Assessment of the California Spiny Lobster (*Panulirus interruptus*)

by

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December 2011

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Executive Summary

This report describes the first iteration of what will be an ongoing stock assessment effort by the California Department of Fish and Game (Department), aimed at the California spiny lobster population off southern California and the commercial and recreational fisheries dependent upon it. Discussions setting the stage for this assessment began in 2008, increased in frequency and focus during 2009, and culminated in a December 2009 lobster data workshop soliciting models and datasets available for the Department's use. Formal work on the stock assessment began in January 2010.

From the outset, the assessment process was faced with a general lack of knowledge concerning spiny lobster life history parameters and limited data from which to evaluate the fisheries. A number of local fishery-independent studies, identified during the 2009 data workshop, were initially considered by the Department. These studies were primarily based on tag/recapture methodologies and, while generally not published on at the time, the related datasets were offered to the Department for this stock assessment. The studies however were not interrelated and there was not sufficient time in the assessment schedule to determine those relationships. Although it has always been the Department's intention to include regional differences, the Department hoped those regional differences would inform a bight-wide view of the stock and fisheries. Since the Department possessed bight-wide data, it was deemed more useful to base the initial assessment on this data instead of using localized data and trying to fill in the gaps between. The present assessment, however, will provide a baseline against which the localized studies can be evaluated and potentially the underlying trends that connect these studies together.

The Department possesses commercial logbook data dating back to 1973, and commercial landing data back to the late 1800s although the generally reported landing recorded starts in 1916. These data for the most part, however, do not exist in computerized form. In January 2010, only the most recent 10 to 12 years of logbook data had been computerized while landing receipts only extended back to the 1978-79 season with complete landing records existing only from the 1987-99 season forward - no fisher identifications or associated logbook numbers are included prior to the 87-88 season. From 1916 to the 1978-79 season, the total annual weight landed across the bight is the only computerized record; the individual landing receipts used to compute these values are lost. .

In early 2010, the Department embarked on an effort to computerize the entire record of logbooks and landing receipts. When funding ended in March 2011, most years of logbook data from the program's inception in 1973 through the present had been entered; only the early 1990s were incomplete. Landing receipts, unfortunately, are shredded by State mandate after 5 years and a similar data entry effort was not possible. During 2010, however, it was discovered that some of the landing receipt records had been stored on microfiche and were being slowly entered by personnel at the National Marine Fisheries Service in Santa Cruz, CA. Once these data were acquired, the Department had most of the daily landing receipt records back approximately through 1968. As data were entered, assessment tools that were previously unusable because of the lack of a sufficiently long time series became available. Where time allowed, these emerging techniques were investigated, otherwise they were set aside for future iterations of this assessment.

There is a single population of California spiny lobster in the Southern California Bight targeted by three separate fisheries: a commercial fishery, a hoop net-based recreational fishery, and a dive-based recreational fishery relying on hand catch. The recreational spiny lobster report card has suffered from low returns since its introduction in 2008 making it impossible to compare dive-based harvest levels to hoopnet harvest levels. Because of this, the harvests from each recreational fishery were combined into a single, combined recreational harvest that initial returns suggest is not insignificant compared to the commercial harvest. As an aside, combining recreational fisheries parallels the Department's management view which treats hoopnets and diving as two gear-types in a single recreational fishery. The historical recreational harvest was estimated from report card data for two seasons (2008-09 and 2009-10) and two Department recreational creel surveys performed in 1992 and 2007.

Overview of Modeling Efforts. A number of models were investigated as part of this stock assessment: Leslie Depletion Models (which do not directly provide management reference points), equilibrium forms of Fox and Shaeffer surplus production models (which are not appropriate for management), and the non-equilibrium surplus production model, ASPIC (Prager, 1994; Prager, 2004), which is part of the National Oceanic and Atmospheric Administration's (NOAA) Fisheries Tool Box. ASPIC ultimately failed to provide usable results and various alternate formulations were suggested. However, time limitations based on the original 12 month timeframe for this assessment effort did not allow for exploration of these alternates. Towards the end of the initial assessment effort, in December 2010, a copy of a age-structured, simulation model (FISMO) suitable for data poor situations was provided to the Department. Since this model provides a reference point ($\mathbf{F_{msy}}$) it was decided to investigate this model for the lobster stock assessment. FISMO was used recently to evaluate the sustainability of the Baja California spiny lobster fishery (Chavez and Gorostieta, 2010).

Leslie Depletion Model runs. Leslie Depletion Models rely on measurements of catch per unit effort (CPUE) accumulated over individual seasons. The models were written in-house and relied on Ricker (1975) for the specific algorithms. We used commercial catch data in pounds from landing receipts, and effort, the number of traps pulls, from commercial logbooks. At the time these models were run, complete seasons of logbook data had been entered only from the 1998-99 season to present. These seasons were divided into weekly sums of both catch and effort across the whole bight. No attempt was made to subdivide the Southern California Bight into geographical regions.

Stock-Production Model Incorporating Covariates (ASPIC). Given the lack of data concerning age or size structure for the spiny lobster population off California, the Department attempted to use surplus production models as the basis for this assessment. Initial efforts relied on the 10 years of data available to us as we developed non-equilibrium Fox and Schaefer models in anticipation of the additional data that was being entered. In discussion with others involved in assessment, however, it was decided to forgo custom development and use the ASPIC model (Prager, 1994; Prager, 2004) from the NOAA Fishery Toolbox instead. It was reasoned that the scientific community would be familiar with this model and its behavior.

ASPIC Fox model runs began around July 2010 using both commercial data and combined commercial plus estimated recreational data from 1965 to 2009. Approximately 80 cases were considered using catchability and initial population estimates from multiyear depletion model runs and estimating MSY and K. Unfortunately, ASPIC failed to converge on a non-trivial solution with this data. The ASPIC configurations using the Fox model were then re-run using a more generalized Pella-Tomlinson fit across the widest possible domain (essentially doing a grid search for a solution) and, again, the model failed to converge or find a non-trivial solution. It was agreed at this point that the landings/effort data did not work given the assumptions that ASPIC was operating under, and ASPIC was abandoned.

As part of the technical review of the completed stock assessment in August 2011 (Cope et al, 2011) one of the reviewers (Chen) applied our data to an independently developed surplus production

Fisheries Simulation Model (FISMO). FISMO (Chavez, 2005; Chavez and Gorostieta, 2010), is a age-structured model relying on Beverton-Holt invariants assuming von Bertalanffy growth (Beddington & Kirkwood, 2005; Beddington & Cooke, 1983; Jensen, 1996). The model requires at least 15 years of catch data (landing weights, maturity age, age at first capture (here assumed to be age at legal size), length/weight power relationship, and the relative independence between spawning stock and recruitment (Table 2). Von Bertalanffy growth parameters: $\mathbf{K}$, $\mathbf{t_0}$, and longevity are also needed. Initial estimates for the number of recruits and $\mathbf{F_{msy}}$ are specified but these values are replaced during the fitting process. FISMO also contains an economic component based on the number of fishermen and costs per boat-day, but this component was not vigorously explored for this assessment. The basic methods in FISMO are suited to data poor and emerging fisheries and are included in discussions of the United Nation Food and Agriculture Organization's (FAO) Fisheries Management Science Programme (Hoggarth et al. (Chapter 4), 2006).

Originally provided as an Excel spreadsheet, the model has been rewritten in Matlab (by Neilson), and expanded. Differences from the stock FISMO model include observed catch years expanded beyond 15, and higher resolution of $\mathbf{F}_{\mathbf{msy}}$ estimates. The Matlab version also provides the user with a streamlined method to test FISMO sensitivity to a range of parameter values along with interactions between varying parameters.

Modeling Results. The non-equilibrium, surplus production model, ASPIC, failed to converge or produce a non-trivial result using both fixed domain and unconstrained grid searches. Approximately 80 different scenarios were tried. Because of this, ASPIC modeling was abandoned.

Leslie Depletion Model results (catchability and fishable population size) suggested the harvest-over-time profiles are similar for all seasons since 2000 and independent of the ultimate harvest size. While recently the combined commercial and recreational harvest totals have diverged from the commercial-only harvest totals, the similarity between seasons suggest little has changed over the decade.

Of the eight scenarios run by FISMO, six produced **F**s in excess of the $\mathbf{F}_{\mathbf{msy}}$. Of these, the last two years of each run - the years most associated with increased recreational hoop netting - were in excess of $\mathbf{F}_{\mathbf{msy}}$ in all six instances. In the remaining two scenarios, both 35 year runs with a high Beverton-Holt recruitment coefficient, $\boldsymbol{\alpha}$, all fishing effort remained below $\mathbf{F}_{\mathbf{msy}}$. Despite fishing at or above the $\mathbf{F}_{\mathbf{msy}}$ in the most recent seasons, FISMO calculated stock biomass remained stable or slightly increasing in all but one scenario. In that scenario, however, any declining trend was minimal. No statistical tests were run to determine the slope of the trend.

Results from fishery-dependent data reviews. The following observations are based on fishing records from calendar year 2000 through 2010. The year 2000 was chosen as the start year because the commercial harvest was increasing from a low in 1976 to 2000 at which point the harvest stabilized at a relative high level of harvest. The observations are:

- The commercial fishery has consistently harvested 300+ tonnes each season.

- The catch over time each season has accumulated at the same rate. The highest total landings occur within the first week or two of the season, and 80 percent of the season total is landed before the end of January, and usually by the end of December.

- The size structure of the catch has not changed significantly. The majority of the harvest is first year recruits to the fishery. The commercial fishery targets this size lobster while the recreational harvest, which targets trophy animals, is constrained to this size probably by availability.

- Based on depletion model results, catchability has not varied significantly from season to season.

- The number of shorts released, as a percent of the total commercial catch, has not changed over the last decade. This statement is true whether considering the entire bight, individual counties, or offshore islands. The percentage is independent of the size of total catch. Bight-wide, 70 percent of the catch is short. Put into perspective, the 480,000 lobster landed in 2009-10 were 28 percent of the total 1.7 million lobster caught.

- The number of commercial operator permits have been declining and the number of active fishermen have also declined since a small jump in the early 2000s. If this trend continues fewer traps will be set in the future leading to reduced pressure on the resource. However, the commercial fishery is transitioning to transferable permits. These will make it easier for inactive permits to be purchased by new operators. Given the high cost of the permit, it would be expected that new permit holders would want to fish at maximum effort in order to recoup their costs. Transferability adds uncertainty to predictions of stability within the fishery.

- Some commercial fishermen have suggested that they are catching less with more effort. The data are mixed on this. CPUE, while currently lower than two or three decades ago, is still within a standard deviation of the average CPUE over the last decade. The CPUE is also higher in the last few years than earlier in the decade.

- Hoop nets have become popular in the recreational fishery since approximately 2005. By 2007, hoop nets accounted for 80 percent of the fished gear based on a bight-wide recreational creel survey. Over this short period of time, the more efficient conical net was also introduced and is becoming the net design of choice among recreational fishermen. Recent lobster report card results suggest that the recreational take adds an additional 44 to 61 percent to the commercial catch.

Conclusions. The spiny lobster population off southern California appears to be stable from both observations and modeled results, and the fisheries targeting this species can be considered, as of today, sustainable. However, the recent increase in the recreational fishery, most notably in hoop netting, contributed to modeled fishing efforts approaching or exceeding estimated $\mathbf{F_{msy}}$ levels. In all but one scenario, the level of effort did not result in a decline in biomass and in the remaining scenario it is questionable whether a decline was in fact occurring. The two scenarios that best supported the stable nature of the stock biomass, relative to the fishing effort, were also the scenarios that best fit an increase in biomass since 1976 that we assume is responsible for the increase in observed landings over the same time period. All the modeling scenarios reflected, as well, a stable estimated stock biomass since 2000. Over that period of time, the commercial landing records reflected a stable, 300+ t record of landing.

Corroboration of a stable fishery can also be found in observed data as well. Relative to the last ten years, the commercial fishery has been consistently harvesting 300+ tonnes each season and the catch each season has been accumulated at the same general rate as the season progresses. The highest total landings occur within the first week or two of the season and 80 percent of the season total is landed before the end of January and usually by the end of December. The average size of commercially caught lobster has been fairly consistent as well at 1.39 ± 0.1 lbs over the decade. Recreationally-caught lobster have also been relatively consistent in size, despite the fact that the recreational fishery targets trophy animals. Based on depletion model results, the catchability has not varied significantly regardless of the ultimate seasonal landing totals. The number of short lobster released as a percentage of the total caught has also remained consistent over the decade, regardless of the overall size of the seasonal harvest. The percentage of shorts is also consistent, whether we are examining individual counties or the entire bight. Retained lobster across the entire bight account for only 20-30 percent of the total lobster caught suggesting a very large, underlying population.

The number of operator permits has been declining despite a jump in the number of active permits in 2006. The number of traps deployed is expected to continue to decline, and the number of permit transfers in any given year (who may fish at higher effort levels) is not expected to be significant. Measured CPUE, while currently lower than two or three decades ago, is still within a standard deviation of the average CPUE over the last decade.

FISMO runs suggest that despite the apparent stability of the recent catch record, the fishery is approaching, or has reached the MSY. While this may mean that increased effort on the part of the fishermen will result in declining increases in catch, the overall stable state of so many population-specific parameters, and no immediate indication that anything is going to change, suggests the fishery is stable. The increasing FISMO biomass estimates over time also corroborated this conclusion. There is a confounding factor, however, and that is the recreational fishery.

The recreational fishery has changed dramatically since 2005 with the introduction and popularization of hoop nets. Preliminary data suggest that the recreational take is substantial, adding the equivalent of another 30 to 60 percent to the commercial harvest. However, because of the limited data, we can not tell if the recreational fishery is stabilizing or continuing to increase its harvest. If the recreational hoopnet fishery continues to increase in popularity and commercial landings remain at current levels, the probability that model runs will exceed the $\mathbf{F_{msy}}$ will increase. Since our report card data collection lags each season by approximately a year and we cannot detect changes in the recreational fishery within that timeframe, rates of change will take longer to quantify. Thus, we might not detect a problem with the recreational effort until commercial catch starts to decline. Future assessment efforts need to fully consider the uncertain state of the recreational effort when predicting the health of the fisheries.

Future Work. The following tasks have been identified as logical next steps and build on work already completed. These efforts were not possible for most of the previous year because of the lack of datasets which are now available on a bight-wide basis:

1. Revisit surplus production models but allow for explicit differentiation of the effects of production, recruitment, and yield. Because of time and the 'black box' nature of ASPIC it was not possible to effectively diagnose why our dataset failed to work with the model.

2. Continue to add to the existing electronic logbook datasets, in particular completing the entry of data from the 1990s. (see Table 3)

3. Develop methodologies to use the CalCOFI phyllosoma data (Koslow et al., 2010) as part of future stock assessments. This data shows promise as an index of abundance of the spawning stock and correlates with the commercial landing record. This data was introduced in December 2010, too late for use in this assessment.

4. Continue to develop FISMO. Immediate changes would include differentiating between male and female growth rates; explicitly splitting harvest between the commercial, diving, and hoop net fisheries; and exploring the effects of other formulations of the Beverton-Holt Stock/Recruitment relationship.

5. Create a Bayesian version of the Leslie Depletion Model allowing catchability to be represented as a probability density function. This was suggested early on in the assessment process and provides a method to estimate the likely value of catchability.

6. Develop a Bayesian formulation along the lines of the Kinlan/McArdle model that can be run, and re-run, in realistic timeframes (using wall clock time). The current version, as provided by Kinlan/McArdle, took too long to run to be viable for the current effort given the amount of time given to finish the effort. This, overall, is considered a long-term goal on the scale of years to complete.

Introduction

This assessment involved two main tasks that were limited by a Department timeline for completion of this effort. First, data sources were identified and evaluated for use. After a brief review, no Southern California bight-wide fishery independent datasets were identified targeting California spiny lobster north of the Mexican border. There are some highly detailed datasets which were made available for our use, both inside and outside the Department, but these were rejected because of their localized nature. The bight-wide, fishery dependent datasets possessed by the Department were considered our best chance at creating an assessment of the entire California lobster population and that would provide a framework of comparison, in the future, for the more localized datasets. However, the Department data mostly existed as paper hardcopies with only the most recent seasons available in electronic format. To rectify this, the Department digitized over 20 years of commercial logbook information as well as the newly introduced recreational lobster report cards. This work occurred in parallel with the formal stock assessment effort. However, datasets of sufficient length and coverage for some approaches were not available until well into the second half of the project. In the case of the recreational catch record, approximately 20 years of harvest were estimated from a single creel survey in 1992, a 2007 creel survey and the initial return of calendar year 2009 lobster report cards.

The second assessment task was to develop models and approaches that could provide reference points for the FMP effort. Initially we developed depletion model formulations based on commercial landings and logbooks from 1998 to 2008 which were the only years with daily records available to us. For reference points, however, we settled on surplus production models which appeared to be the most advanced formulations that did not require size or age structure and could provide a reference point for management. Preliminary steps had been taken to develop a size structure for our stock based on collated logbook and landing receipt data. Logbooks supplied the number of lobster captured in a trap and landing receipts provided the total weight of that trap. Time and the availability of surplus production models, which do not rely on size or age data, delayed the use of any modeled age or size structure data until we acquired the FISMO age-structured recruitment model. Ultimately, both surplus production models, the self-written and the NOAA fishery toolbox version, ASPIC, failed with the dataset available. Follow-up steps are outlined that could resolve the problems encountered in future efforts. In December 2010 we received a copy of the Excel spreadsheet implementation of FISMO which could provide F_{msy}. Given this, and the fact that the lobster fishery management plan (FMP) start date was delayed until later in 2011, additional time was available to explore the new model.

Stock Structure

Little is known about the structure of the California spiny lobster population off California. The Department has proposed the creation of an at-sea sampling program patterned after the voluntary logbook program in New Zealand, but has had little success in implementing it. Not many fishermen were interested and the few that were had issues with the amount of work involved as initially designed. Additionally, some fishermen working solo and close to shore had understandable safety concerns about shifting their attention from their surroundings to measuring and recording information. There are smaller, localized efforts aimed at the same goal as proposed by the Department and discussions with the fishermen have resulted in compromise protocols that will satisfy the statistical needs of the Department as well as the operational and safety issues of the fishermen. The Department will continue pursuing the development of this program since it provides the best chance at determining the underlying size and sex structure of the population.

Life History

Distribution. The California spiny lobster is endemic to the west coast of North America from Monterey, California southward at least as far as Magdelena Bay, Baja California (Wilson, 1948; Schmitt, 1921) (Figure 1), with a small isolated population in the northwestern corner of the Gulf of California (Kerstitch, 1989). Johnson and Snook (1927) reported its occurrence as far south as Manzanillo, Mexico. Sub-adults and adults commonly are found at depths ranging from intertidal to 64 m, while the planktonic larvae have been found offshore as far as 530 km and at depths to 137 m. (California Department of Fish and Game, 2001).

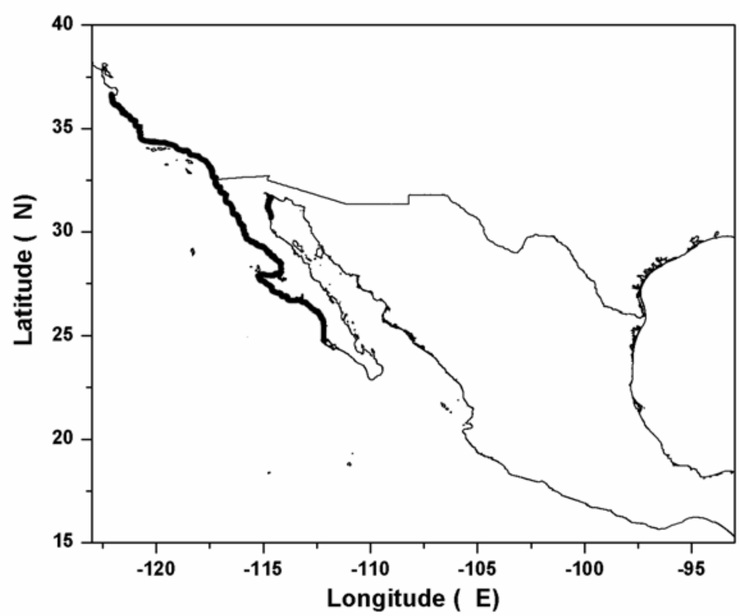

Figure 1. Primary distribution range of the California Spiny Lobster extending from Monterey, California in the north to Magdalena Bay, Baja California with a small population occurring in the northwest portion of the Sea of Cortez. Lobster are considered rare north of Pt. Conception. The center of the population, and the point with the highest concentration of individuals falls in Baja California.

Species Associations. Spiny lobster are found in rocky areas often with plant communities dominated by giant kelp (*Macrocystis* sp.), feather boa kelp (*Egregia* sp.), coralline algae (*Corallina* sp.), and surf grass (*Phyllospadix* sp.) (Lindbergh, 1955).

They are also associated with eel grass (*Zostera* sp.) which flourishes in sandy areas (California Department of Fish and Game, 2001). Spiny lobster are a major predator of benthic invertebrates and act as a keystone species preying on mussels along rocky shores (Robles et al., 1990) and on sea urchins in kelp forests (Tegner and Levin, 1983; Lafferty, 2004). Primary predators on lobster include sheephead (*Semicossyphus pulcher*) and black sea bass (*Stereolepis gigas*) (Loflen, 2007).

Spawning and Early Life History. Spawning occurs once per year during the late spring through summer months (Johnson, 1960). Male lobster place a gummy spermatophore on the underside of the female's carapace, termed plastering. The female produces 50,000 to 800,000 eggs (Allen, 1916; Lindbergh, 1955; Johnson, 1960) which are kept between the underside of her tail and her pleopods. The eggs are fertilized when the female breaks open the attached spermatophore. The eggs are carried on the pleopods under her tail until they hatch.

Upon hatching, the larval lobster (phyllosoma) spends approximately 10 months in the plankton (Mai & Hovel, 2007; Mitchell 1971). The final planktonic stage (puerulus) is the first to resemble an adult lobster, and settles into shallow, vegetated habitats such as eelgrass or surfgrass beds (Mai & Hovel, 2007). Assuming conditions are conducive, the puerulus begins a benthic existence that will last the rest of the lobster's life.

Engel (1979) summarized numerous studies that have published growth information on the California spiny lobster but found little agreement except that the spiny lobster molts once per year once it attains legal size. The age at sexual maturity ranged 3 to 9 years with most suggesting around 5 years. Males matured faster than females. The legal size (82.5 mm CL) was reached when the lobster was from 7 to 13 years old. Again, the male grew faster than the female. For their assessment of the Baja population, Chavez and Gorostieta (2010) used 5 years for the age at sexual maturity.

Fisheries History

South of Point Conception, California there are active commercial fisheries for both the American and Mexican portions of the stock, each managed and fished separately by

California and Mexico. The California recreational fisheries, one dive-based and the other hoopnet-based, target lobster north of the U.S.-Mexican border; Mexico prohibits the recreational harvest of lobster south of the border. The seasons for all three California fisheries coincide, so catch information can be combined into a single estimate of fishing pressure.

Commercial Fishery. The California spiny lobster has been the target of a commercial fishery since at least the first shipment of lobsters from Santa Barbara to San Francisco in 1872 (Odemar et al., 1975). It has also been a fishery dependent on the availability of new areas to fish as market demand increased beyond what the catch could provide (Odemar et al., 1975). By 1894, local ordinances establishing fishing seasons had been enacted in all counties south of Point Conception except Orange County. The State implemented a closed season in 1901 which continues more or less to this day.

In the early 1900s, new fishing grounds were needed but established fisheries had spread along the entire coastline. In response, the California fishery expanded into Mexico and by 1916 had a fully functioning Baja fishery. The State began systematically collecting landing data (Figure 2) in 1916 the same year that the Mexican government opened an office in San Diego to collect fees to fish along Baja. In 1917, they opened a similar office in San Pedro. Between 1916 and 1952, the market for spiny lobster became more and more dependent on the Baja fishery which landed 2 to 3 times the weight of lobster as fishermen working solely in California waters. Both World Wars are apparent in the landings record as deep valleys caused by the decline in fishing effort and demand during the war years. In 1952 the Mexican Government closed Baja

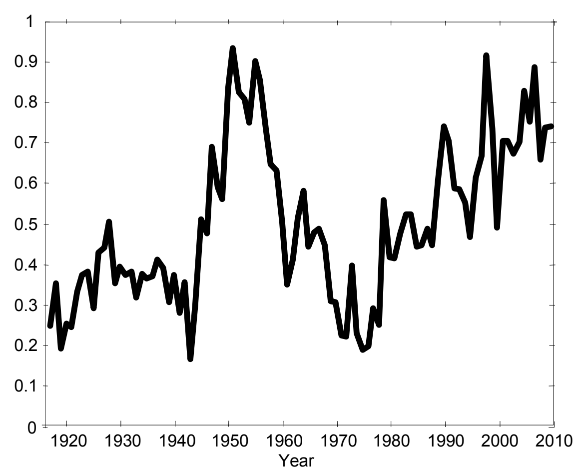

Figure 2. Commercial landings (millions of pounds) of California Spiny Lobster from 1916 to present. This plot reflects only lobster of American-origin and does not include landings from the Baja fishery active from 1916 through 1952.

California to foreign fisherman. This closure coincided with the beginning of a steep decline in the California lobster landings that would continue to the mid-1970s. Lobster that were caught in Baja were never counted in the total landings for California. Thus, their loss did not contribute directly to the decline, although California fishermen operating south of the border probably added to the total effort north of the border following the closure.

Starting in the 1930s there was recognition within the Department that commercial landings contained a large number of undersized lobster although this was not addressed for another 20 years. In 1957, the State Legislature enacted regulations that required spacing between trap mesh that would allow undersized lobster to escape. In 1965, the state began requiring lobster permits to fish commercially for lobster. During the 1973-74 season, logbooks were required for the first time and began providing information on catch location, the numbers of legal lobster retained, and shorts (sublegal lobster) released. Also in the early 1970s, the Department once again recognized that the commercial landings contained large numbers of shorts, and that the number of shorts probably exceeded that of legal lobster, despite the mesh size regulations enacted in 1957. To address this, in 1976, escape ports were first required on all commercial traps. The escape port requirement represents the last regulation enacted aimed at gear, season, or size limits; although regulations concerning catch records and how operator permits could be acquired or exchanged have subsequently been enacted. Figure 3 summarizes the timing of various types of regulatory changes over the years.

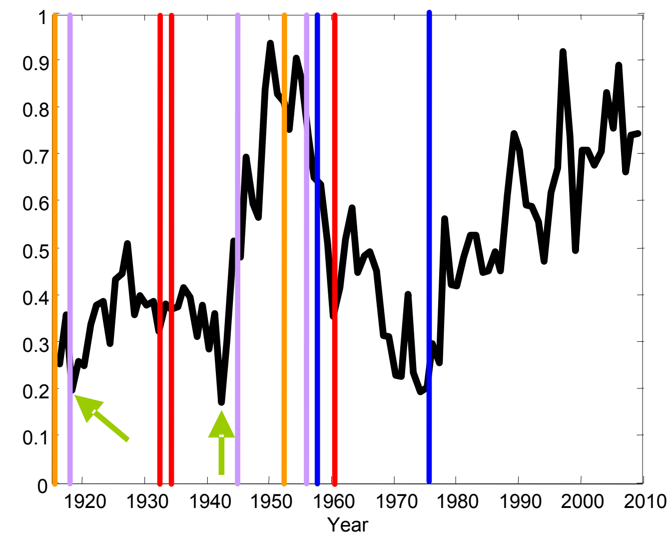

Figure 3. Commercial landings (millions of pounds) of California Spiny Lobster from 1916 to present. Vertical lines represent points at which changes occurred to the fishery and include gear (blue lines), size limit (purple lines), season (red lines) , and war-time reductions (green arrows). Between 1916 and 1952 (orange lines) the fishery operated in Baja as well as north of the Mexican Border. The landings of Baja-originated lobsters are not represented in this graph and equaled approximately twice the total poundage of California-originated lobster landed over the same period of time.

In 1976 the decline in landings that started in the early 1950s ended at approximately 90 t and then began a steady increase until 2000. Since 2000, landings have consistently been in excess of 300 t (Figure 4).

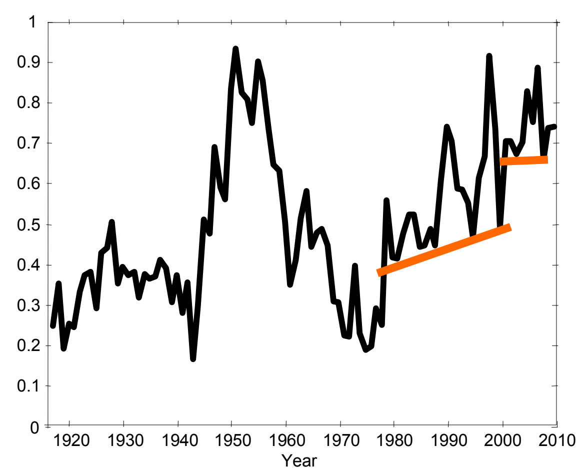

Figure 4. Commercial landings (millions of pounds) of California Spiny Lobster from 1916 to present. The plot does not include landings of Baja-originate lobster (1916 through 1952). Orange lines represent recent trends. The first marks a period of increasing catch beginning in 1976 (the same year that escape ports were mandated). The second reflects a period of

	300+ tonne landings beginning in 2000.

The number of lobster permits available have been steadily declining since 1998 (Figure 5) and the decline will continue as prescribed by statute. Also, a moratorium on new permits was implemented in 1995 in preparation for a transition to a limited entry fishery. A jump in permit holders in 1994 followed the announcement of this moratorium and the decline the following season reflects the number of permits that were not subsequently renewed. In 1996, the limited entry program was initiated with 298 operator permits issued. Despite the decline in available permits, the number of active fishermen has rebounded since 2005 and is currently approximately 155 (Figure 6). Previously non-transferable, two thirds of the lobster permits are now transferable without restriction. The jump in 2006 landings may be the results of new permit owners who, after purchasing previously dormant permits (transferring), are actively recouping their investment in a permit.

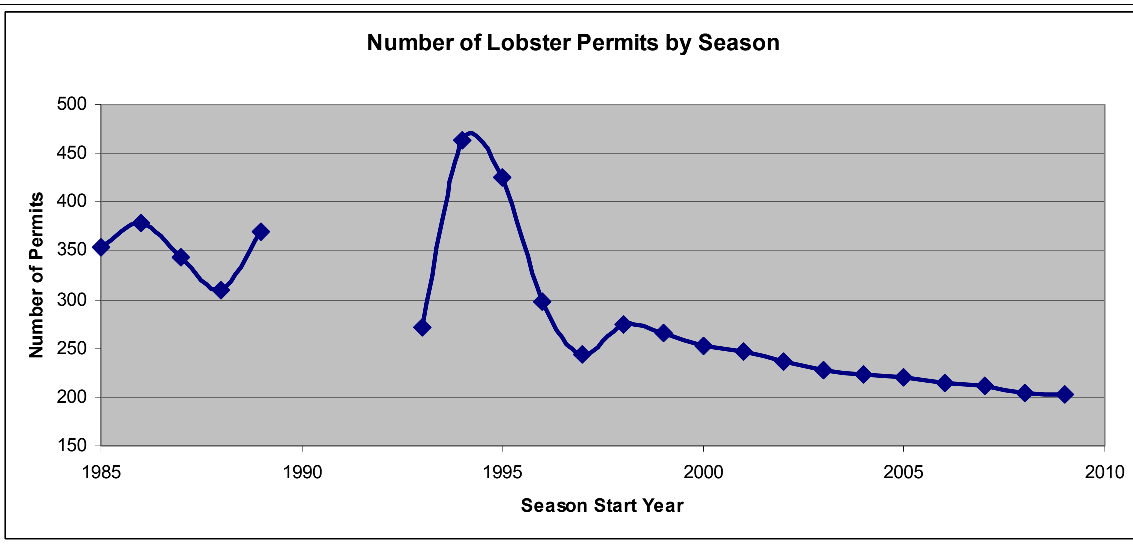

Figure 5. Total number of available operator permits by season from 2005-06 through 2008-09. There has been a steady decline in the number of permits since the 1998-99 season. Seasons without available operator permit totals are left blank.

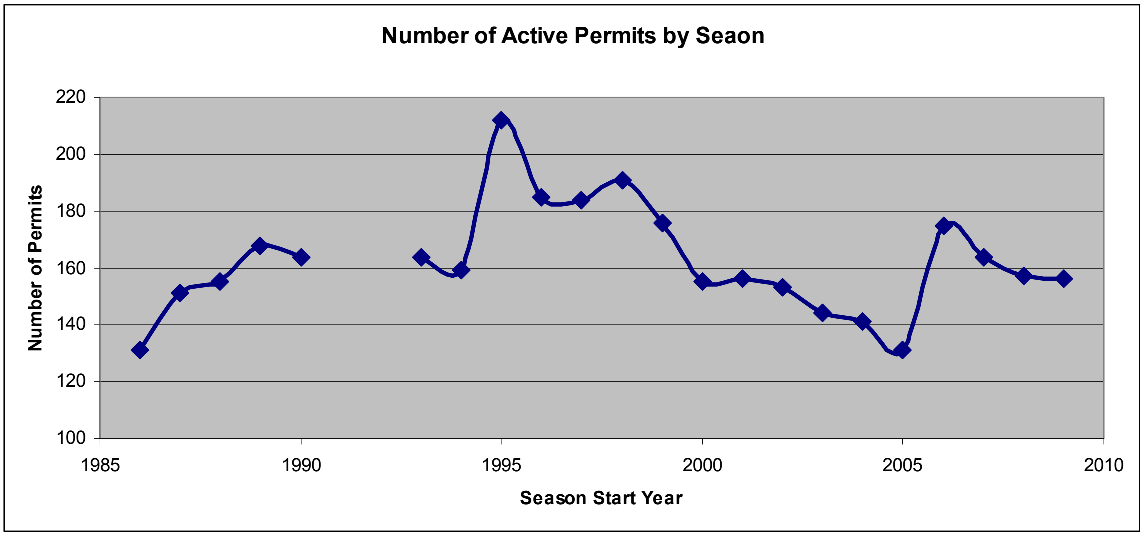

Figure 6. The number of operator permit holders that actually fished for lobster each season between the 1986-87 and 2009-10 seasons. Missing data are represented by spaces in the line. The jump between 2005-06 and 2006-07 is thought to reflect new permit holders (permit transfers) that are acting on their investment.

The entire commercial landings record from 1916 on appears to respond to climatic events leading to in-water changes. Warm and cold water regimes driven by the Pacific Decadal Oscillation (PDO), an atmospheric pattern of high and low pressure oscillations over the eastern and western halves of the North Pacific Ocean, appear correlated to trends in the landing record. Increasing landings tended to occur during warm water periods while declining or sustained landings have occurred during periods of colder water (Figure 7). On sub-decadal scales the pattern is more variable. Comparing landings to the El Niño/Southern Oscillation (ENSO) index, a combined atmospheric and in-water index that varies on a timescale of approximately 4-6 years, landings have varied directly with the index since the mid-1990s (Figure 8). Prior to that the record is not as clear. We did not pursue these climate signals as possible indices for landings but leave that to future incarnations of this assessment.

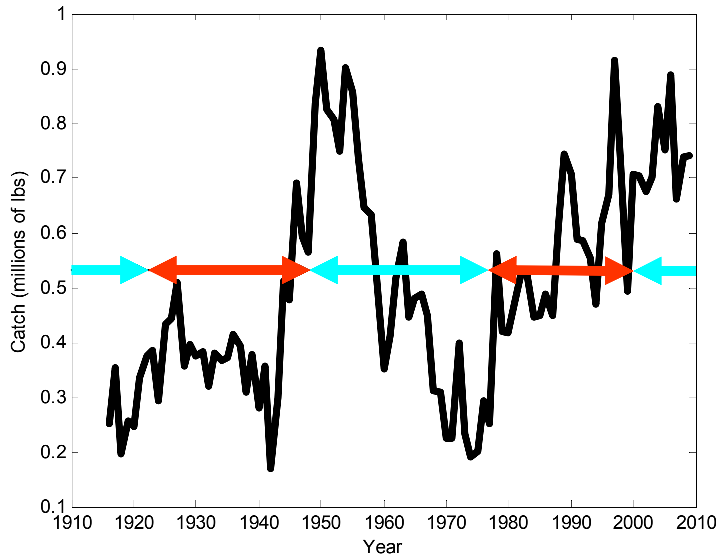

Figure 7. Hot and cold water regimes associated with the Pacific Decadal Oscillation (PDO) superimposed on California spiny lobster landings from 1916 to the present.

