California Spiny Lobster Stock Assessment

Executive Summary

Assessment Conclusions. The spiny lobster population off southern California appears to be stable from both observed and modeled results, and the fisheries targeting this species can be considered, as of today, sustainable.

Stable trends, or trends that over time will favor higher levels of stability, are apparent in a large number of different variables from both fishery independent and dependent observations. Over the last ten years, the commercial fishery has consistently harvested 660,000 lbs (300+ tonnes), accumulated at the same general rate as the season progresses, each season. The average size of commercially caught lobster has been fairly consistent as well at 1.4 ± 0.1 lbs over the decade, with a similar size (1.7 ± 0.5 lbs.) seen in recreationally-caught lobster. A just-legal size lobster weighs approximately 1.3 lbs (0.67 kg), based on a power function fitted to bight-wide creel survey data (R^2=0.77) which, at published rates of growth, means these fisheries are catching lobster within a year or two of recruitment; and the recreational fishery, at least, is targeting trophy-size animals. The lack of larger animals could be a cause for concern, however the sub-recruit population appears large and robust. 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. Although varying by county, the percentage of released shorts is consistent within each county as well as in the southern California bight as a whole. Although no information is available on the frequency of recapturing shorts, shorts released across the entire bight account for 70-80 percent of the total lobster caught indicating the possibility of 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.

Modeled results likewise support a conclusion that the population and its fisheries have been stable over the last decade. Catchability, the percent of the total catch caught with each trap pull and estimated using depletion models, has been consistent since 1998, the earliest year considered. This consistency is seen despite fluctuations in the ultimate size of the catch each season. Using the size-structured, Fishery Simulation Model (FISMO) utilizing von Bertallanfy growth and Beverton-Holt recruitment, estimates of fishing effort (F), effort at the maximum sustainable yield ($\mathbf{F_{msy}}$), and stock biomass also appear to be sustaining. Although the technical review of this assessment identified several things to be investigated or modified before FISMO could be used to fully explore the interplay between lobster life history parameters, catch, and effort, some basic results were found useful (and were corroborated by independent modeling by the Technical Review Panel members).

In all but one of eight scenarios - scenarios differentiated between different levels of recreational catch and changes in life history parameter values - the level of modeled effort did not result in a decline in biomass; and it is questionable, in the remaining scenario 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. Corroboration of a stable fishery can also be found in observed (not modeled) data as well. Model runs using the Fishery Simulation Model (FISMO, description below) suggest that despite the apparent stability of the recent catch record, the fishery is approaching, or has reached the maximum sustainable yield. 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, the data is limited with only about a 12 percent return rate of spiny lobster report cards. We cannot tell if the recreational fishery is stabilizing or continuing to increase its harvest. If the recreational hoop net fishery continues to increase in popularity and commercial landings remain at current levels, the probability that model runs, already approaching or exceeding the $\mathbf{F_{msy}}$, will exceed this level, increases. If $\mathbf{F_{msy}}$ is exceeded by a substantial amount, at some point the modeled stock biomass estimates will decline. If that decline is accompanied by a drop in actual catch the population will definitely be overexploited and action may need to be taken. However, 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.

Similar to the unknown factor presented by the hoop net fishery, transferable commercial operator licenses could also upset the apparent stability in the lobster fisheries. Although it is not expected to be a consistent problem, it is possible for a large number of transfers to occur before any given season. Currently, permits are selling for approximately $75,000 and a purchaser may attempt to recover that cost be increasing the fishing effort relative to the previous permit holder’s fishing effort. A large number of transfers year after year could impact the health of the fishery and as with the recreational hoop net effort, future assessment efforts need to consider this possibility.

Natural and Life History Overview. 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), with a small isolated population in the northwestern corner (Bahia de Los Angeles) of the Gulf of California (Kerstitch, 1989). Johnson and Snook (1927) reported its occurrence as far south as Manzanillo, Mexico.

