GROWTH, MORTALITY, AND REPRODUCTIVE POTENTIAL OF CALIFORNIA HALIBUT (*PARALICHTHYS CALIFORNICUS*) OFF CENTRAL CALIFORNIA

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The Designated Thesis Committee Approves the Thesis Titled

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June 2015

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ABSTRACT

GROWTH, MORTALITY, AND REPRODUCTIVE POTENTIAL OF CALIFORNIA HALIBUT (*PARALICHTHYS CALIFORNICUS*) OFF CENTRAL CALIFORNIA

by Cheryl L. Barnes

Differences in key biological processes, such as growth and reproduction, can greatly influence localized population dynamics. Thus, it is important to evaluate intraspecific variation at several spatial scales to better understand biological limitations and develop management plans that maximize fishery sustainability. In 2011, the California Department of Fish and Wildlife (CDFW) conducted its first comprehensive stock assessment for California Halibut, *Paralichthys californicus*. However, limited life history data were available north of Point Conception. To improve our understanding of central California Halibut biology, 704 fish were collected during 2012 and 2013. Von Bertalanffy growth parameters were estimated at $L_\infty = 1041$ mm and $K = 0.25$ for females and $L_\infty = 824$ mm and $K = 0.22$ for males. Catch curve analysis indicated total mortality at 0.32 for females and 0.47 for males. Incidence of spawning females was used to estimate a seasonal spawning duration of 79 d, and temporal variation in gonadosomatic index identified peak spawning activity in July. The gravimetric method was used to estimate batch fecundity for an average-sized female (850 mm) at 6.0×10^5 eggs ± 6.7×10^4 (SE). Batch fecundity was multiplied by a spawning frequency of 25 to approximate seasonal fecundity at 1.4×10^7 eggs ± 1.3×10^6 (SE). When possible, comparisons were made with southern California Halibut using CDFW-collected data or results from the scientific literature. The information presented enhances our knowledge of California Halibut life history and provides region-specific estimates for future stock assessments.

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The results presented herein are the culmination of efforts from many people across California. This project would not have been possible without the support of countless recreational anglers, commercial hook-and-line fishermen, spear divers, and local seafood processors. Thank you for taking the time to speak with me about my project, put forth effort to better understand the research objectives, and graciously donate portions of your catch for science! My sincere appreciation goes out to the men and women of Capitola Boat and Bait (especially Ed Burrell) and H&H Fresh Fish, who provided the majority of specimens used in this study. Your enthusiasm, patience, and permittance for me to disrupt the natural order of business have not gone unnoticed. Additionally, I would like to thank David ‘Shorty’ Reins (captain, FV Caroline) for allowing me (and my volunteers) to participate in a number of halibut fishing trips during the summer of 2013.

This study would not have accomplished what it had without the help of many dedicated volunteers. Field interns, Alexandra Aines, Daniel Anaya, Caitrin Doles, Rhiannon McCollough, and Elizabeth Schurig spent every weekend during the summer of 2013 scouring wharfs, harbors, and cleaning tables for potential carcass donations from the fishing community. Laboratory interns Kaitlin Beck, Adam Chorazyczewski, Christopher Giordano, Hallie Heath, Serena Lomonico, Nicole Siababa, and Aaron Sloan spent countless hours sampling ovaries, separating eggs, scanning microscope slides, organizing samples, preparing otoliths, entering and checking data...the list goes on! Nikki, Adam, and Kaitie: I am especially indebted to you for working longer hours and many more months than anticipated in order to help this graduate student finish up. Your dedication is admirable.

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Paul Reilly (CDFW Senior Environmental Scientist) and Travis Tanaka (CDFW Environmental Scientist) played an integral role in shaping my thesis by making the ageing components possible. Paul Reilly served as the second, more experienced reader for all otoliths. Travis Tanaka provided substantial support by helping to prepare nearly 500 otoliths and serving as the “dispute settler” when Paul and I disagreed on final ages for a particular fish. CDFW volunteers Dario Caloss, Roger Williams, Richard White, and Richard Locattelli assisted in thin section preparations. Regional comparisons of growth and mortality were made possible by CDFW-collected length and age data for southern California Halibut (special thanks to Kim Penttila, Adrienne Vincent, and Kyle Evans) as well as supplementary data collected north of Point Conception. Additionally, Kristine Lesyna (CDFW Environmental Scientist) and I worked very closely to develop a maturity staging system for California Halibut in order to categorize fish both macroscopically and via histology. Without this partnership and additional support from CDFW, I would not have been able to process and analyze my samples histologically.

Paul Reilly, Travis Tanaka, and Kristine Lesyna...I sincerely appreciate all of your support and constant encouragement. You've been such a pleasure to work with and I am glad that we have become friends in addition to colleagues through the help of our favorite flatfish! I will take with me so many things that I have learned from each of you, hope that I returned the favor and teach you a few things, and look forward to working with you again in the future.

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Finally, to my friends and family: thank you for supporting my aspirations, even though you may not have completely understood them. Jennifer Chatham, thank you for listening to me talk about California Halibut and fisheries science for more hours that either of us care to admit. Grant Waltz and Nancy Brown, thank you for graciously providing your support, friendship, and a comfortable home for me during remote sampling efforts. You made my regular trips to Morro Bay and Port San Luis much more enjoyable than I could have imagined. And for those of you who were directly involved in carcass pickups when I was unable to do so myself, I greatly appreciate your willingness to get a little sticky for the good of the cause. Your data points are in there!

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INTRODUCTION

Due to financial and logistical limitations, the information used in stock assessments is often collected and analyzed at broad (e.g., state-wide, nation-wide) spatial scales. Although averaging the condition of a species across its range simplifies management, fine-scale (e.g., regional) variation in life history characteristics can result in localized over- or under-utilization of the resource (Prince 2010). Without spatially relevant data to account for this variation, we cannot fully understand how populations (or stocks) are differentially affected by fishing pressure (Levins 1969; Adams 1980; Orensanz et al. 2005; Pascoe et al. 2009; Caselle et al. 2011). Thus, evaluating intraspecific variation at several spatial scales provides a better understanding of the biological limitations of economically important species and promotes the development of fishery management strategies that are effective at balancing harvest and conservation throughout a species' range (Clark 1930). This is especially applicable for species with widespread distributions that span distinct biogeographic boundaries (Hedgecock 1994; Somero 2005; Leis 2007; Cope and Punt 2011).

California Halibut, *Paralichthys californicus* (family Paralichthyidae), is an economically important species that exhibits a relatively widespread distribution, spanning Point Conception, which serves as a boundary between two well-known biogeographic regions. The fishery for California Halibut began in the mid-1910s as bycatch from fishing trips targeting rockfishes, *Sebastes* spp. (Kramer et al. 2001). Commercial landings peaked at 1500 t in 1919, whereas recreational landings peaked at 1.2 million fish in 1964. Since 1980, California Halibut landings have fluctuated around 400 t for commercial fisheries and 0.2 million fish for recreational fisheries (Maunder et al. 2011). Due to rapid declines in catch during the latter half of the twentieth century, numerous regulations were placed upon the California Halibut fishery (Allen 1988; CDFG 2011a). Recreational bag limits of three fish per day in central California and five fish per day in southern California were introduced in 1971 to maintain adequate population sizes necessary for stock replenishment. A minimum size limit of 22 inches (559 mm), designed to prevent the harvest of immature individuals, also was established during the 1970s. Finally, variations in gear regulations for bottom trawls and spatial restrictions on gill net use were instituted during the past 60 years to limit take of juvenile California Halibut and nontarget species.

In 2011, the California Department of Fish and Game (CDFG, now known as the California Department of Fish and Wildlife, CDFW) conducted its first comprehensive stock assessment for California Halibut to determine population size and the effectiveness of existing management actions (Maunder et al. 2011). As part of this assessment, fishery-independent and fishery-dependent data were synthesized and incorporated into statistical models developed for two separate stocks, north and south of Point Conception. Although large amounts of biological information were made available during the assessment, life history data pertained primarily to halibut from southern California (e.g., Allen 1988; Allen and Herbinson 1990; Allen et al. 1990; Kramer 1990; Domeier and Chun 1995; Valle et al. 1998; MacNair et al. 2001). The informational void for central California Halibut forced stock assessment scientists to base initial model parameters (e.g., natural mortality, mean length assumed for the oldest fish) on values obtained from the southern California population. Maunder et al. (2011) noted that the central California stock model was “very sensitive to initial parameters...[and] that the values for these parameters determined by the model fitting procedure may not be reliable.” This prompted resource managers to prioritize the collection of sex-specific age, growth, reproduction, and mortality data for California Halibut found north of Point Conception (CDFG 2011b).

To meet the needs of management and enhance our understanding of the biology and ecology of an economically important species, I assessed age, growth, total mortality, and reproductive potential of California Halibut collected north of Point Conception (referred to as “central California Halibut” forward-going). Specifically, I collected length-at-age data, calculated sex-specific von Bertalanffy growth parameters, and used catch curve analysis to approximate total mortality. I also estimated the duration of the summer spawning season, spawning frequency, and batch fecundity to describe the reproductive potential of central California Halibut. Additional CDFW-collected data from both central and southern California were analyzed to make regional comparisons of growth and mortality, enhancing our understanding of spatiotemporal variation in California Halibut life history.

MATERIALS AND METHODS

Study Species

California Halibut can be found as far north as the Quillayute River in Washington and as far south as Magdalena Bay, Baja California Sur, Mexico (Miller and Lea 1972). However, relatively few individuals are encountered north of Bodega Bay in central California. Throughout their range, California Halibut frequently conceal themselves in sandy bottoms adjacent to hard substrate or biogenic habitats (e.g., giant kelp, *Macrocystis pyrifera*, or sand dollar, *Dendraster excentricus*, beds) to evade predators and ambush prey (Feder et al. 1974; Allen 1988). California Halibut feed primarily on small invertebrates (e.g., polychaetes, amphipods, crabs) as juveniles and become increasingly piscivorous with age (Allen 1988). As adults, California Halibut typically prey upon small fishes [e.g., Northern Anchovy (*Engraulis mordax*), Pacific Sardine (*Sardinops sagax*), California Grunion (*Leuresthes tenuis*)] and cephalopods [e.g., Market Squid (*Doryteuthis opalescens*) and *Octopus* spp.] (Frey 1971).

Located to depths of 185 m, adult California Halibut from southern California move into shallower waters (e.g., 6 to 20 m) during the spring (Clark 1930). Some of the greatest larval densities in southern California coincide with these shallow water migrations in both time and space, indicating that inshore-offshore migrations may be related to spawning activity (Clark 1930; Lavenberg et al. 1986; CalCOFI 2014) (fig. 1). A second peak in larval densities occurs in Mexico in June and in southern California in July, demonstrating increased reproductive effort in spring and summer. In laboratory experiments conducted under natural conditions, southern California

Halibut spawned at water temperatures between 15.0 and 16.5°C and on day lengths greater than 10.5 hr (Caddell et al. 1990). Additionally, captive females from this laboratory study broadcasted approximately 589,000 eggs every 14 d for approximately 182 d (April through September), indicating a heterochronal (i.e., multiple spawning) mode of reproduction.

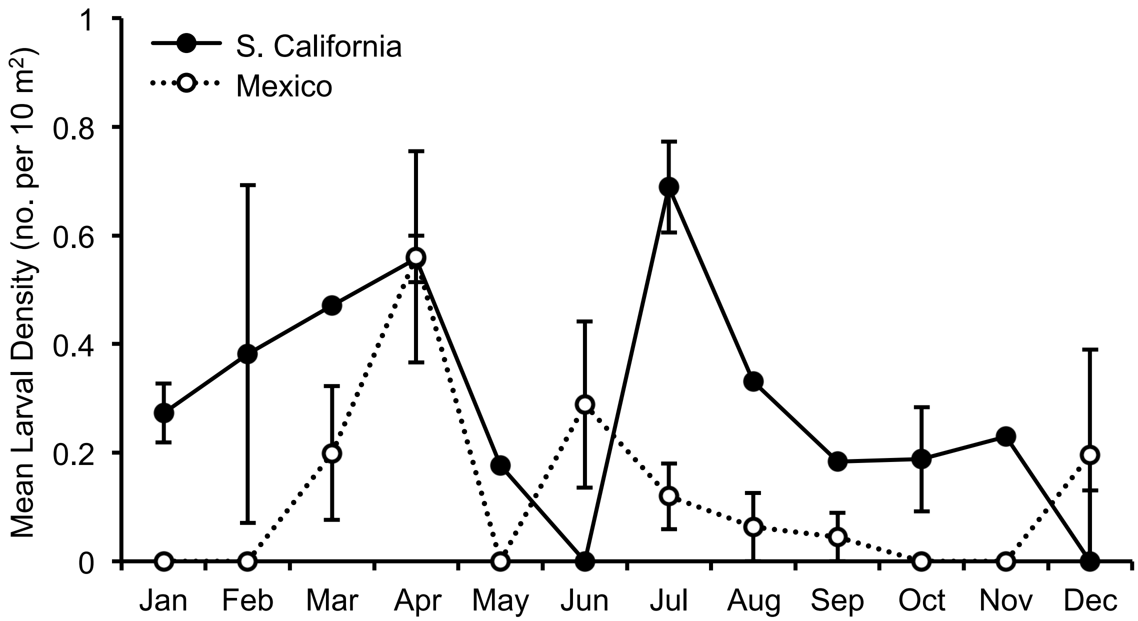

Figure 1. Mean larval density (no. of California Halibut per 10 m^2, wet displacement volume) by month. Error bars represent one standard error. Ichthyoplankton data were collected between 0 and 185 m water depth, from Point Conception (US) to Baja California (MX) (CalCOFI, 1980 to 2011). Closed circles and solid lines indicate southern California transects, whereas open circles and dashed lines denote data collected off of the Mexican coast. Data from central California are not illustrated due to relatively offshore transects and infrequent surveys.

Once hatched, California Halibut experience a relatively short larval duration (Allen 1988). In 20 to 29 d, nearshore pelagic larvae undergo metamorphosis as one eye migrates to the opposite side of the head and swimming behavior transitions from upright to lateralized. When metamorphosis is complete, larvae of approximately 17 mm (standard length) settle into benthic habitats of shallow-water embayments (Kramer 1990). Juveniles, ranging from 140 to 220 mm (standard length), emigrate to the open coast as they begin to mature (Allen 1988; Kramer 1991). Male halibut from southern California have been documented as first reaching sexual maturity at 19 cm (1 yr), whereas females from the same region do not mature until at least 36 cm (2 yr) (Love and Brooks 1990). At the population level, 50% of males are considered mature at 23 cm (1.3 yr) and 50% of females are considered mature at 47 cm (4 yr). All California Halibut males are reproductive by 32 cm (3 yr) and all females are reproductive by 59 cm (7 yr).

MacNair et al. (2001) suggested that southern California Halibut enter the fishery [i.e., reach the minimum legal size limit of 22 inches (559 mm) fork length] at approximately 5.4 yr for males and 9.4 yr for females, whereas central California Halibut attain harvestable sizes at 4.6 for males and 6.7 yr for females, indicating faster growth in central California. The historical maximum length, weight, and age of California Halibut are 152 cm, 32.7 kg, and 30 yr (Frey 1971; Eschmeyer et al. 1983). However, recent maxima for this species have been recorded as 130 cm, 30.4 kg, and 23 yr (CDFW data, 2007 to 2014).

Study Area

California Halibut were collected from shallow (< 40 m), coastal waters near five central California locations: Santa Cruz (36° 57′ N, - 122° 00′ W), Moss Landing (36° 48′ N, - 121° 47′ W), Monterey (36° 18′ N, - 121° 53′ W), Morro Bay (35° 22′ N, - 120° 51′ W), and Port San Luis (35° 10′ N, - 120° 45 W) (fig. 2). A small number of fish were opportunistically collected near San Francisco Bay and Half Moon Bay, CA as well. The nearshore environments at all of these sites consist of benthic habitats that are mixed sand and rock or entirely soft bottom, and are known to accommodate California Halibut. Each of the selected sites also encompasses at least one wharf or harbor that serves as a homeport for fishers actively targeting the species. Finally, collection sites spanned the central California coast to enable characterization of life history traits at the regional spatial scale. Efforts to collect fish from San Francisco Bay were not made because a comparable, CDFW-led study was being conducted in that location during the same time period.

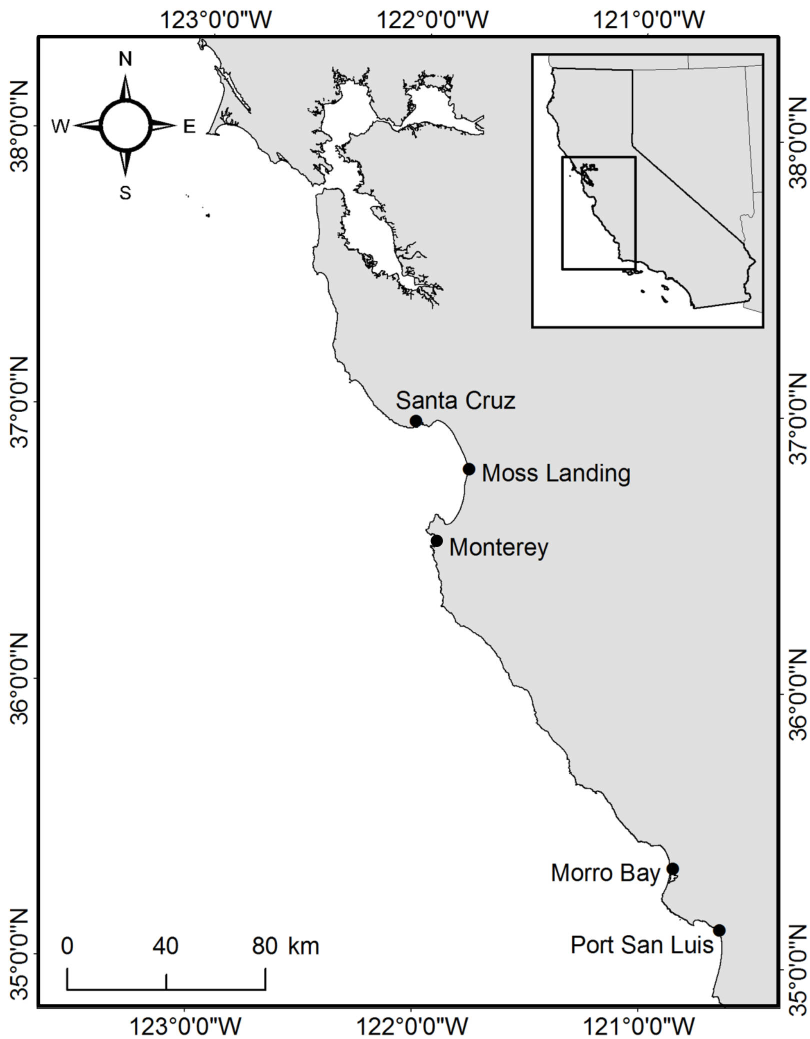

Figure 2. Locations used to sample California Halibut, *Paralichthys californicus*, in central California.

Specimen Collections

Collection efforts were concentrated during the summer months (i.e., end of May to mid September) of 2012 and 2013, when the greatest quantities of halibut are caught in central California (fig 3) (CDFW unpublished data). A variety of gear types (i.e., hook-and-line, spear, beach seine, trawl) were used to capture fish. In an effort to collect sublegal fish, I conducted six, 10-min otter trawl tows offshore of Moss Landing, CA. CDFW staff and I also attempted to catch fish at Del Monte Beach (Monterey, CA) using a 125-ft beach seine one to two days per month from May to September, 2013. However, these combined efforts resulted in only one 394 mm female California Halibut caught via beach seine. Consequently, the majority of samples were collected as carcasses donated from recreational fishers and seafood processors and, thus, were above the legal size limit (559 mm).

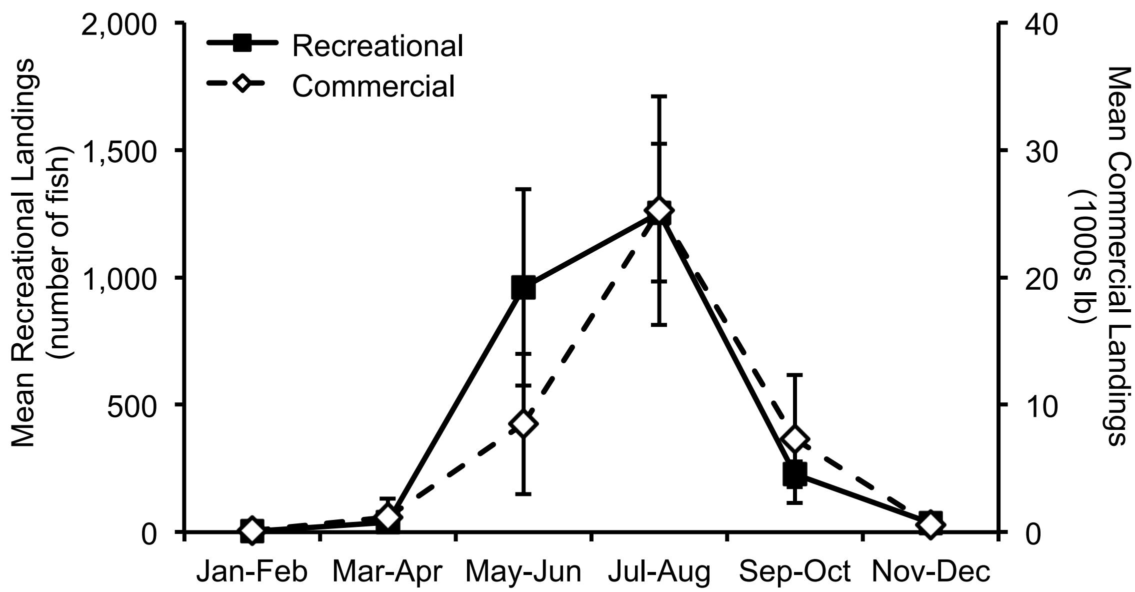

Figure 3. Bimonthly mean landings of California Halibut caught between San Francisco Bay and Morro Bay, CA from 2004 to 2013 (CDFW unpublished data). The solid line represents recreational landings (no. fish) and the dashed line denotes commercial landings (1000s lb). Errors bars indicate one standard error.

Before the sampling seasons of 2012 and 2013, I posted flyers requesting filleted California Halibut carcasses at every major fishing port, harbor master office, wharf, fishing club, and tackle store from Half Moon Bay in San Mateo County to Grover Beach in San Luis Obispo County. Flyers contained a phone number and email address so that fishers could contact me about donating carcasses during the course of the sampling period. In addition to reaching out to the recreational community, I contacted as many local restaurants and seafood processors as possible to obtain samples from the commercial fishery, as commercial fishers sell their catches as whole fish. California Recreational Fisheries Survey (CRFS) samplers also were asked to collect specimens and distribute informational flyers whenever possible.

Throughout the 2012 sampling period, I spent every weekend and two to three days during the week soliciting California Halibut carcass donations at boat launch ramps and fish cleaning tables. Each sampling day lasted from approximately 10 AM, when fishers began to return from early morning trips, to 6 PM or whenever the last boat had returned (whichever came first). One weekend each month, I traveled to Monterey, Morro Bay, and Port San Luis to obtain samples from those locations. However, my sampling efforts were concentrated at Santa Cruz Harbor and Capitola Wharf, where more halibut were being caught recreationally.

In 2013, I enlisted the help of five interns who were each responsible for sampling one of the five sampling locations. Every weekend, from the end of May to the beginning of September, these individuals solicited carcasses from the recreational fishing community in the same way that was described for 2012 sampling efforts. With all locations staffed on weekends, I traveled from site to site, filled in when needed, attended or staffed Commercial Passenger Fishing Vessel (CPFV) trips targeting California Halibut, and picked up carcasses from fishers calling in with donations. In addition, I collected fish carcasses two to three days during the week at locations not already occupied by CRFS samplers. Finally, I sampled commercially-caught halibut from H&H Fresh Fish, a seafood processor in Santa Cruz, once per week as long as halibut were being processed.

Capture date, specific location, and gear type were recorded for all specimens collected. When possible, sex, wet body weight (kg), and pre- and post-fillet lengths (mm) were documented. If specimens had already been filleted upon receipt, however, only post-fillet lengths (mm) were obtained. Whether pre- or post-fillet, fork length was defined as the shortest distance from the anterior-most portion of the snout to the center of the caudal fin (fig. 4).