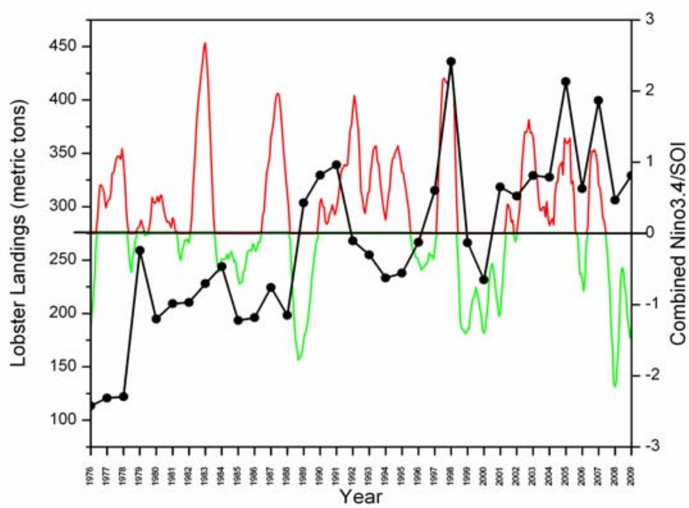

Figure 8. El Niño/Southern Oscillation (ENSO) index (red/green) with superimposed California spiny lobster landings from 1976 to present. Positive indices (red) roughly equate to periods of El Niño while negative indices (green) equate to La Niña.

Recreational Fishery (combined hoop netting and diving). The recreational fishery has been regulated for decades through a seasonal closure and bag limits. Hoop nets were first allowed in 1955. Effort and landings data, however, were not systematically collected until the fall of 2008 season with the introduction of the Recreational Spiny Lobster Report Card.

During the years prior, any changes in catch or effort are impossible to track. This inability is particularly significant because of gear changes that occurred in the fishery. Between 1992 and 2007, an apparent shift (Figure 9) from what was predominately hand collection by divers to hoop net collection has occurred; based on two recreational creel surveys conducted by the Department (Harris et al. 1995; Neilson & Buck, 2008). The abrupt shift appears to have occurred in 2005 (Jim Salazar, pers comm., on Promar hoop net sales) and implies an increase in the number of people fishing for lobster. How much of an increase is not quantifiable. Also, since report card analysis begins a little over a year after the end of any given year, the Department currently has little data to determine whether the recreational trend in catch and effort has stabilized or continues to increase.

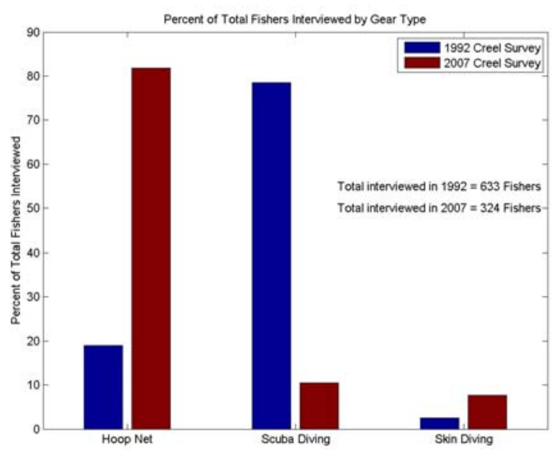

Figure 9. Proportion of recreational fishermen employing hoop nets or diving for lobster during the 1992-93 season (blue bars) and the 2007-08 season (red bars). These results are based on creel survey interviews taken at Dana Landing Launch Ramp, Shelter Island Launch Ramp, and Channel Islands Harbor Launch Ramp which were the three sites common to both the 1992-93 and 2007-08 seasonal creel surveys.

Another factor affecting the recreational fishery is the continuing evolution of hoop net design. A regulatory definition of what constitutes a hoop net has only been in place for a few months (since late 2010). One of the designs that appeared prior to that, and is now codified in the regulation, is the conical hoop net. This design sells very well in local bait shops and has led to an increase in catch efficiency by requiring less skill on the fisherman's part. A study conducted by the Department (Neilson et al., 2008) documented a 57 percent increase in catch numbers with the conical net relative to the traditional, flat hoop nets. Flat hoop nets, as of the 2008-09 season, are still the most popular design generally. However, indications are that conical nets will eventually replace flat nets as the hoop net of choice.

Assessment Data Sources

In December 2009, the Department hosted a workshop to discuss data sources available to the Department for a lobster stock assessment. At that time, numerous academic studies had been completed or were currently underway aimed at localized lobster populations. These populations included those around La Jolla Ecological Reserve, Point Loma Kelp, and San Diego Bay; portions of Catalina Island; Santa Barbara/Ventura coastal; and the Northern Channel Islands. The Santa Barbara/Ventura studies were primarily fishery dependent, while the island and San Diego studies were based on tag/recapture methodologies. No bight-wide datasets were available, however.

Besides summarized time series of commercial lobster catch maintained by NMFS or FAO, the only bight-wide series of both catch and effort is maintained by the Department and includes both landings and logbook data dating back to 1916 and 1973, respectively. Rather than creating an assessment based on smaller studies that together would not fully describe the bight, the Department embarked on an assessment effort utilizing its in-house bight-wide data.

Commercial Landing Receipts. The Department has data for individual landing receipts back through the 1978-79 fishing season and annual totals dating back to the late 1800s. These data are the source for the 100 year commercial landings time series that is commonly reported (Figure 2); Barsky (2001) and California Department of Fish and Game (2008). The information varies by year, but generally includes the port of landing, fish business purchasing the catch, fisherman identification, pounds landed, and the DFG block where the catch originated. No effort information is contained in this dataset, however. Seasons prior to the 1987-88 season have no fisherman identifications or logbook serial numbers with which to calculate associated effort levels. Individual landings between the 1969-70 and 1978-79 season are contained in an associated dataset (see CalCOM description below), and only seasonal or annual totals exist prior to 1969-70. Landing weights are also recorded on one-day commercial logbooks dating from 1973 through their phase-out in the early 2000s.

Landing receipt data used in this assessment were extracted from the Department's Commercial Fisheries Information System (CFIS) and maintained at the Department's San Diego office. Obvious corrections to the data were made where possible, but more involved error checks were not attempted. Landing data based on one-day commercial logbooks were entered and subjected to fairly rigorous error checking, and are maintained at the Department's San Diego office as well.

Trends and patterns. As stated previously, since 1976, the landing weights have gone through two trends (Figure 4). The first trend, beginning in 1976 and lasting until 1999, is marked by a variable but increasing weight in landings up to approximately 300 tonnes. The second trend, ongoing since the 2000-01 season, is characterized by commercial landings consistently above 300 tonnes per season. These two trends are not associated with changes in effort, size of the fishing grounds (essentially the coastal and offshore island regions of the entire bight), or changes in gear. They have also occurred since the last change in the regulations that may have affected the level of catch (Figure 3) with the exception of requiring escape ports enacted in 1976.

The Department divides landings geographically into the individual counties where the catch was landed and three port complexes created by combining Santa Barbara and Ventura counties, Los Angeles and Orange counties, and San Diego alone. By county, Santa Barbara and San Diego dominate the landings with 30 and 33 percent of the total landings averaged over 11 years. The next closest are Los Angeles (16 percent) and Orange (15 percent) with Ventura accounting for only 6 percent. The percentages have remained relatively consistent over the years within each county as well, with no indication of a localized collapse (or bonanza). The catch is split evenly between port complexes. The rate at which lobster are caught also differs between the counties with Santa Barbara maintaining a relatively constant landing rate, while the other counties tend to catch the majority of their lobsters at the beginning of the season as described above. Interestingly, a single DFG block, 860, in San Diego accounts for the majority of San Diego County's catch and 20 percent of the total southern California commercial take. This has been the case for decades and was noted by Odemar et al. (1975). The recreational catch is also very high in block 860 relative to the rest of the southern California Bight.

CalCOM Landings Data. The CalCOM dataset contains Department landing receipt records dating back to 1969. The coverage is spotty in terms of what has been entered and the completeness of seasons, but this dataset represents the only existing record of individual landings prior to the 1978-79 season. The dataset is stored at the National Marine Fisheries Service office in Santa Cruz on microfiche, and is being digitized through yearly contracts. These data contain the same general information as the CFIS-maintained landing records and was used primarily in surplus production model runs which require longer time series than the Department possessed.

Commercial Logbooks. The collection of commercial catch information in the form of logbooks was instituted in time for the 1973-74 fishing season. Logbooks record the daily catch: the number of sublegal lobster released, legals retained, the number of traps pulled, and their soak time. In addition, the pull date, DFG catch block, and closest landmark are also recorded. DFG catch blocks are 10 nm (10 minutes) square and any spatial dependencies in the assessment are at that resolution. Currently, logbooks allow up to three separate trips to be recorded on a single logbook sheet. Prior to the mid-1990s, logbooks recorded a single trip's data and also recorded the weight landed for that trip. Landing weights are no longer recorded on the logbooks, as landing weights are recorded on the landing receipt and the receipt's serial number is recorded on the logbook page.

At the beginning of this assessment effort, only the seasons from 1998-99 through 2008-09 were available as full datasets (Table 3) ready for final editing and quality check. Only since the 2005-06 season has landmark information been entered, and only since 2007-08 has the full landmark name as entered on logbooks been transcribed into CFIS databases. These databases were extracted from CFIS, quality checked, and then maintained, and used for the assessment, as Excel files in San Diego.

Logbook data for the 1989-90 through 1997-98 seasons were thought to have been previously entered; but subsequent examination revealed these seasons to be much smaller in size than post-1998-99 seasons. This suggests these data were entered before the season was over or all logbooks had been turned in. In addition, a number of datasets in this timeframe record only catch data and do not include landmarks or fishermen identifications. Editing or quality checking of the data is impossible in these cases but the patterns in the data compare well with complete seasons over the same seasonal timeframe. Statistical outliers and other 'bad' data points that could be identified by software were removed prior to use. These seasons are scheduled to be re-entered from the original logbooks. Also, seasons 1989-90 through 1996-97 were entered into a database by the Department's Marine Fisheries Statistical Unit (MFSU), but not into CFIS or its precursors. The data, in their original computer formats as dBASE IV files, needed to be converted to Excel before they could be used. Paper copies of the logbook data for the winter portion of the 1992-93 season and about half of the 1979-80 are missing and presumed lost. Finally, there are some anomalies with the 2002-03 logbook data currently found on CFIS. While there is no indication these anomalies are errors, 2002-03 will also be reentered from the original logs at some point in the future; as record by record comparison of what is entered would be prohibitive. Until it has been entered, 2002-03 is being used as is.

Trends and Patterns. Logbooks consistently show high catch rates within the first week or two of the season followed by a rapid decrease in catches with a pattern of random catches emerging as the season progresses (Figure 10).

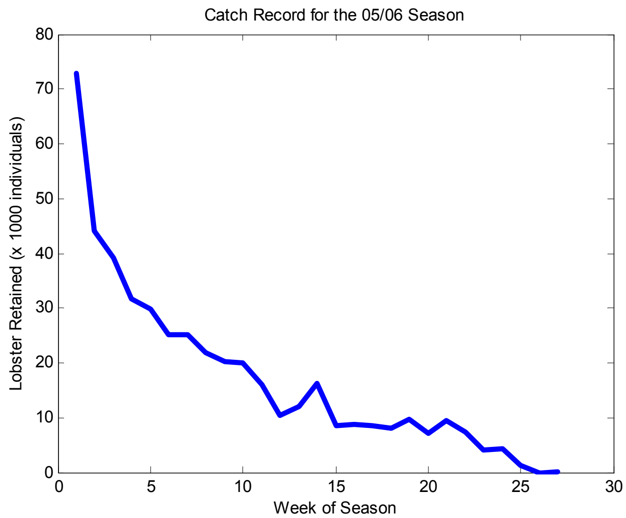

Figure 10. Commercial Catch by week for the 2005-06 season in number of lobster. The decline in catch is similar to the recreational decline in catch (without weekend peaks). The decline mirrors the decline in commercial CPUE over time suggesting a relationship primarily to lobster availability and not to increased fishing effort.

Although there is occasionally an increase in catch around the January timeframe, generally all seasons exhibit a random peak/valley pattern around some low value of catch from January to the end of the season. Eighty percent of the season's catch is landed within the first 12 to 15 weeks of the 26 week season. This pattern exists regardless of whether the season is ultimately a large or small harvest season, a distinction less relevant because of the last 10 years of consistently large harvests. This pattern is also found in the time series of landings.

Over the last 10 years, the number of shorts as a percentage of total catch generally exceeds 50 percent in all regions/counties except the northern Channel Islands (Table 1) which averages 30 percent. For the bight as a whole, shorts comprise 70 percent of the total catch. Also, over the last 10 years the number of shorts in each region has remained relatively constant without any apparent trend. As such, the implication is that variations in the number of individuals caught or thrown back reflect the size of the population in any given season, and not a change in the catch success. As an example of the potential number of animals available, in 2009-10 approximately 480,000 lobster were landed across the bight, which represents 28 percent of the total 1.7 million lobster caught.

Table 1. Percent number of shorts released by location and season from logbook data. Total catch was calculated by adding the numbers of legals retained to the number of shorts reported for each region. Total bight

percentages sum across the entire southern California Bight.

Season	Total Bight	North Channel Islands	South Channel Islands	Santa Barbara County	Ventura County	Los Angeles County	Orange County	San Diego County
2000-01	68.80	40.45	61.02	57.67	49.39	55.97	71.15	77.55
2001-02	68.72	32.13	63.09	54.92	44.15	54.52	71.34	80.11
2002-03	70.35	33.71	66.49	55.28	50.49	55.53	74.59	83.43
2003-04	70.69	27.86	59.60	52.00	38.27	55.12	70.10	83.83
2004-05	65.92	25.17	56.87	48.97	39.72	46.31	66.96	78.27
2005-06	69.79	26.85	64.46	52.39	48.24	53.23	69.27	81.20
2006-07	69.59	27.48	63.60	57.85	25.57	54.23	70.49	78.62
2007-08	73.56	33.46	65.32	62.91	45.98	56.84	74.33	84.47
2008-09	74.10	29.41	69.93	57.14	52.97	58.21	76.03	84.06
2009-10	72.44	27.85	66.86	54.80	53.07	62.11	76.47	83.11

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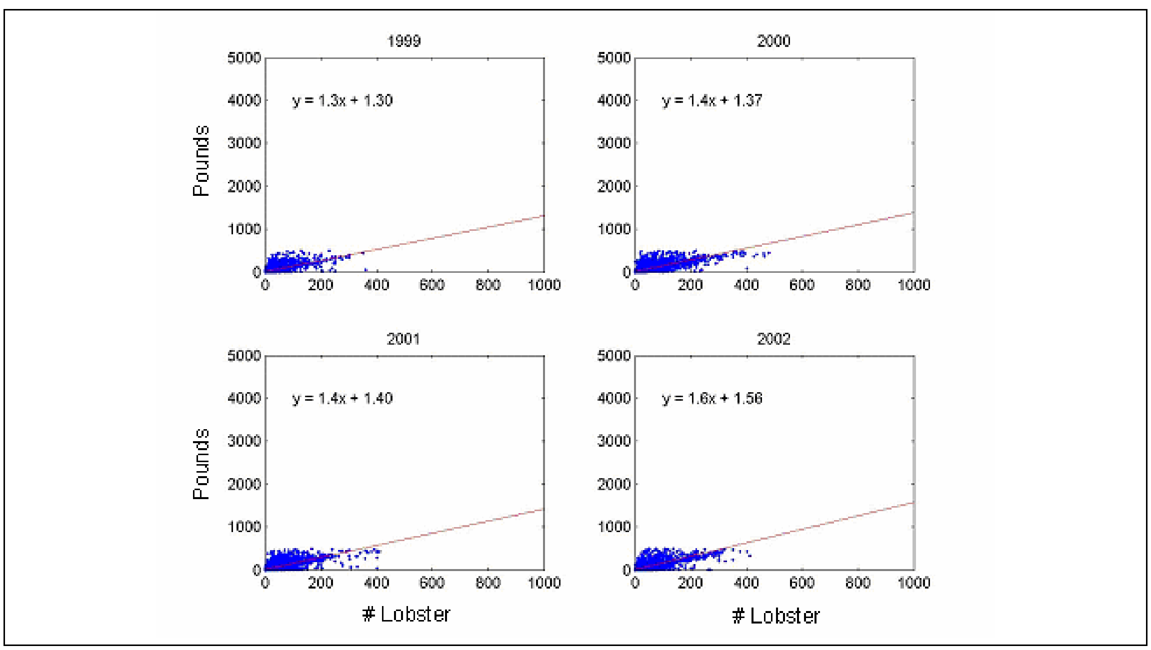
Collated Logbook/Landings Data. We attempted to associate individual landing receipt data with corresponding logbook data back through 1999, as this was the timeframe over which we had complete individual logbook and landing receipt data in digital form. These associations have been less than perfect even when weights were recorded directly on the logbooks. In many cases, landings occurred after multiple trips, and weights were not distributed across the numbers of lobster for each trip; or a landing from a multiday trip was recorded on the last day's logbook but not the rest. Also, weights for personal use, private sales, and receivered lobsters were not always recorded.

Initial attempts involved manually going through the datasets, but took approximately 1.5 man-months per collated season. Although this method was able to associate more landing receipts and logbooks, the amount of time required was prohibitive. As a result, a MATLAB program was created that could identify associated records automatically without human interaction.

To achieve an automated process, the program only correlated single logs that indicated a single landing receipt. Attempts to automatically identify and parcel out weights from multiple landing receipts or, going the other direction, to multiple logbooks did not lead to increased accuracy and the time spent developing the algorithm was again prohibitive. Logbook trips without an associated landing receipt number were excluded although an individual might be able to make an association based on time, location, or other factors. The automated program connected about 60 percent of the documented trap pulls with an associated weight. We were able to produce some useful results but the time required to proof the resulting data for errors was deemed too costly to extend the technique to new seasons. Further work on these associations was put aside until after the initial assessment effort.

Trends and Patterns. Over the 10 seasons from 1998 through 2008 there has generally been a consistency in the weight of lobster caught commercially off California. Weights varied from 1.3 pounds to 1.6 pounds per lobster (based on the slope of the functional regression lines plotted on Figure 11) with an average of 1.39 ± 0.1 pounds per lobster; eight of the ten years had weights of 1.3 or 1.4 pounds per lobster. Based on the Department's 2007 recreational creel survey's length/weight formulation (Figure 19), the weight of a just legal size lobster is approximately 1.3 pounds (0.596 kg on the plot), so the average lobster size caught commercially over the last 10 years has been around the legal size; and the maximum calculated weight (1.6 pound per lobster) would be within ¼ inch of legal size. This result is not unexpected since the commercial fishery targets a consistent-size animal for sale to markets concerned with plate-sized portions.



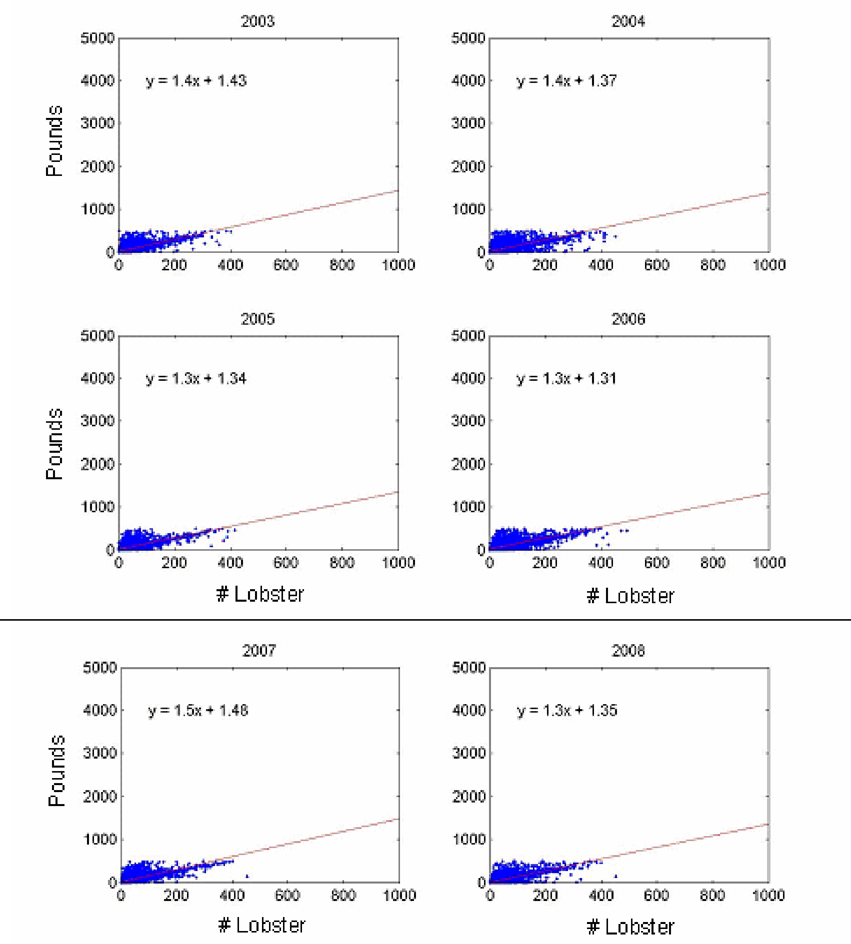


Figure 11. Number of lobster per trap pull (based on logbooks) versus the pounds (from landing receipts) associated with those pulls. The equations' coefficient on x, calculated using GM regression, represent the weight per lobster each season. The average value for the 10 years shown is 1.39 ± 0.1 lbs per lobster. From the 2007 recreational creel survey, a just legal lobster is approximately 1.3 lbs.

The age structure of the commercial catch (Figure 12), assuming a 6mm carapace length per year growth rate (Engel 1979), reinforces this view in which first year recruits dominate the catch and, like the average weight, this has not changed dramatically over the last 10 years.

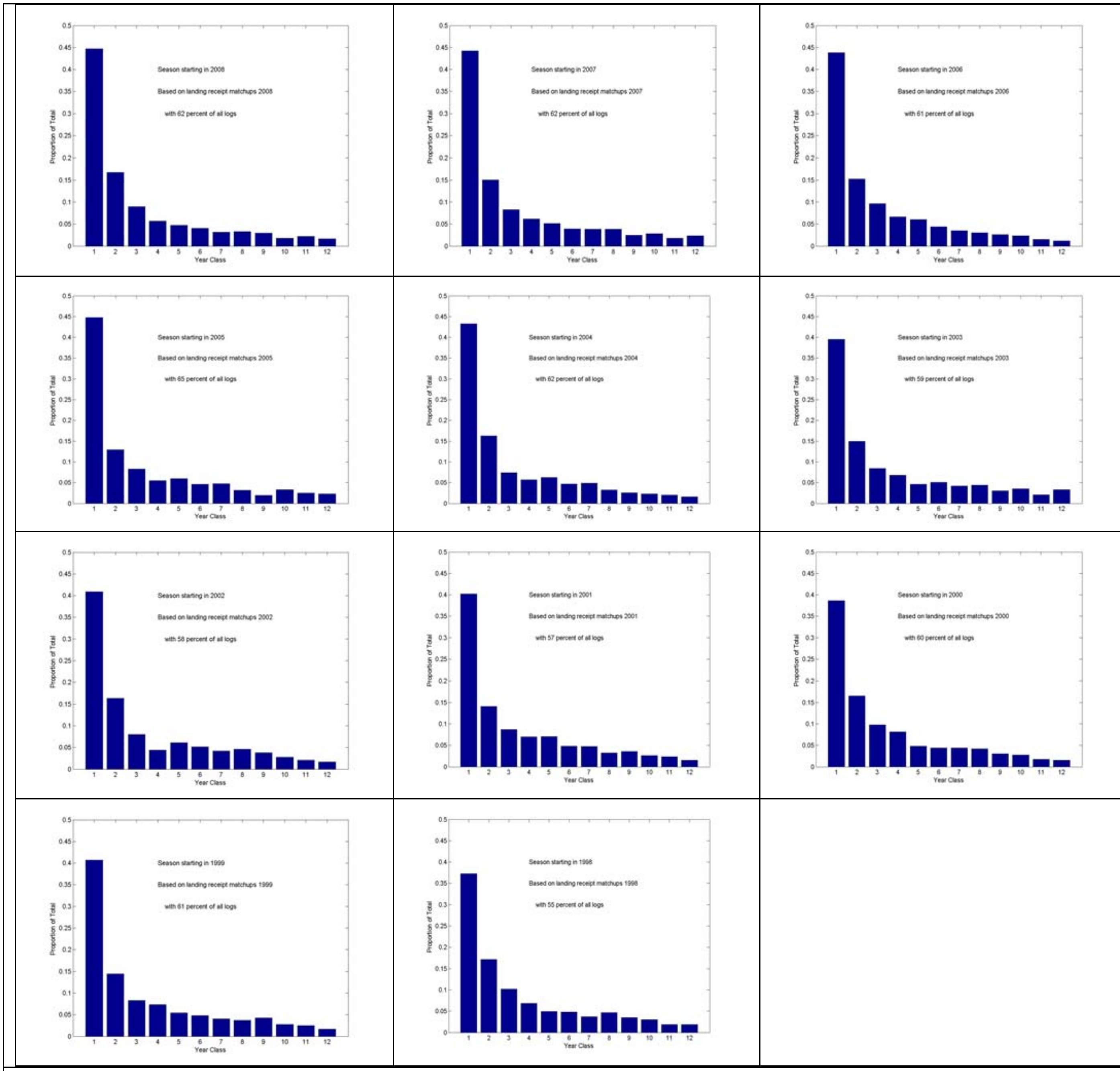


Figure 12. Reconstructed age classes of recruited lobster for seasons 1998-99 through 2008-09 based on collated landing weights and logbook retained lobster counts. The resulting weight per lobster was converted to carapace length using the length/weight relationship derived from the Department's 2007 creel survey data. The growth rate was assumed to be 6 mm CL year^{-1} based on results reported in Engel (1979). The plot was created to show the consistency of size/age within the commercial catch over the last ten years.

As detailed in the discussion of logbook data above, 80 percent of the total seasonal catch occurs within the first 12-15 weeks of the season (Figure 21). In order to examine fishing effort, we focused on this portion of the season, and avoided the portion of the season where landings are affected by random catches. Calculating CPUE as the pounds landed per trap pulled for all available years since 1986, CPUE has been within a standard deviation of the average in all but 5 (out of 22) years (Figure 13).

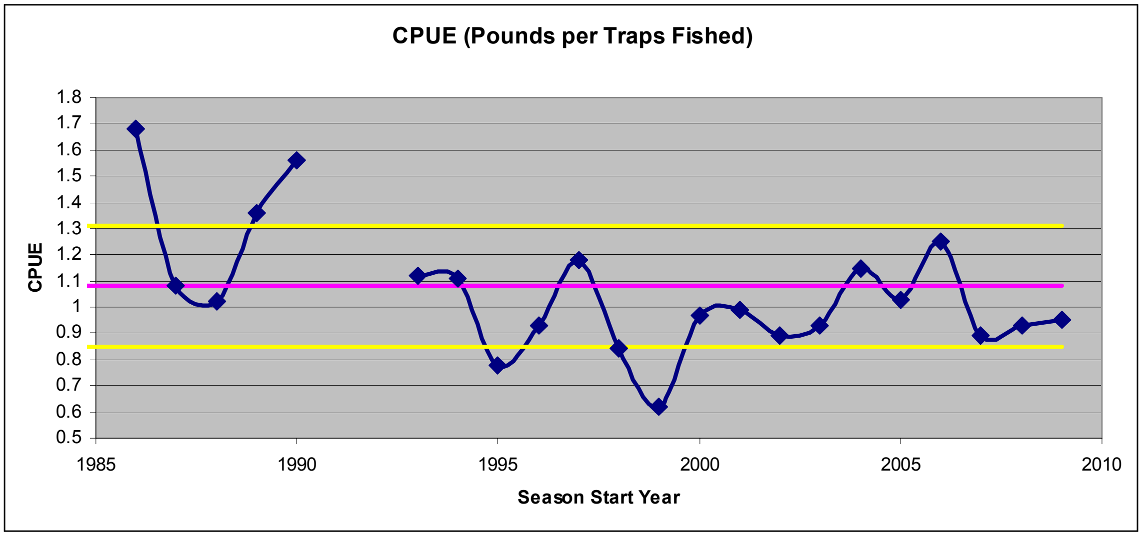


Figure 13. CPUE (pounds landed per trap pulled) for the seasons from 1976-77 through 2009-10. The values used are the totals representing 80% of their respective seasonal totals which were achieved, on average, at 12 weeks into each season. Seasons missing data were excluded. The average CPUE across all seasons is indicated (purple line) as is the range, +/- 1 standard deviation (yellow lines).

All deviations occurred prior to 2000, with three positive deviations occurring in the latter half of the 1980s and two negative deviations in the late 1990s. As with other measurements displaying consistency over the last 10 years of large harvests, the CPUE has not been unusually high or low. However, since 2006 the number of trap pulls has increased almost 50 percent without an analogous increase in catch; suggesting that the fishery may be fishing close to or at the maximum sustainable yield (Figure 14).

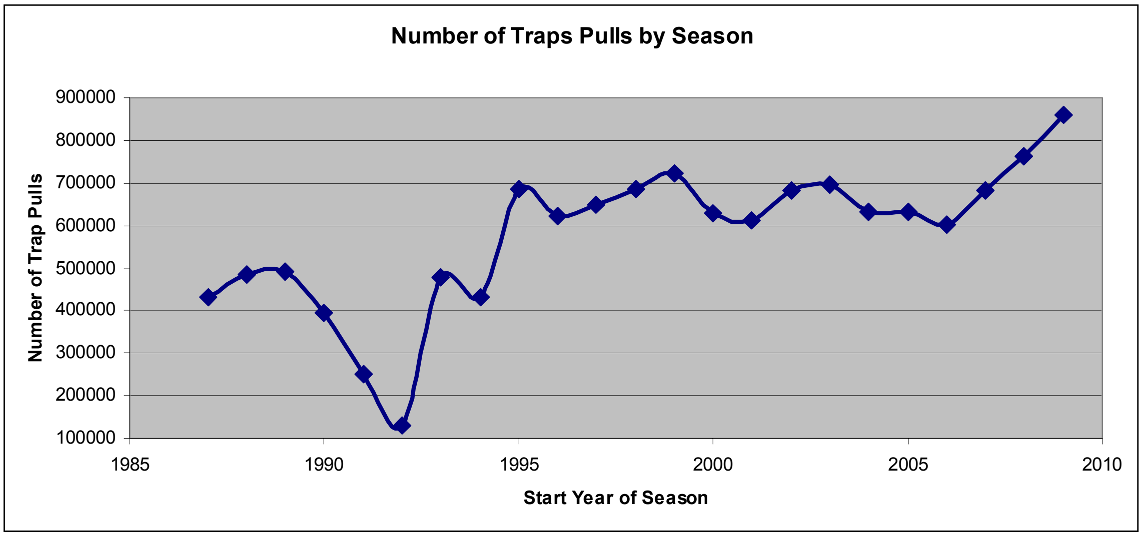


Figure 14. Commercial effort as number of commercial trap pulls by season from 1987-88 through 2009-10. The increase since 2006-07 coincides with an increase number of active operator permits over the same period. Increased effort has not resulted in a comparable increase in landing weights (or individuals), and CPUE dropped after 2006-07 (but remains relatively stable) suggesting the possibility that the fishery is fishing at or near its MSY.

The increase in effort since 2006 may be related to an increased number of transferable lobster permits being transferred; which poses a source of uncertainty to the level of future commercial effort. Although the number of lobster permits has been falling over the last 12 years (Figure 5) the number of transferable permits has increased. Given the current price of a lobster permit ($50,000 to $75,000), fishermen possessing a newly transferred permit would have a significant incentive to maximize effort to recoup their investment, which may account for the jump in effort between the 2005-06 and 2006-07 seasons (Figure 6).

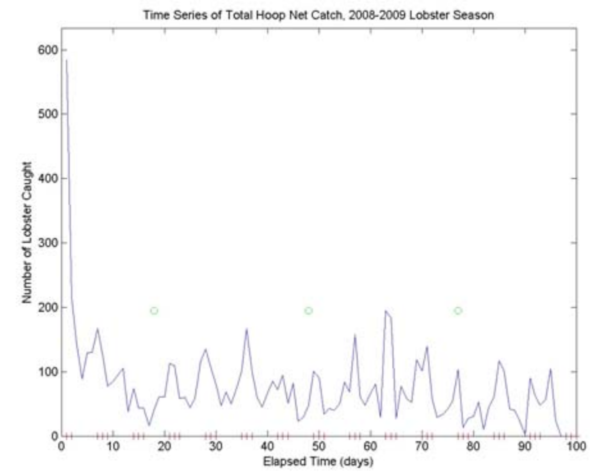
Recreational Spiny Lobster Report Cards. Report cards were introduced in time for the 2008-09 recreational season and must be purchased by every person fishing for lobster in California. This includes children and people fishing from piers or on free-fishing days. The report cards are valid for a single calendar year and expire on December 31 at midnight. Report cards for the previous year must be returned to the Department by January 31 of the following year.

Since lobster season runs from October to March, fishermen are required to buy new report cards if they intend to fish the second half of the season; and those same report cards are good for the first half of the following season as well. As a consequence, the Department does not receive the results for a full season until the following January. Given the amount of time needed to enter this data, a full season's data isn't available until approximately July or August of the following year. The Department started selling report cards at the beginning of the 2008-09 season (fall of 2008). For most of this assessment effort, the Department had access to data covering only the first half of the 2008-09 season. Another issue relevant to this dataset is the poor rate of report card returns to the Department: 22 percent of the 2008 cards, 13 percent of the 2009 cards, and 11 percent for 2010.

The cards record the date, location, gear type, and number of lobster retained. Types of gear cover both recreational fisheries and include conical hoop nets, flat hoop nets, skin diving, and scuba diving. However, the cards do not include the number of nets used, nor the amount of time spent fishing. Additionally there is no convenient way to equate the time spent diving to the time spent hoopnetting. Consequently, the Department uses 'trips', or a single line from the report cards, as its unit of effort. To date, we have not attempted to directly compare the relative effort based on hoop netting to diving.

Trends and Patterns. The Department sold 27,479 report cards in 2008, 30,773 in 2009, and 29,142 in 2010. The in-season harvest record is marked by a peak in catch during the first weekend of the season followed by a relatively low but consistent catch for the remainder of the season (Figure 15, A). Weekends (Friday, Saturday, and Sunday) are peak fishing times with lulls generally during the weekdays. No pattern in catch was detected relative to the phase of the moon. CPUE, with effort measured as the number of trips was fairly consistent across the season. Unlike commercial CPUE, the recreational CPUE did not decline as the season progressed, suggesting legal-size lobster were present during the entire season (Figure 15, B). However, recreational fishermen have access to areas not accessible to commercial fishermen: piers, jetties, and bays, for instance. Thus the consistent availability of lobster to recreational fishermen, while commercial fishermen experience declining catch as the season progresses, may just reflect different fishing grounds.

A



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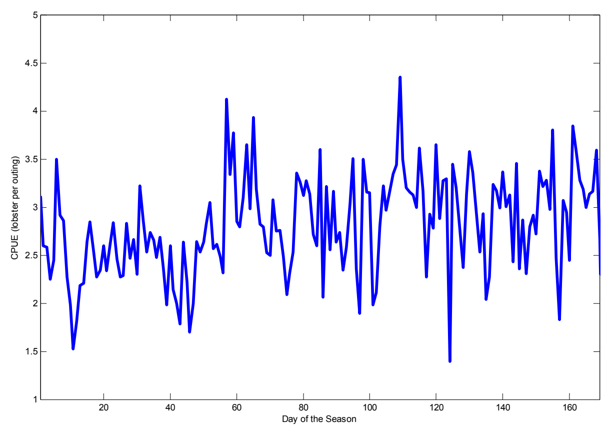

Figure 15. A) Recreational hoop net harvest for 2008-09 season. Weekends (FSS) are marked by red lines on x-axis. Full moons are marked by green circles. B) Recreational CPUE over time. The number of days plotted differ between these two plots. Data from Recreational Lobster Report Cards

The number of lobster caught has not been insignificant compared to the commercial catch although the uncertainty of the actual number is exacerbated by the low return rates. Based strictly on the harvest calculated from returned cards and extrapolated to all report card purchasers, the recreational fishery landed the equivalent of 49 percent of the commercial catch in the first half of the 2008-09 season and the equivalent of 61 percent of the commercial catch in calendar year 2009.