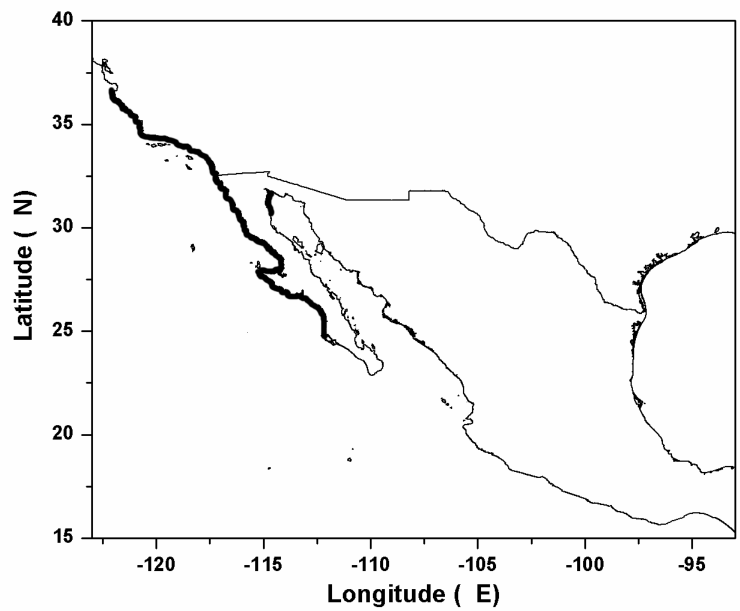

Figure 1. Primary distribution range of the California Spiny Lobster extending from Monterey, California in the north to Magdalena Bay, Baja California with a small population occurring in the northwest portion of the Sea of Cortez. Lobster are considered rare north of Pt. Conception. The center of the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

Spawning occurs once per year during the late spring through summer months (Johnson, 1960). Male lobster attach 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 paddle-like swimming legs (pleopods). The eggs are fertilized when the female breaks open the attached spermatophore, and the fertilized eggs are carried 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. The planktonic larva have been found offshore as far as 530 km and at depths to 137 m. (California Department of Fish and Game, 2001) while post-settled lobster are commonly found at depths ranging from intertidal to 64m.

Engel (1979) summarized numerous studies that have published growth information on the California spiny lobster but found little agreement. Legal size (82.5 mm CL) is reached after 7 to 13 years and, once attained, lobster molt once per year. Males grew faster than females. The age at sexual maturity ranged from 3 to 9 years, with most suggesting around 5 years, and males matured faster than females. From observations of trapped lobster, sexual maturity occurs prior to the attainment of legal size.

Fisheries. The Southern California population of California spiny lobster in the Southern California Bight is considered a single stock targeted by three fisheries: a commercial fishery, a hoop net-based recreational fishery, and a dive-based recreational fishery relying on hand catch. The state of California, and specifically the Fish and Game Commission, is responsible for the regulation of these fisheries. Current regulations cover the commercial fishing effort and a single, combined hoop net and dive-based, recreational fishing effort.

Assessment Background. 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.

Existing Datasets Used. The 2009 lobster data workshop did not identify any Southern California Bight-wide fishery independent datasets targeting California spiny lobster north of the Mexican border. There were some highly detailed studies, carried out both by and independent of the Department, from which data and results were made available for our use. However, there was limited time allotted to this assessment effort, and whether the results from any of these studies could be applied to the bight in general would represent a significant study by itself. For this effort, however, determining the applicability of these studies to the whole bight was unnecessary since the Department possessed a long-term, bight-wide, fishery dependent set of commercial logbook and landings data. In addition, the Department also had bight-wide recreational data from the newly implemented recreational spiny lobster report card. The Department decided to rely on the bight-wide datasets with the expectation that the resulting assessment would provide a contextual framework for interpreting the regional datasets from a bight-wide perspective.

A related effort was also undertaken in parallel with the assessment effort aimed at digitizing the entire available record of commercial logbook data, since over 20 years of the 38-year record (1973 to present) existed as paper hardcopies only. In addition, data from newly-received recreational spiny lobster report cards were digitized. 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.

Since there was insufficient data to isolate the two recreational fisheries, the Department chose, for the current assessment, to combine catch and effort from the two recreational fisheries into a single dataset. Initial results from the Department's recreational lobster report cards, established in the fall of 2008, suggest that the recreational harvest is not insignificant compared to the commercial harvest. The historical recreational harvest was estimated from report card data for two seasons (2008-09 and 2009-10) and two Department-led recreational creel surveys performed in 1992 and 2007. 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.

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 660,000 lbs (300+ tonnes) each season.