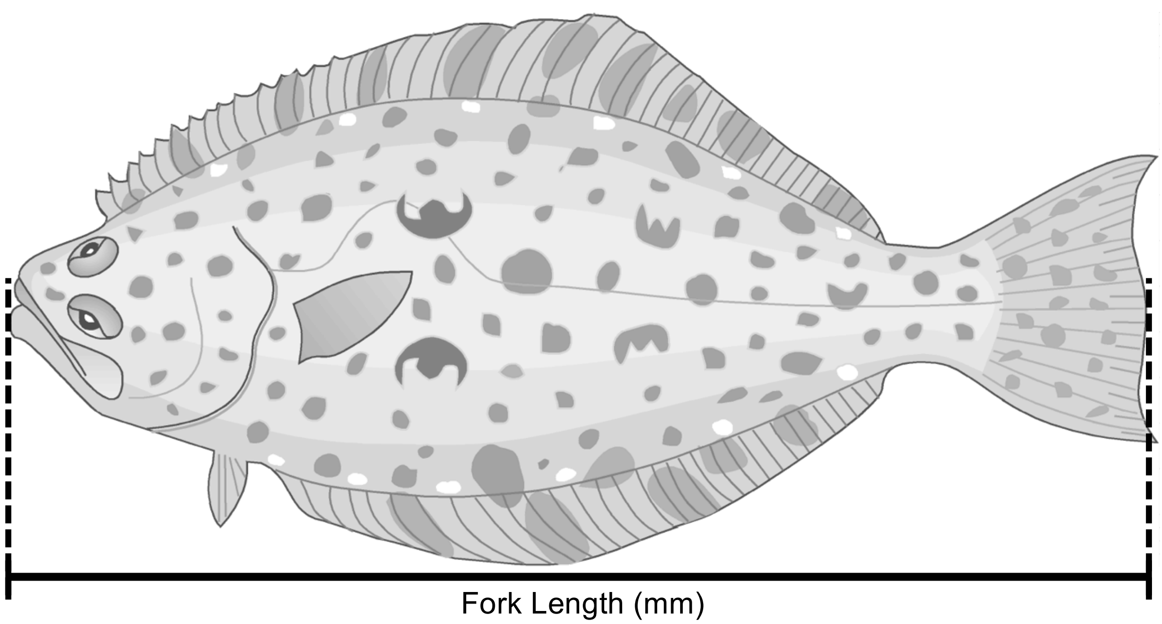

Figure 4. Diagram of fork length measurement. California Halibut, *Paralichthys californicus*, drawing by © Larry G. Allen.

Once fish were measured in the field, specimens were placed on ice until dissections occurred (typically within 24 hr of capture). During dissections, a miniature handsaw was used to slice through the top of the skull directly adjacent to the migratory eye. Sagittal otoliths (i.e., inner ear bones of ray-finned fishes) were then extracted, cleaned using a paper towel, and stored in coin envelopes for subsequent ageing. Gonads and livers were removed and weighed to the nearest 0.1 g for calculations of gonadosomatic and hepatosomatic indices (i.e., GSI and HSI, respectively). Ovaries were preserved in 10% buffered formalin for a minimum of two weeks before being transferred to 70% ethyl alcohol, where they remained until histological analyses and fecundity estimations were conducted. After mass had been recorded, testes were discarded. Finally, stomach contents, white muscle samples, and fin clips were taken and housed at MLML for future use in diet and/or genetic studies. All specimens were collected under CDFW Scientific Collection Permits 10418 and 824, following SJSU's Institutional Animal Care and Use Committee (IACUC) protocol 985. Unless otherwise stated, statistical analyses were conducted using the IBM software package, SPSS (v.22).

Length-Weight Relationships

A Kolmogorov-Smirnov (KS) test was used to compare sex-specific length frequency distributions (LFD), whereas an independent samples t-test was used to compare mean fork lengths and mean body weights of California Halibut, by sex. Sex-structured length-weight relationships were also developed for central California Halibut using the allometric growth model $W = aL^b$, where W is body weight (g), L is fork length (mm), and a (condition factor) and b (measure of curvature) are constants determined by fitting a linear regression to log-transformed length and weight data (Hile 1936, Martin 1949; Le Cren 1951). The slope of the line would correspond to parameter b and the y-intercept to parameter a (log W = log a + b log L). Finally, an analysis of covariance (ANCOVA) was used to compare length-weight relationships for males and females.

Age Determinations

Otoliths were prepared following procedures described by the Committee of Age Reading Experts (CARE 2006). Otoliths were first embedded into a quick set epoxy gel, mounted onto Dennison merchandise tags, and sectioned through the focus (i.e., nucleus or center of the otolith that is defined by the first year of growth) using a Buehler Isomet low-speed saw and 0.5 mm spacer. Thin sections were then mounted onto microscope slides and polished using a Buehler Ecomet III Polisher/Grinder and 800 to 1000 grit sandpaper until opaque-translucent pairs were distinguishable from one another. Because eyed-side otoliths tended to exhibit distorted patterns of growth, blind-side otoliths were selected for ageing whenever possible (fig. 5). If the blind otolith for a particular fish was vateritic (i.e., crystallized), damaged (e.g., broken through the focus), or lost, the eyed-side otolith was sectioned and aged in its place (so long as reading difficulty was minimal).

Sectioned otoliths were read at 50x magnification using a compound microscope and transmitted light. Without prior knowledge of fish sex or size, two readers independently determined the age of each fish to the nearest integer (yr). If the otolith margin represented more than six months of growth, the age of the fish was rounded up, whereas a margin exhibiting less than six months of growth would result in an age that was rounded down. The relative amount of marginal growth was determined by comparing the width of the band with directly adjacent annuli.

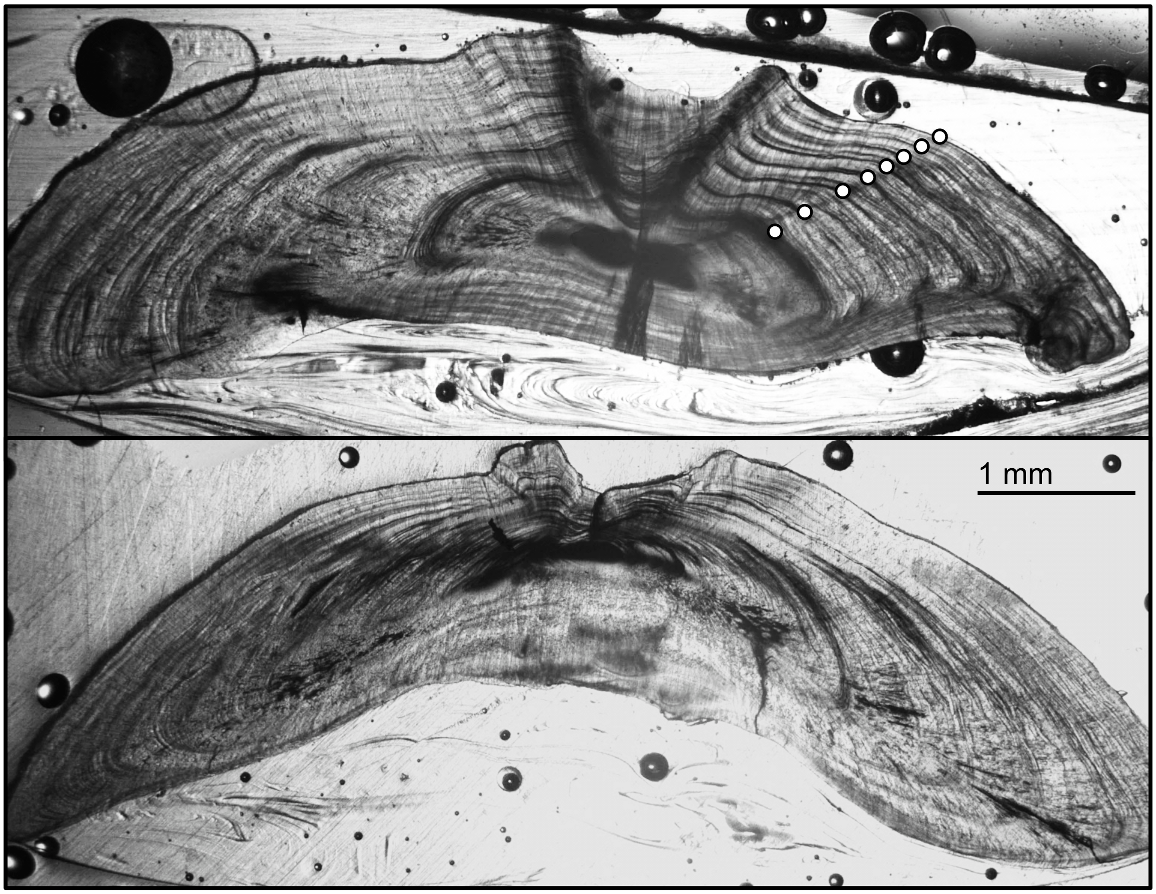

Figure 5. Thin-sectioned sagittal otoliths from two California Halibut, both aged at 8 yr (upper: blind-side otolith, lower: eyed-side otolith). The combination of one opaque and one adjacent, translucent zone represents a single year of growth. White circles (upper image) indicate individual annuli.

Reader 1 (Cheryl Barnes, MLML), less experienced in ageing boney fishes, read each otolith as many times as was necessary to obtain three identical ages. Reader 2 (Paul Reilly, CDFW), more experienced in ageing marine fishes, read each otolith as many times as was necessary to obtain two identical ages. Once age determinations were reached, Reader 1 and Reader 2 compared results. If the two agreed, the commonly determined age was considered final. If the age determinations by Reader 1 and Reader 2 did not reach agreement, a third reader (Travis Tanaka, CDFW) was asked to also blindly and independently age the fish. If Reader 3 agreed with either Reader 1 or Reader 2, that age was considered final. If the age determination made by Reader 3 did not agree with either Reader 1 or Reader 2, a digital image was prepared for discussion purposes. Upon reviewing this image together, all three readers either came to an agreement as to the final age of the fish or decided to exclude it from further analyses because of poor otolith readability. The same ageing procedures were followed for all CDFW-collected data. However, only Readers 2 and 3 were available to age fish collected between 2007 and 2011 and in 2014.

Reader-specific ages for central California Halibut collected during 2012 and 2013 were plotted against one another to evaluate potential biases. Proportional agreement was calculated for each age class to assess between-reader differences for Readers 1 and 2. An independent samples t-test was used to compare mean ages of female and male California Halibut, whereas a Kolmogorov-Smirnov (KS) test compared the shapes of age frequency distributions.

Assessing Rates of Growth

To estimate growth of California Halibut, sex-structured von Bertalanffy growth curves were fit to length (mm) and age (yr) data using the equation $L_t = L_\infty \left(1\text{-}e^{-K(t-t_0)}\right)$, where L_t is the predicted length at age t, L_∞ represents the theoretical maximum length, K is the growth coefficient, and t_0 indicates the predicted age at a length equal to zero (von Bertalanffy 1938). Because the von Bertalanffy growth equation is sensitive to constricted size ranges and few small fish (i.e., under 600 mm fork length) were sampled for this study, t_0 was fixed at zero (e.g., Ferreira and Russ 1994; Robertson et al. 2005; Caselle et al. 2011). Without doing so, mathematical estimations using project data would have resulted in biologically unrealistic lengths for age-zero fish. Growth parameters L_∞ and K were estimated using least squares methods and the Microsoft Excel add-in, Solver. Standard errors for L_∞ and K were determined by means of inverse Hessian and variance/covariance matrices (Quinn and Deriso 1999).

Maximum likelihood techniques (described by Kimura 1980) and the statistical software R (v.3.1.1) were used to estimate sex-specific 95% confidence intervals surrounding L_∞ and K. These 95% confidence intervals, depicted as ellipses around the intersection of L_∞ and K, were plotted and used to statistically evaluate differences between male and female California Halibut. Overlapping ellipses would indicate no significant difference in growth trajectories between the sexes, whereas spatially explicit ellipses would be interpreted as significantly different from one another (e.g., Hamilton et al. 2011). Once this analysis had been completed, length-at-age data collected by CDFW were merged with those collected for this study. The procedures described above were employed to compare sex-specific growth between central and southern California.

Estimating Total Mortality

Age frequency data were used to estimate instantaneous rates of total mortality (Z) through catch curve analysis (Ricker 1975). Linear regressions were fit to natural log-transformed frequency data for central California Halibut collected in 2013. The resulting slopes indicated the instantaneous total mortality rate for each sex. An ANCOVA was used to test for significant differences between natural-log transformed age frequencies and sex and the interaction term. A significant interaction term (i.e., slope) would indicate different rates of total mortality, whereas statistical significance in the sex variable (i.e., y-intercept) would indicate differences in relative abundance. The same procedures detailed above were used to evaluate differences between central and southern California Halibut after incorporation of CDFW-collected data from both regions.

Maturity Staging

Simple determinations of maturity (i.e., immature or mature) were assigned to freshly dead fish using the presence or absence of visible eggs or sperm as criterion (Love and Brooks 1990). In collaboration with Kristine Lesyna (CDFW), who collected large quantities of relatively small individuals (< 600 mm fork length) from San Francisco Bay during 2012 and 2013, I developed a system in which to classify California Halibut into various stages of maturity. Macroscopic criteria were established according to gonadal size, color, texture, and overall appearance, whereas microscopic criteria were developed via histology.

To prepare preserved ovarian tissue for histological analyses, one 3 to 5 mm thick transverse section was removed from all retained ovaries. Anterior, mid, and posterior sections from both eyed- and blind-side ovaries had been preliminarily analyzed for potential differences in the most advanced developmental oocyte stage. Because no differences existed (Kristine Lesyna pers. comm., 350 Harbor Blvd, Belmont, CA 94002), transverse sections were taken only from the mid-portion of blind-side ovaries. Each section was then placed into a 25 x 30 x 4 mm tissue cassette and 70% ethyl alcohol. Labeled cassettes were sent to Diagnostic Pathology Medical Group (DPMG) in Sacramento, CA and processed following Luna (1968). Tissues were dehydrated in alcohol, embedded in paraffin, and sectioned to 3 or 4 μm. Sectioned tissue underwent a six-step procedure [i.e., deparaffinizing, hydrating, hematoxylin and eosin (H&E) staining, dehydrating, clearing, and mounting] that resulted in the illumination of various cellular features (e.g., nuclei, cytoplasm, collagen) via differential incorporation of H&E stains.

Once returned to MLML, histological slides were systematically reviewed under a compound microscope at 50x magnification to determine the first (e.g., hydrated) and second (e.g., final maturation) most advanced stage (MAS) of oocyte development using terminology standardized by Murua et al. (2003) (fig 6). Presence of absence of post-ovulatory follicles (POFs; evidence of recent spawning activity) and rates of atresia (resorption of oocytes) were assessed using techniques described by Hunter and Macewicz (1980; 1985) (fig 7). Microscopic maturity stages were determined based upon the combination of MAS of oocyte development, incidence of POFs, and rates of atresia. Macroscopic and microscopic maturity criteria were then organized to inform a complete staging system, which previously had not been undescribed for this species.

Figure 6. Histological slide of spawning California Halibut ovary indicating various stages of oocyte development used in maturity stage classifications. PV: pre-vitellogenic (i.e., chromatin nuclear, perinucleolar); CA: cortical alveoli; YG: yolk granule; FM: final maturation; HD: hydrated; POF: postovulatory follicle.

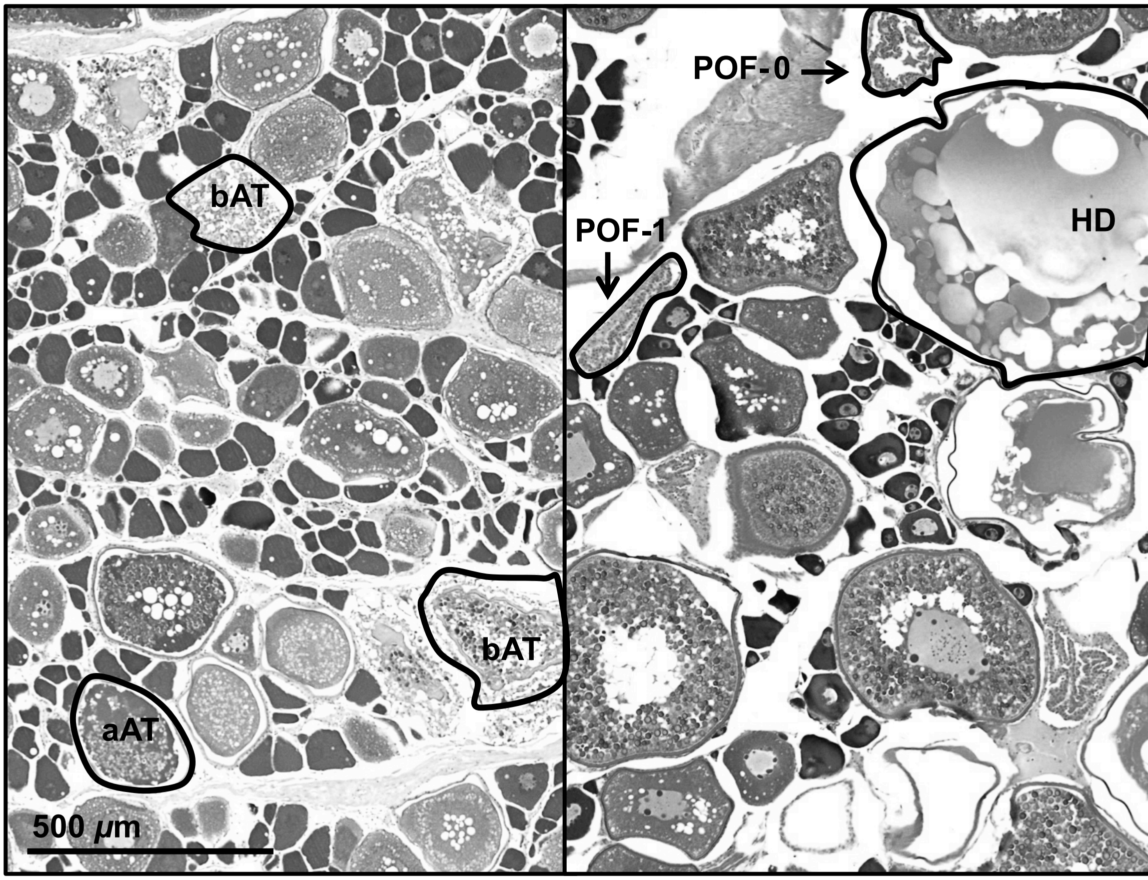

Figure 7. Histological slide of spent (left) and spawning (right) California Halibut ovaries indicating various stages of oocyte development used in maturity stage classifications. HD: hydrated; POF-0: postovulatory follicle theoretically formed on the day of capture; POF-1: postovulatory follicle theoretically formed one day before capture; AT: alpha (primary stage) atresia; bAT: beta (secondary stage) atresia.

Characterization of the Spawning Season

The incidence of spawning females [i.e., those containing hydrated oocytes and/or new (i.e., age 0) postovulatory follicles] was used to determine the duration of the spawning season (e.g., Almatar et al. 2004). In other words, the earliest capture date of an actively spawning female denoted the start of the summer spawning season, whereas the latest capture date of an actively spawning female indicated the termination of the season. Gonadosomatic index (GSI) and hepatosomatic index

(HSI) were calculated throughout the sampling period to illustrate temporal changes in energy allocation, which can be used to illustrate the height of spawning activity and provide support for the duration of a spawning season (Le Cren 1951; Delahunty and de Vlaming 1980; de Vlaming et al. 1982). The equations used to calculate standardized GSI and HSI were:

$$GSI = \frac{\text{ovary mass (g)}}{\text{body mass (g) - ovary mass (g)}} * 100$$

$$HSI = \frac{\text{liver mass (g)}}{\text{body mass (g) - liver mass (g)}} * 100$$

Relatively greater values of GSI represent increased energy allocation toward reproduction at the time of capture. Conversely, greater values of HSI represent increased energy allocation toward growth and maintenance (Delahunty and de Vlaming 1980). However, in oviparous fishes, HSI can increase in conjunction with reproductive activity because synthesis of vitellogenin (the egg yolk precursor protein) takes place in the liver (Wallace and Selman 1979). Therefore, temporal changes in HSI are confounded for females and may only be indicative of changes in energy allocation for males.

Daily Spawning Fraction, Interspawning Interval, Spawning Frequency

To determine the daily spawning fraction (s) of central California Halibut, the number of spawning females sampled was divided by the total number of females capable of reproducing at the time of capture (e.g., Parker 1980; DeMartini and Fountain 1981; Hunter and Macewicz 1985; Caddell et al. 1990; Almatar et al. 2004). Interspawning interval (ISI, in days) was calculated by taking the reciprocal of the daily spawning fraction (ISI = $\frac{1}{s}$; Wootton 1978). Daily spawning fraction and interspawning interval were calculated for each sampling day that produced three or more reproductively capable females. To prevent underestimations of daily spawning fraction due to the ephemeral nature of hydration and spawning, only females possessing postovulatory follicles (POFs) estimated to be one day old were used in the numerator (e.g., Hunter and Goldberg 1980; Hunter and Macewicz 1980; Hunter and Macewicz 1985). Spawning frequency (f), defined as the number of spawning events per female per season, was estimated by dividing the duration of the spawning season by the interspawning interval. Spawning frequency was estimated for central California Halibut for 2012, 2013, and for both years combined.

Batch Fecundity

The gravimetric method of estimating fecundity includes calculating the product of gonad mass (g) and mean oocyte density (number of eggs per gram of ovarian tissue) (Bagenal 1978; Morse 1981; Hunter et al. 1985). For multiple spawning fishes, batch fecundity (i.e., the number of eggs released during a single spawning event) can be determined by incorporating the hydrated oocyte method into the gravimetric method, which means only counting the number of hydrated oocytes in a weighed subsample to establish mean oocyte density before extrapolating to the full mass of the ovary (Hunter and Goldberg 1980; Macewicz and Hunter 1993). Because hydrated oocytes represent the spawning batch and are easily distinguishable from earlier stages of development based on size, color, shape, and obvious presence of an oil globule, this method was selected to estimate batch fecundity for central California Halibut (fig. 8). Therefore, only females with hydrated oocytes at the time of capture were incorporated into this estimate.

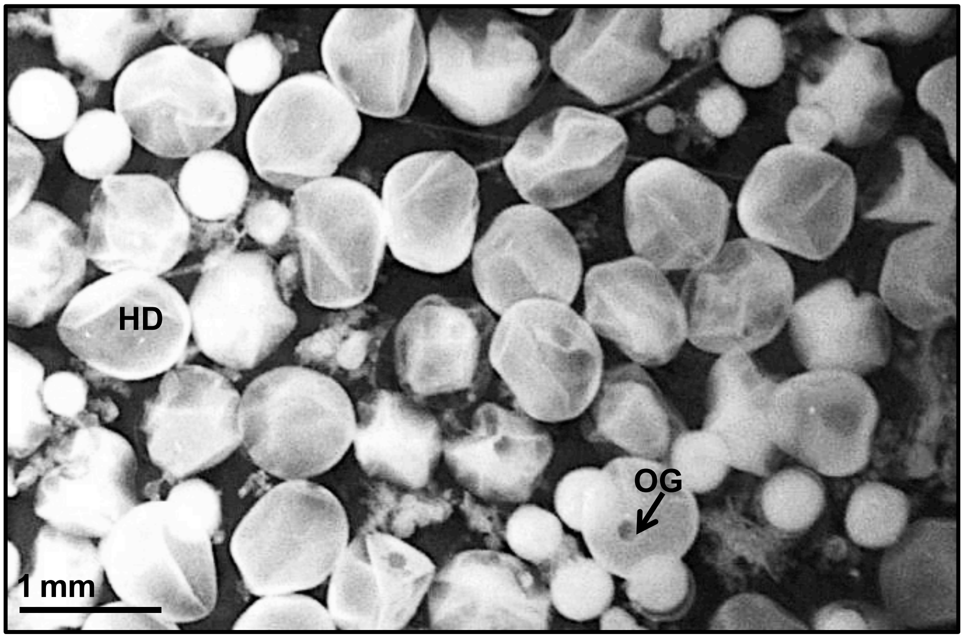

Figure 8. Whole mount image of California Halibut oocytes. Hydrated oocytes (HD) are distinguishable from less developed stages due to their larger size, greater transparency, wrinkled appearance, and obvious oil globule (OG).

