input type="checkbox"/> Minor effect | <input type="checkbox"/> I don't know |

8) If affected, how do you believe the closure affected your business?

9) How would you rate your level of familiarity of management of sport fishing in general?

- Extremely familiar
 Moderately familiar
 Somewhat familiar
 Slightly familiar
 Not at all familiar

10) How would you rate your level of awareness of Pacific halibut sport fishing management?

- Extremely familiar
 Moderately familiar
 Somewhat familiar
 Slightly familiar
 Not at all familiar

11) Do you have any additional comments about the Pacific halibut recreational fishing closure and how it may have affected/continue to affect your business or the local community?

12) What are your thoughts on the Pacific halibut closure?

Business-Related Questions

13) How many of your employees work year-round (2013)? Part time: _____ Full time: _____

14) How many of your employees work seasonally (2013)? Part time: _____ Full time: _____

15) Overall, did you change staff in August 2014?

- No
 Yes, by _____ full-time and _____ part-time positions

16) Were the staff changes because of the loss of business due to the Pacific halibut closures?

- Yes No

17) Please estimate your business' gross revenue for 2013 (check one):

- | | |
|--|---|
| <input type="checkbox"/> Less than \$50,000 | <input type="checkbox"/> \$500,001 - \$1,000,000 |
| <input type="checkbox"/> \$50,001 - \$100,000 | <input type="checkbox"/> \$1,000,001 - \$2,500,000 |
| <input type="checkbox"/> \$100,001 - \$250,000 | <input type="checkbox"/> \$2,500,001 - \$5,000,000 |
| <input type="checkbox"/> \$250,001 - \$500,000 | <input type="checkbox"/> \$5,000,001 - \$10,000,000 |

18) How was your business' gross revenue for 2013 relative to a typical year? (Please check one):

- Much better About the same Much worse
 Somewhat better Somewhat worse

19) In a typical year, how much of your gross revenue is earned during the months of July and August?

TYPICAL JULY

- 0% - 10%
 11% - 20%
 21% - 30%
 31% - 40%
 41% - 50%
 51% - 60%
 61% - 70%
 71% - 80%
 81% - 90%
 91% - 100%

TYPICAL AUGUST

- 0% - 10%
 11% - 20%
 21% - 30%
 31% - 40%
 41% - 50%
 51% - 60%
 61% - 70%
 71% - 80%
 81% - 90%
 91% - 100%

20) How did your business' gross revenues for July 2014 compare to those for the same period last year (July 2013)?

- Higher Lower About the same Not applicable

21) How did your business' gross revenues for August 2014 compare to those for the same period last year (August 2013)?

- Higher Lower About the same Not applicable

22) How much revenue do you estimate you lost in 2014, due to the Pacific halibut closure? _____

23) If August 2014 revenues were higher or lower than August 2013, by how much? (Please leave blank if you marked "about the same" or "not applicable" above.)

- 0% - 10% 21% - 30% 41% - 50% 61% - 70% 81% - 90%
 11% - 20% 31% - 40% 51% - 60% 71% - 80% 91% - 100%

24) What factors do you believe were responsible for your change in revenue, if any, between 2013 and 2014?

25) Finally, do you have any closing comments?

Appendix B

Appendix B: California North Coast Sportfishing Survey

Greetings and thank you for participating in this survey! The purpose of this survey is to understand the effect of the August 2014 Pacific Halibut block closure on recreational fishing in northern California. We would like to know what effect the month-long closure of this fishery has had on your recreational fishing habits.

This survey was developed by the Humboldt Area Saltwater Anglers (HASA), a 503(c)(4) exempt organization, in partnership with Ecotrust, a 501(c)(3) nonprofit organization based in Portland, Oregon.

This survey can be returned by the following ways:

- Mail: HASA, PO Box 6191, Eureka, CA 95502
- Fax: 707-445-9118
- Drop-off: Englund Marine Eureka, Englund Marine Crescent City, Mario's Marina Shelter Cove, or Seascape Pier Trinidad

*1. Have you been saltwater sport fishing off the north coast of California (including the ports of Trinidad, Humboldt Bay, Shelter Cove, and Crescent City) over the 2013 and 2014 seasons?

Yes
 No

*2. If you planned to go but did not ultimately end up going, why not? Please select only ONE answer from the list below.

The weather was unfavorable
 My target species, Halibut, was closed
 No, I never planned to go
 My target species (any other species) was closed (fill in target _____)
 Family emergency
 My plans changed
 Other

Other (please specify _____)

*3. Has Pacific Halibut been one of your primary target species (regardless of catch) during one or more of these trips off the north coast of California over the 2013 and 2014 fishing seasons?

Yes
 No

*4. Approximately how many times have you been to each of the following ports for saltwater sport fishing and over the 2013 and 2014 recreational fishing seasons?

Trinidad _____
Humboldt Bay _____
Shelter Cove _____
Crescent City _____
All others _____

*5. Of these trips, approximately how many of them included Pacific Halibut as the primary target species for the trip (regardless of catch)?

Trinidad _____
Humboldt Bay _____
Shelter Cove _____
Crescent City _____
All others _____

*6. Please rank the importance of each species to your overall saltwater sport fishing experience, from most to least important.

	Most important	Second Most Important	Third Most Important	Second Least Important	Least Important
Albacore	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pacific Halibut	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Salmon	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rockfish/Lingcod	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any Other	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Any Other (please specify)

*7. For how long have you been visiting the north coast of California for sport fishing?

	Just the last year	1-3 years	4-7 years	More than 7 years	All my life
Pacific Halibut fishing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sport fishing overall	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

*8. Weather conditions aside, what are your preferred days of the week for sport fishing? Please select up to TWO days.

- Monday
 Tuesday
 Wednesday
 Thursday
 Friday
 Saturday
 Sunday

The following questions relate specifically to your most recent trip where your primary purpose included fishing for Pacific Halibut (regardless of catch) off the north coast of California (including the ports of Trinidad, Humboldt Bay, Shelter Cove, and Crescent City).

*9. When did the trip occur? Your best estimate is fine.

Date of last trip MM / DD / YYYY

*10. Please estimate the total number of miles you traveled for this trip (round trip).

Total number of miles on land: _____

Total number of miles on water: _____

*11. From which port(s) did you fish during your trip? Please select all that apply.

- Trinidad
 Humboldt Bay
 Shelter Cove
 Crescent City
 N/A
 Other (please specify) _____

*12. If you stayed overnight, in which port/town(s) did you stay? Please select all that apply.

- Trinidad
 Humboldt Bay
 Shelter Cove
 Crescent City

<input type="checkbox"/> I live in the area <input type="checkbox"/> Other (please specify) _____	
<p>*13. For how many nights did you stay in each port/town?</p> Trinidad _____ Humboldt Bay _____ Shelter Cove _____ Crescent City _____ I live in the area _____ Other _____	
<p>*14. Please estimate how much your party spent on the following items over the course of this trip.</p> Parking _____ Food and beverages from a store _____ Food and beverages at a restaurant or bar _____ Souvenirs (t-shirts, posters, gifts, etc.) _____ Sundries (sunscreen, surf wax, motion sickness pills, batteries, film and processing etc.) _____ Boat rental _____ Car rental _____ Boat fuel _____ Car fuel _____ Ramp fees _____ Bait and tackle _____ Lodging (if you stayed overnight) _____ Charter fishing fee _____ Lessons, clinics, camps _____ Fishing license fees _____ Entertainment / casinos _____ Other _____	
<p>*16. Which mode of fishing did you use on your last Pacific Halibut fishing trip? Please select only ONE answer from the list below.</p> <input type="checkbox"/> Rental boat <input type="checkbox"/> Charter/Party boat <input type="checkbox"/> Private boat (personal, friend, or family owned) <input type="checkbox"/> Kayak <input type="checkbox"/> Other (please specify) _____	
<p>*17. How many Pacific Halibut did your party catch?</p> Number of fish caught: _____	
<p>*18. Did you fish for another species besides Pacific Halibut during the course of your trip?</p> <input type="checkbox"/> Yes <input type="checkbox"/> No	
<p>*19. If you fished for Salmon: what was your main motivation for doing so? Please select only ONE answer from the list below.</p> <input type="checkbox"/> Because Pacific Halibut were not biting <input type="checkbox"/> I always planned to fish for this species also <input type="checkbox"/> Because ocean conditions were not right for Pacific Halibut <input type="checkbox"/> Because the closure prevented me from catching Pacific Halibut <input type="checkbox"/> Other (please specify) _____	
<p>*20. If you fished for Albacore: what was your main motivation for doing so? Please select only ONE answer from the list below.</p>	

<input type="checkbox"/> I always planned to fish for this species also <input type="checkbox"/> Because Pacific Halibut were not biting <input type="checkbox"/> Because ocean conditions were not right for Pacific Halibut <input type="checkbox"/> Because the closure prevented me from catching Pacific Halibut <input type="checkbox"/> Other (please specify) _____
<p>*21. If you fished for Rockfish or Lingcod: what was your main motivation for doing so? Please select only ONE answer from the list below.</p> <input type="checkbox"/> I always planned to fish for this species also <input type="checkbox"/> Because Pacific Halibut were not biting <input type="checkbox"/> Because ocean conditions were not right for Pacific Halibut <input type="checkbox"/> Because the closure prevented me from catching Pacific Halibut <input type="checkbox"/> Other (please specify) _____
<p>*22. If you fished for any other species: what was your main motivation for doing so? Please select only ONE answer from the list below.</p> <input type="checkbox"/> I always planned to fish for this species also <input type="checkbox"/> Because Pacific Halibut were not biting <input type="checkbox"/> Because ocean conditions were not right for Pacific Halibut <input type="checkbox"/> Because the closure prevented me from catching Pacific Halibut <input type="checkbox"/> Other (please specify) _____
<p>*23. How likely are you to come to this area for Pacific Halibut sport fishing again when the fishery is re-opened?</p> <input type="checkbox"/> Very likely <input type="checkbox"/> Likely <input type="checkbox"/> Neutral <input type="checkbox"/> Unlikely <input type="checkbox"/> Very unlikely
<p>Please explain briefly the reason for your choice.</p> <hr/>
<p>The next series of questions will ask you about the August closure of the Pacific Halibut fishery, and its impact on your fishing experience.</p>
<p>*24. Over the last month (August 2014), would you have fished for Pacific Halibut off the north coast of California had there not been a closure?</p> <input type="checkbox"/> Yes <input type="checkbox"/> No
<p>25. How many trips do you think you would have made? Number of trips: _____</p>
<p>*26. In what ways has the August 2014 Pacific Halibut closure changed your usual sport fishing experiences in the north coast of California over the 2014 season? Please select all that apply.</p> <input type="checkbox"/> I pursued Pacific Halibut on the north coast area more heavily from May through July and/or plan to do so September through October to account for the closure. <input type="checkbox"/> I pursued or plan to pursue other species instead <input type="checkbox"/> I traveled or plan to travel to areas outside of the closure to continue fishing for Pacific Halibut elsewhere <input type="checkbox"/> I went sport fishing less frequently <input type="checkbox"/> I stopped or plan to stop all sport fishing entirely for that month.

I was impacted in other ways (please specify) _____

*27. If future harvest reductions were implemented, what restrictions would least impact you? Please select only ONE answer from the list below.

Punch cards or stamps (quota)

Monthly block closures similar to August 2014

Closures on specific days of the week (e.g. Tuesday/Thursday/Sunday)

Other (please specify) _____

28. Lastly, are there any overall comments you'd like to make regarding Pacific Halibut sport fishing in the north coast of California (e.g. your experience, its significance to you, the closures, the future of the fishery)?

Appendix C

Appendix C: California North Coast Charter Survey

Dear Humboldt Bay Area Charter Boat Business Owner:

As part of an economic analysis of the August 2014 Pacific Halibut closures, we are asking for your assistance in completing a survey about your business.

The Humboldt Area Saltwater Anglers (HASA), a 503(c)(4) exempt organization, has contracted with Ecotrust, a 501(c)(3) nonprofit organization, to conduct an economic analysis by providing a baseline understanding of the economic contribution of recreational fishing, specifically for Pacific Halibut, to the north coast of California (including the ports of Trinidad, Humboldt Bay, Shelter Cove, and Crescent City) economy. One key component of this project is to better understand the economic impacts to area charter boat businesses. Your information will help us do that.

This survey consists of fourteen questions about the impact of the August 2014 Pacific Halibut block closure on your business. We are only asking for your estimates of impacts – you do not need to record exact dollar values or percentages.

You may be assured of complete confidentiality. By completing the survey, you agree to participate under the following conditions:

Only Ecotrust staff operating under a strict confidentiality protocol will handle the raw data generated by these surveys. All information collected in the interviews is anonymous and confidential on the individual level. All analyses and results will be presented only in aggregate form. The information will be used to create a profile of Humboldt Bay area businesses related to recreational fishing and to provide estimates of the economic impact associated with the August 2014 Pacific Halibut closures.

Your willingness to participate is not only appreciated, but indeed vital to the success of this project. For accuracy of results, please make sure you fill out this survey only once!

Thank you for your time and participation!

*1. Where is your business located?

- Trinidad
 Eureka/Humboldt Bay
 Shelter Cove
 Crescent City
 Other (please specify) _____

*2. How long have you been in business?

- Less than 1 year
 More than 1 and less than 3 years
 More than 3 and less than 5 years
 More than 5 and less than 10 years
 More than 10 and less than 25 years
 More than 25 years

*3. How many of your business' employees, including yourself and any family members, work year round?

Part time: _____

Full time: _____

*4. How many of your business' employees, including yourself and any family members, work seasonally?
 Part time: _____
 Full time: _____

*5. Please estimate your business' gross revenue for 2013:

	<\$50,000	\$50,001-\$100,000	\$100,001-\$500,000	\$500,001-\$1,000,000	\$1,000,001-\$2,500,000	\$2,500,001-\$5,000,000	\$5,000,001-\$10,000,000	>\$10,000,000
Gross business revenue for 2013	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

*6. In your opinion, how important is the availability of recreational fishing to the success of your business?

- Extremely important
- Very important
- Somewhat important
- Not very important
- Not at all important

*7. In your opinion, how important is the availability of recreational Pacific Halibut fishing in particular to the success of your business? Please check one:

- Extremely important
- Very important
- Somewhat important
- Not very important
- Not at all important

*8. How much did the August 2014 Pacific Halibut closure affect your business?

- Enormously
- A lot
- Somewhat
- A little bit
- Not at all

*9. In a typical year, about what percentage of your gross revenue is earned during the months of July and August?

	0%-10%	10%-20%	20%-30%	30%-40%	40%-50%	50%-60%	60%-70%	70%-80%	80%-90%	90%-100%
Revenue in July	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Revenue in August	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

*10. Were your earnings made in July and August this year lower, the same, or higher compared to your earnings made in those same months last year?

	Lower	The same	Higher
July 2014 compared to July 2013 was:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
August 2014 compared to August 2013 was:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

*11. If revenues during these months this year were either lower or higher than during the same months last year, by about how much? (Not necessary to complete if you marked "The same" above)										
	0%- 10%	10%- 20%	20%- 30%	30%- 40%	40%- 50%	50%- 60%	60%- 70%	70%- 80%	80%- 90%	90%- 100%
Percent (%) change in monthly revenues, July 2014 vs. July 2013	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Percent (%) change in monthly revenues, August 2014 vs. August 2013	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
*12. Overall, did your business reduce workforce due to the August Pacific Halibut closure?										
<input type="checkbox"/> Yes										
<input type="checkbox"/> No										
*13. By how many full-time and part-time positions did your business reduce its workforce due to the August 2014 Pacific Halibut closure?										
Full time positions reduced: _____										
Part time positions reduced: _____										
14. Any closing comments on the importance of recreational fishing, Pacific Halibut fishing, or the impact of the August 2014 Pacific Halibut closure to your business?										

Appendix D

Talking points used by HASA when distributing economic surveys:

- HASA and partners with Humboldt State, California Sea Grant, Ecotrust, and the California Department of Fish and Wildlife are conducting this survey to get a better understanding of how the closure of the Pacific halibut sport fishery this year affected businesses and the economy of the North Coast
- The sport fishery for Pacific halibut was closed in California for the month of August for the first time this year.
- The reason for this closure is to bring the amount of fish caught in our area down closer to the tiny fraction of the west coast catch that we have been allotted.
- Recent research (by Humboldt State and by the International Pacific Halibut Commission) suggests that, unlike further north (in Oregon, Washington, Alaska, and Canada) the Pacific halibut in our region are abundant and are not showing signs of overharvest.
- Though the science suggests that the August closure is not necessary, in order to prevent future closures, our region needs to be allocated more catch – and documenting the economic impact of the closure will strengthen the argument for doing this.
- All information you provide will be kept confidential and anonymous and will be analyzed and shared only in aggregate with data from many other businesses.
- The more complete and accurate information you provide, the stronger the conclusions we will be able to reach, and more weight the study will have.
- The results of this study will be presented to the fishery governing bodies (International Pacific Halibut Commission and the National Marine Fisheries Service), in the hopes that halibut allocations could be revisited, and future closures in our area could be prevented.
- If you have any questions, please don't hesitate to contact Miki Takada, Master's student at Humboldt State University, at (XXX) XXX-XXXX.

Appendix E



MEMORANDUM

Date: 9/22/2014

To: Laurie Richmond
Miki Takada

From: Ann Warner Nagy
Institutional Review Board for the Protection of Human Subjects

IRB #: IRB 14-020

Subject: The socio-economic effects of the August Pacific Halibut closure on North Coast businesses

Thank you for submitting your application to the Committee for the Protection of Human Subjects in Research. After reviewing your proposal I have determined that your research can be categorized as Exempt by Federal Regulation 45 CFR 46.101 (b) because of the following:

Your research will involve the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interviews procedures or observation of public behavior, and that information obtained will be recorded in a manner that the human subjects will not be able to be identified directly, or through identifiers linked to the subjects; and any disclosure of the human subjects' responses outside the research would not reasonable place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

The Exempt designation of this proposal will expire on **9/21/2015**. By Federal Regulations, all research related to this protocol must stop on the expiration date and the IRB cannot extend a protocol that is past the expiration date. In order to prevent any interruption in your research, please submit a renewal application in time for the IRB to process, review, and extend the Exempt designation (at least one month).

Important Notes:

- Any alterations to your research plan must be reviewed and designated as Exempt by the IRB prior to implementation.
 - Change to survey questions
 - Number of subjects
 - Location of data collection,
 - Any other pertinent information
- If Exempt designation is not extended prior to the expiration date, investigators must stop all research related to this proposal.
- Any adverse events or unanticipated problems involving risks to subjects or others must be reported immediately to the IRB (irb@humboldt.edu).

cc: Faculty Adviser (if applicable)
Department or Unit Chair
Institutional Review Board for the Protection of Human Subjects

The California State University

Bakersfield • Channel Islands • Chico • Dominguez Hills • East Bay • Fresno • Fullerton • Humboldt • Long Beach • Los Angeles • Maritime Academy • Monterey Bay
• Northridge • Pomona • Sacramento • San Bernardino • San Diego • San Francisco • San Jose • San Luis Obispo • San Marcos • Sonoma • Stanislaus

CHAPTER 2

CHARACTERIZING THE AGE AND GROWTH OF PACIFIC HALIBUT IN
NORTHERN CALIFORNIA AND CENTRAL OREGON

ABSTRACT

Age and growth are important components in stock assessment models, but biological data in general are sparse for populations of Pacific halibut found in northern California. For this reason, I conducted a study that examined the age and growth of Pacific halibut landed in this region, expanding on a previous study to examine possible interannual variation in the age/growth structure, and broadened the study into central Oregon, to compare between two unique bioregions. Results from my study show that the mean size-at-age of female Pacific halibut caught off northern California and central Oregon was similar to that of fish from Oregon and Washington, but larger than that of fish caught off most of Alaska. In addition, fish from this study in northern California and central Oregon were smaller for a given age than those from the 2013 and 2014 studies done in northern California. Possible reasons for the change in size-at-age include poor oceanic conditions during my study, the movement of slower-growing halibut into northern California waters, and sampling error.

INTRODUCTION

Age and growth are important components in stock assessment models, as they are used to determine whether or not fisheries are being managed sustainably (Lux 1959, Chilton and Beamish 1982, Forsberg 2001). Despite the importance of these data, biological data in general are scarce for populations of Pacific halibut found in northern California. Consequently, I conducted a study that examined the age and growth of Pacific halibut landed in this region. Based on data collected and analyzed by Perkins (2015), it appears that Pacific halibut captured off northern California are considerably larger-at-age than Pacific halibut captured in more northern areas. My project expanded on this study, extending the data for an additional year to examine possible interannual variation in the age/growth structure. In addition, I broadened the study into central Oregon (Charleston), which allowed for a comparison between two unique bioregions.

Description of the Northern California and Central Oregon Bioregions

Two counties make up the northern California coastal bioregion – Humboldt and Del Norte. Humboldt County is south of Del Norte County, and includes Humboldt Bay and Cape Mendocino. Humboldt Bay has the deepest harbor in California north of San Francisco, and the second largest estuary in the state (CDFW 2010). Wind regimes differ dramatically north and south of Cape Mendocino, with the main upwelling season occurring earlier in the year and lasting longer south of Cape Mendocino (though the storms north of the cape produce stronger winds; Largier et al. 1993). With three tectonic plates (Gorda, North American, and the Pacific plates) all coming together offshore of

Cape Mendocino, this region is one of the most seismically active in the contiguous United States (USGS 2007).

Rocky shores characterize much of the Humboldt County coastline; Cape Mendocino, Trinidad Head, and Patrick's Point are all found in this region (Figure 2.1). Tidal flats occur at Mad River, Humboldt Bay, and the Eel River Estuary. Mad River Slough is a salt marsh, the entrance of Humboldt Bay and the lower Eel River Estuary are exposed tidal flats, and sheltered tidal flats exist north and south of Humboldt Bay and in the Eel River Estuary. Soft-bottom habitat can be found from Cape Mendocino to Trinidad Head, and nearshore and offshore of Agate Beach to the mouth of the Klamath River. Hard-bottom habitat is observed nearshore from Camel Rock to Wedding Rock, and from the mouth of the Klamath River to Crescent City. Four submarine canyons – Delgada, Spanish, Mattole, and Mendocino canyons – exist along the Humboldt County coast (CDFW 2010).

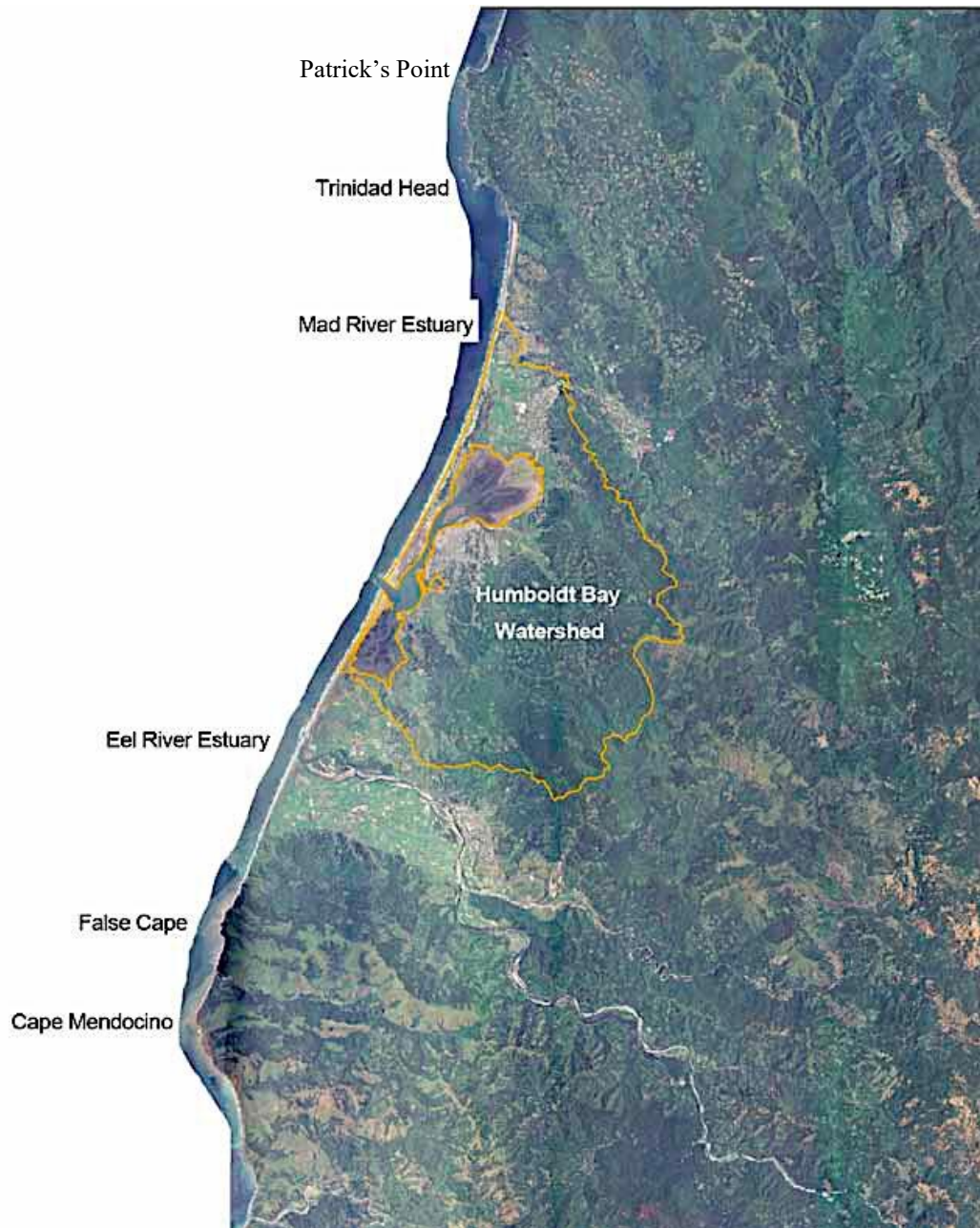


Figure 2.1. Map showing the northern California coast (Schlosser and Eicher 2012).

Jagged coastline and a narrow shelf are the main features of the Del Norte County coastline, with the Smith River (California's largest river system) and the Klamath River flowing into the ocean within the county. The Crescent City Harbor is found in Del Norte

County. Hard-bottom habitat exists offshore from Saint George's Reef to the California-Oregon border (CDFW 2010).

Biologists and oceanographers have identified two physical barriers along the Oregon coast – Cape Blanco and the Columbia River – that affect currents, and thus the movement of organisms. This translates to three bioregions in Oregon – one from the California-Oregon border to Cape Blanco, one from Cape Blanco to the Columbia River, and one from the Columbia River to the Oregon-Washington border (Figure 2.2; Heppell et al. 2008). Charleston is part of the Cape Blanco to Columbia River bioregion, and habitats in this area include rocky shore, sandy beach, rocky subtidal, and soft bottom subtidal (Figure 2.3; ODFW 2012).

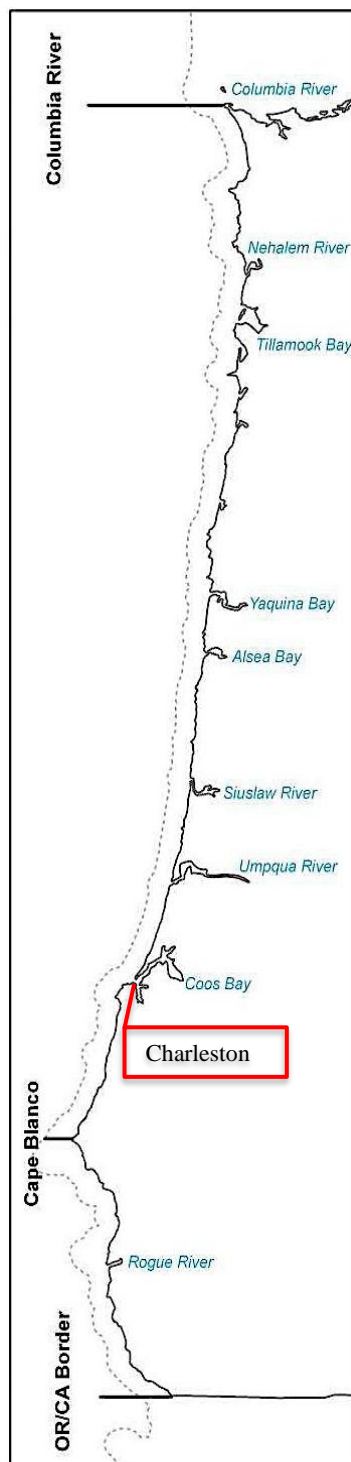


Figure 2.2. The 3 bioregions (the CA/OR border to Cape Blanco, from Cape Blanco to the Columbia River, and from the Columbia River to the OR/WA border) of Oregon (Heppell et al. 2008).