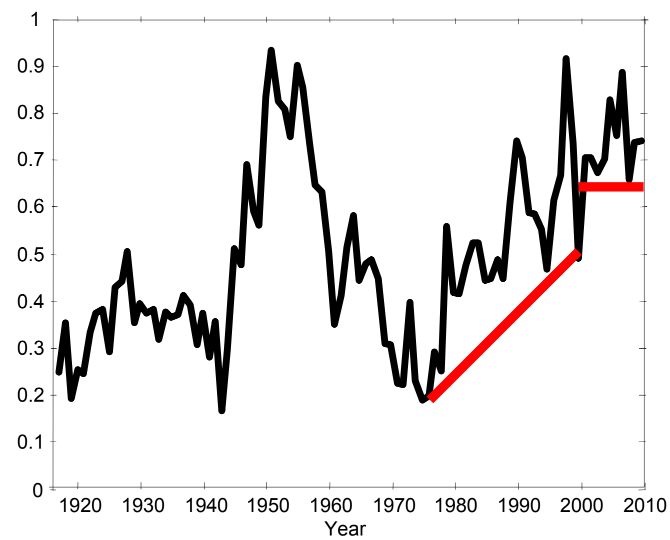

Figure 2. Commercial landings (millions of pounds) of California Spiny Lobster from 1916 to present. This plot reflects only lobster of American-origin and does not include landings from the Baja fishery active from 1916 through 1952.

- 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.

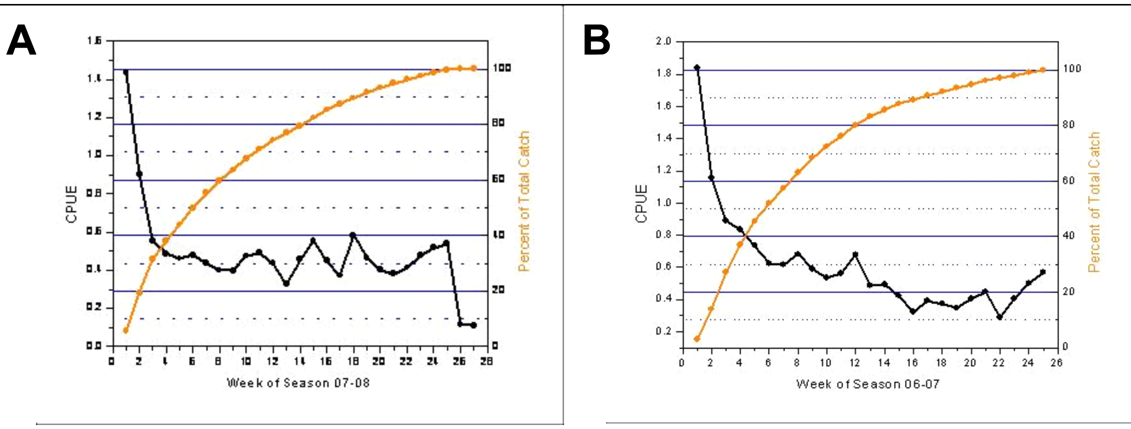

Figure 3. Combined commercial catch trends showing the decline in CPUE (black line) and the percentage of total catch (orange line) by week of the seasons for A) the 07/08 season, and B) the 06/07 season. These seasons are typical for the commercial fishery. Initial high CPUE declines rapidly to a 'background' 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.

- The size structure of the catch has not changed significantly. Assuming a fixed growth rate (6 mm yr^{-1}), 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.