In discussions with fishermen concerning these numbers, they felt the returned cards overestimate the number of people that actually fished, as well as the number of zero-catch trips. They argued that fishermen with ‘no results’ would not return the cards because they either did not understand that ‘no results’ is a valid data point, or they were embarrassed by their perceived failure. In order to address this, we calculated the percent take by assuming that 20 percent of the unreturned cards did not fish and 30 percent of the cards that did fish, caught zero lobsters. These values are fairly arbitrary, but were considered realistic by the recreational fishermen consulted. With the new assumptions the recreational fisheries were estimated to have caught the equivalent of 44 percent of the commercial catch instead of 61 percent. For the purposes of this assessment, two different catch time series were constructed representing the two endpoints: 44 percent and 61 percent of the commercial catch. The total number of lobster caught was evenly distributed between the hoopnet fishery and the dive fishery. This conflicts with creel survey results (see below) which indicated an 80/20 split of the catch favoring hoop nets in 2007. How this data was used for this assessment is described below in the discussion of the interpolated recreational time series created for this assessment.

The recreational hoopnet fishery represents the greatest unknown facing this assessment, in that hoop netting has only become popular in the last few years, and manufacturers in this time period have introduced the more efficient conical form of the net. The recreational fishery has also moved from a being a predominately dive-based fishery to one that is hoop net-based. Since we only just started collecting data on the recreational fishery we have no way of knowing where in this transition period we are. We assume that we will eventually be dealing mostly with efficient, conical hoopnetting across the bight. We are also seeing more instances of charter boats running hoopnet cruises. Although restricted to a total of 10 nets, these cruises do not need to travel far from the dock, saving on both gas and time. San Diego Bay in the 2009-10 season saw the introduction of two vessels conducting such charters, each of which fished inside the bay five days a week (according to their schedule), which had the potential of removing 140 lobster per night (or 700 lobster per week).

The number of lobster caught during the 2008-09 was used as the final endpoint in the reconstructed recreational catch time series described below.

Recreational Creel Surveys. Two creel surveys were undertaken by the Department targeting the recreational fisheries. The data collected included mode, gear, number of hours fished, location, lobster released, and lobster kept. In addition, carapace length, weight, and sex were recorded for each kept lobster.

The first survey occurred on the first two weekends, Saturday and Sunday, of the 1992-93 lobster season and covered three sites in San Diego County: Dana Landing Launch Ramp, Shelter Island Launch Ramp, La Jolla; and Channel Islands Harbor Launch Ramp in Ventura County. Interviews times varied by location and weekend (Table 4) but there were some general patterns. Interviews on Sunday occurred during the day between 10 AM and 6 PM. On the first Saturday, corresponding to the first day of the season, interviews were conducted for 24 hours in three, eight-hour sessions beginning at midnight. The second Saturday covered 16 hours in two, eight-hour sessions beginning at 7 AM. Channel Islands Harbor was offset four hours in its interview day relative to the other three sites. This creel survey devoted most of its time to daytime interviews.

The second survey occurred between opening day of the 2007-08 recreational lobster season (September 29, 2007) and December 2, 2007. Seven two-man teams performed intercept surveys at specific fishery access points across the five coastal counties south of Point Conception, California (Table 5). Santa Barbara, Ventura and Orange counties each had one team conducting surveys while Los Angeles and San Diego counties had two. The teams were usually scheduled for three random nights during the week and two of the three weekend nights (Friday, Saturday, and Sunday). Santa Barbara and Ventura county teams, however, were scheduled the same five nights each week. The teams were active between 6 PM and midnight and no daytime interviews were conducted. The survey locations, and resulting survey schedules, were chosen, with input from Department staff and California Recreational Fisheries Survey (CRFS) personnel. The locations include high activity sites while also including less utilized sites. Each scheduled night was usually split unequally between two locations. Interviewers stayed at the locations for the entire scheduled time (either two or four hours in duration) regardless of whether fishermen were present to be interviewed. The metrics collected were the same as in 1992.

Trends and Patterns. The 1992-93 survey interviewed 633 fishermen split evenly between Dana Landing, Shelter Island, and La Jolla/Channel Island Harbor. The 2007-08 survey involved 1,248 hours spent at 416 locations and resulting in 1243 interviews (some interviews involved multiple fishermen). General results for the 1992-93 and 2007-08 creel surveys can be found in Department reports, Harris et al. (1993) and Neilson & Buck (2008), respectively.

Comparing 1992 to 2007, at the three sites common to both creel surveys, revealed the fundamental shift in the gear reported previously (Figure 16). In 1992, 80 percent of the fishermen interviewed were diving for lobster and only 20 percent were hoop netting. In 2007 this trend had reversed with 80 percent of the fishermen using hoop nets. This discrepancy between report card and creel survey results was taken into consideration during this assessment effort when using either dataset (see Interpolated Recreation Catch, below, for example).

Overwhelmingly, lobster were caught at or near legal size, and the number of lobster caught declined exponentially with increasing CL (Figure 16). Assuming a 6mm per year growth rate for adults lobsters (based on the summary by Engel, 1979), the majority of lobster caught by recreational fishermen were within two years of legal size, and almost half were within one year.

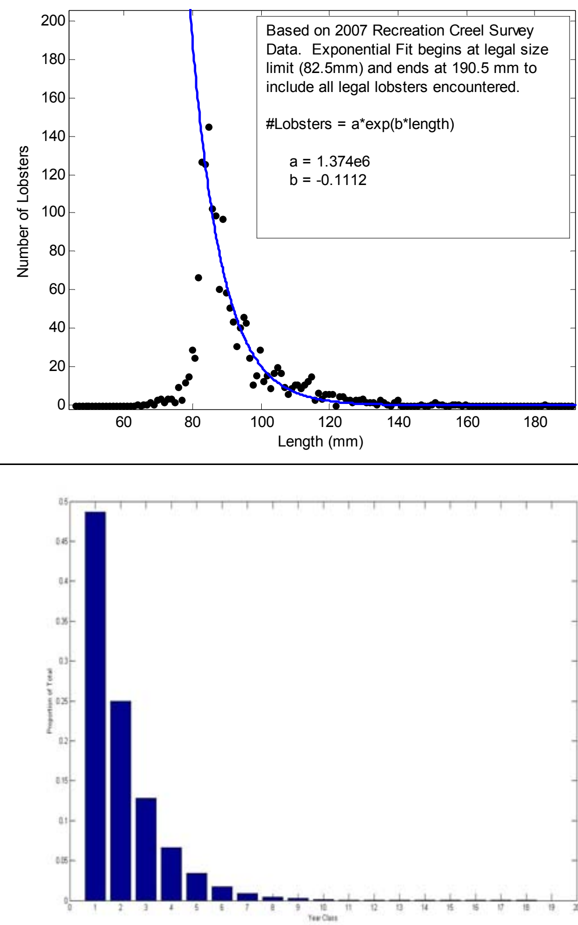

Figure 16. Exponential fits (GM Regression) for the 2007 recreational creel survey data (top) and the age structure (bottom) are based on the 2007 creel survey and assumes a 6 mm year^{-1} uniform growth with the first year class starting when the lobster reaches legal size (recruits to the fishery). The vertical axis of the age structure ranges from percent totals of 0 to 0.5, in increments of 0.05.

Interpolated Recreational Catch. Recreational catch as stated is unknown. However, we reconstructed a trend in recreational catch using the following steps:

1. We assumed that any changes in the recreational fishery, in terms of catch totals, had occurred strictly in the hoop net fishery. This was based on the apparent increase in popularity with this particular gear type between 1992 and 2007 without a similar change in popularity for diving.

2. We used the ratio of divers to hoop net users, established by the two Department creel surveys, along with lobster report card data for 2008-09, to establish the total number of divers active in 1992-93 and 2007-08. The number of divers for 2007-08 was taken directly from the 2008-09 report card data and this number was assumed to be equal to the number of divers in 1992-93. In 1992-93, 80 percent of the catch was taken by divers. We were then able to calculate the harvest by hoop net users in 1992-93 by calculating from the 80 percent diver harvest amount what the total harvest was, and then taking the difference.

3. We then calculated an exponential increase in hoop net use between 1992-93 and 2008-09 following two different trajectories: assuming a smooth exponential increase between 1992-93 and 2008-09, and assuming no change until 2005, at which point we increase hoop net use exponentially until 2008-09. The final interpolated recreational record was the mean between these two trajectories. Post-2008-09 will be based on actual report card results. Prior to 1992-93 we extended hoop net numbers backwards to 1972-73 (providing a 35 year record to 2007-08) using an exponential decline equal to the increase going forward; diving numbers were still held constant. For seasons prior to 1972-73, we extended the values for 1972-73 backwards without modification.

Three separate interpolated datasets were created (Figure 17). The first dataset equated 80 percent hoop net fishing in 2008-09 to 20 percent in 1992-93 as described above. The second dataset, however, followed the report card returns from the first half of 2008-09 (which was all that was available at the time) that equated 50 percent hoop net fishing in 2008-09 to 20 percent in 1992-93. It was decided that the creel survey provided a better estimation of the proportion of hoop net users in 2008-09 than the report card proportion based on a 20 percent return rate. Also, discussing these trajectories with a representative of Promar, a major manufacturer of hoops nets, based on their sales information it became clear that the popularity of hoop nets did not increase until after 2005. The Depletion model was run with datasets constructed from Figure 17, A and B. ASPIC runs used the reconstructions in Figure 17, A and B, but also C. FISMO was run only with a reconstruction based on Figure 17, C. Figure 18 illustrates the result when adding one of these trends to the commercial landings record.

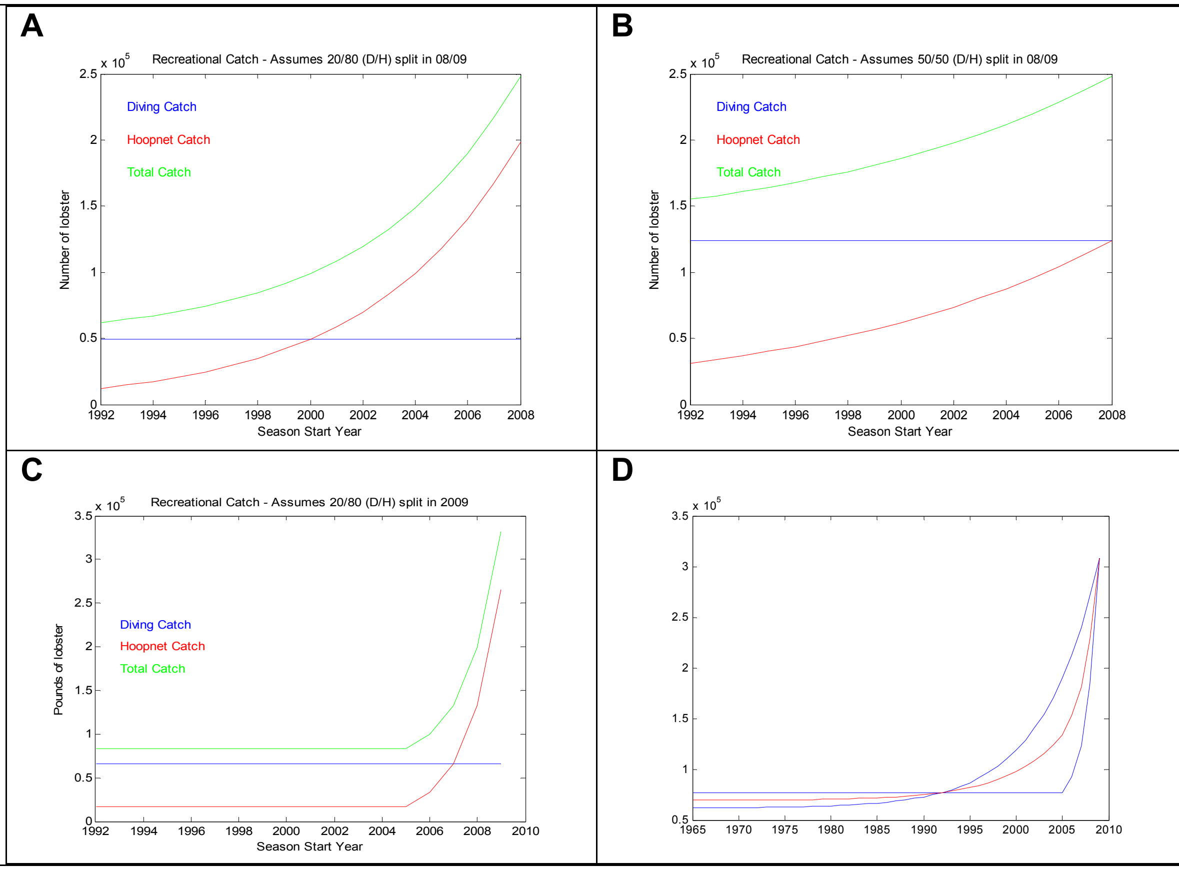

Figure 17. Interpolated recreational catch trajectories (green lines) based on various assumptions about changes in the hoop net fishery-related effort. In all cases, diver-related catch (blue lines) is held constant and diving counts for 20 percent of the total 1992-93 recreational catch while hoop net-related catch (red lines) is allowed to vary. A) Hoop net catch is assumed to count for 80 percent of the total recreational catch in 2008-09, based on results from the 2007 recreational creel survey. B) Hoop net catch is assumed to count for half of the total recreational catch in 2008-09, based on 2008 recreational lobster report card results. C) 20/80 split in the 2008-09 recreational catch (as in upper left) but with the increase in hoop net-based catch beginning in 2005 (based on hoop net sales). D) Interpolated recreational catch (red line) used in assessment which was the average between the total catches (blue lines) from A) and C).

By August 2010 when we had analyzed the bulk of the returning 2009 report cards, the proportion of hoop net users was still evenly split 50/50 with divers, but the return rate of 2009 cards was even worse than in 2008 at only 13 percent.

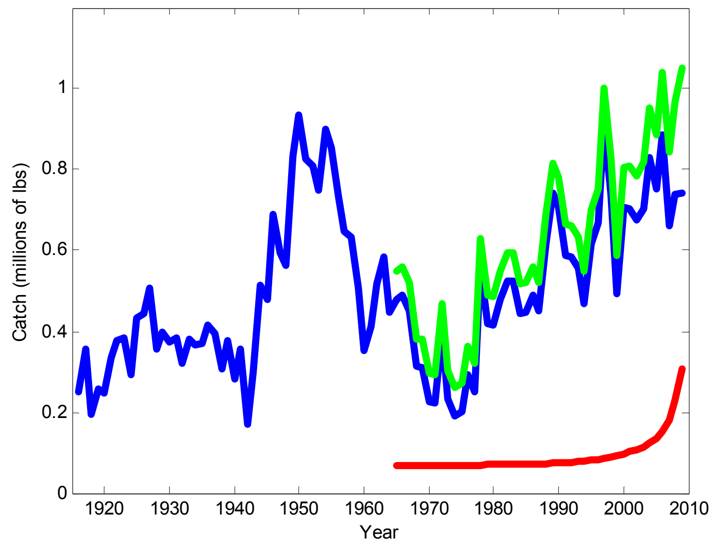

Figure 18. The record of commercial landings (blue line) with interpolated recreational landings (green line) superimposed beginning in 1965. The red line represents the shape of the interpolated recreational landings.

Localized Datasets. The data from a number of studies were made available to the Department, if needed, for this assessment. Without exception, these datasets were localized in nature, and it was decided not to use them during this first effort (exceptions are noted in the list below). This choice was made because of the availability of bight-wide data collected by the Department and the uncertainty involved in validating the bight-wide application of data collected over a small area. These datasets will be critical, however, for future, localized tuning of the bight-wide assessment.

These datasets include:

- Catalina Island tag/recapture study – Carlos Robles (CSULA)
- San Diego Bay tag/recapture and movement study – Kevin Hovel (SDSU) and Doug Neilson (CDFG). This study provided additional length-weight data for the assessment and was used to determine the relationship between carapace length and total length.
- Bren School-related studies – These are various fisheries-dependent studies carried out by graduate students of Hunter Lenihan and others, as part of the commercial fishery collaboration CALobster. These studies have primarily taken place in the Santa Barbara area and northern Channel Islands and include primarily the work of Matt Kay and Carla Guenther. In addition, Matt Kay has provided his tag/recapture data from the northern Channel Islands.

- Brian Kinlan and Deborah McArdle (Bren School, UCSB) made available their model and the data that formed the basis for a portion of McArdle's Ph.D. dissertation. The model addressed the full historical commercial fishing record off California, however, and required weeks of real time to run. Since the Department was interested only in the most recent decades and didn't have the project time available for multiple runs of the model, we decided to concentrate on the Department datasets which had been used in summarized form by McArdle as part of her model time series. The results of this model will be useful for future comparisons as will the model's Bayesian formulation in future iterations of this assessment.
- La Jolla Reserve tag/recapture and movement studies – Kevin Hovel (SDSU).

Biological Parameters

Length/Weight. The relationship between carapace length (mm) and total weight (kg) was estimated by the least-squares method fitting 2007 recreational creel survey data to the $\log_{10}$ transform of the equation

$$W = aL^b$$

After substituting optimal values for a and b, the equation is

$$W = 1.04x10^5 \ L^{2.4829}$$

and is valid for carapace lengths between 58 mm and 183 mm. The fitted line (Figure 19) explains 77 percent of the variability of the data. A just legal size lobster (82.5 mm CL) was found to have an average weight of 0.596 kg (1.3 pounds).

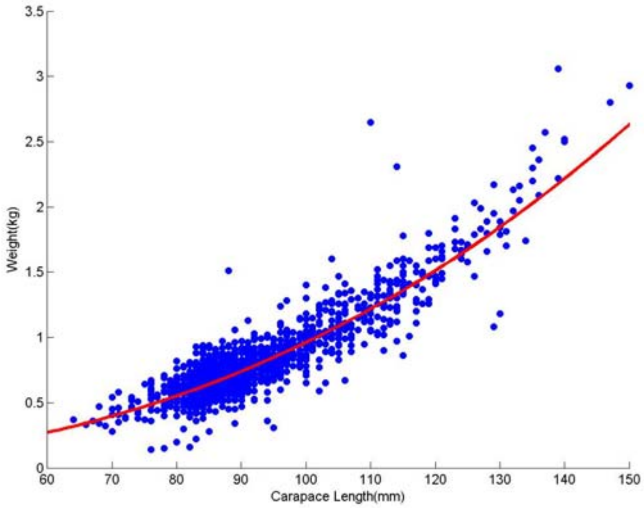

Figure 19. Relationship between carapace length and weight of kept lobsters. The length-weight relationship was estimated by the least-squares method applied to the $\log_{10}$ transform of $W=aL^b$. The resulting equation is log(W) = log(a) + b $\log_{10}$(L), where W is the weight (kg), L is the carapace length (mm), b is the slope, and a is the intercept. Substituting optimal values for a and b, the equation becomes log(W) = log(1.03992E-5) + 2.4829 log(L) and is valid for carapace lengths between 58 mm and 183 mm. The fitted line explains 77% of the variability in the data (R^2 = 0.77) (Source: Neilson et al., 2009)

For FISMO, outliers were removed visually from the dataset, carapace lengths were converted to centimeters, and total weights to grams. FISMO also expects the calculation to relate total length (carapace + tail), not CL, to total weight. Data from a tag-recapture study of San Diego Bay lobster, underway at the same time as this assessment, contained measurements of both tail and carapace length for 611 lobster (Hovel and Neilson, 2011). These lobster ranged in size from 4.0 cm CL to 12.9 cm CL. among these 611 lobster, the tail length was on average 2.00 ± 0.15 times CL, or CL was about one third of the total length of the animal. After multiplying the carapace lengths by 3, the fit was recalculated. The resulting equation as used in FISMO is

$$W = 0.3\ L^{2.51}$$

Where **L** is total length in cm and **W** is total weight in g. FISMO was insensitive to the relatively small differences between this equation and the one presented above that includes outliers.

Using the original equation (with outliers), the weight of an 82.5 mm lobster (just legal size) is 1.3 pounds. We had originally used this value to convert the ‘Legals Retained’ from the sport fishery lobster report cards for our model runs but recognized that we were underestimating the weight of the recreational harvest. We eventually switched to the value of 1.6 pounds per lobster, the median retained lobster weight from the 2007 creel survey. The models that had been run with both values changed slightly in the magnitude of catch calculated but the conclusions of those runs did not change.

Maximum Size. While the California spiny lobster is believed to reach a weight of over 13.6 kg (30 lbs), the largest recorded lobster was 11.8 kg (26 lbs) and caught at San Pedro (Wilson, 1948). Wilson (1948) also pointed out that individuals over 457.2 mm (18 in) in (total) length and 2.7 kg (6 lbs) are rare. This observation could still be applied today, where 2.7 kg (6 lbs) animals are considered trophies.

Odemar et al. (1975) quoted observations from 1895 indicating that at that time, lobster weighed up to 3.9 kg (8.5 lbs), and that lobster were common between 2.7 kg (6 lbs) and 3.2 kg (7 lbs) with an average between 0.9 kg (2 lbs) and 1.8 kg (4 lbs). Today, 2.7 kg and 3.2 kg lobster would be considered trophy animals. Based on recreational take during the first half of the 2007/08 season (Neilson and Buck, 2009), the average weight of a single lobster was 0.81 kg +/- 0.37 kg (1.8 lbs. +/- 0.82 lbs) based on a bight-wide sample of 1626 lobster; the median weight was 0.73 kg (1.6 lbs).

Using the length/weight relationship from the 2007 recreational creel survey, and assuming the relationship holds past the 183 mm maximum sampled lobster, Wilson’s (1948) 26 pound lobster, the largest measured on record, would have a carapace length equal to 274.5 mm (10.81 inches).

Longevity. Since the population has been exposed to an energetic commercial fishery for over a century, it could be argued that even fewer lobster than expected live to the farther reaches of its natural lifespan (its longevity).

The maximum sized lobster encountered during the 2007 creel survey was 4.91 kg (10.8 lbs) with a carapace length of 183mm (7.2 in) – the length/weight equation above, based on all lobster sampled, predicts 192.9 mm (7.6 in) for the same weight. At a growth rate of 6mm year^{-1}, this represents a lobster that has been larger than legal size for approximately 16.8 years. Add 5 to 7 years to attain legal size (Engel, 1978), and this lobster is potentially 22 to 23 years old. The actual longevity of the California spiny lobster is, however, unknown.

Estimates of longevity can be as high as 50 years (DFG and Sea Grant, 2008) while the lower end of the range falls between 20-30 years (McArdle, 2008). The Department has used 26 years although the source of this estimate could not be traced. Chavez and Gorostieta (2010), working on the Baja portion of the population, used 25 years based on the point at which 95 percent of the population reaches 95 percent of the maximum length (560 mm total length for their population). At the beginning of this assessment effort, we selected the Department estimate of 26 years which falls about midway between the range cited by McArdle (2008). Longevity is used to estimate natural mortality (see below) and the difference between an estimate based on 25 years or 26 years was not deemed significant.

Mean Growth. Engle (1979) reviewed growth studies performed at that time and came to the conclusion that little comparability exists between the studies up to that point. The studies were conducted by Department and SDSU scientists (Lindberg, 1955; Backus, 1960; Mitchell et al., 1969; Serfling, 1972; Odemar et al., 1975; Ford and Ferris, 1977) and took place in both the field and laboratory, under different temperature regimes, and aimed at different size ranges. Some of the studies found different growth rates between the sexes and some did not. Backus (1960) is the only study to deal exclusively with legal sized animals which, unlike sublegals, are thought to molt only once per year. His study showed a growth rate of 5.3 mm CL year^{-1} for males and 6.2 mm CL year^{-1} for females.

We decided to use a constant growth for both sexes and chose

$$G = 6.0 \text{ mm CL year}^{-1} \text{ or } (0.24 \text{ inches CL year}^{-1})$$

for legal size growth, primarily to restrict the number of cases to examine later in the current assessment process. This value was reported by Ford and Ferris (1977) for both sexes and approximates the average of the Backus values for males and females. Also, Ford and Ferris agreed with Backus on a number of other parameters although they included lobster as small as 60 mm CL in their study. Examination of other growth rates and their effect on the assessment were reserved for follow on studies to the current effort.

Assuming that this growth rate is constant over the life of the adult (legal-size and up) lobster, and using collated commercial landings/logbook data, we can create an age structure for the commercial catch (Figure 12) which shows a consistent structure over the last 10 seasons. Most lobsters caught are within a year or two of recruitment. Applying the same logic to the 2007 recreational creel survey reveals a similar result (Figure 16) although the proportion of lobster in the older age classes is higher than in the commercial result, a result not unexpected since the recreational fishery targets trophy animals. Even with this target however, the recreational fishery is overwhelmingly landing lobsters within a year or two of recruitment. In this respect, the commercial and recreational fisheries do not differ.

Natural Mortality. Hoenig (1983) equated longevity (t_{max}) of a species with natural mortality (M) using the formulation:

$$\ln M = 1.44 - 0.982 \times \ln t_{\max}$$

Applying a longevity of 26 years leads to a natural mortality estimate (instantaneous rate) of 0.1721 year^{-1}. For comparison, Chavez and Gorostieta (2010), using 25 years, estimate natural mortality as 0.1793.

Growth. Based on the natural mortality calculated above, and following the Beverton and Holt 'Invariants' methodology (Hoggarth et al., 2006; Chavez and Gorostieta, 2010; Jensen, 1996), we calculated the Von Bertalanffy growth constant, **K**, as

$$\mathbf{K} = \mathbf{M} / 1.5 = 0.17 / 1.5 = 0.1133$$

We applied the growth constant to Von Bertalanffy's equation (VBGF) (from Ricker),

$$l_t = L_\infty \left(1 - e^{-K(t-t_0)}\right) \qquad \text{(Ricker, Eq. 9.9)}$$

which relies on **K**; the asymptotic length $\mathbf{L_\infty}$, here approximated by the carapace length of the largest observed specimen: 274.5 mm CL; and $\boldsymbol{t_0}$ which can be calculated by

$$t_0 = \frac{\log_e (c/b)}{K} \quad ; \quad c = be^{Kt_0} \qquad \text{(Ricker, Eq. 9.10)}$$

The constant ***c*** can also be calculated from

$$L_\infty - l_t = ce^{-Kt}$$

Using age class one to solve this equation, the midpoint CL for year one lobster equals 85.5 mm CL (82.5 mm + 3 mm growth). This equation reduces to:

$$274.5 - 85.5 = \boldsymbol{c}\mathrm{e}^{-0.1133}$$

$$\boldsymbol{c} = 211.6739$$

The variable ***b***, in Ricker Equation 9.10, can also be approximated using the asymptotic length, 274.5 mm CL. $\boldsymbol{t_0}$ can then be calculated as:

$$\boldsymbol{t_0} = \log_e(\boldsymbol{c}/\boldsymbol{b}) / \boldsymbol{K}$$

$$= \log_e(211.6739 / 274.5) / 0.1133$$

$$= -2.2939 \text{ mm}$$

The resulting growth curve, using the VBGF is shown in Figure 20.

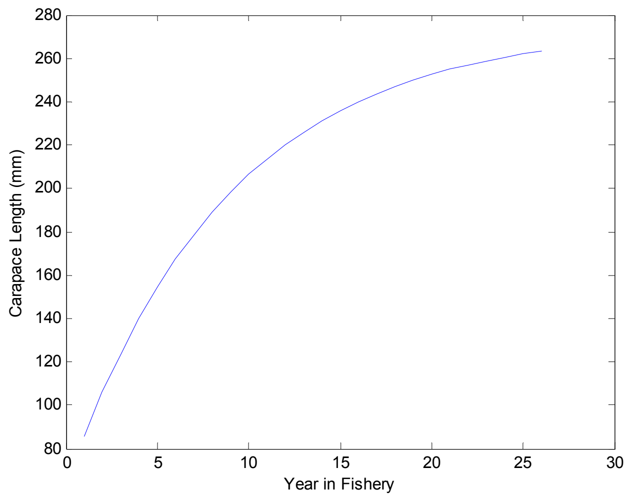

Figure 20. Reconstruction of the growth curve using VBGF and assuming fixed values of 6 mm CL year-1 and the age 1 midpoint measurement of 85.5 mm CL.

Assessment

What the data tell us. The landing record for the commercial fishery has gone through a series of changes in harvest over the decades. Some of these changes can be attributed to specific external factors but potential causes are not as clear cut with others; in particular, the changes seen since 1976. As previously stated, since 2000 the fishery has maintained a high harvest size relative to the immediately preceding decades but the cause for both the change in 2000 as well as the reasons behind the relative stability since, is unknown.

The following conclusions are based strictly on the post-2000 years of sustained large harvests with the assumption that any changes can be traced to changes in the fishery alone.

- The commercial fishery has been consistently harvesting 300+ tonnes each season.
- Over the decade, the catch each season has been accumulated at the same general rate as the season progresses, with the highest total landings occurring

within the first week or two of the season and 80 percent of the season total landed before the end of January and usually by the end of December.

- The size structure of the catch, using 6 mm year-1 for the growth rate, has not changed significantly over the last ten years, with the majority of the catch coming from first year recruits to the fishery.

- The average weight of a commercially caught lobster has varied from 1.3 to 1.6 pounds per lobster with a median weight of 1.6.

- Based on depletion model results, the catchability which is the slope of the line plotting CPUE against total catch to date, has not varied significantly from season to season.

- The number of short lobster released, as a percent of the total catch, has not changed significantly over the last decade. This remains true whether considering the entire bight or individual counties/offshore islands. The percentage is independent of the size of total catch.

- The number of operator permits has been declining and the number of active fishermen has also declined since a small increase in the early 2000s. Unless there is a change in effort on the part of the remaining fishermen (which could occur in the unlikely event of a large number of transferred permits in a given season) these declines in fishermen will likely be reflected in fewer traps set and reduced pressure on the resource.

- Some fishermen have suggested that they are catching less with more effort. The data are mixed on this. CPUE, while currently lower than two or three decades ago, is still within a standard deviation of the average CPUE over the last decade. The CPUE is also higher in the last few years than earlier in the decade. Still, there has been an upswing in the number of traps deployed in recent years which has not resulted in a similar increase in catch, or at least not a consistent trend upwards. This type of pattern (increase effort/even or declining take) is a pattern seen in a fishery that's harvesting close to the MSY. This is sustainable (at least on the lower side of the MSY) but not desirable. Increased effort on the part of the fishermen will not provide a comparable rate of catch and subsequent monetary return.

Based strictly on the trends in the data over the last ten years, we would conclude that the fisheries are currently stable. There is some indication that increasing effort in the last few years on the part of commercial fishermen is not leading to a comparable increase in catch which suggests they are fishing near the $\mathbf{F_{msy}}$. Without a declining trend in catch there is no reason to believe that the underlying population is threatened. However, there is a cautionary note to this conclusion related to changes within the recreational fishery.

The recreational fishery has changed virtually overnight with the introduction and popularization of hoop net gear. Preliminary data suggest that the take is substantial, adding the equivalent of another 30 percent to 60 percent to the commercial harvest. Because of limited data however, we cannot tell if the recreational fishery is still increasing in its harvest or leveling out. If it is increasing, the size of the recreational harvest could change our perception of stability in the combined commercial and recreational catch. Unfortunately, since lobster report card returns lag each season by approximately a year, developing problems with the recreational fishery will not be detectable immediately. We may see indications of a problem with the recreational fishery in the commercial record first. Likewise, problems with the commercial fishery will be reflected in the commercial data before they are seen in the recreational record. Future assessment efforts need to fully consider the uncertain state of the recreational effort when predicting the health of the fisheries.

Modeling Assumptions. The basic assumptions used for all assessment calculations were:

- Spiny lobster in the southern California Bight compose a single stock.

- Spiny lobster are targeted by three fisheries: a commercial fishery using traps; and two recreational fisheries, one using hoop nets and the other hand harvesting via diving.
- Spiny lobsters recruited within the previous year make up the largest proportion of fishable lobster
- The dominant sized lobster fished is approximately legal size. The commercial fishery targets this size to provide a uniform size to dealers and restaurants. Recreational fishermen primarily catch this size as well, although sport fishing is aimed at trophy animals. Earlier modeling runs with ASPIC and the depletion model used 1.3 lbs, the legal size weight determined from 2007 creel survey data, to convert records of retained individuals into retained weights. Early FISMO runs also used this conversion but we ultimately changed to the creel survey's median weight, 1.6 lbs per lobster. This value was deemed more representative of the recreational catch.
- Only hoop-net catch and effort has changed over the decades since 1992 (the year of a departmental creel survey) and that change has occurred only since 2005.
- Catch and effort related to diving was held constant over the years. We used the proportion of diving related harvest from the 1992 and 2007 creel surveys to create an estimate of the harvest by divers. In 1992, therefore, 80 percent of the harvest was equal to 20 percent of the 2007 harvest. The remainder of the recreational harvest over the years was deemed to have been caught by hoop nets. Report card results disagree with the proportions encountered during the 2007 creel survey and show a 50/50 split between hoop nets and divers. Because of the extremely low return rate for the report cards however, we did not feel we could discount uneven returns between the two recreational fisheries. The creel survey, on the other hand covered the entire bight in an organized and statistically robust manner and the results were deemed to be more trustworthy.

Leslie Depletion Runs. The Leslie Depletion Model (Ricker, 1975) assumes a closed system in which CPUE decreases linearly as the cumulative catch increases. The first assumption, a closed system, is a reasonable description of the California spiny lobster fishery. Since the fishery has expanded to all shallow water areas of the Southern

California Bight, the only source for lobster outside the system is from Mexico and there is no evidence of a significant immigration of either adults or larval lobster from Mexico into US waters. Relative to the second assumption of a linear decrease in CPUE as the cumulative catch increases, not all seasons fit this assumption. In particular, the 2002/03 season violates the assumption completely because of an increase in CPUE after January 1. Other seasons, to lesser or greater extent, have this same increase but only 2002/03 continues to fail this assumption even when the calculation is restricted unrealistically to the first month of the season. All of the seasonal log book data (1998-2008) violate this assumption after approximately 12 weeks. The first 12 weeks of data however generally decline for all seasons (excluding 2002/03) and represent approximately 80 percent of the total seasonal catch (Figure 21, orange line). Restricting the calculation therefore to 80 percent provided an acceptable trade-off between capturing the seasonal catch and effort pattern and conformance to the depletion model's assumption. The seasons used also did not follow a strict linear depletion, but the rate of decline is generally the same for each season so the error associated with fitting a line to the decline should be relatively the same for all seasons.