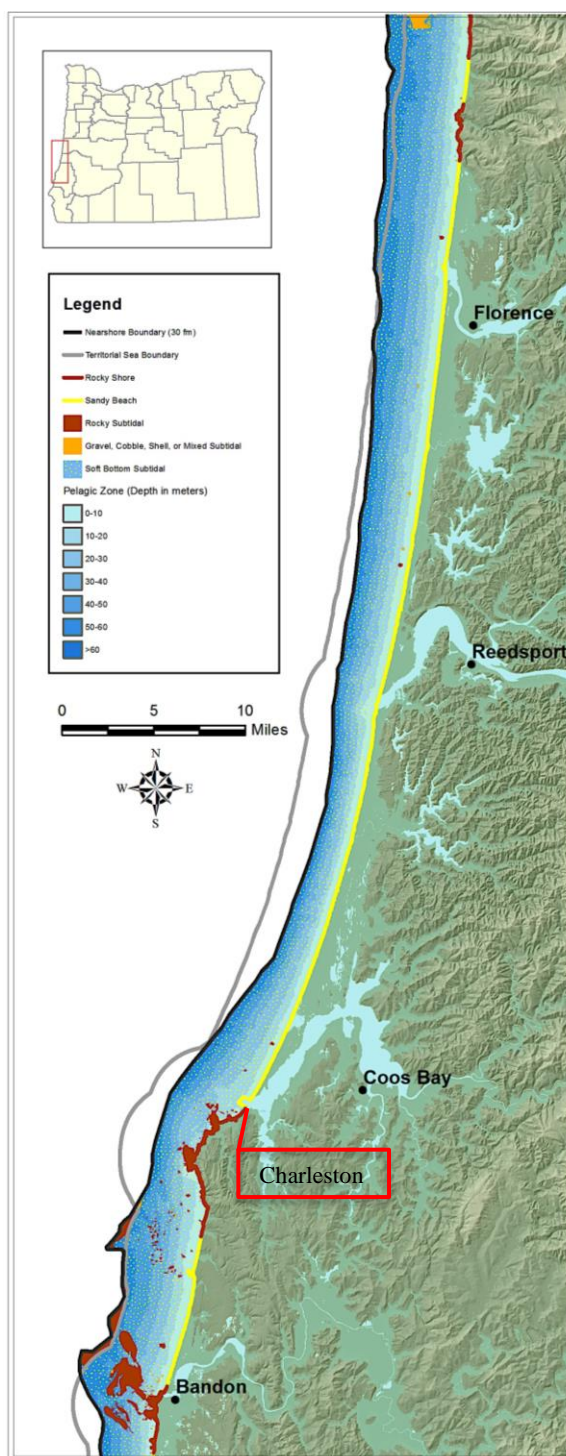


Figure 2.3. Habitats found within the Cape Blanco to Columbia River bioregion (ODFW 2012).

In a similar vein, the Nature Conservancy conducted an ecoregional assessment of the marine environment in the Pacific Northwest in 2013. The study assessed the area between Cape Mendocino, California, and Cape Flattery, Washington, encompassing approximately 100,000 square km, and created four ecoregional sections within this area – from Cape Mendocino to Cape Blanco, from Cape Blanco to Cape Lookout, Oregon, from Cape Lookout to Point Grenville, Washington, and from Point Grenville to the Washington-Canada border (Figure 2.4). The Cape-Mendocino-Cape Blanco section corresponds to the northern California section of my study, while the Cape Blanco-Cape Lookout section corresponds to the central Oregon section of my study. While the bioregion boundaries of this Nature Conservancy assessment and that of the Heppell survey differ somewhat, they both designate Cape Blanco as a major physical barrier that differentiates the area south of the cape to the area north of it. The Cape Mendocino-Cape Blanco region is characterized by strong upwelling zones and a narrow continental shelf along a rocky coastline, with Cape Blanco acting as a biogeographic barrier that limits connectivity between species and populations to the north and south of it. The Cape Blanco-Cape Lookout segment includes shallow offshore banks, where many popular commercial fisheries congregate, and sand is prevalent on the nearshore shelf habitats (Vander Schaaf et al. 2013). Figures 2.5 and 2.6 illustrate the benthic habitats found along the coasts of Charleston, Oregon (Figure 2.5) and northern California (Figure 2.6).

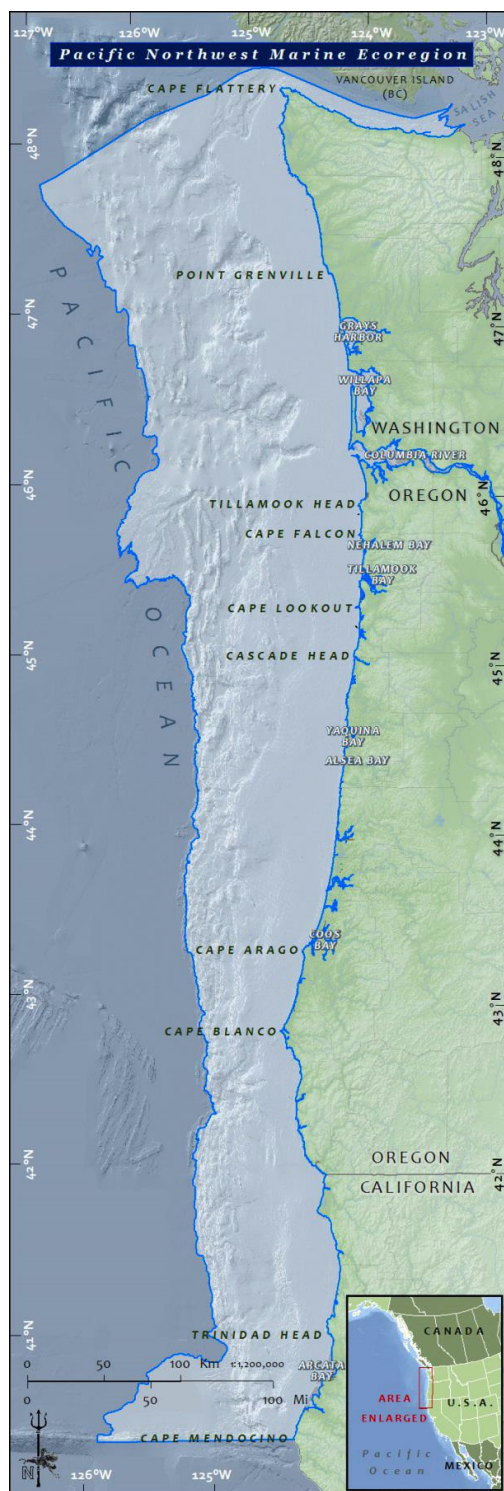


Figure 2.4. Map of PNW marine ecoregions from Cape Mendocino to Cape Flattery (Vander Schaaf et al. 2013).

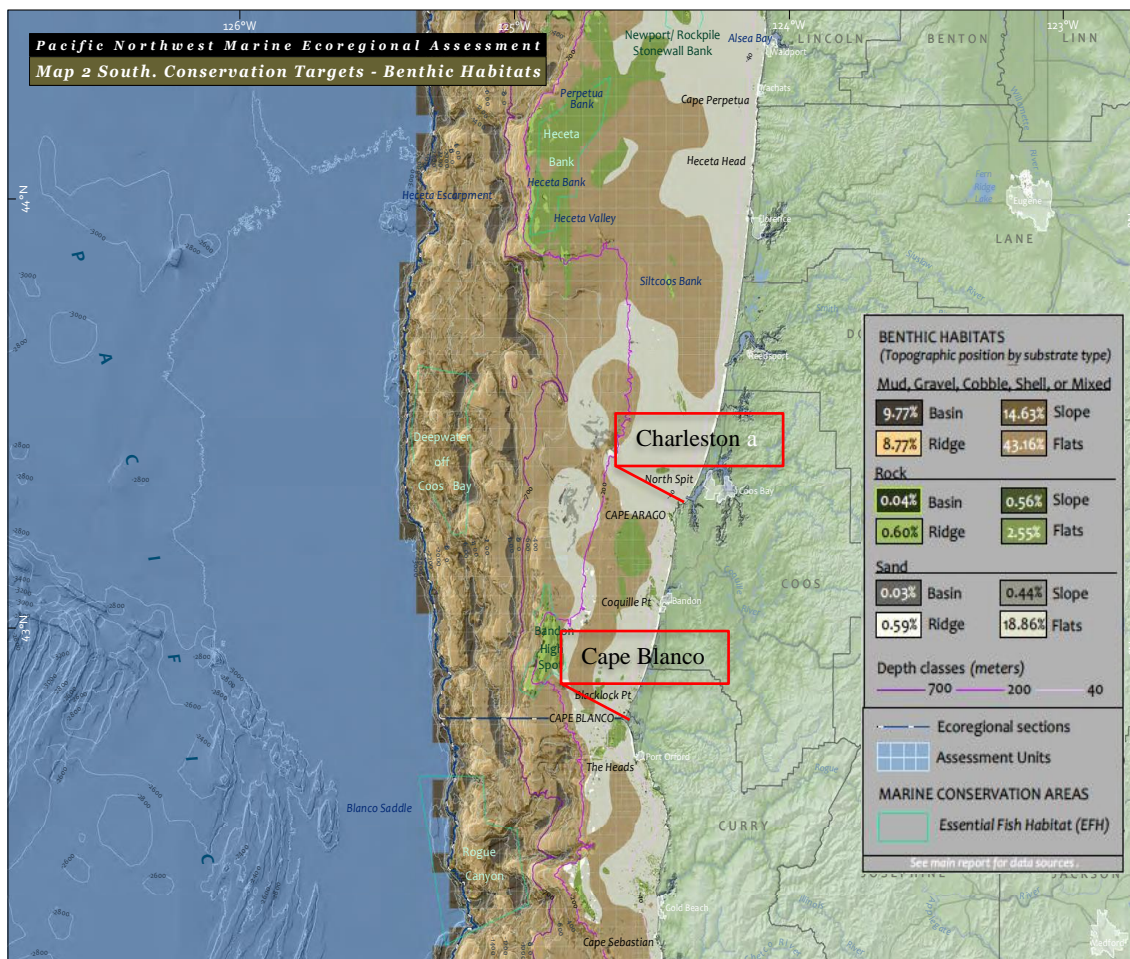


Figure 2.5. Benthic habitats found off the coast of Charleston, Oregon (Vander Schaaf et al. 2013) .

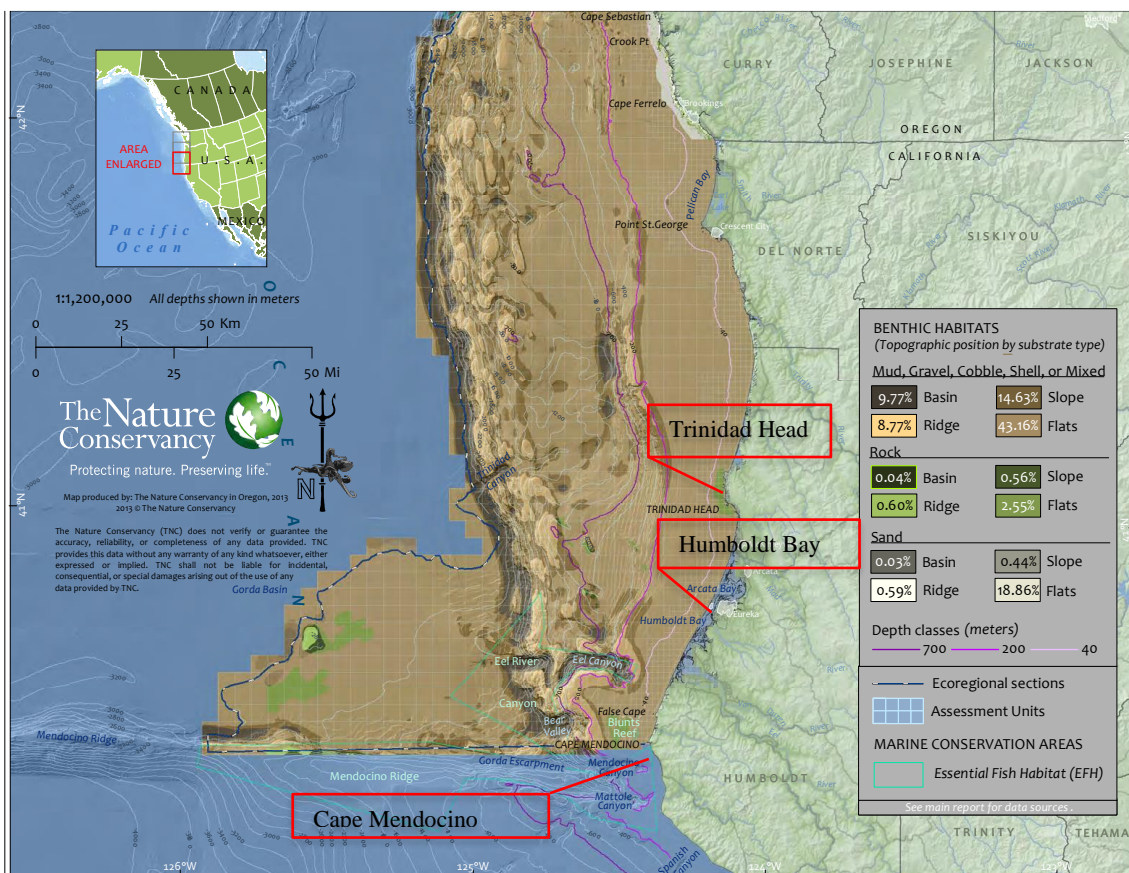


Figure 2.6. Benthic habitats found off the coast of northern California (Vander Schaaf et al. 2013).

MATERIALS AND METHODS

Sample Collection

In California, the 2015 recreational Pacific halibut fishery was open from 1 May to 15 May, 1 June to 15 June, 1 July to 15 July, and 1 August to 13 August (CDFW 2015). The Oregon fishery is split up into three Pacific halibut recreational fishery subareas: the Southern Oregon subarea (the California-Oregon border to Humbug Mountain), the Central Coast subarea (Humbug Mountain to Cape Falcon), and the Columbia River subarea (Cape Falcon to Leadbetter Point, Washington) (ODFW 2015) (Figure 2.7).

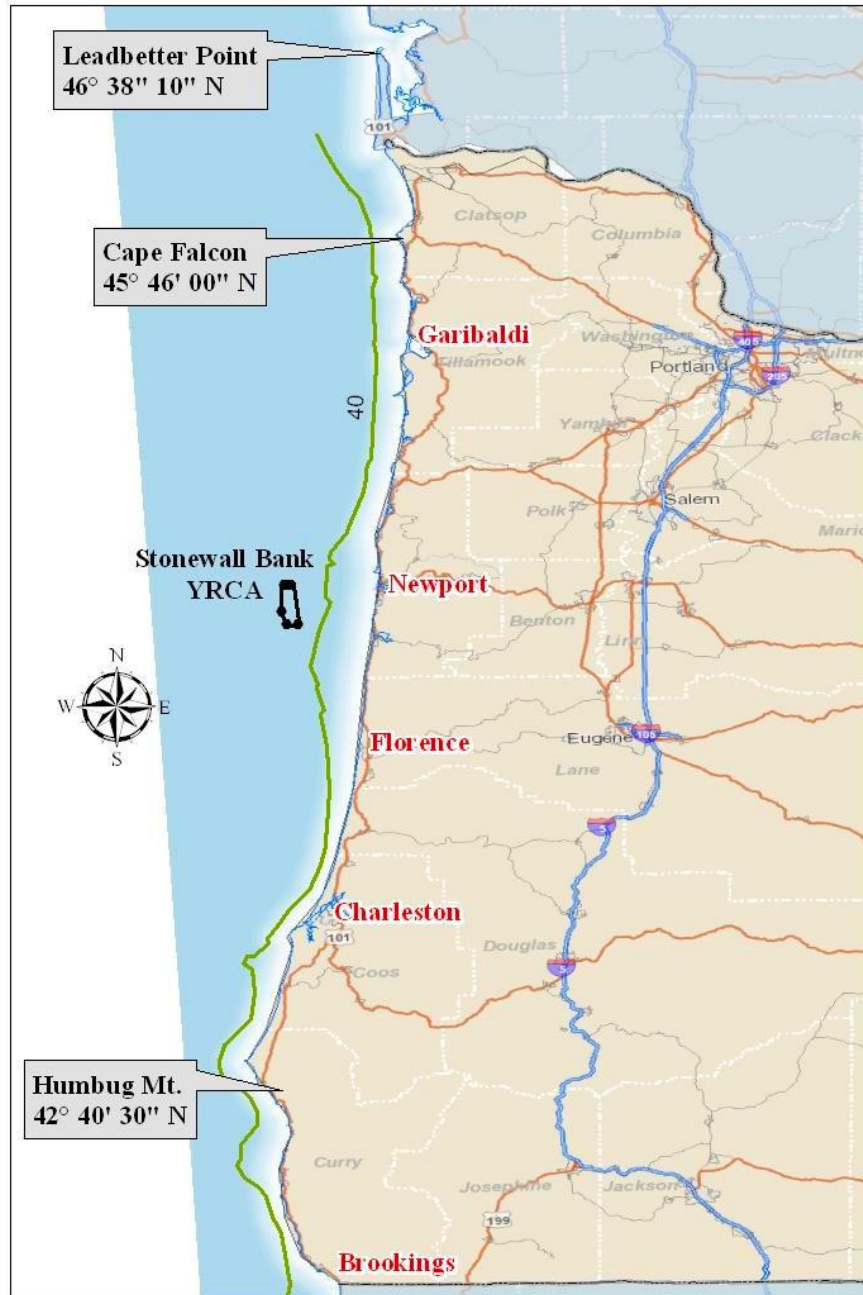


Figure 2.7. Map showing the demarcation of the 3 Pacific halibut recreational fishery subareas in Oregon (ODFW 2016).

In the Oregon Central Coast subarea, which contains the ports of Bandon, Charleston, Winchester Bay, Florence, Newport, Depoe Bay, Pacific City, and Garibaldi,

the 2015 fishery openings were separated into the “spring all-depth,” the “nearshore halibut fishery,” and the “summer all-depth” fishery (Table 2.1).

Table 2.1. Oregon Central Coast 2015 Pacific halibut season opening dates and quotas for each fishery (ODFW 2015).

	Spring all-depth fishery	Nearshore fishery	Summer all-depth fishery
Open Dates	May 14-16 May 28-30 June 11-13 June 25-27	July 1-October 18	August 7-8 August 21-22 September 4-5 September 18-19 October 2-3 October 16-17 October 30-31
Quotas	50,190 kg	9,600 kg	20,590 kg

Prior to the start of the season, I posted flyers at Eureka Public Marina, Woodley Island Marina, and the Charleston Marina (Charleston, Oregon), asking anglers to donate whole Pacific halibut or Pacific halibut carcasses to this project. I also asked businesses that I believed Pacific halibut fishers would frequent, such as Pacific Outfitters, Bucksport Sporting Goods, Mad River Tackle, Englund Marine Supply, and Salty’s Supply Company, to display the flyer at their place of business. A similar request was posted to the Humboldt Tuna Club website (<http://humboldttuna.com/>), a newsletter article was placed in the quarterly Humboldt Area Saltwater Anglers (HASA) newsletter, and I distributed flyers at the annual HASA fundraiser, held in April 2015. The flyers and newsletter article explained the purpose of the study, the data that would be collected, and how donations could be made. I also spoke to the charter boat captains that dock and moor at Woodley Island Marina, and asked them to telephone me if they caught any Pacific halibut.

Two collection bins were placed at Woodley Island Marina, one at the western end of the marina, in close proximity to the Humboldt State University research vessel, R/V Coral Sea, next to the fish cleaning station on Dock A, and the other one just southwest of the Café Marina restaurant; both were secured to a metal pole. Recreational anglers willing to donate their Pacific halibut carcasses after returning from sea could place them in these bins. Anglers were also asked to telephone me directly, in which case I met them at the location of their choosing and I collected my samples there. This allowed me to collect data and samples from whole Pacific halibut, in addition to partial carcasses left in the collection bins, which prevented me from obtaining weight information.

During the Pacific halibut season in California, I inspected the general fish carcass bin at the Eureka Public Marina daily to check for discarded halibut carcasses. Crushed ice, which was donated by local seafood processor Pacific Choice, was placed in the collection bins at Woodley Island Marina, and replaced every three or four days, to ensure that carcasses in the collection bins remained cold. The bins were also checked on a daily basis. While the Oregon Central Coast Pacific halibut season was open, I perused the bins near the fish cleaning stations at the Charleston Marina. In addition, a local charter boat business allowed me to sample all of the halibut caught during their trips.

Data Collection

For each of the Pacific halibut samples I collected, I weighed fish to the nearest tenth of a kg if the carcass was whole (not filleted), and measured the fork length (from the end of the snout to the midpoint of the caudal fin) to the nearest cm (IPHC 2013). To

obtain the otolith, I exposed the sagittal otolith on the blind side of the fish (unless the blind-side otolith was crystallized or broken, in which case I collected the eyed-side otolith) by cutting the gill arch from its dorsal terminal and cutting open the otic capsule with the tip of an eight-inch Dexter butcher knife. I extracted the otoliths using forceps, cleaned the sacculus (a fluid-filled sac in which otoliths are contained), and placed the otoliths in a solution of 50 percent water, 50 percent glycerin, and a minute amount of thymol (recipe: half gallon water, half gallon pure glycerin, 5.5 g thymol dissolved in 20 ml ethanol or isopropanol). Thymol was added to prevent bacterial and fungal growth (Forsberg 2001). The otoliths were stored in this glycerin-thymol solution for three to four weeks to allow for clearing.

In July 2015, I visited the International Pacific Halibut Commission (IPHC) office in Seattle, Washington, and was trained to age otoliths by Joan Forsberg, age room supervisor. While all teleost fishes have three pairs of otoliths, the asteriscae, lapillae, and sagittae, the IPHC has been using the sagittae otoliths for age determination since 1914 due to their larger size (Forsberg 2001).

Otoliths are the preferred method of aging teleost fishes because they continue to grow even after somatic growth has ended, unlike other hard structures, like scales, vertebrae, and spines (Kimura and Matta 2012). Otoliths, also referred to as ear bones or ear stones, are found in the inner ear of the fish, and are vital for balance, hearing, and spatial orientation, though more important for balance and orientation than hearing (Popper et al. 2005). They are formed by the accretion of concentric layers of calcium carbonate (Forsberg 2001) with alternating circles of density. The differing densities

make the layers either opaque (deposited during the summer) or translucent (deposited during the winter), and these optical properties are what are used to age the fish. One opaque and one translucent layer make up a year of growth in otoliths, and when the otolith is placed in front of a dark background under a microscope with reflected light, the opaque growth area appears light, and the translucent area appears dark in color (Matta and Goetz 2012). These one-year increments are what are counted to determine a fish's age.

Misidentifying the first annual mark, “checks,” and miscounting the final annual mark are common ways in which an otolith can be mis-aged. In order to correctly identify the first annual mark, the whole otolith is viewed under a dissecting microscope with reflected light, and the first annual mark is traced for ease of identification once the otolith is broken and burned. “Checks” refer to irregular translucent growth zones, and are sometimes mistaken for annual marks. They can be differentiated from annual marks because the growth line is not continuous throughout the otolith (Matta and Goetz 2012). As for the final annual mark, if otoliths are collected during the summer they may be lacking the translucent outer zone that gets deposited during the winter, which makes it difficult to determine whether the opaque outer edge is from the current or previous spring/summer. The IPHC policy is that the opaque zone on otoliths collected through June are counted if the “edge growth is greater than half the width of the previous opaque (summer) zone in fish older than 10 years, or almost the same width of the previous opaque zone in fish younger than 10 years” (Forsberg 2001).

We utilized two methods to determine the age of the Pacific halibut samples – the

surface method and the break and bake method. For the surface method, otoliths were removed from the glycerin-thymol solution, rinsed, and placed on a dark piece of cloth in a container filled with water. A drop of liquid detergent was added to the water to prevent the glycerin and water from mixing. The dark cloth was used to maximize contrast. This container was placed under a dissecting microscope under reflected light, which is used to minimize glare from the microscope's light source. The translucent zones on the "preferred axis" (when the otolith is held upright so that the annuli are facing the age reader and looks like a right-handed glove, the "preferred axis" is approximately where the middle finger of the glove would be located) of the otoliths were counted. In the 1940s, IPHC director Henry Dunlop discovered that annuli on Pacific halibut are completed between February and May; thus, capture date information is currently utilized to determine whether or not to add an additional year to the age count (see above; Forsberg 2001). Figure 2.8 shows a photograph of an otolith that has been processed and aged using the surface method.

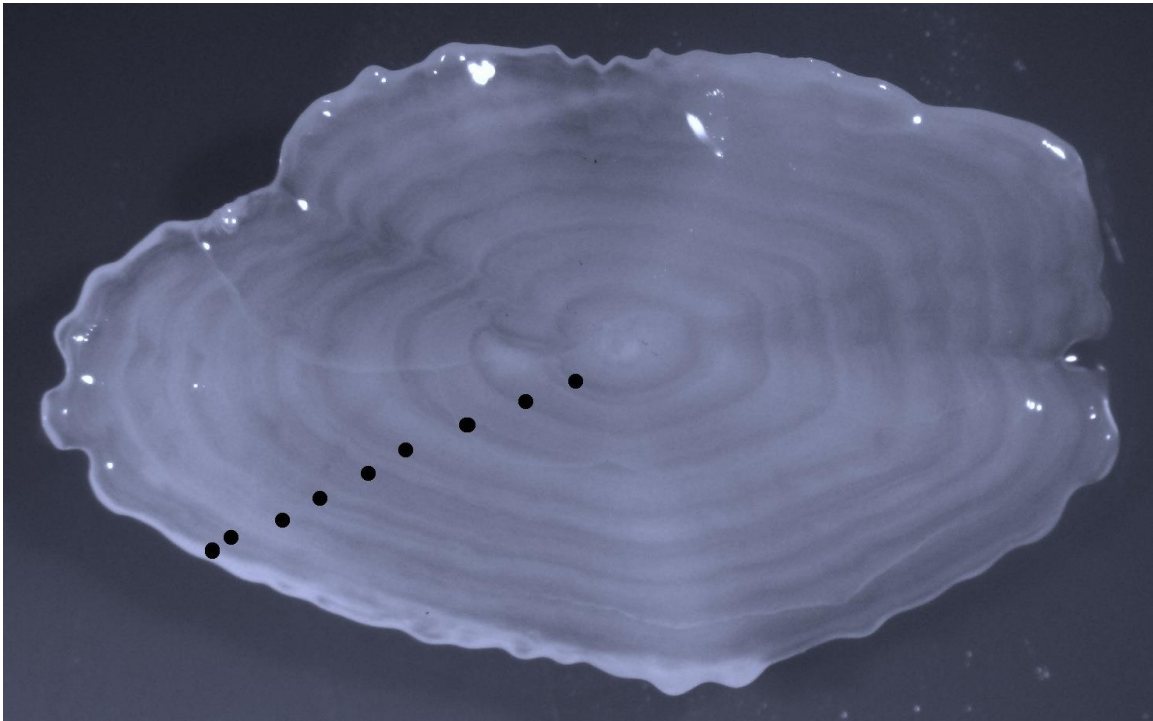


Figure 2.8. Surface photograph of otolith sample 182. Dots mark annuli counted (age=9).

After the otoliths were surface-read to determine their age, they were read again using the break and bake method. Once an otolith was surface-read, the first annulus was outlined under the microscope, using a lead pencil, and then rinsed in water and dried. Once dry, the pencil outline of the first annulus was used to score the otolith through its nucleus using a razor blade. Then, the otolith was placed atop a straightened paper clip and broken into two, dorso-ventrally. The paper clip was placed perpendicular to the otolith, and parallel to the scoring, and with my left index finger on the posterior end of the otolith, and my right index finger on the anterior end of the otolith, pressure was applied on both ends (Forsberg 2001).