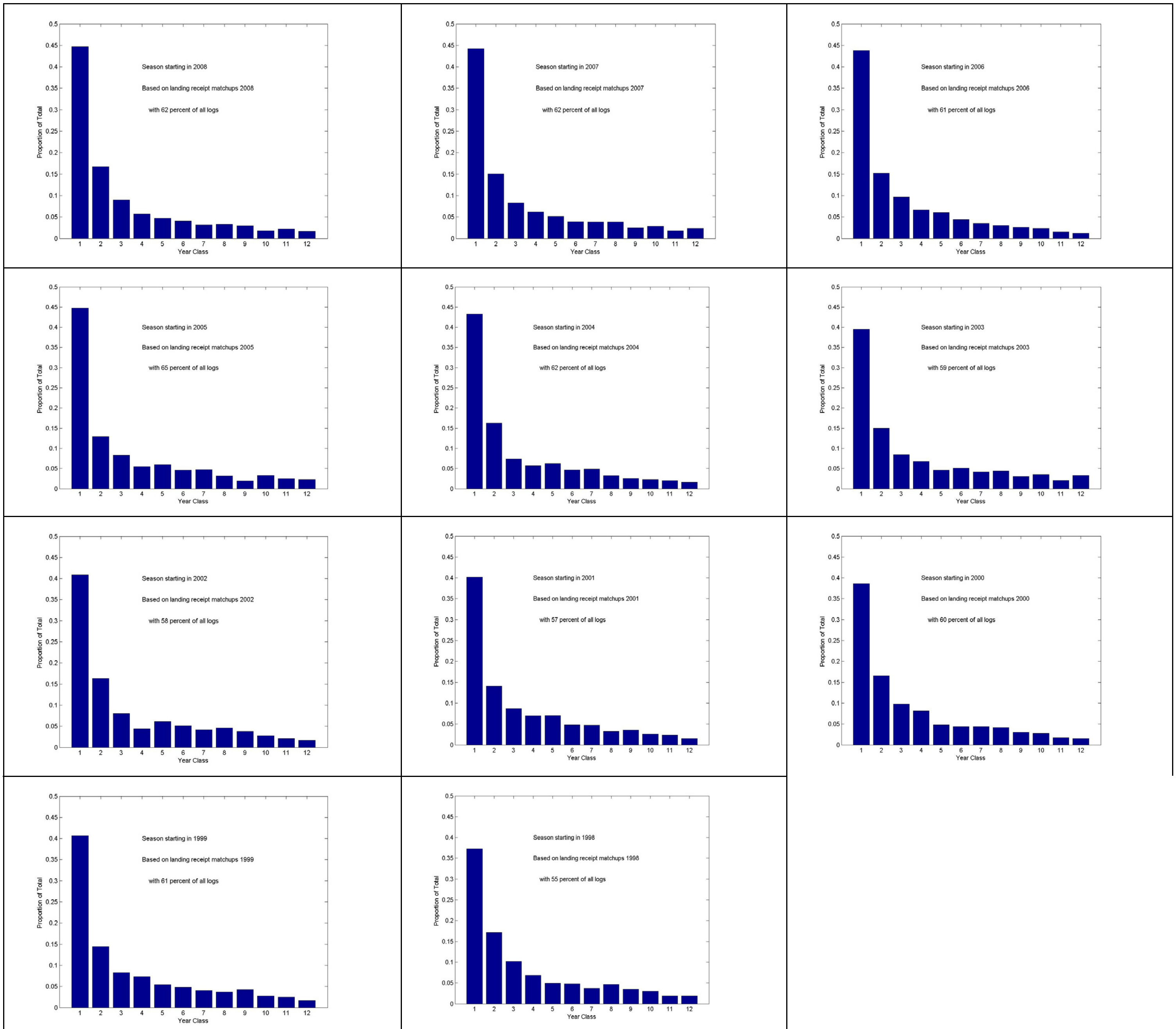

Figure 4. Reconstructed age classes of recruited lobster for seasons 1998-99 through 2008-09 based on collated landing weights and logbook retained lobster counts. The resulting weight per lobster was converted to carapace length using the length/weight relationship derived from the Department's 2007 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.

- Based on depletion model results, catchability – the percent of total seasonal catch caught in each trap pull - has not varied significantly from season to season.

Table 1. Catchability, the percent of total catch caught in each trap pull for the combined recreational and commercial fishery. Extracted from Table 4, below.

Season	Catchability
1999-00	1.10×10^{-6}
2000-01	2.51×10^{-6}
2001-02	1.64×10^{-6}
2002-03	Does not fit Depletion Model assumptions
2003-04	1.21×10^{-6}
2004-05	2.10×10^{-6}
2005-06	1.54×10^{-6}
2006-07	1.85×10^{-6}
2007-08	1.78×10^{-6}
2008-09	1.50×10^{-6}
2009-10	1.31×10^{-6}

- 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.

Table 2. 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

- 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. In addition, new MPAs, set to go into effect on January 1, 2012 will probably increase fishing effort on the non-MPA fishing grounds as displaced fishermen move to new areas. The magnitude of this increase, and its effects, has yet to be determined.