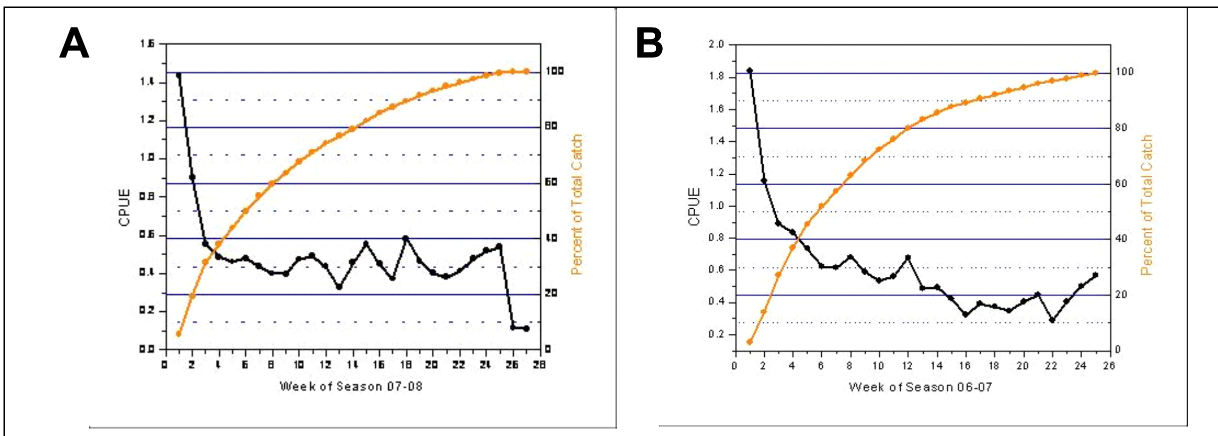

Figure 21. Combined commercial catch trends showing the decline in CPUE (black line) and the percentage of total catch (orange line) by week of the seasons for A) the 07/08 season, and B) the 06/07 season. These seasons are typical for the commercial fishery. Initial high CPUE declines rapidly to a 'background' level of CPUE marked by booms and bust. Booms and busts are indicative of fewer available lobster either because of local fish-out or movement of the fishery into deeper waters with less accurate trap placements relative to resident lobster concentrations.

Inputs. The Leslie depletion model requires catch and effort data within a season at fixed intervals. We selected weekly values and extracted catch data from the Department landing receipt database, and effort data in the form of traps pulled from the Department's logbook database. As previously stated, we restricted the time frame of each season's data to the number of weeks required to catch 80 percent of the total seasonal catch. The 2002/03 season was excluded from this analysis.

Outputs. From the fitted line to each season's data, the y-intercept estimates the initial size of the fishable population each season, while the slope of the line is the catchability, **q**. Using results from consecutive seasons we are able to calculate a simple recruitment (**R**). In this case, **R** is the shortfall in fishable biomass left over from the previous season ($\mathbf{B_{t-1}} - \mathbf{F_{t-1}}$) needed to make up the initial biomass ($\mathbf{B_t}$) for the current season. Natural mortality is not applied in the months between seasons nor do we 'grow' lobster into the fishery during the season. The resulting recruitment estimate also does not truly reflect the total number of lobster recruited to the fishery but only those that actually are fished. The value is calculated by

$$\mathbf{R_t} = \mathbf{B_t} - (\mathbf{B_{t-1}} - \mathbf{F_{t-1}})$$

***Scenarios*. **Two datasets were used. The first dataset relied on commercial catch information while the second combined the commercial catch with interpolated recreational catch information (Figure 17). Commercial effort data were used for both datasets with no attempt to include recreational effort. Since the depletion model results are based on 80 percent of a season's catch, the calculated initial fishable population size was scaled to 100 percent. These datasets were constructed early on in the assessment process and have not been maintained. Subsequent datasets used for other models (ASPIC, FISMO) were based on these data but were augmented with newly available data.

Results. Over the last ten seasons the initial fishable population size (excluding 1999/00) averaged 1.19 ± 0.17 million lobster (Table 6). Including the recreational catch, the fishable population estimates are 1.24 ± 0.22 million lobster (Table 7).

Over this same timeframe the average recruitment (shortfall) was 753,564.8 lbs ± 205,538.9 lbs and 894,020.1 lbs ± 255,386.4 lbs for commercial-only and combined recreational/commercial harvests, respectively. Recruitment trends using combined recreational/commercial harvests have generally followed those using commercial-only harvests although they have become uncoupled in recent years. In 2008/09 and 2009/10 the combined harvest recruitment has increased dramatically while the commercial-recruitment has fallen slightly (Figure 22). This uncoupling is thought to be the result of increased catch in the face of rising hoop net popularity.

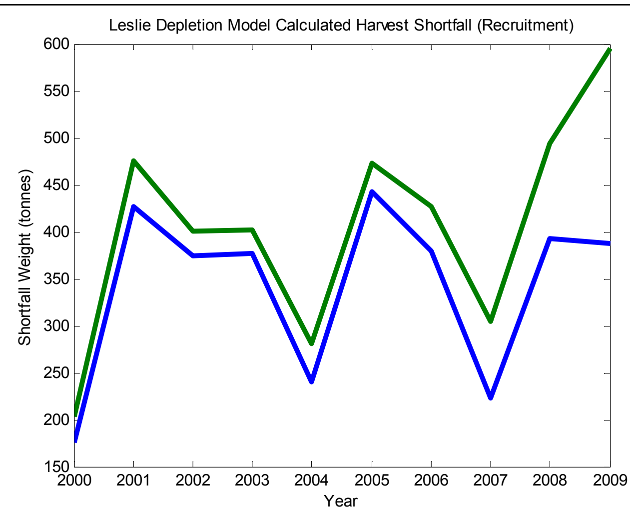

Figure 22. Recruitment estimates for commercial catch (blue line) and the combined commercial and recreational catch (green line) based on Leslie depletion model derived B_0 and the number of traps as recorded in logbooks.

Surplus Production Runs (equilibrium). An initial fit of 10 years of commercial-only catch and effort data was made using both the Fox and Schaeffer models in equilibrium mode. Because of the small amount of data and because they were equilibrium runs, these results are not discussed but plots are provided in the appendices (for information only).

Surplus Production Runs (non-equilibrium - ASPIC). Initially, we started to develop our own surplus production software to calculate a non-equilibrium Fox model solution. It was decided, however, to use the Stock-Production Model Incorporating Covariates (ASPIC) model (Preger, 1994; Prager, 2004) from the NOAA Fishery Toolbox instead since potential reviewers would probably be familiar with it and it would save us time not having to demonstrate the skill of our version. This decision however required us to run ASPIC as something of a black box without full knowledge of the underlying assumptions and behavior of the model.

***Scenarios*.** ASPIC Fox model runs were made with three dataset versions. The first dataset used commercial landings (DFG and CalCOM datasets) while the other two sets combined commercial and interpolated recreational weights (recreational weights were based on the assumption that all lobster caught were at legal-size, or 1.3 pound), and relied on recreational estimates based on the assumption that the 2009 recreational catch was either 44 percent or 66 percent of the commercial catch (based on lobster report card results). The total timeframe modeled was 1965 to 2009. In addition each dataset was run with various starting estimates for catchability (q), B_1/K, MSY, and K.

The value for q was set to the mean value of q estimated from depletion model runs. B_1/K was set to values between 0.1 and 1.0 in 0.1 increments. Once q and B_1/K were set, the program generated starting estimates for MSY and K. ASPIC was further configured to fit the Fox exponential-yield model by direct optimization. Runs were made with all combinations of the starting guesses of B_1/K and q held constant or estimated while MSY and K were estimated in all cases amounting to approximately 80 different cases.

Results. In all cases, ASPIC failed to converge or find a non-trivial solution. The ASPIC configurations using the Fox model were then re-run using a more generalized Pella-Tomlinson fit across the widest possible domain (essentially doing a grid search for a solution) and, again, the model failed to converge or find a non-trivial solution. It was agreed at this point that the landings/effort data did not work given the assumptions that ASPIC was operating under, and ASPIC was abandoned.

Research options (see below) exist that will potentially allow a fit of a Fox surplus production formulation to the landings data but will require writing our own formulation that explicitly allows us to vary parameters that are implicit in the ASPIC formulations, changes in productivity for example.

Semi-automated, age-structured simulation model (FISMO) Runs. NOTE: FISMO uses the term recruitment to mean successfully hatched lobster and not recruitment to the fishery. Also, technically, age one recruits would include larval forms as well as settled juveniles. FISMO (Chavez 2005; Chavez and Gorostieta 2010) relies on the Beverton-Holt (B-H) invariants assuming von Bertalanffy growth (Jensen 1996; Beddington and Kirkwood, 2005; Hoggarth et al. 2006) and calculates a 20-year age structure of the lobster stock for each year of observed catch data. To explore sensitivity to changes in input or calculated parameters, FISMO also creates 31 additional years of this age structure seeded with the recruit estimate from the final year of observed catch. The 31-year structure can be manipulated without changing the fitted solution based on observed catch. The additional years can also be used to explore management decisions and their effect on future stock health but changes in management and policy were not explored for this stock assessment.

Inputs. The model requires at least 15 years of harvest weights, age of maturity, age at first capture (here assumed to be age at legal size), the length-weight power relationship, and the relative independence between spawning stock and recruitment. Von Bertalanffy growth parameters: $\mathbf{K}$, $\mathbf{t_0}$, and longevity are also needed. Initial guesses for the number of recruits and $\mathbf{F_{msy}}$ are specified and then replaced during the fitting process. FISMO also contains an economic component based on the number of fishermen and costs per boat-day, but this component was not vigorously explored for this report.

Table 2. FISMO population parameters (Inputs).

Symbol	Definition	Units	Value used	Notes
L_∞	Maximum attainable total length	centimeters	27.4	
K	VBGF growth rate		0.1133	B-H invariant, K = M / 1.5
t_0	Estimated age at total length = 0	years	-2.3	
M	Natural Mortality		0.1720	B-H invariant, calculated from K
a	Length/Weight power function coefficient		0.2	$W = aL^b$
b	Length/Weight power function coefficient		2.4960	$W = aL^b$
α	Beverton-Holt Recruitment coefficient		0.15-0.50	steepness of slope. Also relative independence of spawning stock and recruitment sizes
β	Beverton-Holt Recruitment coefficient			fitted; data dependent
t_c	Age at first capture	years	7	age at legal size
t_m	Age at maturity	years	5	
Y_i	Annual Landings, **i**=1:n years	tonnes		User Specified. Length is arbitrary
	Number of years to average across for mean catch estimate	tonnes		User can select and arbitrary range to average over.
F_{msy}	initial guess of Fmsy		**M**	replaced by fitting

Outputs. FISMO provides fishing and exploitation reference points, **F_{msy}** and **E_{msy}**, stock biomass estimates, and allows the user to explore sensitivity of the fit to changes in individual parameters.

Model Algorithm. As originally provided, FISMO was implemented by Dr. Chavez as an Excel spreadsheet and used macros for many of the fitting steps. The nature of Excel is that the changes to any cell immediately propagate through all cells in the spreadsheet ultimately dependent on the changed cell. This can make usage of the spreadsheet confusing at first, in particular while in the process of fitting a series of catch observations. Although all cells update, the only values of interest are those associated with the current year being fitted and previously fitted years. After translation to MATLAB, the sequence of steps and what values are currently valid became clearer and the following steps are based on the MATLAB version. Note: Both the MATLAB and Excel spreadsheet, given the same inputs, will produce the same fitted solution.

There are a few basic differences between the MATLAB and Excel versions of the model. The MATLAB version calculates $\mathbf{F_{msy}}$ to three decimal places to match the displayed resolution (in Excel) of the fitted **F** values for individual observed years. The Excel version calculates $\mathbf{F_{msy}}$ with a resolution of 0.05, primarily because the method used requires a cell for each value of **F** plotted (1000 in MATLAB vs. 20 in Excel). The Excel version is also restricted to 15 years of observed catch because of both screen size restrictions and the time needed to fit 15 years of observed data, particularly if problems occur trying to fit an **F** to each of the 15 years. In the Excel version, averages based on the observed catch data currently include all 15 years in the average. The MATLAB version has no restriction on the number of observed years, and additionally allows the user to select a number of ranges for averaging across the observed catch data.

The following steps are performed in the order given:

1. **Create a 20 year weight-at-age estimate**. Calculate the total length of a lobster at each of 20 ages, 1 to 20, using von Bertalanffy growth. Convert the 20 lengths-at-age into 20 biomass-at-age values using the length-weight power relationship.

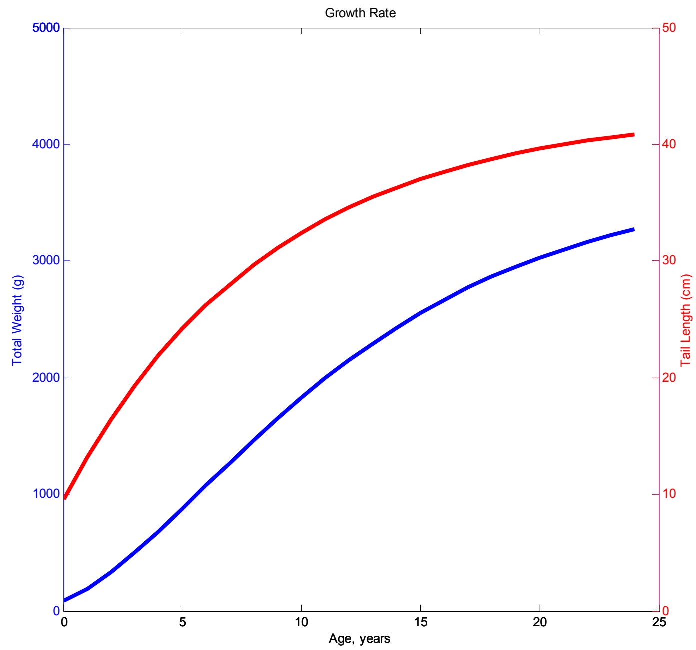

Figure 23. von Bertalanffy growth for the California spiny lobster based on inputs to the FISMO stock assessment model (Chavez 2005). Length in cm (red line), and weight in g (blue line). VBGF parameter values are: L_∞: 43 cm; K: 0.1147 year $^{-1}$; t_0: -2.20.

2. **Calculate the average size of observed catch**. The average observed catch is calculated from some or all of the observed catch (Figure 24). We used three difference ranges of data for this: the entire range, the last 15 years of catch data, and the catch record since 2000. The last two ranges were selected based on the original FISMO spreadsheet provided by Ernesto Chavez, and the timeframe of sustained 300+ tonne harvests, respectively.

Year	Catch tons
	374.2
1995	314.31
1996	330.74
1997	449.83
1998	331.97
1999	255.74
2000	355.11
2001	351.06
2002	353.10
2003	367.95
2004	423.78
2005	381.20
2006	445.50
2007	357.01
2008	418.90
2009	476.87

Figure 24. Example of a 15 year catch record input into FISMO. The average for the 15 years is highlighted in yellow at the top of column 2.

3. **Calculate age classes for the initial cohort based on the average observed catch.** This step creates a 20-year record of survivors based on the initial recruits and using both natural and fishing mortality (Figure 25). Natural mortality is applied to each age class with the addition of fishing mortality for ages greater than the age-at-first-capture. Once this has been completed, all age classes greater than age-at-first-capture are converted to weights and summed into a total weight of harvestable lobster. The catch equation is then applied to this amount and the result compared to the average observed catch. Modifying the initial recruit guess linearly, this step is repeated until the average observed catch is arrived at.

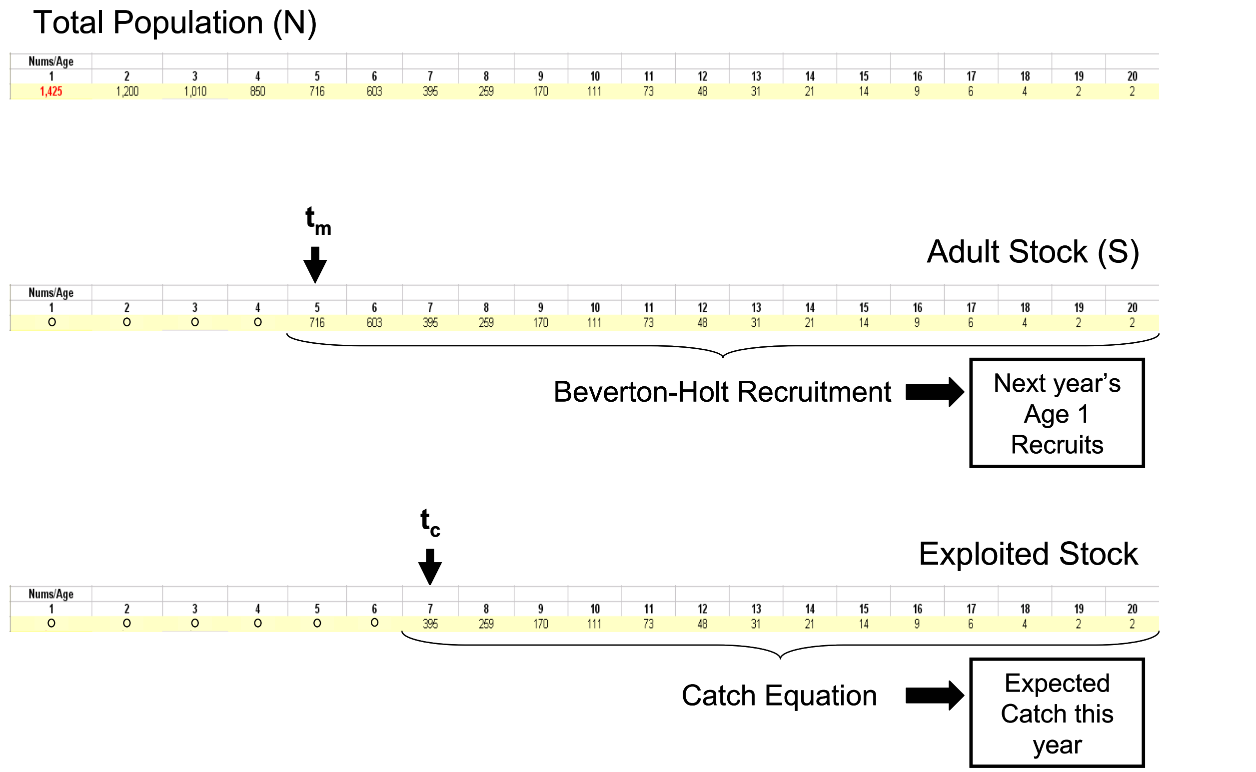

Figure 25. 20 year age class structure for the initial year cohort. The initial number of recruits (age class 1) is modified until the expected catch equals the average catch calculated in step 2. t_m is the age at maturity which, in this example, equals 5 years. t_c is the age at first capture, or age at legal size which in this case equals 7 years.

4. **Fit the Beverton-Holt beta (β) parameter**. Continuing from Step 3, the Beverton-Holt beta parameter is now varied until the next year's Age 1 recruits (Figure 25) equals the initial number of recruits previously calculated (so, assumed an equilibrium condition). The Excel version of FISMO uses the goalseek function for this fitting but the value can be calculated directly by algebraic manipulation which is the method used by the Matlab version of FISMO. The initial number of recruits is not recalculated once we have a fitted Beverton-Holt beta value.

5. **Create a 20 age class x number of years observed catch size structure**. Once we have the initial number of recruits, this is used to seed the age one recruits for the first year of observed data and a 20-year age structure is

calculated for each year of observed data. The table is filled diagonally with age n+1 for catch year y being based on age n for catch year y-1 (Figure 26). Fishing and natural mortality are applied, as in step 2 (but diagonally), according to the age class. The first year of observed catch is filled diagonally from the average-based 20-year age structure calculated in step 2. Once all 20 age classes are filled in for a given catch year, all ages greater than the age of maturity are summed into a spawning stock size for that year and the Beverton-Holt recruitment calculation, using the fitted beta parameter, is applied. The result is used as the number of age one lobster for the next year. This process continues until all 20-year age structures are complete for each year of observed catch. Although not part of the recruit estimation process, we also calculate the estimated catch resulting from the number of fishable adults for each year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	S	R
	1,425	1,200	1,010	850	716	603	395	259	170	111	73	48	31	21	14	9	6	4	2	2	2,464	1,425
1995	1,425	1,200	1,010	850	716	603	418	274	180	118	77	51	33	22	14	9	6	4	3	2	2,531	1,430
1996	1,430	1,200	1,010	850	716	603	417	290	190	125	82	54	35	23	15	10	6	4	3	2	2,574	1,433
1997	1,433	1,204	1,010	850	716	603	375	260	180	118	77	51	33	22	14	9	6	4	3	2	2,474	1,426
1998	1,426	1,207	1,014	850	716	603	413	257	178	124	81	53	35	23	15	10	6	4	3	2	2,523	1,429
1999	1,429	1,200	1,016	853	716	603	441	303	188	130	90	59	39	26	17	11	7	5	3	2	2,641	1,438
2000	1,438	1,203	1,011	855	719	603	417	305	209	130	90	63	41	27	18	12	8	5	3	2	2,652	1,438
2001	1,438	1,210	1,013	851	720	605	419	290	213	146	91	63	44	29	19	12	8	5	3	2	2,669	1,439
2002	1,439	1,211	1,019	853	716	606	422	292	202	148	102	63	44	30	20	13	9	6	4	2	2,679	1,440
2003	1,440	1,212	1,020	858	718	603	419	291	202	140	102	70	44	30	21	14	9	6	4	3	2,676	1,440
2004	1,440	1,212	1,020	858	722	605	398	276	192	133	92	68	46	29	20	14	9	6	4	3	2,618	1,436
2005	1,436	1,212	1,021	859	723	608	409	269	187	130	90	62	46	31	19	13	9	6	4	3	2,611	1,436
2006	1,436	1,209	1,021	859	723	608	386	260	171	119	83	57	40	29	20	12	9	6	4	3	2,529	1,430
2007	1,430	1,209	1,018	859	724	609	413	262	176	116	81	56	39	27	20	13	8	6	4	3	2,556	1,432
2008	1,432	1,204	1,018	857	724	609	391	265	168	113	74	52	36	25	17	13	9	5	4	3	2,506	1,428
2009	1,428	1,205	1,014	857	722	609	355	228	154	98	66	43	30	21	15	10	7	5	3	2	2,368	1,418

Figure 26. Graphic highlighting the logic used by FISMO to calculate an age structure using both annual recruit numbers and mortality. The first row (without an associated year in column 1) follows survivorship of an individual cohort (step 3). All subsequent years follow specific generations of recruits in which age n+1 for year y is based on the survivors from age n in year y-1. The initial equilibrium solution is clear since the initial number of recruits (upper left, in red) is equal to the number of recruits for the first year of observed catch (row 2, column 2). The right two columns are the associated spawning stock (S) and recruits (R) for each year.

6. **Calculate F_{msy}.** Extend the age structure calculated in step 4 for an additional 31 catch years (each with 20 age classes). There are no associated catch observations, we are just extending the structure from step 4 using the same **M**, age at first capture, age of maturity, and Beverton-Holt parameters. The catch equation is applied to each simulated catch year to calculate an associated level of catch (in tonnes). After completing all 31 years, the last 5 catch estimates are averaged into a single catch total. We will repeat step 5 for each value of **F** from 0 to 1 incrementing by 0.001 and save the averaged catch total for each. By plotting catch total against **F**, the **F** associated with the largest catch is F_{msy}. In the literature this is also identified as F_{max} (Figure 27). Which designation is used is dependent on density dependence concerns, but we use F_{msy} for practical reasons. Exploitation **E** (E_{msy}) is calculated directly from **F** (F_{msy}) using the calculation: $E = F / (M + F)$.

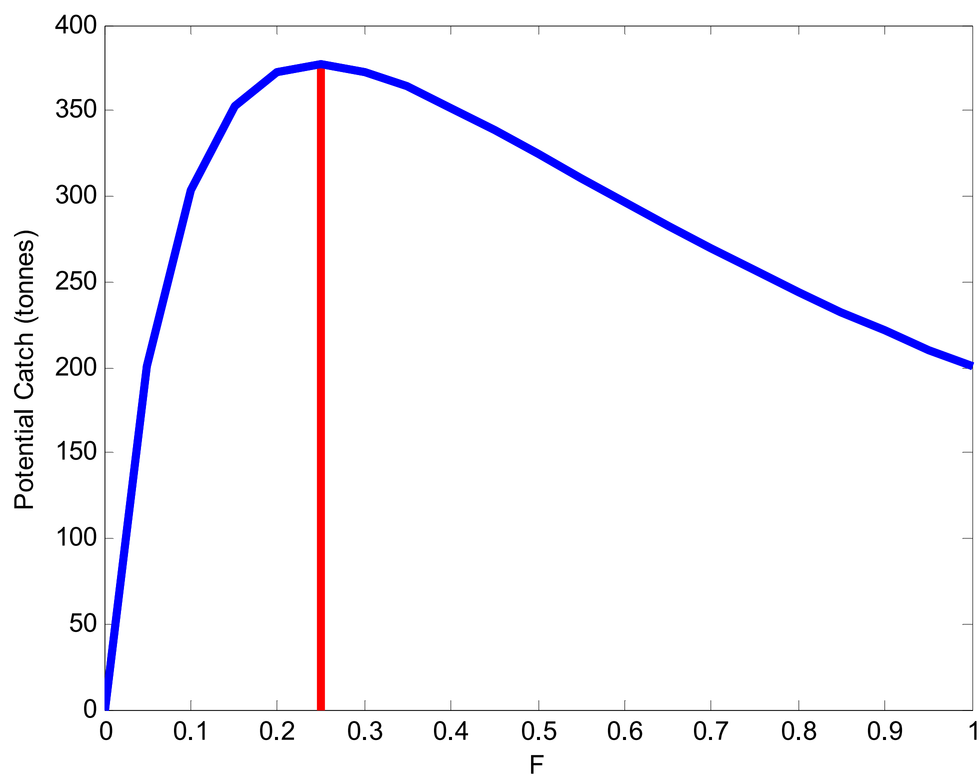

Figure 27. Potential catch (blue line) given specific values of F as calculated by FISMO. The red line indicates the location of F_{msy} in this case 0.25 and associated with the highest point in the plot of potential catch.

7. **Calculate F for each observed catch year starting with the first year**. For each year of observations, set the value of **F** equal to the $\mathbf{F_{msy}}$ calculated in Step 6. Starting at the first year of observed catch, that year's value of **F** is varied linearly until the estimated catch, as calculated in Step 5, for the given year equals the observed catch. Once the proper **F** has been found, the newly calculated number of recruits resulting from that year (also calculated as in Step 5) is used as the age one recruits in the subsequent year and the age structure is updated for all remaining years. This process continues until the initial **F** for each year of observed catch has been replaced with a fitted **F**. The effects of each year's **F**, as reflected in the number of recruits that represent the age one recruits for the subsequent year propagate and build through the table as the fitting process continues. In the Excel version of FISMO the fit is calculated using GoalSeek. The MATLAB version uses a custom routine that replicates the behavior of GoalSeek (see appendices). In Excel, it is possible for GoalSeek to fail at finding a suitable **F** when the estimated **F** exceeds 0.7. When this happens, the user needs to set that years initial **F** to 0.6 and then manually fit that year. While this may fail also, a second failure was never encountered using this procedure. The value of 0.6 was arrived at by Dr. Chavez thru experience with the behavior of the model. After manually fitting the 'failed' year, the fitting process is started over from the first year of observed catch (but maintaining previously fitted **F**s as the new guesses for their associated year). In practical terms, raising the value of **F** to 0.6 has the same effect as raising the number of initial recruits (step 3). In the MATLAB version of FISMO, when the estimate of **F** exceeds 0.6 the value of the initial recruit number is increased by 5 percent and the fitting of the individual **F**s begins over from the first year of observations. The whole process continues, in both the Excel and MATLAB versions, until an **F** is successfully fitted for all observed catch years. With the exception of checking to make sure that the initial number of recruits, if changed during this step, is realistic, the model calculations are complete and the current state of the model represents the fitted solution.

8. **Simulate 31 years into the future**. Keeping all parameters fixed at their current values, extend the age class structure (with associated spawning stock size, number of recruits, and catch estimate for an additional 31 simulated catch years (Figure 28). The 31 years will use the **F** calculated for the last year of observed catch. FISMO also allows stochastic variability to be introduced in the 31 year time series based on the C.V. of the observed catch time series. We did not utilize this feature during this assessment.

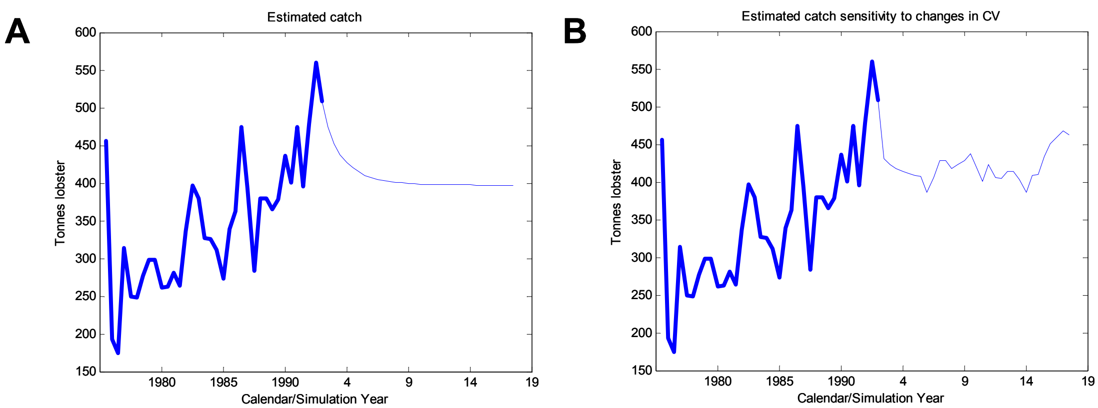

Figure 28. Estimated catch (thick line) plus 31 year simulated catch (thin line) time series from Scenario x (see below). (A) Stochastic variability not applied to the simulated catch. (B) Stochastic variability (CV = 0.2557) applied to simulated catch.

Sensitivity Tests. For sensitivity runs, we used a combined commercial+recreational landings dataset for the 15 years from 1996 through 2010. This dataset was also used for FISMO runs and is described below. In terms of inputs to FISMO, observed values, and calculations based on them, were considered exact and were not varied as part of the sensitivity analysis. Sensitivity testing was restricted to the following parameters, many of which were described earlier in the Life History section of this report:

Age at maturity (t_m). Sexual maturity occurs anywhere from 5-10 years in our spiny lobster with a generally quoted value of 5 years. In general, this parameter is important only when compared to the age at first capture, $\mathbf{t_c}$, since the difference between these two values dictates the number of spawnings that could occur prior to the lobster's recruitment into the fishery. This value is less than $\mathbf{t_c}$

based on field experience where sub-legal females have been caught that are sexually mature (Figure 29).

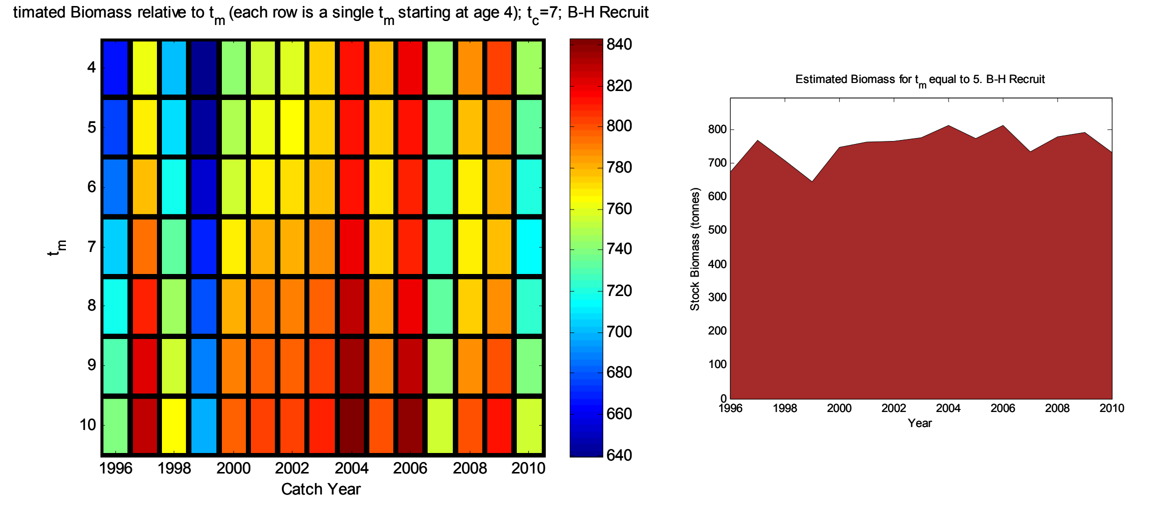

Figure 29. With t_c fixed at 7 years we varied age at maturity between 4 and 10 years (generally accepted range is 5-9 years). We used 5 years for FISMO runs. Values represent the tonnes of stock biomass needed to support the harvest resulting from the settings for t_m and t_c. Graph on right is a side view of the second row where t_m is 5. The lower 3 rows relate to t_m values greater than tc and are not considered realistic (see text). They are included to help illustrate the trend within each year as t_m increases.

Age at first capture (t_c). As with $\mathbf{t_m}$, the time it takes for a lobster to reach legal size is unknown and estimates have ranged from 6 to 11 years. Additionally, as with $\mathbf{t_m}$, the relationship between $\mathbf{t_c}$ and $\mathbf{t_m}$ (i.e., number of spawning years) dictate the response of the model more than just the value of $\mathbf{t_c}$. Changing $\mathbf{t_c}$ will increase or decrease the overall level of estimated biomass each year but will not change the overall relationship between peaks and valleys defined by the observed catch (Figure 30, right graph).

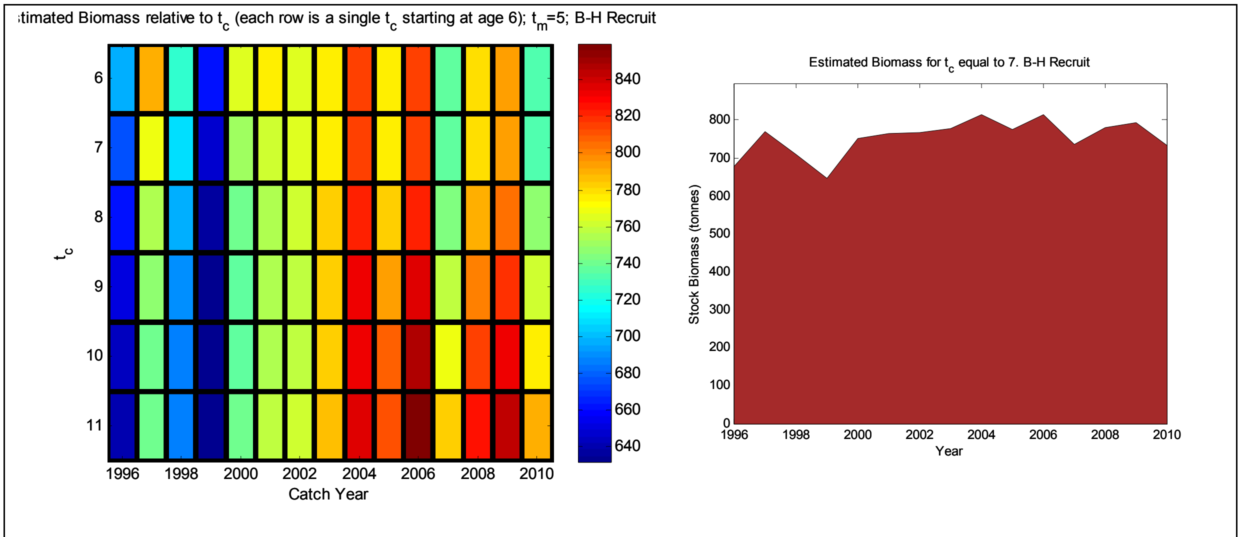

Figure 30. Stock size needed to sustain a fixed level of fishing given age of maturity equal to 5 years, and varying the age at first capture between 6 and 11 years. The accepted range is generally 7 to 10 years. The graph on the right, represents a side view of the second row corresponding to t_c equal to 7.

For a given value of $\mathbf{t_m}$, the value of $\mathbf{t_c}$ will affect the resulting calculation of $\mathbf{F_{msy}}$ and its relationship to the calculated **F**s by season (Figure 31). Again, this is based more on the relationship between $\mathbf{t_m}$ and $\mathbf{t_c}$, but unlike $\mathbf{t_m}$, the value of $\mathbf{t_c}$ can be modified in the field by changing the legal size of a lobster. As such, this provides a potential management solution if the seasonal **F**s exceed the $\mathbf{F_{msy}}$ in such a way as to threaten the sustainability of the fishery.