Once broken in half, the posterior ends of the otoliths were placed in a wellled metal baking tray with 50 indented cells to keep each otolith half separated, and baked in

a toaster oven at 260°C for ten to twenty minutes. A metal lid was placed on top of the tray. After they were “burned,” the otoliths were coated with mineral oil, placed on a piece of modeling clay with a groove to keep the otolith in place, and viewed under a dissecting microscope. When aging the burnt otolith halves, the sulcus edges (the uneven proximal surface) are the preferred reading axes, and the pencil marking the first annulus is the first year that is counted (Forsberg 2001). Figure 2.9 shows a photograph of an otolith that has been “burned” and aged using the break and bake method.

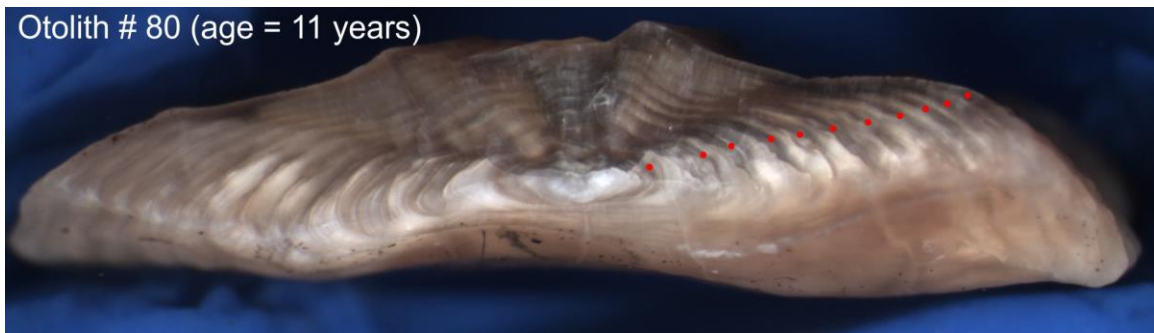


Figure 2.9. Photograph of otolith sample 80 used for break and bake. Dots mark annuli counted (age=11).

Otoliths collected through July 2015 were aged by Forsberg and myself, utilizing both the surface and break and bake methods. I then aged the remaining samples, with Forsberg performing a second, independent (double-blind) reading of these otoliths. All final ages used for my analysis were those of the double-blind readings.

IPHC Regulatory Areas

In order to better categorize catch, biological, biometric, and migration data, the IPHC separated the commercial Pacific halibut fishing grounds into statistical areas in the 1920s. Data are collected from each statistical area and combined into larger regulatory areas, to which management decisions are made. Currently, there are 10 regulatory areas

within the purview of the IPHC. Regulatory Area 2A is the only one within the boundaries of the contiguous United States, and contains fisheries in California, Oregon, and Washington (Kong et al. 2004). Regulatory Area 2B is British Columbia, 2C is southeastern Alaska, 3A is the central Gulf of Alaska, 3B is the western Gulf of Alaska, 4A is the eastern Aleutian Islands, 4B is the central and western Aleutian Islands, 4C is the Pribilof Islands, 4D is the northwestern Bering Sea, and 4E is the Bering Sea flats (IPHC 2016; Figure 2.10).

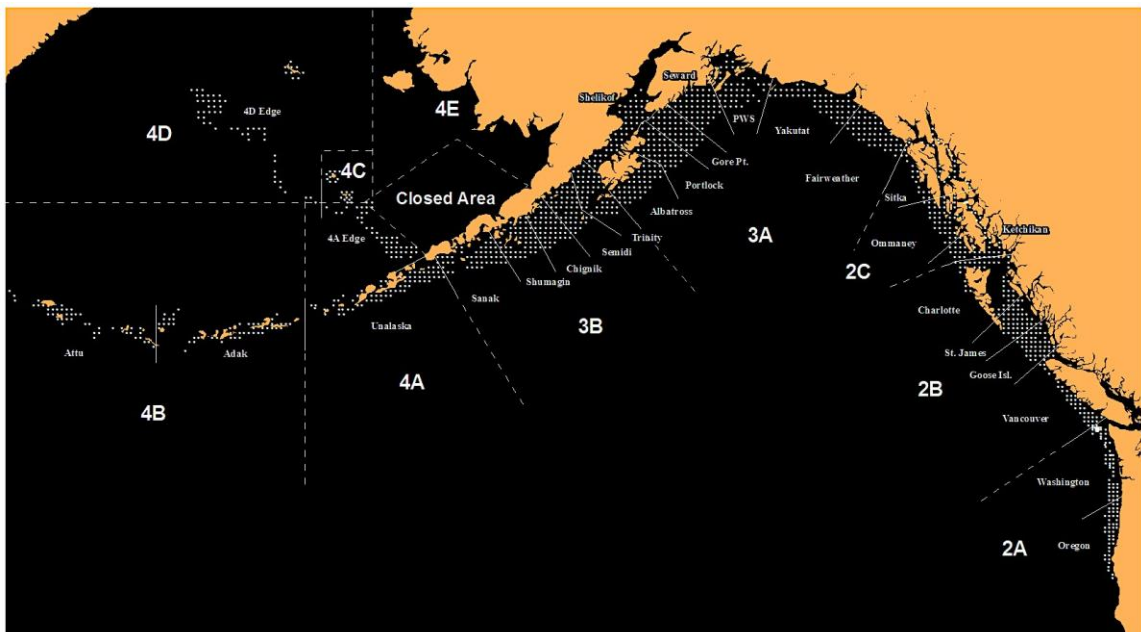


Figure 2.10. Areas where yearly IPHC setline surveys are conducted (IPHC 2015). Survey stations are represented by dots on this map.

Data Analyzed

In order to determine whether there is a difference in mean length-at-age of Pacific halibut caught in northern California and more northern waters, I compared the results of my study with those of the 2015 IPHC stock assessment survey. This survey, conducted during the summer (24 May to 21 August in 2015) by the IPHC, used setline

surveys to gather growth, distribution, biomass, age composition, sexual maturity, and relative abundance data that were then used to assess the health of the Pacific halibut stock along the eastern Pacific Ocean (IPHC 2015). Typically, the setline surveys do not extend into northern California; they are normally conducted from the Bering Sea and Aleutian Islands south and eastward along the West Coast and end at the California-Oregon border. Figure 2.10 depicts the regions that are covered by the annual setline surveys.

I first compared Pacific halibut caught off northern California and central Oregon in 2015 to determine whether there was a difference between these two bioregions. I then compared my 2015 data from California and Oregon with 2014 IPHC setline survey data for Regulatory Area 2A which was extended into northern California that year (Figure 2.11), as well as data from the 2013 study by Perkins (2015), to determine whether there is interannual variation. Thirdly, I contrasted the data I collected with those that the IPHC collected during their setline surveys in Oregon, Washington, and Alaska, to determine whether there is any regional variation. Table 2.2 summarizes the comparisons I made for this project.

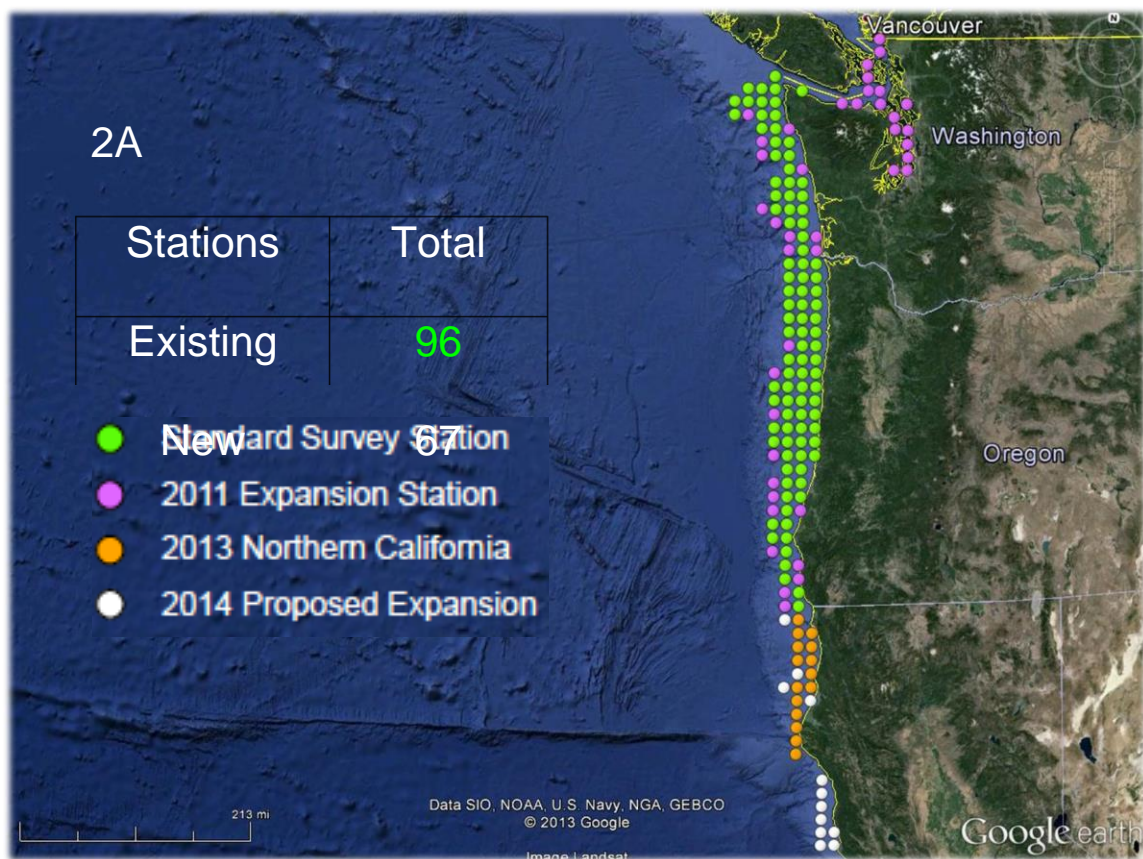


Figure 2.11. Map of the IPHC setline surveys from 2014. Surveys were conducted in California in 2014, but were not conducted in 2015 (Dykstra and Webster 2014).

Table 2.2. Summary of comparisons between data from this study and those from previous samplings (IPHC unpublished data, Perkins 2015).

1. Spatial comparison within this study	<ul style="list-style-type: none"> ● 2015 N. California (this study) ● 2015 C. Oregon (this study)
2. Comparison of interannual variation in N. California	<ul style="list-style-type: none"> ● 2013 N. California (Perkins 2015) ● 2014 N. California setline survey (IPHC) ● 2015 N. California + C. Oregon (this study)
3. Coastwide spatial comparison	<ul style="list-style-type: none"> ● 2015 N. California + C. Oregon (this study) ● 2015 Oregon setline survey (IPHC) ● 2015 Washington setline survey (IPHC) ● 2015 Alaska setline survey (IPHC)

The statistics package R (R Core Team 2015) was used to fit the Von Bertalanffy

growth equation to the length-at-age data, in order to relate the age and size of the individuals collected (Katsanevakis and Maravelias 2008). The Von Bertalanffy equation was fit to female and male data separately, as there was a significant difference in the length-at-age for the two sexes. In general, additive error is utilized when size variability is constant through age; multiplicative error is used when size varies with age (Quinn and Deriso 1999). Because size variability was constant through age, additive error was used to estimate L_{∞} , k , and t_0 , the three parameters of the Von Bertalanffy model using non-linear least squares regression for the length-at-age data collected during the IPHC setline survey. L_{∞} is the asymptotic maximum length, k is the growth coefficient, and t_0 is the hypothetical age that the fish would have been at length zero (Helsler 1995). Maximum likelihood, defined as the technique that finds the model parameters that maximize the probability of generating the observed values given the chosen model and selected parameters (Haddon 2011), was used to analyze my data.

Mean lengths-at-age of the Pacific halibut samples donated by recreational anglers in northern California and central Oregon were compared with those from other regulatory areas using independent sample t-tests.

Ethical Statement

Institutional Animal Care and Use (IACUC, Protocol No. 14/15.F.51-E) was approved for this study, per university requirements. The author sacrificed no animals for this project; all samples were collected from the Pacific halibut recreational fishery, northern California and central Oregon subareas. Pacific halibut are not a protected species.

RESULTS

A total of 268 Pacific halibut carcasses were collected from collection bins and donated by recreational anglers and charter boat operators in Humboldt and Del Norte counties (Fields Landing, Eureka, Trinidad, or Crescent City), California, and Charleston, Oregon between 9 May and 12 August 2015 (Figure 2.12). A total of 20 known donors contributed whole fish or carcasses to this project, and the remainder were anonymously dropped off in the halibut drop boxes in Eureka, or collected from anglers at the Sylvan Harbor RV Park & Cabins in Trinidad, fish carcass boxes in Crescent City or Charleston, or donated to me by customers of Betty Kay Charters in Charleston. Table 2.3 summarizes the total number of Pacific halibut collected, total number of halibut from which I collected otoliths, and the number of halibut collected from each port, by sex, and by whole fish or carcass.

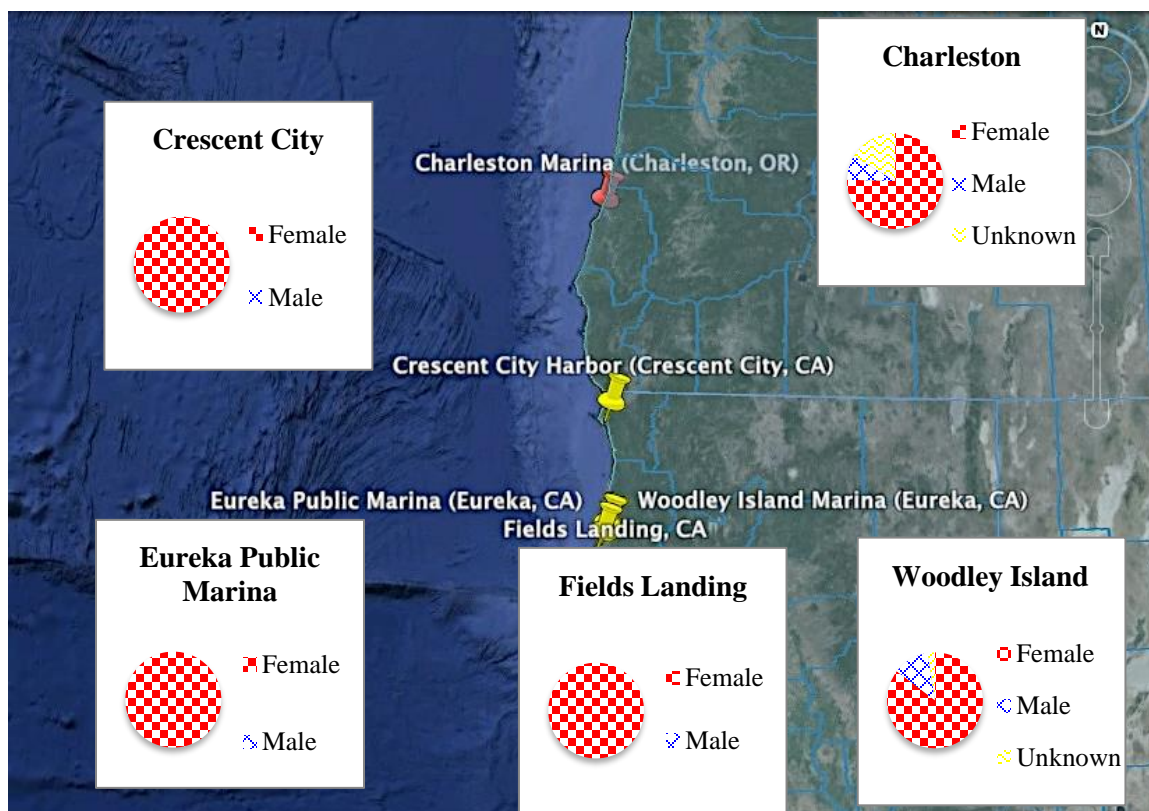


Figure 2.12. Study area and ratio of males to females caught at each location.

Table 2.3. Table containing information on the total number of Pacific halibut collected and total number of otoliths collected from each port (F=female, M=male, U=unsexed, T=total). Instances where the location is unknown are listed under “unknown”.

	Number Collected	Otoliths Taken	Collection Location																							
			Fields Landing		Eureka Public Marina			Woodley Island Marina				Trinidad			Crescent City			Charleston				Unknown				
			F	T	F	M	T	F	M	U	T	F	M	T	F	M	T	F	M	U	T	F	M	U	T	
Whole	36	3	2	2	1	0	1	15	3	0	18	3	0	3	0	0	0	15	0	0	15	0	0	0	0	
Carcass	232	247	0	0	5	0	5	66	7	4	77	25	3	28	1	0	1	77	10	20	107	11	0	0	11	
Totals	268	250	2	2	6	0	6	81	10	4	95	28	3	31	1	0	1	92	10	20	122	11	0	0	11	

A total of 250 otoliths were aged. Otoliths from the remaining samples could not be aged due to breakage or crystallization. The ages that I assigned the otoliths and those determined by the IPHC age lab had a 91 percent +/- one-year agreement, and a 43 percent complete agreement. The oldest individuals sampled were age 15 (one male and one female), while the youngest were age six (three females). A total of 225 Pacific halibut were sexed, had otoliths that were aged, and lengths that were measured reliably. Of these 225 halibut, 204 (90.67 percent) were female and 21 (9.33 percent) were male (Table 2.4).

Table 2.4. Lengths and ages of female and male Pacific halibut collected in 2015 from recreational fishers in northern California and central Oregon.

	Number	Length Range (cm)	Mean Length (cm)	Age Range (years)	Mean Age (years)	Modal Age (years)
Female	204	64-144	88.32	6-15	9.94	10
Male	21	65-94	76.82	7-15	10.23	10
Total	225	64-144	82.57	6-15	10.08	10

The average age of the males sampled was 10.23 years and that of the females sampled was 9.94 years. Male ages ranged from seven to 15 years, while female ages ranged from six to 15 years. The modal age of both males and females was 10 years. The average lengths of males and females were 76.82 cm and 88.32 cm, respectively. Table 2.5 shows the age composition and the range of lengths and mean length-at-age for male and female Pacific halibut collected during this study.

Table 2.5. Age composition, length range, mean length, and sample size of the male and female Pacific halibut collected from recreational anglers in northern California and central Oregon during the summer, 2015.

Age (years)	Females			Males		
	Length Range (cm)	Mean Length (cm)	Sample Size	Length Range (cm)	Mean Length (cm)	Sample Size
6	68-72	70.3	3	-	-	-
7	69-82	75.5	16	65	65	1
8	64-96	75.8	15	65	65	1
9	67-103	82.5	30	69-85	74.8	5
10	64-114	89.4	69	67-84	74.6	7
11	72-144	94.7	42	79-82	80.5	2
12	74-123	99.2	14	80-86	82.5	4
13	87-117	104.8	6	-	-	-
14	111	111	1	-	-	-
15	86	86	1	94	94	1
Total	64-144	88.9	197	65-94	76.6	21

The length-weight relationship of Pacific halibut caught off northern California is shown in Figure 2.13. A linear least squares regression of $\log(\text{length})$ against $\log(\text{weight})$ for the data collected for this study resulted in estimates of allometric length-weight parameters, a and b , of 8.079236×10^{-7} and 3.590683, respectively.

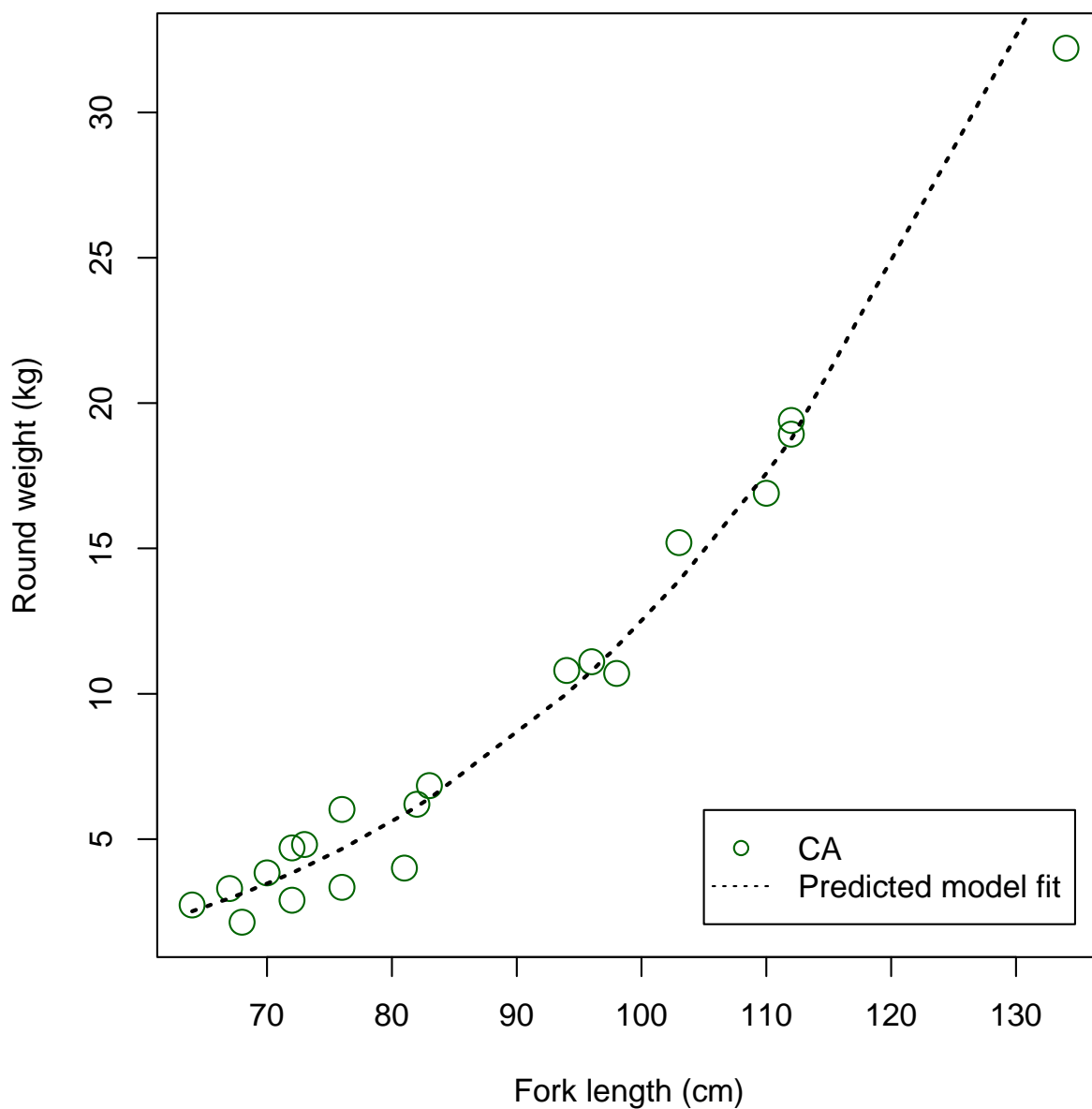


Figure 2.13. Length-weight relationship of Pacific halibut caught in the recreational fishery off northern California in 2015 (green circles) and the predicted model fit of the length-weight relation using multiplicative error (dotted line).

Length-at-age of female Pacific halibut landed for this study off northern California and central Oregon in 2015 is shown in Figure 2.14. Because the length-at-age for most age groups was similar, the data for these two regions were pooled for subsequent analysis.

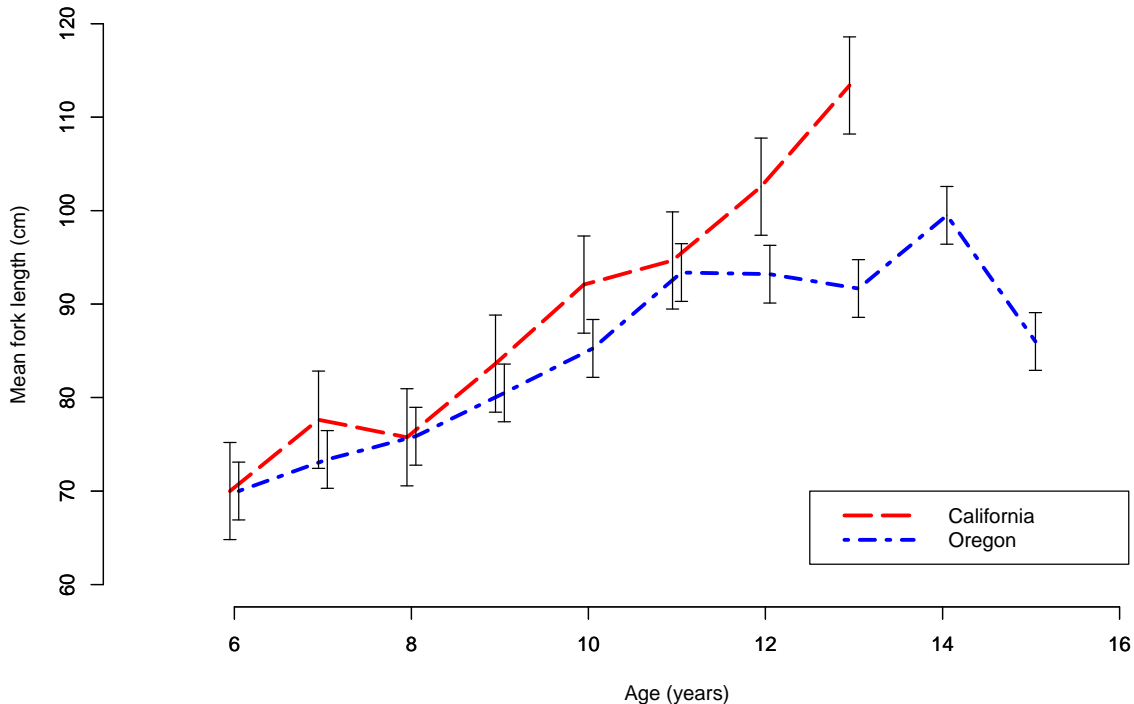


Figure 2.14. Comparison of length-at-age of female Pacific halibut collected from recreational anglers in northern California (blue) and central Oregon (red) during summer, 2015. Error bars are ± 2 standard errors.

Lengths-at-age data for female Pacific halibut landed in 2015 were compared with the data collected by Perkins (2015) in 2013 and to the 2014 setline survey data collected by the IPHC (Figure 2.15). The mean length-at-age of fish sampled in 2015 was lower than fish from 2013 and 2014. Fish in 2014 were larger, compared to 2013 fish, in every age class until age 14; above that age, 2013 fish were larger. Fish in all age classes in 2015 were smaller than those from 2013 and 2014. Results of three independent sample t-tests,

1. comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California during summer, 2013 (Perkins 2015) to mean lengths-at-age of Pacific halibut caught by the IPHC's setline survey in California in 2014 (IPHC unpublished data),
2. comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California during summer, 2013 to mean lengths-at-age of Pacific halibut collected from recreational anglers in northern California and central Oregon during summer, 2015, and
3. comparing mean lengths-at-age of Pacific halibut caught by the IPHC's setline survey in California in 2014 to mean lengths-at-age of Pacific halibut collected from recreational anglers in northern California and central Oregon during summer, 2015

are shown in Table 2.6.