Ovaries of hydrated females (as determined from both macroscopic and microscopic evaluation) were removed from preservative, dried on blotter paper for 2 to 3 minutes, and weighed to the nearest 0.1 g. A length-wise incision was then made along the ovary. If hydrated oocytes had uniformly collected at the innermost and/or anterior-most section(s) of the ovary, this “hydrated-only” portion was washed into a separate container using a standard coffee filter and funnel, left to drain until all solution had percolated through, and weighed to the nearest 0.1 g.

Once the hydrated-only portion had been processed (if applicable), remaining oocytes consisting of assorted developmental stages (including some hydrated oocytes) were separated from the ovarian wall. The ovarian wall was then weighed to the nearest 0.1 g. Both hydrated-only and ovarian wall masses were subtracted from the initial preserved ovary mass to obtain an estimate of mass for the "assorted" portion (g). The assorted portion was then thoroughly mixed before removing five subsamples (0.3 to 0.5 g each). Because the density of hydrated oocytes in assorted and hydrated-only portions were likely to be different (i.e., much greater densities of hydrated oocytes in hydrated-only portions than in assorted portions), five subsamples also were taken from hydrated-only portions.

Hydrated oocytes were counted for three assorted subsamples and three hydrated-only subsamples (if applicable). The coefficient of variation (CV) was used to determine whether or not this sample size was sufficient to precisely estimate batch fecundity of any one fish. If the CV from the first three subsample densities exceeded 0.20, an additional one to two subsamples were counted. The mean subsample density was then calculated and multiplied by the mass of the appropriate assorted or hydrated-only portion. These subtotals were then added together to provide an estimate of batch fecundity for each individual fish. Spawning females with ovaries that had missing portions (as a result of filleting) produced inaccurate preserved masses and were excluded from batch fecundity estimates. Ovaries that had not been properly preserved (i.e., an insufficient ratio of formalin and/or ethanol to tissue) caused degradation and were also excluded from analyses.

California Halibut in a "late hydration" phase of spawning (histologically characterized by possessing hydrated oocytes, but no final maturation stage or new postovulatory follicles) were used to develop a relationship between batch fecundity and fork length (mm). Late hydration phase females were selected in an attempt to reduce the variation in batch fecundity by excluding females that had not yet fully hydrated or that had already released some hydrated oocytes (i.e., the batch fecundity estimate for these fish would be artificially low as result of timing of capture). Curve estimation was used to determine the best-fit model for batch fecundity-at-length. Curve estimation also was used to determine the best-fit model for the relationship between batch fecundity of late hydration or actively spawning females and time (Julian day) to evaluate temporal effects on spawning. Finally, the mean batch fecundity for an averaged-sized female was multiplied by the mean spawning frequency to estimate seasonal fecundity for 2012, 2013, and both years combined.

RESULTS

A total of 704 specimens were collected as part of this study (table 1; appendix I). Sampling efforts resulted in the collection of fish on 46 different days in 2012 and on 72 different days in 2013. Although additional effort was expended, sampling days were not recorded if California Halibut had not been collected.

TABLE 1
Number of specimens collected, by sex and sampling location. Fish listed as central California were caught in San Francisco Bay, Half Moon Bay, or an undetermined location within Monterey Bay.

Location	Sex		Total
	Female	Male	
Central California	13	3	16
Santa Cruz	172	117	289
Moss Landing	177	119	296
Monterey	35	7	42
Morro Bay	19	8	27
Port San Luis	32	2	34
Total	448	256	704

All but three fish were obtained from fishery-dependent sources. Of the 701 California Halibut collected from the fishery, 34% were supplied by the commercial sector (either directly or from seafood processors) and 60% came from recreational anglers and spear divers (table 2). Sources for the remaining 6% could not be determined. The sex ratio of fish collected exclusively for my thesis was 1.8:1 (female to male), which was significantly different from the expected 1:1 ratio ($X^2_{1,702}$ = 52.364, $p < 0.001$). When my data were combined with those collected by

CDFW, the sex ratio for central California became 1.4:1 ($X^2_{1,1297}$ = 26.290, $p < 0.001$). Data for southern California Halibut displayed a sex ratio of 4.3:1 ($X^2_{1,759}$ = 291.512, $p < 0.001$).

TABLE 2
Number of specimens collected, by fishery and gear type. Three additional fish were collected using fishery-independent methods.

	Number of Fish			
Gear Type	Commercial	Recreational	Unknown	Total
Hook-and-Line	235	319	42	596
Spear	0	94	0	94
Unknown	4	6	1	11
Total	239	419	43	701

Length-Weight Relationships

Because specimens were opportunistically collected from commercial and recreational fisheries, many were received as filleted carcasses. Therefore, obtaining pre-fillet fork length (mm) for length-weight relationships was not always possible. To assess the relationship between pre- and post-fillet length, a linear regression was fit to data from 152 individuals for which both pre- and post-fillet fork length measurements existed (fig. 9). The resulting regression equation was $y = 1.01x - 0.94$ ($R^2 = 0.999$, $F_{1,150,}$ = 279210, $p < 0.001$), where x equals pre-fillet fork length (mm) and y equals post-fillet fork length (mm). Given that the relationship between pre- and post-fillet fork length was directly proportional, post-fillet length was converted to pre-fillet length when no pre-fillet length measurement was available. Pre-fillet fork length (mm), either measured or converted, was used in all proceeding analyses and is simply referred to as 'fork length' forward-going.

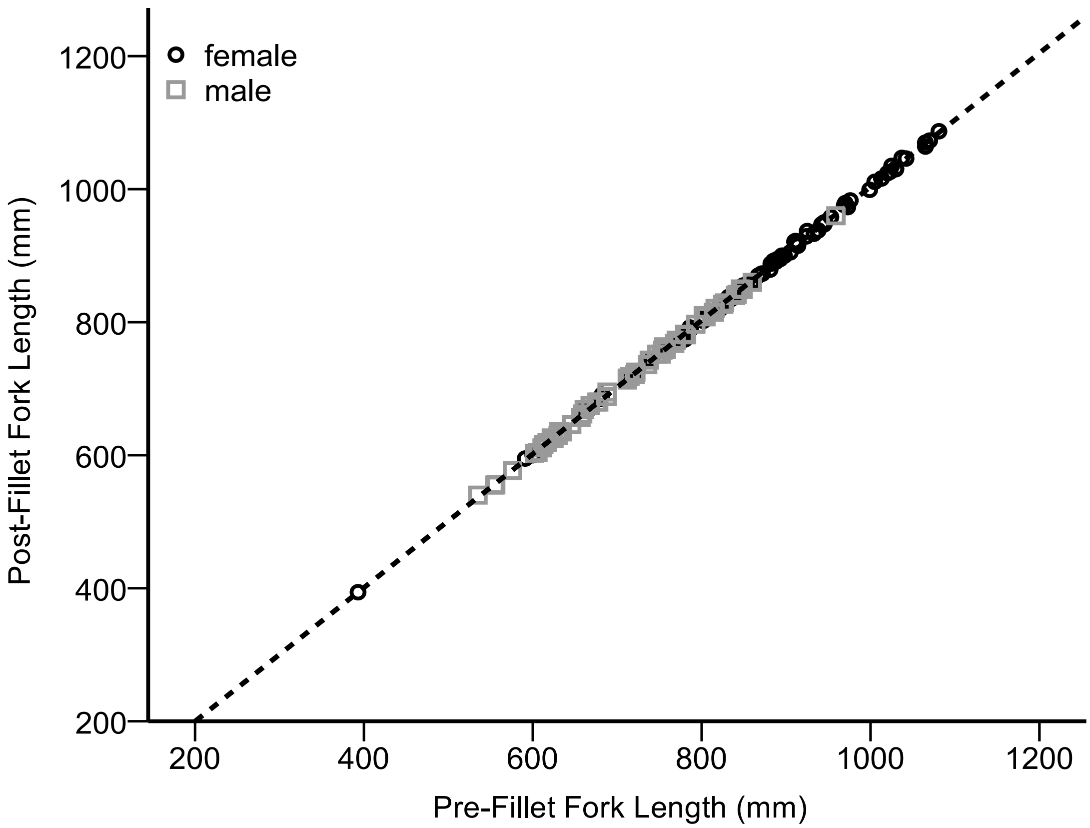

Figure 9. Relationship between pre- and post-fillet fork length (mm) measurements for California Halibut (n = 152). Black circles denote females and gray squares denote males. The black dashed line indicates the predicted post-fillet fork length (mm) at any particular pre-fillet fork length (mm), given the equation y = 1.01x - 0.94 (R^2 = 0.999, $F_{1,150}$ = 279210, p < 0.001).

An independent samples t-test indicated that female California Halibut had a greater mean fork length (mm) than males (t_{627} = 19.018, p < 0.001). Females also attained a greater maximum length, with the largest female measuring 1172 mm and the largest male measuring 977 mm (table 3). A two-sample KS test indicated that length frequency distributions (LFDs) were significantly different between the sexes (D = 0.569, p < 0.001; fig. 10). The female LFD (n = 444) was leptokurtic (kurtosis = 0.655 ± 0.231) and slightly skewed to the left (skewness = - 0.154 ± 0.116), whereas the male LFD (n = 256) was platykurtic (kurtosis = - 0.317 ± 0.303) and slightly skewed to the right (skewness = 0.179 ± 0.152).

TABLE 3
Minimum, mean (standard deviation), and maximum fork lengths (mm) for central California Halibut, by sex. Sample sizes (n) are indicated.

Descriptive Statistic	Fork length (mm) Female (n = 444)	Fork length (mm) Male (n = 256)
Minimum	393	451
Mean (SD)	850 (110)	705 (88)
Maximum	1172	977

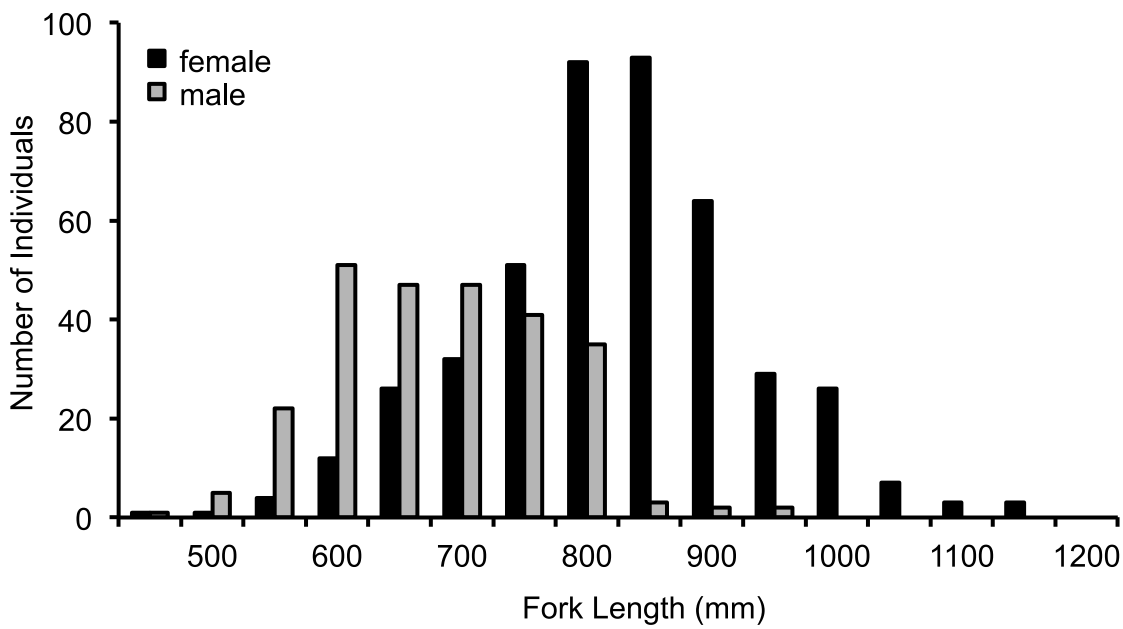

Figure 10. Length frequency distributions for central California Halibut, by sex. Black bars indicate females and gray bars indicate males.

Fitting a linear regression to log-transformed length-weight data resulted in a relationship of $W = 6.421E^{-6} L^{3.090}$ ($R^2 = 0.930$, $F_{1,224} = 2964$, $p < 0.001$) for females and $W = 1.080E^{-5} L^{3.006}$ ($R^2 = 0.940$, $F_{1,109} = 1705$, $p < 0.001$) for males. The relationship between fork length (mm) and wet body weight (g) is a power function, with weight increasing more rapidly at greater lengths, for both sexes (fig. 11).

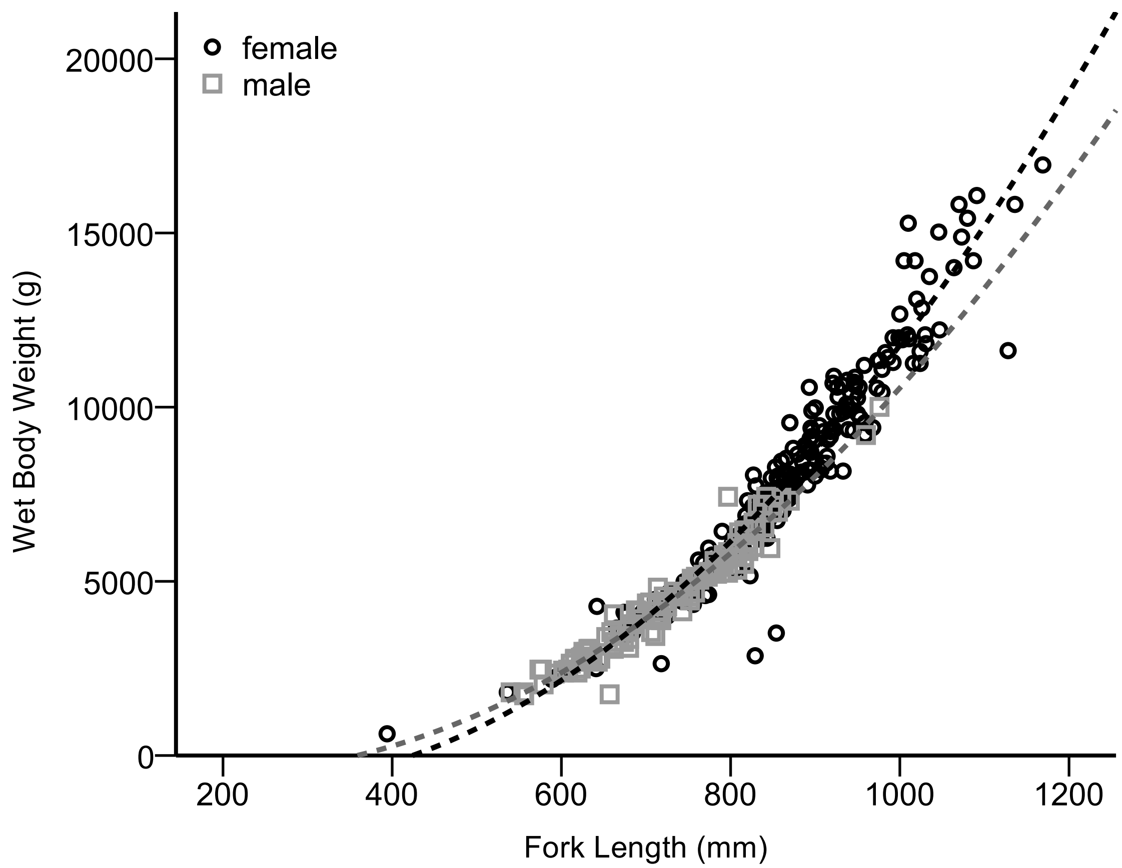

Figure 11. Relationship between fork length (mm) and wet body weight (g) for California Halibut caught off of central California. Black circles represent females and gray squares represent males. The dashed lines with corresponding colors indicate the predicted weight (g) at length (mm).

Although length-weight relationships appear similar to 900 mm, a divergence at greater lengths produced significant differences in the relationships by sex

(ANCOVA, $F_{1,334} = 4.882$, $p = 0.028$). An independent samples t-test indicated that female California Halibut (n = 228) exhibited significantly greater mean body weight (g) than males (n = 111; $t_{332} = 13.884$, $p < 0.001$). Female California Halibut also attained a greater maximum body weight at 16,953 g when compared to males, which measured to a maximum of 10,008 g (table 4). This substantial difference results from a three-fold effect of length on weight and an almost 200 mm difference in maximum lengths between the sexes.

TABLE 4
Minimum, mean (standard deviation), and maximum wet body weights (g) for central California Halibut, by sex. Sample sizes (n) are indicated.

Descriptive Statistic	Wet Body Weight (g)	
	Female (n = 228)	Male (n = 111)
Minimum	624	1,729
Mean (SD)	8,011 (3,040)	4,452 (1,672)
Maximum	16,953	10,008

Reader Agreement in Ageing California Halibut

In ageing central California Halibut, Readers 1 and 2 agreed 51.3% of the time (i.e., 235 out of 457 fish). The maximum difference between age determinations by Reader 1 and Reader 2 was six years. Out of 222 disagreements, 163 were one year apart, 44 were two years apart, and 15 were three to six years apart. From these disagreements, 133 were settled by supplementary reads from Reader 3. The remaining 89 otoliths were photographed and discussed by all three readers until a final age was unanimously determined. Ten otoliths (not listed in the sample sizes above) were excluded from analyses because processing or obscured growth patterns made them too difficult to age.

Readers 1 and 2 tended to age fish more similarly at younger ages than at older ages (fig. 12). When age determinations differed, Reader 2 generally obtained younger values than Reader 1. The linear relationship between ages determined by Reader 1 and Reader 2 was $y = 0.82x + 1.16$ ($R^2 = 0.814$, $F_{1,455} = 1991$, $p < 0.001$). Comparisons of age determinations by Readers 1 and 3 revealed a fluctuation above and below complete agreement throughout the age range ($y = 0.82x + 1.69$, $R^2 = 0.732$, $F_{1,222} = 607$, $p < 0.001$), typically within one year (fig. 13). Age determinations by Readers 2 and 3 were closest to one another ($y = 0.94x + 1.19$, $R^2 = 0.777$, $F_{1,222} = 773$, $p < 0.001$) with exceptions at 3, 11, and 13 years of age, due primarily to small sample sizes for those age classes (fig. 14). A linear regression, fit to proportional agreement at age for Readers 1 and 2, illustrated a decline in agreement with increasing age ($F_{1,14} = 94.508$, $p < 0.001$; fig. 15).

Figure 12. Mean ages (yr) for Reader 2, as compared with ages (yr) determined by Reader 1 (n = 457). Error bars represent one standard error above and below the mean. The dashed line indicates a theoretical one-to-one relationship.

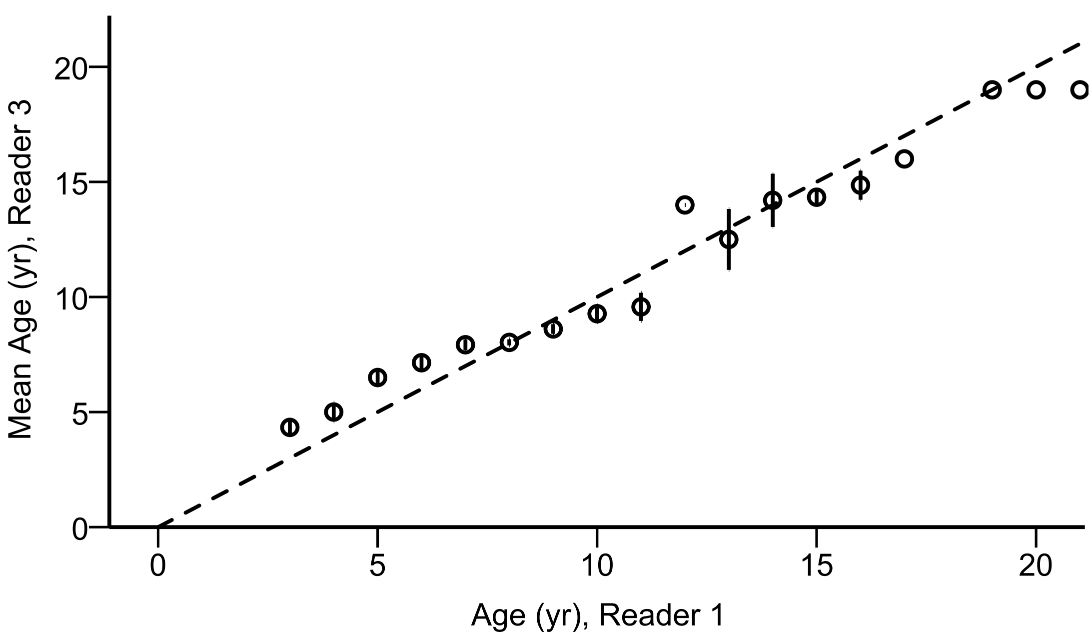

Figure 13. Mean ages (yr) for Reader 3, as compared to ages (yr) determined by Reader 1 (n = 224). Error bars represent one standard error above and below the mean. The dashed line indicates a theoretical one-to-one relationship.

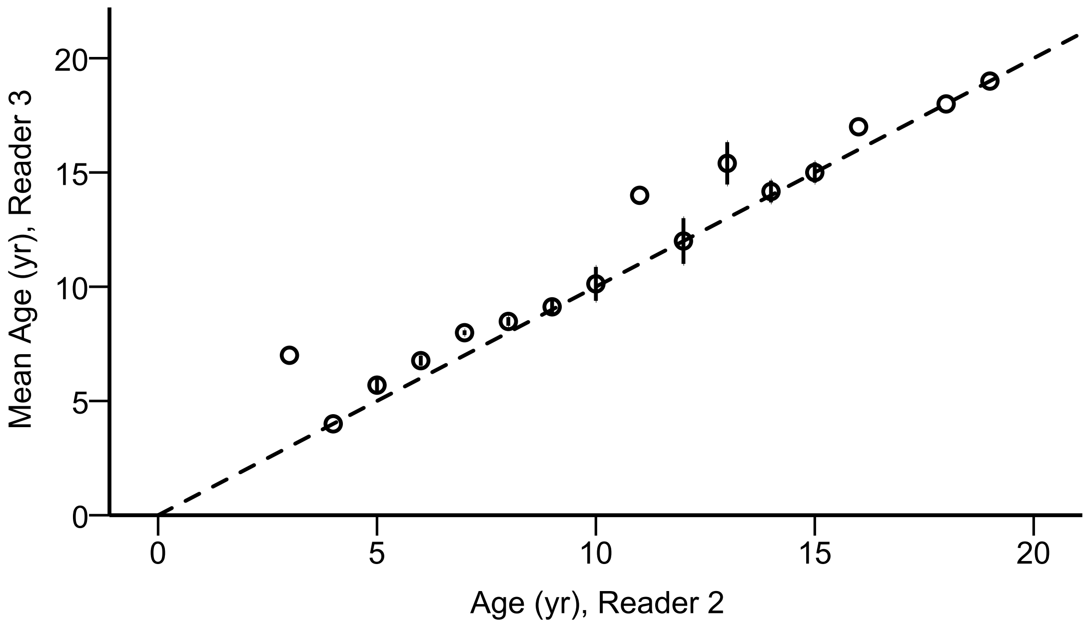

Figure 14. Mean ages (yr) for Reader 3, as compared to ages (yr) determined by Reader 2 (n = 224). Error bars represent one standard error above and below the mean. The dashed line indicates a theoretical one-to-one relationship.