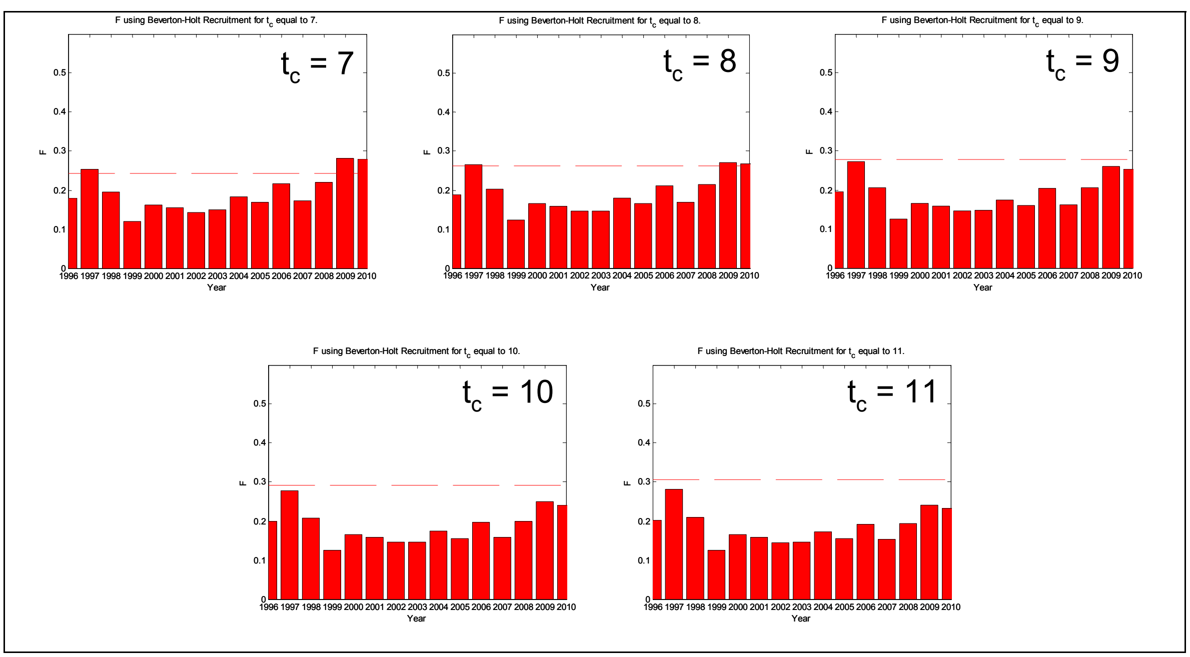

Figure 31. The effect on F (height of bars) relative to F_{msy} (dashed line) as t_c is increased. The larger t_c is, the lower the measured F will be relative to Fmsy. A 1-year increase in t_c corresponds roughly to a one quarter inch increase in carapace length assuming a 6 mm $year^{-1}$ growth rate.

Age at first capture versus age at maturity. $\mathbf{t_c}$ determines what age class fishing mortality is first applied by the model. $\mathbf{t_m}$ specifies the lowest age class included in the calculation of total breeding stock which determines the number of recruits for the following catch year. From a biological point of view, the difference between $\mathbf{t_m}$ and $\mathbf{t_c}$ - and $\mathbf{t_m}$ is always less than $\mathbf{t_c}$ - dictates the number of spawnings (one per year) before a lobster is recruited to the fishery. Increasing the difference between $\mathbf{t_m}$ and $\mathbf{t_c}$ leads to higher, age one recruit estimates for the first observed catch year (Figure 32) , higher estimated biomass over time (in this case after accumulating biomass between 1995 and 2010) (Figure 33), and a higher estimated $\mathbf{F_{msy}}$ (Figure 34). From a practical point of view, changing the difference between $\mathbf{t_m}$ and $\mathbf{t_c}$ is the same as changing the legal size of a lobster will have the same effect as increasing the difference between $\mathbf{t_m}$ and $\mathbf{t_c}$.

As stated previously, FISMO runs were made with the generally accepted values of $\mathbf{t_c}$ equal to 7 and $\mathbf{t_m}$ equal to 5. Any correction based on uncertainty of the actual value that leads to an increased interval between these two will lead to a more favorable conclusion for the stock and fishery. Decreasing the interval will lead to the opposite effect.

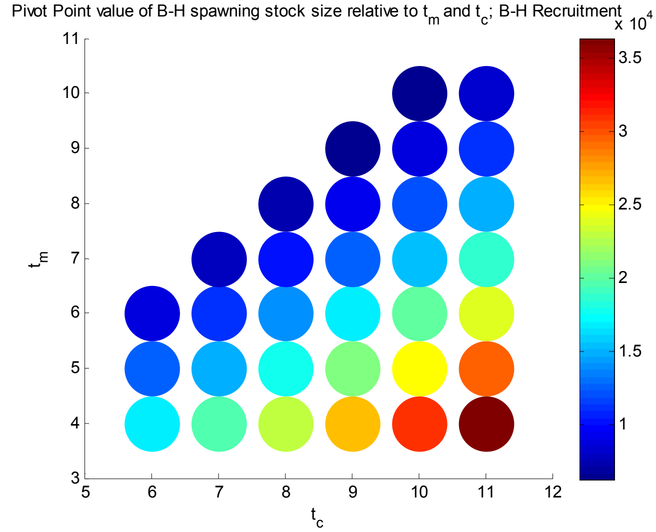

Figure 32. The initial number of recruits relative to t_m and t_c assuming Beverton-Holt recruitment. Only t_c and t_m were varied; all other parameter values were the same across all runs. The size of recruitment will increase as time span between sexual maturity and legal size (age of first capture) increases. Increasing legal size will increase the number of recruits in the system.

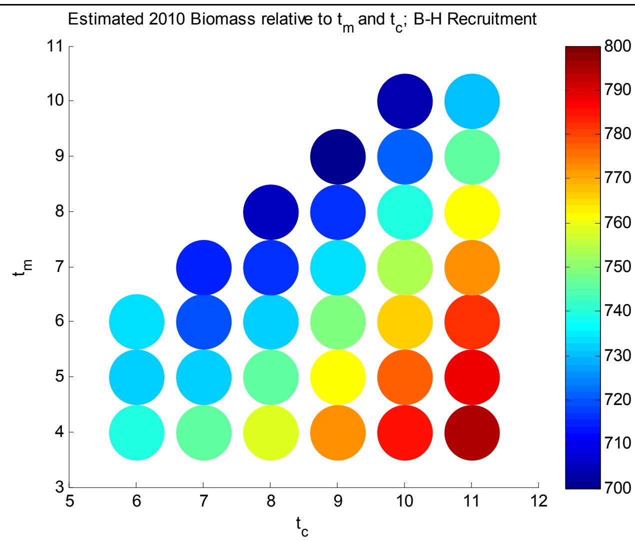

Figure 33. 2010 stock biomass calculated by FISMO relative to t_m and t_c assuming Beverton-Holt recruitment. Only t_c and t_m were varied; all other parameter values were the same across all runs. The stock biomass will increase as time span between sexual maturity and legal size (age of first capture) increases.

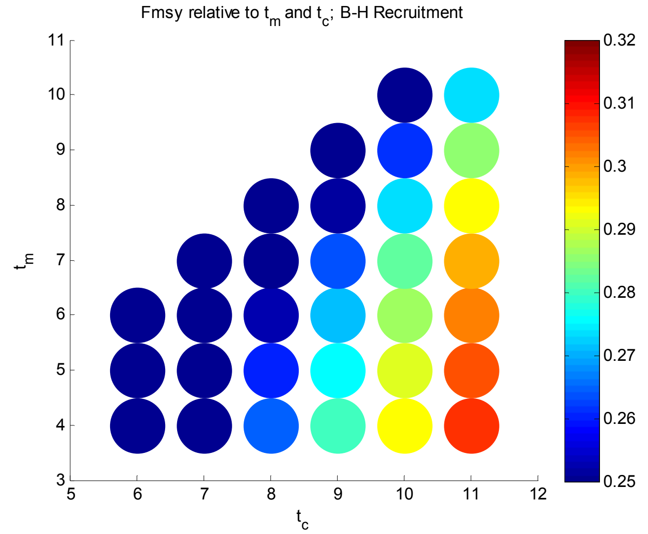

Figure 34. Level of Fmsy calculated by FISMO relative to t_m and t_c assuming Beverton-Holt recruitment. Fmsy increases as the number of years between sexual maturity and age of first capture increases. Higher stock biomass allows for additional fishing pressure.

FISMO, during the fitting of individual **F**s, has an upper allowable **F** of 0.6. The tendency of **F**, once 0.6 is reached during fitting, is to keep increasing leading to an unrealistic value. When 0.6 is surpassed, the model stops the fit, increases the initial number of recruits by 5 percent, and restarts fitting from the beginning of the observed catch years. The probability that the program will exceed 0.6 at some point in the fitting process is sensitive to the number of years between $\mathbf{t_m}$ and $\mathbf{t_c}$ (Figure 35). With a gap of 2 to 3 years between these parameters (we run the model with a usual gap of 2 year), the number of times we can expect to F to exceed 0.6 during fitting is reduced to 0 or 1. Exceeding 0.6 is not critical however, if the model exceeds 0.6 too many times the number of initial recruits can become unrealistically large.

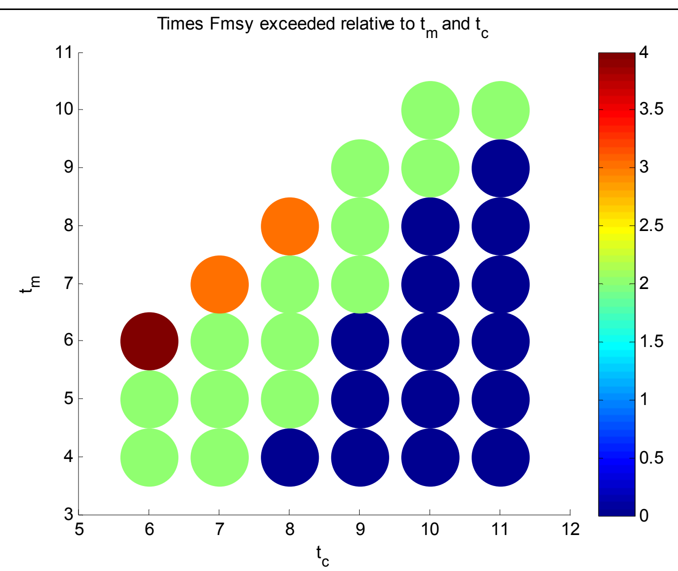

Figure 35. Each time FISMO exceeds F = 0.6 for any given year, the model will increase the calculated size of initial recruits by 5% and start over fitting Fs from the first year of observed catch. Increasing the number of spawn years by increasing t_c relative to t_m, reduces the number of times that an individual F will exceed 0.6.

Beverton-Holt alpha (α). The FISMO algorithm is extremely sensitive to this value and is most clearly seen in the resulting estimate for $\mathbf{F_{msy}}$. Referring to the modified Beverton-Holt recruitment equation used in the model:

$$R_y = \frac{\beta S_y A_T}{S_y + \alpha A_T}$$

S_y is the size of the spawning stock for year y, A_T is the total number of adults calculated by summing the 20 age classes related to the average observed catch. β is fitted by the model and was not varied. α, varying between 0 and 1 dictates the amount of influence the spawning stock has on the number of recruits (R_y) (Figure 36).

If α is set to 0, the number of recruits is independent of the spawning stock size and $R_y = \beta A_T$. If set to 1, the number of recruits is influence at a maximal level by S_y. This relationship is poorly understood in our lobster population since we do not know the abundance of the population, nor the number of recruits. Chavez & Gorostieta (2010) used a low value 0.15 in his modeling of the Baja Fishery. We favor a higher value primarily because the resulting biomass estimates with a higher value more closely mimic what we know of the population from fishing results, that there is no indication over the last ten years that the underlying stock being fished is changing or decreasing in numbers. Ehrhardt and Fitchett (2010), working with *P. argus* found that puerulus settlement (roughly equivalent to our age one recruits) showed that spawning stock abundance is linked to post-larval abundance at least in terms of settlement. They also found no correlation between spawning stock abundance and the number of lobster ultimately recruited to the fishery. Assuming the same trend exists with P. interruptus, this argues for a relatively high value for **α.** Because of this we decided to run two different values for **α**. We used 0.15 to mimic Chavez & Gorostieta's (2010) runs with the Baja fishery and we also ran the same scenarios with 0.50 to mimic higher survival rates during the pre-settlement phase of age one recruits. The choice of 0.50 is arbitrary.

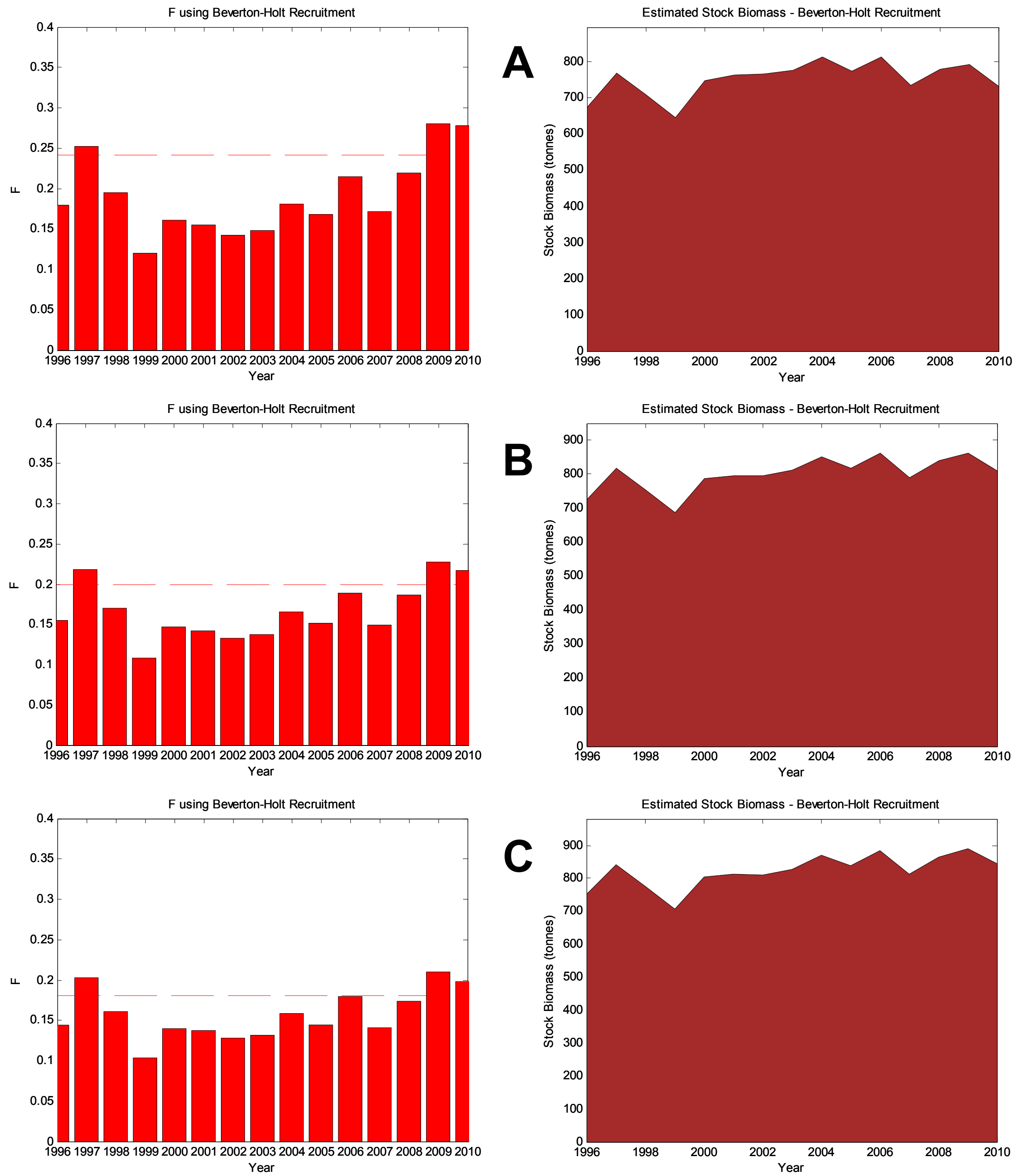

Figure 36. Changes in F_{msy} and estimated stock biomass calculated by FISMO given values of the Beverton-Holt α parameter of (A) 0.15, (B) 0.50, and (C) 0.75. Dataset 2 was used for these runs (see below).

Number of years used to calculate mean observed catch. This is more important with longer time series of observed catch in which the time series exhibits a number of distinct regimes. In the Excel version of FISMO, observed catch is restricted to 15 years and so it makes little difference if the mean is calculated across all 15 years (current method) or shorter years. However, we have a time series of observed catch that extends back 35 years and includes a steadily increasing catch between 1976 and 2000 followed by a sustained high catch from 2001 to present.

By averaging across the entire 35 years the model will calculate initial recruits based on the relatively low observed landings around 1994-1995 and the last ten years (of 300+ tonnes) of harvest will be near or exceeding the calculated $\mathbf{F_{msy}}$ relative to 1995. Based on the master scenario, we opted to calculate the mean across the years since 2000, since the resulting stock biomass estimates and **F** values are more realistic relative to the observed landings.

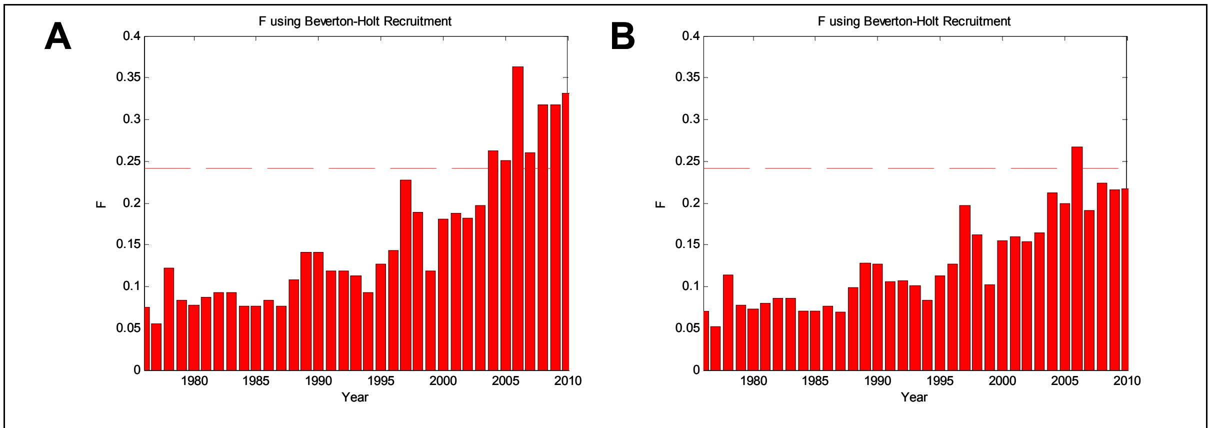

Figure 37. FISMO estimated F using dataset 2 (see below) and basing the initial number of recruits on (A) the average over the entire 35 years of observed catch, (B) the average over the last 11 years (since 2000) of observed catch. In both cases the $\mathbf{F_{msy}}$ was estimated at 0.2420.

Parameter Settings. For all the model runs presented, $\mathbf{t_c}$ was set to 7 years, and $\mathbf{t_m}$ was set to 5 years. Two different values were used for **α** (Beverton-Holt Recruitment): 0.15 reflecting the value used in Chavez and Gorostieta (2009) for the Baja Fishery, and 0.50 reflecting a tighter coupling between the number of adults and the number of recruits the following year. 0.50 is arbitrary since the actual value of this parameter is unknown. The remainder of the user specified parameters (e.g., von Bertalanffy parameters) were set as described above.

Catch datasets used for modeling runs. The catch datasets are:

1. Commercial catch only, ignoring the presence of a recreational fishery. This data is not realistic in that recreational catch is occurring and cannot be excluded from the overall catch record. Results are presented for interest only in the Appendices.
2. Commercial+recreational catch combined and assuming that the recreational catch in 2009 is 44 percent of the total commercial catch. The recreational catch is assumed to have larger numbers of non fishers and zero-catch trips than reflected in the actual report card returns. The levels selected are estimated and were arrived at through discussion with fishermen. This catch record was also used for the depletion model runs.
3. Commercial+recreational catch combined but reflecting the catch and fishing rates as actually seen in returned report cards. Recreational take is 61 percent of the total commercial catch and is considered to be the worst case scenario.

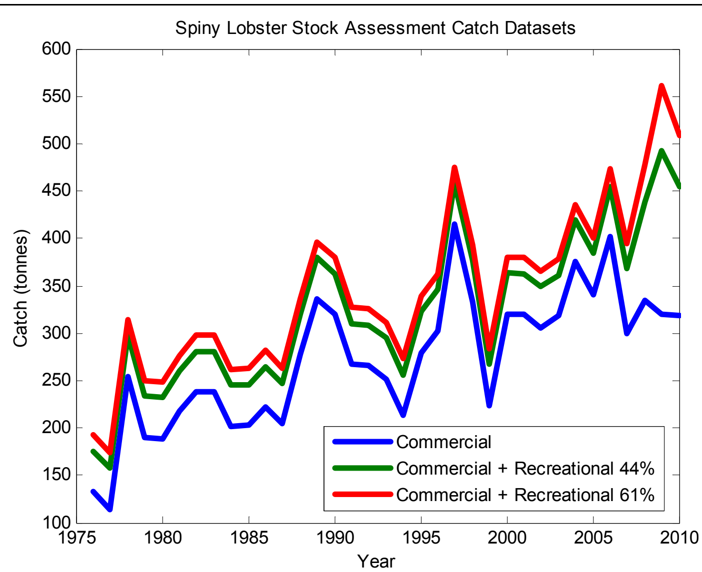

Figure 38. Datasets used for 35 year FISMO runs. Dataset 1 (blue line) is the commercial landings (t) only and was not used for this analysis (see the appendices for results. Dataset 2 (green line) used interpolated recreational catch assuming the 2009 catch is 44% of the total commercial catch. Dataset 3 (red line) is similar to dataset 2 but assumes the 2009 catch is 66% of the total commercial catch.

For each of these datasets, two time frames were considered: 15 years (corresponding to limitations in the original Excel FISMO model), 1996 to 2010; or 35 years, 1976 to 2010. The average observed catch was calculated from 2000 forward in both cases.

Modeling Scenarios

The only difference between scenarios is the choice of combined commercial + recreational observed catch record (i.e., dataset 2 or 3), the value of the Beverton-Holt **α** parameter (0.15 or 0.5), and the length of the observed catch time series (15 or 35 years). All other inputs were set, or initialized if an initial guess, to the same values (Table 2) during model runs. The model scenarios are:

1. Dataset 2, 15 year time series, Beverton-Holt **α = 0.15.**
2. Dataset 3, 15 year time series, Beverton-Holt **α = 0.15.**
3. Dataset 2, 15 year time series, Beverton-Holt **α = 0.5.**
4. Dataset 3, 15 year time series, Beverton-Holt **α = 0.5.**
5. Dataset 2, 35 year time series, Beverton-Holt **α = 0.15.**
6. Dataset 3, 35 year time series, Beverton-Holt **α = 0.15.**
7. Dataset 2, 35 year time series, Beverton-Holt **α = 0.5.**
8. Dataset 3, 35 year time series, Beverton-Holt **α = 0.5.**

For model runs using dataset 1, commercial-only observed catch, refer to the appendices.

Modeling Results

Scenario 1: Dataset 2, 15 year catch record, α=0.15. Considering 15 years only, and assuming the recreational catch represents 44 percent of the total commercial catch in 2009, $\mathbf{F_{msy}}$ is 0.2420 ($\mathbf{E_{msy}}$ = 0.5874), the fitted Beverton-Holt $\boldsymbol{\beta}$ is 0.5804, the initial number of recruits is 7.4 million lobster, and the annual effort is generally less than, but approaching, $\mathbf{F_{msy}}$. The increase in **F** over the latter 2000s is the result of an increase in the recreational catch beginning in 2005. While the combined catch also led to an F in excess of $\mathbf{F_{msy}}$ in 1997, the increase in recreational hoop netting is the reason the final two years (2009 and 2010) exceed $\mathbf{F_{msy}}$ (Figure 39A). Despite this, the estimated stock biomass is relatively stable with no clear decline as the decade progresses (Figure 39B). Exploitation follows the yearly **F** (as would be expected and only exceeds the $\mathbf{E_{msy}}$ in the final two years (excluding 1997)(Figure 39C), Assuming the level of **F** in 2010 is extended 31 years into the future from 2010, and everything else held constant, we would expect to see a decrease in catch to approximately 372 t from 454 t in 2010 (Figure 39D) .

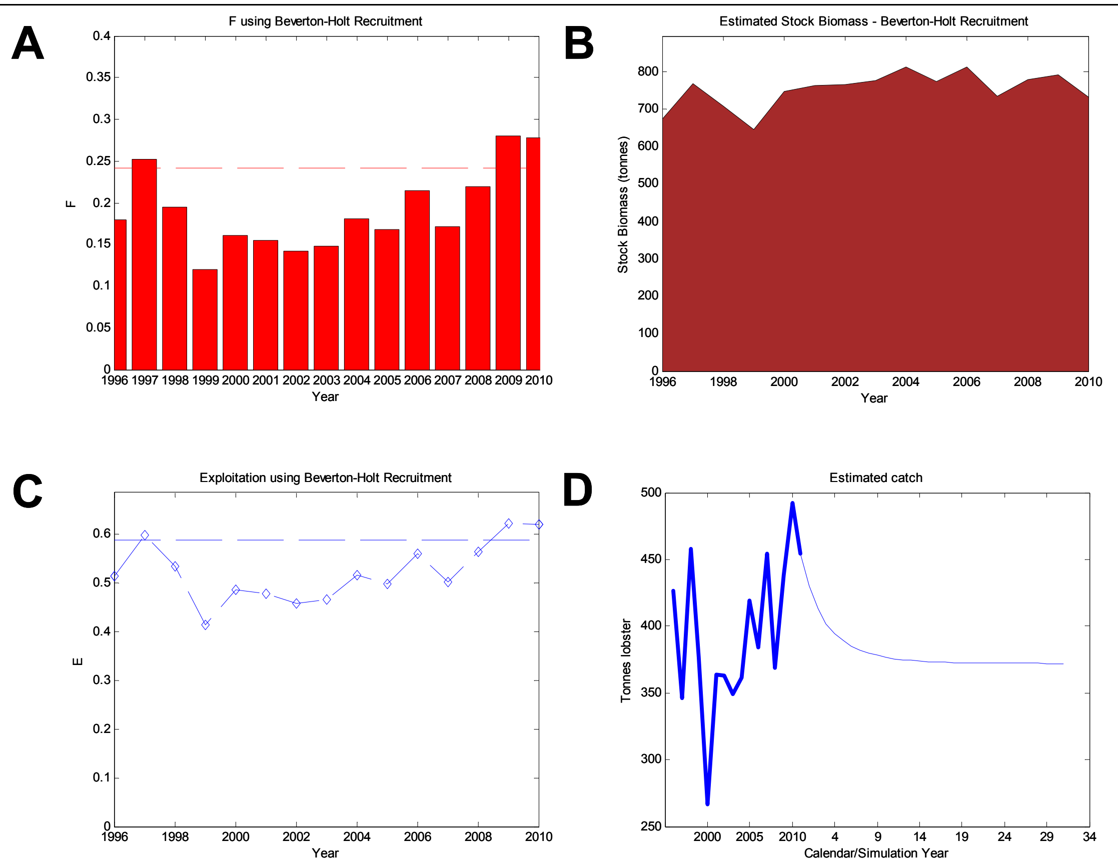

Figure 39. FISMO model results using commercial catch + recreational catch (recreational at 44% of commercial) from 1996 to 2010. Beverton-Holt

α was set at 0.15, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2420. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5874. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.2773).

Scenario 2: Dataset 3, 15 year catch record, α=0.15 This scenario considers 15 years only, and assumes the recreational catch represents 61 percent of the total commercial catch in 2009. As with scenario 1, $\mathbf{F_{msy}}$ is 0.2420 ($\mathbf{E_{msy}}$ = 0.5874), the fitted Beverton-Holt **β** is 0.5804, and the initial number of recruits is 8.2 million lobster. However, in this scenario, 1997 no longer exceeds the $\mathbf{F_{msy}}$ and the effort is dominated in the last two years, both of which exceed $\mathbf{F_{msy}}$ to a greater extent than in scenario 1. Again, the increase in the the final two years (2009 and 2010) is attributable to increased hoop net related effort. (Figure 40A). The estimated stock biomass, however, is stable and we can conclude that the level of fishing has been sustainable over the observed years (Figure 40B). Exploitation follows the yearly **F** and is provided here for interest only (Figure 40C), Assuming the level of **F** in 2010 is extended 31 years into the future from 2010, and everything else held constant, we would expect to see a decrease in catch from 508 t to approximately 395 t before leveling out (Figure 40D).

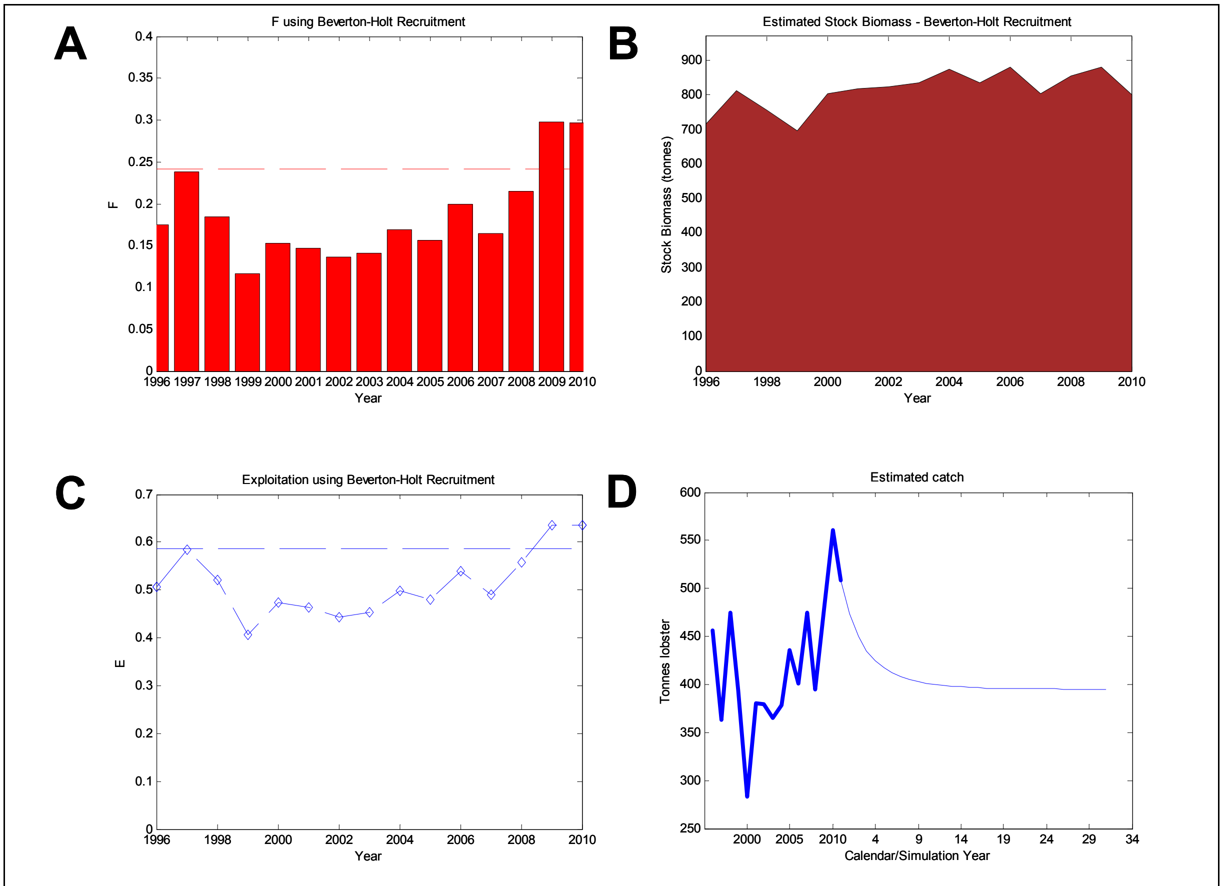

Figure 40. FISMO model results using commercial catch + recreational catch (recreational at 61% of commercial) from 1996 to 2010. Beverton-Holt α was set at 0.15, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year

(bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2420. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5874. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.2968).

Scenario 3: Dataset 2, 15 year catch record, α=0.50 This scenario mimics scenario 1 but sets the Beverton-Holt ***α*** to 0.50 (instead of 0.15). From sensitivity runs we would expect a lower calculated $\mathbf{F_{msy}}$, potentially leading to lower **F**s relative to the $\mathbf{F_{msy}}$. Indeed, both the $\mathbf{F_{msy}}$ (0.2) and $\mathbf{E_{msy}}$ (0.5406) are lower (0.2420 and 0.555, respectively for scenario 1). However, the same years (1997, 2009, and 2010) are still in excess, although not by as great a margin. The fitted Beverton-Holt **β** is 0.7571 and the initial number of recruits is 7.7 million lobster. The increase in F over the latter 2000s is still attributable to the increase in the recreational catch beginning in 2005 (Figure 41A). The estimated stock biomass is stable and may even be increasing slightly as the decade progressed (Figure 41B). Exploitation follows the yearly **F** (as would be expected and only exceeds the $\mathbf{E_{msy}}$ in the final two years (excluding 1997) (Figure 41C), Assuming the level of **F** in 2010 is extended 31 years into the future from 2010, and everything else held constant, the decrease is comparable to scenario 1, ending at 386 t (instead of 372 t as in scenario 1). (Figure 41D)

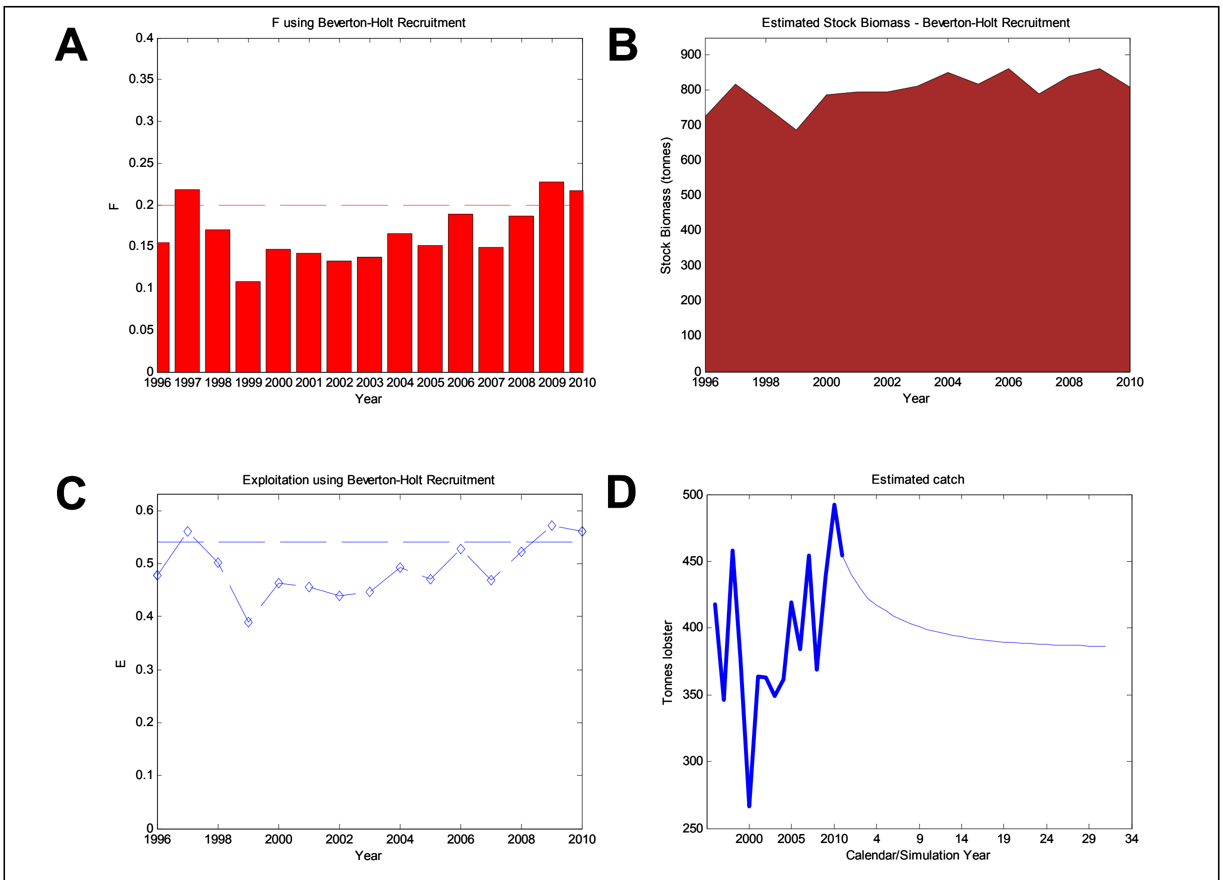

Figure 41. FISMO model results using commercial catch + recreational catch (recreational at 44% of commercial) from 1996 to 2010. Beverton-Holt α was

set at 0.50, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2000. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5406. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.2174).