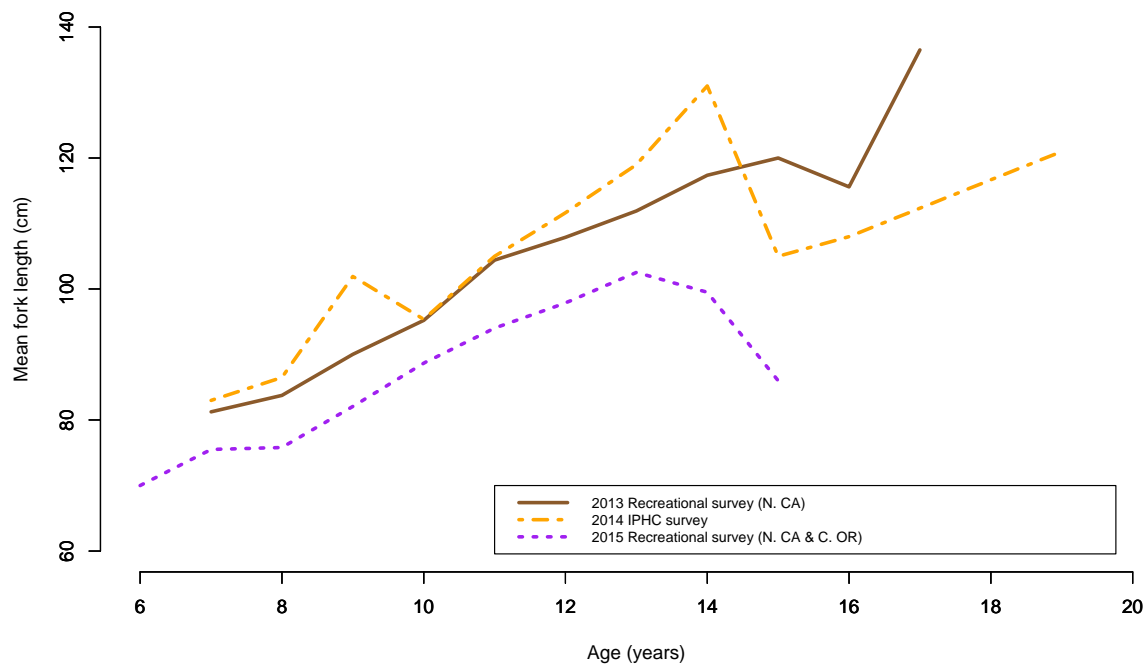


Figure 2.15. Comparison of length-at-age of female Pacific halibut collected from recreational anglers in northern California and central Oregon during summer, 2015 (purple) to Pacific halibut caught by the IPHC's setline survey in California in 2014 (orange; IPHC unpublished data) and recreational anglers in northern California during summer, 2013 (black; Perkins 2015).

Table 2.6. Results of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California during summer, 2013 (Perkins 2015) to mean lengths-at-age of Pacific halibut caught by the IPHC's setline survey in California in 2014 (IPHC unpublished data), comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California during summer, 2013 to mean lengths-at-age of Pacific halibut collected from recreational anglers in northern California and central Oregon during summer, 2015, and comparing mean lengths-at-age of Pacific halibut caught by the IPHC's setline survey in California in 2014 to mean lengths-at-age of Pacific halibut collected from recreational anglers in northern California and central Oregon during summer, 2015.

Years Compared	T	df	p	Mean length (cm)
2013 vs. 2014	-0.0473	19.528	0.963	2013: 105.81
2013 vs. 2015	2.9912	17.49	0.008	2014: 106.13
2014 vs. 2015	3.362	18.587	0.004	2015: 87.20

I also compared the length-at-age data collected from the recreational fishery in northern California and central Oregon in 2015 against those collected by the 2015 IPHC stock assessment setline surveys in the following Regulatory Areas:

- 2A, statistical areas 009, 010, 020, and parts of 008 (Oregon; Table 2.8);
- 2A, statistical areas 030, 040 and 050 (Washington including Puget Sound; Table 2.8);
- 2B (British Columbia; Table 2.8);
- 2C (Southeast Alaska; Table 2.8);
- 3A (central Gulf of Alaska; Table 2.7);
- 3B (western Gulf of Alaska; Table 2.7);
- 4A (eastern Aleutian Islands of Alaska; Table 2.7);
- 4B (central/western Aleutian Islands; Table 2.8);
- 4C (Pribilof Islands; Table 2.7)
- 4D (northwestern Bering Sea; 2.7)
- 4E (Bering Sea flats; Table 2.7)

Based on two sample t-test comparisons (Table 2.7), female Pacific halibut caught off northern California and central Oregon were found to have a larger average size-at-age for most ages than Pacific halibut caught in Regulatory Areas 3B (western Gulf of Alaska), 4A (eastern Aleutian Islands), 4C (Pribilof Islands), 4D (northwestern Bering

Sea), and 4E (Bering Sea Flats). Because so few 14- and 15- year-old samples were collected in my study, I can only make reliable observations of female Pacific halibut captured in 2015 up to age 13. For this age range, female Pacific halibut from northern California-central Oregon were longer at a given age than those from Regulatory Areas 3B and 4A but similar in size to those from Washington. The youngest fish in this analysis, age four, was collected in Regulatory Area 3B, while the oldest fish, age 30, was collected in Regulatory Area 4A (Figure 2.16).

Table 2.7. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in central Gulf of Alaska (Regulatory Area 3A). Asterisks denote significant difference between means at $\alpha=0.05$.

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (3A)			
Females					
6	70	61	5.89	2.88	0.01 *
7	75.5	72.6	1.57	43.85	0.12
8	75.80	70.82	1.99	21.01	0.06
9	82.42	76.61	3.63	49.18	<0.001 *
10	89.44	78.70	6.83	105.72	<0.001 *
11	94.28	85.13	3.64	52.85	<0.001 *
12	99.21	89.74	2.12	15.10	0.051
13	105.25	96.84	1.33	7.88	0.22
14	99.50	96.13	0.29	1.04	0.82
Males					
9	74.80	65.93	3.00	4.51	0.03 *
10	74.57	68.70	2.54	6.74	0.04 *
11	80.50	70.95	6.02	1.25	0.07
12	82.50	73.98	5.15	4.42	0.005 *

Table 2.7. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in western Gulf of Alaska (Regulatory Area 3B). Asterisks denote significant difference between means at $\alpha=0.05$ (continued).

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (3B)			
Females					
6	70.00	60.55	5.19	8.59	<0.001 *
7	75.50	67.74	3.84	39.14	<0.001 *
8	75.80	69.99	2.35	19.99	0.03 *
9	82.42	72.29	6.17	53.70	<0.001 *
10	89.44	74.77	9.64	94.37	<0.001 *
11	94.28	81.09	5.27	52.14	<0.001 *
12	99.21	88.27	2.46	14.87	0.03 *
13	105.25	93.60	1.85	7.80	0.10
14	99.50	92.43	0.61	1.04	0.65
Males					
9	74.80	65.06	3.32	4.38	0.03 *
10	74.57	66.16	3.62	6.88	0.01 *
11	80.50	68.63	7.36	1.34	0.048 *
12	82.50	71.09	6.96	4.28	0.002 *

Table 2.7. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in the eastern Aleutian Islands (Regulatory Area 4A). Asterisks denote significant difference between means at $\alpha=0.05$ (continued).

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (4A)			
Females					
6	70	58	6.98	6.58	<0.001 *
7	75.50	65.09	7.70	35.95	<0.001 *
8	75.80	68.31	2.72	28.24	0.01 *
9	82.42	74.44	4.82	54.72	<0.001 *
10	89.44	77.10	7.71	112.48	<0.001 *
11	94.28	83.46	4.35	50.97	<0.001 *
12	99.21	88.93	2.34	14.08	0.03 *
13	105.25	90.70	2.33	7.54	0.0499 *
14	99.50	96.14	0.29	1.05	0.82
Males					
9	74.80	65.04	3.27	4.66	0.02 *
10	74.57	67.60	2.96	7.25	0.02 *
11	80.50	70.65	6.05	1.39	0.06
12	82.50	74.45	4.93	4.19	0.01 *

Table 2.7. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in the waters surrounding the Pribilof Islands (Regulatory Area 4C). Asterisks denote significant difference between means at $\alpha=0.05$ (continued).

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (4C)			
Females					
6	70	60	6.73	5.04	0.001 *
7	75.50	64.77	6.37	35.76	<0.001 *
8	75.80	66.78	3.68	19.13	0.002 *
9	82.42	72.59	6.02	52.02	<0.001 *
10	89.44	75.93	8.39	113.09	<0.001 *
11	94.28	84.92	3.53	64.36	0.001 *
12	99.21	92.01	1.63	14.46	0.12
13	105.25	100.63	0.71	8.82	0.50
14	99.50	111.42	-0.98	1.25	0.48
Males					
9	74.80	66.29	2.64	6.27	0.04 *
10	74.57	66.94	3.13	8.27	0.01 *
11	80.5	74.0	2.16	9.81	0.06
12	82.50	75.17	3.60	9.10	0.006 *

Table 2.7. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in the northwestern Bering Sea (Regulatory Area 4D). Asterisks denote significant difference between means at $\alpha=0.05$ (continued).

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (4D)			
Females					
7	75.50	65.88	5.67	29.50	<0.001 *
8	75.80	71.66	1.59	23.88	0.12
9	82.42	75.97	3.74	60.67	<0.001 *
10	89.44	78.78	6.77	105.82	<0.001 *
11	94.28	83.92	4.06	55.99	<0.001 *
12	99.21	87.53	2.66	14.19	0.02 *
13	105.25	90.53	2.37	7.35	0.047 *
14	99.50	96.35	0.27	1.04	0.83
Males					
9	74.80	68.74	2.05	4.52	0.10
10	74.57	71.33	1.31	8.84	0.22
11	80.50	75.13	3.21	1.55	0.12
12	82.50	76.85	3.21	5.64	0.02 *

Table 2.7. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) near the Bering Sea flats (Regulatory Area 4E). Asterisks denote significant difference between means at $\alpha=0.05$ (continued).

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (4E)			
Females					
6	70	60	6.73	5.04	0.001 *
7	75.50	64.77	6.37	35.76	<0.001 *
8	75.80	66.78	3.68	19.13	0.002 *
9	82.42	72.59	6.02	52.02	<0.001 *
10	89.44	75.93	8.39	113.09	<0.001 *
11	94.28	84.92	3.53	64.36	<0.001 *
12	99.21	92.01	1.63	14.46	0.12
13	105.25	100.63	0.71	8.82	0.50
14	99.50	111.42	-0.98	1.25	0.48
Males					
9	74.80	69.67	1.71	4.71	0.15
10	74.57	90.00	-5.13	4.04	0.007 *
11	80.5	77.6	0.67	4.80	0.54
12	82.50	79.11	1.06	10.86	0.32

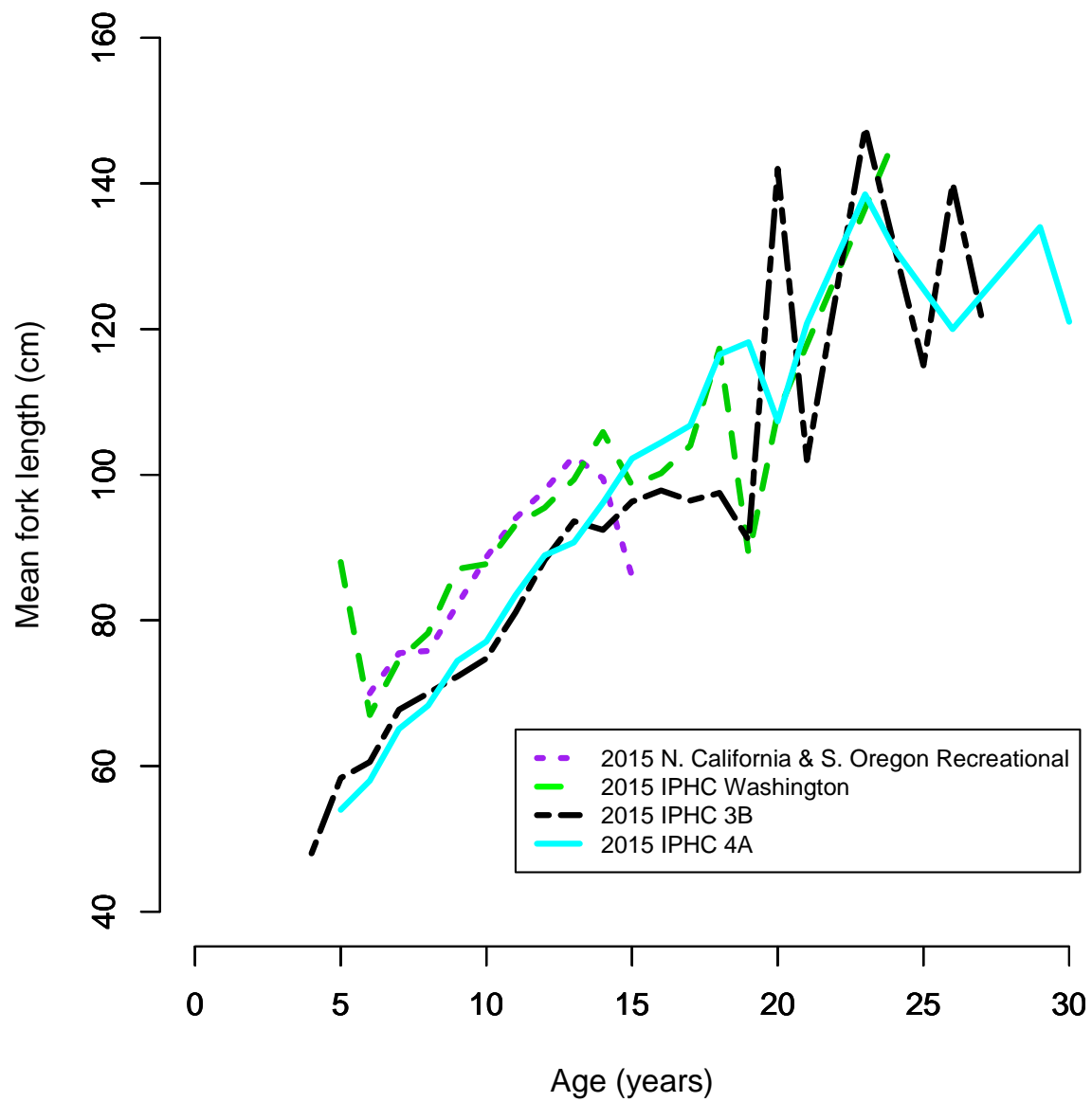


Figure 2.16. Comparison of length-at-age of female Pacific halibut collected from recreational anglers in northern California and central Oregon during summer, 2015 (purple) to Pacific halibut caught by the IPHC’s setline surveys in: Washington in 2015 (green; IPHC unpublished data) and Regulatory Areas 3B (black; IPHC unpublished data) and 4A (cyan; IPHC unpublished data).

For males, Pacific halibut caught off northern California and central Oregon had a larger average size-at-age for most ages than those caught in Regulatory Areas 3B (western Gulf of Alaska), 4A (eastern Aleutian Islands), 4C (Pribilof Islands), and 3A

(central Gulf of Alaska), based on two sample t-test comparisons (Table 2.7). The IPHC collected males from more diverse age classes (both younger and older fish) than I did for my study (Figure 2.17). Starting at age seven, the length-at-age of fish from northern California-central Oregon was larger than those from IPHC Regulatory Areas 3B and 4A but of similar size to those from Washington; this continues for all age classes in which northern California-central Oregon fish are represented. As with the females, the youngest fish, age 4, were collected in IPHC Regulatory Area 3B, while the oldest, age 36, were collected in Regulatory Area 4A.

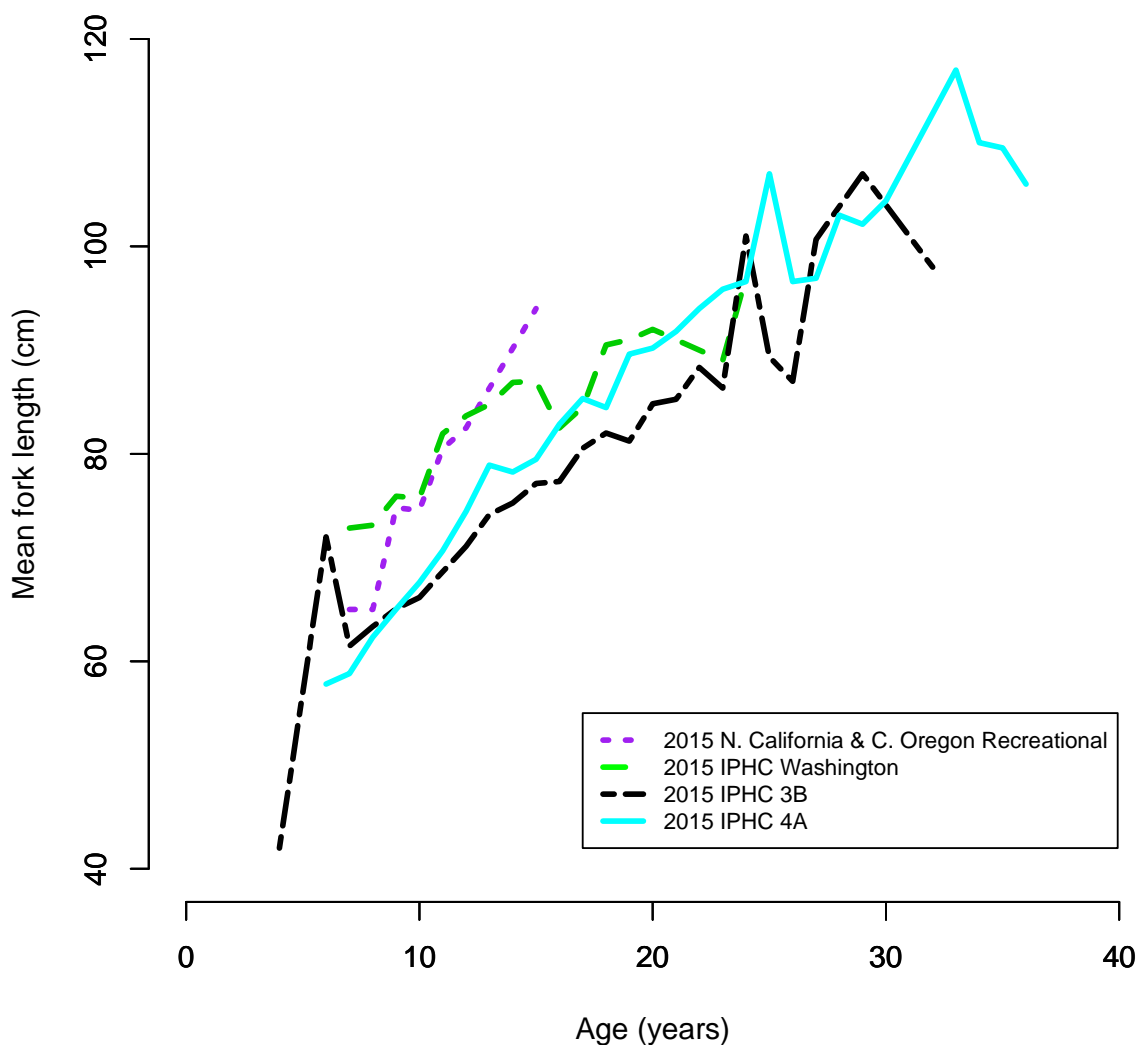


Figure 2.17. Comparison of length-at-age of male Pacific halibut collected from recreational anglers in northern California and central Oregon during summer, 2015 (purple) to Pacific halibut caught by the IPHC's setline surveys in: Washington in 2015 (green; IPHC unpublished data) and Regulatory Areas 3B (black; IPHC unpublished data) and 4A (cyan; IPHC unpublished data).

Two sample t-test comparison results (Table 2.8) showed that there were no significant differences in the average size-at-age for most ages of female Pacific halibut caught off northern California and central Oregon versus those caught off Oregon (Regulatory Area 2A), Washington (Regulatory Area 2A), and Regulatory Areas 2B (British Columbia), 2C (southeastern Alaska), 3A (central Gulf of Alaska), and 4B

(central/western Aleutian Islands). For males, no significant differences were detected between the average size of age for most ages caught off northern California/central Oregon and Oregon (Regulatory Area 2A), Washington (Regulatory Area 2A), Regulatory Areas 2B (British Columbia), 2C (southeastern Alaska), 4B (central/western Aleutian Islands), 4D (northwestern Bering Sea), and 4E (Bering Sea flats).

Table 2.8. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in Oregon (Regulatory Area 2A, statistical areas 009, 010, 020, and parts of 008). Asterisks denote significant difference between means at $\alpha=0.05$.

Age	Mean length (cm)		T	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (2A- OR)			
Females					
6	70	81	-1.55	2.11	0.25
7	75.50	75.78	-0.11	23.47	0.91
8	75.80	82.27	-2.16	32.79	0.04 *
9	82.42	91.98	-3.95	81.72	<0.001 *
10	89.44	96.96	-3.65	153.94	<0.001 *
11	94.28	103.30	-3.08	82.58	0.003 *
12	99.21	104.33	-1.10	22.94	0.32
13	105.25	109.58	-0.58	13.54	0.57
14	99.50	112.54	-1.10	1.15	0.45
Males					
9	74.80	82.54	-2.16	8.82	0.06
10	74.57	79.62	-1.72	15.65	0.11
11	80.5	83.4	-1.16	5.74	0.29
12	82.5	84.0	-0.49	8.63	0.64

Table 2.8. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in Washington (Regulatory Area 2A, statistical areas 30, 40, and 50). Asterisks denote significant difference between means at $\alpha=0.05$ (continued).

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (2A- WA)			
Females					
7	75.50	74.59	0.50	42.76	0.62
8	75.80	78.17	-0.87	27.12	0.39
9	82.42	87.21	-2.83	59.63	0.006 *
10	89.44	87.95	0.95	107.48	0.35
11	94.28	93.34	0.37	55.73	0.71
12	99.21	96.31	0.64	16.10	0.53
13	105.25	99.80	0.85	8.33	0.42
14	99.50	105.88	-0.53	1.17	0.68
Males					
9	74.8	75.91	-0.36	5.09	0.73
10	74.57	75.74	-0.49	7.67	0.64
11	80.50	81.96	-0.79	2.26	0.50
12	82.50	83.66	-0.64	6.09	0.54

Table 2.8. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in British Columbia (Regulatory Area 2B, statistical areas 60, 70, 80, 90, 91, 100, 102, 112, 121, 130, 131, 132, 133, 134, 135). Asterisks denote significant difference between means at $\alpha=0.05$ (continued).

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (2B)			
Females					
6	70.00	80.25	-1.94	7.65	0.09
7	75.50	75.70	-0.09	57.24	0.93
8	75.80	77.18	-0.49	31.13	0.63
9	82.42	82.26	0.09	61.33	0.93
10	89.44	84.55	3.13	103.94	0.002 *
11	94.28	90.70	1.41	55.10	0.16
12	99.21	93.97	1.16	15.67	0.26
13	105.25	99.52	0.90	8.04	0.39
14	99.50	108.99	-0.81	1.06	0.56
Males					
9	74.80	73.10	0.51	7.19	0.63
10	74.57	72.22	1.02	6.61	0.34
11	80.50	73.87	3.68	2.07	0.06
12	82.50	77.81	2.77	4.84	0.04 *

Table 2.8. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in southeastern Alaska (Regulatory Area 2C, statistical areas 140, 141, 142, 143, 144, 150, 151, 152, 153, 160, 161, 162, 163, 170, 171, 173, 181, 182, 183). Asterisks denote significant difference between means at $\alpha=0.05$ (continued).

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (2C)			
Females					
6	70.00	71.89	-0.36	8.75	0.73
7	75.5	74.0	0.76	75.61	0.45
8	75.80	78.52	-1.09	20.76	0.29
9	82.42	81.77	0.38	64.34	0.71
10	89.44	85.84	2.28	109.47	0.02 *
11	94.28	91.54	1.07	56.03	0.29
12	99.21	99.62	-0.09	15.33	0.93
13	105.25	105.86	-0.10	7.69	0.92
14	99.50	110.96	-0.98	1.05	0.50
Males					
9	74.80	73.49	0.43	5.00	0.68
10	74.57	67.60	2.96	7.25	0.02 *
11	80.50	70.65	6.05	1.39	0.06
12	82.50	74.45	4.93	4.19	0.01 *

Table 2.8. Result of the independent sample t-test comparing mean lengths-at-age of Pacific halibut from recreational anglers in northern California and central Oregon in this study (2015 N. CA/C. OR Rec) with mean lengths-at-age from the 2015 IPHC setline survey (IPHC unpublished data) in the central/western Aleutian Islands (Regulatory Area 4B, statistical areas 400, 410, 420, 430, 440, 450, 460, 470, 480, 490, 500, 513277, 513278, 520173, 520174, 520175, 520176, 520179, 520277, 520278, 520279, 523173, 523179, 523273, 523274, 530272). Asterisks denote significant difference between means at $\alpha=0.05$ (continued).

Age	Mean length (cm)		t	df	p
	2015 N. CA/ C. OR Rec	2015 IPHC Survey (4B)			
Females					
6	70.00	63.42	4.16	6.20	0.006 *
7	75.50	71.05	3.02	45.23	0.004 *
8	75.80	76.92	-0.45	19.68	0.65
9	82.42	81.45	0.61	49.60	0.55
10	89.44	87.45	1.19	131.85	0.24
11	94.28	100.00	-2.16	64.07	0.03 *
12	99.21	107.70	-1.83	17.48	0.08
13	105.25	115.43	-1.54	9.44	0.16
14	99.50	117.64	-1.51	1.19	0.34
Males					
9	74.80	74.67	0.04	4.35	0.97
10	74.57	77.30	-1.18	6.65	0.28
11	80.50	80.07	0.26	1.43	0.82
12	82.50	85.37	-1.71	4.74	0.15

For northern California and central Oregon, I was only able to accurately generate Von Bertalanffy growth curve estimates for females (Figure 2.18) because so few males were collected. A Von Bertalanffy growth curve was also generated for Regulatory Area 4D, because this area had the closest parameter estimates to northern California (Figure 2.19), as well as for females in northern California for sampling years 2013, 2014, and 2015 (Figure 2.20). Because I had insufficient length-at-age data to show asymptotic growth (Knight 1968), I was not able to fit the Von Bertalanffy model using non-linear

least squares in the R environment for my 2015 recreational data; consequently, I used maximum likelihood. I used non-linear least squares for the data that were collected by the IPHC setline surveys because those surveys had sufficient length-at-age data to show asymptotic growth. However, non-linear least squares regression and maximum likelihood produced similar L_{∞} , k , and t_0 values, with slight differences attributed to rounding error.

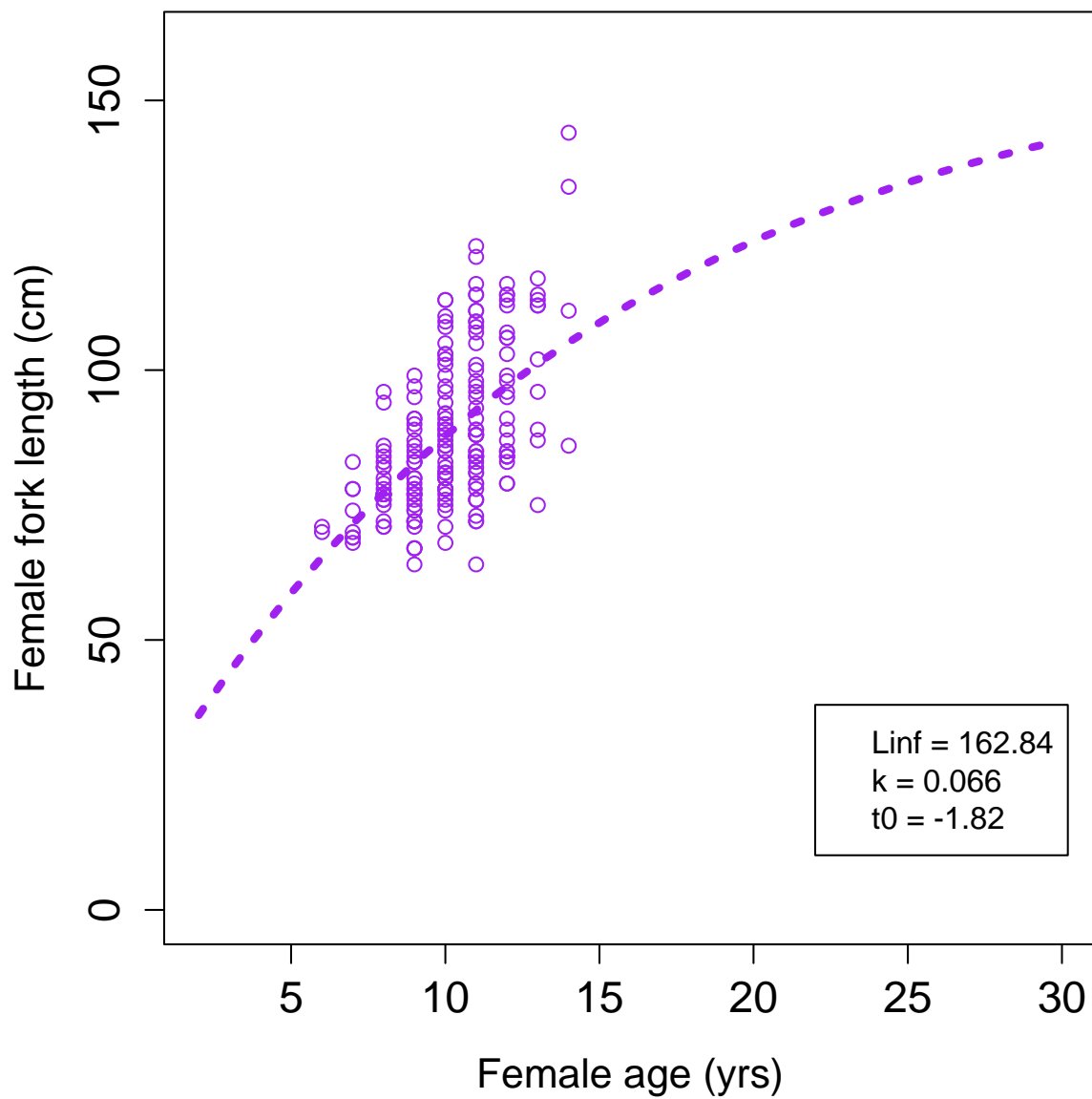


Figure 2.18. Fitted Von Bertalanffy growth curve and estimate model parameters for female Pacific halibut caught by recreational anglers off northern California and central Oregon in 2015.