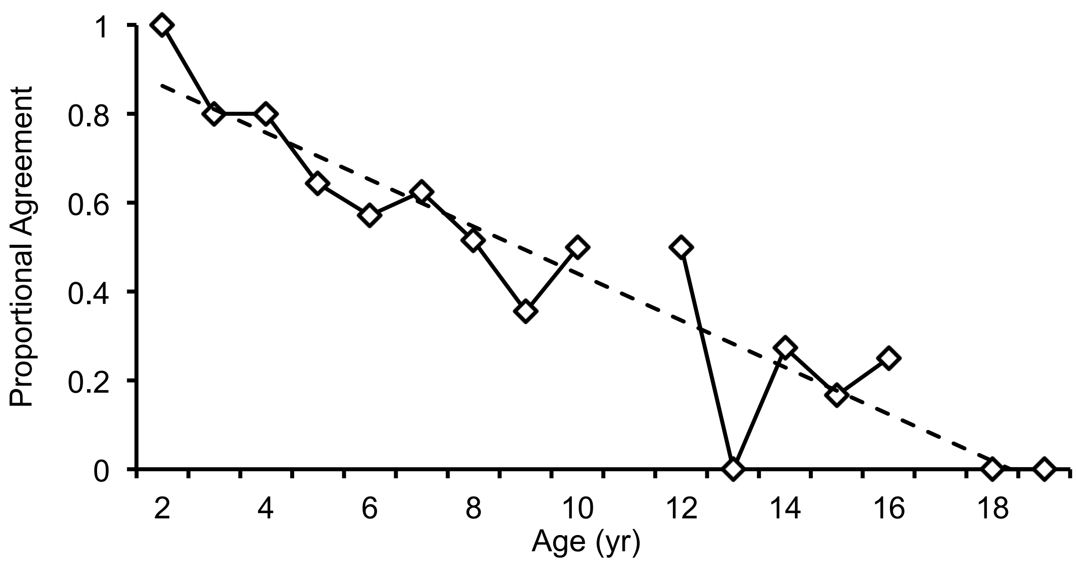

Figure 15. Proportional agreement between Reader 1 and Reader 2, by age (yr). The dashed line represents the best-fit linear relationship between age and proportional agreement ($y = -0.05x + 0.92$; $R^2 = 0.871$, $p < 0.001$, $n = 457$).

Age Compositions

An independent samples t-test indicated that there was no significant difference in mean ages of female (n = 280) and male (n = 177) California Halibut collected as part of this study ($t_{455} = 0.624$, $p = 0.553$). However, females reached an older maximum age of 19 yr, whereas males were aged to 16 yr (table 5).

TABLE 5
Minimum, mean (standard deviation), and maximum ages (yr) for central California Halibut, by sex. Sample sizes (n) are indicated.

	Age (yr)	
Descriptive Statistic	Female (n = 280)	Male (n = 177)
Minimum	2	3
Mean (SD)	8.1 (2.4)	8.0 (2.1)
Maximum	19	16

A two-sample KS test indicated similar age structures for female and male California Halibut (D = 0.085, p = 0.409). Both age frequency distributions were highly leptokurtic (kurtosis: female = 6.251 ± 0.290, male = 5.227 ± 0.363 SE) and skewed to the right (skewness: female = 1.738 ± 0.146, male = 1.872 ± 0.183). A peak was evident for fish aged between 7 and 9 yr, corresponding with the 2006, 2005, and 2004 year classes (fig. 16). Additionally, low frequencies of 11, 12, and 13 year-old fish from the 2002, 2001, and 2000 year-classes were evident.

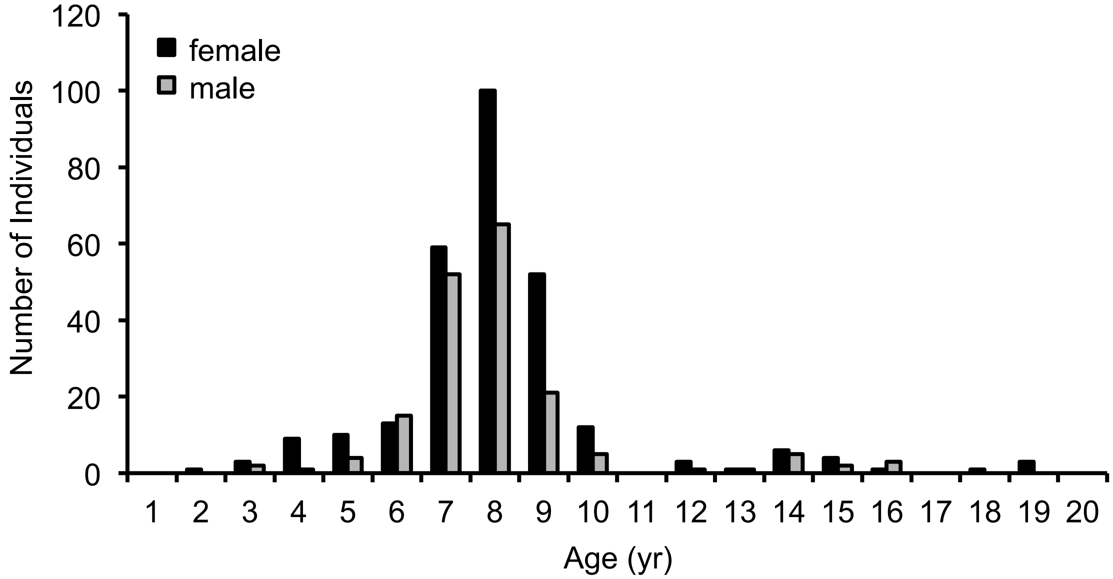

Figure 16. Age frequency distributions for central California Halibut, by sex. Black bars indicate females and gray bars indicate males.

Growth Rates

A total of 275 females and 177 males were used to estimate von Bertalanffy growth parameters for central California Halibut (fig. 17). For females, L_∞ and K were estimated at 1041 mm and 0.22. For males, L_∞ and K were estimated at 824 mm and 0.25. L_∞ and K were significantly different between the sexes, as indicated by non-overlapping 95% confidence intervals (fig. 18). These results indicate greater maximum sizes and faster growth (i.e., larger size at age) of female California Halibut from this subset of fish collected north of Point Conception.

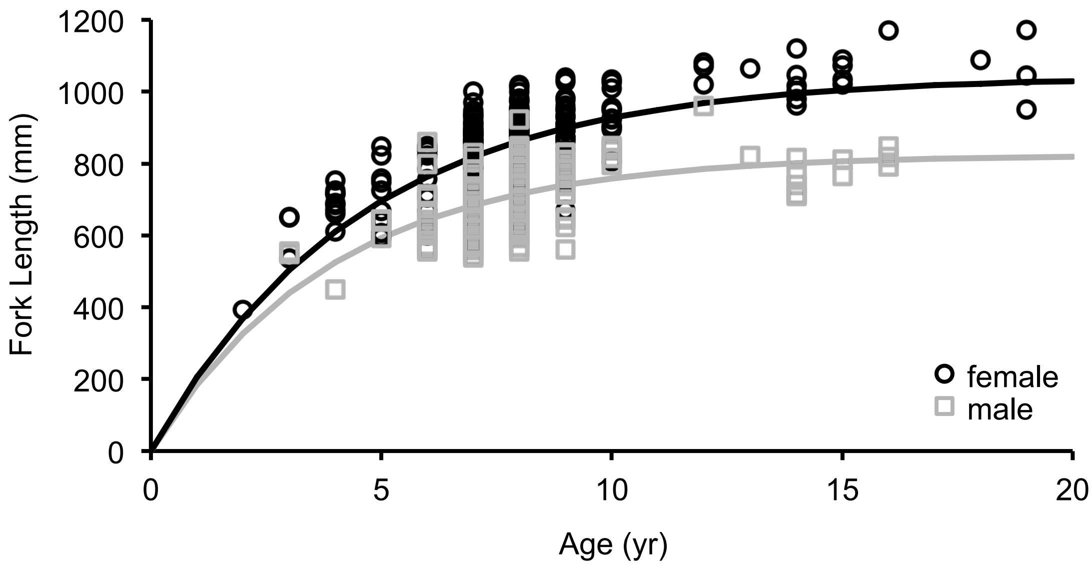

Figure 17. Length (mm) at age (yr) data for central California Halibut, by sex (Barnes data). Black circles denote females and gray squares denote males. Solid lines indicate predicted length-at-age, given the von Bertalanffy growth equations $L_t = 1041\ (1 - e^{-0.22\ (t+0)})$ for females and $L_t = 824\ (1 - e^{-0.25\ (t+0)})$ for males.

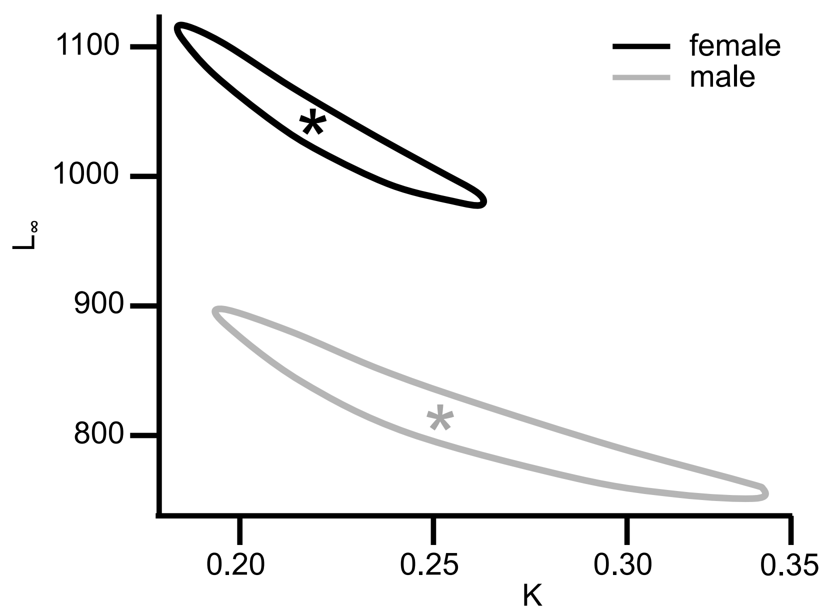

Figure 18. Von Bertalanffy growth parameters K and L_∞, denoted by asterisks (Barnes data). Ellipses indicate the 95% confidence intervals for female (black) and male (gray) California Halibut collected north of Point Conception.

When merging my thesis data, which was collected from central California in 2012 and 2013, with CDFW-collected data from central and southern California between 2007 and 2014, sample sizes reached 1299 for central California and 760 for southern California. By estimating sex- and region-specific von Bertalanffy growth parameters, I found larger values of K and smaller values of L_∞ for central California Halibut (table 6). This translates to faster growth, but smaller maximum sizes for halibut collected north of Point Conception (figs. 19 and 20).

TABLE 6
Von Bertalanffy growth parameters L_∞ and K for California Halibut (Barnes and CDFW data), by sex and region. Standard errors are shown in parentheses.

von Bertalanffy growth parameter	Female		Male	
	central CA	southern CA	central CA	southern CA
L_∞	1049 (15)	1304 (35)	820 (14)	1048 (60)
K	0.21 (0.01)	0.12 (0.01)	0.25 (0.01)	0.15 (0.01)

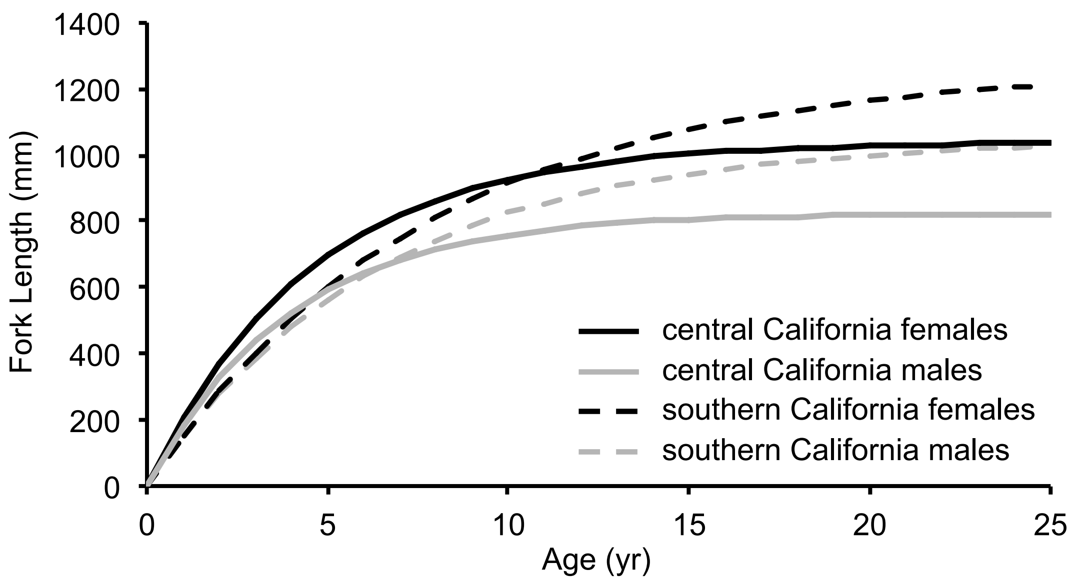

Figure 19. Von Bertalanffy growth curves for central (solid lines) and southern (dashed lines) California Halibut (Barnes and CDFW data). Expected lengths (mm) at age (yr) are shown in black for females and gray for males.

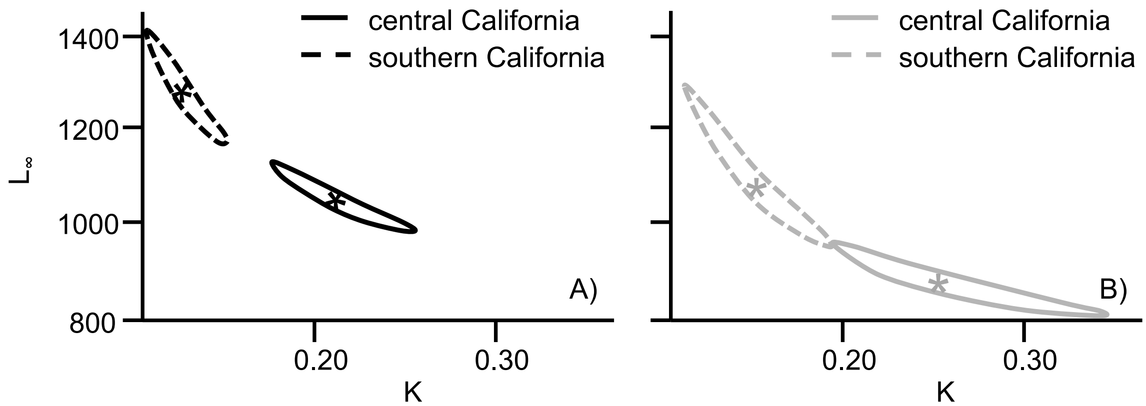

Figure 20. Von Bertalanffy growth parameters K and L_∞, illustrated by asterisks (Barnes and CDFW data). Ellipses denote the 95% confidence intervals. Females are shown in black (left) and males are shown in gray (right). Solid ellipses indicate central California Halibut and dashed ellipses indicate southern California Halibut.

Instantaneous Total Mortality

Natural log-transformed age frequency data for central California Halibut were plotted for each sex (fig. 21). Catch curve analysis indicated that female halibut from central California experienced lower rates of instantaneous total mortality ($Z = 0.32$) than males ($Z = 0.47$) from the same region. Although statistical comparisons of slope (i.e., Z or total mortality) yielded non-significant results ($F_{1,11} = 0.655$, $p = 0.435$), graphical representations demonstrated a notable difference. No differences existed between the y-intercepts of males and females ($F_{1,12} = 2.520$, $p = 0.138$), indicating no difference in relative abundance between female and male halibut collected off of central California in 2013.

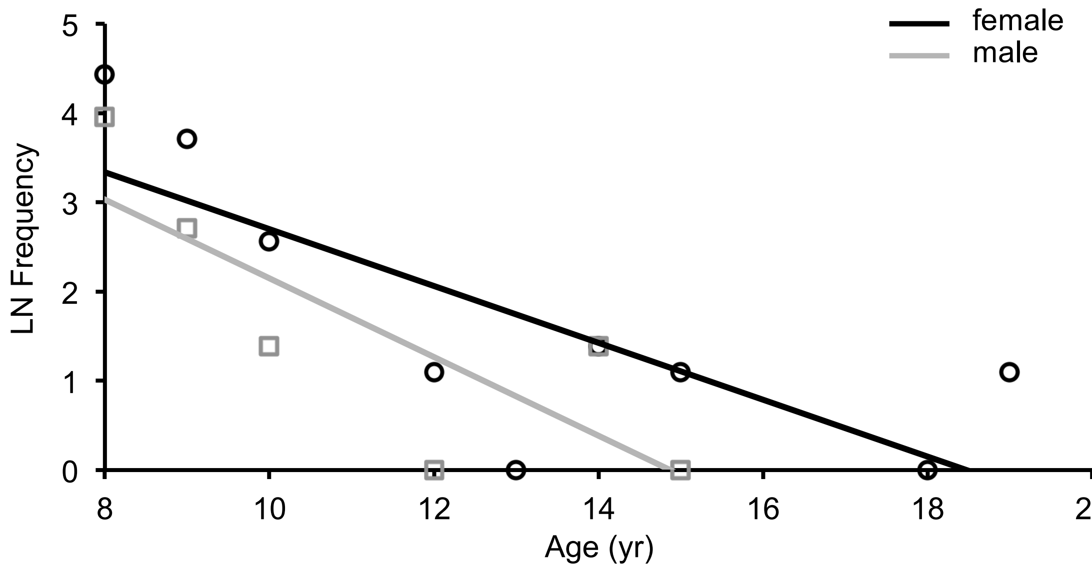

Figure 21. Instantaneous total mortality for central California Halibut caught in 2013 (Barnes data), given log-linear frequencies of age classes ≥ 8 yr. Female total mortality is represented by the equation $y = 5.93 – 0.32x$ ($R^2 = 0.617$, $p = 0.012$) and male total mortality is represented by $y = 6.83 – 0.47x$ ($R^2 = 0.710$, $p = 0.035$).

When comparing catch-at-age data using all fish (i.e., those collected for my thesis and by CDFW), I found no sex-based differences in total mortality for either region (central California: $F_{1,12} = 0.166$, $p = 0.691$; southern California: $F_{1,13} = 0.006$, $p = 0.937$). Mathematical estimates of total mortality were very similar for males ($Z = 0.35$) and females ($Z = 0.36$) from southern California. Though non-significant, the calculation of total mortality for males from central California ($Z = 0.42$, changed from 0.47 using only thesis data) was considerably greater than that for females ($Z = 0.34$, changed from 0.32 using only thesis data) from the same region.

When comparing sex-specific estimates of total mortality by region, I found no significant difference ($F_{1,16} = 0.035$, $p = 0.854$) between females from central and southern California and an apparent, but non-significant difference between males ($F_{1,9} = 0.123$, $p = 0.734$) (fig. 22). Additionally, the number of southern California males sampled was statistically less (as indicated by differences in the y-intercept) than females from the same region ($F_{1,14}$ = 69.150, p = 0.004).

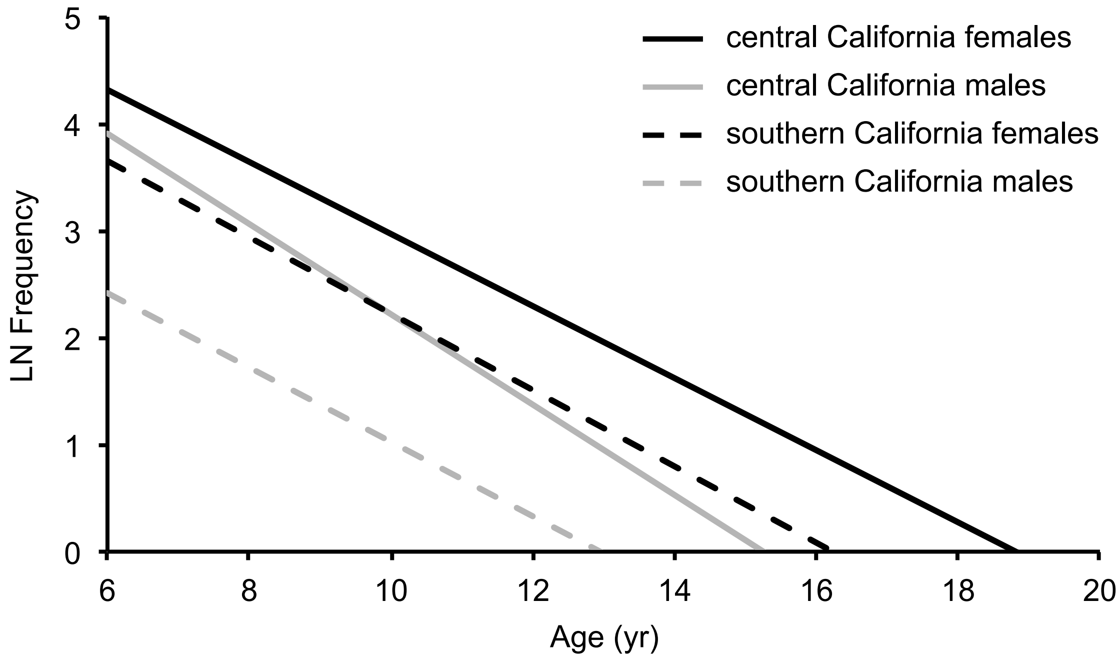

Figure 22. Instantaneous total mortality for California Halibut, *Paralichthys californicus*. Fish collected from central California in 2013 (Barnes and CDFW data) are represented by solid lines and fish collected from southern California in 2012 (CDFW data) are represented by dashed lines. Females are shown in black and males are shown in gray.

Proportional Maturity

Based upon macroscopic maturity assignments (i.e., presence of visible eggs or sperm indicating maturity and lack thereof denoting immaturity), 87.4% of central California females (n = 304) and 96.3% of central California males (n = 239) were considered reproductively mature at the time of capture. The remaining 12.6% of females (n = 44) and 3.7% of males (n = 3), termed immature, had either not yet reached sexual maturity or had reached maturity, but were not reproductively active at the time of capture. When assessing only legal-sized fish (≥ 559 mm fork length), 87.9% of females (n = 346) and 96.6% of males (n = 235) were considered mature. All mature, legal-sized males were also actively spawning (i.e., extruding milt) at the time of capture.

Because it is difficult to macroscopically discern immature individuals from those that are sexually mature, but reproductively inactive during the particular season (i.e., resting or skip spawning), histological analyses were used to determine precise maturity stages. The most advanced stage (MAS) of oocyte development, presence or absence of POFs, and rates of atresia were recorded for 206 female California Halibut (40 from 2012 and 166 from 2013). Microscopic maturity assignments resulted in 2.9% (n = 6) immature or resting, 9.7% (n = 20) maturing, 50.5% (n = 104) mature, 34.0% (n = 70) spawning, and 2.9% (n = 6) spent females. Once maturity stages were assigned microscopically, digital images of ovaries from the same fish were referenced to help describe macroscopic traits (table 7).

TABLE 7

Simplified maturity staging system for female California Halibut, *Paralichthys californicus*. The microscopic terms used are consistent with Murua et al. (2003). MAS: most advanced stage of oocyte development.

Maturity Stage	Macroscopic Characteristics	Microscopic Characteristics
immature	ovaries small; pale in color	MAS: chromatin nuclear or perinucleolar
maturing	ovaries deep orange in color	MAS: cortical alveoli
mature	ovaries yellow-orange in color; oocytes visible to the naked eye; red blood vessels branched	MAS: yolk granule or final maturation
spawning (gravid or running ripe)	hydrated oocytes interspersed throughout ovaries and may be accumulated near vent	MAS: hydrated; new (< 1 d) postovulatory follicles (POFs) may be present
spent	oocytes visible to the naked eye; histology necessary to assess frequency of atresia	MAS: yolk granule; more than 50% vitellogenic oocytes undergoing atresia
resting	ovaries small; deep orange in color; white (i.e., empty) blood vessels present	MAS: perinucleolar

Characterization of the Summer Spawning Season

Spawning females were found from June 17 to September 6 in 2012 and June 22 to September 5 in 2013. This demonstrated a summer spawning duration of 82 d in 2012 and 76 d in 2013. By averaging these two years, the central California Halibut summer spawning season was estimated at 79 ± 3 d, from mid June to early September.

In addition to using the incidence of spawning females as an indicator of summer spawning duration, relative proportions of each maturity stage provided further support of temporally-influenced spawning activity in 2013 (fig. 23). From June to August, proportional maturity stages remained relatively constant, with mature stages representing 0.55 (n = 76) and spawning stages representing 0.37 (n = 51) of females sampled. However, by the end of August and into September, spent stages made up increasing greater proportions (0.12 and 0.33, respectively), indicating a cessation of spawning activity and conclusion of the summer spawning season. Relatively few individuals were caught before June, when summer spawning is thought to have commenced, or after mid-September, when spawning activity appeared to be in decline.