Scenario 4: Dataset 3, 15 year catch record, α=0.50. The results for scenario 4 (Considering 15 years only, and assuming the recreational catch represents 61 percent of the total commercial catch in 2009) compared to scenario 2 are similar to the comparison between scenarios 1 and 3. Compared to scenario 2, $\mathbf{F_{msy}}$ (0.2) and $\mathbf{E_{msy}}$ (0.5406) are lower, there is a slightly smaller decrease (to 411 t) in catch over 31 simulated years (Figure 42D), and the estimated biomass is increasing over the decade (Figure 42B). $\mathbf{F_{msy}}$ and $\mathbf{E_{msy}}$ are exceeded primarily in 2009 and 2010 (Figure 42A & C). The fitted Beverton-Holt **β** is 0.7571 and the initial number of recruits is 8.2 million lobster. Despite fishing over the $\mathbf{F_{msy}}$ in the two most recent years the estimated stock biomass is stable with no indication of imminent problems in future years.

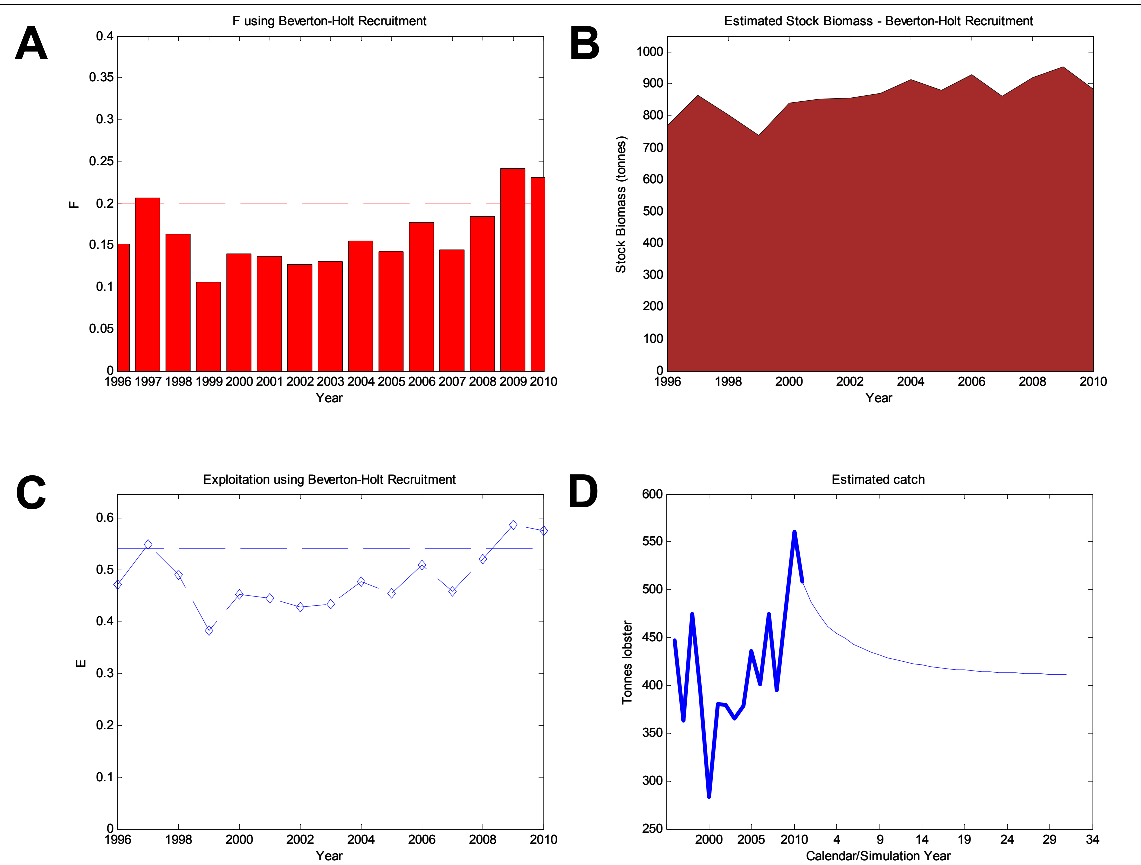

Figure 42. FISMO model results using commercial catch + recreational catch (recreational at 61% of commercial) from 1996 to 2010. Beverton-Holt α was set at 0.15, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2000. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5406. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for

2010 (0.2305).

Scenario 5: Dataset 2, 35 year catch record, α=0.15. Using 35 years of catch data (recreational catch is 44 percent of commercial catch in 2009) but averaging the catch only over the last 11 years (for the initial recruit estimate), clearly results in a gradual increase in fishing effort over time. The **F** time series builds towards the $\mathbf{F_{msy}}$ and finally exceeds it with an increase in the most recent 2 years (Figure 43A)**.** The estimated biomass exhibits a lower trend line around 750 t over the last decade but a declining trend in peak values since 2005 suggests the population may be impacted by fishing (Figure 43B). Overall, however, the estimate stock biomass since 2000 appears stable. The 31 year simulated catch estimate stabilizes at a harvest level of 373 t, down from 454 t in 2010 (Figure 43D), which is not inconsistent with the other scenarios. $\mathbf{F_{msy}}$ is 0.2420 ($\mathbf{E_{msy}}$ = 0.5874; Figure 43C), the fitted Beverton-Holt **β** is 0.5804, and the initial number of recruits is 7.7 million lobster.

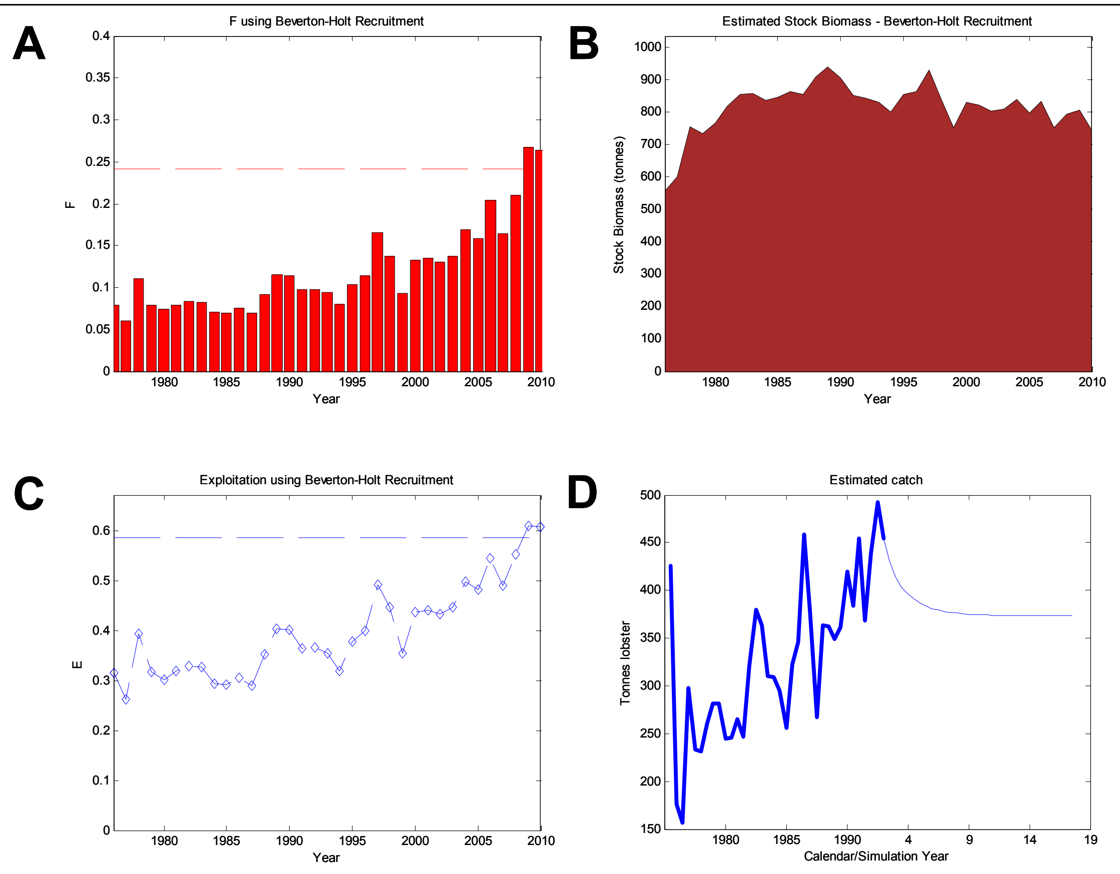

Figure 43. FISMO model results using commercial catch + recreational catch (recreational at 44% of commercial) from 1976 to 2010. Beverton-Holt α was

set at 0.15, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2420. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5876. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.2642).

Scenario 6: Dataset 3, 35 year catch record, α=0.15. As with scenario 5, the yearly **F**s build over time towards the $\mathbf{F_{msy}}$ but only exceed it, in a jump, in the last 2 years (Figure 44A). The estimated stock biomass is clearly stabilized, however since 2000 without any indications that the high level of **F** in 2009 and 2010 is having an impact on biomass (Figure 44B). Any additional effort however in the future could have a negative impact however, especially if there is an associated increase in catch (which would not be expected fishing over the $\mathbf{F_{msy}}$). In this scenario, the recreational catch is 61 percent of the total commercial catch in 2009, $\mathbf{F_{msy}}$ is 0.2420 ($\mathbf{E_{msy}}$ = 0.5874), the fitted Beverton-Holt **β** is 0.5804, and the initial number of recruits is 8.2 million lobster.

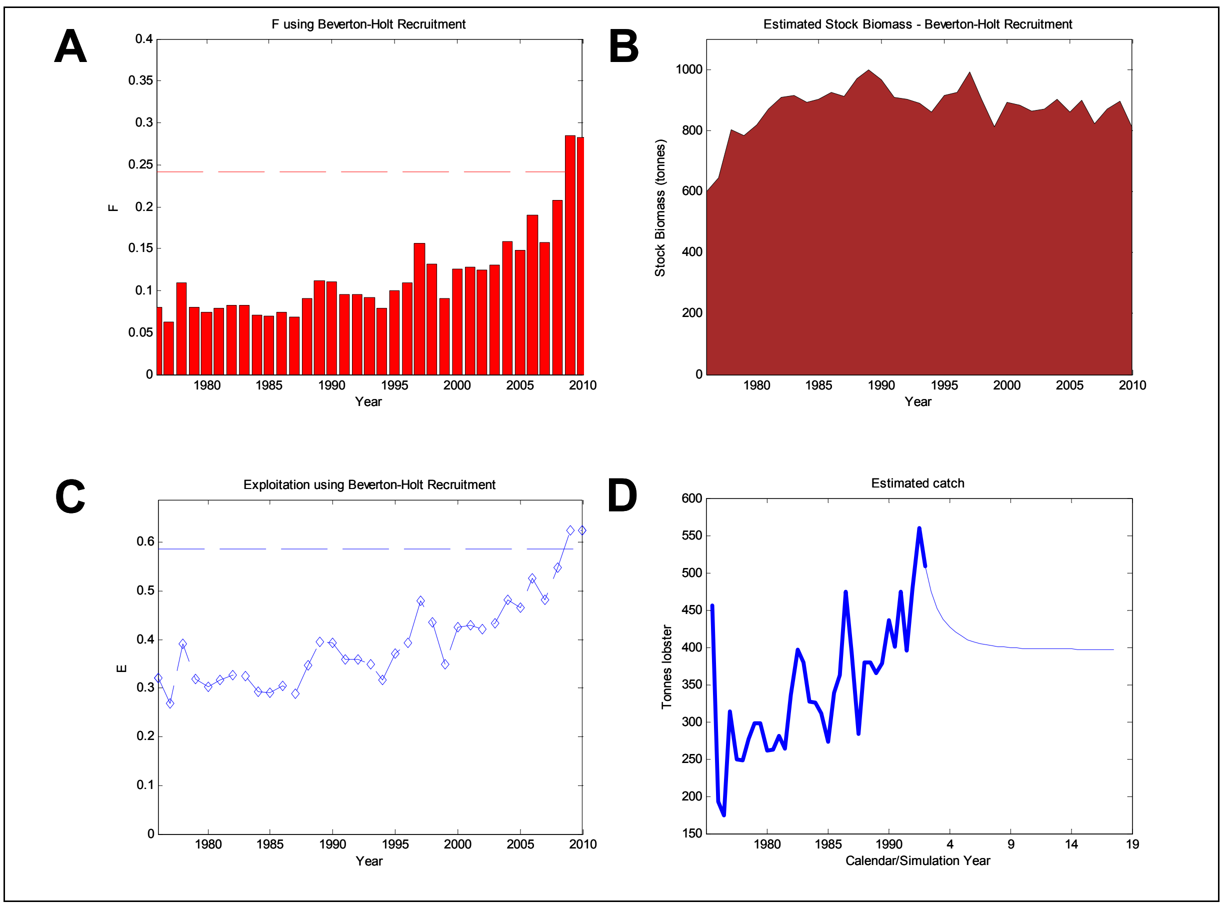

Figure 44. FISMO model results using commercial catch + recreational catch (recreational at 61% of commercial) from 1976 to 2010. Beverton-Holt α was set at 0.15, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2420. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5874. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.2829).

Scenario 7: Dataset 2, 35 year catch record, α=0.50. This scenario results in a steadily increasing F over the decades towards $\mathbf{F_{msy}}$ without ever exceeding it (Figure 45A). The estimated stock biomass also represents the best fit to the assumption that the lobster stock had reached a bottom in 1976 but, with the introduction of escape ports, rebuilt its stock numbers until reaching a plateau (Figure 45B). The plateau is reflected in the high, 300+ tonne annual landings since 2000. There was still a jump in **F** associated with hoop net popularization but the overall picture is one of a stable fishery that has yet to reach the Fmsy. In this scenario, the recreational catch represents 44 percent of the total commercial catch in 2009, $\mathbf{F_{msy}}$ is 0.2 ($\mathbf{E_{msy}}$ = 0.5406), Beverton-Holt **β** is 0.7571, and the initial number of recruits is 7.7 million. Over 31 years. assuming the level of **F** in 2010 is extended, the catch decreases to approximately 386 t, from 454 t in 2010 (Figure 45D) .

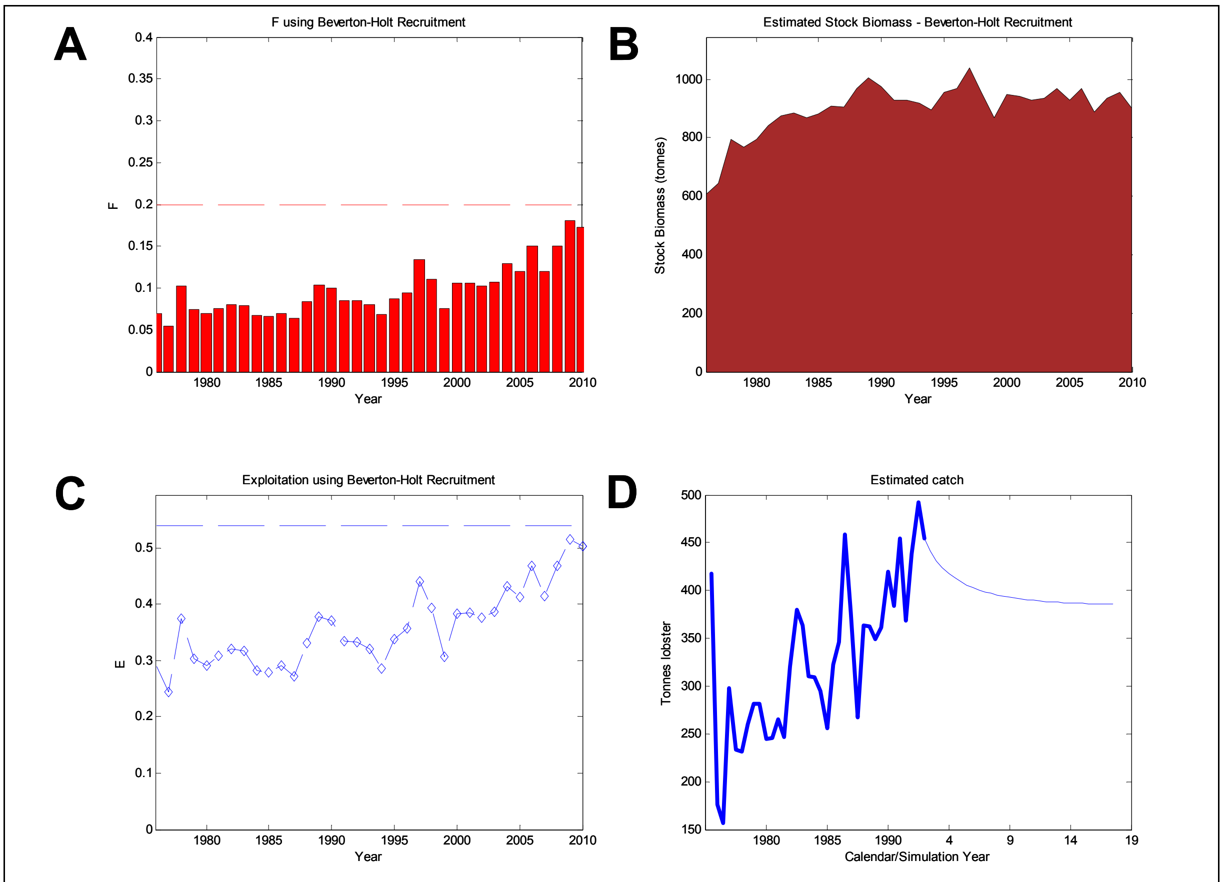

Figure 45. FISMO model results using commercial catch + recreational catch (recreational at 44% of commercial) from 1976 to 2010. Beverton-Holt α was set at 0.50, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2000. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year

(diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5406. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.1723).

Scenario 8: Dataset 3, 35 year catch record, α=0.50. Despite using a recreational catch based on the levels being equal to 61 percent of the total commercial catch (see the discussion for scenario 7), the seasonal **F**s were still below the $\mathbf{F_{msy}}$ (Figure 46A). The effort time series was increasing towards $\mathbf{F_{msy}}$ however and, if that continues, the fishery would start to waste extra effort on diminishing returns. At the moment though, in this scenario, the fishery is below $\mathbf{F_{msy}}$, and the estimated stock biomass is stable (Figure 46B). Like scenario 7, these results suggest the fishery is sustainable given the conditions of the run. The $\mathbf{F_{msy}}$ is 0.2 ($\mathbf{E_{msy}}$ = 0.5406), the fitted Beverton-Holt **β** is 0.7571, the initial number of recruits is 8.2 million lobster, and the annual effort is generally less than, but approaching, $\mathbf{F_{msy}}$. As with all the scenarios, the increase in **F** over the latter 2000s is the result of an increase in the recreational catch beginning in 2005. Assuming the level of **F** in 2010 is extended 31 years into the future from 2010, and everything else is held constant, we would expect to see a decrease in catch to approximately 414 t from 508 t (Figure 46D).

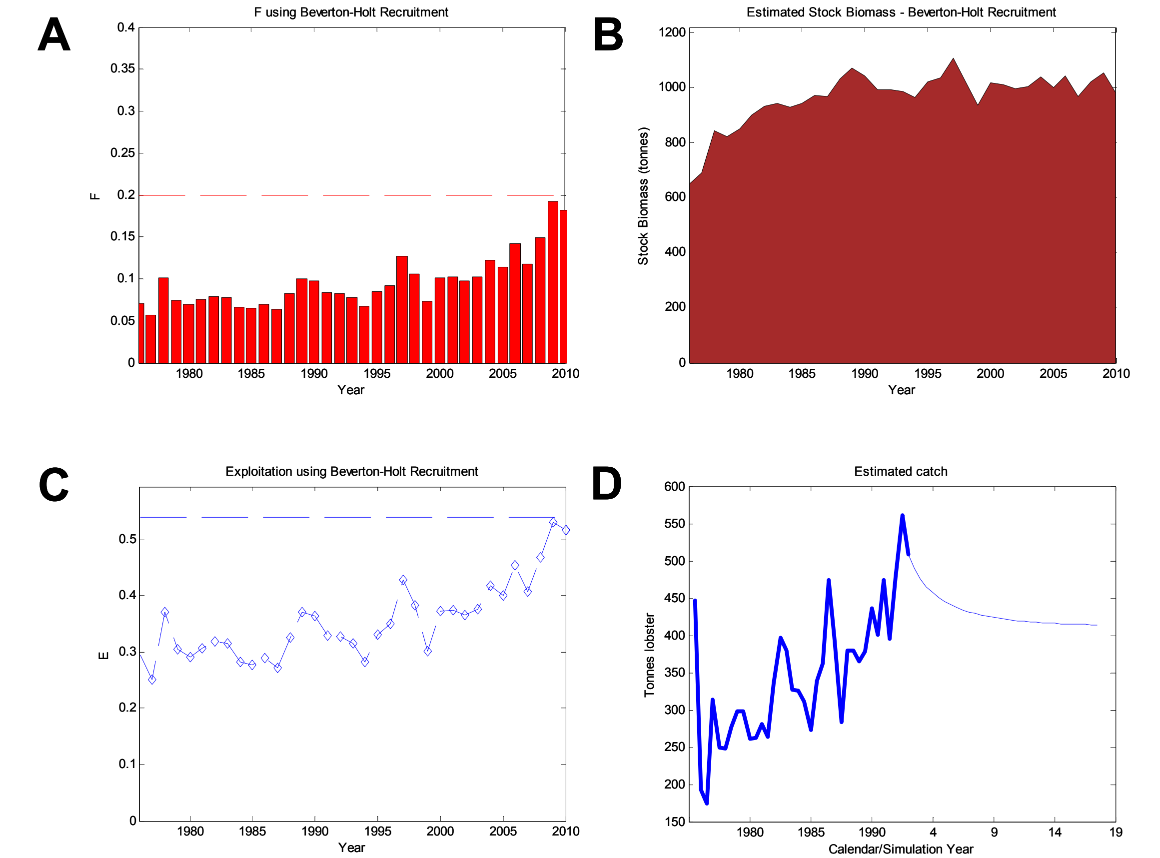

Figure 46. FISMO model results using commercial catch + recreational catch (recreational at 61% of commercial) from 1976 to 2010. Beverton-Holt α was set at 0.50, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2000. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5406. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.1823).

Conclusions. Of the 8 scenarios run by FISMO, 6 produce **F** values in excess of the **F_{msy}**. The last two years (2009 and 2010), associated with increased recreational hoop netting, were in excess of **F_{msy}** in all 6 instances. In the remaining two scenarios, both 35 year runs with high **α** (strong stock-larval recruitment relationship), all fishing effort remained below **F_{msy}**. In all scenarios, including those ultimately in excess of **F_{msy}**, the estimated stock biomass was stable although a single scenario might be interpreted as starting to decline. Based on these results we can conclude that the combined fisheries have been sustainable and are currently stable. However, the influence of the recreational fishery on recent high levels of **F**, couple with our inability at this time to determine if the popularity of hoop netting is continuing to increase, or has stabilized is a cautionary note to our conclusions.

The following scenario represents our overall interpretation of the combined recreational and commercial harvest record as suggested by the result of FISMO. In 1976, commercial landings had hit a historical low and the lobster population was probably relatively depleted. This occurred through a combination of heavy fishing and the large take of sub-legal lobsters. Essentially the population was being denied the few years of spawning prior to recruitment into the fishery and the stock collapsed. After introduction of the escape port, and perhaps in conjunction with a coincidental oceanic regime shift in 1976/1977, the stock slowly began to rebuild. Over the years, the stock increased as did the size of landings until around the year 2000, the commercial fishery neared $\mathbf{F_{msy}}$ and landings stabilized. All indications are that the fishery, even if at $\mathbf{F_{msy}}$, is stable and harvesting mostly from new recruits each year. Recreational take added to the overall harvest but the population appeared to be able to handle it. In 2005 however, hoop net popularity began to increased dramatically at the same time that more efficient, conical nets were introduced, and the recreational take increased substantially. For the last 10 years, the commercial catch has remained the same relative to the rate of catch over the season, size of animal caught, and percent of total catch represented by the legal lobsters. The number of permit holders has dropped over the same period although the number of active permit holders has remained relatively constant. What has changed, is the recreational fishery. If the total fishery is now at, or over, the $\mathbf{F_{msy}}$, it would be because of the increased recreational harvest since 2005. The population is still apparently stable but the recreational take needs to be watched closely since we do not have information on whether the size of the recreational fishery is increasing, stable, or decreasing and cannot predict from observations if there is cause for future concern.

Conclusions

The spiny lobster population off southern California appears to be stable from both observations and modeled results, and the fisheries targeting this species can be considered, as of today, sustainable. However, the increase in the recreational fishery, most notably in hoop netting, in recent years contributed to modeled fishing efforts approaching or exceeding estimated $\mathbf{F_{msy}}$ levels. In all but one scenario, the level of effort did not result in a decline in biomass and in the remaining scenario it is questionable whether a decline was in fact occurring. The two scenarios that supported best the stable nature of the stock biomass, relative to the fishing effort, were also the scenarios that best fit an increase in biomass since 1976 that we assume is reflected on the observed landing. All the modeling scenarios reflected, as well, a stable estimated stock biomass since 2000. Over that period of time, the commercial landing records reflected a stable, 300+ t record of landing.

Corroboration of a stable fishery can also be found in observed data as well. Relative to the last ten years, the commercial fishery has been consistently harvesting 300+ tonnes each season and the catch each season has been accumulated at the same general rate as the season progresses. The highest total landings occur within the first week or two of the season and 80 percent of the season total is landed before the end of January and usually by the end of December. The average size of commercially caught lobster has been fairly consistent as well at 1.39 ± 0.1 lbs over the decade. Recreationally-caught lobster have also been relatively consistent in size, despite the fact that the recreational fishery targets trophy animals. Based on depletion model results, the catchability has not varied significantly regardless of the ultimate seasonal landing totals. The number of short lobster released as a percentage of the total caught has also remained consistent over the decade, again regardless of the overall size of the seasonal harvest. The percentage of shorts is also consistent, whether we are examining individual counties or the entire bight. Retained lobster across the entire bight account for only 20-30 percent of the total lobster caught suggesting a very large, underlying population.

The number of operator permits has been declining and, despite a jump in the number of active permits in 2006, the number of traps deployed is expected to continue to decline, and the number of transfers in any given year (who may fish at higher effort levels) is not expected to be significant. Measured CPUE, while currently lower than two or three decades ago, is still within a standard deviation of the average CPUE over the last decade.

FISMO runs suggest that despite the apparent stability of the recent catch record, the fishery is approaching, or has reached the MSY. While this may mean that increased effort on the part of the fishermen will result in declining increases in catch, the overall stable state of so many population-specific parameters, and no immediate indication that anything is going to change, suggests the fishery is stable. The increasing FISMO biomass estimates over time also corroborated this conclusion. There is a confounding factor, however, and that is the recreational fishery.

The recreational fishery has changed dramatically since 2005 with the introduction and popularization of hoop nets. Preliminary data suggest that the recreational take is substantial, adding the equivalent of another 30 percent to 60 percent to the commercial harvest. Because of the limited data however, we can not tell if the recreational fishery is stabilizing or continuing to increase in its harvest. If the recreational hoopnet fishery continues to increase in popularity and commercial landings remain at current levels, the probability that model runs will exceed the $\mathbf{F_{msy}}$ will increase. Since our report card data collection lags each season by approximately a year and we can not detect changes in the recreational fishery within that timeframe, rates of change will take longer to quantify. Because of this, there is the danger that we will not know whether there is a problem with the recreational effort until commercial catch starts to decline. Future assessment efforts need to fully consider the uncertain state of the recreational effort when predicting the health of the fisheries.

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Acknowledgements

This assessment would not have been where it is without the help of Ernesto Chavez. He kindly provided a copy of his model FISMO and helped immensely with the learning curve on how to use it. Without his help I would not have been able to understand his model, write my own version and extend its functionality, and generate results in the 3-4 months I had. He also provided insights into the interpretation of FISMO results. Meisha Key of the Department of Fish and Game and Alec MacCall of the National Marine Fisheries Service gave freely of their time concerning the use of ASPIC. As ASPIC failed to work with our data, their insights into the model and underlying assumptions were invaluable. They also were able to finally confirm that we had exhausted all avenues trying to make ASPIC work with our data. Mark Maunder of the

Inter-American Tropical Tuna Commission, and Tom Barnes of CA Fish and Game provided helpful insights on assessments in general. The Lobster project members: Pete Kalvass, Kristine Barsky, and Travis Buck were also available whenever I needed help with this effort. Matt Kay of the Bren School at UCSB provided insights and comparison data from the northern Channel Islands. Finally, our data entry folk: Josh De Los Santos and Christy Juhasz performed miracles in entering as much data as they have over the last year.

Appendices

Appendix A. FISMO mathematical details.

In the description that follows, the steps listed do not correlate to the steps used in the FISMO Excel file nor in the body of this report. They are provided as a detailed breakdown of what occurs in both the Excel and Matlab version of FISMO.

Step 1: Determine the weight and length at age. Age-based size is calculated using the von Bertalanffy growth function (VBGF) for 24 years (Figure 23), and is used to establish a weight per lobster at age needed later for total stock biomass calculations. The VBGF formulation used is:

$$l_t = L_\infty \left(1 - e^{-K(t - t_0)}\right)$$

This is identical to the growth equation described earlier (and referenced as equation 9.9 in Ricker (1953)). The parameter values used are the same as described earlier, and summarized in Table 2. Growth in length is calculated over 24 years and then each year's length is converted to an associated weight using the standard power function, $\mathbf{W} = \mathbf{aL^b}$. The data used to derive the power function's values for **a** and **b** are the same (2007 DFG Recreational Creel Survey data) as described above (Figure 19). The creel observations were also expressed in centimeters for the purposes of FISMO instead of millimeters as displayed in Figure 16. Finally, it was recognized that the weights recorded on landing receipts, and used in FISMO, were based on whole lobster weights while lengths were for the carapace only. Approximately 600 lobsters from San Diego Bay were measured both ways (i.e., carapace only and whole body length) and the carapace was about 1/3 of the total length. Because of this we continued to use the same values for **a** and **b** as previously calculated. There was a difference in the proportion of tail to total length based on sex but since the ratio of males to females is unknown, we relied on an average of all lobster regardless of sex.

Step 2: Determine the initial number of recruits. FISMO's basic calculations rely on a population age structure derived from a single initial number of recruits calculated by fitting the estimated catch, based on the number of recruits, to the average catch, $\boldsymbol{Y_T}$, over a user-specified range of years of observed catch data. The basic calculation creates a 20-year average age structure using both fishing and natural mortality. Catch-at-age is calculated by applying the catch calculation to each age class. An estimated total catch is then calculated by summing all age classes. Initially, an arbitrary recruit abundance is used and is varied linearly until the estimated catch equals the average observed catch.

Note: Age 1 realistically starts with settlement (approximately 10 months after hatching) although the time spent in planktonic form is also included in Age 1. Larval mortality is not included in the equations directly.

Initial guesses are enclosed in parentheses.

A. Choose arbitrary starting values for the initial number of recruits, $\boldsymbol{R_e}$ (500,000). Natural mortality, $\boldsymbol{M}$, is assumed to be constant (0.1720) and calculated from $\boldsymbol{K}$ (0.1133 year^{-1}) using B-H invariant calculations described above. Fishing mortality, $\boldsymbol{F}$ is initialized to **M**. Values for age at maturity, $\boldsymbol{t_m}$, and age of first capture, $\boldsymbol{t_c}$, are also set at this time (refer to test scenarios for specific values).

B. Create a 20-year age composition $\boldsymbol{A_a}$ assuming an exponential decay in abundance following the age-related total mortality (**Z**):

$$A_{a+1} = A_a \times e^{-Z}$$

where

$\boldsymbol{a}$ = ages 2 to 20.

$\boldsymbol{A_1}$ = $\boldsymbol{R_e}$ = arbitrary initial recruit abundance estimate

if $\boldsymbol{a} < \mathbf{t_c}$, lobster is less than legal size age

$\boldsymbol{Z} = \boldsymbol{M}$ natural mortality only

otherwise

$\boldsymbol{Z} = \boldsymbol{M} + \boldsymbol{F}$ natural plus fishing mortality

Mortality is non-compensatory.

C. Using the VBGF-derived weights at age, W_a, calculated in Step 1, convert the abundance of lobster at age N_a into their equivalent biomass, B_a, The weights, W_a, represent kilograms which will be converted to tonnes.

$$B_a = A_a \times W_a$$

D. Calculate the catch-at-age Y_a from the catch equation (Equation 4.2.7, Sparre and Venema, 1998) for legal-size lobster only (those susceptible to being caught):

If a >0 t_c

$$Y_a = B_a \times \frac{F}{Z} \times \left(1 - e^{-Z}\right)$$

otherwise

$$Y_a = 0$$

and since we are only considering lobster that were caught, total mortality (Z) is

$$Z = M + F$$

E. The estimate of total catch, Y_e, is calculated by summing the catch-at-age, Y_a:

$$Ye = \sum Y_a$$

F. By repeating substeps B through E once more, and adding 100 to R_e, It is then possible to calculate the exact amount (δ) that needs to be added to the initial guess to achieve an exact fit with the observed average catch (Y_T).

$$\delta = \frac{\left|Y_T - Y_{+100}\right| / 100}{Ye \ - Y_{+100}}$$

Where:

$\boldsymbol{Y_T}$ = the average observed catch (over user-specified range of years)

$\boldsymbol{Y_{+100}}$ = the estimated catch after adding 100 to $\boldsymbol{R_e}$

The sign on δ is determined by the calculation's denominator. The initial recruitment $\boldsymbol{R_i}$ is then calculated as:

$$\boldsymbol{R_i} = \boldsymbol{R_e} + \delta$$

Step 3: Determine the best fit estimate for the initial slope, β, of the Beverton-Holt Stock-Recruitment Relationship.

[NOTE: The Technical Review Panel evaluated this B-H formulation and found it provided no advantage over the traditional B-H formulation. Future versions of FISMO will rely on the traditional B-H relationship. The following discussion, however, describes the version used by FISMO at the time of the technical review.]

[NOTE: In most formulations of the B-H recruitment relationship, ***α*** is used to denote the initial slope and ***β*** denotes the maximum number of adults in the population. The Excel spreadsheet swapped these symbols but used the values for slope and maximum adults correctly in the calculations. The following discussion uses the notation found in the spreadsheet.]

FISMO uses a slightly modified (the addition of ***α***) version of the B-H Stock-Recruitment Relationship:

$$R_{y+1} = \frac{\beta S_0 S_y}{S_y + \alpha S_0}$$

Where:

$\boldsymbol{\beta}$ = initial slope of the stock-recruitment curve. Estimated in this step.

$\boldsymbol{\alpha}$ = maximum number of adults possible as a proportion of total population. Set to 0.15 or 0.5 in test runs.

$\boldsymbol{S_0}$ = Maximum number of adult lobster

$\boldsymbol{S_y}$ = Total adult lobster in year ***y***

$\boldsymbol{R_{y+1}}$ = Total one-year-old recruits in year ***y***

The best fit estimate for $\boldsymbol{\beta}$ is determined by direct calculation of the $\boldsymbol{\beta}$ that results in a value of $\boldsymbol{R_{y+1}}$ equal to the initial recruit estimate, $\boldsymbol{R_i}$, calculated in *Step 2* (equilibrium conditions). Since we only have a single age composition, $\boldsymbol{A_a}$, also calculated in Step 2 and based on the average observed catch, $\boldsymbol{S_0}$ and $\mathbf{S_y}$ are set to the same value:

$$A_T = \sum_{a=t_m}^{20} A_a$$ Note: only ages ≥ the age of maturity are included.