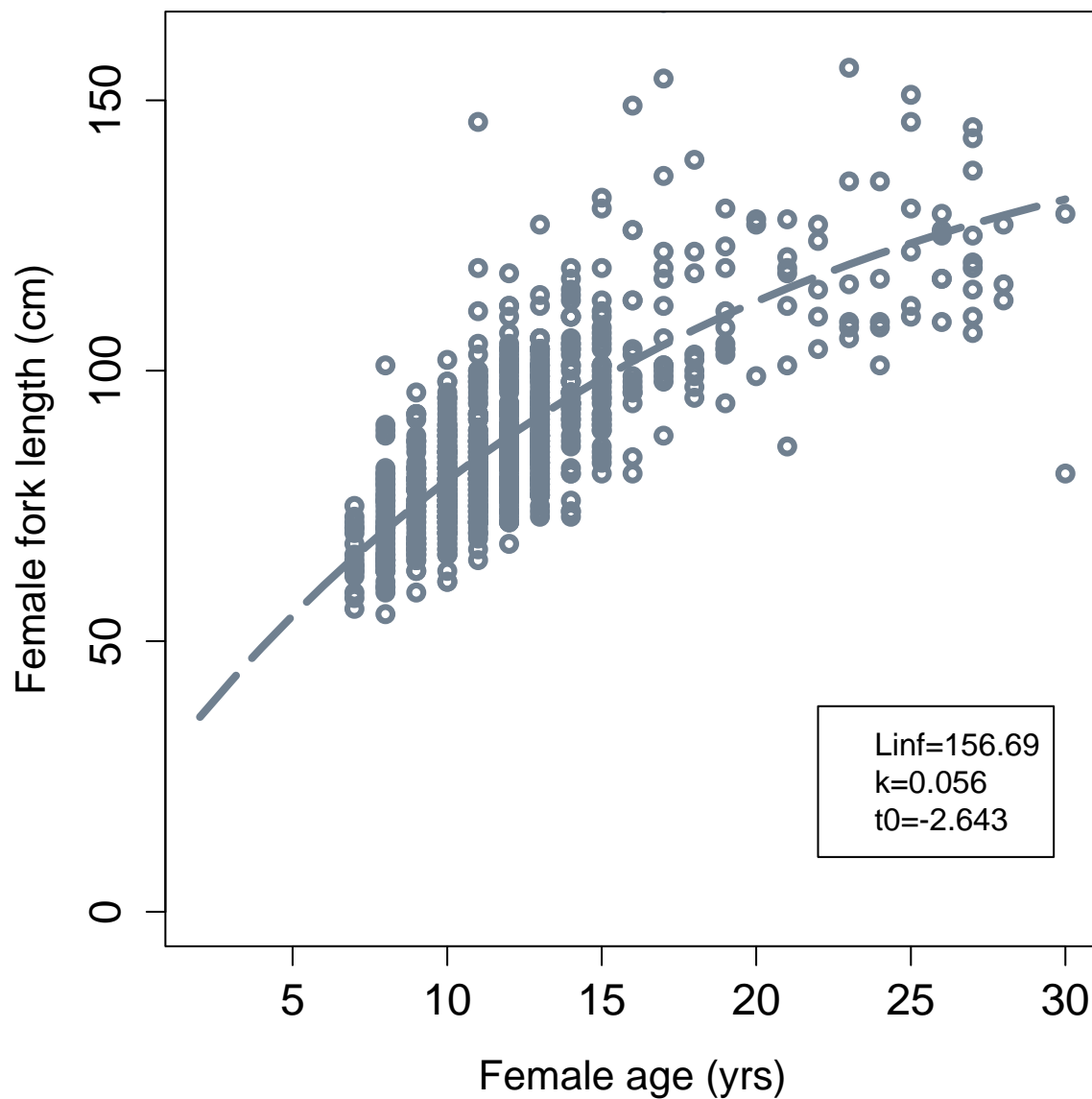


Figure 2.19. Fitted Von Bertalanffy growth curve and estimate model parameters for female Pacific halibut caught during the 2015 IPHC setline survey (IPHC unpublished data) in Regulatory Area 4D.

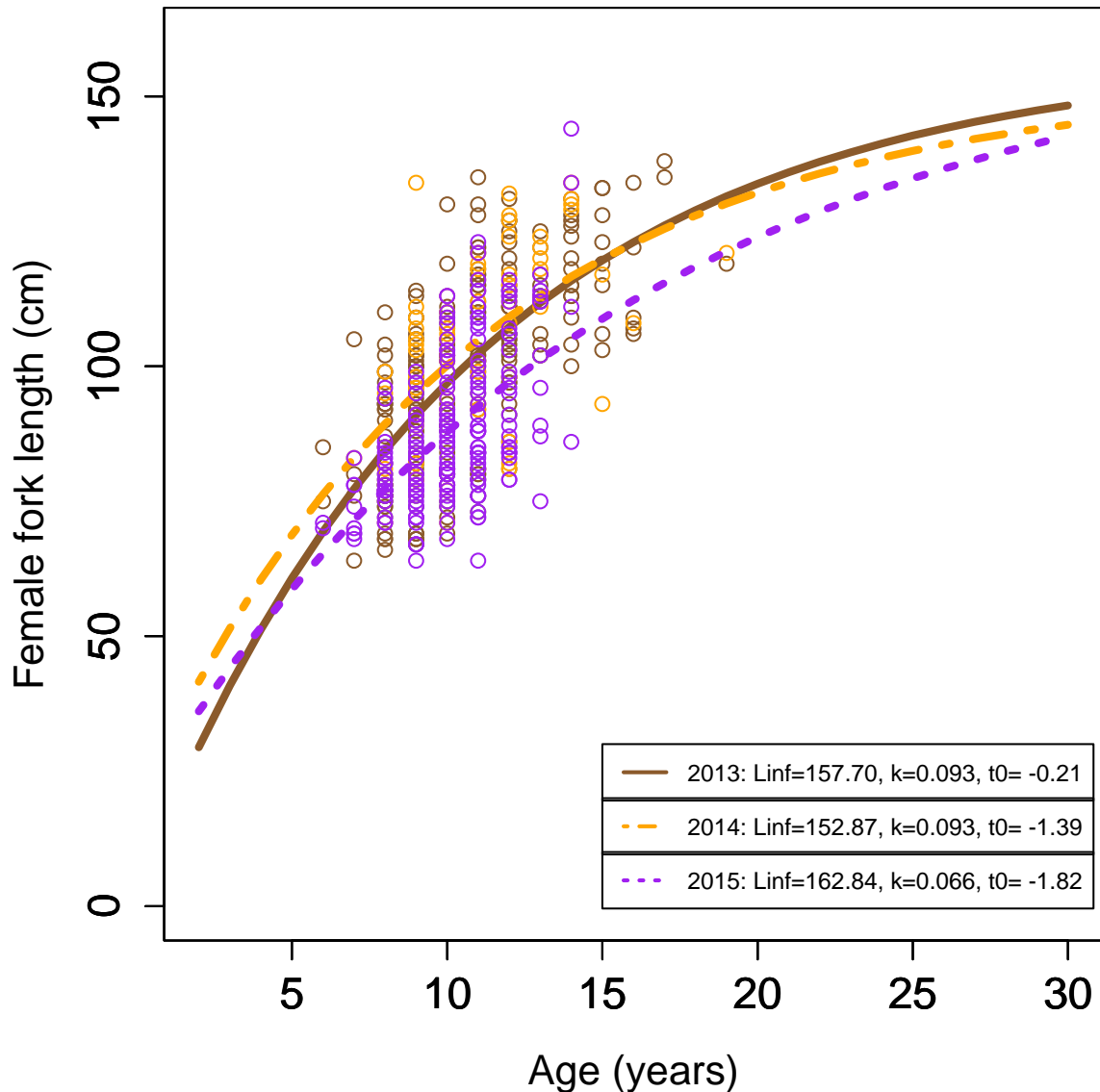


Figure 2.20. Fitted Von Bertalanffy growth curve and estimate model parameters for female Pacific halibut caught during the 2013 (Perkins 2015), 2014 (IPHC unpublished data), and 2015 (this study) sampling years in northern California.

Using the Von Bertalanffy growth equation, I estimated the maximum length (L_{∞}) of female Pacific halibut landed off northern California and central Oregon to be 162.84 cm. The range of maximum length estimates for females, generated using IPHC survey data for various areas in the Pacific Northwest and Alaska, ranged from 123.98 cm

(Washington) to 324.54 cm (British Columbia). The female maximum length estimate for northern California and central Oregon was greater than the maximum length estimated for Oregon, Washington, Area 3A (Gulf of Alaska), and 4D (Bering Sea) (Table 2.9).

While the maximum length (L_{∞}) of female Pacific halibut landed off northern California and central Oregon in 2015 (162.84) appears to be larger than in 2013 (157.70) and 2014 (152.87), the Von Bertalanffy growth curve for 2015 shows slightly smaller size-at-age over the sampled age range versus the curves for 2013 and 2014 (Figure 2.20).

Table 2.9. Von Bertalanffy growth model parameter estimates for female Pacific halibut caught by recreational anglers during the summer of 2015 in northern California (CA Recreational), Central Oregon (OR Recreational), combined northern California and central Oregon (CA/OR Recreational) and by the 2015 IPHC setline survey (IPHC unpublished data) in 9 areas (Area 2A [Oregon], Area 2A [Washington], 2B [British Columbia], 2C [Southeast Alaska], 3A [Gulf of Alaska], 3B (south of Alaska Peninsula], 4A (eastern Aleutian Islands], 4B [central Aleutian Islands], and 4D [Bering Sea] in addition to parameter estimates for female Pacific halibut caught coastwide during the 2015 IPHC setline survey. Asterisk denotes von Bertalanffy model parameter estimates that were obtained using maximum likelihood instead of least squares. L_{∞} is the asymptotic maximum length, k is the growth coefficient, and t_0 is the hypothetical age at length zero.

	L_{∞}	K	t_0
CA Recreational	158.97*	0.075*	-0.864*
OR Recreational	150.39*	0.064*	-3.388*
CA/OR Recreational	162.84*	0.066*	-1.818*
2A (Oregon)	137.98	0.126	0.408
2A (Washington)	123.98	0.107	-1.850
2B (British Columbia)	324.54	0.019	-6.454
2C (Southeast Alaska)	268.22	0.032	-2.510
3A (central Gulf of Alaska)	150.69	0.069	-1.193
3B (western Gulf of Alaska)	199.36	0.035	-4.025
4A (eastern Aleutian Islands)	164.86	0.056	-1.528
4B (western Aleutian Islands)	165.4	0.096	1.607
4D (northwestern Bering Sea)	156.69	0.056	-2.643
Coastwide	188.00	0.047	-2.692

DISCUSSION

Age and growth data on halibut sampled in 2013 by Perkins (2015) showed that Pacific halibut caught off northern California in both her study and the IPHC setline survey were larger at a given age than halibut from farther north. Additionally, Perkins hypothesized that the large regional differences in mean size-at-age of Pacific halibut suggest high site fidelity, as considerable interregional mean size-at-age differences tend to be seen in fishes that show feeding philopatry (Perkins 2015). These findings are important factors in determining how best to manage the Pacific halibut fishery because the size-at-age of Pacific halibut has been declining over the past decade, especially farther north (Stewart and Martell 2014).

One of the most obvious patterns in the length-at-age data from this study, Perkins (2015), and the 2014 IPHC survey, is that the size-at-age for 2014 is greater than 2013 and 2015 for nearly every cohort and every age class (Figure 2.21). This suggests that something about the oceanography or other growing conditions that year allowed more rapid growth (Thorson and Minte-Vera 2016). The period prior to the summer 2015 halibut season was characterized by the emergence of the anomalous “warm blob” that rapidly warmed the coastal waters of the Pacific Northwest starting around September 2014 and the subsequent strong El Niño that began in early 2015 (Leising et al. 2015; Figure 2.22). The “warm blob” and El Niño had similar, likely synergistic effects, increasing seawater temperatures and reducing coastal upwelling and productivity (Leising et al. 2015). While this difference may help explain why length-at-age in 2015

might be lower, it does not explain why length-at-age in 2014 was higher than 2015 and 2013. There was no El Niño or other warm water event in 2012 or 2013 and temperatures (Figure 2.22) and coastal upwelling (Figure 2.23A) during that period were fairly typical. One possible explanation for the greater length-at-age in 2014 is that the distribution of other species (particularly prey) could have shifted in response to these anomalous ocean conditions, providing the Pacific halibut with plentiful food. One example of such a range shift is the California market squid (*Doryteuthis opalescens*), which is normally caught in Bodega Bay and south, but was caught in significant quantities in Eureka in 2014 (CDFW 2014).

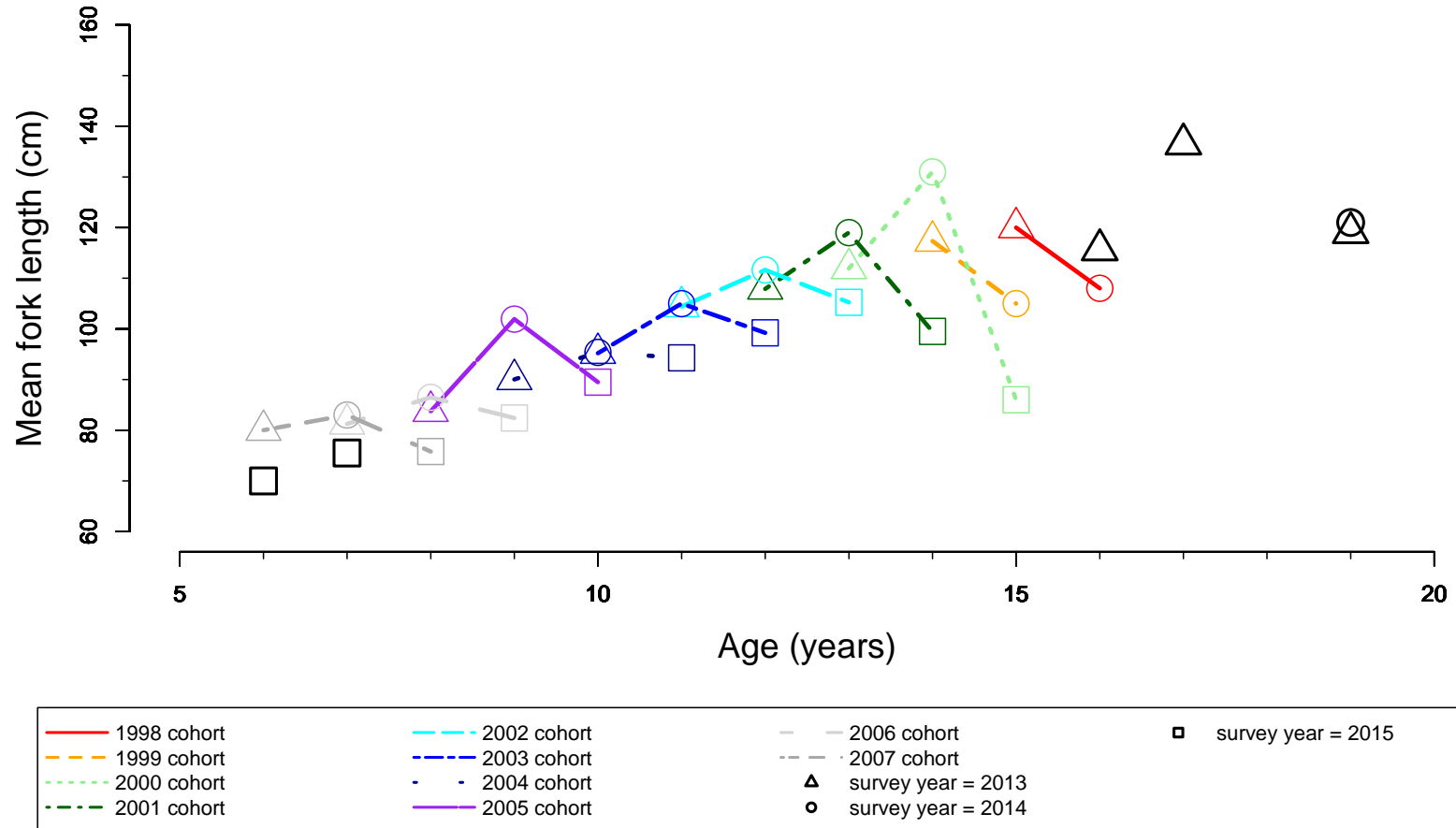


Figure 2.21. Mean length versus age of Pacific halibut landed in California by cohort. Data are from surveys conducted in 2015 (this study); 2014 (IPHC unpublished data); and 2013 (Perkins 2015).

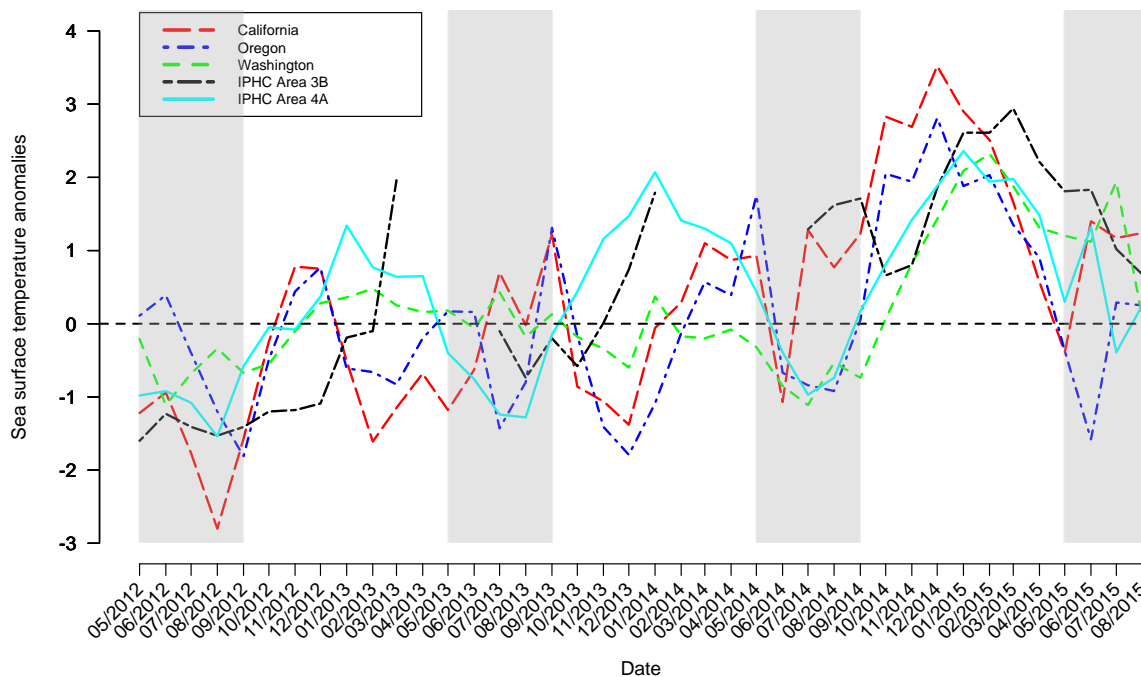


Figure 2.22. Sea surface temperature anomalies (deviation from long-term averages; NOAA 2017) for California, Oregon, Washington, and IPHC Regulatory Areas 3B and 4A from May 2012 to August 2015 (NOAA 2016a). Dotted line denotes no average sea surface temperature differences between long-term averages and the actual temperatures for those months. Shaded areas denote summertime during 2012, 2013, 2014, and 2015.

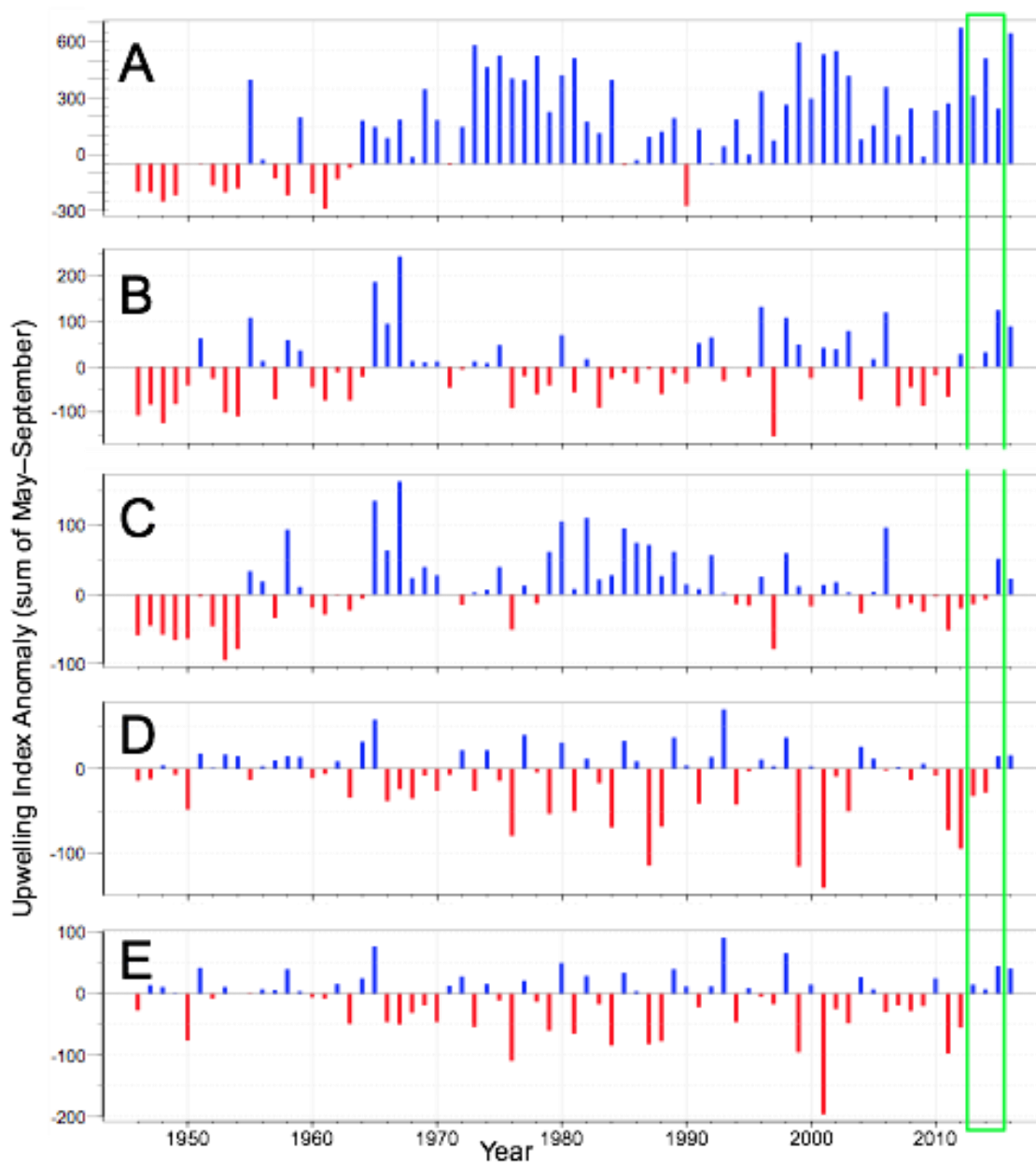


Figure 2.23. Upwelling Index anomalies from May to September for northern California (A), Oregon (B), Washington (C), western Gulf of Alaska (IPHC Area 3B) (D), and eastern Aleutian Islands (IPHC Area 4A) (E) from 1946 to 2016 (NOAA 2016c); the summers of 2013 to 2015 are highlighted by the green box.

Figure 2.21 shows the relationship between mean length and age of Pacific halibut landed in California by cohort. Each color or non-solid symbol corresponds with a particular cohort year. The shape of the symbols denotes whether the mean fork length datum is from 2013, 2014, or 2015. The 2000 (light green) and 2005 (purple) cohorts stand out as having particularly high values in 2014, while 2000 has an especially low 2015 value.

The Cumulative Upwelling Index (CUI) estimates the total annual wind-driven upwelling forcing which is an important determinant of productivity and ecosystem structure (NOAA 2016b), while the Cumulative Index anomaly is the difference between the CUIs and the monthly averages between 1967 and 1991 (Schwing et al. 1996). Anomalies of the Upwelling Index are provided for northern California (Figure 2.23A), Oregon (Figure 2.23B), Washington (Figure 2.23C), and IPHC Regulatory Areas 3B (western Gulf of Alaska; Figure 2.23D) and 4A (eastern Aleutian Islands; Figure 2.23E). Northern California had considerably stronger coastal upwelling forcing than the other areas; this difference in levels of upwelling may partially explain the regional differences in mean length-at-age, particularly between northern California (Figure 2.23A) and Alaska (Figures 2.23D and 2.23E).

As in the 2013 northern California study by Perkins (2015), the mean size-at-age of female Pacific halibut from northern California and central Oregon in 2015 was similar to those from Oregon and Washington, but larger than those from the IPHC setline surveys in much of Alaska. However, the Pacific halibut caught off northern California and central Oregon in 2015 were, on average, smaller for a given age than

those from the 2014 IPHC setline survey data for California, and of similar size or smaller than those from the 2013 study conducted by Perkins (2015) in northern California (Figure 2.21) though this trend was not statistically significant (Figure 2.24).

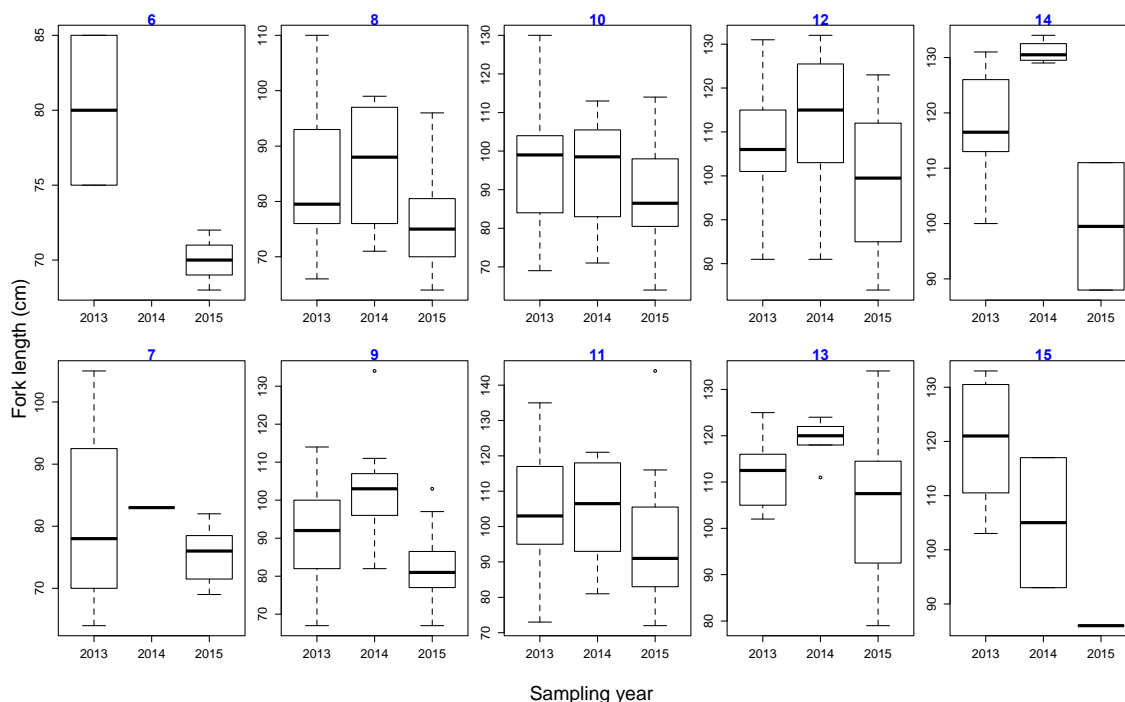


Figure 2.24. Size-at-age boxplots by age for Pacific halibut collected off northern California. Ages are indicated in blue above each panel. Data are from surveys conducted in 2015 (this study); 2014 (IPHC unpublished data); and 2013 (Perkins 2015).