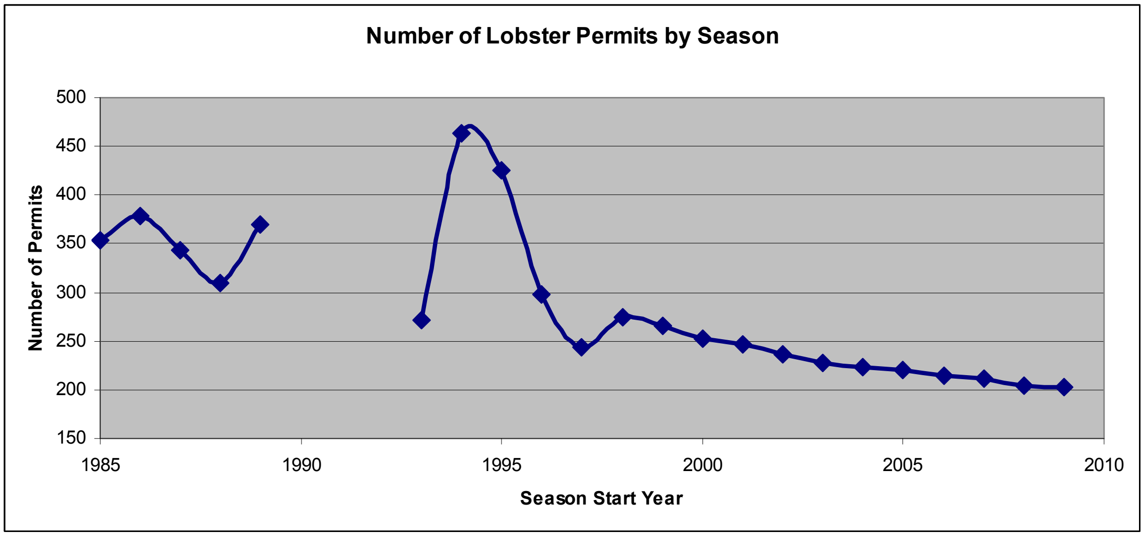

Figure 2. Total number of available operator permits by season from 2005-06 through 2008-09. There has been a steady decline in the number of permits since the 1998-99 season. Seasons without available operator permit totals are left blank.

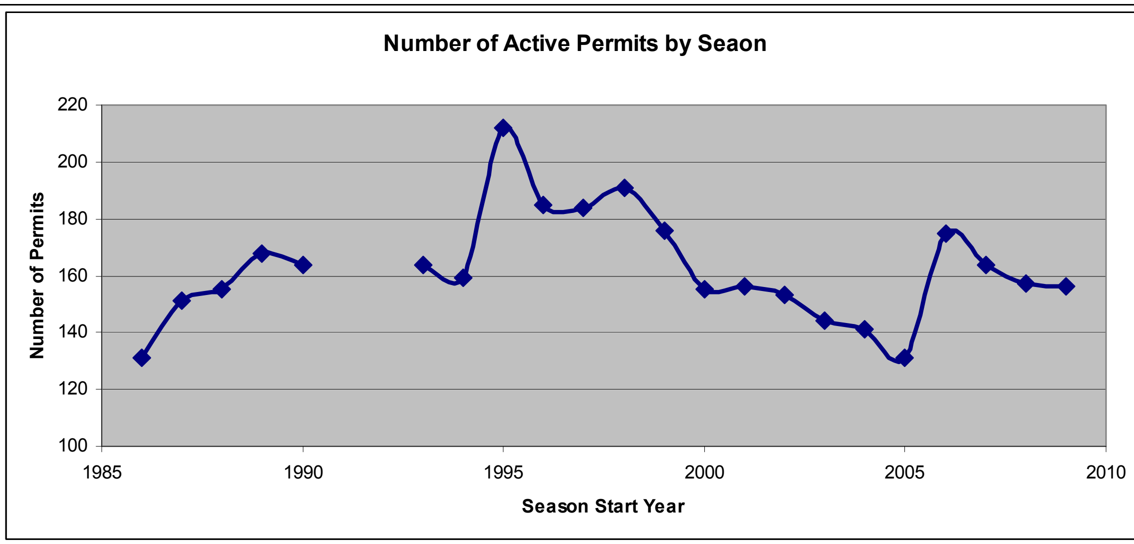

Figure 3. The number of operator permit holders that actually fished for lobster each season between the 1986-87 and 2009-10 seasons. Missing data are represented by spaces in the line. The jump between 2005-06 and 2006-07 is thought to reflect new permit holders (permit transfers) that are acting on their investment.

- 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.