The S-H stock-recruitment formula then becomes:

$$R = \frac{\beta A_T A_T}{A_T + \alpha A_T}$$ dropping the symbol $\boldsymbol{R_{y+1}}$

and the value for $\boldsymbol{\beta}$ such that $\boldsymbol{R}$ equals $\boldsymbol{R_i}$ can be calculated as

$$\beta = \frac{R_i\left(A_T + \alpha A_T\right)}{A_T A_T}$$

This value for $\boldsymbol{\beta}$ is used for all subsequent calculations involving the B-H stock-recruitment formulation.

Step 4: Calculate the age composition for each of the observed catch years using $\boldsymbol{\beta}$, $\boldsymbol{N_T}$, and initial guesses at $\boldsymbol{F}$ (for each year).

A. Create an array of ***F*** values for each of the years of catch data and set them to the same value as ***F*** in Step 2 (initialized to **M**):

$$F_y = M \qquad \text{for } y = 1 \text{ to n}$$

B. From the age composition calculated in Step 2, the number of lobster available as recruits (age 1) at the beginning of catch year 1 of the observed catch is equivalent to the number of lobster in age class 2 calculated from the average catch.

$$N_{1,1} = A_2 \times e^{-M}$$

See Step 2B for detail of A_2 calculation.

C.1. Create a 20-year age composition assuming an exponential decay in abundance following the age-related total mortality (***Z***):

If ***y*** = 1

$$N_{y,a+1} = A_a \times e^{-Z}$$

otherwise

$$N_{y,a+1} = N_{y-1,a} \times e^{-Z}$$

based on the previous age from the **PREVIOUS** year

where

a = ages 2 to 20.

if $a < t_c$, lobster is less than legal size age

$$Z = M$$

natural mortality only

otherwise

$$Z = M + F_y$$

natural plus year-specific, fishing mortality

C.2. After finishing the 20-year age composition for a given year, FISMO must calculate the recruits available for the next year prior to continuing. This is based entirely on the breeding stock, $\boldsymbol{S_y}$ – lobster older than the age of maturity, $\boldsymbol{t_m}$

$$S_y = \sum_{a=t_m}^{20} N_{y,a}$$

C.3. Calculation the number of recruits $\boldsymbol{R_y}$ based on the B-H stock recruitment formula and the value of $\boldsymbol{S_y}$ The second application of the B-H formula is replaced in subsequent steps by a stochastic reduction in the number of recruits based on a user-specified coefficient of variability and random noise.

The value for the maximum size of the adult population is equal to $\boldsymbol{A_T}$ calculated in Step 3.

$$R_y = \frac{\beta S_y A_T}{S_y + \alpha A_T}$$

C.4 This value is assigned as the size of age class 1 for year $\boldsymbol{y}$+1. $\boldsymbol{N_{n,1}}$ will be used to initialize another age composition time series in a later step.

$$\boldsymbol{N_{y+1,1} = R_y}$$

At this point we can proceed with the next year (up to 15) starting at step 4.C.1 again.

D. After all n x 20 values have been calculated, FISMO converts the values from numbers of individuals to biomass. FISMO then calculates the total exploited biomass using the VBGF-derived weights at age, $\boldsymbol{W_a}$, calculated in Step 1, and converts the abundance of lobster at age $\boldsymbol{N_{y,a}}$ into their equivalent biomass, $\boldsymbol{B_{y,a}}$. The weights, $\boldsymbol{W_a}$, represent kilograms which will be converted to tonnes.

$$B_{y,a} = N_{y,a} \times W_a$$

E. Calculate the catch-at-age $Y_{y,a}$ from the catch equation (Equation 4.2.7, Sparre and Venema, 1998) for legal-size lobster only (those susceptible to being caught):

If ***a*** >0 t_c

$$Y_{y,a} = B_{y,a} \times \frac{F_y}{Z_y} \times \left(1 - e^{-Z}\right)$$

otherwise

$$Y_{y,a} = 0$$

and since we are only considering lobster that were caught, total mortality (**Z**) is

$$Z_y = M + F_y$$

F. The estimate of total catch, Ye_y, is calculated by summing the catch-at-age, $Y_{y,a}$:

$$Ye_y = \sum Y_{y,a}$$

Ye_y will be recalculated for each year in a later step to fit yearly values of ***F*** to the observed catch data.

Step 5: Calculate a 31-year age class structure for both forecasting and estimating F_{msy}. FISMO creates a series of 31-year age class structure (20 age classes) forecasts applying a fixed value of ***F*** for all 31 years. The creation of this structure follows the method used to create an age composition from the **n** years of observed catch data. Once the 31 year structure is complete an estimated catch is calculated from the 31 year average catch. FISMO uses this structure after the model is fitted to perturb specific parameters and the effect on the fitted solution. FISMO also uses this same structure to estimate F_{msy} during the fitting process (refer to Step 6) which is the reason it is described here. The resulting 31 year x 20 age composition will be referred to as $\check{N}_{y,a}$.

Proxies are used for ***F*** , ***t**$_m$*, and ***t**$_c$* which are denoted with ***'***. Additionally, stochastic variability can be introduced by varying a coefficient of variability, **CV** (pertaining to the catch). During the fitting process ***F'*** and ***t**$_c$**'*** are the same values as used to calculate the age structure associated with the 15 years of observed catch, and **CV** is set to zero (i.e., no stochastic variability). During the forecasting process these values are modified, from those used to fit the observed catch age structure, as necessary for the given circumstance.

A. Once the entire age structure is complete for all n years, FISMO extends the age structure for an additional 31 years. The first of 31 years is based on year n of the n x 20 age composition, $\boldsymbol{N_{n,a}}$. This 31x20 array will be referred to as $\boldsymbol{\breve{N}_{y,a}}$.

The following substeps mirror substeps 4.B and 4.C.1 through 4.C.4 (with differences noted in the step description).

$$\breve{N}_{1,1} = R_n$$

See Step 4 for details of $\boldsymbol{R_n}$ calculation.

B.1. Create the 20-year age composition assuming an exponential decay in abundance following the age-related total mortality (***Z***):

If ***y*** = 1

$$\breve{N}_{y,a+1} = N_{15,a} \times e^{-Z}$$

otherwise

$$\breve{N}_{y,a+1} = \breve{N}_{y-1,a} \times e^{-Z}$$

based on the previous age from the **PREVIOUS** year

where

y = 1 to 31

a = ages 2 to 20.

if $a < t_c'$,   lobster is less than legal size age

$$Z = M$$ natural mortality only

otherwise

$$Z = M + F'$$ natural plus fishing mortality

B.2. Patterned after section 4.C.2, FISMO must calculate the recruits available for the next year prior to continuing. This is based entirely on the breeding stock, $\breve{S}_y$ – the ages older than the age of maturity, t_m'

$$\breve{S}_y = \sum_{a=t_m'}^{20} \breve{N}_{y,a}$$ for y = 1 to 31

B.3. Calculate the number of recruits available for the following year using the B-H stock recruitment formula. The value for the maximum size of the adult population is equal to N_T calculated in Step 3. Both the n year age composition and the 31 year age composition uses the same value for N_T (which is based on the n year average observed catch).

$$\breve{R}_{first} = \frac{\beta \breve{S}_y N_T}{\breve{S}_y + \alpha N_T}$$

B.4. Stochastically vary the recruit estimate based on the coefficient of variability (***C.V.***) and a randomly varied ***C.V.*** In practice, FISMO allows the user to specify the allowable size of the ***C.V.*** or calculate it from the observed catch, which is set to zero (0) for the current runs. ***rand()*** returns a random value between 0 and 1.

$$\breve{R}_y = \breve{R}_{first} - \left(2\breve{R}_{first} \times C.V. \times rand(\;)\right) + \left(\breve{R}_{first} \times C.V.\right)$$

B.5. This value is assigned as the size of age class 1 for year y+1.

$$\check{N}_{y+1,1} = \check{R}_y$$

At this point we can proceed with the next year (up to 31) starting at step 5.B.1 again.

C. After all 31x20 values have been calculated, FISMO converts the values from numbers of individuals to biomass and then calculates the total exploited biomass. Using the VBGF-derived weights at age, W_a, calculated in Step 1, convert the abundance of lobster at age $\check{N}_{y,a}$ into their equivalent biomass, B'_a. The weights, W_a, represent kilograms which will be converted to tonnes.

$$B'_{y,a} = \breve{N}_{y,a} \times W_a$$

D. Calculate the catch-at-age $Y'_{y,a}$ from the catch equation (Equation 4.2.7, Sparre and Venema, 1998) for legal-size lobster only (those susceptible to being caught):

If a >0 t_c'

$$Y'_{y,a} = B'_{y,a} \times \frac{F}{Z} \times \left(1 - e^{-Z}\right)$$

otherwise

$$Y'_{y,a} = 0$$

and since we are only considering lobster that were caught, total mortality (Z_y) is

$$Z' = M + F'$$

Note: F' is held constant for all 31 years of catch estimates calculated in this step, essentially asking the question 'What is the long-term consequence of this level of fishing effort?'.

E. The estimate of total catch, Y'_y, is calculated by summing the catch-at-age, Y'_a:

$$Y'_y = \sum Y'_{y,a}$$

Step 6: Calculate Fmsy and Emsy from B-H stock-recruitment information.
FISMO calculates the Fmsy by executing Step 5 twenty different times, each with a different value of ***F'.*** The values for ***F'*** cover the range 0 to 1 in increments of 0.05.

Note: The Excel spreadsheet version of FISMO increments by 0.05 providing a resolution of two decimal places. This was changed in the Matlab version to increments of 0.001 (resolution to three decimal places). For each value of F' the potential resulting catch is calculated as the mean of the last 5, of 31, years of catch forecasts:

$$\overline{Y'} = \sum_{27}^{31} Y'_y$$

The F_{msy} is the value of ***F*** associated with the highest value of the average catch (Figure 34). Exploitation level, E_{msy}, as a percent of total mortality is calculated :

$$E_{msy} = {F_{msy}} \Big/ \left(M + F_{msy}\right)$$

At this point in the model, FISMO has calculated optimal values for initial recruits, initial slope of the B-H curve, and F_{msy}. FISMO is now ready to fit yearly values of ***F*** to the observed catch record. FISMO initializes all values of ***F*** previously used in Steps 3 through 5 with F_{msy}, and recalculates Steps 3 through 5.

[Note: although technically the catch values based on the average total catch (see step 2) would also change because FISMO now has a fitted F_{msy} to use for ***F***, FISMO does not recalculated the initial recruits or the B-H beta value at this point.

Step 7: Fit an associated F to each of the n observed years of catch. FISMO fits an ***F*** to each year's observed catch by repeating Step 4 with varying values of F_y until the estimated total catch, $\boldsymbol{Ye_y}$, for that year equals the observed catch, $\boldsymbol{Yo_y}$. FISMO uses the Excel linear solver function, GoalSeek (Appendix II), to locate the correct value of $\boldsymbol{F_y}$. Once the value of $\boldsymbol{F_y}$ is found FISMO moves on to the next year until all years, 1 through n, are fitted. Excel, because of its nature, will recalculate the entire n x 20 age composition matrix each time a value for $\boldsymbol{F_y}$ is found but the solution only relies on those values between year 1 and the current year being fitted. The substeps from Step 4 are duplicated here with Step 7-specific commentary. These steps are used for EACH of the n years of observed data.

A. Initialize $\boldsymbol{F}$ to $\boldsymbol{F_{msy}}$:

$$\boldsymbol{F} = \boldsymbol{F_{msy}}$$

B. Initialize the number of lobsters available at the start of the 20-year age composition (i.e., the size of age class 1). The calculation of $\boldsymbol{R_i}$ was previously describe.

if year = 1

$$N_{1,1} = R_i$$

otherwise

$$N_{y,1} = R_{y-1}$$

C.1. Create a 20-year age composition assuming an exponential decay in abundance following the total mortality ($\boldsymbol{Z}$):

If $\boldsymbol{y}$ = 1

$$N_{y,a+1} = N_a \times e^{-Z}$$

otherwise

$$N_{y,a+1} = N_{y-1,a} \times e^{-Z}$$

where

a = ages 2 to 20.

if $a < t_c$, lobster is less than legal size age

$Z = M$ natural mortality only

otherwise

$Z = M + F$ natural plus year-specific, fishing mortality

NOTE: Although FISMO manipulates each year individually in this process, each year requires the information from the previous year. Subsequent years used the values reflecting the fitted ***F***s from previous years.

C.2. After finishing the 20-year age composition for a given year, FISMO must calculate the recruits available for the next year prior to continuing. This is based entirely on the breeding stock, S_y – lobster older than the age of maturity, t_m

$$S_y = \sum_{a=t_m}^{20} N_{y,a}$$

C.3. Apply the modified B-H stock recruitment formula to S_y

The value for the maximum size of the adult population is equal to N_T calculated in Step 3.

$$R_y = \frac{\beta S_y N_T}{S_y + \alpha N_T}$$

C.4 This value is assigned as the size of age class 1 for year y+1. $N_{n,1}$ will be used to initialize another age composition time series in a later step.

$$N_{y+1,1} = R_y.$$

D. FISMO converts the age class values from numbers of individuals to biomass. FISMO then calculates the total exploited biomass using the VBGF-derived weights at age, W_a, calculated in Step 1, and converts the abundance of lobster at age N_a into their equivalent biomass, B_a, The weights, W_a, represent kilograms which will be converted to tonnes.

$$B_a = N_a \times W_a$$

E. Calculate the catch-at-age Y_a from the catch equation (Equation 4.2.7, Sparre and Venema, 1998) for legal-size lobster only (those susceptible to being caught):

If a >0 t_c

$$Y_a = B_a \times \frac{F}{Z} \times \left(1 - e^{-Z}\right)$$

otherwise

$$Y_a = 0$$

and since we are only considering lobster that were caught, total mortality (**Z**) is

$$Z = M + F$$

F. The estimate of total catch, Ye, is calculated by summing the catch-at-age, Y_a:

$$Ye = \sum Y_a$$

Ye is the value that will be checked against the observed catch value. FISMO will continue to modify F and repeat substeps 7.B through 7.F until the estimated total catch equals the observed catch. The variation of **F** will be accomplished using the logic of Excel's GoalSeek function (Appendix II).

During the fitting process it is possible that FISMO will fail to converge on a specific value of ***F***. This condition occurs when ***F*** exceeds approximately 0.6 and is tied to the initial recruit size previously calculated; the initial recruit size is too small. When this happens FISMO will increase the size of initial recruits by 5 percent and start Step 7 over from the beginning, recalculating the fit for any previous years when necessary with the new initial recruit number. These increases and restarts are executed whenever ***F*** exceeds 0.6 and will continue until all years are successfully fitted.

Once all n years have been fitted to a year-specific **F** value, FISMO considers the fitting process to be complete. All subsequent steps are aimed at varying specific parameters and observing the changes to the fitted results. The fitted results are not overwritten by these manipulations.

Appendix B. Pseudo-code and description of Excel's GoalSeek function as used by the Matlab-version of FISMO.

GoalSeek is a black-box function provided with Excel to perform unidirectional linear searches for a single parameter's value that causes a formula relying on that parameter to evaluate as a pre-specified target value. The following pseudo-code is not official – Microsoft hasn't published the algorithm for GoalSeek – but is based on a snippet of Matlab code that produces results equivalent to GoalSeek with the same inputs. Comments are preceded by '%'. This routine is not entirely 'hands off'. There are situations in which the routine doesn't find a solution (or the step increment is so small that a solution is for all intents and purposes never reachable). These cases were rare and the code was then run manually to diagnose the problem, always with success.

```
step = zeros(length(F_), 1);
step(year) = 0.0001;
step_init = 0.00001;
step_size = step_init;

% figure out if we are above or below the goal with our initial estimate.
% This will allow us to tune the step increment, if needed, so that we don't
% initially overshoot the goal

catch_est_initial = Calculate_Catch_Estimate(F_);
old_step_sign = sign(Goal_CatchTons(year) - catch_est_initial(year));
new_step_sign = old_step_sign;
catch_est_temp(year) = catch_est_initial(year);

% start iterating by incrementing F_ by very small steps.  If we iterate
% past the solution then back up to the last value of F_ that didn't, reduce
% the size of the step and try again.  Step size will be reduced until the
% increment to F_ doesn't jump over the solution and the program will then
% proceed at the smaller step.  This is repeated if the step once again jumps
% over the solution.

Changing_F = F_;
while round(catch_est_temp(year)*100) ~= round(Goal_CatchTons(year)*100)
   Old_F = Changing_F;
   Changing_F = Changing_F + step * old_step_sign;
   catch_est_temp = Calculate_Catch_Estimate(F_);
   new_step_sign = sign(Goal_CatchTons(year) - catch_est_temp(year));

   if old_step_sign ~= new_step_sign
       step(year) = step_init/10;
       step_size = step_init/100;
       step_init = step_init/10;
       Changing_F = Old_F;
   else
       step(year) = step(year) + step_size;
   end

% The following if-statement is not coded into the Excel version but Excel
% exhibits a behavior where Excel fails to find a solution if the F_ value
% exceeds 0.59.  In that case, the user manually sets F_ to 0.6 and
% increases the size of the initial recruitment by 5%, and starts all over
% with the estimate of the year 1 F_ value.  This if-statement duplicates
```

```
% that behavior automatically.  At some point, why Excel fails at higher
% levels of F_ will be investigated and corrected in the math and the
% following if will not be necessary.  The user also needs to be aware that
% 0.6 is an artificial restriction and the actual value of F_ may be above
% 0.6 in reality.

   if Changing_F(year) > 0.6
       status = -1;
       catch_est = 0;
       return;
   end
end

catch_est = catch_est_temp;
status = 1;
```

Appendix C. Historical Commercial Lobster Logbook Date Entry Status

Table 3. Status and Availability of Digital Commercial Logbook Records. Entries in red can be used without filtering although some editing may still be occurring. Entries in black either haven't been checked for obvious typos or were entered in mid-season and do not represent a full season. These records are still usable although care must be taken when comparing to seasons in red. Non-bold faced entries are currently being entered from paper logs for the first time and are unavailable for use. Seasons 1998-99 through 2008-09 were the only edited seasons available at the beginning of this stock assessment effort.

Season	Entry Status	Repository	Approximate Date Available	Notes
1973-74	ENTERED	SD DFG	1/8/2011	Incomplete Seasons based on computer printouts – logs lost
1974-75	ENTERED	SD DFG	12/20/2010	Incomplete Seasons based on computer printouts – logs lost
1975-76	ENTERED	SD DFG	11/29/2010	Incomplete Seasons based on computer printouts – logs lost
1976-77	ENTERED	SD DFG	11/16/2010	Full Entry
1977-78	ENTERED	SD DFG	9/28/2010	Full Entry
1978-79	ENTERED	SD DFG	8/26/2010	Full Entry
1979-80	ENTERED	SD DFG	7/30/2010	Half of the season logs are lost - Full Entry
1980-81	ENTERED	SD DFG	7/30/2010	Full Entry
1981-82	ENTERED	CFIS	3/2011	Full Entry
1982-83	ENTERED	SD DFG	4/26/2010	Full Entry
1983-84	ENTERED	SD DFG	6/8/2010	Full Entry
1984-85	ENTERED	SD DFG	11/16/2010	Full Entry
1985-86	ENTERED	CFIS	3/2011	Full Entry
1986-87	ENTERED	SD DFG	1/13/2011	Full Entry
1987-88	ENTERED	SD DFG	11/3/2010	Full Entry
1988-89	ENTERED	SD DFG	1/13/2011	Full Entry
1989-90	ENTERED	SD DFG	12/1/2009	Incomplete Entry of Season Logs
1990-91	ENTERED	SD DFG	12/1/2009	Incomplete Entry of Season Logs
1991-92	ENTERED	SD DFG	12/1/2009	Incomplete Entry of Season Logs
1992-93	ENTERED	SD DFG	12/1/2009	2nd half of season data lost - Incomplete Entry of Season Logs
1993-94	ENTERED	SD DFG	12/1/2009	Incomplete Entry of Season Logs
1994-95	ENTERED	SD DFG	12/1/2009	Incomplete Entry of Season Logs
1995-96	ENTERED	SD DFG	12/1/2009	Incomplete Entry of Season Logs
1996-97	ENTERED	SD DFG	12/1/2009	Incomplete Entry of Season Logs
1997-98	ENTERED	SD DFG	12/1/2009	Incomplete Entry of Season
1998-99	ENTERED	CFIS	12/1/2009	No Landmark Data
1999-00	ENTERED	CFIS	12/1/2009	No Landmark Data
2000-01	ENTERED	CFIS	12/1/2009	No Landmark Data
2001-02	ENTERED	CFIS	12/1/2009	No Landmark Data
2002-03	ENTERED	CFIS	12/1/2009-Being Re-entered	No Landmark Data
2003-04	ENTERED	CFIS	12/1/2009	No Landmark Data
2004-05	ENTERED	CFIS	12/1/2009	No Landmark Data
2005-06	ENTERED	CFIS	12/1/2009	Limited Landmark Data

2006-07	ENTERED	CFIS	12/1/2009	Limited Landmark Data
2007-08	ENTERED	CFIS	12/1/2009	Full Entry
2008-09	ENTERED	CFIS	12/1/2009	Full Entry
2009-10	ENTERED	CFIS	Approx. 10/1/2010	Full Entry

Appendix D. Recreational Creel Survey Details for 1992 and 2007 surveys.

Table 4. 1992 Creel Survey Coverage and Interview Statistics.

County	Location	Targeted Site Priority	Realized Site Priority	# Visits	Hours on Site	# Interviews	# Interviews / Visit	# Interviews / Hour
San Diego	Dana Basin Launch Ramp	1	1	7	56	205	29.29	3.66
	Shelter Island Launch Ramp	1	1	7	56	223	31.86	3.98
	La Jolla to Bird Rock BB	1	2	6	48	109	18.17	2.27
Ventura	Channel Islands Harbor Launch Ramp	1	3	5	39.5	108	21.60	2.73
Total				25	199.5	633	100.92	23.58

Table 5. 2007 Creel Survey Coverage and Interview Statistics.

County	Location	Targeted Site Priority	Realized Site Priority	# Visits	Hours on Site	# Interviews	# Interviews / Visit	# Interviews / Hour
San Diego	Dana Basin Launch Ramp	1	1	23	82.67	107	4.65	1.29
	Shelter Island Launch Ramp	1	1	25	99.10	214	8.56	2.16
	Ocean Beach Pier	1	1	20	68.10	245	12.25	3.6
	Oceanside Launch Ramp	2	2	11	37.33	18	1.64	0.48
	Shelter Island Pier	2	1	19	40.12	28	1.47	0.7
	La Jolla to Bird Rock BB	3	3	9	21.13	7	0.78	0.33
	Oceanside Pier	4	2	13	31.53	42	3.23	1.33
	South Shores Launch Ramp	4	4	2	3.67	1	0.5	0.27
	Zuniga Jetty	4	4	1	1.23	0	0	0
Orange	Dana Point Launch Ramp	1	1	21	74.88	72	3.43	0.96
	Laguna Beach (Abalone Pt.-Aliso Beach)	1	1	17	63.88	38	2.24	0.59
	Irvine Coast	2	2	9	26.95	9	1	0.33
	San Clemente Pier	3	1	17	31.68	98	5.76	3.09
	Newport Pier	3	2	11	28.27	0	0	0
	Newport Dunes Launch Ramp	4	2	9	21.25	4	0.44	0.19
	Sunset Aquatic Park Launch Ramp	4	3	6	15.07	1	0.17	0.07
Los Angeles	Dave's Launch Ramp	1	1	17	75.75	70	4.12	0.92
	Cabrillo Beach Launch Ramp	1	3	6	17.25	6	1	0.35
	Palos Verdes BB - Malaga Cove to Long Pt.	1	1	21	76.67	22	1.05	0.29
	Marina del Rey Launch Ramp	1	1	13	45.75	51	3.9	1.11
	Redondo Beach Pier	2	1	19	55.75	27	1.42	0.48
	Royal Palms BB	2	4	3	5.75	0	0	0
	Pt. Vicente Fishing Access	3	4	3	4.50	0	0	0
	King Harbor Small Pier	3	3	9	22.87	6	0.67	0.26
	King Harbor Jetty	3	4	3	4.48	1	0.33	0.22
	Belmont Pier	4	3	10	20.58	2	0.2	0.1

County	Location	Targeted Site Priority	Realized Site Priority	# Visits	Hours on Site	# Interviews	# Interviews / Visit	# Interviews / Hour
Ventura	**Ventura Harbor Launch Ramp**	**1**	**1**	**18**	**109.50**	**102**	**5.67**	**0.93**
	Deer Creek BB	**1**	**2**	**10**	**18.95**	**3**	**0.3**	**0.16**
	Leo Carrillo State Beach	**1**	**2**	**10**	**20.97**	**6**	**0.6**	**0.29**
	Channel Islands Harbor Launch Ramp	**1**	**1**	**21**	**95.75**	**56**	**2.67**	**0.58**
	Port Hueneme Pier	**2**	**3**	**7**	**14.00**	**0**	**0**	**0**
	Channel Islands South Jetty	**2**	**4**	**2**	**1.15**	**2**	**1**	**1.74**
	Kiddie Beach	**2**	**4**	**3**	**9.32**	**4**	**1.33**	**0.43**
	Ventura Pier	**2**	**4**	**2**	**3.00**	**1**	**0.5**	**0.33**
Total				**390**	**1248.85**	**1243**	**70.88**	**23.58**

Appendix E. Leslie Depletion Results.

Table 6. Leslie Depletion Model results considering only commercial catch and effort. Calculations are based on the number of weeks required to catch approximately 80% of the season total. Initial fishable biomass (B_0) is represented relative to 80% of the total catch and also extrapolated to 100% of the total catch. The data for season 2002-03 did not fit the model assumptions and the model results for that season are excluded from the table. q_t is the catchability; the percent of the 80% total catch caught on each trap pull.

Season	# Weeks Selected	Percent of total Catch	q_t	Optimal B_0 (80%) (pounds)	Upper B_0 (80%) (pounds)	Lower B_0 (80%) (pounds)	Total B_0 (100%)	Total Catch (pounds)	Total # Traps	Total CPUE
1999-00	15	78.09	1.05×10^{-6}	785348.4	916952.2	696059.5	1005697	486215.2	791,658	0.62
2000-01	12	78.03	2.63×10^{-6}	707163.7	750892.2	671649.3	906271.6	705106.3	789,632	1.00
2001-02	12	78.42	1.70×10^{-6}	895569.1	989800	824921.7	1142016	696179.5	773,891	0.78
2002-03	Data doesn't fit assumptions							700670.0	850,362	0.82
2003-04	13	79.70	1.17×10^{-6}	1116979	1250542	1017499	1401479	733373.3	857,266	0.66
2004-05	12	78.13	2.15×10^{-6}	934814.1	983781.5	893341.5	1196485	856363.1	801,098	0.92
2005-06	12	77.91	1.51×10^{-6}	1026516	1114192	956721.5	1317566	762568.6	789,694	0.74
2006-07	10	76.96	1.86×10^{-6}	1070922	1141752	1012312	1391531	888783.1	826,815	0.83
2007-08	12	77.65	1.90×10^{-6}	771182	877065.8	698747.6	993151.4	663030.9	785,623	0.86
2008-09	11	77.72	1.56×10^{-6}	929449.4	1056412	840588.8	1195895	737681.2	873,797	0.79
2009-10	12	77.53	1.37×10^{-6}	1016708	1108999	944348.3	1311374	742057.0	831,059	0.73

Table 7. Leslie Depletion Model results using combined recreation and commercial catch data. Effort (total # of traps) is based on commercial catch only. Calculations are based on the number of weeks required to catch approximately 80% of the season total. Initial fishable biomass (B_0) is represented relative to 80% of the total catch and also extrapolated to 100% of the total catch. The data for season 2002-03 did not fit the model assumptions and the model results for that season are excluded from the table. q_t is the catchability; the percent of the 80% total catch caught on each trap pull.

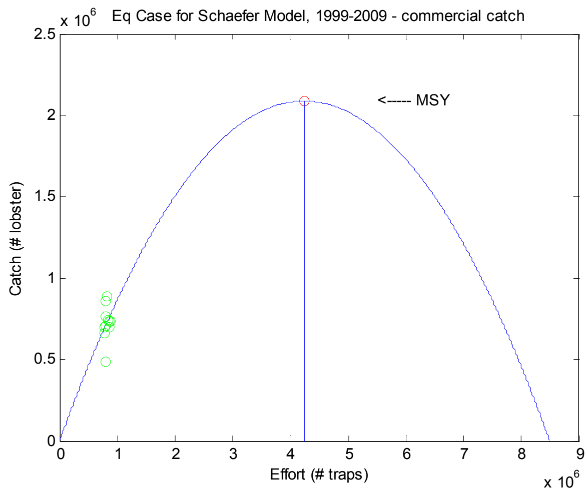
Season	# Weeks Selected	Percent of total Catch	q_t	Optimal B_0 (80%) (pounds)	Upper B_0 (80%) (pounds)	Lower B_0 (80%) (pounds)	Total B_0 (100%) (pounds)	Total Catch (Y) (pounds)	Total # Traps	Total CPUE
1999-00	15	78.09	1.10×10^{-6}	890,843.6	1026200	796574.3	1140791	563296.9	791,658	0.71
2000-01	12	78.03	2.51×10^{-6}	799,685.1	855250.4	755429.8	1024843	782188.0	789,632	0.99
2001-02	12	78.42	1.64×10^{-6}	1,013,663.4	1130903	927639	1292608	773261.2	773,891	1.00
2002-03	Data doesn't fit assumptions							777751.8	850,362	0.90
2003-04	13	79.70	1.21×10^{-6}	1203887	1,355,501	1092825	1510524	810455.0	857,266	0.95
2004-05	12	78.13	2.10×10^{-6}	1029940	1,088,332	981040.1	1318239	933444.8	801,098	1.17
2005-06	12	77.91	1.54×10^{-6}	1113215	1,218,740	1031190	1428847	839650.2	789,694	1.06
2006-07	10	76.96	1.85×10^{-6}	1176968	1,269,050	1103093	1529325	981281.1	826,815	1.19
2007-08	12	77.65	1.78×10^{-6}	946485.7	1,094,848	848567	1218913	786361.8	785,623	1.00
2008-09	11	77.72	1.50×10^{-6}	1182661	1,374,390	1055051	1521695	922677.4	873,797	1.06
2009-10	12	77.53	1.31×10^{-6}	1481307	1,671,891	1343686	1910624	1050384.0	831,059	1.26

Appendix F. Equilibrium solutions for Schaefer and Fox surplus production Models

Equilibrium models, as the name implies, assume the population being modeled is at equilibrium. This is rarely true and we have no way, in any case, to determine the correctness of the assumption as applied to the California spiny lobster. Equilibrium conditions do not generally apply in fisheries that are changing or still in their early stages of exploitation. Neither of these conditions strictly applies to the commercial lobster fishery which has been heavily fished at its greatest geographical extent for over 100 years. At the very beginning of the assessment effort, our best data extended back only 11 years but covered a decade of stable high harvests. We expected that some utility might be gained from using Fox and Schaefer models assuming equilibrium conditions existed.

Although these runs (and similar runs using weights) indicate current fishing levels well below MSY, they became less important and less useful as data entry efforts increased our dataset sizes enough to use more acceptable, non-equilibrium versions. These equilibrium runs were also inadvisable as emerging report card results indicated recreational harvests large enough that we could not ignore them in our calculations; and the recreational fishery is in transition because of changing gear and popularity. Under these circumstances we agree with Hilborn & Walters (1992) that equilibrium models should be avoided .

A



B

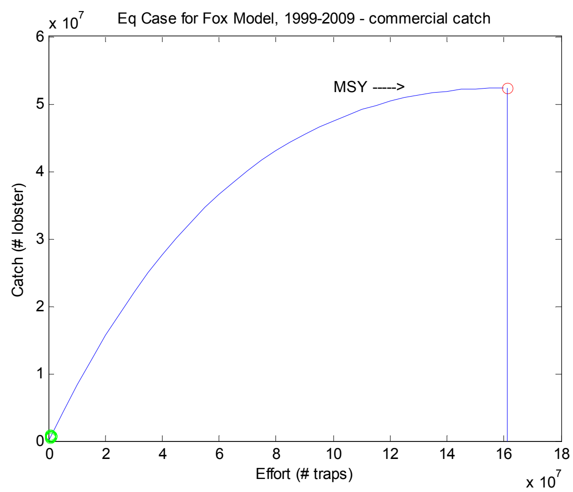
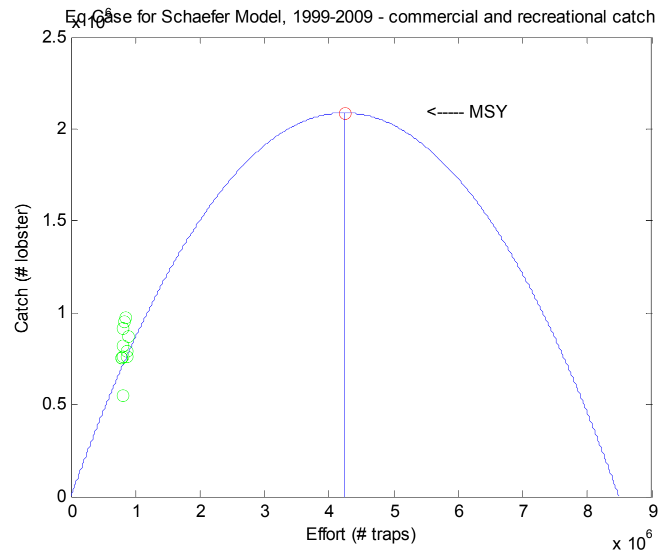


Figure 47. Solutions for A) Schaefer and B) Fox Models using 10 years of Commercial Logbook Data.

A



B

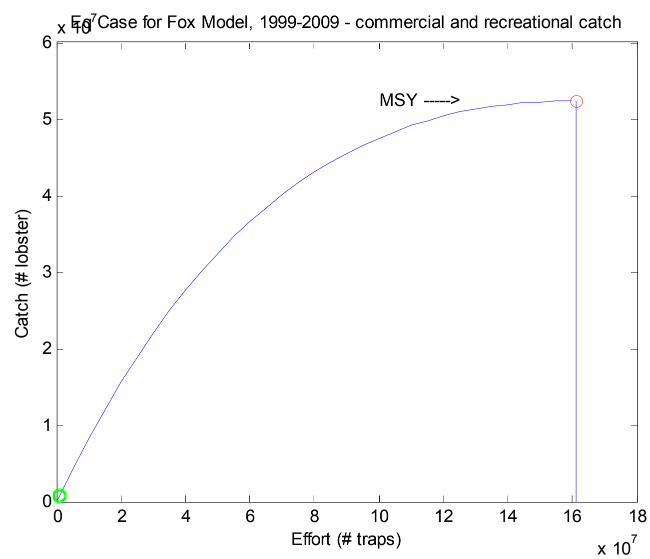


Figure 48. Solutions for A) Schaefer and B) Fox Models using 10 years of Commercial Logbook Data combined with Interpolated Recreational Data.

Appendix G. FISMO results using only the commercial catch and excluding the recreational catch.

The following FISMO scenarios are based on the commercial catch only; no recreational catch is included. They are included for information only since scenarios that ignore the recreational catch are considered unrealistic by the Department.

Scenario 1: Dataset 1, 15 year catch record, α=0.15 Using a relatively low value for ***α*** (the size of recruitment is not strongly tied to the spawning stock size), the seasonal values of **F** are below $\mathbf{F_{msy}}$ for all but two years (1997 and 2006 (Figure 49A). Since 2008, the level of F has been decreasing relative to $\mathbf{F_{msy}}$. The trend is stock biomass is declining since 2006 but in the middle of the range over the entire 15 year time series of observed catch. (Figure 49B). These results suggest the fishery may be non-sustainable (based on the decline since 2006) but would require more years of observations to accept that the stock biomass is at the beginning of a sustained fall. The $\mathbf{F_{msy}}$ is 0.2420 ($\mathbf{E_{msy}}$ = 0.5874), the fitted Beverton-Holt **β** is 0.5804, the initial number of recruits is 6.3 million lobster, and the annual effort is generally at the $\mathbf{F_{msy}}$.