Figure 2.24 shows size-at-age boxplots by age for Pacific halibut collected off northern California in 2013, 2014, and 2015. Only boxplots for ages 6 through 15 are shown because those were the only years in which data for all three survey years (2013, 2014, and 2015) were available. While it appears as though the fork length was longer in 2014 than in 2013 and 2015 for most ages, the error bars indicate that these differences are not statistically significant.

Size-at-age boxplots by cohort for Pacific halibut collected off northern

California in 2013, 2014, and 2015 are shown in Figure 2.25. Only boxplots for the 2000 to 2007 cohorts are shown because those were the only years in which data for all three survey years (2013, 2014, and 2015) were available. While it appears as though the fork length was longer in 2014 than in 2013 and 2015 for most cohorts, the error bars indicate that these differences are not statistically significant.

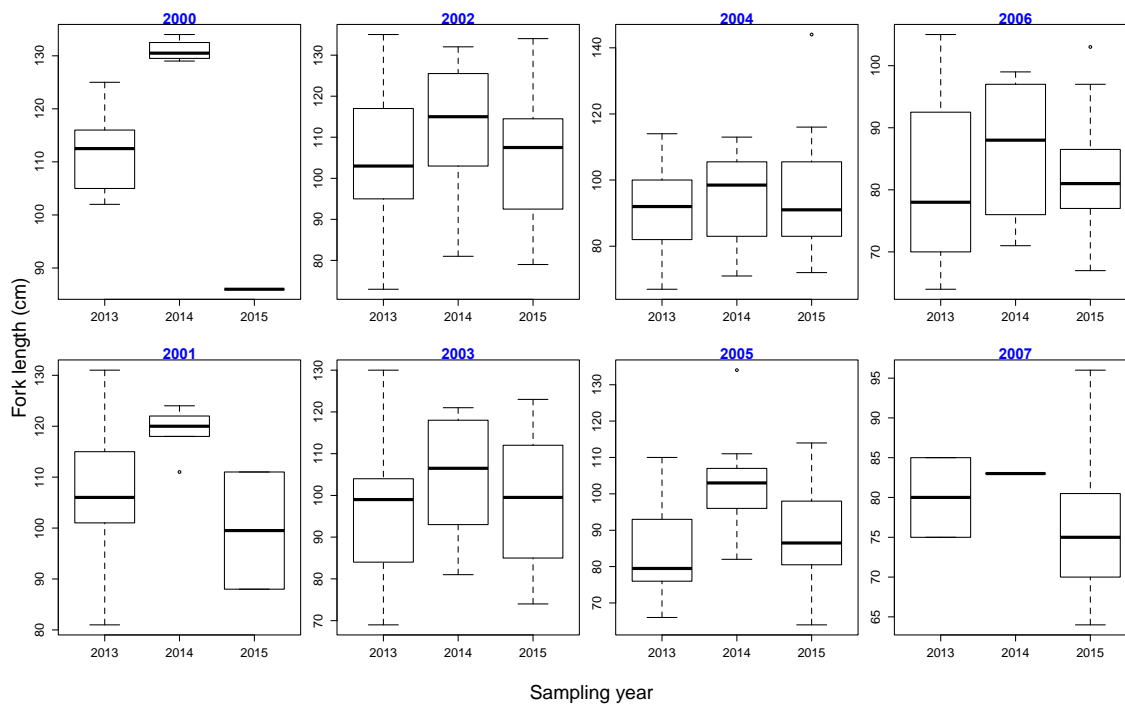


Figure 2.25. Size-at-age boxplots by cohort for Pacific halibut collected off northern California. Cohorts are indicated in blue above each panel. Data are from surveys conducted in 2015 (this study); 2014 (IPHC unpublished data); and 2013 (Perkins 2015).

Potential explanations for the trend of larger size-at-age of Pacific halibut in 2014 versus 2013 and 2015 both within cohorts (Figure 2.21, Figure 2.25), and within age-classes across cohorts and years (Figure 2.21, Figure 2.24) include sampling error, a shift in fish migration patterns, or that the period prior to the 2014 fishing season had more favorable, productive ocean conditions that resulted in more rapid growth.

This study found no significant differences in the length-at-age of Pacific halibut landed in northern California versus central Oregon (Figure 2.14). While the nearshore benthic habitat of these two bioregions is different, it does not appear to affect the length-at-age of Pacific halibut caught in these two regions. Consistent differences in length-at-age among regions at larger scales (Regulatory Areas) found in this study and that by Perkins (2015) may be the result of a variety of factors from local habitat characteristics, to broad geographic trends (decreasing temperature with latitude), to large scale ocean circulation patterns (Figure 2.26).

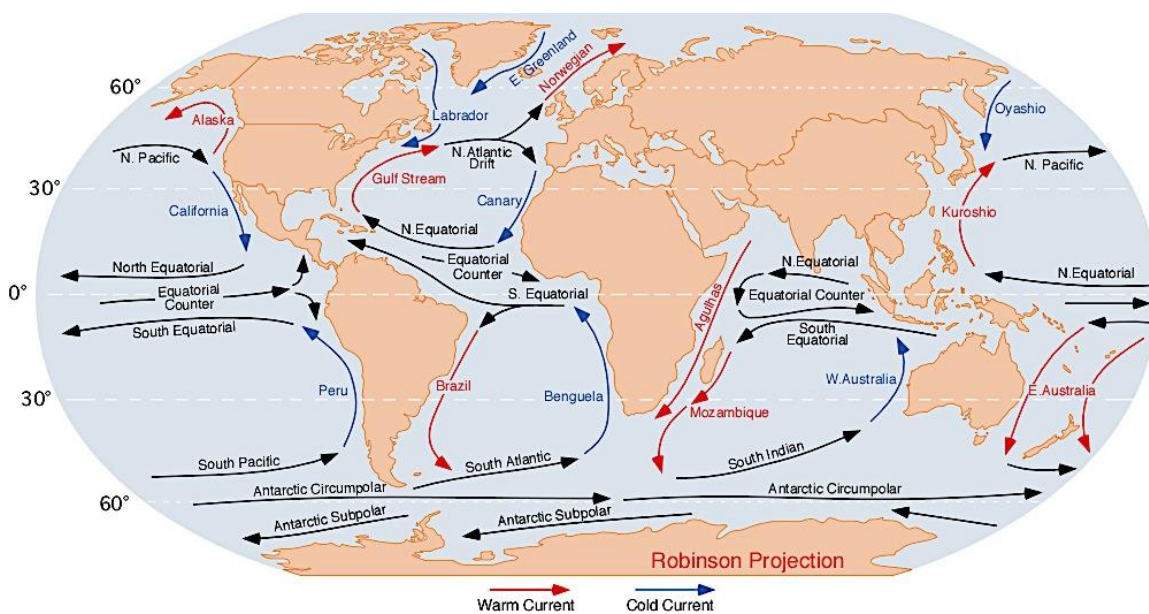


Figure 2.26. The ocean currents of the world (Pidwirny 2007).

The California Current (Figure 2.26) is an eastern boundary current that forms the south flowing branch of the North Pacific Current. It brings cold water from British Columbia to Baja California, and this combined with upwelling, makes the waters off the West Coast of North America some of the most productive in the world. Eastern boundary currents are associated with strong upwelling because of the Coriolis effect, which moves southward-flowing ocean currents away from the shore, allowing the colder, deeper water to replace the nutrient-depleted surface water. The cold, nutrient-rich waters promote vigorous phytoplankton growth (NASA 2016a), which, ultimately is responsible for the productive and commercially valuable fisheries and abundant marine life along the Pacific Coast (Brink 2004).

The Alaska Current (Figure 2.26), the northward flowing portion of the bifurcated North Pacific Current, brings warm water (unlike the California Current) in a counterclockwise direction to the Gulf of Alaska (Freeland 2006), before it becomes the Alaskan Stream. The Alaskan Stream flows along the Alaskan Peninsula and Aleutian archipelago, before it reunites with the North Pacific Current (Weingartner et al. 2009).

The strong upwelling and resulting high productivity of the California Current System may be responsible for the higher growth rate and greater length-at-age noted in Pacific halibut landed in northern California, Oregon, and Washington, in contrast to the less rapid growth and smaller length-at-age seen in Alaska (Freeland 2006).

Upwelling systems, as described previously, are disrupted by El Niños. When the trade winds, which usually blow from east to west, weaken or reverse, a warm water mass propagates across the Pacific to the West Coast, resulting in a thick warm water

layer that inhibits upwelling circulation even if upwelling wind forcing occurs (Herring 1999).

Without the usual nutrient-rich water that upwelling provides, phytoplankton abundance is reduced during El Niños, meaning lower food availability at the base of the food web (NASA 2015). The difference in upwelling between 2013, 2014, and 2015 is shown in data collected by NOAA (Figure 2.27; NOAA 2016b). Eureka, where most of my samples were collected, is at approximately 39°N; near Eureka, upwelling in 2013 (in cyan) was the strongest observed (in this data set which extends back to 1967); while 2014 (blue) was lower than 2013, and 2015 (red) was lower still, cumulative upwelling during all three years was significantly above the long term average (black). Between the years 2011 and 2015, upwelling was lowest in 2011 (green) and 2015 (red). This difference in upwelling levels between 2013, 2014, and 2015 does not provide any obvious explanation for the difference in mean lengths-at-age over this timespan.

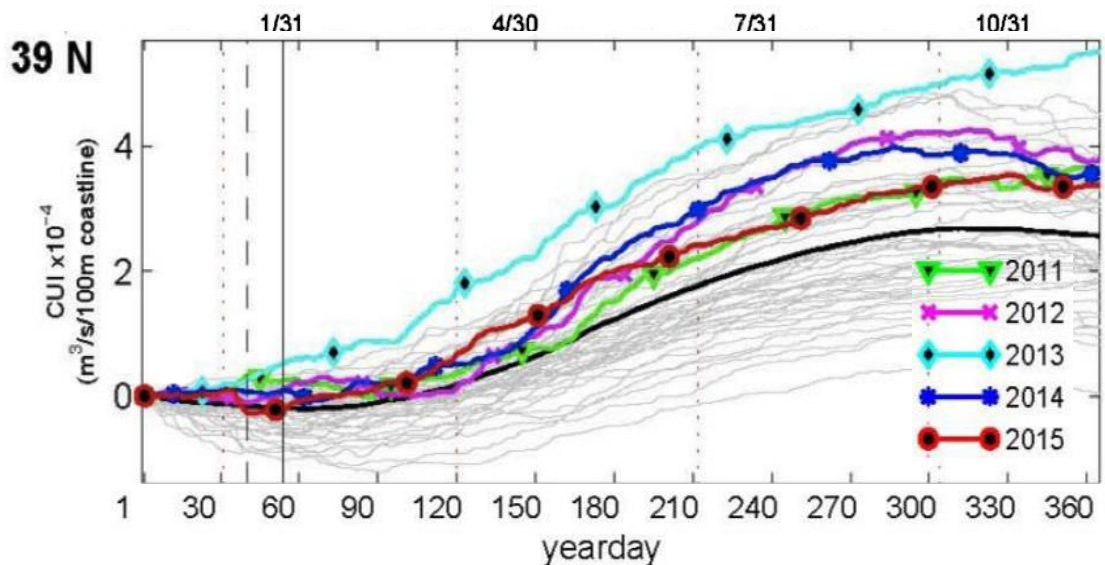


Figure 2.27. Cumulative Upwelling Index for 39°N for the years 1967 to 2015. Grey lines=1967-2010, black line= long-term average, green line=2011, mauve line=2012, cyan line=2013, blue line=2014, red line=2015 (NOAA 2016b).

Because it is too soon to tell what the effects of the 2015-2016 El Niño will be, scientists at the National Aeronautics and Space Administration (NASA) are looking at previous El Niño events for guidance, mainly the most recent El Niño event of 1997-1998. They conclude that the warm water in the two El Niño events was seen in different geographical locations (Figure 2.28); during the 1997-1998 event, warm waters and low chlorophyll levels were seen in the eastern Pacific Ocean, while they are being observed in the central Pacific Ocean during the 2015-2016 El Niño (NASA 2016b).

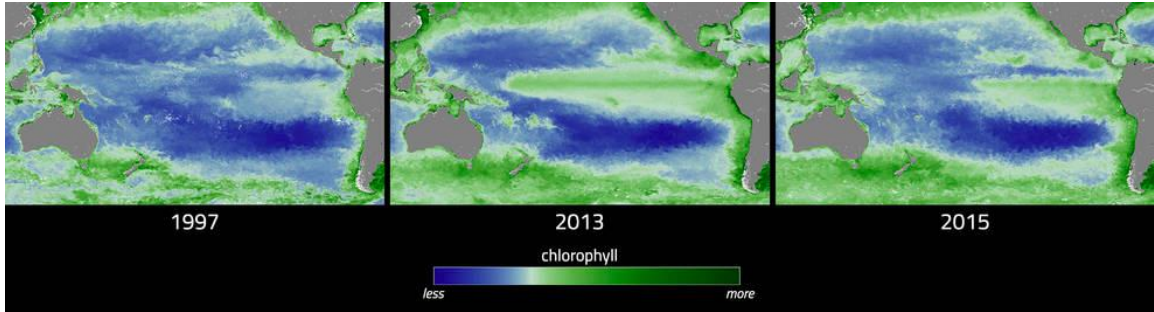


Figure 2.28. Phytoplankton abundance during the previous El Niño event in December 1997 (left), December 2013 which was a normal year (center), and December 2015, the current El Niño event (right), (NASA 2016b).

From 1962 through 1990, the IPHC estimated the size of halibut from the dimensions of their otoliths (Clark 1992), suggesting that the growth of fish each year is related to the width of the otolith annulus they add during that year. One would surmise that had ocean productivity been especially poor in 2014 and 2015, the outermost annulus (growth ring) of otoliths from fish caught in 2014 and 2015 would be more closely spaced compared to other years. However, that is not what was observed, suggesting that something other than ocean productivity may be behind the reduction in size-at-age.

Upwelling index data as well as the fact I did not observe closely spaced outer otolith annuli that might indicate slow growth due to unproductive ocean conditions, taken together suggest that while upwelling levels in California were lower in 2015 than they were in 2013 or 2014, productivity was still higher along the northern California coast than it was farther north.

NASA scientists are also attempting to forecast the effect that the reduced phytoplankton abundance during the current El Niño event will have on fisheries. The previous El Niño event had a disastrous effect on the Chilean anchovy fishery, so

fisheries managers along the East Coast of the Pacific Ocean are hoping that these forecasts will enable them to estimate how the El Niño will affect catches and populations. Current forecast models are not predicting fisheries collapses during this El Niño, mainly because the warm waters, and consequently, the reduced phytoplankton abundance, are being seen in the center of the Pacific Ocean, as opposed to the eastern Pacific Ocean (NASA 2016b).

There are many examples of fish populations that have been affected by poor oceanic conditions, with many cold-water species being negatively impacted by warmer waters (NOAA 2015) and weak upwelling. Low salmon numbers in recent years have been attributed to poor oceanic conditions, including the 2015-2016 El Niño event (NOAA 2016d). Cold-water copepods high in lipids are transported from higher latitudes by southward upwelling currents, which sustain juvenile coho, Chinook, and other predator fishes. Though bountiful during strong upwelling years, the proportion of lipid-rich northern copepods falls during El Niño events, when upwelling is weak and more of the copepods are warm-water, southern-affinity species that contain less energy. This occurred during the 1997-1998 El Niño event, which led to decreased salmon runs (Fisher et al. 2015).

A report on the effects of ocean ecosystem indicators on the survival of juvenile salmon off Oregon and Washington in 2015 tells a similar story. The strongly positive Pacific Decadal Oscillation (PDO), when winter winds from the southwest lead to warmer temperatures in the Northern California Current, combined with the “warm blob” (a mass of warm water that began to form in fall 2013 in the Gulf of Alaska) led to

warmer-than-usual temperatures off Newport for most of 2015, and lipid-rich zooplankton were replaced with lipid-poor copepods and gelatinous zooplankton, which are not suitable prey items for krill and small fishes, which are, in turn, food for juvenile salmonids (Peterson et al. 2015).

Scientists have also shown that there is a correlation between PDO and salmon returns in the Pacific Northwest. During years of cool PDO, such as the period between 1947 and 1975, Chinook and coho salmon returns in Oregon rivers were high, whereas they dropped significantly in the years to follow (1977-1998), during the warm PDO cycle (Mantua et al. 1997).

Another possible reason for the greater size-at-age of 2014 Pacific halibut (versus 2013 and 2015) is the migration of faster-growing fish from other areas to northern California. While we are unable to confirm whether this occurred, both old and recent tagging studies undertaken by the IPHC have shown that some Pacific halibut migrate great distances. The longest distance travelled by a Pacific halibut was nearly 4,000 km, from Atka Island, Alaska to Coos Bay, Oregon. Another halibut, tagged at Cape Navarin, Russia, was recovered 1,600 km away near Shumagin Islands, Alaska (Skud 1977). A coastwide tagging study undertaken by the IPHC starting in 2001 showed that fish that were tagged and released in British Columbia, southeast Alaska, and the Aleutian Islands were recovered in Regulatory Area 2A (of which California is a part), and tagged fish that were released in Regulatory Area 2A were recovered in Regulatory Area 2B (Webster et al. 2013). Another tagging study in which Pacific halibut were recovered from 2003 to 2009 show that migration rates from Regulatory Area 4A to Regulatory

Area 2A was 0.003, from Area 2C to 2A was 0.012, from Area 2B to 2A was 0.014 (Valero and Webster 2011). The authors noted that these estimates are based on very few data points, and should be treated with caution. However, these studies, together, show that it is plausible for Pacific halibut from outside of the area to migrate to northern California. That said, the combined estimate of the migration rate into Area 2A from Areas 4A, 2B, and 2C is 0.029 (less than 3 percent), so even if this migration estimate is too low, it appears unlikely that the decline in size-at-age can be explained solely by immigration of slower-growing fish.

Several recommendations for future research can be made. First, an investigation into the migration patterns of fish from California using popup satellite tags could provide valuable information about the extent of population connectivity. This seems especially relevant given the significant changes in size from year to year for the cohorts in Figures 21, 24, and 25. HASA, the aforementioned non-profit organization in Humboldt County, has shown interest in this investigation. Additionally, it is recommended that the annual IPHC Pacific halibut setline surveys be extended to northern California, the southern end of their range, if not annually, at least at some regular interval. Setline surveys have been conducted in northern California in the past, and the results from Perkins (2015) and this study, will hopefully influence the IPHC to continue such studies in the future. Finally, surveys of recreationally caught Pacific halibut in northern California should be continued to provide a consistent record of size-at-age that is comparable to data from IPHC setline surveys. These data can help inform

sustainable management of Pacific halibut, which has become an important recreational fishery in the area.

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CHAPTER 3

CHARACTERIZING THE MATURITY OF PACIFIC HALIBUT IN
NORTHERN CALIFORNIA AND CENTRAL OREGON

ABSTRACT

The maturity stage of female gonads is one of the most important components in stock assessment models, but biological data on populations of Pacific halibut found in northern California are scarce. For this reason, I conducted a study that characterized the maturation of Pacific halibut landed in northern California and central Oregon. I also compared the macroscopic maturity staging method currently utilized by the International Pacific Halibut Commission (IPHC) against the more rigorous histological methods (measurement of oocyte diameter under a microscope). Results were consistent with those of a previous study by Perkins (2015) with Pacific halibut caught off northern California and central Oregon maturing three years earlier than those caught during the IPHC setline surveys off Alaska, and roughly one year earlier than those caught off Oregon and Washington. This consistency despite contrasting oceanic conditions and size-at-maturity trends in my study versus Perkins', supports the hypothesis that maturation occurs at some critical age, and that this age increases with latitude and decreasing average temperatures. I also used histology to validate the IPHC's macroscopic and staging methods and found that though macroscopic analysis of resting and immature ovaries has limited accuracy (as low as 66 percent), mature ovaries were accurately classified nearly 94 percent of the time, resulting in minimal error in length- and age-at-maturity analysis. Mature samples had the largest mean oocyte diameter, due to the presence of vitellogenic oocytes. This trend however, was not significant because

there was significant overlap in oocyte diameter among the three maturity stages, likely explained by the fact that oocyte development occurs in a continuum.

INTRODUCTION

The maturity stage of female gonads, in addition to age and growth, is one of the most important components in stock assessment models, which are used to determine whether fisheries are being managed sustainably (Lux 1959, Chilton and Beamish 1982, Forsberg 2001). Despite the importance of such data, little biological information is available on populations of Pacific halibut found off northern California. Based on data collected and analyzed by Perkins (2015), it appears that Pacific halibut captured off northern California mature at a younger age than do Pacific halibut captured in more northern areas. My project expanded on this study, adding an additional year and broadening the study into central Oregon (Charleston). In addition, I developed histological maturity staging methods for female Pacific halibut, and used them to analyze fish caught off northern California and central Oregon.

IPHC Regulatory Areas

In order to better categorize catch, biological, biometric, and migration data, the International Pacific Halibut Commission (IPHC) separated the commercial Pacific halibut fishing grounds into statistical areas in the 1920s. Data are collected from each statistical area and combined into larger regulatory areas, to which management decisions are applied. Currently, there are 10 regulatory areas within the purview of the IPHC. Regulatory Area 2A is the only one within the boundaries of the contiguous United States, and contains fisheries in California, Oregon, and Washington (Kong et al. 2004). Regulatory Area 2B consists of British Columbia, 2C is southeastern Alaska, 3A is the

central Gulf of Alaska, 3B is the western Gulf of Alaska, 4A is the eastern Aleutian Islands, 4B is the central and western Aleutian Islands, 4C is the Pribilof Islands, 4D is the northwestern Bering Sea, and 4E is the Bering Sea flats (IPHC 2016a) (Figure 3.1).

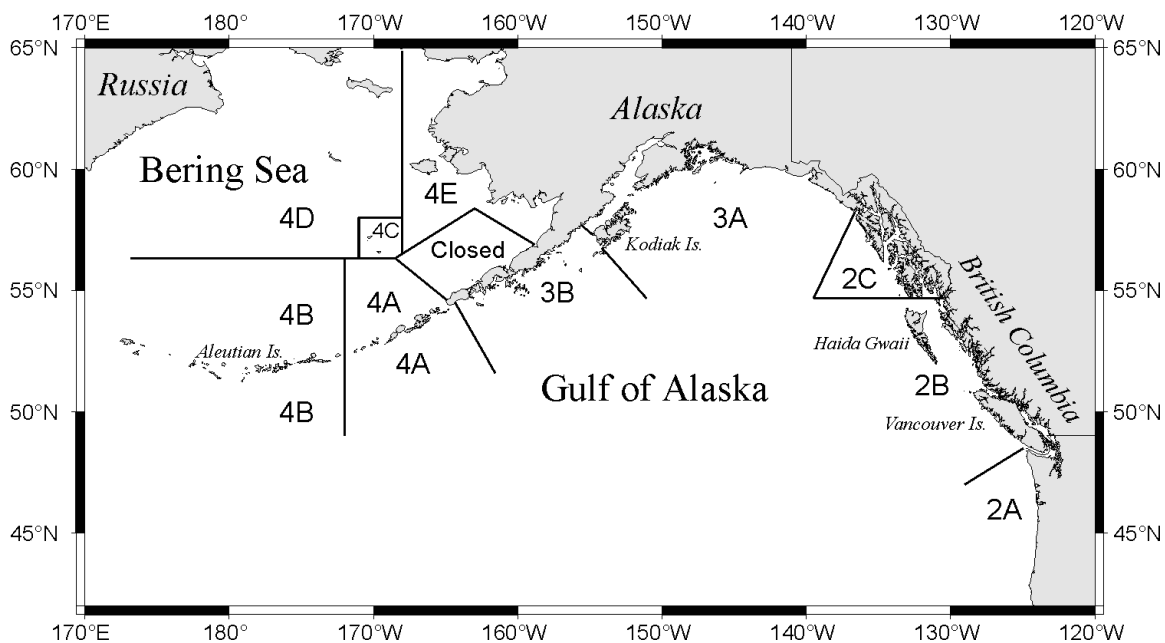


Figure 3.1. Regulatory areas as defined by the IPHC (IPHC 2016b).

IPHC Maturity Staging Method

The ovarian maturity staging classification system used by the IPHC has undergone considerable changes over the past 20 years. The IPHC utilized a seven-stage system until 1994, at which time the system was simplified to a four-stage system. A more refined four-stage system, which yields less ambiguity and variation, was adopted in 1999, and is still currently being used (Wilson 2004). This four-stage system is described in the 2013 IPHC standardized stock assessment survey manual; the four stages are immature, mature, spawning, and resting, and are identified macroscopically using both internal and external characteristics of the ovary. External characteristics include the

shape, size, color, and level of capillary development, while internal characteristics include visibility of oocytes and membrane thickness (IPHC 2013). Table 3.1 summarizes the stages of female Pacific halibut maturity.

Table 3.1. Female Pacific halibut maturity stages based on the protocol included in the IPHC stock assessment survey manual (IPHC 2013).

	Immature (Stage I)	Mature (Stage II)	Spawning (Stage III)	Resting (Stage IV)
External characteristics	Ovary small, firm, tightly packaged; slightly developed capillaries	Ovary larger than immature; well-developed and branched purple capillaries	Ovary large and swollen; capillaries thin and small	Ovary flaccid/shrunken, and collapsed; deflated and large capillaries
Internal Characteristics	Ovary has very thin membrane (may be pink to red in color); oocytes not visible to the naked eye	Ovary has thicker membrane (clear); opaque eggs visible	Ovary has even thicker membrane (clear); large, fully developed eggs visible	Ovary has thickest membrane (opaque in color); no eggs visible, except possible resorbed/developing eggs

The IPHC manual also describes two stages of male gonad maturity: immature and mature. Immature testes are small (<five cm in diameter), smooth, paired, and lack crenulations (irregular waves), while mature testes are larger, plump, swollen, and crenulated. Immature male fish will not spawn in the upcoming season, whereas mature fish will spawn in the upcoming season (IPHC 2013). There is considerable variation in the age of maturity for males, but the IPHC has estimated that they mature by eight years of age (IPHC 1987).

Researchers have noted that it is sometimes difficult to differentiate between immature and mature female fish (Gunderson et al. 1980), as the characteristics used to determine maturity stages are seen as crude and subjective (Costa 2009, Ferreri et al. 2009, McPherson et al. 2011, Midway and Scharf 2012). Furthermore, a 2003 study,

whose results were published in a report by the IPHC in 2004, found that there were inconsistencies between the designations of mature and resting female Pacific halibut, depending on whether quantitative or qualitative data were used in maturity staging. The quantitative data collected by the IPHC staff included gonad width, length, mean weight, and volume of both ovaries. Qualitatively, they analyzed the gonads using the four-stage method described in Table 3.1 above. The staff also compared the maturity staging results done quickly aboard fishing vessels against the analyses done by staff in a laboratory setting, once all the samples had been collected. They concluded that mature and resting females were the most difficult to differentiate, and noted discrepancies in the way the gonads were quantitatively and qualitatively analyzed. Few discrepancies were seen between immature and mature females, and none existed between immature and resting females. Additionally, the results showed that when given more time (in the laboratory), staff were more likely to designate a fish as being mature, rather than resting, and when a quick analysis (aboard the fishing vessel) was done, they were more likely to assign them a mature designation. Comparing quantitative and qualitative analysis results, the conclusion was that there was no strong correlation between fork length and stage of maturity (Wilson 2004).