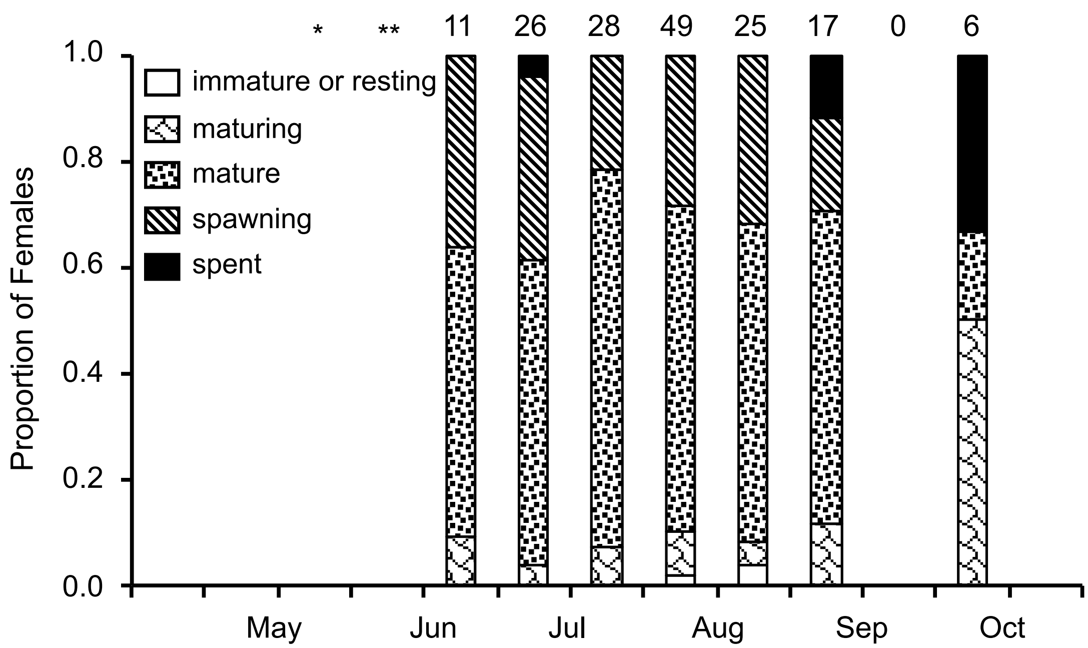

Figure 23. Proportions of females sampled in central California (2013), by microscopic maturity stage and month. Sample sizes are indicated above each bar, which represents a 14 d sampling period. * = one mature fish sampled; ** = two maturing fish sampled.

Temporal variations in gonadosomatic index (GSI) of female California Halibut also supports the estimated duration of spawning activity in 2013. In the beginning of June, GSI for mature and spawning females was relatively low, ranging from 2.0 to 4.0. From mid-June to the end of July, mean GSI for the same maturity stages reached values greater than 4.0. An increase in GSI (> 6.0) was observed during the first two weeks in July, indicating a peak in reproductive effort during that time period. By August, mean GSI of mature and spawning females began to decrease again, demonstrating a reduction in spawning activity toward the end of summer. The incidence of spent females with GSI values less than 2.5 at the end of August and beginning of September indicated relatively little investment in reproduction and a cessation of spawning activity for sampled fish (fig. 24). Mean GSI for females categorized as immature, maturing, or resting at the time of capture did not change throughout the sampling period.

Though hepatosomatic index (HSI) was calculated throughout the 2013 summer season, no clear pattern was evident to support seasonal changes for female California Halibut (fig. 25).

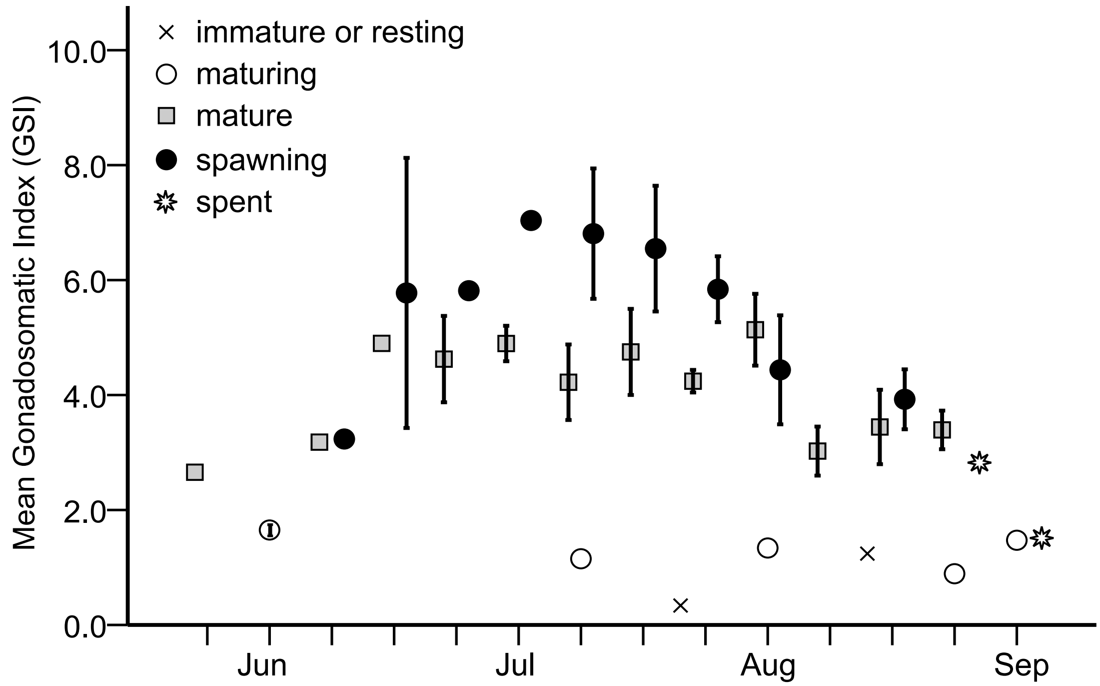

Figure 24. Mean gonadosomatic index for female California Halibut caught in central California (2013), by week and maturity stage. Error bars denote one standard error.

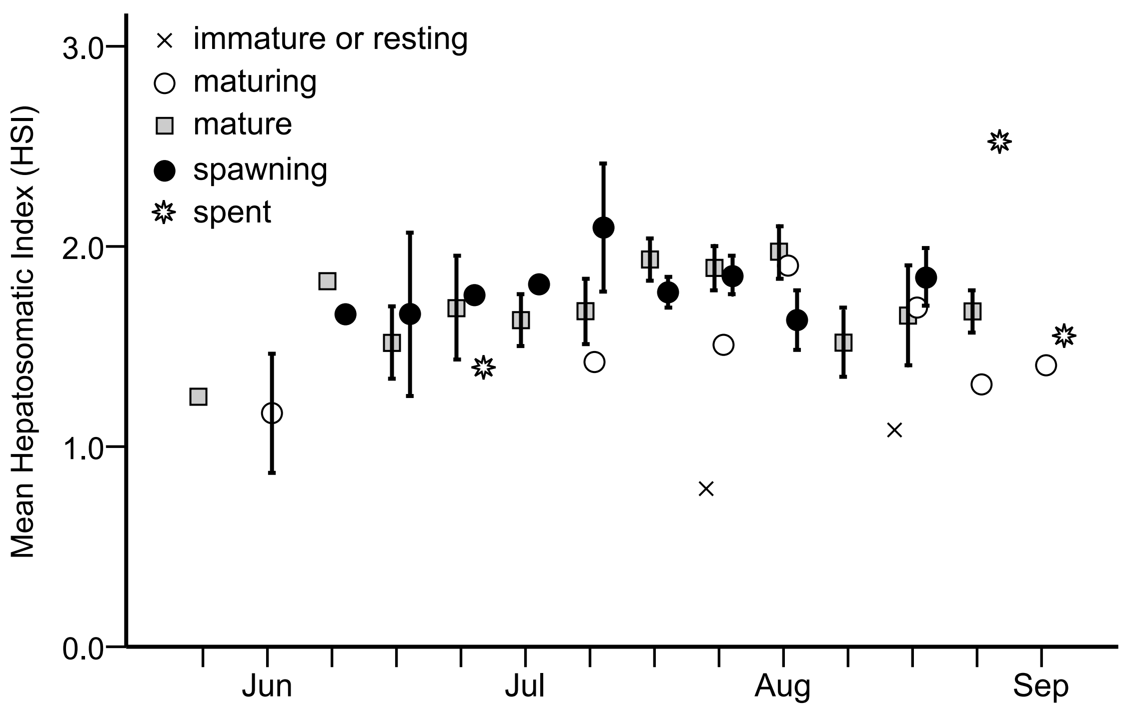

Fig. 25. Mean hepatosomatic index for female California Halibut caught in central California (2013), by week and maturity stage. Error bars denote one standard error.

Daily Spawning Fraction, Interspawning Interval, and Spawning Frequency

The mean daily spawning fraction (s) for female California Halibut (i.e., those with POFs estimated to be one day old) was calculated at 0.33 (n = 1) for 2012 and 0.29 ± 0.1 (n = 21) for 2013. The mean daily spawning fraction for both years combined was 0.31 ± 0.0 (n = 22). The interspawning interval ($\frac{1}{s}$) was 3.0 d in 2012 and 3.4 d in 2013. For both years combined, the interspawning interval was 3.2 d. Finally, the spawning frequency (f) for central California Halibut was determined by dividing the duration of the summer spawning season by the interspawning interval (table 8). In 2012, the spawning frequency was approximately 27 events per season, whereas the spawning frequency in 2013 was 22 events per season. The mean for both years combined was 25 events per summer spawning season. Due to a sample size of one day in 2012, no statistical comparisons of year were made.

TABLE 8
Summary of reproductive parameters for female California Halibut, by year. Sample size (n) indicates the number of days used in each calculation (≥ 3 reproductively active females were required for inclusion).

	2012 (n = 1)	2013 (n = 21)	Both Years (n = 22)
Duration of Spawning Season (d)	82	76	79
No. Spawning Females	2	29	31
Total No. Reproductive Females	3	100	103
Mean Spawning Fraction (SE)	0.33 (N/A)	0.29 (0.05)	0.31 (0.02)
Interspawning Interval (d)	3.0	3.4	3.2
Spawning Frequency	27	22	25

Batch Fecundity

Because California Halibut are multiple spawners for which the time of day that batches of eggs are released is unknown, batch fecundity estimates were limited to spawning females exhibiting GSIs within one standard deviation of the mean. In theory, this eliminated individuals that had recently spawned a large proportion of eggs and/or were very early in the hydration process, thereby possessing far fewer hydrated oocytes than would have been produced for the spawning event in progress.

Among the 40 individuals that met the above criteria, batch fecundity ranged from 39,681 to 1,474,584 oocytes (appendix II). The mean batch fecundity was 498,830 ± 44,163. However, this included estimates from female California Halibut ranging in fork lengths from 685 to 929 mm and capture dates throughout the reproductive seasons of 2012 and 2013. When considering only spawning females within one standard error of the mean fork length (850 mm), mean batch fecundity was estimated at 599,378 ± 67,204 (n = 3). This is considered a conservative estimate of batch fecundity for an average-sized female, as the elapsed time between hydration and spawning is likely on the order of hours (Hunter et al. 1985; Kurita et al. 2011). Therefore, the quantity of hydrated oocytes for a spawning female is highly susceptible to timing of capture and is likely less than the ephemeral absolute maximum (e.g., if spawning is initiated at night, females captured in the early morning would likely possess relatively few hydrated oocytes; fig. 26).

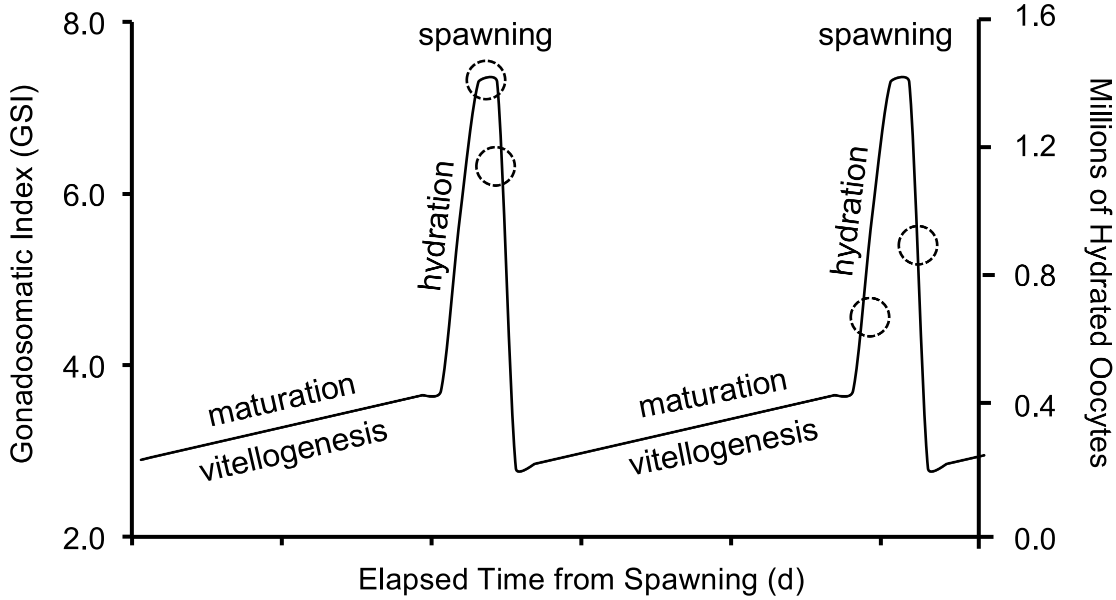

Figure 26. Maturation cycle of a California Halibut female throughout a given spawning season [based upon gonadosomatic index (GSI), batch fecundity (millions of hydrated oocytes), and interspawning interval (i.e., elapsed time from spawning in days)]. Dashed circles illustrate hypothetical sampling events, with the ideal capture time located at peak values. Figure adapted from Hunter et al. (1985).

To evaluate the relationship between fork length (mm) and batch fecundity, I plotted data from female California Halibut considered to be in the late hydration phase of spawning at the time of capture (fig. 27). Curve estimation software determined that the best-fit model was the power function $F = 3.65 \times 10^{-12} L^{5.86}$ ($R^2 = 0.480$, $F_{1,15} = 13.837$, $p = 0.002$). As with many other fish species, batch fecundity exponentially increased with increasing length.

The procedures detailed above were also used to evaluate the relationship between batch fecundity and time (represented as Julian days) in 2013. A significant relationship existed for females in the late hydration and actively spawning phases, given the quadratic function $y = - 502x^2 + 214759x - 22307777$ ($R^2 = 0.258$, $F_{2,24} = 4.183$, $p = 0.028$; fig. 28). This relationship demonstrated that the largest batch fecundities were found in the beginning of August (around Julian day 215), which corresponds with the approximate middle of the summer spawning season previously described.   Conversely, the smallest batch fecundities were found in the beginning of July and very end of August, approaching the beginning and end of the spawning season.

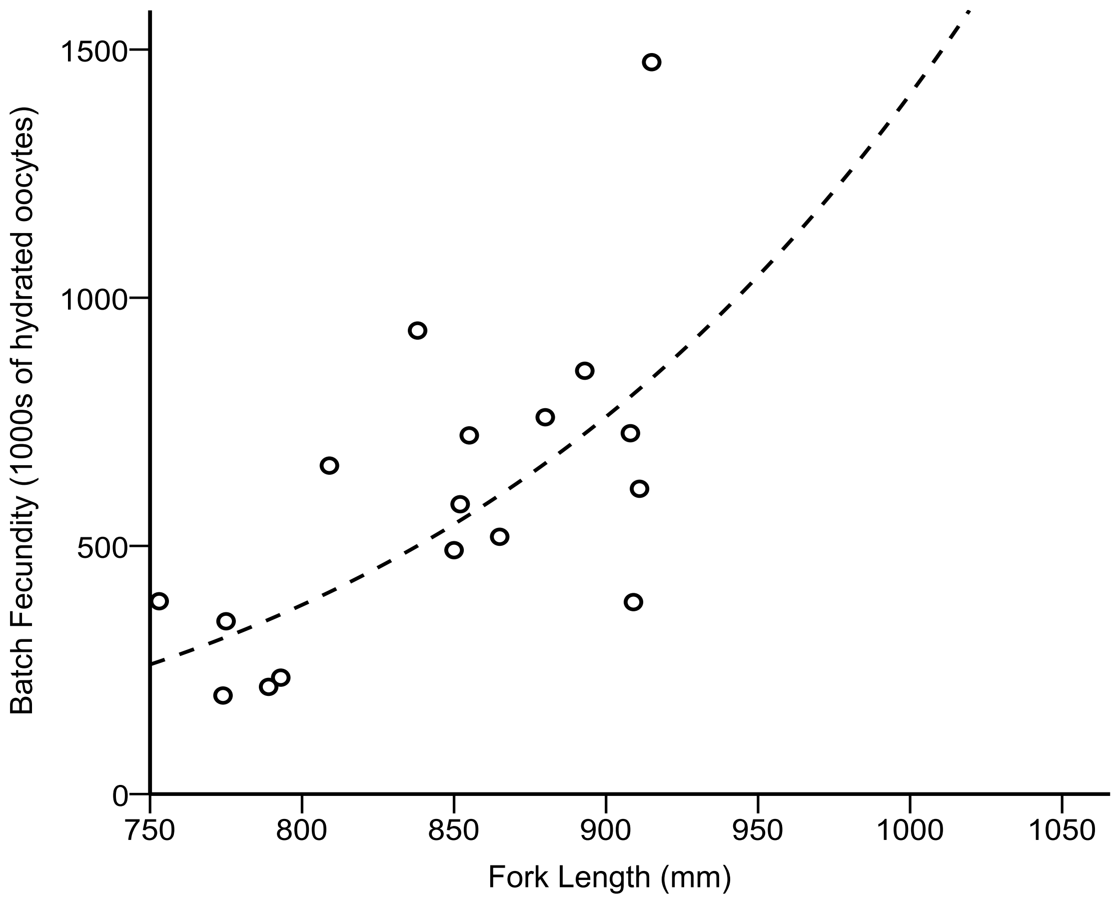

Figure 27. Relationship between fork length (mm) and batch fecundity (thousands of eggs) for female California Halibut in the late hydration phase of spawning (i.e., presence of hydrated oocytes, no final maturation stage or post ovulatory follicles). The dashed line indicates the expected batch fecundity at length (n = 17).

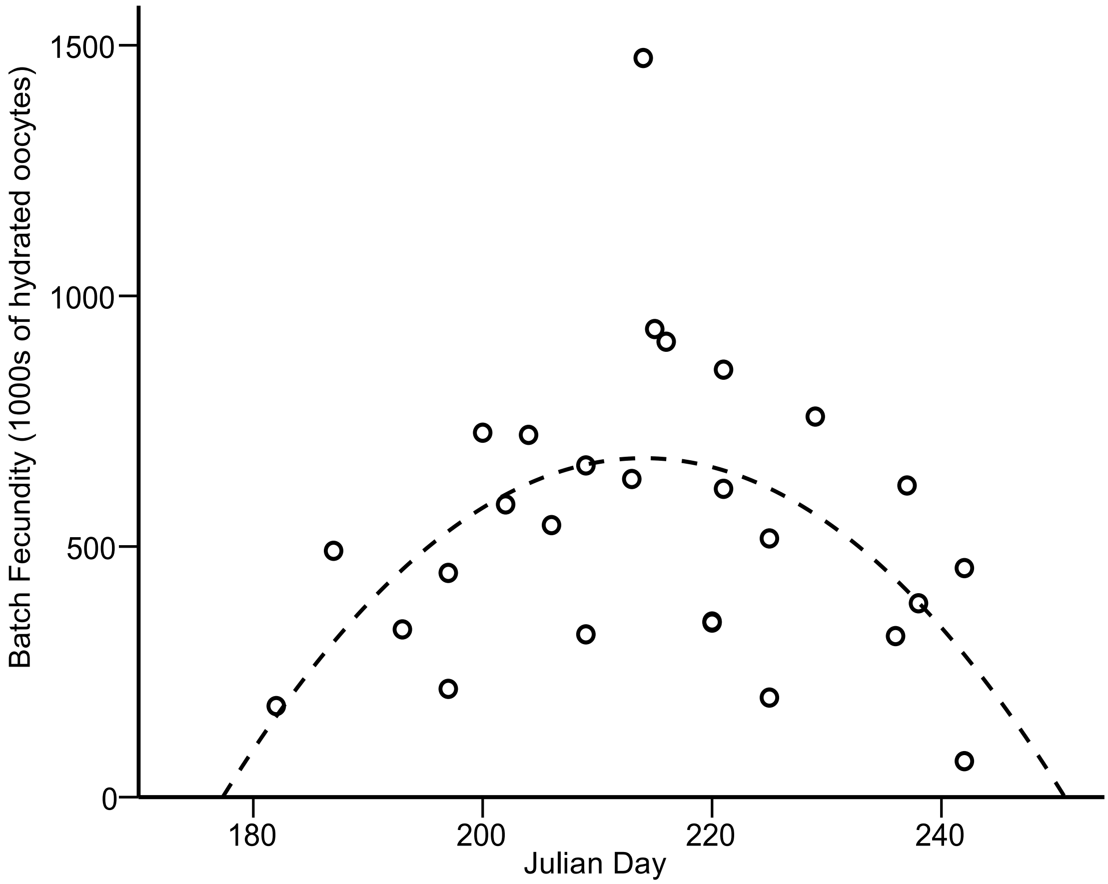

Figure 28. Batch fecundity (thousands of hydrated oocytes) of California Halibut, by Julian day (2013). Circles represent estimates for spawning females in the late hydration (i.e., presence of hydrated oocytes, no final maturation stage or new postovulatory follicles) or actively spawning (i.e., presence of hydrated oocytes and new postovulatory follicles) phases (n = 33). The dashed line indicates the expected batch fecundity at length, given the equation $F = -8.3x10^{7} + 1.6x10^{6}L - 84.1L^{3}$.

Reproductive Potential

The seasonal reproductive potential of an average-sized California Halibut (i.e., 850 mm) was determined by multiplying a mean batch fecundity of 599,378 eggs and spawn frequency of 25 events per season. This produced a seasonal fecundity of 14,984,450 eggs (table 9). Again, this is likely a conservative estimate because it is based upon opportunistic sampling and an unknown spawning behavior (e.g., timing of broadcast events) for the study species.

TABLE 9
Parameters used to calculate seasonal reproductive potential of an average-sized central California Halibut female.

Reproductive Parameter	Value
interspawning interval	3.2 d
duration of summer spawning season	79 d
spawning frequency	25 events per season
batch fecundity	599,378 eggs per event
potential seasonal fecundity	14,984,450 eggs per season

DISCUSSION

A stock assessment is a systematic procedure in which fishery scientists estimate and forecast biological parameters such as population size, growth, recruitment, and mortality (both natural and fishing). Contemporary stock assessment models also include information about environmental variation, uncertainty in data or model outcomes, and levels of risk associated with various predictions (e.g., Garcia et al. 1999; Patterson 1999). Resource managers utilize the results of an assessment to balance biological and socioeconomic objectives while making regulatory decisions about allowable catch, fish sizes, gear types, effort restrictions, and spatiotemporal closures (Rice et al. 2005). Because regulatory measures affect the biological parameters used in stock models, a positive feedback loop exists between fishery assessment and management. Therefore, it is essential that biological data adequately represent the fishery in question, both in time and in space, so that the effectiveness of management actions can be appropriately evaluated.