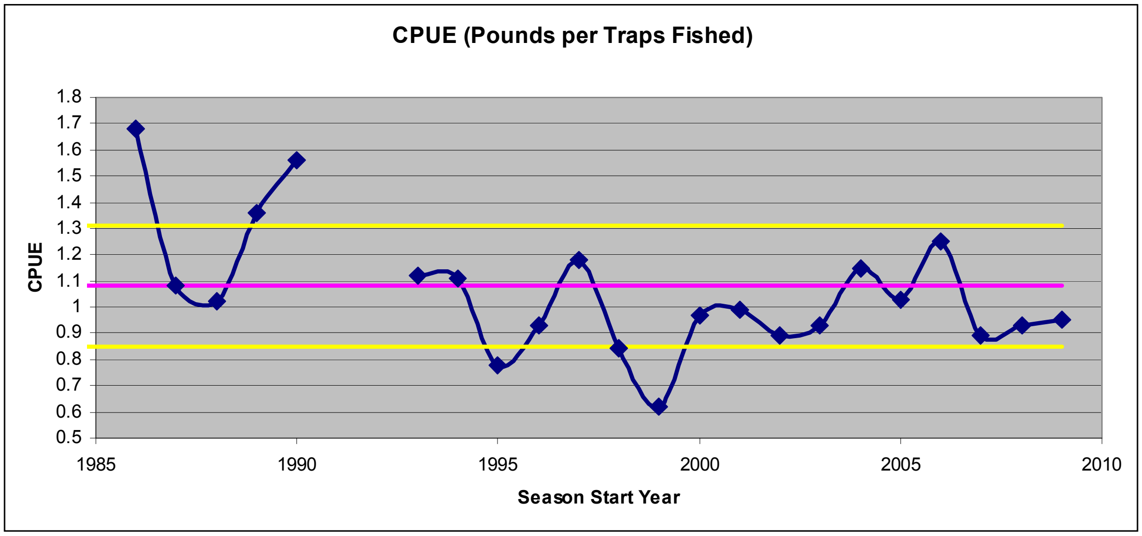

Figure 4. CPUE (pounds landed per trap pulled) for the seasons from 1976-77 through 2009-10. The values used are the totals representing 80% of their respective seasonal totals which were achieved, on average, at 12 weeks into each season. Seasons missing data were excluded. The average CPUE across all seasons is indicated (purple line) as is the range, +/- 1 standard deviation (yellow lines).

- 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 30 to 60 percent to the commercial catch.

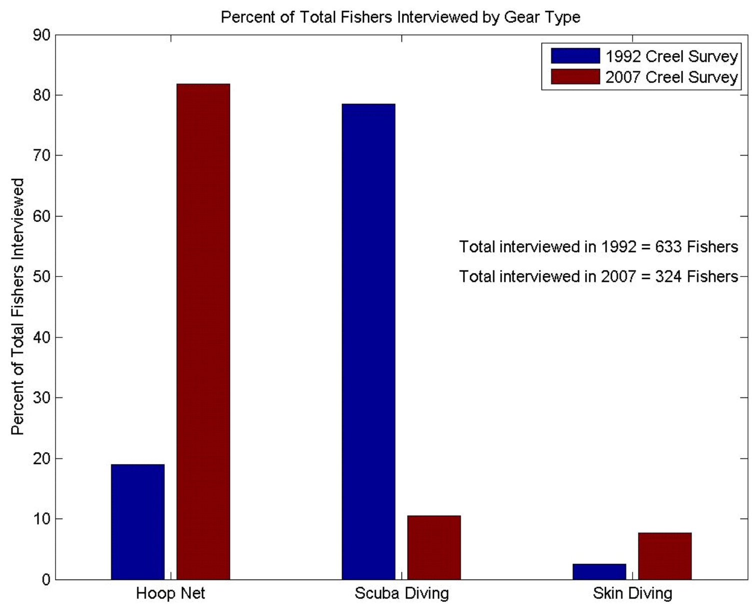

Figure 5. Proportion of recreational fishermen employing hoop nets or diving for lobster during the 1992-93 season (blue bars) and the 2007-08 season (red bars). These results are based on creel survey interviews taken at Dana Landing Launch Ramp, Shelter Island Launch Ramp, and Channel Islands Harbor Launch Ramp which were the three sites common to both the 1992-93 and 2007-08 seasonal creel surveys.