In 2009, the IPHC conducted another study in which the maturity of female Pacific halibut was classified using ultrasound. Before fish were sacrificed, they obtained both ultrasound images and Maximum Posterior Gonad Extension (MPGE) measurements (a proxy for gonad length), which was obtained by matching an anal fin ray number to the posterior margin of an ovary; once killed, total gonad length was

obtained. They discovered that while the relationship between MPGE and the proportion of the fish's gonad to total body length (proportional gonad length) was statistically significant, proportional gonad length was a more accurate tool for maturity classification (Stephens 2009).

To date, maturity stages of Pacific halibut have been determined by macroscopic, visual inspections, but the IPHC is currently re-evaluating their classification criteria for females. In 2014, the IPHC started a project to reevaluate the maturity staging classification currently utilized to assign maturity to female Pacific halibut. One of the characteristics used to classify females as immature was being observed in both immature and mature females (IPHC 2016c).

With the help of NOAA Southwest Fisheries Science Center researchers, I have developed a different, and potentially more accurate method of assessing female reproductive maturity using histological methods. The two methods I used to determine maturity stages were a) an examination of the most advanced, mature oocyte, and b) oocyte diameter.

MATERIALS AND METHODS

Sample Collection

In California, the 2015 Pacific halibut fishery was open from 1 May to 15 May, 1 June to 15 June, 1 July to 15 July, and 1 August to 13 August (CDFW 2015). The Oregon fishery is split up into three Pacific halibut recreational fishery subareas: the Southern Oregon subarea (CA/OR border to Humbug Mountain), the Central Coast subarea (Humbug Mountain to Cape Falcon, Oregon), and the Columbia River subarea (Cape Falcon to Leadbetter Point, Washington) (Figure 3.2; ODFW 2015).

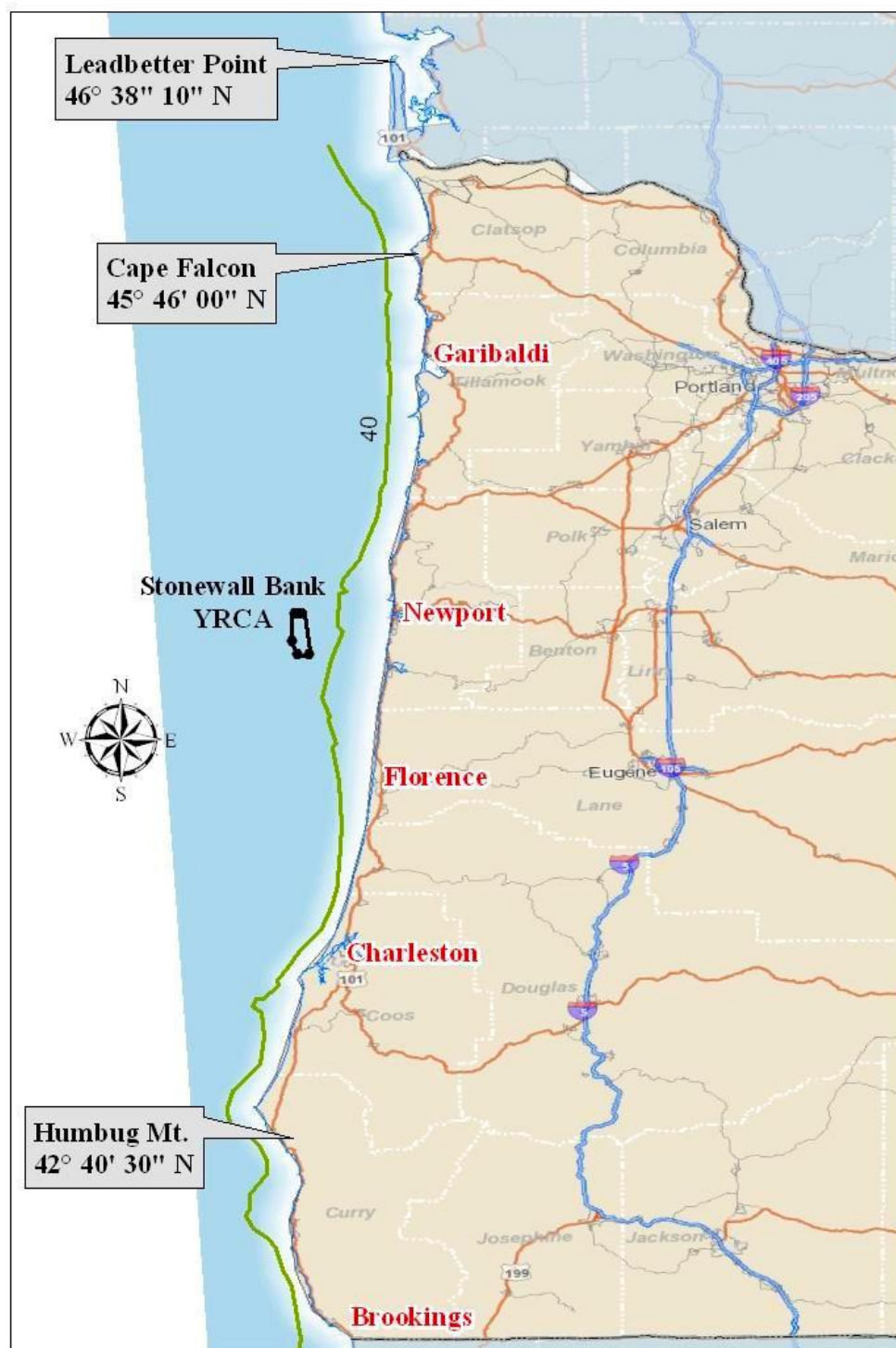


Figure 3.2. Map showing the demarcation of the 3 Pacific halibut recreational fishery subareas in Oregon (ODFW 2015).

In the Oregon Central Coast subarea, which contains the ports of Bandon, Charleston, Winchester Bay, Florence, Newport, Depoe Bay, Pacific City, and Garibaldi, the 2015 fishery openings were separated into the “spring all-depth,” the “nearshore halibut fishery,” and the “summer all-depth” fishery (ODFW 2015). The season opening dates, as well as the quotas for each fishery in the Oregon Central Coast subarea, are listed in Table 3.2.

Table 3.2. Oregon Central Coast 2015 Pacific halibut season openings (ODFW 2015).

	Spring all-depth fishery	Nearshore fishery	Summer all-depth fishery
Open Dates	May 14-16 May 28-30 June 11-13 June 25-27	July 1-October 18	August 7-8 August 21-22 September 4-5 September 18-19 October 2-3 October 16-17 October 30-31
Quotas	50,190 kg	9,600 kg	20,590 kg

Prior to the start of the season, I posted flyers at Eureka Public Marina, Woodley Island Marina, and the Charleston Marina (Charleston, Oregon), asking anglers to donate whole Pacific halibut or Pacific halibut carcasses to this project. I also asked businesses that I believed Pacific halibut fishers would frequent, such as Pacific Outfitters, Bucksport Sporting Goods, Mad River Tackle, Englund Marine Supply, and Salty’s Supply Company to display the flyer at their place of business. A similar request was posted to the Humboldt Tuna Club website (<http://humbolddtuna.com/>), a newsletter article was placed in the quarterly Humboldt Area Saltwater Anglers (HASA) newsletter, and I distributed flyers at the annual HASA fundraiser, held in April 2015. The flyers and

newsletter article explained the purpose of the study, the data that would be collected, and how donations could be made. I also spoke to the charter boat captains that dock and moor at Woodley Island Marina, and asked them to telephone me if they caught any Pacific halibut.

Two collection bins were placed at Woodley Island Marina, one at the western end of the marina, in close proximity to the Humboldt State University research vessel, R/V Coral Sea, next to the fish cleaning station on Dock A, and the other one just southwest of the Café Marina restaurant; both were secured to a metal pole. Recreational anglers willing to donate their Pacific halibut carcasses after returning from sea could place them in these bins. Alternatively, anglers were asked to telephone me directly, in which case I would meet them at the location of their choosing and I would collect samples there. This allowed me to sample whole Pacific halibut from which I could obtain complete data including weight, unlike carcasses left in the collection bins.

Crushed ice, which was donated by Pacific Seafood, a local seafood processor, was placed in the collection bins at Woodley Island Marina, and replaced every three or four days to ensure that any carcasses left in the bins would be kept cold. These bins as well as the general fish carcass bin at the Eureka Public Marina were checked for halibut carcasses on a daily basis during the Pacific halibut season in California. While the Oregon Central Coast halibut season was open, I perused each of the bins that were placed near the fish cleaning stations at the Charleston Marina. In addition, a local charter boat business allowed me to sample the carcass of each of halibut that was caught on their trips.

Macroscopic Determination of Maturity

For each of the Pacific halibut samples collected, the gonads were examined macroscopically to determine sex and maturity using the IPHC protocol described in the 2013 IPHC standardized stock assessment survey manual (IPHC 2013). Once external characteristics were assessed, I cut the ovary open, in order to look at the internal characteristics. Male gonads were also examined for maturity stages.

I compared the data I collected in northern California and central Oregon with those that the IPHC collected during their 2015 setline surveys in Oregon, Washington, and Regulatory Areas 3B and 4A to determine whether there were statistical differences in length and age at maturity. The statistics package R (R Core Team 2015) was used for all statistical analysis.

Among the variables that make up a maturity staging assessment, maturity ogives (the percentage of mature fish across all represented age classes) is one of the most critical (Vitale et al. 2006). Mature and resting fish were defined as mature; because this fishing season did not coincide with the spawning season, I did not expect to find spawning-stage fish. This expectation was confirmed. To determine the length at which Pacific halibut mature, I calculated the fraction of samples that were mature in one cm increments, and fitted the following logistic model:

$$P_L = \frac{1}{1 + e^{(a+bL)}}$$

where P_L is the probability of maturity at fork length L , and a and b are constants that describe the shape and location of the curve (Gunderson et al. 1980, Hannah et al. 2009). I also calculated the probability of maturity at age Y using the same logistic model,

replacing P_L with P_Y . Both length-at-50%-maturity and age-at-50%-maturity were calculated using $\hat{L}_{50\%} = \frac{-a}{b}$. The a and b parameters are the same as those used for P_L/P_Y , and $L_{50\%}$ is the length/age at which fish are 50% mature (Rickey 1995).

The delta method was used to estimate standard error using this equation:

$$\hat{L}_{50\%}: \hat{V}(\hat{L}_{50\%}) = \frac{1}{b^2} \hat{V}(\hat{a}) + \frac{\hat{a}^2}{b^4} \hat{V}(\hat{b}) - \frac{2\hat{a}}{b^3} \widehat{cov}(\hat{a}, \hat{b})$$

(\hat{a}, \hat{b}) , where the estimates for $\hat{V}(\hat{a})$, $\hat{V}(\hat{b})$ and $\widehat{cov}(\hat{a}, \hat{b})$ correspond to the results of the fitted logistic regression analysis described above (Seber 1982) and the vcov function in Program R was used to obtain the estimation. Ninety-five percent confidence intervals for $\hat{L}_{50\%}$ were calculated as $\hat{L}_{50\%} \pm 2\sqrt{\hat{V}(\hat{L}_{50\%})}$ (Rickey 1995), and were compared against confidence intervals of other regulatory areas.

Microscopic Determination of Maturity – Mature Oocyte

In order to make the results as comparable to those of the IPHC as possible, my methods for processing gonad samples and preparing and staining slides are based on those used by the contractor that does this work for the IPHC (the contractor prepares slides from samples for the aforementioned maturity reevaluation project). After being removed from female fish, gonads were placed in a solution of 10 percent neutral buffered formalin (NBF) in order to fix them (L. Brown pers. comm. 2015). Then, I followed the general procedure outlined in “Theory and Practice of Histotechnology” (Sheehan and Hrapchak 1987) for tissue processing. Once the gonads were fixed, a transverse section of five mm thickness was removed from the center of each ovarian section, dehydrated through a sequence of alcohol and solvent solutions, embedded in

paraffin, sectioned using a microtome set to four μm , stained using hematoxylin and eosin, and cover-slipped (Farrell et al. 2012, L. Brown pers. comm. 2015). The exact steps are outlined in Appendix F. These slides were examined using a compound microscope under 100x magnification.

The IPHC previously determined that the left lobe of the ovary contains a greater number of eggs than the right (Schmitt and Skud 1978); however, there appears to be no difference in maturity stages between the two lobes. Furthermore, I took sections from the anterior (closest to the head), middle, and posterior (closest to the caudal fin) on both lobes and compared them, and found that the maturity stage was the same in all six sections. Figure 3.3 shows photographs of histological slides of the anterior, middle, and posterior sections of a mature, female Pacific halibut.

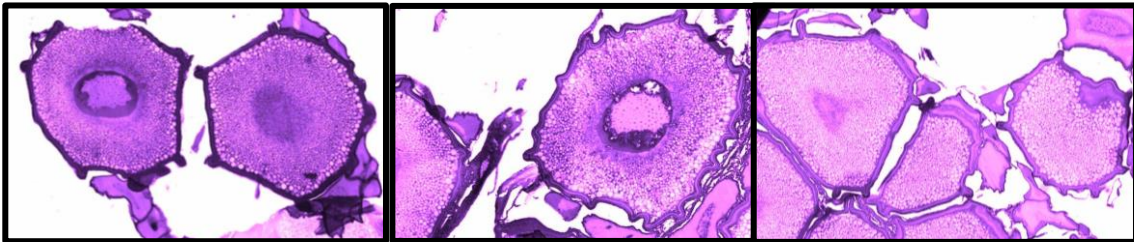


Figure 3.3. Photographs of histological slides of the anterior (left), middle (middle), and posterior (right) sections of a mature sample of *H. stenolepis*. No spawning females were observed during this study. All photographs taken at 100x magnification.

In January 2016, I trained with Lyndsey Lefebvre, an expert in reproductive biology and age and growth of groundfish species, at the NOAA Southwest Fisheries Science Center (SWFSC), Santa Cruz, California. Histology of reproductive tissues is used in stock assessments of several groundfish species at the SWFSC, including several

rockfish species and Pacific sanddab. I worked with Lefebvre in order to microscopically inspect the slides of female halibut gonads I prepared to determine maturity stages. Lefebvre performed a second, independent (double blind) reading on gonad slides for which I was uncertain of the maturity stage. I compared the maturity data that I gathered from both macroscopic and microscopic observations to determine the level of agreement between the two methods.

While some in the field of fisheries reproductive biology call for a standardization of terms (Lowererre-Barbieri et al. 2011), I have continued to use the stages “immature,” “mature,” “spawning,” and “resting” to remain consistent with the IPHC. For instance, Brown-Peterson et al. (2011) states that these are the standardized terms of developmental phases that ought to be used to describe ovarian development: (1) immature, (2) developing, (3) spawning-capable, (4) regressing, and (5) regenerating. The stage in reproduction prior to maturity is called the immature stage. During the immature stage, the oocytes are uniform in size, and none are undergoing atresia, the degeneration of ovarian follicles that did not ovulate during the previous spawning cycle (Brown-Peterson et al. 2007). Cortical alveoli (CA) oocytes are the most advanced oocytes seen in this stage. Blood vessels are not seen in immature ovaries. During the mature stage, the ovarian walls are thick, and most of the oocytes are vitellogenic (actively forming yolk); no atresia is seen. Because my sample season did not coincide with the Pacific halibut spawning season, none of the samples collected for my project were spawning-stage females. During the resting stage, both atretic and primary growth

(PG) oocytes are visible, and the ovarian wall is very thick (Figure 3.4). Figure 3.5 shows oocytes at various levels of maturity.

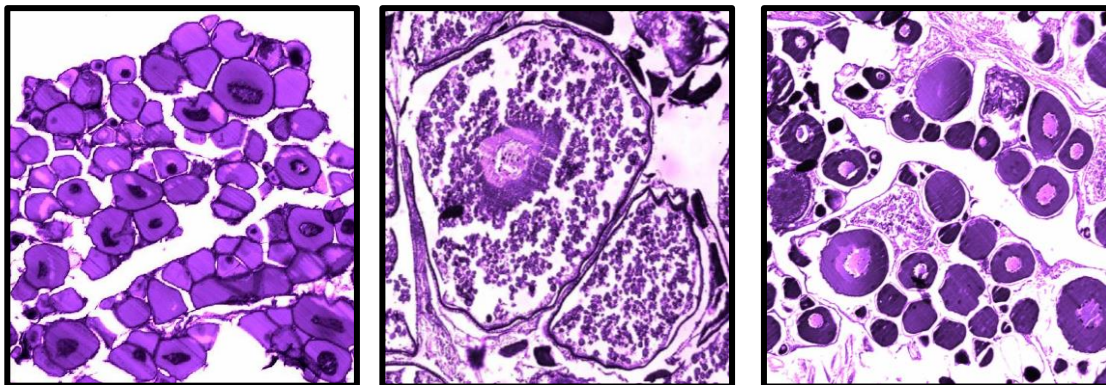


Figure 3.4. Progression in oocyte maturation in female Pacific halibut from immature (Stage I, left), mature (Stage II, center), and resting (Stage III, right); no spawning females were observed during my study. All photographs taken at 100x magnification.

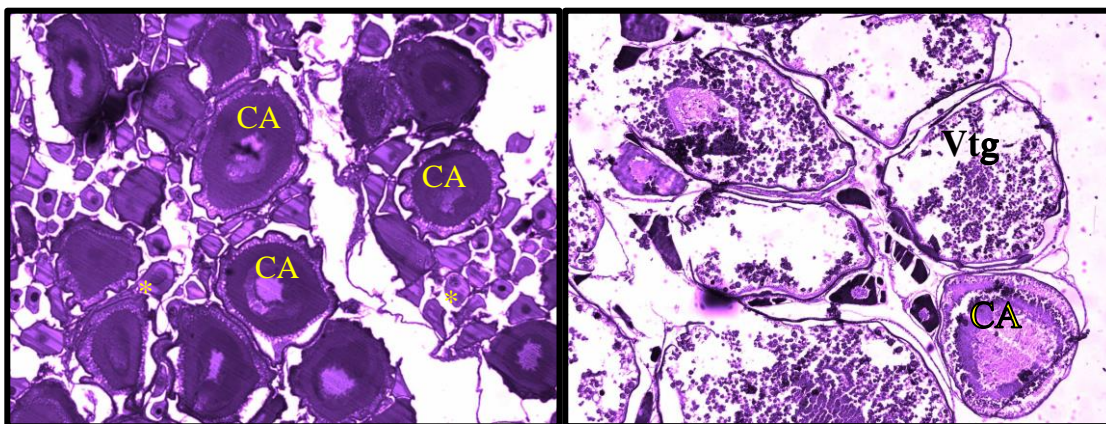


Figure 3.5. Oocytes at various levels of maturity. An immature sample on the left (CA=cortical alveolar oocyte, *=primary growth oocyte); mature sample on the right (Vtg=vitellogenic oocyte). All photographs taken at 100x magnification.

Microscopic Determination of Maturity – Oocyte Size

In order to study oocyte development, I measured the oocyte diameter for samples with the highest quality ovary sections. Image J Insight (Rasband n.d.) was used to capture and save images of the sectioned ovaries and to measure oocyte diameter; only those oocytes that were sectioned through the nucleus were measured. The average diameter (the two perpendicular lines that go through the center) was calculated for each oocyte to minimize variance associated with irregular shape (not perfectly spherical) resulting from preservation and histological processing (West 1990). Average diameter was measured for the five largest non-atretic oocytes in each section for each sample to determine the mean maximum oocyte diameter (MMOD) (Hannah and Parker 2007). The MMOD of immature, mature, and resting individuals were then compared.

Ethical Statement

Institutional Animal Care and Use (IACUC, Protocol No. 14/15.F.51-E) was approved for this study, per university requirements (Appendix G). The author sacrificed no animals for this project; all samples were collected from the Pacific halibut recreational fishery, northern California and central Oregon subareas. Pacific halibut are not a protected species.

RESULTS

Macroscopic Staging Method

Of the 217 Pacific halibut examined macroscopically, 196 (90.32 percent) were female and 21 (10.66 percent) were male. Sixty percent (117) of the 196 females were immature and would not have spawned during the following winter, 16 percent (32) were mature, and would have spawned that winter, and 24 percent (47) were resting, and would have probably spawned during the following spawning season (Table 3.3). Of the 21 males from the study, 52 percent (11) were immature and 48 percent (10) were mature (Table 3.4).

Table 3.3. Number of immature, mature, and resting (based on macroscopic analysis) female Pacific halibut collected from recreational anglers in northern California and central Oregon in 2015 in each length interval (10 cm intervals).

Females					
Length interval (cm)	Number Immature	Number Mature	Number Resting	Total Sample Size	Mean Age
64-69	8	1	0	9	8.22
70-79	50	0	3	53	8.87
80-89	44	3	15	62	9.98
90-99	15	4	10	29	10.34
100-109	0	4	16	20	10.8
110-119	0	18	2	20	11.15
120-129	0	2	0	2	12
130-139	0	0	0	0	0
140-149	0	0	1	1	11
Totals	117	32	47	196	

Table 3.4. Number of immature and mature male Pacific halibut collected from recreational anglers in northern California and central Oregon in 2015 in each length interval (10 cm intervals).

Males				
Length interval (cm)	Number Immature	Number Mature	Total Sample Size	Mean Age
65-69	3	1	4	8.5
70-79	4	4	8	9.75
80-89	4	4	8	11
90-99	0	1	1	15
Totals	11	10	21	

Realistic maturity ogives were generated only for female Pacific halibut; I was unable to generate maturity ogives for males because of the small sample size. Figure 3.6 represents fitted length-at-maturity, and shows that length-at-50%-maturity for female Pacific halibut caught off northern California and central Oregon is slightly smaller than those caught off Oregon, Washington, and IPHC Regulatory Areas 3B and 4A.

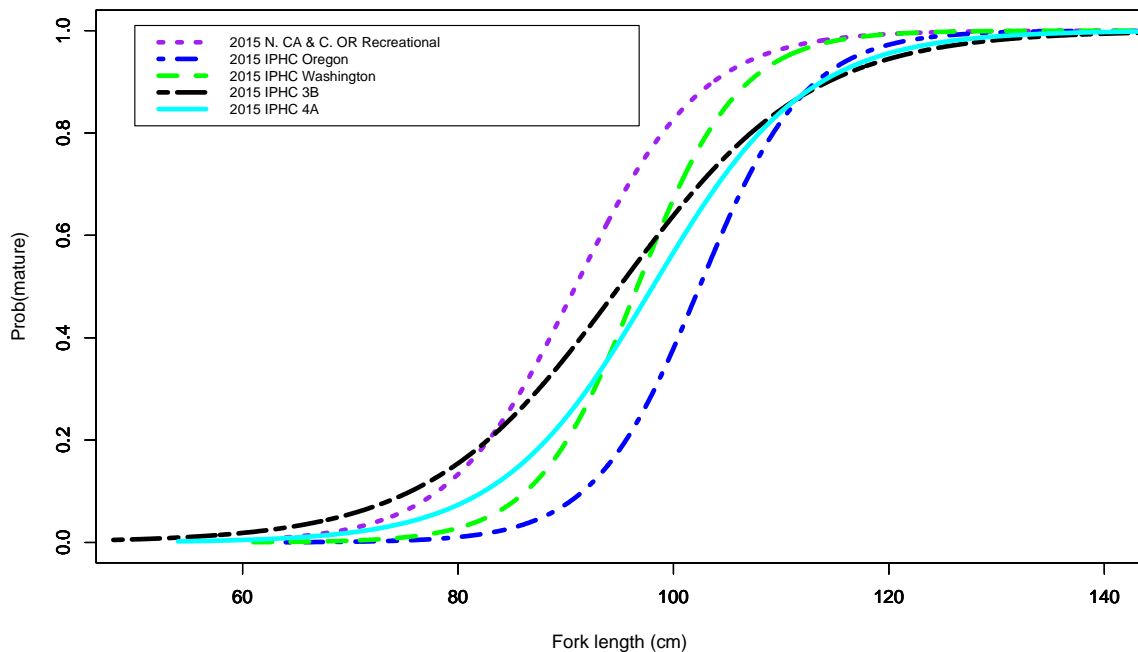


Figure 3.6. Fitted length-based female maturity ogives for Pacific halibut from the 2015 northern California and central Oregon recreational fishery (2015 N. CA & C. OR Recreational, purple) compared to those collected by the IPHC setline survey (IPHC unpublished data) during the summer of 2015 in Oregon (2015 IPHC Oregon, blue), Washington (2015 IPHC Washington, green), western Gulf of Alaska (2015 IPHC 3B, black), and eastern Aleutian Islands (2015 IPHC 4A, cyan) using macroscopic staging.

Estimated lengths-at-50%-maturity for the combined northern California and central Oregon recreational fishery was 90.9 cm (standard error=1.27 cm), as compared to 102.6 cm (standard error=0.91 cm) for the IPHC setline survey in Oregon, 96.7 cm (standard error=0.57 cm) for the IPHC setline survey in Washington, 95.0 cm (standard error=0.85 cm) for the IPHC setline survey in Regulatory Area 3B, and 98.1 cm (standard error=0.89 cm) for the IPHC setline survey in Regulatory Area 4A (Table 3.5).

Table 3.5. Estimates, standard error, and 95% confidence intervals for length-at-50%-maturity and age-at-50%-maturity for Pacific halibut captured by recreational anglers in 2015 in northern California and central Oregon, and IPHC setline surveys (IPHC unpublished data) for Oregon, Washington, and Regulatory Areas 3B and 4A using macroscopic staging.

	Length-at-50% maturity			Age-at-50%-maturity		
	Estimate	Standard Error	95% CI (± 2 SE)	Estimate	Standard Error	95% CI (± 2 SE)
N. CA/C. OR Rec	90.9	1.27	88.36-93.44	10.6	0.23	10.14-11.06
IPHC OR	102.6	0.91	100.78-104.42	11.2	0.26	10.68-11.72
IPHC WA	96.7	0.57	95.56-97.84	12.0	0.20	11.6-12.4
IPHC 3B	95.0	0.85	93.3-96.7	13.4	0.14	13.12-13.68
IPHC 4A	98.1	0.89	96.32-99.88	13.5	0.15	13.2-13.8

While the fitted length-at-maturity for northern California and central Oregon and IPHC Regulatory Areas 2A (Oregon and Washington), 3B, and 4A were quite similar (Figure 3.6), with a range of 90.9 cm (northern California and central Oregon recreational fishery) to 102.6 cm (IPHC Regulatory Area 2A, Oregon), there were considerable differences in the fitted age-at-maturity for the same regions (Figure 3.7). Like length-at-maturity, age-at-50%-maturity for female Pacific halibut caught off northern California and central Oregon is less than those caught in Oregon, Washington, and IPHC Regulatory Areas 3B and 4A; these differences are more substantial than the differences in fitted length-at-maturity.