However, a number of species (e.g., many flatfishes from the order Pleuronectiformes) are managed as complexes rather than individual component species (e.g., Wilderbuer and Nichol 2013). Represented by 14 different families, 121 genera, and 716 species, flatfishes exhibit substantial variation in growth (i.e., maximum sizes from 2 cm to over 2 m and 300 kg), reproductive strategies (e.g., total vs. batch spawning, pelagic vs. demersal eggs), spawning durations (i.e., 2 months to year-round), and longevity (i.e., 1.5 to 60 yr) (Gibson 2005). Additionally, widespread distributions and subsequent differences in environmental (e.g., temperature, irradiance) and/or ecological (e.g., prey availability, predation) characteristics lead to intraspecific variation in flatfish life history traits (e.g., Witthames et al. 1995; Spencer 2008; Nissling and Dahlman 2010).

Many large-tooth flounders (family Paralichthyidae) have been shown to exhibit spatiotemporal differences in growth and reproduction. There is evidence that the Southern Flounder, *Paralichthys lethostigma*, grows at different rates along the northwestern Atlantic and in the Gulf of Mexico (Etzold and Christmas 1979; Nall 1979). Latitudinal trends have also been observed in the maturation rates of Japanese Flounder (*Paralichthys olivaceus*), with fish becoming reproductive at earlier ages in more southern locations (Yoneda et al. 2007). Because of such support for spatially explicit life history traits, questions have been raised about the potential for multiple populations of flatfishes with widespread distributions (e.g., Summer Flounder, *Paralichthys dentatus*, Packer et al. 1999), leading to discussions about whether or not these species should continue to be managed as single stocks.

Although Maunder et al. (2011) defined two separate stocks of California Halibut, limited life history data forced assessment scientists to fix many of the central stock model parameters based upon data collected from southern California. Because spatial complexity and fine-scale environmental variability generate differences in key biological processes (e.g., growth rates, timing of maturation, reproductive potential, population abundance, mortality) within continuously distributed species, CDFW recognized a need to collect life history data for California Halibut at multiple spatial scales (CDFW 2011b). Model sensitivity to regional estimates of natural mortality, average length of the oldest fish, and relative abundance made this especially important, as outputs from the assessment are used to inform policy decisions.

My masters thesis research, which provides a detailed account of sex-specific growth, reproduction, and mortality, attempts to enhance our understanding of localized population dynamics and better inform resource managers about the spatial structure of California Halibut life history. Although similar studies have been conducted, my work uniquely provides comprehensive data from a wide size range of fish, including older, larger individuals from central California. This is also the first study to estimate batch fecundity and seasonal reproductive activity of wild-caught California Halibut.

The sex ratio calculated for central California Halibut as part of this work (1.4:1) differs from previous estimates for juveniles caught in Mexico (1:2.2, Hammann and Ramirez-Gonzalez 1990) and slightly smaller adults in central (1.1:1) and southern (1:2.2) California (MacNair et al. 2001). Similarly sized halibut from southern California have exhibited a sex ratio of 4.3:1 (Sunada et al. 1990), which matches my calculation made using CDFW-sampled fish between 2007 and 2014. The disproportionate sex ratios between central and southern California may be due to sex- and region-based differences in natural or fishing mortality. However, additional research is necessary to elucidate potential mechanisms, which can also include variation in habitat use by sex and ontogenetic stage.

In ageing thesis-collected fish from central California, 431 blind-side otoliths were evaluated. An additional 26 (5.7%) eyed-side otoliths replaced blind-side otoliths that were missing, broken, or unusable due to crystallization around the margin. Without comparing reads from blind- and eyed-side otoliths of the same fish, potential differences in interpretation or bias remain unknown. Instead, I made the assumption that there was no difference in age determinations of blind- and eyed-side otoliths, as long as readability generated agreement between at least two independent readers.

Age frequency distributions of central California Halibut indicated a pulse in recruitment between 2004 and 2006. The presence of these exceptionally strong year-classes, when combined with weak 2000 to 2002 year-classes, demonstrates considerable variability in California Halibut recruitment. The strong 2004 to 2006 year-classes coincided with periods of relatively weak upwelling, whereas the weak 2000 to 2002 year-classes coincided with periods of strong, persistent upwelling in central California (Caselle et al. 2010). This suggests that upwelling may have a negative effect on central California Halibut recruitment, due to larval advection offshore, an intolerance to cold sea surface temperatures at early life history stages, increased predation from upwelling-favorable species, or some other factor. Additionally, prolonged periods of above average sea surface temperatures may enable greater egg production of adults and larval survivorship for this warm-temperate, subtropical species. However, additional research is necessary to evaluate cause-and-effect relationships between California Halibut recruitment and localized environmental conditions.

Consistent with existing scientific literature, female California Halibut sampled as part of this study grew faster and to larger sizes than male conspecifics (MacNair et al. 2001). However, regional comparisons, which included CDFW-collected length-at-age data (2007 to 2014), showed that central California Halibut grew faster, but reached smaller maximum sizes than fish from southern California. This contradicts results from MacNair et al. (2001), which showed larger maximum sizes for California Halibut collected north of Point Conception. The growth parameters estimated herein likely provide more realistic predictions of length-based age than those provided by MacNair et al. 2001 due to the fact that t_0 was fixed at zero and larger (i.e., older) individuals were sampled more adequately.

Fixing t_0 at zero forced the von Bertalanffy growth curves through the origin. Without doing so and not having properly sampled new recruits, a calculated t_0 would have produced unrealistic estimates of length-at-age for younger fish [e.g., predicted length of approximately 200 mm age for an zero fish, as in MacNair et al. (2001)]. Sampling more of the larger, older individuals also produced estimates of L_∞ that were anchored by data as opposed estimates that were more predictive because of sampling efforts that focused on collecting smaller, younger individuals (MacNair et al. 2001).

In addition to enabling a characterization of California Halibut growth, age data provided sex-structured estimates of instantaneous total mortality (Z) [Z = fishing mortality (F) + natural mortality (M)]. Maunder at al. (2011) incorporated M values of 0.2 for females and 0.3 for males into both the central and southern California stock models. Without estimates of natural mortality available for California Halibut at the time of assessment, these values were based upon information from Summer Flounder (longevity of 15 yr). Subsequent to the stock assessment, total mortality estimates for southern California Halibut females were made available [Z = 0.53 from Sunada et al. (1990) data and Z = 0.36 from CDFW unpublished data). My estimates of Z for central (0.34 for females and 0.42 for males) and southern (0.36 for females and 0.35 for males) California Halibut could be used in conjunction with a tagging study (estimating F) to better parameterize region-specific M. Because the stock models used for California Halibut are sensitive to M (as indicated by Maunder et al. 2011), empirically determined natural mortality would likely provide more reliable outputs than when M is assigned based upon a congener from the east coast of the United States.

In determining maturity for 346 female and 235 male legal-sized California Halibut, I found that the vast majority of males (i.e., 96.6%) and females (87.9%) sampled were reproductively active at the time of capture. Additionally, most of the inactive females were considered temporarily maturing or resting, and had likely spawned earlier in the season of capture or during previous years. This information indicates that the legal “population” of California Halibut north of Point Conception is primarily reproductive. Additionally, this suggests that the minimum size limit of 559 mm (fork length) is effective at protecting immature fish and allowing central California Halibut to reproduce at least once (and probably many more times) before being harvested.

California Halibut have been described as exhibiting year-round reproduction, with peak activity between late winter and spring in southern California (Haaker 1975; Lavenberg et al. 1986; Love and Brooks 1990). Recent ichthyoplankton surveys (CalCOFI unpublished data, 1980 to 2011) have indicated that the greatest larval abundances of California Halibut are found in April (southern California and Mexico), June (Mexico), and July (southern California). Given a larval duration of 20 to 29 d, spawning effort (represented by applying a 30 d correction to larval density data) would be expected to be greatest in March (southern California and Mexico), May (Mexico), and June (southern California). Although CalCOFI data effectively demonstrate spawning patterns of California Halibut south of Point Conception, relatively infrequent and offshore surveys north of Point Conception make comparisons among Mexico, southern California, and central California impossible. This is the reason behind comparing corrected larval density data from southern California and Mexico with GSI data collected from central California.

GSI data for central California were limited to the summer months of 2012 and 2013. I was unable to evaluate winter- or spring-time spawning activity in central California due to a lack of commercially and recreationally caught fish during those time periods. The absence of fish caught during winter and spring is thought to result from seasonal, inshore-offshore migrations along central California. Because the vast majority of fish collected as part of this study were found in a reproductively active state, seasonal migrations would suggest a cessation of spawning (at least the population level) during times when California Halibut are not found en masse nearshore. However, movement patterns of adult California Halibut, especially north of Point Conception, remain undocumented. Therefore, a tagging study is necessary to test this hypothesis of seasonal migrations off of central California and to identify potential drivers of such migrations, if any were found.

Using reproductive data from all three regions (i.e., corrected larval densities from southern California and Mexico and GSI data from central California), I was able to detect patterns in spawning activity of California Halibut. During the spring, increases in reproductive effort appear to be synchronized in southern California and Mexico, but are undocumented or non-existent in central California. Additionally, a latitudinal gradient in summer spawning activity is evident, with peaks earliest in Mexico in May, followed by southern California in June, and finally by central California in July. Though this pattern matches that of other West Coast flatfishes (e.g., *Citharichthys* spp, Chamberlain 1979), it is opposite to other *Paralichthys* spp. studied along the east coast of the United States, where spawning takes place earliest in northerly regions (e.g., Summer Flounder, Smith 1973).

In a captive study using natural conditions for southern California, Caddell et al. (1990) suggested that temperature and photoperiod were the most important factors influencing the spawning activity of California Halibut. Spawning was observed at sea surface temperatures between 15.0 and 16.5 °C and day lengths greater than or equal to 10.5 hr. However, my data from central California Halibut show that spawning can occur in waters much cooler than 15.0°C. In central California, strong and persistent upwelling tends to advect pelagic larvae offshore (Morgan 2014). Perhaps relaxation events, which increase larval retention and nearshore settlement (Johannes 1978), are more important drivers of spawning north of Point Conception. Because this is purely conjecture, additional research about the abiotic impacts on California Halibut reproduction and larval survivorship are necessary, both to provide stronger inferences and to enable predictive capabilities that are useful for resource management.

In addition to reproducing at different times and under different conditions, central California Halibut spawned much more frequently than previously described for southern California conspecifics. Wild-caught specimens from my study were estimated to spawn once every 3.2 d (25 times per summer season), whereas captive fish from southern California spawned once every 14.0 d (13 times per season) (Caddell et al. 1990). Under artificial conditions, southern California Halibut were found to spawn once every 4.7 d (55 times per season) (Caddell et al. 1990).

Mean batch fecundity from my study and that of Caddell et al. (1990) was 498,830 and 589,000 eggs, respectively. These estimates produce a mean seasonal fecundity of 12,470,750 eggs per female in central California and 7,657,000 eggs per female in southern California. However, there are issues associated with both studies that cause these estimates of fecundity to be conservative.

Estimates of batch fecundity from my study in central California are considered conservative due to the ephemeral nature of oocyte hydration and release. Additionally, financial and logistical limitations prevented the design of a sampling program that would have maximized the number of hydrated oocytes in wild-caught fish (i.e., fishery-independent sampling efforts that adjusted the timing of capture to just before spawning, when eggs were fully hydrated, but not yet released). Although California Halibut have been observed spawning in the late afternoon and throughout the night (Caddell et al. 1990), when low-light conditions reduce the probability of predation (Johannes 1978), commercial and recreational fishers put forth the most effort during early morning and daytime hours. Opportunistic sampling, therefore, led to the collection of females that were in various stages of hydration and spawning, when the number of eggs would have most likely been less than the absolute maximum. Batch fecundity counts for females undergoing hydration were underestimated because fully mature (i.e., final maturation) oocytes, which are likely to hydrate and be released along with co-occurring hydrated oocytes found in the ovary at the time of capture, were not counted because of great difficulty in differentiating them from maturing (i.e., yolk granule) oocytes. For fully hydrated females, batch fecundity counts were underestimated due to a release of some hydrated eggs either prior to or during capture, as evidenced by the presence of new postovulatory follicles.

Although utilizing the help of the fishing community greatly increased my sample sizes for fecundity estimation, it primarily yielded females from one of the two categories detailed above and reduced the probability of sampling fully hydrated, pre-spawning females. Therefore, further research aimed at determining the exact timing and biological and/or environmental drivers of California Halibut spawning, combined with an appropriately-timed sampling program, would increase the accuracy of batch fecundity estimates concerning wild fish.

The laboratory study conducted by Caddell et al. (1990) is also considered conservative because of physiological limitations to spawning fish in captivity. The egg collection method that is often used to estimate fecundity in a captive setting is problematic because the person conducting the study is unable to discern which eggs came from which female. Thus, Caddell et al. (1990) made the assumption that each female spawned independent of all others. The authors indicated that this assumption probably inflated the interspawning interval (i.e., ISI = 14 d) because it is highly likely that multiple females spawned simultaneously. Another issue associated with fecundity estimates made by Caddell et al. (1990) is that the authors averaged the total number of eggs collected by the total number of females present in that particular tank. This assumes that all females in the tank contributed to the total number of eggs produced during that event. Along with less than ideal spawning conditions that are inherent in artificial environments, this procedure likely produced lesser estimates of individual batch fecundity.

Although much remains to be learned about California Halibut spawning behavior, the co-occurrence of postovulatory follicles (a sign of recent spawning activity) and maturing oocytes, makes it clear that California Halibut exhibit a heterochronal (i.e., multiple) spawning strategy, similar to that described by Holden and Raitt (1974). Additionally, a random mixture of oocytes from all maturity stages was observed in mature fish, indicating asynchronous development (Marza 1938; Wallace and Selman 1981). This asynchronous development is evidence of persistent vitellogenesis (i.e., egg production), indicating extreme indeterminate fecundity, where yolked oocytes continue to develop and mature throughout the spawning season (Hunter et al. 1985). The reproductive tactic of indeterminacy found for California Halibut fits within the existing paradigm for species with warm temperate or subtropical distributions (Blaxter and Hunter 1982; Hunter et al. 1992, Armstrong and Witthames 2012) and protracted spawning seasons (Hickling and Rutenberg 1936; Rijnsdorp and Witthames 2005).

Though California Halibut was already recognized as a multiple spawner, this is the first description of its indeterminate reproductive strategy and method of ovarian development. This is also the first attempt to describe fecundity for wild-caught California Halibut and put together the components of spawning activity to assess seasonal reproductive potential for this species.

The proportion of reproductive females, when combined with sex ratio, size structure, and abundance estimates, will allow fishery scientists to estimate spawning stock biomass, a parameter useful in the stock assessment process. If a similar study were to be continued, time series data could also provide insight into the spawner-recruitment relationship for California Halibut, which is currently estimated from data pertaining to another flatfish species (Maunder et al. 2011). Additionally, total mortality estimates, obtained from age frequency data, can be used in conjunction with estimates of fishing mortality to approximate natural mortality for California Halibut. However, a longer time series of total mortality estimates, which would encompass variation in California Halibut recruitment strength, would be valuable because catch curve analysis is sensitive to both strong and weak recruitment events.

Overall, this research provides sex-specific and spatially-explicit compositional data, growth rate information, estimates of reproductive potential, and an evaluation of total mortality for California Halibut. Reproductive components of this work will be combined with similarly collected data by CDFW staff in San Francisco Bay to enable the construction of maturity curves for central California Halibut. Finally, the results from this thesis have been made available to the California Department of Fish and Wildlife for incorporation into the next stock assessment and are expected to better inform future management strategies pertaining to the harvest and conservation of California Halibut.

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APPENDIX I

Data associated with California Halibut collected off of central California (2012 and 2013). Site: SFB = San Francisco Bay, HMB = Half Moon Bay, SC = Santa Cruz, ML = Moss Landing, MT = Monterey, MB = Morro Bay, PSL = Port San Luis; Fishery: C = commercial, R = recreational; Gear Type: H&L = hook-and-line, SP = spear, SE = seine; Sex: F = female, M = male; Macro[scopic] Mat[urity]: 0 = immature, 1 = mature; Micro[scopic] Mat[urity]: 1 = immature, 2 = maturing, 3 = mature; 4 = spawning, 5 = spent, 6 = resting. Missing values are a result of fish that were donated as filleted carcasses, not retained, or not fully processed due to some sort of damage (e.g., cut organs, broken otolith).

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
1	06/03/12	SC	R	H&L	F	725		3997	16.2	32.1	0	
2	06/14/12	SC	R	H&L	F	770	8	4593				
3	06/14/12	SC	R	H&L	F	823	6	5160				
4	06/16/12	SC	R	H&L	F	705	8		138.1	51.6	1	3
5	06/17/12	SC	R	H&L	F	756	6	4338	112.7	48.6	1	3
6	06/17/12	SC	R	H&L	M	809	8		284.0	57.6		
7	06/17/12	SC	R	H&L	M	847	16	5954	387.4	39.2		
8	06/18/12	PSL	R	SP	F	741	8		38.7	50.3	0	2
9	06/20/12	SC	R	H&L	F	803	7		241.1	73.7	1	4
10	06/22/12	MT		H&L	F	668	6		77.0	65.7	0	3
11	06/23/12	MB	R	H&L	M	819	16	6095				
12	06/24/12	PSL	R	SP	F	641	5	2495	25.7	26.1	0	2
13	06/29/12	PSL	R	SP	F	740	8		77.1	52.3	0	3
14	06/30/12	SC	R	H&L	M	548	3		65.1	15.2	1	
15	07/01/12	SC	C	H&L	M	645	9	2778	86.6	26.7	1	
16	07/01/12	SC	C	H&L	M	602	6	2438	81.5	19.3	1	
17	07/01/12	SC	C	H&L	F	843		6832	307.7	112.0	1	3
18	07/01/12	SC	R	H&L	F	836	6	6209	186.1	86.9	1	4
19	07/01/12	SC	R	H&L	M	572	6		117.4	20.3		
20	07/01/12	SC	R	H&L	M	559			98.8	12.8	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
21	07/03/12	SC	R	H&L	F	812	8		235.9	72.6	1	3
22	07/04/12	SC	R	H&L	F	893	9		353.4	82.7	1	4
23	07/04/12	SC	R	H&L	F	783	7			85.6	1	
24	07/06/12	SC	R	H&L	M	707	6		106.7	27.4	1	
25	07/06/12	SC	R	H&L	M	792	16		160.2	36.5	1	
26	07/09/12	SC	R	H&L	M	692	7		47.1	30.9	1	
27	07/11/12	SC	R	H&L	F	904	7		460.9	129.5	1	4
28	07/11/12	SC	C	H&L	F	884	7		441.3	150.8	1	4
29	07/12/12	SC	R	H&L	F	705	6				1	
30	07/12/12	SC	R	H&L	F	820				97.3	1	
31	07/13/12	MT	R	H&L	F	793	8		283.5	86.2	1	4
32	07/14/12	HMB	R	H&L	F	827	9		154.8	108.1	1	3
33	07/14/12	SC	R	H&L	F	649	3		31.5	42.3	0	1 or 6
34	07/14/12	SC	R	H&L	M	624	8		83.9	24.4	1	
35	07/15/12	PSL	R	H&L	F	835	9	6719	79.0	74.2	0	2
36	07/15/12	PSL	R	H&L	F	895	7	8193	340.2	123.6	1	4
37	07/15/12	SC	R	H&L	M	793	8		182.8	38.8	1	
38	07/15/12	PSL	C	H&L	F	840	8	7031		100.3	1	
39	07/15/12	SC	R	H&L	M	605	6		73.2	13.3	1	
40	07/20/12	SC	R	H&L	F	865	9		371.1		1	4
41	07/21/12	SC	R	H&L	F	936	9		362.8	138.4	1	3
42	07/21/12	SC	R	H&L	M	724	7		79.9	18.7	1	
43	07/21/12	SC	R	H&L	M	735	7		45.6	17.4	1	
44	07/22/12	SC	R	H&L	M	568	8		40.5	13.1	1	
45	07/22/12	SC	R	H&L	F	651	3		86.6	27.4	1	3
46	07/22/12	SC	R	H&L	M	836	10		180.0	529.7	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
47	07/22/12	SC	R	H&L	F	862	8		305.1	102.2	1	4
48	07/22/12	SC	R	H&L	F	887	7			123.4	1	
49	07/22/12	SC	R	H&L	M	556	6		50.4	11.9		
50	07/22/12	SC	R	H&L	F	643	8			26.0	1	
51	07/22/12	SC	R	H&L	F	725	4			51.3	1	
52	07/23/12	SC	R	H&L	F	820	7			62.5	1	
53	07/23/12	SC	R	H&L	M	791	9		162.0	31.9	1	
54	07/23/12	SC	R	H&L	M	661	8		85.1	21.1	1	
55	07/23/12	SC	R	H&L	F	716	6		168.9	57.7	1	3
56	07/23/12	SC	R	H&L	F	892	8		205.9	105.2	1	
57	07/23/12	SC	R	H&L	M	820	13		203.6	41.5	1	
58	07/24/12	SC	R	H&L	F	790	7				1	
59	07/24/12	SC	R	H&L	F	653	7				1	
60	07/25/12	SC	R	H&L	M	719			149.1	24.2	1	
61	07/26/12	SC	R	H&L	M	651	7		86.6	22.9	1	
62	07/26/12	SC	R	H&L	M	694	8		61.7	27.1	1	
63	07/26/12	SC	R	H&L	M	717	7		76.8	27.2	1	
64	07/26/12	SC	R	H&L	F	760	8		203.8	77.1	1	3
65	07/27/12	SC	R	H&L	M	740	14		157.6	43.4	1	
66	07/27/12	SC	R	H&L	F	935	7			129.7	1	
67	07/28/12	SC	R	H&L	F	1021	15		659.5	174.5	1	4
68	07/28/12	SC	R	H&L	M	608	8	2466	69.7	17.7	1	
69	07/28/12	SC	R	H&L	M	816	7	5500	127.7	34.5	1	
70	07/28/12	SC	R	H&L	F	851	8		260.8	124.4	1	4
71	07/28/12	SC	R	H&L	M	806			100.4	38.7	1	
72	07/28/12	SC	R	H&L	M	592	7	2353	62.1	16.2	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
73	07/28/12	SC	R	H&L	F	1169	16	16953	656.4	245.6	1	
74	07/29/12	SC	R	H&L	F	1003	14		434.8	119.6	1	3
75	07/29/12	SC	R	H&L	M	709	7		57.5	31.0	1	
76	07/29/12	SC	R	H&L	F	670	7		130.6	46.3	1	4
77	07/29/12	SC	R	H&L	F	753	9		255.8	53.8	1	4
78	07/29/12	SC	R	H&L	M	617	6		38.4	22.2	1	
79	07/29/12	SC	R	H&L	F	691	7		52.8	43.7	1	
80	07/30/12	SC	R	H&L	F	630		2693				
81	07/30/12	SC	R	H&L	F	714		3941				
82	07/30/12	SC	R	H&L	F	778		5755				
83	07/30/12	SC	R	H&L	M	546				13.3		
84	07/30/12	SC	R	H&L	F	830	7			60.1	1	
85	07/30/12	SC	R	H&L	M	729	7		101.8	29.6	1	
86	07/30/12	SC	R	H&L	M	662	7		58.7	20.2	1	
87	07/30/12	SC	R	H&L	M	650	7		93.3	21.4	1	
88	07/30/12	SC	R	H&L	F	694	8		110.3	33.7	1	3
89	07/30/12	SC	R	H&L	M	653	7		63.2		1	
90	07/31/12	SC	R	H&L	F	796	8			70.0	1	
91	07/31/12	SC	R	H&L	M	715	7		51.9	19.0	1	
92	07/31/12	SC	R	H&L	M	629	6		79.0	24.2	1	
93	07/31/12	SC	R	H&L	M	758	8		66.2	40.9	1	
94	07/31/12	SC	R	H&L	M	587	7		51.3	14.9		
95	07/31/12	SC	R	H&L	M	559	7		70.4	7.7	1	
96	07/31/12	SC	R	H&L	M	679	7			25.8	1	
97	07/31/12	SC	R	H&L	M	631	6	2693	43.2	19.0	1	
98	07/31/12	SC	R	H&L	M	718	7	3941	87.4	37.5	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
99	07/31/12	SC	R	H&L	M	643	6		36.2	17.0	1	
100	07/31/12	SC	R	H&L	M	643	5					
101	07/31/12	SC	R	H&L	M	662	8		77.5	21.8	1	
102	07/31/12	SC	R	H&L	M	703			76.2	26.3	1	
103	07/31/12	SC	R	H&L	F	785	6		196.6	67.6	1	4
104	07/31/12	SC	R	H&L	F	767	7			57.0	1	
105	07/31/12	SC	R	H&L	F	1028	9		503.5	171.2	1	3
106	08/01/12	PSL	R		F	717	7	4451	73.6	67.8	0	5
107	08/01/12	SC	R	H&L	M	841			140.7	45.0	1	
108	08/01/12	SC	R	H&L	F	742	8			72.6	1	
109	08/01/12	SC	R	H&L	F	660				42.0	1	
110	08/01/12	SC	R	H&L	M	592	8		52.8	13.9	1	
111	08/03/12	SC	R	H&L	M	711	8		58.5	40.8	1	
112	08/03/12	SC	R	H&L	F	701	7		168.2	64.0	1	4
113	08/05/12	SC		H&L	F	536	3	1814		18.0	0	1 or 6
114	08/05/12	SC	R	H&L	M	783	9		130.9	38.5	1	
115	08/05/12	SC	R	H&L	M	751	8	4848	93.5	29.7	1	
116	08/05/12	SC	R	H&L	M	808	9	5330	147.0	42.3	1	
117	08/05/12	SC	R	H&L	M	621	7			12.7	1	
118	08/05/12	SC	R	H&L	F	712	7				1	
119	08/11/12	PSL	R	H&L	M	662		3062			1	
120	08/11/12	PSL	R	H&L	F	754		4905				
121	08/11/12	PSL	R	H&L	F	827		8051				
122	08/11/12	PSL		H&L	F	939		9356				
123	08/11/12	PSL	R	H&L	F			7711				
124	08/11/12	PSL	R	H&L	F	611	7		28.4	31.4	0	1 or 6