Overview of Modeling Efforts I. 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. We were able to investigate runs based on 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. Surplus production models appeared to be the most appropriate models since they do not require size or age structure and could provide a reference point for management. However, ASPIC ultimately failed to provide usable results. Various alternate formulations were suggested, but time limitations based on the original 12 month timeframe for this assessment effort did not allow for exploration of these alternatives.

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's catch. Towards the end of the initial assessment effort, in December 2010, a copy of a 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 log books. 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 runs began around July 2010 when we finally had enough data available in electronic format for statistical rigor. ASPIC Fox model runs were made 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.

Fisheries Simulation Model (FISMO). FISMO (Chavez, 2005; Chavez and Gorostieta, 2010), is a size-structured model relying on Beverton-Holt invariants assuming Von Bertalanffy growth (Beddington & Kirkwood, 2005; Beddington & Cooke, 1983; Jensen, 1996). 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).

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. Von Bertalanffy growth parameters: **K**, $\mathbf{t_0}$, and longevity are also needed. Although the ranges of published values for these parameters were fully explored, most FISMO runs were made with the age of maturity set at 5 years, age at first capture set at 7 years, and Von Bertalanffy parameters calculated assuming 6mm year^{-1} growth.

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 $\mathbf{F_{msy}}$ 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. As stated previously, the non-equilibrium, surplus production model ASPIC, failed to converge or produce a non-trivial result using both fixed domain and unconstrained grid searches. All surplus production modeling was then 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.

Table 3. 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 4. 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

Of the eight scenarios run by FISMO, six produced **F**s in excess of the **F$_{msy}$**. In these six, the last two years of each run - the years most associated with increased recreational hoop netting - were in excess of **F$_{msy}$**. In the remaining two scenarios, both 35-year runs, all fishing effort remained below **F$_{msy}$**. Whether fishing at or above the **F$_{msy}$** 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.