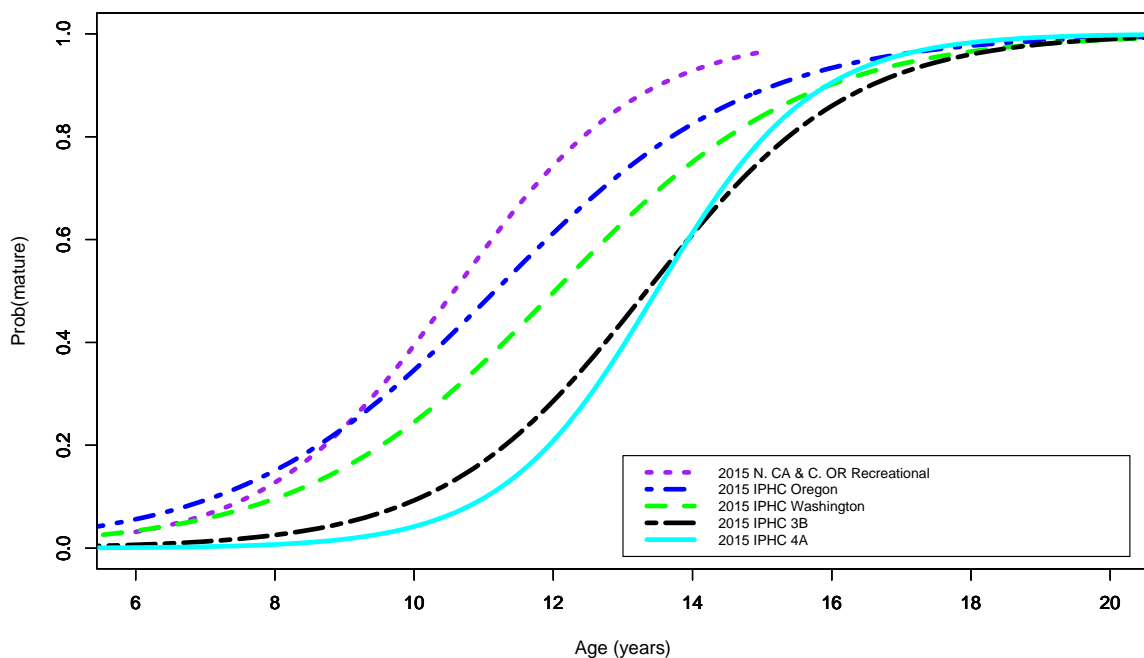


Figure 3.7. Fitted age-based female maturity ogives for Pacific halibut collected from the 2015 northern California and central Oregon recreational fishery (2015 N. CA & C. OR Recreational, purple) compared to those collected by the IPHC setline survey (IPHC unpublished data) during the summer of 2015 in Oregon (2015 IPHC Oregon, blue), Washington (2015 IPHC Washington, green), western Gulf of Alaska (2015 IPHC 3B, black), and eastern Aleutian Islands (2015 IPHC 4A, cyan) using macroscopic staging.

Estimated age-at-50%-maturity was 10.6 years (standard error=0.23 years) for the northern California and central Oregon recreational fishery, compared to 11.2 years (standard error=0.26 years) for the IPHC setline data collected in Oregon, 12.0 years (standard error=0.20 years) for the IPHC data in Washington, 13.4 years (standard error=0.14 years) for the IPHC survey data in Regulatory Area 3B, and 13.5 years (standard error=0.15 years) for the IPHC survey data in Regulatory Area 4A (Table 3.5).

Microscopic Staging Method

The maturity analysis based on results of the more rigorous microscopic staging method was subsequently run. Figure 3.8 represents the fitted length-at-maturity using the microscopic staging results, and shows that length-at-50%-maturity for female Pacific halibut caught off northern California and central Oregon remains smaller than those caught off Oregon, Washington, and IPHC Regulatory Areas 3B and 4A.

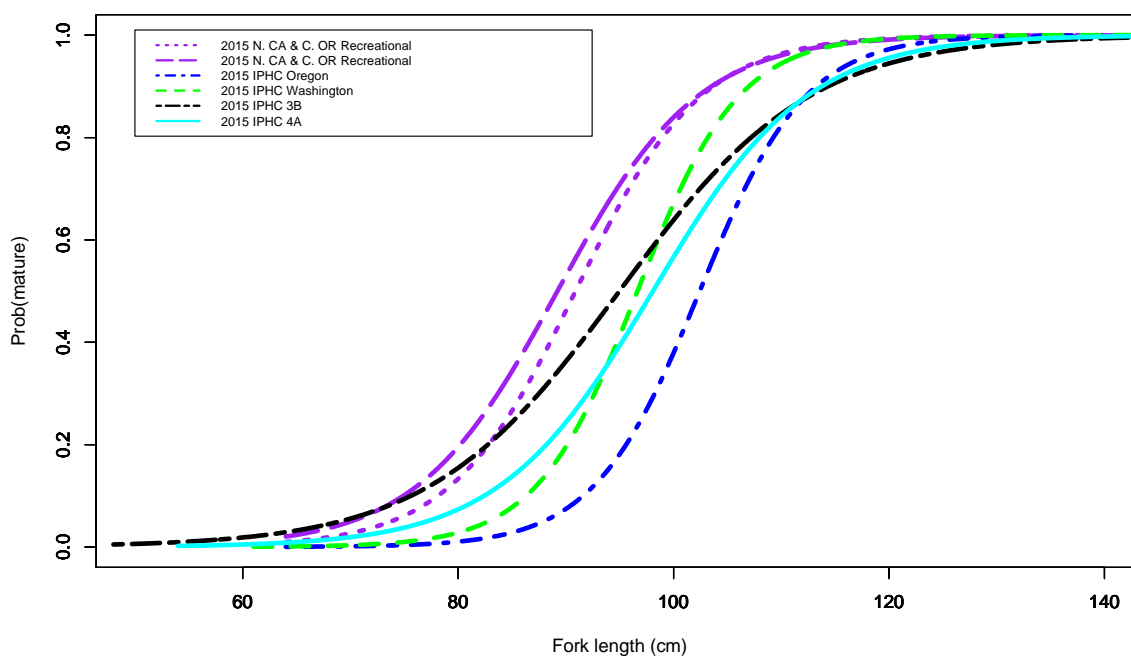


Figure 3.8. Fitted length-based female maturity ogives for Pacific halibut collected for this study (2015 N. CA & C. OR Recreational, purple) compared to Pacific halibut collected by the IPHC setline survey (IPHC unpublished data) during the summer of 2015 in Oregon (2015 IPHC Oregon, blue), Washington (2015 IPHC Washington, green), western Gulf of Alaska (2015 IPHC 3B, black), and eastern Aleutian Islands (2015 IPHC 4A, cyan) using microscopic staging. Dotted line indicates microscopic staging, solid lines denote macroscopic staging.

Estimated lengths-at-50%-maturity for the combined northern California and central Oregon recreational fishery was 89.2 cm (standard error=1.32 cm) using the

microscopic method, as compared to 90.9 cm (standard error=1.27 cm) using the macroscopic staging method (Table 3.6).

Table 3.6. Comparison of the estimates, standard error, and 95% confidence intervals for length-at-50%-maturity and age-at-50%-maturity for Pacific halibut captured by recreational anglers in 2015 northern California and central Oregon, using macroscopic staging and microscopic staging.

	Length-at-50% maturity			Age-at-50%-maturity		
	Estimate	Standard Error	95% CI (±2 SE)	Estimate	Standard Error	95% CI (±2 SE)
Macroscopic staging	90.9	1.27	88.36-93.44	10.6	0.23	10.14-11.06
Microscopic staging	89.2	1.32	86.56-91.84	10.3	0.18	9.84-10.66

Figure 3.9 represents the fitted age-at-maturity using the microscopic staging results, and shows that age-at-50%-maturity for female Pacific halibut caught off northern California and central Oregon remains smaller than those caught off Oregon, Washington, and IPHC Regulatory Areas 3B and 4A.

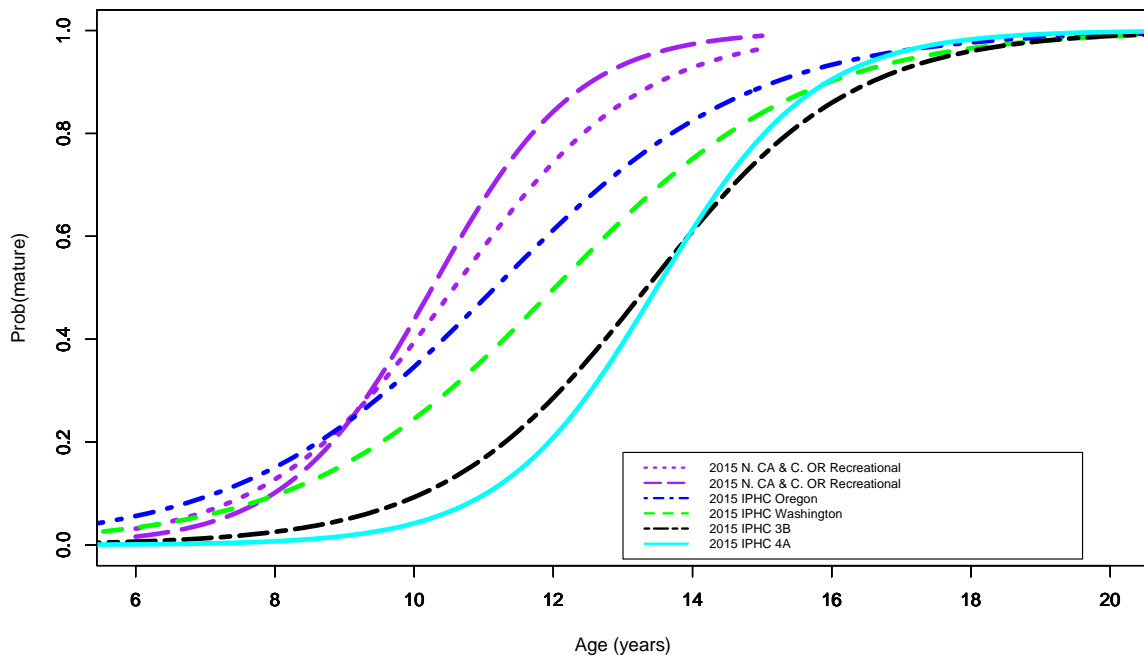


Figure 3.9. Fitted age-based female maturity ogives giving probability of maturity-at-age for Pacific halibut collected for this study (2015 N. CA & C. OR Recreational, purple) compared to Pacific halibut collected by the IPHC setline survey (IPHC unpublished data) during the summer of 2015 in Oregon (2015 IPHC Oregon, blue), Washington (2015 IPHC Washington, green), western Gulf of Alaska (2015 IPHC 3B, black), and eastern Aleutian Islands (2015 IPHC 4A, cyan) using microscopic staging. Dotted line indicates microscopic staging, solid lines denote macroscopic staging.

Estimated age-at-50% maturity for the northern California/central Oregon recreational fishery was 10.3 years (standard error 0.18 years) using the microscopic staging, as compared to 10.6 years (standard error 0.23 years) using the macroscopic staging method (Table 3.6).

I also compared the percentage agreement between macroscopically examined gonad samples and the microscopic approach (Table 3.7). The most agreement between

the macroscopic and the microscopic staging was seen in mature samples, with 94 percent agreement. The next highest level of agreement was seen in immature samples, with the maturity stage of approximately 80 percent samples in agreement; approximately 70 percent of resting samples saw agreement between macroscopic and microscopic methods. No ovaries that were identified as mature using the macroscopic method were classified as immature using the microscopic approach. Similarly, no ovaries that were classified as immature using the macroscopic method were identified as mature using the microscopic technique, and no ovaries that were macroscopically determined to be resting were later classified as mature, microscopically.

Table 3.7. Percentage agreement and disagreement between microscopic and macroscopic female maturity staging of *H. stenolepis* ovaries. Numbers differ slightly from those in Table 3 because of a small number of samples for which good slides could not be produced.

		Microscopic maturity stages			Percent Agreement (%)
		Immature	Mature	Resting	
Macroscopic maturity stages	Immature	99	0	16	86.09
	Mature	0	31	2	93.94
	Resting	16	0	35	68.63
Percent agreement (%)		86.09	100.00	66.04	

Microscopic – Oocyte Diameter Method

To determine the range of oocyte diameters found in each maturity stage, oocyte diameter was measured for oocytes that had a nucleus (Table 3.8). The average oocyte diameter of immature gonads was smallest (107.23 μm), with a range of 66.02 μm to 155.51 μm . Mature oocytes were largest, with an average oocyte diameter of 238.65 μm ,

and a range of 130.55 μm to 499.55 μm . Resting gonads were of an intermediate size, with an average oocyte diameter of 163.03 μm and a diameter range of 93.98 μm to 246.04 μm . Many more immature oocytes were measured than mature or resting oocytes.

Table 3.8. The stages of oocyte development of *H. stenolepis* and average oocyte diameter and oocyte diameter range.

Maturity Stage	Oocyte stage	Number measured	Average oocyte diameter (μm)	Oocyte diameter range (μm)
Immature	I	101	107.23	66.02-155.51
Mature	II	26	238.65	130.55-499.55
Resting	IV	61	163.03	93.98-246.04

DISCUSSION

The results from a 2013 study conducted by Perkins (2015) showed that Pacific halibut caught off northern California matured approximately three years earlier than those caught in the northern-most areas of the 2013 IPHC setline survey. However, the length-based maturation ogives from these 2013 studies were similar from Alaska to northern California, with northern California Pacific halibut reaching maturity at a slightly larger size than those from farther north (Perkins 2015).

My study found similar results for age-at-50%-maturity, with Pacific halibut caught in the northern California and central Oregon recreational fishery maturing approximately three years earlier than those caught during the 2015 IPHC survey in waters off of Alaska (Figure 3.9). Pacific halibut caught in Oregon and Washington in the IPHC setline surveys matured at an age closer to those caught in the northern California-central Oregon recreational fishery.

The results I obtained for length-at-50%-maturity showed that Pacific halibut in the northern California-central Oregon recreational fishery were reaching maturity at a smaller size than those caught in the IPHC setline survey, in contrast to Perkins' results, but there was no obvious geographic pattern in Pacific halibut in northern versus southern waters.

The finding by Perkins (2015), that Pacific halibut caught in northern California in 2013 matured three years earlier, but at a similar or slightly larger size than those

further north, is consistent with the hypothesis that maturation occurs when some critical size is obtained rather than a given age (Alm 1959, Pitt 1975, Meyer et al. 2003).

However, the result of this 2015 study that northern California and Southern fish were also maturing three years earlier than those further north, but at a smaller size suggests that Pacific halibut may actually mature at a specific age rather than a critical size – but that this age increases with latitude. Both Perkins' (2015) study in 2013 and this study (Table 3.5) conducted in 2015 found not only a consistent gradient of increasing age-at-50%-maturity with latitude in Pacific halibut, but they found very similar ages for each region: 10 to 11 years for northern California, 12 years off Washington, and 13 to 14 years in Regulatory Areas 3B and 4A further north. This consistency supports the hypothesis that Pacific halibut mature at a critical age that increases with latitude.

Roff noted the important role that size plays in the reproductive life history of fishes when he observed the large difference in the age of maturity and life expectancy of female American plaice (*Hippoglossoides platessoides*) and witch flounder (*Glyptocephalus cynoglossus*) off Newfoundland and Scotland. In Scottish waters, female American plaice mature at three, and live to six years of age, whereas those caught off Newfoundland mature at 14, and live to 24 years of age. Roff conjectured that the age of maturity is size-dependent, not age-dependent, because the sizes at maturity for males and females are similar, while the ages at maturity for the Newfoundland and Scottish stocks are considerably different (Roff 1982). Additionally, there was only a gradual increase in the in size-at-maturity of American plaice between the 1950s and 1970s,

despite a substantial decrease in the age-at-maturity (Pitt 1975). Witch flounder landed in Scottish waters mature at three years of age, whereas those caught off Newfoundland mature at seven years of age. Because many fish species, including both American plaice and witch flounder that live in Newfoundland waters, fast during the winter months (which is when reproductive tissues undergo development), Roff concluded that these fishes undergo maturation at a larger size, when the stresses associated with utilizing energy reserves stored in the liver and muscle tissues, and the resulting muscle tissue degradation, are less than when the fish is smaller. Once a larger size is attained, predation risk is also reduced (Roff 1982).

Morgan and Colbourne analyzed biological data collected from 1972 to 1995 for populations of American plaice off the Canadian east coast (Grand Bank, St. Pierre Bank, Newfoundland, and Labrador) to compare their age and size at maturity over a 30-year period (from the early 1960s to 1990s). The results showed that populations found in higher temperatures matured at a younger age and a smaller size than those in colder climates (Morgan and Colbourne 1999). My results as well as those of Perkins (2015) that found Pacific halibut landed from the comparatively warm waters off of northern California and central Oregon maturing earlier, and age-at-maturity in other regions increasing with distance north and decreasing temperatures, are largely consistent with the findings of Morgan and Colbourne (1999). Both Perkins' previous study in 2013 and this one in 2015 found not only the same trend of increasing age-at-maturity with latitude, but very similar values for age-at-maturity for each Regulatory Area despite

contrasting patterns in size-at-age. Moreover, this consistency in age-at-maturity was seen in both studies despite contrasting ocean conditions in the periods preceding the 2013 and 2015 summer fishing seasons (Figure 3.10). The period prior to the summer 2015 halibut season was characterized by the emergence of the anomalous “warm blob” that rapidly warmed the coastal waters of the Pacific Northwest starting around September 2014 and the subsequent strong El Niño that began in early 2015 (Leising et al. 2015).

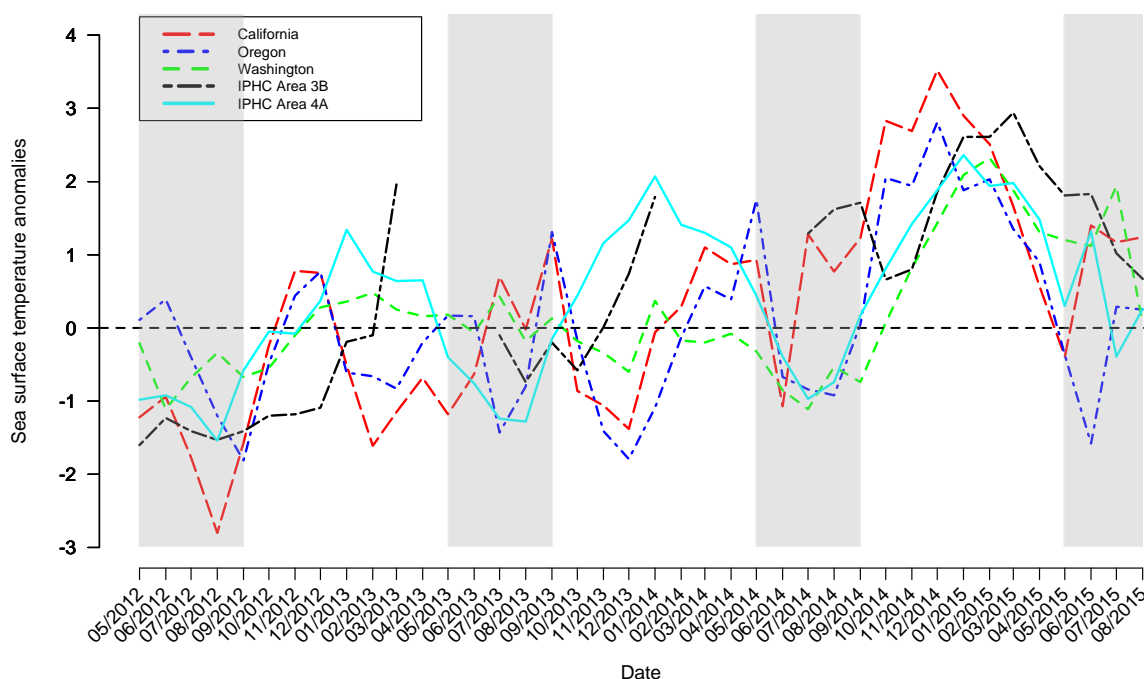


Figure 3.10. Sea surface temperature anomalies (difference from long-term averages) for California, Oregon, Washington, and IPHC Regulatory Areas 3B and 4A from May 2012 to August 2015 (NOAA 2016a). Dotted line denotes no average sea surface temperature differences between long-term averages and the actual temperatures for those months. Shaded areas denote summertime during 2012, 2013, 2014, and 2015.

Ordinarily, the waters off northern California are extremely productive, with upwelling driving nutrient-rich waters to the surface along the coast (Vander Schaaf et al., 2013, NASA 2016), but the “warm blob” and El Niño had similar, likely synergistic effects and caused elevated temperatures and reduced coastal upwelling and productivity (Leising et al. 2015). This difference in upwelling and productivity levels between 2013 and 2015 may explain why Pacific halibut caught off northern California and central Oregon in 2015 matured at a smaller size than fish caught further north, and the contrasting size-at-maturity pattern seen by Perkins (2015).

While the IPHC currently utilizes a macroscopic approach to maturity staging female Pacific halibut, they are in the process of reevaluating the criteria assigned to each maturity stage, as there appear to be discrepancies in the current classification method. Comparing macroscopic staging and microscopic oocyte diameter methods of maturity staging, I found at least 65 percent agreement between the two methods for all three maturity stages examined (no spawning stage samples were observed as the study was not conducted during the spawning season), with the highest level of agreement seen in mature ovaries. The disagreements between the two methods of maturity staging do not appear to significantly affect length- and age-at-maturity estimates for these fish.

Oocyte diameter was also measured to obtain the range of diameters that are seen in each maturity stage. Mature samples appeared to have the largest average oocyte diameter, because vitellogenic oocytes, only seen in mature samples, appear to have the largest diameter of all the different types of oocytes. However, as others have stated

(Farrell et al. 2012), oocyte development occurs on a continuum; this may explain the overlapping ranges in average oocyte diameter.

This study used histology to validate the IPHC's methods of macroscopic maturity staging of female gonads based on external appearance in Pacific halibut. While macroscopic maturity staging of female gonads is the simplest, quickest, most popular, and least expensive method, this study shows it to be somewhat less accurate than histological analysis, particularly for immature and resting stage fish. This study showed that the macroscopic staging method was nearly 94 percent accurate in identifying mature stage females, and the inaccuracy (for immature and resting fish) had little impact on estimates of length- and age-at-maturity method.

Several recommendations for future research can be made. It is recommended that the annual IPHC setline surveys be extended to northern California, the southern end of their range, if not every year at least at some regular interval. Setline surveys have been conducted in northern California in the past, and the results from this study and that by Perkins (2015), will hopefully influence the IPHC to continue such studies in the future.

Secondly, surveys of recreationally caught Pacific halibut in northern California should be continued, as this local effort produces size-at-age and maturity data comparable to that from IPHC surveys for this important recreational fishery but requires far less funding. Continuing this sampling will ensure the availability of local fishery data for this species since the IPHC may sample south of Oregon only occasionally.

Finally, an investigation into the migration patterns of fish from California using popup satellite tags could provide valuable information about potential population structure. HASA, the aforementioned non-profit organization in Humboldt County, has shown interest in this investigation.

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Appendix F

Appendix F: Instructions for histological slide preparation to assess female reproductive maturity.

- 1) Remove the ovaries from Pacific halibut females. The amount to be removed depends on the size of the female, but the sample should be no thicker than 3 millimeters:
 - a. If large (ripe fish gonads that are six to over 10 centimeters in length and over four centimeters in diameter), harden and fix in 10% neutral buffered formalin on ice for one to two hours before slicing, using a sharp, single-edge razor blade.
 - b. If medium-sized (one to three centimeters in diameter by three to five centimeters length), utilize the entire gonad, and choose a section of the gonad and cut it into sample size.
 - c. If small (ropy or less than 1 centimeter in the longest dimension), use the entire gonad (Florida Fish and Wildlife Conservation Commission 2015).
- 2) Fix the tissues in 10% neutral buffered formalin (NBF) and process using the following overnight schedule:
 - a. Stations 1 and 2: 50% alcohol solution for 30 minutes each
 - b. Station 3: 70% alcohol for one hour
 - c. Stations 4 and 5: 95% alcohol for 30 minutes each
 - d. Stations 6 and 7: 100% alcohol for two hours each
 - e. Stations 8, 9, and 10: xylene for 30 minutes each
 - f. Stations 11, 12, 13, and 14: paraffin, for 30 minutes each.
- 3) Embed the tissues in paraffin and utilize a microtome to cut the tissues at 4 micron increments
- 4) Place the slides in an oven at 75°C for 30 minutes; stain the slides using an auto slide stainer using the following schedule:
 - a. Stations 1 and 2: xylene for three minutes each
 - b. Stations 3 and 4: 100% alcohol for three minutes each
 - c. Station 5: water wash for two minutes
 - d. Station 6: hematoxylin for 16 minutes
 - e. Station 7: water wash for two minutes
 - f. Station 8: acid alcohol for three minutes
 - g. Station 9: water wash for two minutes
 - h. Station 10: bluing station for two minutes
 - i. Station 11: water wash for two minutes
 - j. Station 12: 95% alcohol for two minutes
 - k. Station 13: eosin for five minutes

- l. Stations 14 and 15: 100% alcohol for two minutes each
 - m. Stations 16 and 17: xylene, for two minutes each
- Apply a coverslip and label the mounting medium for each of the slides (L. Brown, personal communication, 22 April 2015)

Appendix G

HUMBOLDT STATE UNIVERSITY INSTITUTIONAL ANIMAL CARE AND USE PROTOCOL ROUTING SLIP

FEB 10 2015

College of Natural Resources & Sciences
Humboldt State University

The attached protocol for the humane care and use of live vertebrate animals was submitted on 2/10/15 by Tim Mulligan for FISH690
(date) (faculty project leader) (course # if appropriate)

Check whether the work described in this protocol will be supported by funding administered by the
 () HSU Foundation, () another administrative unit *-list* _____, or (x) will be unfunded.

Animals used for this project will be housed in the following facilities (please check all that apply):
 () Animal Rooms; () Fish Hatchery; () Game Pens; () Telonicher Marine Lab;
 () Natural History Museum; (x) Other, specify site and room Halibut carcasses will be sampled at local docks, then returned to the respective angler.

Person / phone number (or e-mail) to contact: Miki Takada / 858-472-4938 / mtt106@humboldt.edu

Project Title: Age/Growth and Reproductive Status of Pacific Halibut in Northern California and Southern Oregon

♦ **ROUTE FIRST TO THE CHAIR OF THE IACUC** BRING THIS FORM TO THE COLLEGE OF NATURAL RESOURCES AND SCIENCES (RM. 101 IN THE FORESTRY BUILDING). Please allow ten working days for review of proposals to conduct minimally invasive procedures and an excess of one month for review of proposals to conduct invasive procedures; note that these time periods are minimal and assume that no revisions will be necessary prior to approval. ALWAYS VERIFY APPROVAL (OFFICE OF THE CHAIR OF THE IACUC; 826-3256) BEFORE STARTING YOUR PROJECT.

THE REMAINDER OF THIS PAGE IS FOR THE USE OF THE INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE

Date 1 st Received	<u>2/10/2015</u>	REVIEW	No. <u>14/15.F.51-E</u>
<input checked="" type="checkbox"/> E- Procedures are exempt from full IACUC review because they are purely observational, non-invasive, and produce no perceptible discomfort or they concern only the use of tissues from dead animals. To be considered exempt, tissues from dead animals must be obtained from animals euthanized or otherwise killed by means, and for purposes, unrelated to the proposed project. The procedure may be approved by the Chair one additional member of the IACUC.			
() A- Procedures will be minimally invasive or produce relatively little discomfort. Protocols may involve, bleeding, injections, minimal sampling, anesthesia or humane euthanasia without prior invasive manipulation. The procedure may be approved by the Chair and two additional members of the IACUC. Project topics will be reviewed by the IACUC at the next scheduled meeting.			
() B- Procedures will involve prolonged manipulation or be invasive. Protocols may involve surgical or other stimuli inducing pain or distress, but all pain or distress will be mitigated with appropriate anesthetics or analgesics. The procedure may be initially approved by the Chair, the Campus Veterinarian and one additional member of the IACUC. Protocols will be reviewed by the IACUC at the next scheduled meeting.			
() C- Procedures will be invasive and may cause prolonged physiological or psychological stress. Pain, considerable distress, or discomfort may be induced and not mitigated by anesthesia or adequate analgesia (e.g. LD50 experiments, long-term food or water deprivation, etc.). These protocols will be reviewed thoroughly by the IACUC prior to commencement of the project.			
<input checked="" type="checkbox"/> Requires Health Assurance			
Signature, IACUC Member	<u>Meredith A. Beach</u>	Date	<input checked="" type="checkbox"/> Approved () Denied
Signature, IACUC Member	<u>[Signature]</u>	Date	<input checked="" type="checkbox"/> Approved () Denied
Signature, IACUC Chair	<u>[Signature]</u>	Date	() Approved () Denied
Final Committee Decision. All protocols must be approved prior to the start of research.			

cc: () Project Leader, () Animal Facility Supervisor, () Department Chair

Routing slip revision 09/14