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
125	08/19/12	SC	C	H&L	M	800	6		184.5	37.0	1	
126	08/24/12	ML	C	H&L	M	621	8		85.2	18.2	1	
127	08/24/12	ML	C	H&L	M	666	7		121.6	21.6	1	
128	08/24/12	ML	C	H&L	F	842	7		283.2	122.8	1	3
129	08/24/12	ML	C	H&L	F	840	8		176.3	116.2	1	
130	08/24/12	SC	R	H&L	M	815	14		106.1	61.2	1	
131	08/28/12	SC	C	H&L	F	755						
132	08/28/12	SC	C	H&L	M	622					1	
133	08/28/12	SC	C	H&L	F	833						
134	08/28/12	SC	C	H&L	F	806					1	
135	08/28/12	SC	C	H&L	F	733						
136	08/28/12	SC	C	H&L	M	732					1	
137	08/28/12	SC	C	H&L	M	783					1	
138	08/28/12	SC	C	H&L	F	731						
139	08/28/12	SC	C	H&L	F	583						
140	08/28/12	SC	C	H&L	M	544	7		37.5	16.3	1	
141	08/28/12	SC	R	H&L	M	561	9		8.2	13.0	1	
142	08/31/12	SC	R	H&L	M	691	7			51.3	1	
143	08/31/12	SC	R	H&L	M	812	15		52.7	62.1	1	
144	08/31/12	SC	R	H&L	M	669	7		24.8	40.1	1	
145	08/31/12	SC	R	H&L	M	650	9		31.8	21.7	1	
146	09/02/12	SC	R	H&L	F	832						
147	09/02/12	SC	R	H&L	F	861					1	
148	09/06/12	MB	R	H&L	F	876	8		194.8	123.6	1	4
149	09/06/12	MB	R	H&L	M	667	7		26.2	37.0	1	
150	09/08/12	PSL	R	H&L	F	671	9		39.9	55.4	0	2

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
151	09/18/12	PSL	R	H&L	F	910	9				0	1 or 6
152	09/18/12	PSL	R	H&L	F	823	5				0	
153	09/21/12	SC	R	H&L	M	593	5					
154	09/21/12	SC	R	H&L	F	742	7		152.1		1	
155	05/11/13	MB	R	H&L	M	832	9	7200	169.6		1	
156	05/11/13	MB	R	H&L	M	830	8	6500	198.9	45.9	1	
157	05/27/13	SC	R	H&L	F	895	10	9400	243.3	116.0	1	3
158	06/11/13	SC	R	H&L	M	688	8	4167	67.0	29.9	1	
159	06/14/13	SC	R	H&L	F	922	8	9809	153.0	141.4	0	2
160	06/14/13	MT	R	SP	F	1024		11255	190.2	97.3	0	2
161	06/15/13	SC	R	H&L	F	830	7			83.7	1	
162	06/16/13	ML		H&L	F			8420				
163	06/16/13	ML		H&L	F			8647				
164	06/16/13	ML		H&L	F			9384				
165	06/16/13	ML		H&L	F			9923				
166	06/16/13	ML		H&L	F			10631				
167	06/16/13	ML		H&L	M			5585			1	
168	06/16/13	ML	C	H&L	F	918	8	9157	282.3	164.3	1	3
169	06/21/13	SC	R	H&L	M	561	6		37.1	24.8	1	
170	06/21/13	SC	R	H&L	M	714	8		146.0	32.3	1	
171	06/22/13	ML		H&L	F			3515				
172	06/22/13	ML		H&L	M			3062			1	
173	06/22/13	ML		H&L	M			3600			1	
174	06/22/13	ML		H&L	M			7000			1	
175	06/22/13	ML	C	H&L	F	812	9		263.0	107.9	1	4
176	06/22/13	ML	R	H&L	F	900	8	9979	312.7	163.1	1	4

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
177	06/22/13	ML		H&L	M	657	7	1758	72.4	19.6	1	
178	06/22/13	ML	C	H&L	M	749	8					
179	06/22/13	MT		H&L	M	775	8		92.0	37.1	1	
180	06/22/13	SC	R	H&L	F	660	4		40.5	29.5	0	2
181	06/23/13	SC	R	H&L	F			3515			1	
182	06/23/13	SC	R	H&L	F	668	5	3657	121.2	37.2	1	4
183	06/23/13	ML	C	H&L	F	725	5	4536	245.9	69.6	1	4
184	06/24/13	MT	R	SP	F	907	8			164.8	1	
185	06/25/13	ML	R	H&L	F			14203				
186	06/25/13	ML	R	H&L	F	824	9	6719	313.8	111.8	1	3
187	06/25/13	ML	R	H&L	M	636	7	2693	83.8	18.1	1	
188	06/25/13	ML	R	H&L	F	950	8	9809	737.2	230.0	1	4
189	06/25/13	ML	R	H&L	F	817	9	6521		86.5	1	3
190	06/26/13	SC	R	H&L	M	710	14		138.8	33.1	1	
191	06/26/13	SC	R	H&L	F	786	9		275.6	98.6	1	4
192	06/28/13	SC	R	H&L	F	846	8				F	3
193	06/28/13	ML	R	H&L	M	698	8		107.7	35.6	1	
194	06/28/13	ML	R	H&L	M	659	7		96.4	20.9	1	
195	06/30/13	SC	R	H&L	M	611	8	2637	72.9	18.0	1	
196	07/01/13	SC	R	H&L	F	783	8	5557	99.1	76.5	0	5
197	07/01/13	SC	R	H&L	F	759	8		194.7	53.8	1	4
198	07/02/13	ML	R	H&L	M	763	9	5046	139.8	50.6	1	
199	07/02/13	ML	R	H&L	M	635	8	2807	111.6	32.8	1	
200	07/02/13	ML	R	H&L	F	834	8	6549	337.8		1	3
201	07/02/13	ML	R	H&L	M	773	9	5131	136.6	52.0	1	
202	07/02/13	ML	R	H&L	F	1016	14	11255	458.9		1	3

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
203	07/02/13	ML	R	H&L	M	821	8	5868	205.2	53.3	1	
204	07/05/13	SC	R	H&L	F	600	6	2325	131.0	49.7	1	3
205	07/06/13	SC	R	H&L	F	743	7	4423	235.1	67.0	1	3
206	07/06/13	SC	R	H&L	F	947	7	10631	193.1	141.8	1	3
207	07/06/13	SC	R	H&L	M	797	9		196.4	35.7	1	
208	07/06/13	SC	R	H&L	F	873	9	7768	426.9	134.1	1	4
209	07/06/13	SC	R	H&L	F	850	6		401.9	97.8	1	4
210	07/06/13	SC	R	H&L	M	620	8		43.2	18.2	1	
211	07/07/13	ML		H&L	F			4678				
212	07/07/13	ML		H&L	F			3459				
213	07/07/13	ML		H&L	M			2041			1	
214	07/07/13	ML		H&L	M			3260			1	
215	07/07/13	ML		H&L	M						1	
216	07/07/13	ML		H&L	M						1	
217	07/07/13	SC	R	H&L	F	872	9		142.6	72.6	0	2
218	07/07/13	SC	R	H&L	M	540	7	1814	64.7	17.9	1	
219	07/07/13	SC	R	H&L	M	809			139.9	39.3	1	
220	07/07/13	SC	R	H&L	M	768	14	5188	105.2	46.2	0	
221	07/10/13	MT	R	H&L	M	842	10	7428	223.7	55.6	1	
222	07/10/13	MT	R	H&L	M	860	6	7399	220.4	59.9	1	
223	07/10/13	ML	R	SP	F	767	7		191.9	92.0	1	3
224	07/12/13	MB	R	H&L	F	1035	10	13750	697.7	266.3	1	3
225	07/12/13	MB	R	H&L	F	894	8	9100	608.1	162.5	1	4
226	07/12/13	MB		H&L	F	685	4	3912	253.0	69.3	1	4
227	07/12/13	ML	C	H&L	F	690	8			77.4	1	
228	07/12/13	ML	C	H&L	M	651	7		181.1	40.6	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
229	07/12/13	ML	C	H&L	M	611	8		71.4	20.2	1	
230	07/12/13	ML	C	H&L	M	619	7		106.5	24.2	1	
231	07/12/13	ML	C	H&L	F	611	6			44.4	1	
232	07/12/13	ML	C	H&L	M	624	7			16.8	1	
233	07/12/13	ML	C	H&L	M	699	8		72.7	35.4	1	
234	07/13/13	MB	R		F	1171	19				1	
235	07/13/13	MB	R		F	871	9				0	
236	07/13/13	MB			F	962	9				1	
237	07/13/13	MB	R	H&L	F	835	8	6832	245.9	118.4	1	3
238	07/13/13	ML	C	H&L	F	928	9		446.9	198.9	1	3
239	07/13/13	MB	R		F	789	8				1	
240	07/13/13	SC	R	H&L	F	607	5			27.3	0	
241	07/13/13	ML	R	SP	F	983	9	11567	554.8	144.5	1	3
242	07/13/13	ML	R	SP	F	806	10	6095		103.5	1	3
243	07/13/13	ML	R	SP	F	1011	8	11964	620.4	168.4	1	3
244	07/13/13	ML	R	SP	M	781	8	5585	211.4	50.8	1	
245	07/13/13	ML	R	SP	M	840	8	6549	211.9	64.0	1	
246	07/13/13	ML	R	SP	F	691	4	3799	177.3		1	3
247	07/13/13	SC	R	H&L	F	857	8		254.3	86.3	1	3
248	07/13/13	SC	R	H&L	F	774	7	4621		78.2	1	
249	07/13/13	ML		H&L	F	826	8		139.5		1	3
250	07/14/13	MB		H&L	M	796	10	5642	103.4	44.0	1	
251	07/14/13	MB	R		F	861	7				1	
252	07/14/13	MB	R		F	860	9		255.1	82.6	1	3
253	07/14/13	MTB	C	H&L	M	765	15		191.0	45.2	1	
254	07/14/13	ML	C	H&L	M	696	7		151.5	29.2	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
255	07/15/13	ML	R	SP	F	1019	8		949.6	351.9	1	
256	07/15/13	ML	C		F	1010	10		518.1		1	4
257	07/15/13	ML	R	SP	F	753	4		234.9	89.9	1	3
258	07/15/13	ML	R	SP	F	832	9		475.4	137.1	1	3
259	07/15/13	ML	R	SP	F	920	8		422.1	153.2	1	
260	07/15/13	ML	R	SP	F	905	9					
261	07/15/13	ML	R	SP	M	732	8		185.2	33.4	1	
262	07/16/13	MT	R	H&L	M	850	8	7173	168.1	63.0	1	
263	07/16/13	MT	R	H&L	F	921	8	10688	534.1	184.3	1	3
264	07/16/13	MT	R	H&L	F	838	9	7343	347.1	113.0	1	4
265	07/16/13	MT	R	H&L	M	758	7	4678	87.7	34.5	1	
266	07/16/13	ML	R	SP	F	789	7	5600	456.4	144.3	1	4
267	07/16/13	ML	R	SP	F	1020	12	13100	268.8	255.2	1	3
268	07/16/13	ML	R	SP	F	859	7	7399	391.4	144.1	1	3
269	07/17/13	SC	R	H&L	F	1090	15			185.8	1	3
270	07/19/13	ML	R	SP	F	908	8		578.6	192.6	1	4
271	07/19/13	SC	R	H&L	F	803	8		213.3	75.5	1	3
272	07/19/13	SC	C	H&L	M	625	7	2835	90.9	22.4	1	
273	07/19/13	SC	C	H&L	M	603	7	2381	79.4	17.4	1	
274	07/19/13	SC	C	H&L	M	680	8	3090	75.3	21.3	1	
275	07/19/13	SC	C	H&L	M	721	8	4423	136.9	42.8	1	
276	07/19/13	SC	C	H&L	F	671	4	3572	137.4	52.5	1	
277	07/19/13	SC	C	H&L	M	616	8	2750	95.1	23.7	1	
278	07/19/13	SC	C	H&L	M	556	3	1729	45.8	15.9	1	
279	07/19/13	SC	C	H&L	F	816	9	6634		106.3	1	
280	07/19/13	SC	C	H&L	M	849	10	6974	155.8	79.6	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
281	07/19/13	ML	R	SP	F	887	8		371.3	135.1	1	3
282	07/19/13	ML	R	SP	F	771	8		293.4	123.6	1	3
283	07/19/13	SC	C	H&L	M	752	8	4451	88.9	55.9	1	
284	07/19/13	SC	C	H&L	M	646	8	2778	84.8	26.2	1	
285	07/19/13	SC	C	H&L	F	838	9	6464	298.5	95.9	1	3
286	07/19/13	SC	C	H&L	F	835	7	6974	270.5	78.0	1	
287	07/19/13	SC	C	H&L	F	835	7	6294	202.9	71.5	1	3
288	07/20/13	ML	R	SP	F			5528			1	
289	07/20/13	ML	R	SP	F			7456			1	
290	07/20/13	ML	R	SP	F			12672			1	
291	07/20/13	PSL	R	H&L	F			11598			1	
292	07/20/13	PSL	R	H&L	F			7149			0	
293	07/20/13	ML	R	SP	M			5046			1	
294	07/20/13	PSL	R	H&L	F	1031		11822				
295	07/20/13	PSL	R	H&L	F	1030	9	12077	137.5	169.4	0	2
296	07/20/13	ML	C	H&L	M	604	7		98.3	23.6	1	
297	07/20/13	ML	C		M	675	8		102.1	26.6	1	
298	07/21/13	ML	R	SP	F			8448				
299	07/21/13	ML	R	SP	F			8278				
300	07/21/13	ML	R	SP	F			9327				
301	07/21/13	ML	R	SP	F			10291				
302	07/21/13	ML	R	SP	M			5103			1	
303	07/21/13	ML	R	SP	M			6464			1	
304	07/21/13	ML	R	SP	M			2693			1	
305	07/21/13	ML	R	SP	M			2778			1	
306	07/21/13	PSL		H&L	F	852	8	7626	471.5	155.0	1	4

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
307	07/23/13	MB		H&L	F		8	10569		241.9	0	
308	07/23/13	ML	R	SP	F	855	8	7966	464.7	158.7	1	4
309	07/24/13	SC	R	H&L	F	709	8		41.1	43.5	1	3
310	07/24/13	SC	R	H&L	M	668	8			21.8	1	
311	07/24/13	SC	C	H&L	F	981	8		641.0	275.8	1	
312	07/25/13	ML	R	H&L	F			4678				
313	07/25/13	SC	C	H&L	F			5613				
314	07/25/13	SC	C	H&L	F			7626				
315	07/25/13	SC	C	H&L	F							
316	07/25/13	SC	C	H&L	M			4564			1	
317	07/25/13	SC	C	H&L	M			3544			1	
318	07/25/13	SC	C	H&L	M			3260			1	
319	07/25/13	SC	C	H&L	M			3941			1	
320	07/25/13	SC	C	H&L	M			4394			1	
321	07/25/13	SC	C	H&L	F			2183				
322	07/25/13	ML	R	SP	M	716		4026	190.6	38.2	1	
323	07/25/13	ML	R	SP	M	827	8	6691	292.0	53.9	1	
324	07/25/13	ML	R	SP	M	725	7	4281	151.5	40.0	1	
325	07/25/13	ML	R	SP	F	905	9	9469	438.4	156.9	1	4
326	07/25/13	SC	C	H&L	F	845	8	6776	367.4	140.6	1	3
327	07/25/13	SC	C	H&L	F	950	19	10263	447.3	196.8	1	3
328	07/25/13	SC	C	H&L	F	892	9	8732	450.2	178.1	1	3
329	07/25/13	SC	C	H&L	F	961	14			123.2	1	
330	07/25/13	SC	C	H&L	F	953	10		443.9	167.6	1	3
331	07/27/13	SFB	C		F	956	10				1	
332	07/27/13	SFB	C		F	862					1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
333	07/27/13	ML	R	H&L	M			3402			1	
334	07/27/13	PSL	R	H&L	F	745	9	4990	251.2	87.3	1	4
335	07/27/13	PSL	R	H&L	F	840	6	7286	138.1	111.7	1	3
336	07/27/13	ML	R	H&L	M	797	8	7428	154.5	31.4	1	
337	07/27/13	SC	R	H&L	M	570	7		90.5	15.7	1	
338	07/28/13	PSL	R	SP	F	610	4		20.2	22.7	0	2
339	07/28/13	ML	R	H&L	F	929	9	9809		156.7	1	4
340	07/28/13	SC	R	H&L	F	618	6		87.8	32.6	1	3
341	07/28/13	SC	R	H&L	F	718	4	2637	151.4	50.7	1	3
342	07/28/13	SC	R	H&L	F	809	8	6322	500.3	107.7	1	4
343	07/29/13	ML	R	H&L	F	820	8		247.7	100.0	1	3
344	07/29/13	ML	R	H&L	M	766	8		179.7	44.0	1	
345	07/29/13	MT		SE	F	394	2	624	2.1	4.9	0	1 or 6
346	07/29/13	ML	R	H&L	M	732	8		202.0		1	
347	07/30/13	ML	R	H&L	M	815	8	5698	142.5	51.7	1	
348	07/30/13	ML	R	H&L	F	726	7	4309	205.2	89.4	1	4
349	07/30/13	ML	R	H&L	M	669		3430	111.9	31.7	1	
350	07/30/13	ML	R	H&L	M	782	7	5301	229.2	62.5	1	
351	07/30/13	ML	R	H&L	M	751	8		50.3	35.1		
352	07/31/13	SC	R	H&L	M	680	8	3345	178.4	26.2	1	
353	07/31/13	ML	C	H&L	F	999	8	11992	468.9	241.9	1	3
354	08/01/13	ML	C	H&L	F			5443				
355	08/01/13	ML	C	H&L	F			7484				
356	08/01/13	ML	C	H&L	F			9044				
357	08/01/13	ML	C	H&L	F			9356				
358	08/01/13	ML	C	H&L	F			10575			1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
359	08/01/13	ML	C	H&L	F			10886				
360	08/01/13	ML	C	H&L	F			3657				
361	08/01/13	ML	C	H&L	F			4479			1	
362	08/01/13	ML	C	H&L	F			4111				
363	08/01/13	ML	C	H&L	M			4649			1	
364	08/01/13	ML	C	H&L	M			4706			1	
365	08/01/13	ML	C	H&L	M			5273			1	
366	08/01/13	ML	C	H&L	M			5755			1	
367	08/01/13	ML	C	H&L	M			3033			1	
368	08/01/13	ML	C	H&L	M			3062			1	
369	08/01/13	ML	C	H&L	M			3771			1	
370	08/01/13	ML	C	H&L	M			4139			1	
371	08/01/13	ML	C	H&L	F	831	8		107.8	141.2	0	2
372	08/01/13	SC	R	H&L	M	644	5					
373	08/01/13	ML	C	H&L	F	802	9	6095	407.2	122.7	1	4
374	08/01/13	ML	C	H&L	F	1047	14	12219	626.9	211.5	1	4
375	08/01/13	ML	C	H&L	F	1035	15		468.2	185.0	1	3
376	08/02/13	MT	R	H&L	F			7371				
377	08/02/13	MT	R	H&L	F			3969				
378	08/02/13	MT	R	H&L	F			4026				
379	08/02/13	MB	R	H&L	F	841	8	7541	239.6	148.1	1	3
380	08/02/13	MT	R	SP	F	915	7	9072	550.9	173.9	1	4
381	08/03/13	ML	R	H&L	F			4536				
382	08/03/13	MT	R	H&L	F			9894			1	
383	08/03/13	ML	R	H&L	F							
384	08/03/13	ML	R	H&L	M						1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
385	08/03/13	ML	R	H&L	F							
386	08/03/13	PSL	R	H&L	F	879	8	7995		118.8	0	2
387	08/03/13	ML	R	SP	F	949	9		476.6	145.9	1	3
388	08/03/13	PSL	R	H&L	F	1087	18	14203	588.3	218.1	1	3
389	08/03/13	PSL	R	H&L	F			14203				
390	08/03/13	ML		H&L	M	663	6			21.2	1	
391	08/03/13	ML		H&L	F	863	8		360.1	96.2	1	4
392	08/03/13	ML	R	H&L	M	806	8	5900	252.0	37.0	1	
393	08/03/13	SC	R	H&L	F	663	8		71.3	31.8	1	3
394	08/03/13	MT	C	H&L	F	838	8		607.7	125.3	1	4
395	08/03/13	MT	C	H&L	F	817	7		296.9	130.0	1	3
396	08/04/13	SC	R	H&L	F			6237				
397	08/04/13	SC	R	H&L	M	593					1	
398	08/04/13	MT	R	SP	F	1070	12	15819	836.1	302.7	1	
399	08/04/13	MT	R	SP	F	976	9	11340	539.8		1	3
400	08/04/13	MT	R	SP	F	937	8	10093	427.7	210.7	1	3
401	08/04/13	MT	R	SP	F	891	8	7768	592.8	110.2	1	4
402	08/04/13	MT	R	SP	F	759	5	5018	199.2	84.4	1	3
403	08/04/13	MT	R	SP	F	792	8	5557	237.1		1	3
404	08/04/13	ML	R	H&L	F	873	8	7995	349.8	155.3	1	4
405	08/04/13	ML	R	H&L	M	752	8	4564	39.9	40.3	1	
406	08/04/13	ML	C	H&L	F	797	9		225.7	89.9	1	3
407	08/04/13	ML	R	H&L	M	662	8	4054	156.3	46.4	1	
408	08/04/13	ML	R	H&L	F	900	8	8023	309.8	130.4	1	4
409	08/06/13	ML	R	H&L	M	641	7		126.0	21.4	1	
410	08/06/13	ML	R	H&L	M	642	5		126.1	22.7	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
411	08/06/13	ML	R	SP	F	895	8	8703	298.6	143.1	1	3
412	08/06/13	ML	R	SP	M	827	9	5982	275.2	39.2	1	
413	08/07/13	ML	C	H&L	F	678					0	
414	08/07/13	ML	C	H&L	F	708					1	
415	08/07/13	ML	C	H&L	F	837					1	
416	08/07/13	ML	C	H&L	F	986						
417	08/07/13	ML	C	H&L	M	548					1	
418	08/07/13	ML	C	H&L	M	600					1	
419	08/07/13	ML	C	H&L	M	615					1	
420	08/07/13	ML	C	H&L	M	625					1	
421	08/07/13	ML	C	H&L	M	633					1	
422	08/07/13	ML	C	H&L	M	653					1	
423	08/07/13	ML	C	H&L	M	655					1	
424	08/07/13	ML	C	H&L	M	676					1	
425	08/07/13	ML	C	H&L	M	687					1	
426	08/07/13	ML	C	H&L	M	697					1	
427	08/07/13	ML	C	H&L	M	745					1	
428	08/07/13	ML	C	H&L	M	769					1	
429	08/07/13	ML	C	H&L	M	795					1	
430	08/07/13	ML	C	H&L	M	802					1	
431	08/07/13	ML	C	H&L	M	834					1	
432	08/07/13	ML	C	H&L	M	842					1	
433	08/07/13	ML	R	SP	F	947	10	10858	591.0	241.1	1	3
434	08/07/13	MT	C	H&L	F	942	8		520.0	232.3	1	
435	08/07/13	MT	R	H&L	F	907	8	8200	192.4	113.3	1	3
436	08/07/13	ML	R	H&L	F	950	8			201.5	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
437	08/07/13	ML	R	H&L	F	882				147.2	1	
438	08/07/13	ML	R	H&L	F	813	8			110.2	1	
439	08/07/13	ML	R	H&L	F	821	8		267.9	111.8	1	
440	08/07/13	ML	R	H&L	F	892	8		469.7	141.6	1	
441	08/07/13	ML	R	SP	F	1073	15	14884	868.7	336.7	1	
442	08/07/13	ML	R	SP	F	973	8	10546	518.0	198.4	1	3
443	08/07/13	ML	R	SP	F	870	8	8080	355.1	166.1	1	
444	08/07/13	ML	R	SP	F	848	5	6946	407.7	143.8	1	3
445	08/07/13	ML	R	SP	F	938	7	10773	732.1	245.4	1	3
446	08/07/13	SC	R	H&L	M	923	8		1.8	88.8	0	
447	08/08/13	ML	C	H&L	F			6407				
448	08/08/13	ML	C	H&L	F			6804				
449	08/08/13	ML	C	H&L	F			8703				
450	08/08/13	ML	C	H&L	F			8817				
451	08/08/13	ML	C	H&L	F			9299				
452	08/08/13	ML	C	H&L	F			9554				
453	08/08/13	ML	C	H&L	F			10093				
454	08/08/13	MTB	C	H&L	F			9554				
455	08/08/13	PSL	R	H&L	F	882	7		317.1	182.8	1	4
456	08/08/13	MT	R	H&L	F	974	8	11340	724.2	187.8	1	
457	08/08/13	MT	R	H&L	F	1080	12	15422	750.9	255.5	1	4
458	08/08/13	SC	R	H&L	F	775	8	5188	343.8	65.9	1	4
459	08/09/13	ML	R	SP	F			8392				
460	08/09/13	MB	R	SP	F	818	9	6662	88.0	124.5	0	2
461	08/09/13	PSL	R	H&L	F		9		121.1	214.6	0	2
462	08/09/13	SC	C	H&L	F	950	9		574.0	142.8	1	3