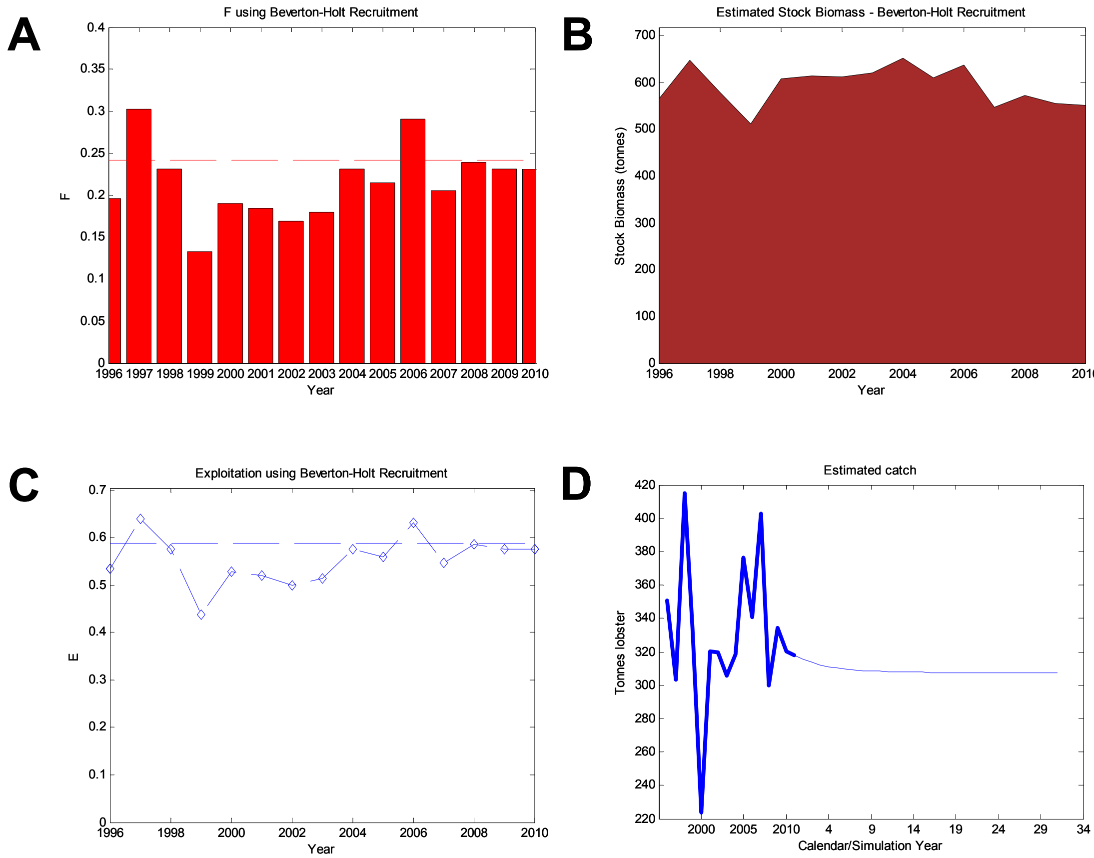


Figure 49. FISMO model results using commercial catch only from 1996 to 2010. Beverton-Holt α was set at 0.15, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2420. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5874. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.2312).

Scenario 2: Dataset 1, 15 year catch record, α=0.50 Using a value for ***α*** (the size of recruitment is not strongly tied to the spawning stock size) in the middle of the range, the seasonal values of **F** are at or below $\mathbf{F_{msy}}$ for all but 3 years (1997, 2004, and 2006 (Figure 50A). Since 2006, the effort was also below $\mathbf{F_{msy}}$ (although close). Biomass is higher than in Scenario 1 but still needs additional years of observation to access the current trend (decline or stable). (Figure 50B). The $\mathbf{F_{msy}}$ is 0.2 ($\mathbf{E_{msy}}$ = 0.5406), the fitted Beverton-Holt **β** is 0.7571, and the initial number of recruits is 6.3 million lobster.

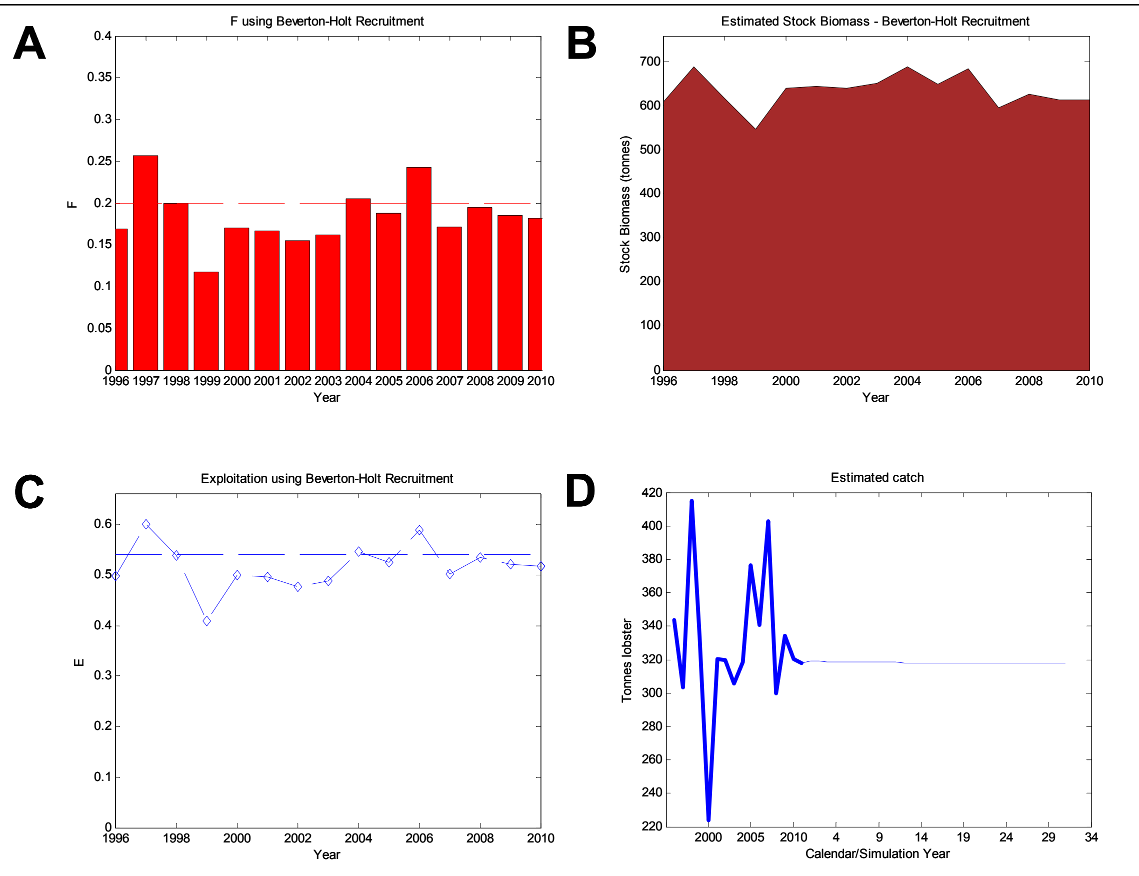


Figure 50. FISMO model results using commercial catch only from 1996 to 2010. Beverton-Holt α was set at 0.50, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2000. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5406. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.1823).

Scenario 3: Dataset 1, 35 year catch record, α=0.15 Comparing 35 years of observed catch relative to the average over the last 11 years, the commercial effort is continuously increasing towards the $\mathbf{F_{msy}}$ although it only exceeds it in 2006 (Figure 51A). The biomass, however, is declining (Figure 51B), suggesting that the fishery is over-exploiting the stock. The $\mathbf{F_{msy}}$ is 0.2420 ($\mathbf{E_{msy}}$ = 0.5874), the fitted Beverton-Holt **β** is 0.5804, and the initial number of recruits is 6.3 million lobster.

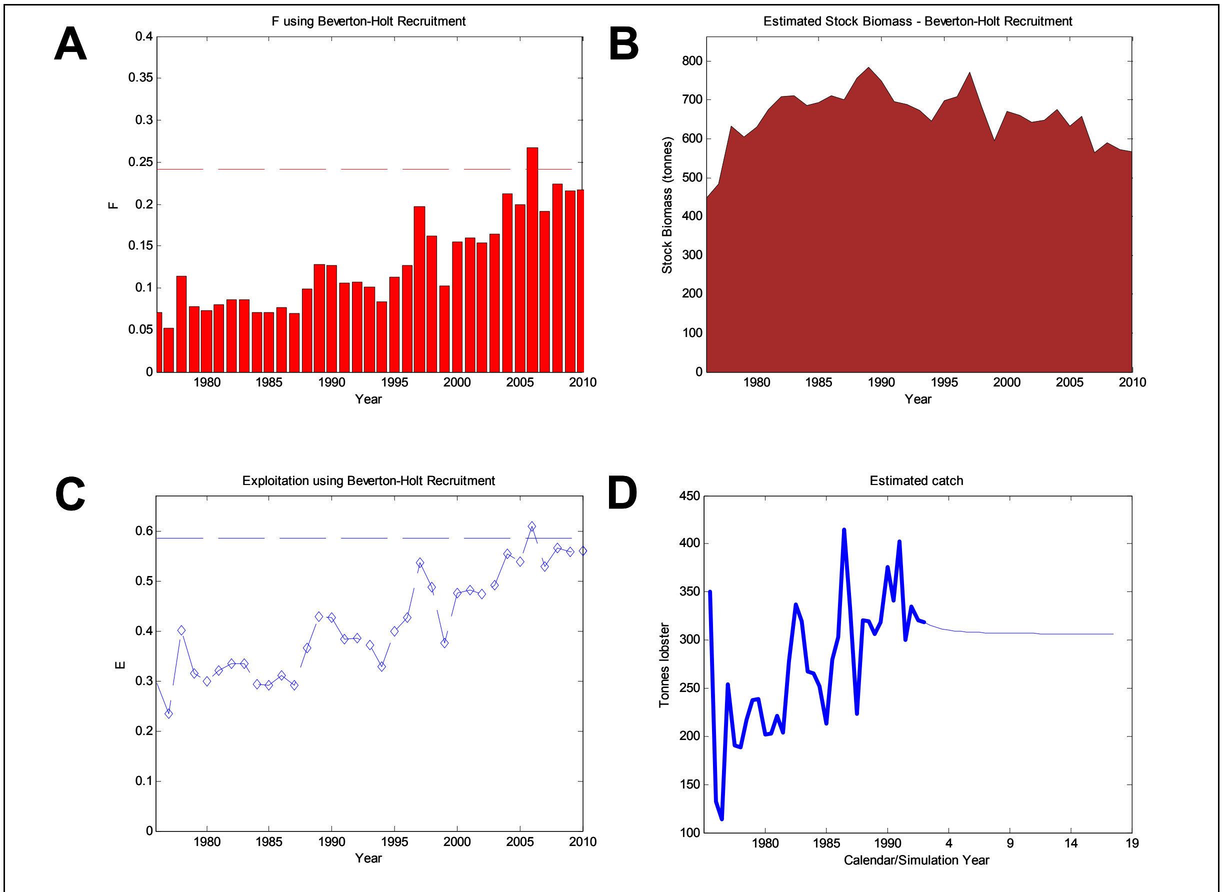


Figure 51. FISMO model results using commercial catch only from 1976 to 2010. Beverton-Holt α was set at 0.15, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2420. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5874. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.2167).

Scenario 4: Dataset 1, 35 year catch record, α=0.50 This scenario produces the the most favorable picture of the commercial-only harvest. Comparing 35 years of observed catch relative to the average over the last 11 years, no years exceed the $\mathbf{F_{msy}}$ in effort although there is a continuous increase towards $\mathbf{F_{msy}}$. (Figure 52A). The biomass is still declining slightly (Figure 52B) but could be considered stable without further observations. The $\mathbf{F_{msy}}$ is 0.2 ($\mathbf{E_{msy}}$ = 0.5406), the fitted Beverton-Holt **β** is 0.7571, and the initial number of recruits is 6.3 million lobster.

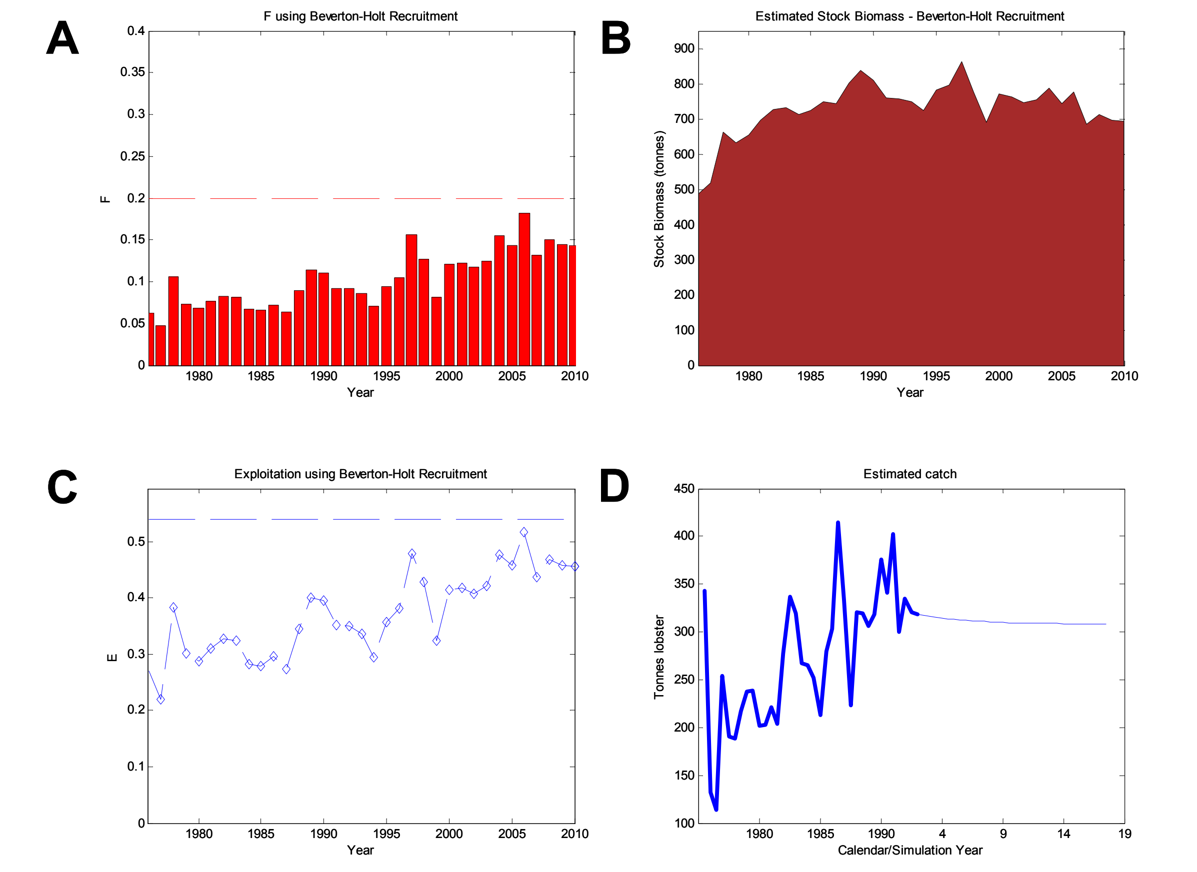


Figure 52. FISMO model results using commercial catch only from 1976 to 2010. Beverton-Holt α was set at 0.50, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2000. (B) Estimated Stock Biomass (tonnes) for each year. (C) Exploitation rate, E, for each year (diamond line) plotted againt E_{msy} (dashed line). E_{msy} = 0.5406. (D) Estimation of observed catch (thick line) with 31 year simulation (thin line) extending from 2010 results and using the estimated fishing pressure for 2010 (0.1432).

Appendix H. List of Analyses requested by the Technical Review Panel and the outcomes from Day 1 of the Stock Assessment Technical Review.

The following Analyses were requested by the Technical Review Panel and presented during Day 2 of the Technical Review. The list of requests and responses has been copied from the Official Technical Review Panel Report.

Request #1: Provide a scatterplot between spawning stock biomass (SSB) and the numbers of adults (N).

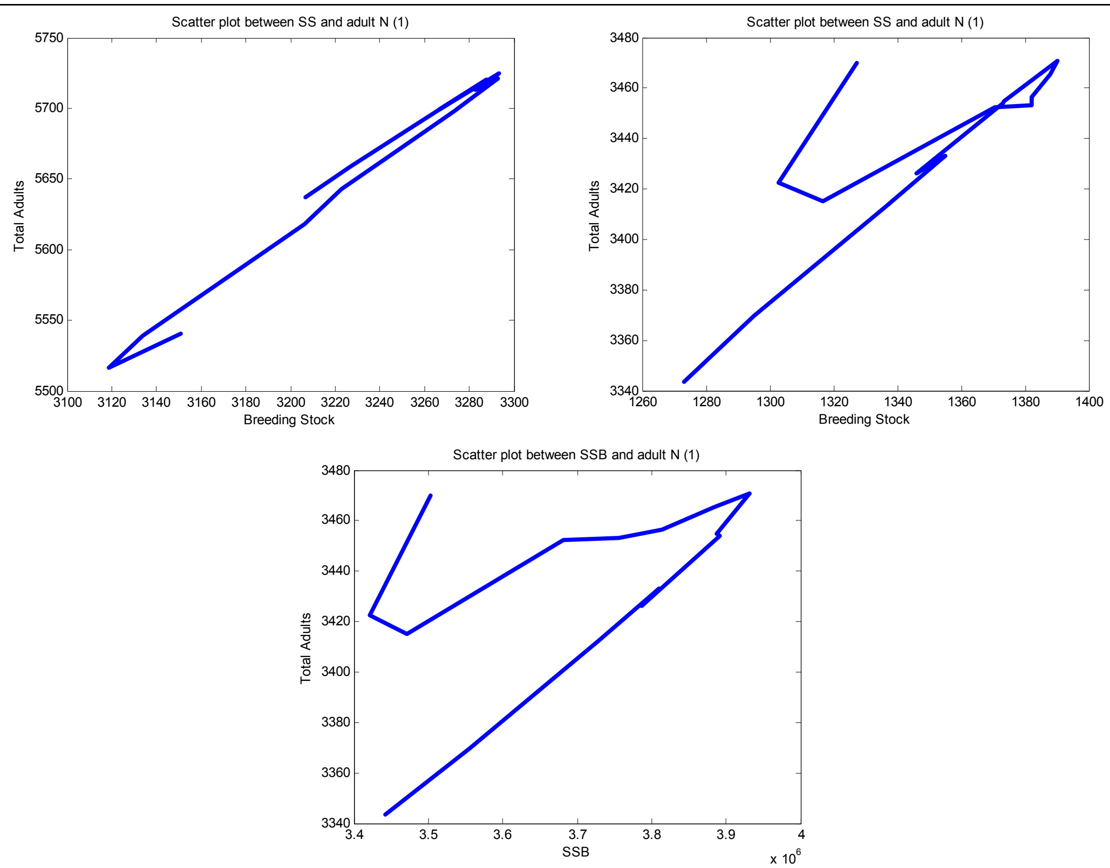


Figure 53. Comparison of breeding stock and total number of adults based on FISMO runs that include recreational take (upper left, upper right), and spawning stock biomass versus total number of adults, again including recreational take (bottom)

Response: There is little contrast between SSB and N, demonstrating that the current formulation of the Beverton-Holt relationship in FISMO is not gaining anything over the traditional Beverton-Holt reparameterization using steepness.

FISMO is being modified to remove the existing B-H relationship and replace it with the traditional formulation.

Request #2: Estimate *k* using L_∞ and using an annual 6 mm size increment at the age of recruitement to the fishery.

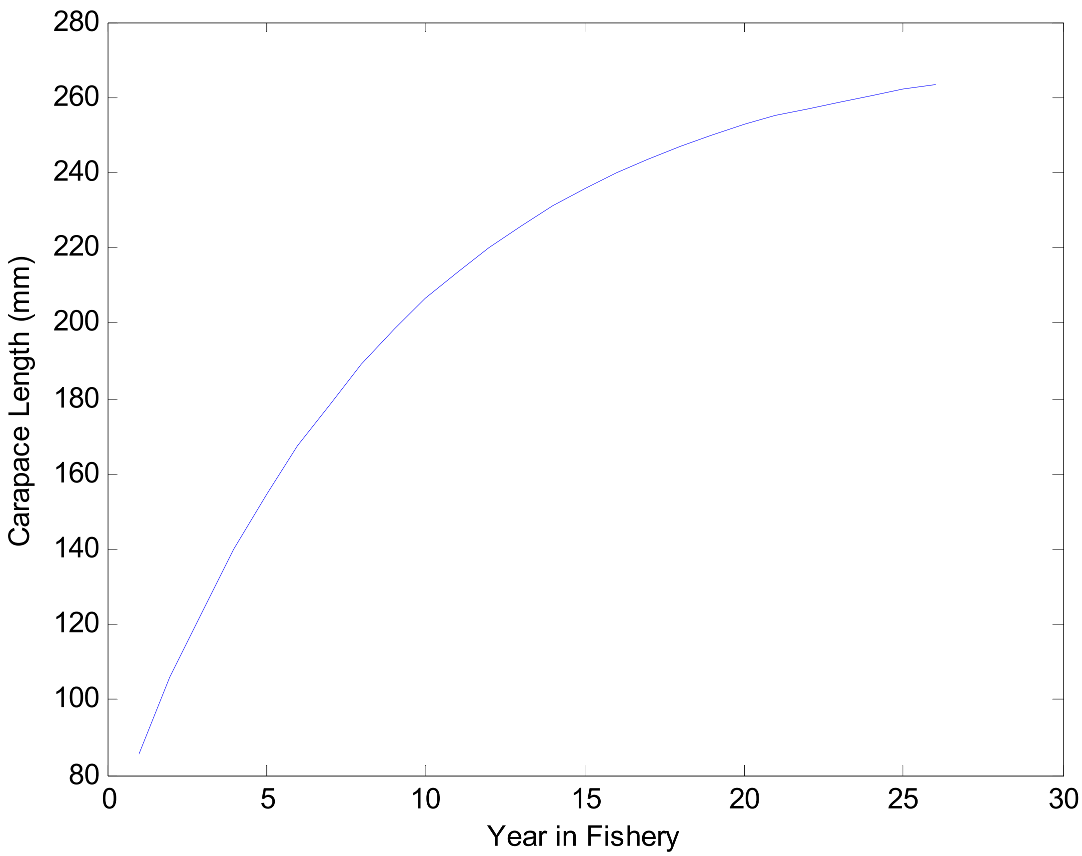


Figure 54. Reconstruction of the growth curve using VBGF and assuming fixed values of 6 mm CL year-1 and the age 1 midpoint measurement of 85.5 mm CL.

Response: The assessment team calculated that given a 6mm size increment, the estimate value of *k* would be 0.1147. FISMO used two values of *k* depending on L_∞, 0.1133 for 26 years, and 0.0604 for 50 years. Comparison to 26 years which most closely approximates our knowledge of growth for the spiny lobster, confirms the value of *k* used by FISMO is consistent with our knowledge of the growth.

Request #3: Plot the Von Bertelanffy Growth Function (VBGF) growth model prediction vs. the growth curve predicted using 6 mm CL size per year increment

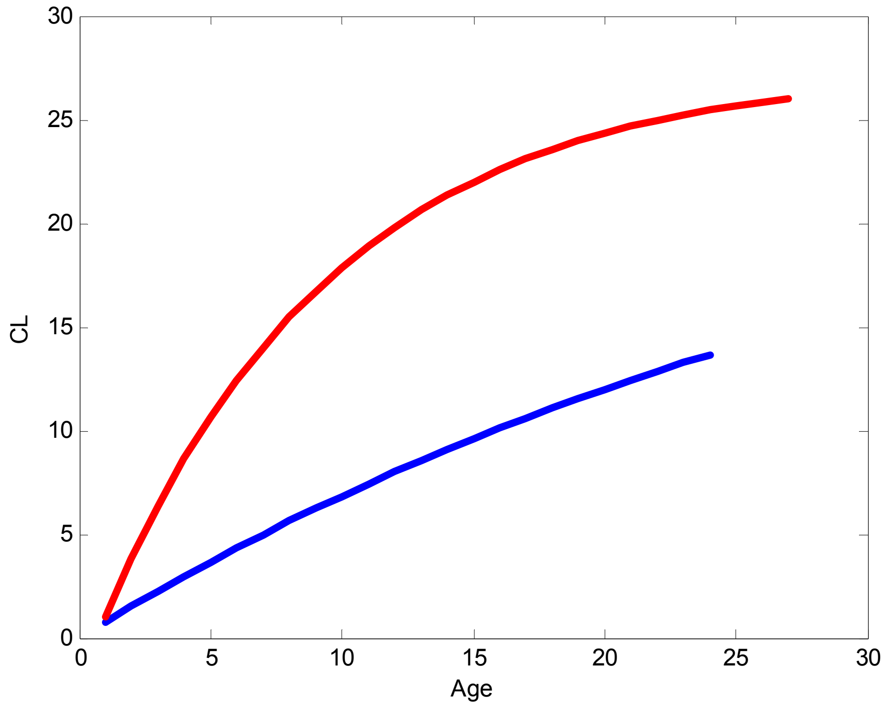


Figure 55. Von Bertalanffy Growth (Red Line) versus a constant 6mm CL growth rate per year (Blue Line). VBGF assumes an L_∞ of 27.45 cm CL.

Response: The plot shows a significant difference between these two realizations of growth. Any interpretation that assumes 6 mm growth across all ages will be different than assuming the VBGF and will tend to underestimate age at length.

Request #4: From Depletion analysis, provide a plot of the CPUE versus cumulative catch for each year since 1997-98. This request was misunderstood, in part, by the assessment team which provided a set of plots showing CPUE versus cumlative catch. However, the plots did not extend far enough along the x-axis to provide a clear intercept based on a linear regression of the data in each plot. This value is equal to an estimate of B_0 and the assessment team referred the technical review panel to Table 6 and Table 7 in Appendix E (column labeled Total B_0).

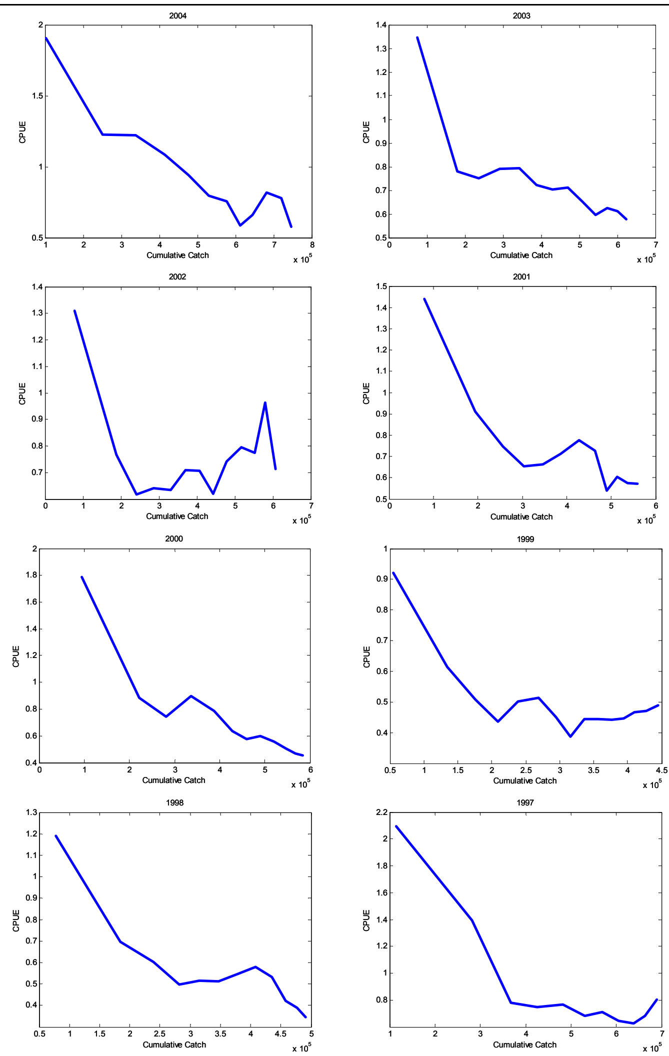


Figure 56. Commercial CPUE versus cumulative catch for seasons beginning in 1997 through 2004 (1997-08 to 2004-05). These curves were created as part of depletion analysis. Plotting a regression against these curves will produce the hypothetical B_0 at the x-intercept while the slope of the regression line equals the catchability (*q*). The panel was also provided with 2005 through 2008 which are not reproduced here. The trends in 2005 through 2008 were similar to the other seasons.

Response: The curved relationship suggests two phases: an initial straight depletion of vulnerable individuals and a subsequent removal phase that catches lobster as they diffuse out from a less vulnerable state (habitat and behavior). Stock biomass is believed much larger than that estimated from the Leslie depletion approach and cannot be quantified by this approach.

Request #5: Provide harvest rates and subsequent Fs based on the Leslie depletion estimate and total catch. This provides a harvest rate to compare to FISMO.

No product was provided to the Review Panel which relied on assorted plots and tables from this document for this analysis.

Response: Harvest rates were shown to be >0.7, which is much higher than FISMO F and is consistent with levels typical of lobster fisheries around the world. This is an ongoing research topic for FISMO which in its current form becomes unstable at F higher than 0.69 (or combined F + M greater than approximately 0.85).

Request #6: Summary of catch at age estimated from FISMO for each year.

Table 8. Typical catch-at-age matrix from excel version of FISMO. Age 1 technically includes pre-settlement. The first 6 years are zero since, in this example, the age at first capture is 7 years. Values are in thousands of kilograms.

Year \ Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Age where catch exceeds 50% of total
1995	0	0	0	0	0	0	68	44	29	19	13	8	5	4	2	2	1	1	0	0	8
1996	0	0	0	0	0	0	68	47	31	20	13	9	6	4	2	2	1	1	0	0	8
1997	0	0	0	0	0	0	90	63	43	28	19	12	8	5	3	2	1	1	1	0	8
1998	0	0	0	0	0	0	71	44	30	21	14	9	6	4	3	2	1	1	0	0	8
1999	0	0	0	0	0	0	53	36	23	16	11	7	5	3	2	1	1	1	0	0	8
2000	0	0	0	0	0	0	68	50	34	21	15	10	7	4	3	2	1	1	1	0	8
2001	0	0	0	0	0	0	67	46	34	23	14	10	7	5	3	2	1	1	1	0	8
2002	0	0	0	0	0	0	67	46	32	24	16	10	7	5	3	2	1	1	1	0	8
2003	0	0	0	0	0	0	69	48	33	23	17	12	7	5	3	2	1	1	1	0	8
2004	0	0	0	0	0	0	79	55	38	27	18	13	9	6	4	3	2	1	1	1	8
2005	0	0	0	0	0	0	74	49	34	24	16	11	8	6	4	2	2	1	1	0	8
2006	0	0	0	0	0	0	88	59	39	27	19	13	9	7	5	3	2	1	1	1	8
2007	0	0	0	0	0	0	74	47	32	21	14	10	7	5	4	2	2	1	1	0	8
2008	0	0	0	0	0	0	86	58	37	25	16	11	8	5	4	3	2	1	1	1	8
2009	0	0	0	0	0	0	101	65	44	28	19	12	9	6	4	3	2	1	1	1	8

Response: The assessment team provided the review panel with the catch at age matrix from the EXCEL version of FISMO run so they could consider this request. Half of the catch biomass is contained in size classes greater than those appearing in the fisheries (where most of the catch is found in the 2 years after recruitment). This indicates that the FISMO estimation of fishing mortality is not matching the intensity of the fishery based on the observed rates used in Request 5. (Translation: there are too many large-sized individuals in the FISMO-derived catch).

Request #7: Further explore surplus production model (catch versus CPUE) by providing data to the TRP.

Table 9. ASPIC Model Input Data. Based on commercial CPUE and combined recreational and commercial catch in pounds

Year	CPUE	Combined Recreational/Commercial Catch (Pounds)
1965	-1	5.499495E+05
1966	-1	5.587125E+05
1967	-1	5.195085E+05
1968	-1	3.821075E+05
1969	-1	3.790965E+05
1970	-1	2.950235E+05
1971	-1	2.941105E+05
1972	-1	4.678859E+05
1973	-1	3.029003E+05
1974	-1	2.607232E+05
1975	-1	2.712676E+05
1976	-1	3.624691E+05
1977	-1	3.216081E+05
1978	0.52	6.311419E+05
1979	0.68	4.898340E+05
1980	0.78	4.867130E+05
1981	0.94	5.495165E+05
1982	1.01	5.955772E+05
1983	0.99	5.962413E+05
1984	1.13	5.164629E+05
1985	1.04	5.196772E+05
1986	0.99	5.610746E+05
1987	0.94	5.225664E+05
1988	0.72	6.842386E+05
1989	0.70	8.166526E+05
1990	0.69	7.802761E+05
1991	0.90	6.651452E+05
1992	0.95	6.626235E+05
1993	0.84	6.328821E+05
1994	1.02	5.501856E+05
1995	1.15	6.983308E+05
1996	1.12	7.526308E+05
1997	0.95	1.002058E+06
1998	1.10	8.255792E+05
1999	1.56	5.867062E+05
2000	1.18	8.040133E+05
2001	1.10	8.078791E+05
2002	1.21	7.827643E+05
2003	1.24	8.176944E+05
2004	0.98	9.535081E+05
2005	1.06	8.854179E+05
2006	0.95	1.040242E+06
2007	1.24	8.422870E+05
2008	1.19	9.657830E+05
2009	1.13	1.050384E+06

Response: Data was taken from the ASPIC runs and provided to the technical panel. Attempts by the review panel to apply this data to alternative surplus-production models did not yield viable results. Translation: Surplus production models are not appropriate for this fishery (using the data available).

Request #8: Plot SSB from FISMO versus CPUE from the depletion models (normal and log transformed). The normal plot was provided and it was decided there was no need to see the log transformed version.

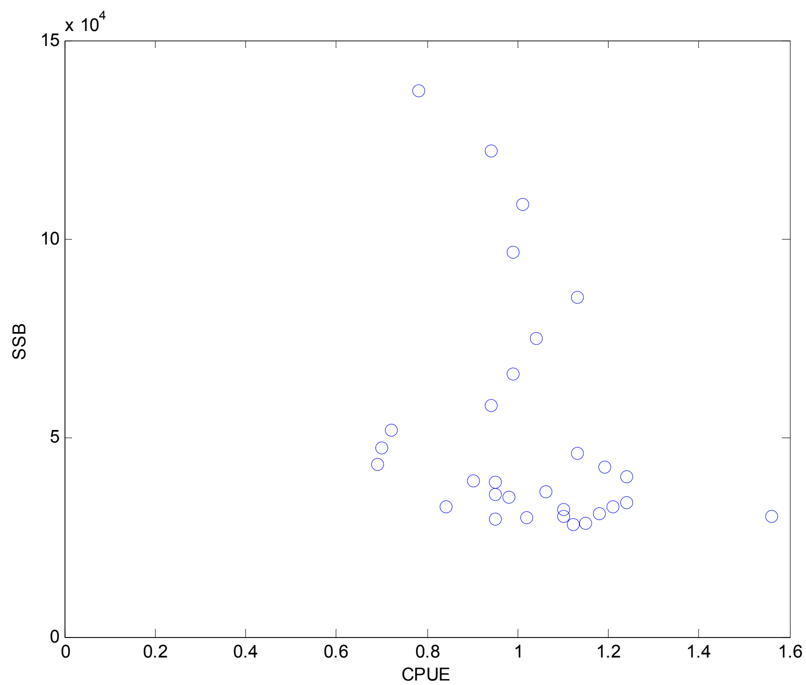


Figure 57. Spawning Stock Biomass (SSB) versus CPUE. SSB is calculated by FISMO while the CPUE was extracted from leslie depletion model run input files (also the same CPUE used in ASPIC model runs) for the same years, 1978-2009.

Response: There is no apparent relationship between SSB provided by FISMO and the CPUE used in the depletion models.