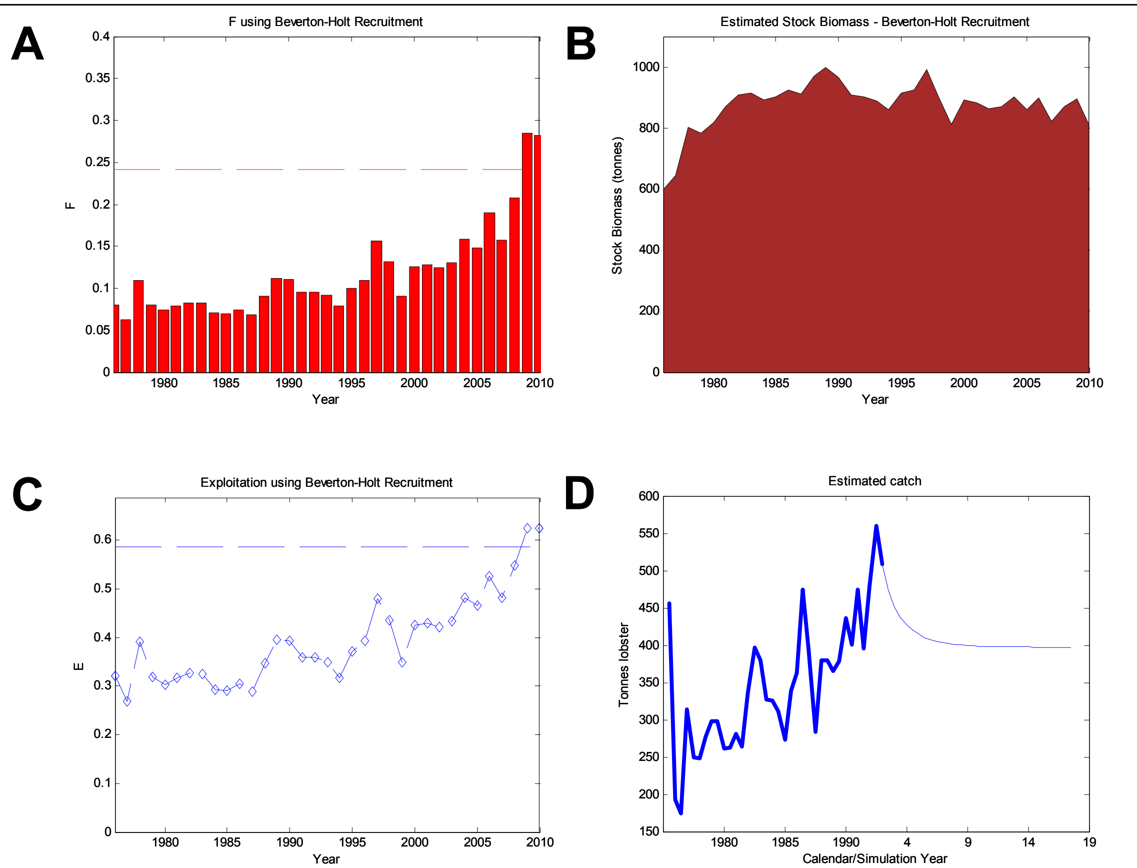

Figure 9. FISMO model results using commercial catch + recreational catch (recreational at 61% of commercial) from 1976 to 2010. Beverton-Holt α was set at 0.15, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2420. (B) 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).

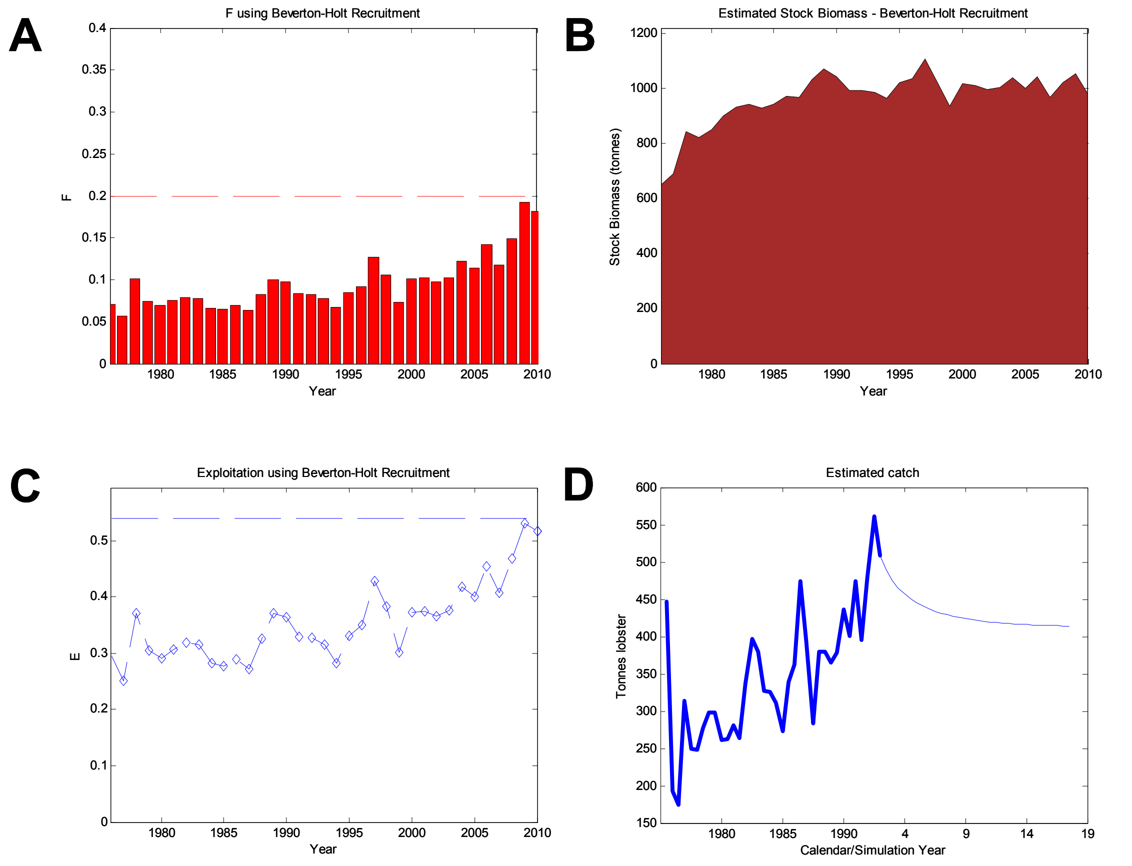

Figure 10. FISMO model results using commercial catch + recreational catch (recreational at 61% of commercial) from 1976 to 2010. Beverton-Holt α was set at 0.50, t_c to 7, t_m to 5. (A) Fitted fishing effort, F, for each observed year (bars) relative to the F_{msy} (dashed line). F_{msy} = 0.2000. (B) 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).