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
463	08/09/13	SC	C	H&L	F	930			436.9	218.1	1	3
464	08/09/13	SC	C	H&L	F	831	7		409.1	109.9	1	4
465	08/09/13	MTB	C	H&L	M	644	7		43.7	27.8	1	
466	08/09/13	MTB	C	H&L	F	893	8		583.4	201.3	1	4
467	08/09/13	MTB	C	H&L	F	911	7		604.9	213.8	1	4
468	08/09/13	MTB	C	H&L	M	729	7		115.5	66.2	1	
469	08/09/13	MTB	C	H&L	F	901	10		385.9	154.3	1	
470	08/10/13	MT	C	H&L	F			7343			1	
471	08/10/13	MT	C	H&L	F			9866			1	
472	08/10/13	MT	C	H&L	F			2863			1	
473	08/10/13	MT	C	H&L	F			4111			1	
474	08/10/13	MT	C	H&L	M			2835			1	
475	08/11/13	ML	C	H&L	F			6889			1	
476	08/11/13	MT	R	H&L	F			8789			1	
477	08/11/13	ML	R	H&L	F			9214			1	
478	08/11/13	ML	C	H&L	F			11624			1	
479	08/11/13	ML	C	H&L	F			12077				
480	08/11/13	ML	C	H&L	M			3147			1	
481	08/11/13	ML	R	H&L	F	868	7		289.4	189.1	1	4
482	08/11/13	MT	R	H&L	F	910	8		433.9	177.0	1	3
483	08/11/13	ML	R	H&L	F	694	8			50.4		
484	08/11/13	ML	R	H&L	F	790	7	5755	100.4	99.3	1	4
485	08/11/13	ML	R	H&L	M	743	8	4139	178.8	26.3	1	
486	08/11/13	ML		H&L	F	855	7	6747			1	
487	08/12/13	HMB	R	H&L	F	801	9		369.9		1	
488	08/13/13	ML	R	H&L	F	820		6492	341.4	134.2	1	3

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
489	08/13/13	ML	R	H&L	F	774	8	5954	229.7	107.5	1	4
490	08/13/13	ML	R	SP	F	871	8	7711	277.0	98.1	1	4
491	08/13/13	ML	R	SP	F	953	9		287.3	129.5	1	
492	08/13/13	ML	R	SP	F	880	7		276.5	194.4	1	3
493	08/13/13	ML	R	H&L	M	695	8	3912	91.1	25.1		
494	08/13/13	ML	R	H&L	M	718	9	3884	102.6	30.4		
495	08/13/13	ML	R	H&L	F	818	8	6889	484.2	134.5	1	4
496	08/13/13	SC	R	H&L	M	450	4		17.7	5.4	1	
497	08/14/13	SC	R	H&L	F	641	5				1	
498	08/14/13	SC	C	H&L	F	668					1	
499	08/14/13	SC	C	H&L	F	759					1	
500	08/14/13	SC	C	H&L	F	768					1	
501	08/14/13	SC	C	H&L	F	794					1	
502	08/14/13	SC	C	H&L	F	795					1	
503	08/14/13	SC	C	H&L	F	811					1	
504	08/14/13	SC	C	H&L	F	815					1	
505	08/14/13	SC	C	H&L	F	828					1	
506	08/14/13	SC	C	H&L	F	835					1	
507	08/14/13	SC	C	H&L	F	836					1	
508	08/14/13	SC	C	H&L	F	846					1	
509	08/14/13	SC	C	H&L	F	871					1	
510	08/14/13	SC	C	H&L	F	914					1	
511	08/14/13	SC	C	H&L	F	944					1	
512	08/14/13	SC	C	H&L	M	662					1	
513	08/14/13	SC	C	H&L	M	665					1	
514	08/14/13	SC	C	H&L	M	707					1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
515	08/14/13	SC	C	H&L	F	856	7	8023		149.4	1	
516	08/14/13	SC	C	H&L	M	623	9	2807	68.7	17.6	1	
517	08/14/13	SC	R	H&L	M	737	9		193.2	26.8	1	
518	08/14/13	SC	R	H&L	F	908	8			103.1	1	
519	08/14/13	SC	C	H&L	F	842	8	7286	222.0	131.0	1	3
520	08/14/13	SC	C	H&L	M	574	7	2466	47.1	20.4	1	
521	08/14/13	SC	R	H&L	F	982				146.3	1	
522	08/14/13	SC	R	H&L	M	618	7		96.1	18.4	1	
523	08/14/13	SC	R	H&L	M	699	8		87.8	32.2	1	
524	08/14/13	SC	R	H&L	F	830	7		267.0	117.1	1	
525	08/15/13	ML	R	H&L	M	797	8	5840	222.8	49.3	1	
526	08/15/13	ML	R	H&L	F	979	14	11085	434.2	187.7	1	3
527	08/15/13	ML	R	H&L	F	931	9			185.2	1	
528	08/15/13	ML	R	H&L	F	799	9				1	
529	08/15/13	ML	R	H&L	M	745	9		129.2	37.0	1	
530	08/15/13	MT	R	H&L	F			4281		77.0	1	
531	08/15/13	ML	R	H&L	F	844	8	7456		116.0	1	3
532	08/15/13	ML	R	H&L	F	846	6			105.5	1	
533	08/16/13	MT	C	H&L	F			5358			1	
534	08/16/13	MT	C	H&L	F			9412			1	
535	08/16/13	MT	C	H&L	F			9554			1	
536	08/16/13	ML	C	H&L	M	695	7		208.1	29.2	1	
537	08/16/13	ML	C	H&L	F	928	7			174.6	1	
538	08/16/13	ML	R	H&L	M	804	8		128.4	69.2	1	
539	08/16/13	ML	C	H&L	M	575	7		128.7	12.1	1	
540	08/17/13	ML		H&L	F			5954				

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
541	08/17/13	ML	C	H&L	F			8136				
542	08/17/13	ML	C	H&L	F			11283			1	
543	08/17/13	ML		H&L	F			15819				
544	08/17/13	ML	C	H&L	M			3430			1	
545	08/17/13	ML	R	H&L	M			4139			1	
546	08/17/13	HMB	R	H&L	F	862	7		423.6		1	
547	08/17/13	ML	R	H&L	F	1120	14		550.7	225.2	1	3
548	08/17/13	SC	R	H&L	F	880	7		481.7	115.1	1	4
549	08/17/13	ML	C	H&L	M		7	3544	94.6	29.7	1	
550	08/18/13	SC	R	H&L	F			9163				
551	08/18/13	PSL	R	H&L	F	862	7	7031	138.2	62.4	1	3
552	08/18/13	ML		H&L	M	815	10		380.3	50.5	1	
553	08/18/13	SC	R	H&L	F	857	7	7853		164.9	0	
554	08/18/13	ML	R	SP	F	970			417.7	158.3	1	3
555	08/18/13	ML	R	SP	F	823	8			113.3	1	
556	08/18/13	ML	R	SP	F	1039	9		714.2		1	3
557	08/18/13	ML	R	SP	M	632	8		138.0	31.9	1	
558	08/18/13	ML	R	SP	F				373.2		1	
559	08/18/13	ML	R	SP	M	837	8		192.9	51.1	1	
560	08/18/13	ML	R	SP	F	970	7		275.5	166.7	1	3
561	08/18/13	ML	R	SP	F	922	10		295.2	135.1	1	3
562	08/18/13	ML	R	SP	M	745	8		118.5	40.0	1	
563	08/18/13	ML	R	SP	M	791	8		190.3	65.8	1	
564	08/18/13	ML	R	SP	F	907	9				1	
565	08/18/13	ML	R	SP	M	815	8			52.4	1	
566	08/18/13	ML	R	SP	M	714	9				1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
567	08/18/13	ML	R	SP	M	738	8			49.5		
568	08/18/13	ML	R	SP	M	704	8				1	
569	08/18/13	ML	R	SP	M	769	9		123.7	47.1	1	
570	08/18/13	ML	R	SP	F	884	8		447.7		1	4
571	08/18/13	ML	R	SP	F	747	5			69.7	1	
572	08/18/13	SC	R	H&L	F	831	9	6889		125.8	0	
573	08/18/13	SC	R	H&L	M	619	8	2381	41.3	20.0	1	
574	08/18/13	SC	R	H&L	F	843	7	6237	174.3	96.3	1	3
575	08/18/13	SC	R	H&L	F	855	7				0	
576	08/20/13	SC	R	H&L	F	875	8		287.4	103.0	1	3
577	08/24/13	MB		H&L	M	960	12	9200	117.4	104.8	1	
578	08/24/13	PSL	R	H&L	F	595	5	2268	27.8	24.6	0	1 or 6
579	08/24/13	SC	R	H&L	F	781		5557				
580	08/24/13	ML	R	SP	F			7144				
581	08/24/13	PSL		H&L	F			7286				
582	08/24/13	ML	R	SP	F			7598				
583	08/24/13	ML	R	SP	F			8533				
584	08/24/13	ML	R	SP	M			7201			1	
585	08/24/13	ML	R	SP	M			4139			1	
586	08/24/13	ML	R	H&L	F	893	8	8193	322.1	113.6	1	3
587	08/24/13	SC	R	H&L	F	907	8		551.8	139.5	1	4
588	08/24/13	SC	R	H&L	M	724	8		79.1	37.0	1	
589	08/25/13	MB	C	H&L	F	850	7	7399	201.3	138.2	1	3
590	08/25/13	SC	R	H&L	M	661	7		78.0	33.8	1	
591	08/25/13	MB		H&L	F	715	4	4111	32.3	68.5	0	2
592	08/25/13	ML	C	H&L	F			9299				

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
593	08/25/13	ML	C	H&L	F			11425				
594	08/25/13	ML		H&L	M			4366			1	
595	08/25/13	MB	C	H&L	F	820	7	7314	401.4	142.5	1	4
596	08/25/13	SC	R	H&L	F	895	8			124.1	1	
597	08/25/13	MT	C	H&L	F	872	9	7881			1	
598	08/25/13	MT	C	H&L	M	784	8	5216	110.1	45.9	1	
599	08/26/13	SC	R	H&L	F	818	8		166.4	44.6	1	4
600	08/26/13	SC	R	H&L	F	907	10		389.9	134.0	1	4
601	08/26/13	ML		H&L	F			5103				
602	08/26/13	ML	C	H&L	F			5500				
603	08/26/13	ML	C	H&L	F			9696				
604	08/26/13	ML	R	SP	F			10575				
605	08/26/13	ML	R	SP	F			11992				
606	08/26/13	ML	C	H&L	F							
607	08/26/13	ML	C	H&L	F							
608	08/26/13	ML	C	H&L	F							
609	08/26/13	ML	C	H&L	F							
610	08/26/13	ML	C	H&L	F							
611	08/26/13	ML	C	H&L	F							
612	08/26/13	ML		H&L	M			5075			1	
613	08/26/13	ML	R	SP	M			5245			1	
614	08/26/13	ML	C	H&L	M			7314			1	
615	08/26/13	ML	C	H&L	M						1	
616	08/26/13	ML	C	H&L	M						1	
617	08/26/13	ML	C	H&L	M						1	
618	08/26/13	ML	R	SP	F	914	8	8590	316.3	132.5	1	4

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
619	08/26/13	ML	R	SP	M	785	9	5415	117.1	44.6	1	
620	08/26/13	ML	R	SP	F	829	8	6691	200.6	96.9	1	4
621	08/26/13	ML	R	SP	F	909	9	8392	327.8	167.0	1	4
622	08/26/13	ML	R	SP	F	1001	7	11935	329.9	253.3	1	4
623	08/28/13	ML	R	H&L	M	736	8	4564	124.1	35.2	1	
624	08/28/13	ML	C	H&L	F			4649				
625	08/28/13	ML	R	H&L	F			5812				
626	08/28/13	ML	C	H&L	F			7144				
627	08/28/13	ML	C	H&L	F			7002				
628	08/28/13	ML	C	H&L	F			7740				
629	08/28/13	ML	C	H&L	F			7966				
630	08/28/13	ML	C	H&L	F			8165		123.6		
631	08/28/13	ML	C	H&L	F			9157				
632	08/28/13	ML	R	H&L	F			10433				
633	08/28/13	ML	C	H&L	F			10716				
634	08/28/13	ML	C	H&L	F			11935				
635	08/28/13	ML	R	H&L	F			16074			1	
636	08/28/13	ML	C	H&L	M			5472			1	
637	08/28/13	ML	R	H&L	M			10008			1	
638	08/28/13	SC	R	H&L	F	925	10		481.8	184.5	1	3
639	08/28/13	SC	R	H&L	F	883	8		149.0	104.7	0	5
640	08/28/13	ML	C	H&L	F	1046	19	15026			1	
641	08/28/13	ML	C	H&L	F	1026	10	12843	352.7	316.2	0	5
642	08/28/13	ML	C	H&L	M	810	9	6407	137.1	46.6	1	
643	08/28/13	ML	C	H&L	M	626	7	2977	101.7	29.9	1	
644	08/28/13	ML	C	H&L	F	888	7	8902	193.6	141.7	1	3

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
645	08/28/13	ML	C	H&L	M	630	6	2977	34.7	33.0	1	
646	08/28/13	ML	C	H&L	F	1064	13	14005	424.5	273.8	1	3
647	08/29/13	SC	R	H&L	M	629	8		78.6	21.7	1	
648	08/30/13	SC	R	H&L	F	982	9		457.9	148.2	1	4
649	08/30/13	SC	R	H&L	F	777	8		84.1	50.0	1	3
650	08/30/13	SC	R	H&L	F	874	9		299.5	133.6	1	4
651	08/30/13	SC	R	H&L	F	866	9		204.7	85.3	1	4
652	08/30/13	SC	R	H&L	F	895	7		232.1	99.5	1	3
653	08/31/13	ML	C	H&L	F			7144				
654	08/31/13	ML	C	H&L	F			7569			1	
655	08/31/13	ML		H&L	F			8051				
656	08/31/13	ML		H&L	F			15281				
657	08/31/13	ML	C	H&L	M			2495			1	
658	08/31/13	PSL	R	H&L	M	759	7	5131	25.6	53.1	1	
659	08/31/13	PSL	R	H&L	F	835	7	7088	62.6	91.7	0	2
660	08/31/13	SC	R	H&L	M	555	8	1814	31.3	18.3	0	
661	09/01/13	ML	R	H&L	M	714	14	4820	233.7	51.3	1	
662	09/01/13	SC		H&L	F	896	8	9327	368.8	164.2	1	3
663	09/01/13	ML	R	H&L	F	863	8		241.0	143.5	1	3
664	09/02/13	MB		H&L	F	725	7				1	
665	09/02/13	MB		H&L	F	790	8				0	2
666	09/02/13	SC	R	H&L	F	911	9		420.9	130.7	1	3
667	09/02/13	ML	R	H&L	F	890	9	8845	331.2	133.1	1	3
668	09/02/13	SC	C	H&L	F	933	8	8165	284.5	116.4	1	3
669	09/04/13	SC	R	H&L	M	715	9		33.2	31.3	1	
670	09/05/13	SC	C	H&L	M	577	7	2466	53.2	18.1	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
671	09/05/13	SC	C	H&L	F	700					1	
672	09/05/13	SC	C	H&L	F	732					1	
673	09/05/13	SC	C	H&L	F	751					1	
674	09/05/13	SC	C	H&L	F	755					1	
675	09/05/13	SC	C	H&L	F	770					1	
676	09/05/13	SC	C	H&L	F	779					1	
677	09/05/13	SC	C	H&L	F	788					1	
678	09/05/13	SC	C	H&L	F	790					1	
679	09/05/13	SC	C	H&L	F	793					1	
680	09/05/13	SC	C	H&L	F	805					1	
681	09/05/13	SC	C	H&L	F	827					1	
682	09/05/13	SC	C	H&L	F	831					1	
683	09/05/13	SC	C	H&L	F	836					1	
684	09/05/13	SC	C	H&L	F	853					1	
685	09/05/13	SC	C	H&L	F	873					1	
686	09/05/13	SC	C	H&L	F	895					1	
687	09/05/13	SC	C	H&L	F	919					1	
688	09/05/13	SC	C	H&L	F	930					1	
689	09/05/13	SC	C	H&L	F	930					1	
690	09/05/13	SC	C	H&L	F	1015					1	
691	09/05/13	SC	C	H&L	F	1023					1	
692	09/05/13	SC	C	H&L	M	575					1	
693	09/05/13	SC	C	H&L	M	758					1	
694	09/08/13	MB		H&L	M	808	9	6100	39.3	45.8	1	
695	09/08/13	ML	R	H&L	M	829	7		67.7	50.0	1	
696	09/15/13	MB	R	H&L	M	713	6	4281	23.7	59.9	1	

No.	Date	Site	Fishery	Gear Type	Sex	Length (mm)[1]	Age (yr)	Body Mass (g)	Gonad Mass (g)	Liver Mass (g)	Macro Mat	Micro Mat
697	09/19/13	SC	R	H&L	M	635	7		42.2	27.4	1	
698	09/30/13	SC	C	H&L	F	958	8	11198	162.6	155.3	0	2
699	09/30/13	MTB	C	H&L	F	757	8		73.8	66.8	0	5
700	09/30/13	SC	C	H&L	F	891	8	8193	122.0	125.4	0	5
701	09/30/13	MTB	C	H&L	F	788	9		125.9	71.0	0	3
702	09/30/13	MTB	C	H&L	F	891	8		125.8	142.8	0	2
703	10/18/13	MTB	C	H&L	F	868	7		77.9	74.4	0	2
704	11/25/13	SC	R	H&L	F	790	8	6435	184.0	87.6	1	3

[1] Post-fillet length (mm) reported.

APPENDIX II

Fecundity data associated with central California Halibut, 2012 and 2013. 'No.' corresponds to the same fish number in Appendix I. Spawning phase: EH = early hydration, LH = late hydration, AS = active spawning, ST = spent. HD = hydrated only egg mass, OW = ovarian wall. Missing values are a result of fish lacking loose hydrated oocytes (i.e., all hydrated oocytes were mixed throughout the ovary and encompassed in 'assorted' densities).

No.	Spawning Phase	Ovary Mass (g)	'HD' Mass (g)	OW Mass (g)	'Assorted' Mass (g)	'Assorted' Density (HD/g)	'HD' Density (HD/g)	'Assorted' No.	'HD' No.	Batch Fecundity
9	AS	192.2	11.7	26.1	154.4	79	2349	12202	27480	39681
18	EH	324.6		32.6	292.0	2225		649760		649760
27	AS	428.5		28.6	399.9	1379		551595		551595
31	LH	272.0		24.7	247.3	949		234621		234621
36	EH	342.2		34.9	307.3	304		93394		93394
40	LH	337.2		27.0	310.2	1671		518403		518403
77	LH	232.3		17.3	215.0	1808		388557		388557
112	AS	134.1	9.7	18.2	106.2	71	3775	7576	36618	44320
197	AS	178.1	29.1	16.0	133.0	296	4893	39323	142378	181700
209	LH	362.2	13.9	26.2	322.1	1393	3071	448737	42688	491426
226	AS	236.8	53.3	16.3	167.2	551	4551	92069	242590	334659
264	AS	334.0		22.6	311.4	1437		447353		447353
266	LH	410.2		42.8	367.4	588		216009		216009
270	LH	523.2	11.2	39.6	472.4	1491	2027	704340	22699	727039
306	LH	442.2		32.5	409.7	1425		584010		584010
308	LH	447.1		26.6	420.5	1719		722700		722700
325	AS	410.8	43.1	35.2	332.5	1130	3875	375700	166996	542696
334	EH	239.1		17.5	221.6	2064		457365		457365
342	LH	451.5	14.6	26.2	410.7	1611		661776		661776
373	AS	392.4	111.5	33.4	247.5	241	5156	59720	574945	634666
380	LH	505.0		23.7	481.3	3064		1474584		1474584

No.	Spawning Phase	Ovary Mass (g)	'HD' Mass (g)	OW Mass (g)	'Assorted' Mass (g)	'Assorted' Density (HD/g)	'HD' Density (HD/g)	'Assorted' No.	'HD' No.	Batch Fecundity
391	ST	323.5	82.4	30.1	211.0	99	5340	20949	439987	460935
394	LH	549.6	40.6	36.2	472.8	1726	2900	816162	117726	933888
401	AS	519.0	41.8	38.9	438.3	1648	4454	722397	186190	908587
455	AS	298.0	21.1	30.1	246.8	1063	4176	262261	88117	350377
458	LH	303.6		24.4	279.2	1247		348215		348215
464	EH	365.0	13.8	25.4	325.8	2058	3800	670349	52442	722791
466	LH	518.8	13.4	47.4	458.0	1766	3282	808864	43975	852838
467	LH	531.6		42.0	489.6	1256		615099		615099
481	EH	276.9		30.0	246.9	2378		586986		586986
489	LH	205.1		28.4	176.7	1124		198608		198608
495	AS	452.0	118.7	28.7	304.6	70	4168	21347	494757	516104
548	LH	444.9		43.6	401.3	1892		759241		759241
587	AS	517.7	39.3	42.0	436.4	420	3511	183277	138002	321279
595	AS	355.7	104.0	20.6	231.1	165	5611	38191	583566	621757
600	EH	329.6	85.7	43.5	200.4	203	5595	40593	479459	520052
605	AS	424.4	63.3	37.5	323.6	147	4377	47695	277061	324756
621	LH	294.0		33.7	260.3	1486		386761		386761
650	AS	287.0	67.4	36.3	183.3	542	5307	99267	357665	456932
651	AS	184.5	10.2	17.1	157.2	46	6329	7232	64556	71788